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Input Use Efficiency in Agriculture - Issues and Strategies

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FOREWORD

Indian agriculture has witnessed rapid growth during the last five decades, owing largely to the intensive input based modern agriculture. Intensive use of inputs imposes a lot of stress on the natural resources comprising of soil, water, vegetation and climate which form the essence of all kinds of life and provide support to its various processes. The resulting change in the agro-system environment has questioned the sustainability of the production system. Over the years, there is a sharp decline in factor productivity, shift in insect pests and weed spectrum, increasing deficiency of secondary and micronutrients in the soil profile, shifts in climate, twin problems of water logging and salinity under irrigated areas, water pollution, continuous depletion of water table and stagnation in water and fertiliser use efficiency. Most of these problems are closely associated with increased but inefficient and isolated use of the various inputs used in crop production, particularly water, nutrients and pesticides. The declining efficiency in the use of inputs also increases the cost of cultivation without any yield dividends. Therefore, it is an opportune time to review our past accomplishments and assess both the strengths and weaknesses in order to reorient the research agenda for increased input use efficiency in agriculture for the future.

I am happy that the Kerala Agrl University is organizing a National Symposium on "Input use efficiency in agriculture- issues and strategies" during November 25- 27, 2004 with the financial assistance of ICAR to review the current knowledge and formulate future strategies for improving the use efficiency of various production inputs. The proceedings, containing the invited papers, attempt to take stock of the achievements made in the area of input use efficiency in Indian agriculture and to focus on the challenges ahead in the years to come.

The valuable contribution made by the authors in formulating measures for improving the use efficiency of various production inputs and making the symposium highly successful is greatly appreciated. I also congratulate profusely the editors for their sincere and dedicated efforts in bringing out this excellent publication. I am confident that the publication would provide valuable information on the ways and means for improving the use efficiency of various inputs to make agriculture profitable, sustainable and environment friendly.

I congratulate Dr. Jose Mathew, Organizing Secretary of National Symposium, Dr. C. T. Abraham, Head of Department of Agronomy, Dr. G.S.L.H.V. Prasada Rao, Associate Dean and his dedicated team for the initiative taken.

Prof. K. V. Peter
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PREFACE

Ever since the advent of the green revolution, a continuous increase in the level of input use has characterized Indian agriculture. The objective of this practice was to sustain self-sufficiency in the production of food grains. This is true with most of the inputs such as water, fertilizers and agricultural chemicals. The increased use of various inputs, however, has not only failed to yield the desired results, but ironically, has also led to stagnating trends in crop productivity in several crops. This paradoxical situation is mainly attributed to a steady decline in the efficiency of most of the inputs used in crop production over the years. Apart from low yields, poor efficiency of fertilizers and agricultural chemicals also adversely affect soil health and quality of food and environment. Declining efficiency is also noticed in several agronomic practices such as field preparation, sowing operations, harvesting and labour use. The situation warrants a focused review of the present status of input use efficiency in key areas of Indian agriculture. The National Symposium on "Input use efficiency in agriculture- issues and strategies" is organized with this background at KAU Main Campus, Vellanikkara during November 25-27, 2004 to discuss the current issues and formulate future strategies for increasing the use efficiency of the various inputs and agricultural practices that are relevant to various agro-climatic zones in the country in a changed agricultural scenario.

This publication consists of the lead papers presented in various technical sessions of the symposium. In addition to an introductory session, five sub- theme areas have been identified for the symposium and the articles have been arranged under these sub themes. They are i. Efficiency in water use ii. Efficiency in agronomic practices iii. Efficiency in nutrient use iv. Efficiency in the use of agro-chemicals and v. Cropping patterns and farming systems for improved resource use efficiency.

Expert editorial guidance provided by Dr. G.S.L.H.V. Prasada Rao, Associate Dean and Chairman and Dr. C.T. Abraham, Associate Professor & Head, Department of Agronomy and Co- Chairman, Organizing Committee is gratefully acknowledged. We also extend our grateful appreciation to the Editorial Committee Members, Dr. K.E. Savithri, Dr Mercy George, Dr. A. Latha, Dr. George Thomas, Dr. I. Johnkutty, Dr. E.K. Lalitha Bai, Dr. Reena Mathew, Dr. Maicykutty P. Mathew and Dr. Mini Abraham.

Editors

I. INTRODUCTORY SESSION

Input use efficiency in agriculture: conceptual issues and empirical evidences

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'the economist, the engineer and the policy maker all have great stakes in the study of efficiency'

-Yotopoulos and Nugent

Expansion of irrigated area, high yielding varieties, chemical fertilizers and pesticides helped the country to achieve significant increase in crop productivity since yearly seventies. But in international comparison, our productivity levels are very low. Indian agriculture has to become more efficient with higher productivity levels to take advantage of the new international trade regime. Only a dynamic and rapidly growing agriculture can generate the sustained surpluses necessary to drive the economic transformation (Timmer 1988). But the productivity gains from green revolution technologies in Asia and particularly in India have essentially ended (USAID 2003, Sharma 2003, and Ramasamy 2004). The daunting task of increasing efficiency in agriculture has to be viewed in the back drop of declining capital formation in agriculture, degrading natural resources like land and water, predominance of small farms and increasing pressure on land due to population exploitation.

Why Efficiency Analysis?

A proper measurement of productivity of inputs and farming practices is essential for understanding the efficiency and competitiveness of agriculture. From the point of view of the planner, the technical efficiency of a firm or plant indicates the undisputed gains that can be achieved by simply 'gingering up' of the management, while its price efficiency indicates the gain that, on certain assumptions about the future price structure, can be obtained by varying the input ratios (Farrell, 1957). If farmers are not efficiently using the existing technology then efforts designed to improve efficiency may be more cost effective than introducing new technologies as a means of increasing agricultural productivity (Shapiro 1983; Belbase and Grabowski 1985). When adoption of technology became widespread, the higher yields resulted in a lower unit cost in real terms (Misra, 1993;Kumar and Rosegrant,1994), but it was also argued new technology achieved greater production at greater cost per unit of output at constant prices (Nadkarni, 1988). The decline in unit cost was mainly due to increased productivity and decline in the expenditure on human labour, bullock labour and manure (Prudhvikar Reddy, 1997). Fraser and Cordina (1999) documented the usefulness of efficiency analysis for promoting best agricultural management practices. Operating at best practice, farmers would be able to release input for use in alternative economic activities or use cost savings to purchase new technologies such as improved seeds, fertilizers and land improvement. Also, benchmarking using the efficient farms would be helpful for setting targets and finding the weakness of current practices (Dhungana et al; 2004).

In developing countries most new agricultural technologies have only been partially successful in improving productivity (Xu and Jeffrey 1998), which is often attributed to a lack of ability and/or an unwillingness to adjust input levels on the part of producers resulting from the familiarity with traditional agricultural systems and or the presence of institutional and cultural constraints (Ghatak and Ingerset 1984). In his "poor but efficient" hypothesis Schultz (1964) argues that traditional farmers (those who, over a long period of time, have learned their production process) will identify the optimal sets of inputs and outputs for cultivation of their respective crops. He suggests then that agricultural development policies should adopt an approach that expands the smallholder's production frontiers through technological change, as this would be the most cost-effective means to increase these low income farmers' welfare. Some studies have rejected the Schultz hypothesis after finding widespread technical inefficiency among smallholder producers and recommended farmer extension and educational services to improve technical efficiency (Sherlund et al, 1998; Ali and Chaudhry 1990).

Concept of Efficiency

Growth in productivity is achieved through technological innovation or through more efficient use of inputs or through combinations of both. Productivity measurements were refined over years to capture the complexities of agricultural production. Partial productivity measures such as yield per hectare (land productivity) or output per person (labour productivity) are the simplest measures of efficiency. Such productivity measures can be misleading if considerable input substitution occurs. Although partial productivity measures provide insights into the efficiency of a single input in the production process, they mask many of the factors accounting for observed productivity differentials. They may be misleading measures of relative farm performance and also inter farm performance differentials are hidden in such measures (Coelli et al 2002).

These concerns are addressed by the concept of economic efficiency, which is generally composed of two major components: technical efficiency and price or allocative efficiency. Technical efficiency is defined as the ability of a farm to either produce the maximum possible output from a given bundle of inputs and a given technology, or to produce the given level of output from the minimum amount of inputs for a given technology. Technical efficiency can be decomposed into two components: pure technical efficiency and scale efficiency. When the scale effect is separated from the technical efficiency the pure technical efficiency is obtained. Scale efficiency relates to the most efficient scale of operation which maximizes the average productivity. In a scale efficient farm, technical efficiency and pure technical efficiency are same. Allocative efficiency is achieved when the value of marginal product is equal to the marginal cost.

Traditionally production functions of different forms were used to study the allocative efficiency of individual crops. Since the pioneering work of Farrell in 1957, which drew upon the works of Debreu (1951) and Koopmans (1951), a considerable effort has been directed at refining the measurement of technical efficiency. Since the absolute efficiency position is usually not known, the problem is to measure the efficiency of one farm relative to others. Empirical studies using frontier production function methodology to measure productive efficiency can be differentiated on the basis of two criteria. The first of these relates to the use of parametric methods versus nonparametric methods. Parametric methods involve specification of a particular functional form, while nonparametric methods do not have this requirement. Production efficiency studies may also be differentiated on the basis of whether they utilize deterministic or stochastic methods (i.e., the second criterion). Deterministic methods assume that all deviations from the frontier function result from inefficiency. Stochastic methods allow for some deviation to be attributable to statistical noise. The vast majority of empirical studies have utilized parametric approaches to measuring production efficiency. Battese (1992) provides a review of parametric efficiency models, both deterministic and stochastic. Deterministic frontier functions can be estimated using two alternative approaches; programming models and statistical models (i.e., econometric analysis). Stochastic frontier functions are estimated through the use of statistical models. Both deterministic and stochastic modeling approaches have received widespread use in the analysis of production efficiency. Comprehensive review of frontier production function approaches are provided by Kalirajan and shand(1999), Lovell and Schmidt(1988), Coelli (1995), Coelli et al (1994), Charnes et al (1994), Bravo Ureta and Pinheiro (1993), and Greene(1993).

Total Factor Productivity (TFP) is a conceptually superior measure of productivity. It is the ratio of aggregate outputs to aggregate inputs used in the agricultural production process. Total output and total input are measured in an index form. There are two basic approaches to the measurement of productivity: the growth accounting approach, which is based on index numbers, and the parametric approach, which is based on an econometric estimation of production, cost or profit functions. Total factor productivity indices are constructed to compare performance of a given system at two points in time (inter-temporal TFP indices) or to compare two systems at a given point in time (interspatial TFP indices). If the ratio of total outputs to total inputs is increasing, then the ratio can be interpreted to measure that more outputs can be obtained for a given input level. Productivity, or TFP, captures the growth or changes in outputs not accounted for by the growth or changes in production inputs. Differences in TFP over time or across farming types can result from several factors (Ahearn et al. 1998), such as: (i) differences in efficiency (less than the maximum output is produced from a given input bundle), (ii) variation in scale or level of production over time, as the output per unit of input varies with the scale of production or (iii), technical change. Technical change itself can result from quality improvement in input or quality improvements in the production process. The major problem with the index number approach lies in deriving aggregate output and input measures that represents the numerous outputs and inputs involved in most production processes. The most popular indexing procedure is the Divisia index, which is exact for the case of homogenous translog functions. The translog function does not require inputs to be perfect substitutes, but rather permits all marginal productivities to adjust proportionally to changing prices. Recently several studies used parametric production frontier approach to identify the sources of output growth in agriculture (Fan,1991; Ahmad and Bravo-Ureta,1995; Wu,1995; 1996; Kalirajan and Shand, 1997; *Giannakas et al.*, 2000; and Karagiannis *et al.*, 2004) and output growth is attributed to factor accumulation (input growth), technical change, and changes in technical inefficiency.

Empirical Evidences of Efficiency in Indian Agriculture
A. Land productivity

Productivity growth of crops, at the macro level, measures the land productivity in general. Low growth rate in productivity coupled with low growth rate in area in 90s compared to 80s for all the major categories of the crops resulted in low growth in production as evident from Table 1. What is alarming is that the deceleration in productivity has happened at low average productivity of crops compared to other countries. The average yields of important crops like rice, wheat, maize and groundnuts, etc., are not only lower than the world average but are considerably below the average yield in China, Indonesia and Japan. The average yield of rice in India at 2,890 kg per hectare was less than 50 per cent of the level of the productivity in China (6,059 kg) and Japan (6,354 kg) and lower than Indonesia at 4,179 kg. The case of maize is more striking. Against the average yield of 1,613 kg per acre in India, the average yield in Japan, China and Indonesia were 8,439 kg, 5,210 kg and 5,210 kg respectively.

This decelerating trend in productivity was observable in Kerala and Tamil Nadu also for major crops in 1980s and 1990s and the rate of deceleration was more in 1990s.

Spatially there was wide variation in productivity across crops and states. For example the rice productivity ranges from 3545 kg ha in Punjab to 1480 kg ha in Bihar. It is also interesting to note that Punjab

Table 1. All India compound growth rate in area, production and productivity

Crops	Area		Production		Productivity	
	80-81 to 89-90	92-93 to 01-02	80-81 to 89-90	92-93 to 01-02	80-81 to 89-90	92-93 to 01-02
Food grains	-0.2	-0.2	2.93	1.91	3.13	2.11
Cereals	-0.22	-0.01	3.01	2.08	3.24	2.09
Coarse cereals	-1.15	-1.69	0.77	0.1	1.95	1.73
Pulses	-0.09	-1.07	2.05	-0.41	2.14	0.67
Oilseeds	2.43	-0.82	5.99	0.44	3.48	1.27
Cotton	-1.25	1.7	1.8	0.07	3.08	-1.6
Sugarcane	2.06	1.72	4.15	2.4	2.05	0.68

Source: Govt. of India (2004), Report of the commission for Agricultural Costs and Prices, New Delhi.

with highest productivity in rice only contributed 9.47 per cent of the total production, on the other hand West Bengal which ranks fifth in productivity contributed the largest share of 16.39 per cent in total rice production of the Country. Uttar Pradesh with second largest share in total production of rice stands at eighth place in productivity.

B. Water Productivity

Water is one of the crucial inputs in agricultural production. Agriculture currently consumes 70 percent or more of the world's developed freshwater supplies. The fact that 2000 to 5000 liters of water is required to produce enough food to feed one person each day, underscore the importance of increasing the productivity of water in agriculture. Conventionally water productivity is studied through production function approach that uses water as one of the inputs of production. At macro level water use efficiency needs to be analyzed at various levels as shown in Table 2.

Table 2. Water productivity concerns at different levels

	Crop	Field	Farm	Irrigation system	Basin
Processes	Uptake and use of water and nutrients, Photosynthesis etc.	Tillage, Mode of application, mulching etc.	Choice of crops, season, field channels etc.	Distribution of water to farms, operation and maintenance, charges fees etc.	Allocation across uses, Pollution problems etc.
Scientific Interest	Breeders, Physiologists	Soil scientists, Crop scientists	Engineers and Economists	Engineers and social scientists	Economists, hydrologists, engineers

In India only 40 per cent of the agricultural land is under irrigation and the rest sixty percent area is rain fed. There was a declining trend in irrigated area after 70s, but 90s witnessed slight increase in the growth rate of irrigated area (Table.3). Declining public investment in agriculture is a major constraint in increasing area under irrigation.

Table 3. Compound growth rate of area irrigated in India

Period	CGR(%)
1961-70	2.06
1971-80	2.56
1981-90	1.52
1991-02	1.81

Source: Estimated from FAOSTAT data, 2004.

The declining growth in irrigated area, competing demand for domestic and industrial uses and the fact that 60 per cent of the arable land is still under rain fed conditions calls for efficiency in water use.

Water productivity in agriculture varies across regions and crops. For example the water productivity in rice cultivation is 0.1 to 0.14 kg per cubic meter compared to 0.4 to 0.6 kg per cubic meter in China. The water productivity in rice in India is one of the lowest in the world (Table 4).

Table 4. Water productivity estimates for Rice (1995)

Region	kg per cubic meter	
	Rice	Other cereals
India	0.1 to 0.14	0.32 to 0.41
Sub Saharan Africa	0.10 to 0.25	-
China and South- east Asia	0.4 to 0.6	0.95 to 1.71
Developed countries(average)	0.47	1
Developing countries(average)	0.39	0.56

Source: Cai., (2003) based on IFPRI's IMPACT-WATER[1] model

The Marginal Physical Product (MPP) of water for tomato, maize and cotton are given in Table 5. The Value Marginal Product (VMP)[2] of water varied widely among these crops. It shows the differential productivity of water across crops and the importance of the choice of crops in increasing the water use efficiency. Another source of inefficiency arises from the absence of appropriate pricing mechanism for water. Under pricing of water, through low water charges for canal irrigation or through free electricity for well irrigation, results in allocative inefficiency.

Table 5. Estimates of VMP of irrigation water for different crops in Tamil Nadu

Crops	MPP of water (q)	Price of output (Rs. /q)	VMP of water in agriculture (Rs/ha-cm)
Tomato	1.4227	300	426.81
Maize	0.4722	380	179.44
Cotton	0.3731	2300	858.13

C. Productivity of other inputs

i. Macro Level Trends and Efficiency

Wide disparity in input use across crops is reflected in the variation in productivity differences. The coefficient of variation of per hectare use of different inputs was high across states in rice production. The coefficient of variation was highest in the use of animal power followed by manures, fertilizers and in human labour use. But the states with higher per hectare consumption of inputs are not the ones with higher productivity. For example Karnataka which ranks first in terms of per hectare consumption of fertilizers and human labour ranks only sixth in terms of productivity. Notwithstanding the variation in agro climatic and physical conditions across the states, it is evident that existence of inefficiency in input use is a major cause for low productivity and profitability of agriculture.

The trend in per cent share of input cost in rice cultivation in Tamil Nadu indicate animal power declined about 13 per cent per annum and human labour declined about 3 per cent in the last decade. But cost of machine power and fertilizers increased at an annual rate of 3 per cent and 5 per cent respectively.

Table 6. Compound growth rate of consumption of major fertilizers in India

Period	N	P_2O_5	K_2O	Total
1950-51 to 60-61	16.99	29.98	25.12	19.49
1961-62 to 70-71	22.76	26.36	27.65	23.92
1971-72 to 80-81	9.99	10.56	9.07	9.98
1981-82 to 90-91	7.40	10.14	7.04	8.01
1991-92 to 01-02	3.73	5.32	5.28	4.22

Source: Estimated from the data in 'Agricultural Statistics at Glance (2003)'.

The total consumption of the major fertilizers like nitrogen, Phosphorous, Potash exhibited declining growth rate from 1970s. There was sharp decline in the rate of growth in 1990s during which a series of policy interventions were made in the fertilizer pricing (Table 6). The per hectare consumption of fertilizer among the major rice producing countries is given in Table 7. Our per hectare consumption of fertilizers is more than that of China while productivity is less than that of China. Among the countries listed in

Table 7. Fertilizer consumption and rice yield for select countries (2001)

Countries	Fertilizer Consumption (kg per ha)	Rank in Fertilizer Consumption	Rice yield kg/ha	Rank in yield
Bangladesh	159.6	1	3402	5
China	63.7	7	6152	2
India	95.8	4	3138	7
Indonesia	58.9	8	4388	3
Pakistan	108.4	2	2754	8
Philippines	64.1	6	3187	6
Sri Lanka	103.8	3	3523	4
Thailand	83.7	5	2620	9
USA	47.7	9	7278	1

Source: Estimated from FAOSTAT data, 2004.

Table 7, India ranks 4th in terms of fartiliser consumption but 7th in terms of per hectare yield of rice while China which stands 7th in fertilizer consumption but ranks 2nd in productivity. Similarly, Indonesia which ranks 8th in fertilizer consumption, ranks 3rd in productivity. Average Annual Growth Rate in Fertilizer consumption in India during 1989 to 99 was -0.8 while countries like China, Bangladesh and Pakistan registered positive growth rate during the same period.

Inefficiency in fertilizer use is also reflected in the imbalance in NPK ratio. At all India level the NPK ratio has deviated more from the desirable 4:2:1 ratio in 1990s. Spatially, Maharashtra had the most favorable ratio while Punjab had least favorable ratio (Table 8).

Table 8. Imbalance in NPK Ratio

States	1970s	1980s	1990s
Andhra pradesh	10.19-3.24-1.00	8.86-2.89-1.00	8.00-3.31-1.00
Karnataka	3.01-1.15-1.00	2.78-1.17-1.00	3.22-1.71-1.00
Kerala	1.99-1.00-1.34	1.79-1.00-1.39	1.87-1.00-1.71
Tamil Nadu	3.65-1.00-1.18	3.45-1.00-1.35	2.59-1.00-1.25
Maharashtra	3.66-1.18-1.00	4.03-1.39-1.00	4.76-2.7-1.00
Punjab	15.11-4.86-1.00	18.02-7.18-1.00	54.27-15.66-1.00
India	6.18-1.82-1.00	5.94-1.94-1.00	7.56-2.70-1.00
Desirable Ratio	-	-	4.00-2.00-1.00

Pesticide consumption registered negative growth in the last decade (Table 9). The reversal of trend in pesticide use may be due to popularization of Integrated Pest Management (IPM) strategies, increasing awareness about the health and environmental implications of pesticides, development of resistant cultivars and introduction of more efficient molecules. The consumption of pesticide came down to 275 grams per hectare in 2000-01 from 349 grams in 1974-75. But distribution of certified quality seeds increased at a compound growth rate of 5 per cent per annum in 1991-92 to 2001-02 period. This may be due to increased public and private participation in seed industry in the 90s.

Table 9. Compound growth rate of consumption of pesticides and seeds in India

Period	Pesticides	Certified seeds
1991-92 to 01-02	-5.37	5.00

ii. Micro Level Estimates of Efficiency

While macro level analysis reveal the overall efficiency position, micro level studies throw lights on the crop specific technical and allocative efficiencies. Fertilizer is the major purchased input which had high yield response in the 70s and 80s. It was one of the important driving forces behind green revolution in India. The role of efficiency in fertilizer use hence needs no mention. But yield response to fertilizer declined over years. For example the Marginal Physical Product (MPP) of NPK for rice declined in 80s and 90s as shown in Table 10.

Table 10. Yield response of Rice and allocative efficiency in Tamil Nadu.

Year	MPP			VMP/Pf Ratio		
	N	P	K	N	P	K
1981-82	1.89	10.21	8.53	0.57	2.79	6.05
1989-90	2.92	9.45	8.57	1.10	3.23	8.12
2000-01*	1.13	4.03	2.18	0.75	1.23	1.55

Source: Chandrasekaran(1996) and *estimated from CCPC scheme data.

The allocative inefficiency in nitrogen use is reflected in the ratio of Value Marginal Product (VMP) to factor price in 2000-01. The ratio which was favorable at 1.1 in 89-90 declined to 0.75, which indicate over use of nitrogen. The MPP of Phosphorous and Potash also reduced in this period signaling the declining response. But allocative efficiency of Phosphorus and Potash had increased between 89-90 and 2000-01.

A recent study on pesticide use revealed that output elasticity of pesticide was negative for major vegetables like chillies, brinjal and bhendi. It indicates one per cent increase in the value of chemicals applied above the existing mean level results in decline in yield of chillies, brinjal and bhendi by 0.40, 5.8 and 0.43 per cent, respectively. In rice production, one per cent increase in the expenditure on pesticide increased the yield by 0.06 per cent. But current level of pesticide use was allocatively inefficient as evident from the VMP/pf ratio of 0.81.

Table 11. Output elasticity for pesticide in different crops in Tamil Nadu

Crops	Output Elasticity	VMP/Pf
Rice*	0.06	0.81
Chillies	-0.40	-17.14
Cauliflower	0.20	2.46
Brinjal	-5.80	-7.99
Bhendi	-0.43	-9.51

Source: Jeyanthi(2002) and *estimated from NATP scheme data.

D. Total Factor Productivity

Total factor productivity growth has contributed roughly 1.1 percent per year to crop production growth in India, matching the contribution from growth in conventional inputs since 1956. The high rates of return, particularly to public agricultural research and extension, indicate that the Government of India is not over investing in agricultural research and investment, but rather the current levels of public investment could be profitably expanded (Rosegrant and Evenson, 1995).

Total factor productivity indices[3] for four major crops in Tamil Nadu were presented in Table 12. The TFP index for rice is 1.00. It measures the increase in total output which is not accounted for by increases in total inputs. In other words it is the growth rate in total output less the growth rate in total inputs. The annual growth rate of TFP was very low in groundnut and cotton while the growth rate was better in sugarcane. It emphasizes the need for stepping up research and extension in the crops with lower TFP growth rate.

Table 12. Annual Growth rate of Total Factor Productivity in Tamil Nadu (1971-97)

Crop	Growth rate (per cent per annum)
Rice	1.00
Cotton	0.51
Ground nut	0.31
Sugarcane	1.30

Source: Ramasamy et al (2002)

Strategies to Improve Input Use Efficiency in Agriculture

Identification of the sources of inefficiency and the most efficient uses of inputs and available technologies becomes fundamental to the development process including agriculture, especially in this competitive globalized world. The approach to raising agricultural productivity is multidimensional. Public policies and private initiatives should be aimed at macro and micro levels. Certain issues which has got direct bearing on agricultural productivity is discussed here.

The studies on Total Factor Productivity substantiate the need for increasing investment in research and extension. But Public capital formation which increased at 9.5 per cent in 1970, declined markedly in 1980s and 1990s. This was mainly because a large proportion of the allocation for agricultural sector went to current expenditure on subsidies for fertilizers, irrigation, electricity, credit and other agricultural inputs, rather than investment during this period (Mallick, 1993). Private capital formation though increased over years, the rate of growth was lower in 1990s. But one can not complacent with this because the main factors influencing private investment include the level of public investment, profitability of production and availability of farm credit (Ramasamy, 2004). So there is an urgent need to reverse the trend in public capital formation through suitable policy initiatives.

Productivity of inputs depends upon the level of technology generation and adoption. Many studies support 'fatigue' in green revolution technologies. Biotechnology offers powerful new tools for improving agricultural productivity, environmental quality, and the nutritional quality of staple foods. At the same time, some applications of biotechnology raise concerns of safety, access, and equity in benefits. Development of biotechnology as a component of our strategy to increase agricultural productivity and economic growth needs to be explored.

Most of the productivity measurement framework treats the natural resource stock as static with out accounting the changes in the quality of the resource stock. But the degradation of land and water adversely influence productivity. This is because for a given input bundle, decreases in resource abundance shift the production function, decreasing output. Land degradation, especially soil erosion and depletion of soil nutrients, is widespread. Nearly 175 million hectares were estimated to be affected by different types of degradation. At macro level, integrate the management of 'blue' water – from rivers and reservoirs – with green water – rainfall stored in the soil profile or in aquifers. Take a basin perspective on water productivity. Create policies and institutions to support the uptake of technologies and practices that will improve water productivity and reduce degradation of agro-ecosystems. At micro level agronomic research should be strengthened to increase water productivity. Conservation strategies should be built right from the individual farm level to the national level policies.

Precision farming is an integrated agricultural management system incorporating several technologies. The technological tools often include the global positioning system, geographical information system, yield monitor, and remote sensing. At farm level precision farming techniques needs to be popularized to increase the input put use efficiency and to reduce environmental pollution from agrochemicals.

Most efficient use of technology and inputs becomes fundamental in accelerating agricultural development. It is also vital to improve the living conditions of small family farm households and integrate them into the market as competitive members.

Notes

1. IMPACT-WATER model accounts the relationships between water availability and food production at various spatial scales, from river basins, countries or regions to the global level, over a 30-year time horizon.

2. If VMP/Pf ratio is < 1, allocative efficiency is improved by decreasing use of the particular input and vice versa. Value of Marginal Product (VMP) = Marginal Physical Product (MPP) x Price of Output; Pf = Price of factor/input.

3. YLD = a + b WATER + c OTHER COST+ d LABOUR, Where YLD is yield in Quintals, Water in ha cm, other Costs and labor in man days. Estimated as log-linear function.

4. Total factor Productivity is computed through Tornqvist-Theil TFP indices.

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Weather based forewarning models for efficient crop protection

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Introduction

About 30 per cent of the food production in the country is lost due to attack of insect pests and diseases. Of this loss in food production, losses by weeds are 33 per cent and by diseases 26 per cent, by insects and rodents 26 per cent, with birds; nematodes, etc. accounting for rest. So far, use of pesticides dominated the pest control strategies in India. The average consumption of pesticides in the country has gone up from 3.2 g/ha in 1954-55 to 640 g/ha (David, 1986). The indiscriminate use of pesticides led to problems of pest resistance to chemicals, resurgence of pests and risks to human and animal health besides environmental pollution. The strategy of Integrated Pest Management (IPM) has emerged with the sole objective of reducing losses from pests with minimum ecological implications. Weather based prediction and control of pests is a part of the broader integrated pest management strategy.

Though these sporadic studies on weather and pest/disease relationships proved to be important in understanding the role of weather on pest/disease dynamics, they served a limited purpose. There is an urgent need to forecast the occurrence of pests and diseases based on the prevailing weather conditions for serving a better purpose by providing lead time and saving on resources of farming community. Previous research results it is feasible potential occurrence of an epidemic has been established in case of a number of pests and diseases in other countries. Weather-based warnings have been reported to have led to a saving of 2½ billion francs per year in France due to judicious use of sprays in grape against viny mildew (Venkatraman, 1992).

Pesticide consumption statistics show that crops like cotton and rice receive >70 per cent of pesticides sold in India. Often indiscriminate use of pesticides is resorted to by farming community due to lack of awareness of the minimum threshold values and weather conditions conducive or otherwise for pest outbreak. There is thus a need to develop weather based prediction models for diseases and pests for minimising the use of pesticides and degradation of environment. For further systematic studies towards understanding the relation between weather and pests a mission mode project was formulated under the aegis of All India Co-ordinated Research Project on Agricultural Meteorology (AICRPAM), with Central Research Institute for Dryland Agriculture (CRIDA) as its main lead centre. The project aims at development of weather based forewarning models based on historical data for identified pests and diseases under six target crop programmes namely cotton, rice, groundnut, sugarcane, pigeonpea and mustard. The project is being implemented at 6 lead centres, 14 co-operating centres and 4 co-operating institutions with main lead center being AICRPAM, CRIDA, Hyderabad. Testing and refinement of the models was done using the data generated during the project period through field experiments and farmers' field surveys.

Materials and Methods

Long-term data (Historical data) of pests and diseases of six crops was collected to accomplish one of the objective of the project i.e. creating a database of the long-term data which is a pre-requisite for developing any model. Field experiments were conducted at twenty centres to generate data sets for development of models on pests and diseases. Further real time farmers' field surveys were also carried out to assess the pest and disease situation in field. The data collected was subjected to statistical analysis and different models were developed i.e. regression models for quantitative data (Yellow stem borer on rice, rice leaf blast, bacterial leaf blight of cotton, gram pod borer, pod fly, phytopthora blight on pigeonpea and mustard aphid), simple weather based prediction rules, (rice leaf blast, pink bollworm on cotton, gram pod borer on pigeonpea), neural network model (Yellow stem borer on rice), decision support model (late leaf spot on groundnut), logistic model for qualitative (Pyrilla on sugarcane) and degree-day model (mustard aphid). A brief description of the model along with validation for some of the models are presented.

Results

Prediction of Yellow Stem Borer (YSB) in Rice

Long-term YSB adult population from 1975-2002 was collected and subsequently analyzed for predicting the YSB population. The analysis of 27 years YSB population during *kharif* indicated that the peak adult population period was in the months of September, October and November. Therefore an attempt was made to predict the adult YSB population during the above mentioned months.

The regression model developed for the month of October is given below:

$$YSB_{Oct} = 27566 + 172\,A_{20RF} + 0.86\,YSB_{Sep} + 3202.5\,J_{10RD} + 625\,A_{30MaxT} + 470\,J_{10MinT} - 140\,A_{10MaxT} + 14\,S_{10RH2}$$

$R^2 = 0.96$

Where:

YSB_{Oct} = YSB population in the month of October
A_{20RF} = Average of August 10 to 20 rainfall
YSB_{Sep} = Average YSB population in the month of September
J_{10RD} = Average of July 1 to 10 rainy days
A_{30MaxT} = Average of August 20 to 30 maximum temperature
J_{10MinT} = Average of July 1 to 10 minimum temperature
A_{10MaxT} = Average of August 1 to 10 maximum temperature

The actual and predicted values of YSB in October at Hyderabad is presented in Fig.1.

Fig. 1. Actual and predicted values of YSB in October at Hyderabad

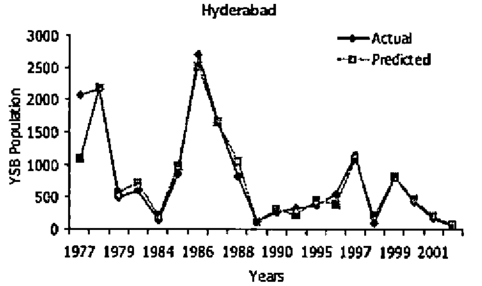
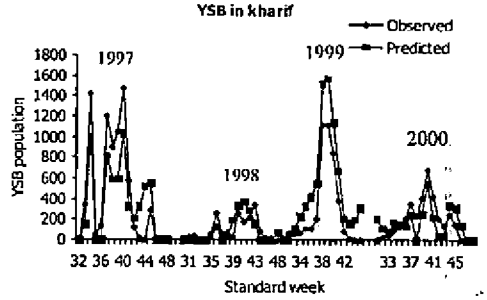


Fig. 2. Validation of neural network model on rice YSB in kharif



Neural Network Model for Yellow Stem Borer

Data mining-technique was also applied to analyze the long-term data on trap catches of Yellow stem borer and established association rules between trap catch and weather. The neural network was trained with YSB data from 1975-96 and subsequent years data (1997-2000) was used for validation as independent data sets. The neural network model was able to predict the occurrence of YSB peak incidence one week in advance. The validation of neutral network model on rice YSB in kharif is presented in Fig. 2.

Prediction equation developed for rice leaf blast at Palampur

A prediction model was developed using 8 years data (1991-1996 and 1998-99) from HPKV, Palampur.

$$\text{Leaf blast}_N = -29.3 + 0.96\ \text{Blast}_c - 0.006\ \text{CumRF} - 0.02\text{BSS} + 0.012\ \text{MRh} + 1.7\ \text{MinT}\ (R^2 = 0.89)$$

Where

Leaf Blast_N	= % Rice blast incidence after one week
Blast	= % Blast incidence in current week
CumRF	= Cumulative rainfall from August 1st week to current week
BSS	= Average Bright sunshine hours of current and previous week
MRh	= Average relative humidity of current and previous week
Min T	= Average minimum temperature of current and previous week

The equation developed was validated with the rice blast data sets of 1997 and 2000

Simple prediction rules for rice blast

The following criteria were developed at HPKV, Palampur for predicting leaf blast incidence in the Kangra district of Himachal Pradesh.

Y= 10-30% (TN*) or 5-10% (TP)

Where

Y= Disease variable TN = Trap nursery TP = Trap plant

* On susceptible cultivar at 15 days interval starting from 1st June.

If RH ≥ 80%, T_{min} 16-19°C and T_{max} < 28°C for 5 to 6 days or cloudy weather and 5-6 rainy days in a week prevails, disease can occur. This method is being used for predicting blast occurrence in Agro advisories in the Kangra area.

Cotton

Prediction rules for pink bollworm

The weather and pheromone trap data of pink bollworm from 1983-96 at Nagpur were analyzed to identify weather factors responsible for out break/severity of the pest. The earlier work done was also consolidated compiled through global literature survey. Using all the information, the following weather based criteria and prediction rules were developed.

Criteria		**Condition**
A	Total Rainfall during 32-40 met. Week	<500mm
B	Total Rainfall during 41-52 met. Week	>20mm
C	Average Tmax during 41-52 met. Week	<33°C
D	Average RH during 41-52 met. Week	>70%

Prediction rules

Case 1 If all the above criteria are satisfied- the pest incidence is expected to be **Severe**
Case 2 If two or three criteria are satisfied- pest population is expected to be **Moderate**
Case 3 If none or one criterion is satisfied pest incidence is expected to be **Low.**

The predicted pest levels were found to close to that of observed levels in 10 out of 13 years at Nagpur. The rules thus can be used to forewarn pink bollworm **based on weather forecast.** The prediction rules were also validated with pheromone trap data (2001 & 2002) collected from 4 cotton centres.

Model for prediction of bacterial leaf blight on cotton

Long-term data from 1982-1994 on bacterial leaf blight was compiled and an empirical model for predicting the occurrence of bacterial leaf blight **one week in advance** was developed using previous week's and current week's incidence level and 3 week moving averages of minimum temperature and rainy days. The equation developed is as under

$$BLB_N = 20.138 + 0.68\,BLB_C + 0.147\,BLB_P - 0.0251\,\text{Min T} - 0.423\,\text{SW} + 1.483\,\text{RD} \quad (R^2=0.74^{**})$$

Where

BLB_N = Expected bacterial leaf blight incidence (%) in next week

BLB_C = Bacterial leaf blight incidence (%) in current week

BLB_P = Bacterial leaf blight incidence (%) in previous week

Min T = Average minimum temperature of past 3 weeks

SW = Standard week number

RD = Average rainy days of past 3 weeks

Groundnut

A decision support model for prediction of late leaf spot on groundnut

A computerized decision support model was developed to predict the disease initiation and progress of late leaf spot in groundnut. Inputs for the model are i) Daily weather data viz., maximum temperature, minimum temperature, relative humidity (morning), relative humidity (evening), sunshine hours and rainfall ii) Plant age and iii) Disease inoculum potential. Daily environmental conditions are classified according to conduciveness for late leaf spot development from June to October.

This model is based on a three-day summation of risk values assigned to each parameter. Based on favorable conditions each parameter is assigned risk values viz., 1,2, and 4. These values are accumulated for three consecutive days. Based on the accumulated risk values the three-day period is classified as **favorable, semi-favorable and unfavorable** for disease initiation. Once the disease initiation occurs this model predicts the disease progress and level of the disease (**Severe, moderate,** low or '**No**' disease) for next week.

The model was developed for late leaf spot incidence during *kharif* season using data collected on TMV-2 variety at Tirupati. This model assumes that inoculum is always present in the air. Whenever favorable weather condition occurs in the appropriate growth stage of the crop i.e. flowering stage (from 35 days after sowing), the disease initiates and develops rapidly. Java software was used to develop this model. The programme provides the user with greater flexibility because the parameter values of the model can be altered within user set boundaries and also to use/fit the model for different locations. The model was validated using data from Tirupati (1996-2000), Vriddhachalam (2001) and Coimbatore (2001).

Groundnut leaf miner model

The model is developed for leaf miner incidence using data collected on TMV-2 variety during *kharif* season cultivation in the Pavagada - Sirsa region of Karnataka by IISc, Bangalore. In the model it is assumed that leaf miner population is continuously present at a low level. Whenever favorable weather conditions occur in the appropriate growth stage of the crop, pest population builds up rapidly. However, if a drenching shower (> 2 cm/day) occurs in the first 14 leaf miner days (starting 35 days after sowing), it is assumed that the leaf miner is eliminated. In this model the loss in crop yield due to leaf miner incidence is taken to depend upon the number of leaf miner days. Leaf miner day (LMD) is defined as a non- rainy day with dry soil (< half of the available soil moisture). Inputs to the model are Weather (Daily) - Max T, Min T, wet bulb temperatures and rainfall; Soil – Depth, field capacity, permanent wilting point and daily soil moisture; Crop – Date of sowing & variety. Leaf miner incidence period and % yield loss are the outputs.

Sugarcane

Logistic model for *Pyrilla*

A simple logistic model was developed from historical database (1977-1988) collected from Muzaffarnagar, western UP. Low population of the pest infestation has been classified as non-occurrence (y=0) where as medium and high populations have been clubbed together as occurrence (y=1). Models were developed using weather data from May to November. The model description is given below

$$P(Y=1) = \frac{1}{1+e^{-Z}} + e$$

Where

$Z = a + bX + bX$
X = Maximum temperature
X' = mean RH, e is random error distributed as $N(0, \sigma^2)$
P = Probability of occurrence of the event

Prediction Criteria

If P ³ 0.5 the decision is that.pest is likely
P < 0.5 pest not likely
The predictions from the model were validated with observations recorded for 1989, 1990 and 1991.

Pigeonpea

Models were developed for historical annual pest incidence data at Kanpur (single point data during the crop season) available for pod borer, pod fly and *Phytophthora* blight.

Model for *H.armigera* damage on early pigeonpea at Kanpur

Annual incidence data of gram pod borer in early pigeonpea at Kanpur for the period 1985-86 to 1997-98 (13 years) was correlated with weather data up to 5 weeks lag (from week of forecast). The equation for example developed for 39th SW (last week of September) based on the point data is as under

$$Y_{39} = -76.23 + 0.01\,Z_{13} - 0.09\,Z_{15} + 0.04\,Z_{45} + 1.33\,Z_{1} \quad (R^2=0.91)$$

Where

X_1 = Max. Temp. X_2 = Min. Temp X_3 = RH 1
X_4 = RH 2 X_5 = Rainfall Y = Mean % pod damage
Z = Composite index as weighted accumulation, weights being correlation coefficient or weighted accumulation of product of two weather variables.

Model for prediction of podfly damage on late pigeonpea

Based on annual incidence data of podfly in late pigeonpea at Kanpur for the period 1985-86 to 1996-97 (12 years) and up to 4 weeks lag weather data, pod fly damage for example in 50th SW (second week of December) could be predicted using the equation:

$$Y_{50} = -89.29 + 0.10\,Z_{12} + 0.02\,Z_{13} + 0.08\,Z_{24} \quad (R^2=0.71)$$

Where

X_1 = Max. Temp. X_2 = Min. Temp X_3 = RH 1
X_4 = RH 2 Y = Mean % pod damage
Z = Composite index as weighted accumulation, weights being correlation coefficient or weighted accumulation of product of two weather variables.

A weather based rule for prediction of *Helicoverpa armigera*

Based on the analysis of 6 years data (1982-83 to 1988-89) on average weekly catches of adult male moth of *H.armigera*, a simple rule was developed to predict the build up of moth population and subsequent infestation of pod borer in long duration pigeonpea crop at Kanpur. Further analysis of 8 years data (1989-90 to 1995-96 and 2000-01) has enabled to modify the rule. According to the modified rule *"A sudden rise in the minimum temperature (>5°C) around 7-8 standard weeks and rainfall during 1-9 standard weeks along with a considerable adult moth population (above 15 per week) during 5-7 standard weeks trigger a major rise in the pest population during 10-14 standard weeks"*. (5 Weeks advance forecast)

This prediction rule was validated at Kanpur during years 2001-02, 2002-03 and 2003-04. The validation revealed that during 2001-02, only one factor (rainfall) was positive hence the population of moth and pod borer damage was estimated to be low (observed population was also low during 10-14 standard weeks). In contrast, During 2002-03 all the three factors (rainfall, sudden rise in minimum temperature and good base population) were positive predicting a high pest infestation, the population actually observed was also very high indicating the validitity of the forecast. During 2003-04 only two factors (rainfall and base population) were in agreement and a moderate infestation was expected according the prediction rule. Although the maximum moth population was slightly higher, the overall damage to the crop has been recorded to be only moderate in 2003-04.

Mustard

A day-degree model for forewarning mustard aphid*

Based on the analysis of 9 years data, a hypothesis "aphid population in a year would be more when the degree-day accumulation is slower during January and vice versa" based on temperature sum starting from 1st January has been proposed. To enable early prediction using lesser period data the lowest and highest rates of accumulation of heat units for three cut-off dates over the years were considered, for study. The observed infestation levels at three locations based on accumulated GDD for 15, 20, and 25 days during 2002 are presented below. It can be seen that even by 15th or 20th January, using accumulation of GDD it is possible to predict the intensity of aphid population expected one month later (in February).

Models for predicting population dynamics of mustard aphid

Using weekly data on weather parameters starting from week of sowing up to 50th SMW (2nd week of December) for several years, models for forecasting time of first appearance of aphid, time of maximum aphid population and amount of maximum aphid population were developed for Behrampur, Pantnagar, Hissar, Ludhiana, Morena & Bharatpur (taken together as they fall in the same agro-climatic zone) and Kanpur. The weather variables considered were maximum temperature (MAXT), minimum temperature (MINT), maximum relative humidity (RH1), minimum relative humidity (RH2) and bright sunshine hours (BSH) – [X_1 to X_5].

For Morena & Bharatpur the models are based on only first four variables. For Kanpur, the variables considered were maximum temperature (MAXT), minimum temperature (MINT), mean relative humidity (RHM), wind speed (WS) & evaporation (EV) – [X_1 to X_5]. The results from the models, using both weighted and unweighted indices, are given in Tables 1, 2 and 3.

Table 1. Models for forecasting crop-age at first appearance of aphid

Centre	Model	R^2
Behrampur	$Y = -32.75 + 0.009 Z_{121} - 0.73 Z_{20}$	0.99
Pantnagar	$Y = 431.04 + 2.68 Z_{31}$	0.56
Hissar	$Y = 56.72 + 0.029 Z_{241} + 2.74 Z_{11}$	0.60
Ludhiana	$Y = 198.12 + 0.14 Z_{351} + 0.08 Z_{451} - 0.011 Z_{130}$	0.92
Morena & Bharatpur	$Y = -112.91 + 0.02 Z_{131} + 4.98 Z_{11}$	0.71
Kanpur	$Y = 7.96 + 0.42 Z_{241}$	0.86

Table 2. Models for forecasting crop-age at maximum aphid population

Centre	Model	R^2
Behrampur	$Y = 52.48 + 0.02 Z_{121} + 1.58 Z_{51}$	0.84
Pantnagar	$Y = 53.75 + 0.02 Z_{120}$	0.56
Hissar	$Y = 102.19 + 0.30 Z_{121} + 1.20 Z_{50}$	0.85
Ludhiana	$Y = -133.56 + 0.09 Z_{241}$	0.67
Morena & Bharatpur	$Y = 77.1 + 0.03 Z_{121}$	0.63
Kanpur	$Y = 74.07 + 0.04 Z_{231}$	0.92

3. Models for forecasting maximum aphid population

Centre	Model	R²
Behrampur	$Y = 327.34 - 0.039 Z_{230} + 0.06 Z_{141}$	0.99
Pantnagar	$Y = 168.81 + 3.40 Z_{241} + 101.22 Z_{21}$	0.82
Hissar	$Y = 88.47 + 5.03 Z_{121} - 0.33 Z_{450}$	0.98
Ludhiana	$Y = -6114.29 + 9.46 Z_{30} + 3.55 Z_{451} + 113.07 Z_{11} + 2.56 Z_{131}$	0.95
Morena & Bharatpur	$Y = 690.77 + 79.29 Z_{21} - 0.019 Z_{340}$	0.65
Kanpur	$Y = 7531.96 + 882.83 Z_{41} - 0.65 Z_{130}$	0.75

Note: Z = Composite index as weighted accumulation, weights being correlation coefficient of one weather variable or weighted accumulation of product of two/three weather variables.

Future Goals

With regards to model development and operational use, it is felt that empirical models already developed could be validated before their operational use in the coming seasons. This would be a short-term goal. However, in the long run the approaches to be adopted could be:

1. With regard to forewarning of insect pests, **development of crop-wise and pest-wise insect phenology models** that have the advantage of being generally applicable to most environments need to be attempted. This would entail a systematic effort to collate existing information on stage-wise rates of development of key insect pests in relation to weather. Where such information is lacking it is necessary to initiate such studies. The idea is to develop models based on biological and physical processes. Such models would have wider applicability across locations whereas purely empirical models would be more location specific.
2. With regard to forewarning of diseases, models should again be based on biological and physical processes. Further sufficient understanding and quantification of how interactions change under varying environmental conditions is essential. **Reliable algorithms** are needed to compute variables that are not directly measured from standard weather stations such as surface leaf wetness, which is an important variable for disease models.
3. **Crop system models** can be used to generate information on the status of crop, its pests/diseases and its environment under different scenarios, including different management options. However, at present there are few examples of these models world over that can include all the necessary components and can be used for practical decision-making. However, efforts could be made by modeling groups to analyze individual crop and pest components separately at the same time to give information that can improve decisions.
4. There is a need to transform the outputs of quantitative tools and scenarios resulting from models into management recommendations for dissemination and operational use through agro-advisories.

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Role of weather in input use efficiency under the humid tropics

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Weather plays a vital role in input use efficiency depending upon the phenology of crop if other environmental factors are not limiting. There should be enough and sufficient soil moisture for efficient utilization of nutrients by plants. Even the soil moisture is optimum, the uptake of nutrients is restricted by plants if evapotranspiration is less, which is driven by principal weather variables viz., solar radiation, air temperature, vapour pressure deficit and wind. It is the case in the humid tropics during the monsoon period in which rainfall is high and sunlight is low, thereby evapotranspiration is restricted. In addition, waterlogging is seen in mid-and-low lands during the monsoon period. It may restrict aeration in the root zone system, which may adversely affect the input use in plants. During the summer, the reverse takes place. If the sunlight is the maximum and soil moisture is limited, the available nutrients in the soil may not be available to plants. The efficiency of input use is better in crops provided enough sunlight is available under optimum soil moisture conditions. Keeping this in view, an attempt has been made to understand the weather constraints and suggest various agrmeteorological tools, such as rainfall and potential evapotranspiration for defining crop growing season, dynamic crop simulation models, optimum time of sowing/transplanting and right time of application of inputs based on crop phenology (which is influenced by weather variables) and light regimes, for better input use efficiency in the humid tropics. The crops chosen for the study were rice, cashew, cocoa, coffee and coconut depending upon the nature of crop and availability of literature.

1. Crop growing season

Though the rainfall is the main source for water supply of plants, the plant growth does not depend on rainfall alone, but it should balance the evapotranspiration of crops. Based on rainfall and potential evapotranspiration, crop growth periods can be adjusted. For most of the crops, the period during which the rainfall exceeds the PET is the best suited for the maximum growth period. Of course, this is the period during which surplus rainfall leads to run off and in the absence of drainage facilities, the crops are subjected to waterlogging and it is detrimental to crops. The early vegetative phase including sowing period and the later phase that is ripening period can be adjusted when the rainfall is less than PET (the rainfall should be at least 50 % of PET). The above conditions hold good in India wherever seasonal crops are grown only under rainfed conditions. At the same time; it does not hold good under rainfed conditions in the humid tropics since rainfall is abundant during the monsoon season. The

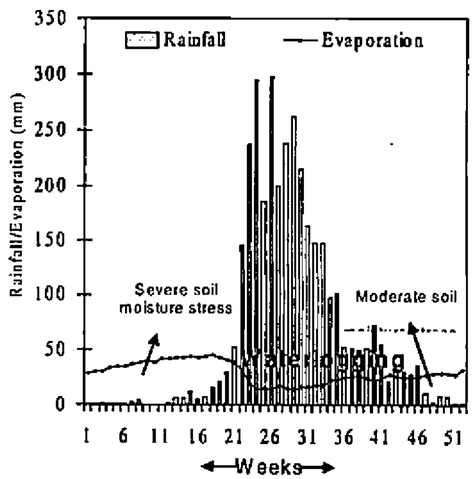


Fig. 1. Weekly rainfall and evaporation at RARS, Pilicode (12° 12'N and 75° 10'E) – A model in the humid tropics

surplus water during the first crop season leads to waterlogging which is detrimental to crops. The second and third crops suffer due to soil moisture stress and crop failure is a common phenomenon during the above seasons if irrigation is not assured. The irrigation schedule or surplus water could be determined based on precipitation and potential evapotranspiratiaon of a particular location (Fig 1). In case of plantation crops, the length of crop growing season based on precipitation and potential evapotranspiration is not applicable as they grow round - the- year. However, the assured weekly rainfall and its probability and occurrence of dryspells during monsoon will help in choosing the best time for application of nutrients under rainfed conditions so that the use efficiency in intake of nutrients is much better.

2. Crop growth simulation models

Input use efficiency is a very complex phenomenon, which is dependent on several factors viz., abiotic stress, biotic stress and the genotype. When the genotype interacts with season, the crop phenology varies depending upon the time of planting. The genotype may be of different in nature viz., long day, short day and day- neutral plants and respond differently to different agro-climatic types depending upon the geographical location. It also may depend on length of crop growing season in case of seasonal crops. The abiotic stress may be due to crop management practices, soil factors and weather aberrations, which influence the plant nutrient use efficiency to a large extent. When the soil and crop management factors are not limiting, weather plays a predominant role in terms of optimum time of planting, thermal regime, light regime, water regime and crop growing season (Fig 2). The optimum time of planting can be simulated along with various phenological events, nutrient management and biomass production using IBSNAT – DSSAT – CERES models in case of seasonal crops. Several such simulation models are in use inside and outside the country for agrotechnology transfer. DSSAT v3.5 was used in case of rice for obtaining optimum time of transplanting in central part of Kerala, which is discussed in the next section under optimum time of planting.

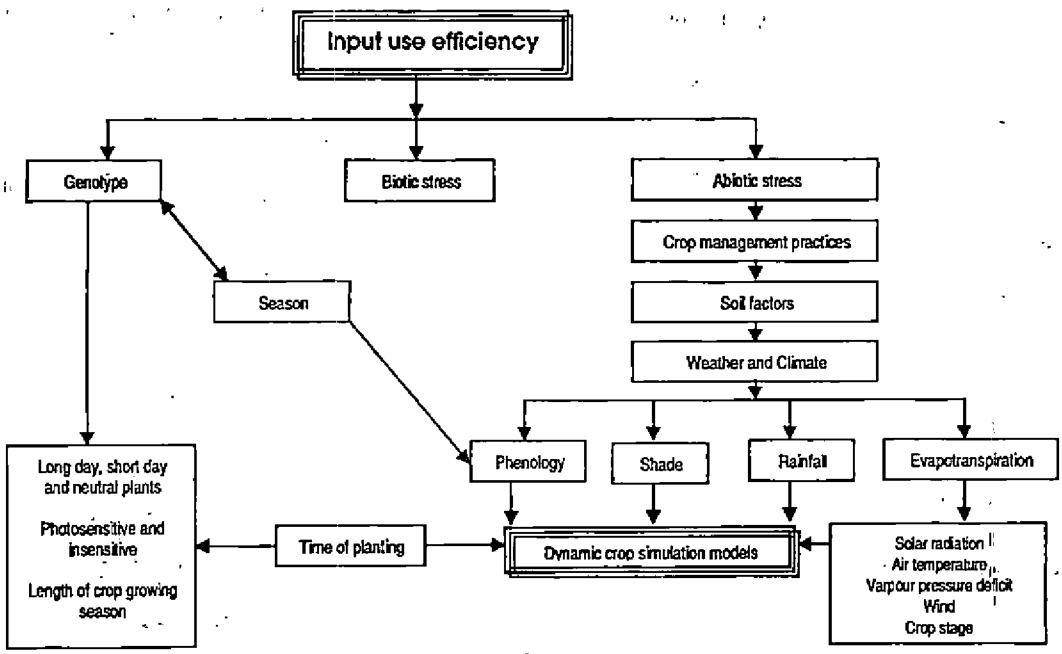


Fig. 2. Role of dynamic crop simulation models in input use efficiency

IBSNAT- International Benchmark Sites Network for Agrotechnology Transfer
DSSAT – Decision Support System for Agrotechnology Transfer .
CERES – Crop Estimation through Resources and Environment Synthesis

2.1 Optimum time of planting

In photosensitive rice cultivars, the crop duration is short when the time of transplanting is delayed, resulting in low grain yield. In case of local cultivar Allikkannan, the grain yield was 3.66 t/ha when transplanted on 8th June while it was only 1.36 t/ha when transplanted on 20th July (Table1), indicating a drastic decline of 62.8 % in grain yield. It is not the case with photoinsensitive varieties as they respond to light regime when other environmental factors are not limiting though the variations in grain yield are not uncommon with the time of transplanting or season.

Table 1. Effect of time of planting on crop duration and grain yield of Allikannan (1984 -1988)

Time of planting	Crop duration (No. of days)	Grain yield (t/ha)	Percentage decline in grain yield
8th June	144	3.66	-
22nd June	139	2.92	20.2
6th July	131	2.30	37.2
20th July	126	1.36	62.8

(Source: Rao, 1994)

The delay in time of planting on grain yield was not conspicuous in all the three-photoinsensitive varieties tested during *kharif* and *rabi* unlike in case of photosensitive varieties (Table 2). The study at RARS, Pattambi revealed that the content and uptake of nutrients by the crops was uniform and satisfactory and it could not be attributed as a reason for the high spikelet sterlity. It was the reason for wide variation in grain yield among the different dates of transplanting (Table 3). The spikelet sterility was attributed to strong winds prevail from 15th November to 15th January due to Palghat Gap in the central part of Kerala. It was suggested that low nitrogen dose and application of silicate fertilizers might be conducive against high spikelet sterility in addition

Table 2. Effect of time of planting on grain yield of rice at Pilicode (1992-93 to 1994-95)

Season	Time of planting	Grain yield (t/ha)		
		Jaya	Jyothi	Thriveni
Kharif	8th June	4.4	5.4	4.5
	15th June	5.1	5.7	5.1
	22nd June	4.5	5.0	4.8
	29th June	3.9	4.6	4.4
	6th July	4.1	5.1	4.6
Rabi	15th October	3.6	4.0	4.1
	22nd October	4.1	4.7	5.2
	29th October	4.3	4.3	5.4
	5th November	4.8	4.1	5.4
Average grain yield (t/ha)		**4.3**	**4.8**	**4.8**

(Source: KAU, 1996)

Table 3. Effect of time of planting on grain yield (t/ha) at Pattambi from 1983-84 to 1985-86

Time of planting	Grain yield (t/ha) in test varieties				
	Bharathi	Jaya	IR8	IR20	Mean
Aug 22	3.5	3.7	3.4	3.8	3.6
Sept 5	3.8	3.5	3.1	3.1	3.4
Sept 18	3.1	3.1	3.2	3.4	3.2
Oct 3	3.2	2.8	2.4	2.9	2.8
Oct 16	2.2	2.6	2.9	3.2	2.7
Oct 30	3.3	3.5	3.4	3.9	3.5
Nov 12	3.9	3.2	3.0	3.8	3.5
Mean	3.3	3.2	3.1	3.4	3.2

(Source: Viswambharan *et al.*, 1989)

to windbreaks in rice fields. However, studies in detail are to be taken up in this direction to highlight the nutrient management against high winds.

The time of transplanting versus grain yield were simulated using DSSAT v3.5 CERES – Rice model using daily rainfall, sunshine, maximum and minimum temperatures, collected at the State Seed Farm, Alathur, Palghat District. The test variety was Jyothi. The simulated grain yield in rice across the Palghat District is relatively less if the transplanting is taken up after 25th September under rainfed conditions. The simulated grain yield is less up to 50 per cent if the transplanting is taken up after 10th October (Fig 3). It is possible because the reproductive and ripening phases of the crop will be under severe soil moisture stress under rainfed conditions if the time of transplanting is delayed further. The potential grain yield and phenological events were also simulated across the State of Kerala (Saseendran *et al.*, 1998 and Rao *et al.*, 1999) using the CERES-Rice model. The multidisciplinary group for decision making at farm level for agrotechnology transfer can use it.

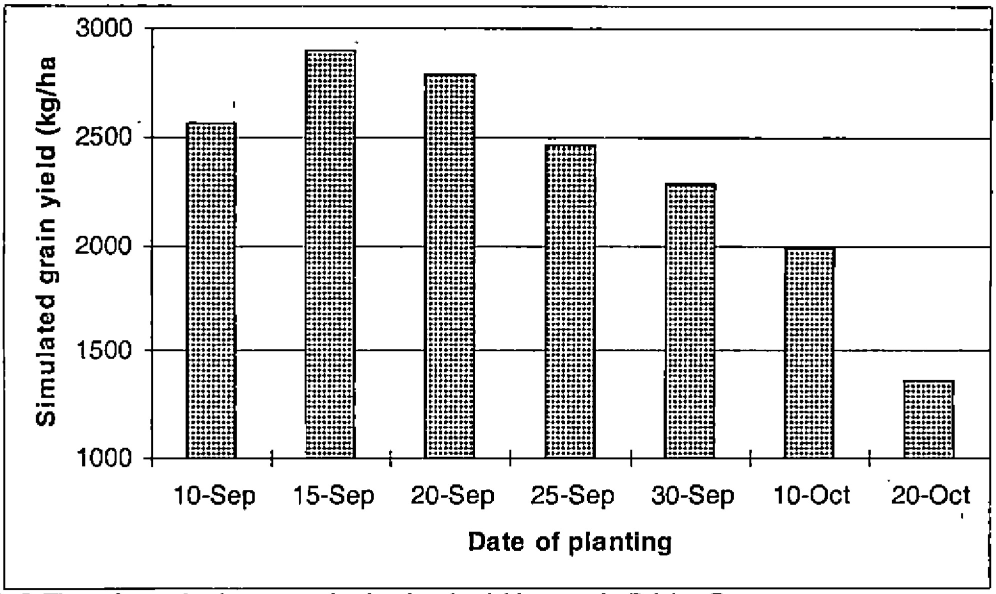


Fig 3. Time of transplanting versus simulated grain yield across the Palghat Gap

3. Dry spell versus bud break in cashew

On an average, a dry spell of 12 to 16 days (may be continuous or intermittent with one or two showers) was noticed prior to bud break of cashew depending upon genotype. There was no significant difference in duration of dry spell prior to bud break among the four test varieties. A dry spell of five to nine days was also noticed 27 to 32 days prior to bud break (Table 4). In both the cases, the mean number of bright sunshine hours varied between 6.20 and 8.51 h/day. It revealed that the occurrence of dry spell 30 days prior to bud break may be the right time for application of fertilizer as the initiation of primodium takes place during that time though the bud break in cashew is seen visually after 30 days of its physiological stimuli.

Table 4. Occurrence of dry spell and bud break of cashew at RARS Pilicode

Variety	Occurrence of dryspell prior to bud break	Occurrence of dry spell one month prior to bud break	Duration of dry spell one month prior to bud break
Ank-1	15 days	32 days	5 days
Mdk-1	12 days	31 days	5 days
Mdk-2	16 days	27 days	9 days
Kanaka	13 days	28 days	6 days
Mean	14 days	30 days	6 days

(Source: Rao, 2002)

A close examination on the daily distribution of rainfall from August to December during 1995, 1996, 1997 and 1998 (Fig 4) indicated that early cessation of rains and intermittent dry spells between August and September, 1995 might have led to early bud break in cashew during that year.

In contrast, it was not the case during 1998, which led to delay in bud break of cashew. However, the delay in bud break of late variety was distinct as seen in MDK-2 during 1997. It might be due to the distribution of rainfall between November and December. Such studies provide an insight into application of fertilizers in right time so that better use efficiency of inputs can be obtained.

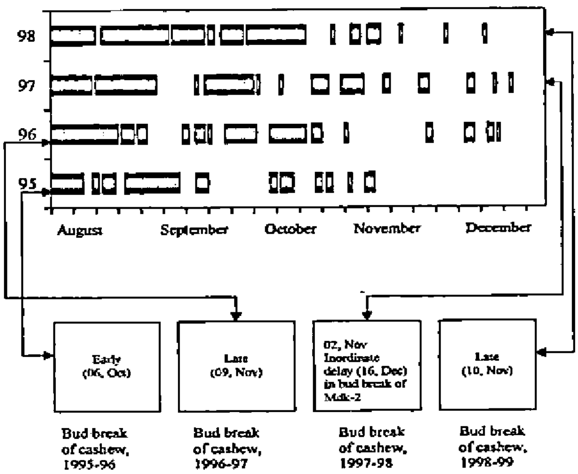


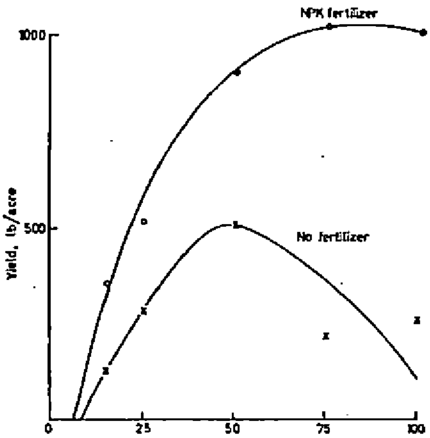
Fig. 4. Occurrence of bud breaks in cashew from 1995-96 to 1998-99 at RARS, Pilicode

4. Nutrients and light regime in cacao

In a unique experiment in Trinidad, Murray (1972) found that cacao yields are low with heavy shade, and increase with increasing light up to the 50 per cent level of light. Above this level, yield is affected by the presence or absence of fertilizer. With added fertilizer, yields increase almost up to full light, whereas in the absence of fertilizer yields fall off (Fig 5). The theory has therefore been advanced that the light regime for optimum yield of cacao is a function of its mineral nutrition. It is also suggested that the agronomic problem of fertilizer requirement cannot be decided without knowledge of the micrometeorology of the trees' environment. In contrast, studies in coffee indicated that the internodal length and leaf area in test varieties were much better under shade when compared to that of open in low night temperature conditions during winter. It reveals that the nutrition management is a function of light and thermal regimes depending upon the crop if the soil moisture is enough to maintain it.

5. Season versus nutrient uptake in coconut

Heavy rains during the monsoon and prolonged dry spell during summer are the major climatic constraints for not obtaining better coconut yield in the humid tropics like Kerala. This phenomenon is more predominant towards northern districts of Kerala. Studies revealed that irrigation and manuring of the existing coconut gardens alone have been found to double the present coconut production in the State. In this context, the use of efficiency of inputs play a major role in increasing coconut productivity as there is only limited scope for expansion of area.



Degree of shading, percent of full daylight transmitted

Fig. 5. Effect of fertilizer application on yield of cacao grown at different light levels; 3-year-old plants

Nitrogen content of the coconut leaf declined with the onset of monsoon and increased following the application of fertilizers in September (Fig 6). Heavy leaching of soil N during the rainy months of June to October must be responsible for the reduced uptake of soil N by the palms. Unlike N, there was a steady absorption of K by the palm with the onset of monsoon, which declined, however, in December (Wahid *et al.*, 1988). Probably, the low N uptake during the rainy season may be the causal factor for negative correlations between rainfall during the southwest monsoon and nut yield in the following year (Patel and Anandan, 1936 and Rao, 1988). Unlike other crops, nuts are produced every month in coconut with a long reproductive phase of about 44 months, commencing from primodium initiation to nut harvest and it is a continuous process in steady bearing coconut palms. In such a continuous reproductive phase, the time of application of N fertilizers could be at any time, avoiding heavy monsoon with low light regime for better input use efficiency in the humid tropics. By providing drainage facilities during the monsoon period, the nut yield also could be increased as waterlogging and consequent lack of aeration of soil may restrict the efficiency of input use.

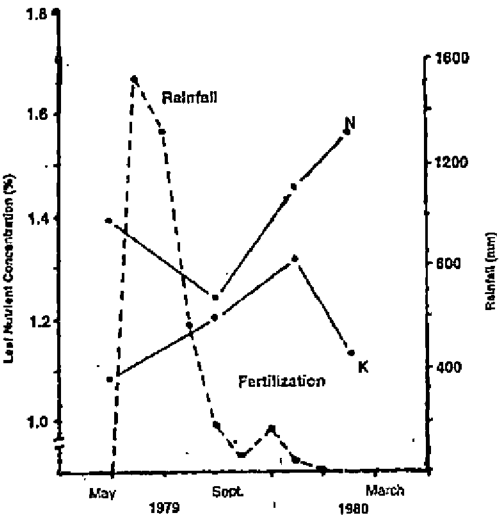


Fig. 6. Seasonal variations in nutrient concentration in the coconut leaf

Conclusions

Low light regime due to overcast sky in addition to high rainfall during the monsoon (June-September) and insignificant rainfall from December to May are the major weather constraints across the humid tropics like Kerala. High wind is another constraint across the Palghat Gap in the central part of Kerala, starting from 15th November to 15th January. These factors lead to reduce the input use efficiency to a large extent; thereby low crop yield is expected. To overcome this, information on the optimum time of planting and selection of variety (short, medium and long duration) in case of seasonal crops like rice during the second crop season is very important, which can be simulated through dynamic crop simulation models for different agroclimatic regions and tested. The nutrient management in photosensitive local cultivars of rice and against high winds is another area to be tackled on priority basis.

Information on probable occurrence of dry spells during the monsoon period or avoiding it is the right choice for application of fertilizers in perennial crops like coconut under rainfed conditions in the humid tropics. As the light regime is a function of nutrient management in case of shade loving crops like cacao, the nutritional requirement under different light regimes can be worked out in the case of intercrops like medicinal plants and other perennials so that the input use efficiency could be maximized for obtaining better crop yields. In a changed concept of zero-tillage, a close examination in the area of input use efficiency is the need for addressing sustainability concerns arising out of the intensive farming like multi-tier cropping systems and homestead gardens, which are the niche areas in the humid tropics. The studies on "Role of weather in input use efficiency in Agriculture" under the humid tropics in relation to the niche areas mentioned above are sporadic and they need to be initiated with interdisciplinary approach.

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Recent Trends in Climate Change and their possible impacts on Agriculture

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Introduction

Anthropogenic interventions in global climatic systems through increased concentration of green house gases in the atmosphere has led to serious concerns to the mankind because of their induced impacts which include climate change and climate variability. The gradual build up of the green house gases in the atmosphere during the last century, resulting from increased human activity had already brought about many visible environmental impacts across the world. These activities not only enhanced the processes of climate change, increasing the mean global temperatures by 0.6°C during the past 100 years but have also induced increased climatic variability in many parts of the world. Studies indicate that the last decade (1990-2000) across the globe have recorded the warmest years during the past century, the three years, viz., 1997, 1998 and1999 recording more warmer conditions, increasing in sequence. Summer 2002 and 2003 were declared as warmest years on record by NOAA especially in the Asian sub continent and in Europe where the temperatures remained extremely high for long periods resulting in death of 20,000 human populations in Europe alone. Scientists attribute this to a long-term warming trend over the globe.

It is evident that there was, there is and there will be climate variability at global, regional and local levels. Since climate is closely related to human activities and economic development including agricultural system, there is a serious concern about its stability (Sinha *et al.*, 2000). The awareness of the magnitude of the impact of climate change on society by the various governments led to adoption of an International Convention on Climate Change by United Nations in 1992. Article 2 of this convention called the UN Framework Convention on Climate Change (UNFCCC) makes two relevant stipulations relevant and important to agriculture, which is (a) prevent dangerous anthropogenic interference with the climatic system, and (b) to ensure that food production is not threatened. The two are related and need in-depth analysis.

Some of the atmospheric constituents such as water vapour, carbon dioxide, methane, and nitrous oxide are transparent to short wave solar radiation and opaque to long wave radiation emitted by earths surface, thus, trapping the heat from sunlight near the Earth's surface known popularly as green house effect. This effect keeps the planet 33°C warmer than it would otherwise be, allowing the earth to support life. With the advent of the industrial revolution, there has been a tremendous growth in the fossil-fuel utilization leading to increased carbon dioxide emissions over the globe especially since 1950s. In addition to this, the emission of chlorofluorocarbons (CFCs) and other chlorine and bromine compounds used in refrigeration and other industrial uses not only have an impact on the radiative forcing, but also have led to the depletion of the stratospheric ozone layer. Land-use change, due to urbanization and deforestation and agricultural practices, affect the physical and biological properties of the Earth's surface. Such effects also change the radiative forcing and have a potential impact on regional and global climate.

Studies indicate that if no corrective measures are taken, the atmospheric temperatures may increase by 1.4 to 5.8° C by the year 2100 (IPCC 2001). This will have serious impacts on day-to-day life. Some of the projections made are as follows:

- Inundation of coastal areas and seashore recession due to rise in sea level
- Disruption of ecosystem complexes
- Shifts in rainfall pattern and length of growing season
- Shifts in cropping pattern, geographical crop preferences
- Higher ET rates

Global Scenario

Weather observations indicated that the global average surface temperature has increased by 0.6°C (IPCC, 2001) since the 19th century. The rate of warming is faster than at any other time, during the past 100 years, which is attributed to the increase in the proportion of carbon dioxide and other greenhouse gases in the atmosphere over the last century. Observations also indicated that all the warmest years during the past century across the globe occurred in the last 2 decades (1981-1990 and 1991-2000). Among these years, 1998 was the warmest year on record (IPCC, 2001). Increasing concentrations of greenhouse gases are likely to accelerate the rate of climate change. Model output estimates that the average global surface temperature could rise 0.6 to 2.5°C in the next fifty years, and 1.4 to 5.8°C in the next century, by doubling the concentrate of CO_2 with significant regional variation. The expected rise in temperature in higher latitudes will be much more than at equatorial regions. Also the increase in rainfall is not expected to be uniform.

Other than the changes in air temperature, global warming has potential impact on global precipitation patterns and the frequency of droughts and floods. Many researchers are of the opinion that an increase in temperature could lead to a more intensive use of water. The rates of evaporation from soils and water, as well as transpiration from plants, and the quantum of rainfall could increase. Dai *et al.* (1997) observed a linear increasing trend (~2.4 mm/decade) in global precipitation during 1900-1988. Climate models based solely on the effects of greenhouse gases predicted an increase in the amount of precipitation in the next 100 years.

Many scenarios of climate change due to doubling of CO_2 concentration were developed. The results of simulation studies from GCM models, on temperature and precipitation as computed by Fischer *et al.* (1996) (Table 1) indicated that the temperature changes (4.0 to 5.2 °C) as simulated by these models are near the upper end of the range projected for doubled CO_2 by the IPCC. The GISS and GFDL scenarios are, however, near the mean temperature change of 3.8°C for doubled CO_2 as estimated by IPCC (1992). The projections of the abovementioned GCMS show a northward shift in thermal regimes, major expansion of tropical zones and a consistent increase in arid areas in developing countries (Fischer *et al.*, 2002).

Table 1. GCM doubled CO_2 climate change scenario

Model	Year	CO_2	Change in average global	
			Temperature (°C)	Precipitation (%)
GISS	1982	630	4.2	11
GFDL	1988	600	4.0	8
UKMO	1986	640	5.2	15

Source: Fisher *et al.* (1996)
GISS : Goddard Institute of Space Studies
GFDL : Geophysical Fluid Dynamics Laboratory
UKMO: United Kingdom Meteorological Office

Other impacts of global warming include mean sea level rise as a result of thermal expansion of the oceans and the melting of glaciers and polar ice sheets. The global mean sea level is projected to rise by 0.09 to 0.88 meter over the next century. Due to global warming and sea level rise, many coastal systems can experience increased levels of inundation and storm flooding, accelerated coastal erosion, seawater intrusion into fresh groundwater and encroachment of tidal waters into estuaries and river systems. Climate change and global warming also affect the abundance, spawning, and availability of commercially important marine fisheries. Increase in sea surface temperature adversely affects coral and coral associated flora (sea grass, sea weed etc.) and fauna.

Observed changes in climate in India

Confirmative evidences of climate variability and change are difficult to obtain, as often the signals are confusing. However, few evidences are available, which need further critical analysis for their confirmation. For example, a look at the long-term series of reconstructed summer monsoon rainfall series (1810-1995) of India by Scientists of IITM, Pune (Sontakke and Singh, 1996) and the All India Rainfall Series (Schaefer, 2001) indicates that there is no significant secular change.

However, the All India Rainfall Series (ARIS) has to be considered as an overall generalization of rainfall over India as it does not reflect the year-to-year fluctuations for all the areas because the geophysical area of India is too large and it cannot be regarded as a single unit (Normand, 1953). Rainfall variability and trends over India show a high temporal and spatial variability. Studies conducted to understand the temporal and spatial characteristics of rainfall over India through analysis of the long-term changes in rainfall quantum across individual meteorological sub-divisions indicate that not only there are regions which have recorded increase or decrease of annual rainfall on a long-term basis (1871-1999) but also there has been a south ward shift in the surplus rainfall zones (Schaefer, 2001), when one compares the last four decade means with the long term means.

The spatial trend pattern during the recent four decadal period (1961-1999) indicates decreasing trends in western parts, most southern parts and central parts of India. Along the eastern coast and also in northwestern parts especially in Punjab and western Rajasthan, an increasing trend is seen. However, the highest increasing trends were seen in Gangetic West Bengal (26%) and sub-Himalayan West Bengal (14%). This shift can have significant implications on the changes in the crops and cropping patterns across these regions. Another change of importance is the shifts in the rainfall distribution and peaks, within the crop-growing period. An example is that of Bangalore where a perceptible shift in the rainfall pattern could be observed (Rajegowda *et al.*, 2001).

A comparison of the mean monthly distribution of rainfall between 1972-1990 with that during 1990-2000 indicate that the July rains have decreased from 114 mm to 73 mm while the August rains increased from 109 to 179 mm. This shift influences the sowing of crops adversely as the crops now experience delay in the availability of assured moisture regime for their establishment as June and July rains are more suitable for land preparation only. Also a shift in the peak rains is observed. The peak earlier observed in September (217 mm) has now shifted to October (238 mm). September rains indicate a decline by 17 mm while October rains (227 mm) indicate a substantial increase of 92 mm along with a corresponding increase in rainy days. Though the period of analysis is short to draw any firm conclusions, the pattern implies a shift in rainfall pattern by 2 to 3 weeks. One has, therefore, to critically look for such shifts in rainfall distribution patterns occurring elsewhere also as they can have a significant influence on the cropping and crop management strategies to be adopted. Similarly, trends of decreasing pattern in pre-monsoon rainfall were observed in some parts of Chhattisgarh region (Sastri and Urkurkar, 1996) in the months of May and June, proving detrimental to pre-sowing operation of rice crop. Many parts of Chhattisgarh also recorded continuously below normal rainfall during the last decade

Climate Change and Agriculture

Several predictions have been made on the possible changes in climate due to increased concentrations of GHG and their impacts on agriculture. The general circulation models (GCM) indicate that doubling of CO_2 concentration by 2030 will increase average global temperature by 1-3°C. Govinda Rao *et al.* (1994) indicated a decrease in cereal production and increase in tropical cyclonic activity, posing serious flood damages along their tracks. Similarly, increase in rainfall by 5 to 15% in South Asian region was predicted by Houghton et al (1990) due to enhancement in GHG concentration.

The effect of temperature rise will lead to an increase in biological activity as well as the physical and chemical processes. Increase in CO_2 concentration can lower pH, thereby, directly affecting both nutrient availability and microbial activity. Climate change is also expected to bring about the changes in the amount, intensity and distribution pattern of rainfall. The changes in the crop yield depend not only on the change in rainfall but also on the changes in CO_2 concentration. While positive changes in the above two parameters can lead to increase in crop yield, the impact of temperature is generally negative in the tropics. Thus it is necessary to ascertain whether the impact of increased rainfall and CO_2 will overwhelm the impact of increased temperature and hence, evapotranspiration. However, it is not clear that over the Indian region whether temperature and rainfall will simultaneously increase (Gadgil, 1996). Rosenzweig and Parry (1994) estimated that the net effect of climate change may lead to reduce global cereal production up to 5 per cent. They further indicated that production in the developed world would increase while it may decline in developing countries. Doubling of CO_2 concentration may increase the photosynthetic rates by as much as 30-100 per cent. C_3 plants such as wheat, rice, soybean will become more water efficient as they quickly grow. However, the response in C_4 plants such as maize, sorghum, sugarcane, millets, etc. may not be spectacular (IUCC, 1992). The effect of increased CO_2 and temperature on Indian agriculture was carried by Aggarwal (1993) and predicted a shift in wheat production belt.

The average temperatures are expected to increase more near the poles than at equator, the shift in climatic zones will be more pronounced in the higher latitudes. In mid-latitudes, the shift is expected to be 200-300 km for every increase of 1°C (IUCC, 1992). These projections indicate that increased temperature resulting from global warming is likely to reduce the profit from wheat cultivation and will compel farmers of lower latitudes to opt for maize and sorghum which are better adopted to higher temperature. Morey and Sadaphal (1981) reported a decrease of wheat yield by 400 kg ha^{-1} for a unit increase of 1°C maximum temperature and 0.5 hr sunshine. The effect of temperature on the phenology and yield of important crops grown in Punjab has been worked out (Hundal and Kaur, 1996) using crop weather simulation models. In similar studies, Ramakrishna et al (1996) have estimated a fall in productivity of pearl millet in Rajasthan by 10-15 per cent due to increase in temperature by 2°C.

Studies of Lal et al (1998) using wheat and rice models showed higher yields of both crops under elevated CO_2 levels (28 and 15%, respectively, for a doubling of CO_2). A 3°C (2°C) rise in air temperature nearly cancels out the positive effect of elevated CO_2 on the wheat (rice) yields. They concluded that acute water shortage conditions combined with the thermal stress would adversely affect both the wheat and more severely the rice productivity in NW India even under the positive effects of elevated CO_2 levels in the future.

Likely impacts of climate change on agricultural productivity in India is causing a great concern to the scientists and planners as it can hinder their attempts for achieving household food security. Food grain requirements in the country (both human and cattle) would reach about 300 m in 2020. The question that is of great concern is that, with the alarming increase in GHG concentration and its expected impact on climate, will it be possible to achieve the targeted production? Sinha et al (1998a) observed that during the past 25 years, significant changes in climate are observed over different regions of the country. For example, many parts of northern India show increase in minimum temperature by about 1°C in rabi cropping season. However, mean temperatures are misleading as some of the individual regions could exhibit a larger variation with a larger impact on rabi crop production. For example, Sinha and Swaminathan (1991) presented a case study of actual change in temperature in North India. They brought out that while the mean air temperatures over the wheat growing regions were high by 1.7°C over a period of 15 days (January 16 to February 1), the actual temperature rise was 2.3 to 4.5°C in the major wheat-producing region of Punjab and Haryana. Through these studies they projected the serious effects of regional temperature on productivity of major crops. Sinha et al (1998b) also observed a 10 per cent decline in solar radiation in NW India. Since solar radiation influences the photosynthesis and productivity, such a decrease will adversely affect the productivity and to an extent unnoticeably, nullifies the positive effects due to improved management practices. They further added that in view of the proportionate production changes in major food crops, viz., rice and wheat, over the years, the dependence on rice and wheat has increased considerably. Therefore, any factor that would influence the productivity through climatic change would affect the food security of the Nation, as both these crops are sensitive to temperature variations.

Conclusions

There are some indications that though India as a whole does not exhibit significant impacts of climate change, on a regional basis, there have been some changes with respect to moisture and thermal regimes which have significant influence on the agriculture and food security of the country. For the current scenario, the climate variability is of immediate concern. There is a need to analyse the available evidences of climate change and variability more critically to identify the specific regions, where such changes are causing hindrance to enhance agricultural productivity and posing a threat to food security. Results from these can help in planning ameliorative measures that can be adopted to attain sustainability in agricultural production. Some of the possible research priorities on the following would be given priority to cope up with the climate change. Several experts have identified research areas that would reduce uncertainty and improve knowledge to face the consequences of climate change and provide improved planning. The following are some of the points for consideration.

- Quantitative assessment of specific crop responses at different crop stages to enhanced levels of GHG, precipitation and UV-B radiation.
- Breeding agricultural crops for tolerance to high temperatures.
- New area that is made available for agriculture is to be properly categorized and mapped to avoid chances of in appropriate land-use choices.
- Probabilities of occurrence of extreme weather events (droughts & floods) and their impacts on plant growth.
- The impacts of elevated CO_2 on plant soil-water balances and the corresponding crop growth should be linked.
- Water balance for drought or flood prone regions in different parts of the world for changing climatic conditions.
- The quality of global modeling projections is further improved with suitable modifications in the global circulation models.
- The databases for all the parameters need to be strengthened.

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More efficient plants in a CO_2 enriched future world: there is more than what meets the eyes

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Rising concentration of CO_2 in the atmosphere: the prognosis

Atmospheric CO_2 concentrations (Ca) have been rising since the beginning of the industrial revolution and this has perhaps contributed the most to global warming and climate changes. For several thousands of years prior to the industrial revolution, Ca remained around 270 ppm. Between 1850 and 1998, the gross emission of CO_2 into the atmosphere has been about 405 Pg (IPCC, 2000), sufficient to raise its concentration in the atmosphere by about 190 ppm. Today, Ca is around 372 ppm (Prentice *et al.*, 2001) suggesting that approximately 187 Pg of CO_2 has been refixed into terrestrial and oceanic ecosystems from the atmosphere during the above period. Out of the approximately 100 ppm rise in CO_2 Ca that has occurred between 1850-1998 (roughly @ 0.67 ppm/year), almost 60 ppm rise has occurred in the second half of the 20^{th} century alone (see Fig 1) suggesting a higher rate of CO_2 buildup in the atmosphere (@1.2 ppm/year) during this period.

The 1980s and 1990s saw even greater rate of increase in Ca largely due to increased fossil fuel combustion and cement manufacture which together released roughly 5.4 Pg C/year in the 1980s and 6.3 Pg C/year in the 1990s. During this period, land use change, mostly deforestation and conversion of pastures into agricultural lands released nearly 1.6 Pg C/year. Estimates show that after accounting for terrestrial and aquatic sequestration, a net amount of about 3.3 Pg C was stored in the atmosphere every year (equivalent to an increase of nearly 1.6 ppm CO_2/year) during the 1980s and 1990s (Dixon *et al.*, 1994; Watson *et al.*, 2000). Thus, the anthropogenic addition of CO_2 into the atmosphere is increasing at an increasing rate, and this can have serious environmental consequences in terms of global warming and other climatic effects such as droughts, floods etc.

It is indicated that at the present rate of CO_2 emission, its concentration in the atmosphere would go upto 800-1000 ppm by the turn of the current century if no efforts are made to reduce emission and increase its sequestration from the atmosphere. Since 1970, the mean global temperature has gone up by more than 0.5 °C (GISS, 2004; Table 1) which is extremely significant at the global scale. Close to 90% of the world commercial energy production is from fossil-based fuels (Raven and Berg, 2001; Table 2) and this trend is likely to continue. The continued large dependence on fossil-based fuels coupled with increased rate of deforestration still occurring in many parts of the world will further increase the Ca unless effective mitigation efforts are taken. A doubling of Ca could raise the mean temperature of the earth's surface by 1.5 to 4.5°C, but due the uncertainties in the estimates, this could be lower than 1.5°C or higher than 4.5°C (Mahlman, 1997). To keep global warming to less than 2°C, we need to limit CO_2 to below 550 ppm in the atmosphere, which is roughly twice the pre-industrial level.

In a country like ours that depends so much on rain-fed agriculture, the adverse impact of global warming resulting from increased concentrations of CO2 and other green house gases (GHGs) in the atmosphere can be particularly hard, especially on the agrarian rural poor and the socially and economically weaker sections of the society. One immediate and direct consequence of this would be increased demand for water, a resource that is fast becoming scarce as a result of GHG-forced climate changes.

What does elevated atmospheric CO_2 mean to plants?

Today's terrestrial vegetation is exposed to an elevated Ca that has not been experienced by plants for several millions of years (Pearson and Palmer, 2000). Understanding how plants respond and adapt to such a dramatic and sudden increase in Ca unprecedented in the evolutionary history of the plants is critical. Several studies have been made in glasshouses, control environmental chambers and open fields on the short and long term effects of elevated Ca on native and cultivated plant species (See reviews by Devakumar and Jacob, 1997; Drake *et al.*, 1997; Jacob *et al.*, 2001; Long *et al.*, 2004, Norby *et al.*, 1999). This article is an attempt to summarize the results of some of these studies with particular emphasis on water, nitrogen and light use efficiencies (Table 3) and the resulting consequences.

Plants respond to ambient CO_2 concentration through the processes of photosynthesis, respiration and transpiration. Stomata, being the facilitator of CO_2, O_2 and water vapor fluxes between leaf and the ambient atmosphere play an important role in these processes.

Photosynthesis

Under normal ambient conditions of Ca, gs regulates the flux of CO_2 from air into leaf intercellular spaces in relation to the CO_2 concentration gradient existing between the ambient atmosphere and leaf intercellular spaces (Ci) and the mesophyll capacity to utilize CO_2 in the photosynthetic reduction process in such a way that the ratio of Ci to Ca is generally maintained at about 0.7. In most of the studies this ratio did not change as Ca was increased although gs reduced in response to increasing Ca (Drake *et al.*, 1997). Thus reduced gs does not appear to limit the supply of CO_2 for photosynthesis in the mesophyll cells.

Leaf photosynthesis rate directly responds to changes in Ci (Jacob *et al.*, 1995). In general, C_3 plant shows more response than C_4 and CAM plants. In the current levels of Ca, C_3 photosynthesis is CO_2 limited. This is because the primary carboxylaze enzyme in C_3 plants, Rubisco has a low affinity for CO_2 and all its reaction sites are not saturated with CO_2. Oxygen competes with CO_2 to bind with Rubisco resulting in photorespiration and thus decreasing the net rate of photosynthetic CO_2 assimilation.

Table 1. Mean global temperature, 1970 to 1998 (GISS, 2004)

Year	Temp (°C)	Year	Temp (°C)	Year	Temp (°C)
1970	14.02	1980	14.18	1990	14.40
1971	13.93	1981	14.30	1991	14.36
1972	14.01	1982	14.09	1992	14.11
1973	14.11	1983	14.28	1993	14.12
1974	13.92	1984	14.13	1994	14.21
1975	13.94	1985	14.10	1995	14.38
1976	13.81	1986	14.16	1996	14.32
1977	14.11	1987	14.28	1997	14.40
1978	14.04	1988	14.32	1998	14.57
1979	14.08	1989	14.24		

Table 2. Percentage of world commercial energy production (1997) from various sources

Source	Percentage of the total energy generated
Oil	39
Coal	24
Natural Gas	22
Hydroelectric	7
Nuclear	6
Alternatives	<1

At high Ca, Rubisco becomes more saturated with CO_2 and thus it will function more as a carboxylase than as an oxygenaze. This results in substantial increase in net CO_2 assimilation with increase in Ca. In most studies with annual and perennial species - both cultivated and native vegetation - elevated Ca increased photosynthesis substantially compared with the rate of plant grown in normal ambient Ca (Long *et al.*, 2004).

An increase in Ca is associated with global warming. Reduced transpiration rates also would increase leaf temperature as Ca increases. Rubisco functions more as an oxygenase than as a carboxylase as the temperature increases (Long *et al.*, 2004). As temperature increases, Rubisco looses its affinity for CO_2 relative to oxygen. In addition, availability of CO_2 to Rubisco also declines compared to oxygen because of greater reduction of solubility in CO_2 relative that of oxygen at warmer temperature. Thus at higher temperatures, relative to CO_2 more O_2 becomes available at Rubisco. However, when Ca is increased, this is reversed and hence a greater inhibition in photorespiration leading to a greater stimulation in net CO_2 is observed at warmer than at cooler temperatures (Table 4).

Table 3. Long-term effects of continuous exposure to elevated CO_2 in a wetland ecosystem dominated by *Scirpus olneyi*, a C_3 sedge

Single leaf level	**% change compared to normal ambient CO_2**
Photosynthesis	+20 to 100
Carbohydrates	+25 to 50
Soluble Proteins	-40 to 52
Rubisco	-30 to 55
Tissue N content	-18
Nitrogen Use Efficiency	+60 to 80
Respiration Ecosystem level	-30
Photosynthesis	+40
Respiration	-45
Evapotranspiration	-20
Water Use Efficiency	+79
Shoots & leaves	+12 to 15
Roots	+40
Insects & Fungi	-30
Decomposition	-22
Soil invertebrates	+25 to 100
Soil C	+5

Table 4. Extent of elevated CO_2 stimulated leaf photosynthetic rates at 30°C and 10°C

Species	Measurement Temperature 10° C			Measurement Temperature 30° C		
	CO_2=350 ppm	CO_2=700 ppm	% increase	CO_2=350 ppm	CO_2=700 ppm	% increase
Scirpus	5.5 (1.1)	6.9 (1.8)	25	14.3 (2.1)	24.5 (2.9)	71
Scrub oak	2.5 (0.8)	3.4 (1.1)	36	8.6 (1.7)	14.5 (2.1)	69
Hevea	3.4 (1.2)	4.1 (0.9)	21	11.5 (2.9)	18.7 (3.7)	63
Sunflower	13.7(2.2)	16.7 (3.9)	22	23.5 (3.2)	35.8 (4.1)	52
Wheat	14.4 (2.9)	17.1 (3.4)	26	21.5 (2.8)	32.4 (3.7)	51

It is often seen that the initial stimulation in photosynthesis due to rising Ca is not sustained in the longer turn. However, the photosynthetic rates measured at elevated Ca remain higher than that measured at normal Ca. Acclimation of photosynthesis to elevated Ca in the long term in associated with increased concentrations of carbohydrates, decreased contents of total soluble proteins, especially Rubisco, (Jacob *et al.*,) restricted routing volume, limiting nutrient supply etc. In most studies the total nitrogen content decreases resulting from decreased protein content (Drake *et al.*, 1997; Devakumar and Jacob, 1997; Jacob *et al.*, 1995, 2001). Given that there was no compensatory decrease in LAI, stimulation in net CO_2 assimilation rate at the unit leaf area leads to increased total canopy photosynthesis increases under elevated Ca (Drake *et al.*, 1997).

Under natural conditions, light limited photosynthesis plays an important role in the total carbon budget of the plant. In forest under-growth and crop canopies with high LAI, low light photosynthesis is highly significant. The maximum quantum yield of photosynthesis, defined as the slope of the response of photosynthesis to light (when the net CO_2 assimilation starts to become positive), is constant in all C_3 terrestrial plants (Nie *et al.*, 1993). Elevated Ca increases photosynthetic light use efficiency. The increase in photosynthetic light use efficiency would result in large increase in net photosynthesis by leaves growing under light limited conditions etc.

Transpiration

As the ambient CO_2 concentration increases stomata tend to close leading to a reduction in stomatal conductance (gs). From more than 40 observations covering about 30 species gs showed an average reduction by 20% (Drake *et al.*, 1997). Stomatal responses to increasing Ca have been highly variable and in some cases no response was observed in the case of tree seedlings (Curtis, 1996).

A reduction in gs will certainly reduce leaf transpiration rates on a unit leaf area basis. This will lead to reduced crop transpirational loss from a unit land area provided elevated Ca does not stimulate increased leaf area production. Long-term exposure to elevated Ca does not result in any substantial increase in LAI (Drake *et al.*, 1997). Thus the reduced gs lead to reduced water consumption by the crop as the Ca increased. Reduced leaf transpiration causes warming of the leaves which can have significant effects on leaf metabolism independent of the direct effects of an elevated Ca.

Dark respiration

As Ca increases dark respiration decreases within minutes. This reduction has been about 20% for a doubling of the atmospheric Ca (Drake *et al.*, 1997). Two key enzymes of the mitochondrial electron transport chain namely cytochrome C oxidase and succinate dehydrogenase are severely inhibited at elevated Ca (Gonzalez

–Meier *et al.*, 1997) irrespective of the type of the tissue. But alternative oxidase is not affected by elevated Ca. The reduced respiration observed at single leaf level reflects at the ecosystem level as well.

More efficient plants: the consequences

Plants become more efficient in using water, nitrogen and light when grown at elevated Ca. Almost all of the studies show that elevated Ca resulted in greater carbon assimilation per unit amount of water, tissue nitrogen content and amount of absorbed light. Instantaneous water use efficiency (WUE) is defined as the ratio of net CO_2 assimilation rate to transpiration rate at the leaf level at any given time. Increase in Ca increases the instantaneous WUE. Stomata may acclimate over a long period of exposure to elevated Ca, but the persistent stimulation in net CO_2 assimilation coupled with no increases in LAI ensures that the cumulative WUE of the crop for the entire crop growth period also increases with exposure to elevated Ca. Stimulation in photosynthesis at low light levels ensures increased light use efficiency as Ca increases. Maintenance of high rates of CO_2 assimilation with low tissue protein content indicates high nitrogen use efficiency in plants exposed to elevated Ca.

Increased efficiency of water, nitrogen and light use by plants is possible only due to continued stimulation in the net CO_2 assimilation rate at elevated Ca. This is largely due to inhibition in photorespiration which is generally regarded as a "wasteful" process, but that may not be so always. For example, in plants experiencing environmental stresses such as drought, cold etc. concomitant with high light, photorespiration provides a safe vent for the excess energy trapped in the photosynthetic apparatus that cannot be utilized effectively due to impaired Calvin cycle activity (Kozaki and Takeba, 1996). Even under non-stressful conditions, nitrate assimilation and amino acid metabolism are tightly coupled to photorespiration (Rachmilevitch *et. al.*, 2004). Therefore, impaired nitrate metabolism resulting from inhibited photorespiration may be responsible for the reduced protein content in the leaves of plants grown at elevated Ca. Will long-term acclimation in the protein metabolism associated with inhibited photorespiration negate the stimulatory effects of elevated Ca on photosynthesis? It is difficult to predict the long-term consequences of such an acclamatory mechanism on the protein metabolism and its impact on photosynthesis of plants exposed to elevated Ca permanently as would be case in the years ahead. In addition to affecting its physiological performance, the reduced protein status of the plant may also have several environmental consequences such as reduced nutrient value affecting tissue decomposition and grazing by insects and herbivores (Drake *et al.*, 1997).

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II. SESSION ON EFFICIENCY IN WATER USE

Exploiting micro irrigation and fertigation for efficient water and nutrient management

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1. Introduction

Globally, 3240[3] m km fresh water is being utilized, out of this 69% is being used in agriculture sector, 8% in domestic, 23% in industrial and other sectors. In India around 88% water is being used in agriculture sector, which covers around 80 m ha area under irrigation. Due to the liberalisation of industrial policies and other developmental activities, the demand for water in industrial and domestic sectors is increasing day by day, which forces to reduce the percentage area under irrigation. Expected annual water demand by various sectors in the year 2025 is given in Fig.1a. The current irrigated area of around 38% of total cultivated area. The growing demand from the population calls for more efforts to enhance agricultural production activity covering cereal, millets, oilseeds and horticultural crops (Alam and Kumar, 2001).

Sustainable development of land and water resources is very important for a country like India which shares 16% of the global population with only 2.4% of land and 4% of water resources. Efforts were therefore made to develop irrigation potential during the Plan periods. However, simultaneously efforts were not made to utilise irrigation water more efficiently. The conventional system of irrigation employing different methods like flooding, furrow, border irrigation revolved around the concept of replenishing the moisture level to full Field Capacity (FC) only after depletion by 50% to 60% of FC. The system did not permit the restricting of irrigation only to meet the requirement of the root zone, thus leading to excessive percolation and other losses. It, therefore, resulted in problems like water logging, soil salinity and even drought like conditions in tail ends of the system. These conditions have created the low productivity levels of 2-3 t/ha in irrigated agriculture against 4-6 t/ha at research levels. Also, the overall efficiency of the system ranged between 25%-40%. To meet the food security, income and nutritional needs of the projected population in 2010 the food production in the country will have to be almost doubled. Thus, judicious use of irrigation water is more important to enhance total production and area under irrigated agriculture (Chauhan, 2002). It can be achieved by introducing advance method of irrigation like micro-irrigation coupled with other improved water management practices (Jain, 2001).

There has been a great deal of intensive and serious thought about the limited availability of earth's fresh water resources and management since the 1992 International Conference on Water and the Environment in Dublin and the June 1992 United Nations Conference on Environment and Development in Rio de Janerio. This has brought out worldwide reforms in the water sector. The Agenda 21 of the Conference says: "*Sustainability of food production increasingly depends on sound and efficient water use and conservation practices consisting primarily of irrigation development and management with respect agriculture, livestock water supply, inland fisheries and agro forestry. Achieving food security is a high priority in many countries including India, and agriculture must not only provide food for rising population, but also save water for other uses. The challenge is to develop and supply water saving technology and management methods and, through capacity building enable farming communities to adopt new approaches in irrigated agriculture*".

2. Micro irrigation system

Micro-irrigation system is an irrigation system with high frequency application of water in and around the root zone of plant system. The micro-irrigation system consists of a network of pipes along with a suitable emitting device. Micro irrigation is based on the fundamental concept of irrigating only the root zone of the crop rather than the entire land surface, as done during surface irrigation. Micro irrigation system is known to be able to achieve high water use efficiency, and also results in improved crop yield (Patel and Rajput, 2003a). In traditional type of surface irrigation, huge amount of water is lost through seepage and conveyance of water from the source to field. This loss can be avoided to a greater extent by adopting micro irrigation. In conventional irrigation methods, the plants are stressed for a good part of irrigation interval from the desirable water regime of field capacity of root zone (Sivanappan and Padmakumari, 1980). On the other hand, micro irrigation system allows frequent application of small quantities of water, which ultimately provides a nearly constant low-tension soil water condition in the major portion of the root zone.

Keeping these factors in view, major emphasis has been laid, since the VIII Plan, on improving water use efficiency by promoting micro irrigation in the country (Fig. 1). The total cropped area suitable for micro irrigation in the country is to the tune of 27 million ha (Table 1). This technology has been prevalent in developed countries like USA, Israel etc. Micro irrigation has high water use efficiency and can save water up to 70% as compared to conventional methods. Moreover, effective use of micro irrigation system can make even water scarce areas bloom. Horticultural crops in particular benefit the most from micro irrigation and with this facility can be cultivated profitably even in marginally productive lands (Singh, 2001). Micro irrigation not only makes such lands productive but also environmentally beneficial. It can help in arresting soil erosion and other types of degradation. The efforts of GOI in promotion of micro irrigation have resulted in bringing about three lakh ha under micro irrigation (Table 1). It is estimated that in all, about 4.5 lakh ha has been covered under micro irrigation, which includes the 3.5 lakh ha covered under GOI schemes.

Comparison of micro irrigation system over conventional systems of irrigation

Micro irrigation system has a number of advantages over the conventional irrigation methods like border, check basin, furrow or surge irrigation. The following table shows some of the important points of difference between two methods of irrigation.

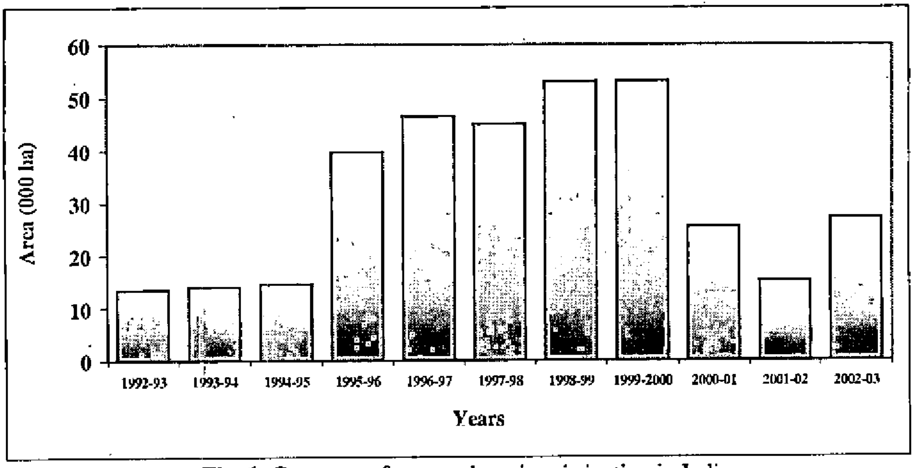

Fig. 1. Coverage of area under micro irrigation in India

Performance indicator	Conventional irrigation Methods	Micro irrigation method
Water saving	Wasteful of water, losses occur due to percolation, runoff and evaporation percolation losses are nil or negligible	40-100% of water can be saved over flood method. Runoff and deep
Water use efficiency	30-50%, because losses are very high	90-95%
Labour use	Labour engaged per irrigation is high	Labour is required only to start or stop the system
Weed problem	Weed infestation is very high due to less wetting of soil	Weed infestation is very less or almost nil
Use of saline water	Concentration of salts increases and adversely affects the plant growth. Saline water can not be used for irrigation	Frequent irrigation keeps the salt concentration within root zone soil below harmful level
Disease and pest problems	High	Relatively less because of less atmosphericumidity
Suitability under physical soil constraints	Deep percolation is more in light soil and with limited soil depths. Runoff loss is more in heavy soil.	Suitable under various soil physical constraints as flow rate can be controlled.
Water control	Inadequate	Very precise and easy
Efficiency of fertilizer use	Efficiency is low because of heavy losses due to leaching and runoff	Very high due to reduced loss of nutrients through leaching and runoff water
Soil erosion	Soil erosion is high because of large stream sizes used for irrigation.	Partial and controlled wetting of soil surface eliminates any possibility of soil erosion
Crop yield	Non-uniformity of available moisture reduce the crop yield	Frequent watering eliminates moisture stress and yield can be increased up to 20-100% as compared to flood method

3. Advantages of micro irrigation system

i. Modification of crop geometry to reduce system cost

Micro irrigation is designed to irrigate a limited part of land containing plant roots only. It encourages the scientists to investigate different planting arrangements for maximizing the crop yields and reducing system cost (Rajput and Patel, 2001). Different investigations carried out at different research centres throughout India has brought out the effect of crop geometry on the yield and water saving and is depicted in the Table 2.

ii. Micro-irrigation with Poor Quality Water

The adoption of poor quality water in agriculture with traditional irrigation practices causes serious problems of salt accumulation. With the greater demand for agricultural production and with the need to utilise world's non-saline water resources for direct human consumption, the need to use saline water for irrigation has become the need of the day. Studies have shown large yield increases in vegetable crops when saline water was used with micro-irrigation system (EC of 3mmhos per cm). In one of the study, it was found that the total pepper yield was reduced by about 14% with the use of saline water with micro-irrigation system whereas under furrow and sprinkler irrigation the yields were reduced up to 94 %.

Table 1. Theoretical potential for micro irrigation (area in Million ha)

Crop	Total area	Area suitable for micro irrigation
Cereals and millets	100.40	00.00
Pulses	22.50	00.00
Sugarcane	4.10	4.10
Condiments and spices	2.19	1.40
Fruits	3.40	3.40
Vegetables	5.30	5.30
Coconut	1.90	1.90
Oilseeds	26.20	1.90
Cotton	9.00	9.00
Others	1.40	00.00
Total	**176.39**	**27.00**

Table 2. Effect of crop geometry on yield and water saving

Crop	Location	Recommended row to row and plant to plant spacing	% Increase in yield	% Water saving
Okra	Delhi	30 cm x 15 cm	66	71
Tomato	Delhi	40 cm x 40 cm	81	54
Banana	Coimbatore	2m x 4m	70	-
Pea	Solan	20 cm x11.5 cm	80	-
Cabbage	Hyderabad	20 cm x 72 cm	50	50
Chilli	Coimbatore	20 cm x 72 cm	50	50
Sugarcane	Navsari	60 cm x 120 cm	17	46

Micro-irrigated plants using saline water respond differently for different species and levels of salinity. Under micro-irrigation, salts move in soil according to the flux of water i.e. salts accumulate at the surface where evaporation occurs. The repeated water replenishments create a continuous flushing action in small soil volumes. Roots concentrate in the wetted regions of lower salt content. Thus micro-irrigation should be designed to maintain a sufficiently large leached soil volume to permit adequate root development while minimising root contact with highly saline condition (Table 3).

Table 3. Effect of salinity on radish and potato

Method of irrigation	Radish		Potato	
EC (dS/m)	6.5		4.0	
	Yield (t/ha)	WUE	Yield (t/ha)	WUE
Surface	15.7	17.5	30.5	93.5
Drip	23.6	26.2	20.8	78.5
Ridge-furrow	9.9	8.7	19.2	53.6

iii. Effect of micro irrigation and mulching on crop yield and water saving

The plastic mulching performance was evaluated on the horticultural crops like banana, kinnow, lemon, pineapple, colocasia, ginger, turmeric, brinjal, chilli, tomato, okra, cabbage, cauliflower, coconut etc (Tiwari *et al.*, 1998 and Srivastava *et al.*, 1994). Trials have also been conducted on low tunnel cultivation, particularly on aspects like year round cultivation of mushroom, raising of seedlings and root cuttings, raising softwood cuttings of flowers like carnation and rooting of jasmine. The summary results of some of the studies conducted on micro irrigation is given in the Table 4 (Anonymous, 2001).

Table 4. Result of Studies on micro irrigation

Crop	Yield (q/ha)		Irrigation (cm)		WUE (q/ha-cm)		Advantages of micro irrigation (%)	
	Surface	Micro	Surface	Micro	Surface	Micro	Saving	Increase in yield
Beet	5.7	8.9	86.0	18.0	0.07	0.5	79.1	56.1
Bitter Gourd	32.0	43.0	76.0	33.0	0.42	1.3	56.6	34.4
Brinjal	91.0	148.0	168.0	64.0	0.55	2.3	61.9	62.6
Broccoli	140.0	195.0	70.0	60.0	2.00	3.2	14.3	39.3
Cauliflower	171.0	274.0	27.0	18.0	63.0	15.2	33.3	60.2
Chilly	42.3	60.9	109.0	41.7	0.39	1.5	61.7	44.0
Cucumber	155.0	225.0	54.0	24.0	2.90	9.4	55.6	45.2
Lady's Finger	100.0	113.1	53.5	8.6	1.87	13.2	84.0	13.1
Onion	284.0	342.0	52.0	26.0	5.50	13.2	50.0	20.4
Potato	172.0	291.0	60.0	27.5	2.90	10.6	54.2	69.2
Radish	10.5	11.9	46.0	11.0	0.23	1.1	76.1	13.3
Sweet Potato	42.4	58.9	63.0	25.0	0.67	2.4	60.3	38.9
Tomato	61.8	88.7	49.8	10.7	1.24	8.2	78.5	43.5
Banana	575.0	875.0	176.0	97.0	3.27	9.0	45.0	52.2
Grapes	264.0	325.0	53.0	28.0	5.00	11.6	47.2	23.1
Papaya	130.0	230.0	228.0	73.0	0.60	3.2	67.9	76.9
Pomegranate	34.0	67.0	21.0	16.0	1.62	4.2	23.8	97.0
Water Melon	82.1	504.0	72.0	25.0	5.90	20.2	65.3	513.9

4. Fertigation

Fertilizer application through the micro irrigation system i.e. fertigation is the most advanced and efficient practice of fertilization. Fertigation combines the two main factors in plant growth and development, water and nutrients. The right combination of water and nutrients is the key for high yield and quality of produce. Fertigation is the most efficient method of fertilizer application, as it ensures application of the fertilizers directly to the plant roots (Rajput and Patel, 2002). In fertigation, fertilizer application is made in small and frequent doses that fit within scheduled irrigation intervals matching the plant water use to avoid leaching. Significant savings in the use of fertilizers and increase in yield (Table 5) have been reported by different research workers (Anonymous, 2001; Hayness, 1988 and Patel and Rajput, 2003b).

Table 5. Savings in fertilizer and increase in crop yield under fertigation as compared to conventional method

Crop	Saving in fertilizer (%)	Increase in yield (%)
Okra	40	18
Onion	40	16
Grapes	20	37
Broccoli	40	10
Banana	20	11
Castor	60	32
Cotton	30	20
Potato	40	30
Sapota	20	74
Tomato	40	33
Sugarcane	50	40

Points needed to be considered for efficient fertigation

All chemicals applied through irrigation system must avoid corrosion, softening of plastic pipe and tubing, or clogging any component of the system. It must be safe for field use, must increase or at least not decrease crop yield, must be soluble or emulisifiable in water, and it must not react adversely to salts or other chemicals in the irrigation water. In addition, the chemicals or fertilizers must be distributed uniformly throughout the field. Uniformity of distribution requires efficient mixing, uniform water application and knowledge of the flow characteristics of water and fertilizer in the distribution lines (Rajput and Patel, 2003 and 2004). To avoid clogging, chemicals are applied through micro irrigation systems to dissolve the deposits in micro lines.

i. Fertilizer solubility

An essential pre-requisite for the granular fertilizer use in fertigation is its complete dissolution in the irrigation water. Examples of highly soluble fertilizers appropriate for their use in fertigation are: ammonium nitrate, potassium chloride, potassium nitrate, urea, ammonium monophosphate and potassium monophosphate (Kessel, 2001). The solubility of fertilizers depends on the temperature (Table 6).

Table 6. Fertilizer solubility and temperature (g/100 g water)

Temperature	Fertilizers				
	KCl	K_2SO_4	KNO_3	NH_4NO_3	Urea
10°C	31	9	21	158	84
20°C	34	11	31	195	105
30°C	37	13	46	242	133

ii. Mobility of fertilizers in soil

The ability of a fertilizer to dissolve in water does not always give a good indication of the potential for the fertilizer or its components to move through the soil. Table 7 gives a general guide to the mobility of fertilizer (McNab *et al.*, 1995) components in soil. Another point to remember is that although one may apply a fertilizer of lower mobility i.e. ammonium, it will be naturally broken down in the soil to form nitrate, which is very mobile. As a result, care should be taken during irrigation to minimize leaching of mobile nutrients.

Table 7. Mobility of different fertilizers in soil

Fertilizers	Mobility
Urea	Good
Nitrate	Good
Ammonium	Low
Potassium	Low
Phosphate	Low

iii. Fertilizer compatibility

Mixing the solutions of two or more than two water soluble fertilizers can sometimes result in the formation of a precipitates. Such cases indicate that these fertilizers are not mutually compatible and special attention has to be paid to avoid mixing them in one tank. Their solutions should be prepared in two separate tanks. It is clear from Table 8 (Montag, 1997) that neither phosphoric- nor sulphatic fertilizers can be mixed with calcium fertilizers in the same tank.

Table 8. Compatibility chart among different fertilizers

Fertilizers	*Urea*	*Ammonium Nitrate*	*Ammonium Sulphate*	*Calcium Nitrate*	*Mono Ammonium Phosphate*	*Mono Potassium Phosphate*	*Potassium Nitrate*
Urea		C	C	C	C	C	C
Ammonium Nitrate	C		C	C	C	C	C
Ammonium Sulphate	C	C		LC	C	C	LC
Calcium Nitrate Mono	C	C	LC		NC	NC	C
Ammonium Phosphate Mono	C	C	C	NC		C	C
Potassium Phosphate	C	C	C	NC	C		C
Potassium Nitrate	C	C	L	C	C	C	

C- Compatible, NC = Not Compatible LC = Limited compatible

iv. Fertilizer injection devices

Pressurized irrigation methods require fertilizer injector for injection of fertilizers into the irrigation water. There are two concepts on the basis of which the fertilizer injectors are designed. The total amount of fertilizers applied in both the cases should be equal since the requirement of nutrients of plant is independent to the injection device and method of fertilization.

Proportional concept is characterized by constant concentration of the fertilizer solution (Montag, 1999) in irrigation water throughout the irrigation duration . Fertilizer injection devices such as venturi pump and fertilizer injection pump operate on this principle. The main advantage of this concept is that it enables a delivery of constant concentration during the entire irrigation duration.

Quantitative or non-proportional concept is characterized by change in the concentration of fertilizers in irrigation water. Concentration of fertilizer decreases gradually with the irrigation duration. Fertilizer tank is one such device that works on this principle (Montag, 1999).

Fertilizer Tank Method (By-Pass System): This method employs a tank into which the fertilizer solution is filled. The tank is connected to the main irrigation line by means of a by-pass so that a part of the irrigation water flows through the fertilizer tank and dilutes the fertilizer solution.

Venturi pump: Venturi consists of a converging section, a throat and a diverging section. When the flowing water passes through the constricted throat section, its velocity increases and the pressure reduces, creating a suction effect. Due to suction, liquid fertilizer enters into the Micro system through a tube from the fertilizer storage tank connected to the throat. To start the venturi system the desired pressure difference across the venturi is created by using pressure regulating valves to enable the flow of fertilizer into the micro system (Fig.5). The rate of flow is regulated by means of the valves. The venturi system works because of differential pressure in the system (usually 20 %) (Snyder and Thomas, 1994) from one side of the device to the other. Injection rate depends on the pressure difference and pressure fluctuations in the system change the injection rate.

Fertilizer injection pump: In this method a pump is used to draw the fertilizer stock solution from a storage tank and inject it under pressure into the irrigation system. Injection rates can be easily set to create a desirable mixing ratio. The solution is normally pumped from an un-pressurized reservoir, and the choice of pump type used is dependent on the power source.

5. Constraints in fertigation

In India, growth of adoption of micro irrigation system has taken place during last decade and mostly horticultural farmers are adopting this technology to save irrigation water and enhancing the water-use efficiency. Although, fertigation offers numerous advantages but it is not being used widely due to the reasons given below:

- There is lack of research and developmental information in respect of its rate of application, amount applied and frequency adopted. However, research efforts are being focused on this aspect but there is a lack of information in respect of varied agro-climatic conditions and crops.
- In India, there is a subsidy policy for normal NPK fertilizers in specified grades. However, for fertigation the requirement of fertilizer is in different grades and it should be 100 per cent water soluble for its effective application. The fertigation material is either not available in desired form or available at higher price, than the conventional fertilizer.
- The fertigation practice, when being followed along with micro irrigation system causes higher clogging. The farmers must be trained to adopt fertigation along with other chemigation techniques.

6. Recommendations to promote micro irrigation and fertigation

The unbalanced growth of micro irrigation limiting mainly to the Southern States is yet another area of concern. Some of the reasons for the uneven development in the micro irrigation are:

- Inadequate awareness about the advantages of micro irrigation.
- Lack of trained manpower.
- Inadequate credit facilities for the farmer.
- The availability of the system and its spares are not uniform in the country.
- The distribution network at rural areas have inadequate facilities in terms of material availability and technical know-how.
- Industrial growth of micro irrigation system in India favors the widespread use but industry needs discipline for quality and providing services to safeguard the technology.
- Micro irrigation research in India has received attention but integration among different programs are lacking. Through effective integration and linkages more useful information could be generated and duplication could be avoided.
- There is a need to strengthen the information system on micro irrigation, which should be user's friendly and guide to farmers.
- There is also a need to attract more investment for capital formation and technology should be designed to have shift from subsidy-driven mode to farmer-driven mode.

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Efficiency in irrigation water management

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Water is a prime natural resource, precious, and a basic human need. In view of its limited supply and increasingly competing demands, it is imperative to use it with utmost care. With about 85% of the developed water resources being used in agriculture in India, it is all the more necessary to use water efficiently in this sector. The efficiency with which water is used will largely determine whether agriculture can take advantage of the changing economic opportunities. The irrigation potential created at the end of 1996-97 was 90.8 mha as against 22.6 mha in 1951. However the level of productivity from irrigated agriculture has not been in tune with the investments for the infra structural development. Emphasis should be given on the effect of utilization of the created irrigation potential, rather than on the physical facilities.

The sustenance and eco development of Kerala State are largely dependent on her own water resources due to the uniqueness in physiography. The State is bounded by the Western Ghats on the east and Arabian Sea on the west. Hence the major ground water basins in the State do not have any significant inter state component. Besides, majority of the rivers of Kerala originate and flow exclusively within the State boundaries and have no inter state implications. All these indicate that Kerala may be the only state in the country which is considered as "Hydrologically land locked".

Water resources of Kerala

Kerala state is situated between 8° 18' and 12° 48' North latitude and 74° 52' and 77° 22' East longitude. The state has a total area of 38864 km^2 and the population is 318 lakhs (ie, 3.6 times more than the National scenario). Physiographically, the state is divided into three distinct parallel zones; the western lowland (<7.5m), the midland (7.5m to 75m) and the eastern high land (>75m) (PWD, 1974). The total length of the state is about 700km with the width varying from 15-120 km. Within this narrow strip of land there are areas lying below the sea level and peaks ranging from 2500 to 3000m above MSL. This region is the center of all the river systems that sustain the agro economy of Kerala.

The State has 44 rivers, all short, fast flowing and monsoon fed. But as per National Norms (Rao, 1979), Kerala does not have a single major river and has only four medium rivers (Chaliyar, Bharathapuzha, Periyar and Pamba), with a total drainage area of 8250 sq.km. The remaining 40 rivers are only minor rivers with a total catchment area of 19489 sq km. The total catchment area of all the 44 rivers together is only 28739sq.km whereas a single river like Godavari in Andhra Pradesh has a catchment area of 312812sq.km (KSCSTE, 1998). Since rain fed, these rivers hardly contain any water during the summer months. The total annual utilizable yield of all the rivers is about 42,750 MCM. Total irrigation potential is 25 lakh hectares.

The total replenishable ground water resources in Kerala is estimated to be 7048.66 MCM/year and the net gross potential for irrigations is 6430.06 MCM/year. The gross ground water draft is 2696.94 and the net availability for future irrigation is 3126.13 MCM/year (Farm Guide, 2004). Low pH, high Fe, high hardness, high TDS and salinity are the common quality problems identified (Nazimuddin and Basak, 1998)

The average annual rainfall of about 3000mm is contributed by South - West monsoon (June to September) and North - East monsoon (October to December). The percentage of contribution of these to the total rainfall is in the order of 68 and 18 percent respectively. In addition, summer showers brings about 14 percent of the total rainfall received. In lowlands, the average annual rainfall ranges from 900mm in the South to 3500mm in the North. In the midlands, it ranges from 1400mm in the south to 4000mm in the north. The variation in highlands is from 2500mm in the south to about 6000mm in the north. There are areas like Attapadi, where the rainfall received is as low as 600mm. This spatial and temporal distribution pattern is mainly responsible for the frequent floods and droughts in Kerala.

With about 3m of rainfall, chains of backwater bodies, reservoirs (about 910),tanks, ponds, springs (about 240, with 10- 100 l/m discharge) and wells (200/sq.km), Kerala is considered as land of water. Yet, the state is frequently facing severe droughts followed by acute drinking water scarcity for the last two decades. Due to steep and undulating topography, rain water is not much retained on the land, thereby obviating the advantages of having high rainfall to a great extent. Deforestation and increasing population also contribute to dry riverbeds and increasingly dry wells in the state.

Irrigation scenario in Kerala

There are 16 major and minor irrigation projects completed and taken up by the Command Area Development Authority in the State, covering a total ayacut of about 2.03 lakh hectars (CADA, 2002-03) The gross irrigated area is 4.32 lakh ha (Table 1) which is 14.4 % of the gross cropped area. The net irrigated area is 3.77 lakh ha which is 17.21% of the net area sown (Farm Guide, 2004).

Table 1. Crop wise gross area under irrigation

Crop	Area ('oooha)	Per cent of irrigation
Rice	184.00	42.57
Tubers	0.97	0.22
Vegetables	8.97	2.08
Coconut	158.05	36.57
Arecanut	31.47	7.28
Cloves	0.33	0.08
Nutmeg	2.17	0.50
Other spices	3.11	0.72
Banana	24.37	5.68
Betelvine	0.94	0.27
Sugarcane	3.27	0.75
Other trees	14.57	3.37

Rainfall is the major source of water for cultivation in the state and the first crop season is entirely rainfed. Irrigation is generally needed only after the cessation of North- East monsoon and the irrigation requirement is met from different sources (Table 2)

Table 2. Different sources of irrigation

Source	Area ('000 ha)	Per cent of irrigated area
Govt. canals	95.27	25.26
Pvt. Canals	4.41	1.17
Govt. tanks	1.96	0.52
Pvt. Tanks	47.98	12.70
Govt. wells	0.22	0.06
Pvt. Wells	86.07	22.82
Minor lift irrigation	7.58	2.01
Other sources	103.21	27.36
Tube wells	30.45	8.07

Increasing water use efficiency in agriculture

Efficiency concept in any system is based on a measure of output obtainable from a given unit of input. In agriculture, efficient water utilization reflects how efficiently water is stored, distributed and used in crop production. The application of the amount of water required to bring the root zone up to field capacity is considered as efficient irrigation. Water use efficiency or water productivity is the crop production per unit of water used. It is the ratio of crop yield per unit area to the depth of water lost in evapotranspiration per unit area during the crop growth period.

The limitations of the water supply sector of Kerala have been well recognized. The gap between supply and demand for irrigation water is increasing drastically due to rise in population, and domestic, industrial and other uses. Thus the emerging shortage of water has become a growing concern. Under these circumstances, increasing WUE through improved irrigation management assumes prime importance

Irrigation scheduling

Scheduling of irrigation, ie, the time interval at which a crop is irrigated is based on soil factors, crop characteristics, growth stages and climatic demand. The soil factors refers to depletion of available moisture at the root zone. About 25 – 30% soil moisture depletion for forage and vegetative crops and 50 – 60% depletion for cereal and grain crops could be used as a criteria for scheduling irrigation.

Recommended irrigation schedules for different crops of Kerala

Rice

Rice is the staple food of the state and the total area under rice is 3.22 lakh ha of which 1.84 lakh ha is irrigated. The production of rice is almost stagnant for the last two decades and the gap between availability and requirement of rice is widening alarmingly. The double cropped paddy lands of the state are liable to water scarcity during early virippu (Kharif) and later mundakan (rabi) due to failure of timely rainfall. Summer rice entirely depending upon irrigation water suffers from acute shortage of water which compels the farmer to keep the land fallow without raising any crop or raise short duration non-cereal crop. The water requirement of rice crop vary with season, soil type and duration of the crop. In sandy loam soils water requirement of rice works out to 2362 mm for medium duration rice in rabi season and 2528 mm for short duration summer rice.

In rabi season, irrigation to rice can be postponed upto 3 days after disappearance of ponded water without any appreciable reduction in yield under conditions of shallow water table and low atmospheric evaporative demand. Under conditions of limited availability of water, intermittent irrigation of 7 cm submergence 5 days after disappearance of ponded water can be practiced.

A phasic stress irrigation schedule can be followed for summer rice in areas where supply of water is limited and this can save substantial quantity of water. Depending upon the time and availability of water, any of the following schedule can be adopted.(KAU, 2002).

Schedule	**Stages**		
	Rooting to max. tillering	Max. tillering to heading	Heading to maturity
Category I	Continuous submergence	Saturation point*	Saturation point*
Category II	Saturation point*	Continuous submergence	Continuous submergence
Category III	Continuous submergence	Continuous submergence	Hair cracking on surface*
Category IV	Hair cracking on surface*	Continuous submergence	Hair cracking on surface*

***Irrigation at 5 cm to be given at the stages marked.**

Coconut

Kerala has nearly 9.05 lakh ha of land under coconut cultivation. It is mainly grown in the homesteads and small farmers of Kerala. It is grown mainly as rainfed crop. Irrigation during dry months not only increase the yield of coconut by as much as 50-100% but also ensure stability in production.
Recommended irrigation schedule for high water use efficiency:

1) 50 mm water at 50 mm CPE through basin of 1.8 m radius in sandy loam soils (KAU, 2002).
2) The quantity of water/irrigation/palm for different types of soils is worked out to be 600, 900, 1300, 1600 litres for sandy, sandy loam, loam and silty clay soils respectively (KAU, 2002).
3) 30 litres / palm/day under drip (CWRDM, 1989).

Arecanut

Arecanut is an important cash crop of Kerala and 57% of the arecanut cultivated in India is in Kerala. About 27% of the arecanut palms are irrigated.

- The water requirement is determined as 175 litres per palm through surface irrigation once in 7-8 days during Nov.- Dec., once in 6 days during Jan.- Feb. and once in 3-4 days during Apr.- May (KAU,2002).

Pepper

Pepper an important spice crop of Kerala, is very sensitive to climatic parameters especially the pattern of rainfall. It is mainly raised as rainfed crop. The flowering and fruiting synchronise with the rainy season and a dry spell before flower is advantageous for flushing, flowering and higher yields. Irrigation should be given at IW/CPE 0.25 from November- December till the end of March. The depth of application is 10 mm and is to be given in basins at a radius of 75 cm around the plant (KAU,2002). For Bush Pepper irrigation could be given through drip at the rate of 8 litres/day (Thankamony, C.K.,2000).

- 15 litres/palm/day under drip irrigation (CWRDM,1989)
- 30 mm at IW/CPE ratio of 1.0 (Bhatt and Abdul Khader, 1982)

Minor crops

The recommended irrigation schedule for other crops is given below.

Table 3. Recommended irrigation schedule for other crops

Crops	Depth of irrigation/ quantity	Scheduling basis		Remarks	References
		IW/CPE	CPE/others		
Cardamom	30 litres/clump			From December	Gurumurthy, *et al.*, 1996
	25mm		10-12days interval		Konkanthimath, 1994
	10-15 litres/clump		daily	Drip	Kurup, 1978
	10litres/ clump		daily	Drip	CWRDM, 1989
Coffee	32-42mm		20-25 days	Sprinkler	Sopal Ram *et al.* 1994
	8 litres/plant		daily	Drip	
Tea	21mm		7 days interval	Sprinkler	Varadan *et al.* 1988
Cashew	200 litres/tree		Fortnightly interval		Yadukumar and Mandal, 1994.
Oil Palm	90 litres/palm		daily		Varghese, T.P., 1994
Sugarcane	50mm		fortnightly	Furrow, trash mulch	Mathew. T. 2001
Cowpea (grain)	50mm	0.75		Summer fallow	Mathew *et al.*, 1983
Cowpea (vegetable)	20mm		10mm	Microsprinkler	Geetha, V., 1999
Black gram	30 mm	0.75		Sprinkler	Varghese, *et al.*, 1986
Sesamum	40 mm	0.75		-do-	Mathew *et al.*, 1989
		Three sprinklings at initial soaking, flowering and pod formation		-do-	*
Ground nut	50 mm	0.90		do	Mathew *et al.* 1983
	50mm	0.75		do	Muktha, 1995
	50mm	1.00		Lateritic soil, rabi	Bhoopathy, 2003
Ginger	50 mm	1.00		January planted	Sreekumaran *et al.*, 1998
Tapioca	50 mm	1.00	furrow	For harvest at 9th month	Sushama *et al.*, 1982
	50 mm	0.50	furrow	For harvest at 11th month	Sushama *et al.*, 1982
	25 mm		100 mm	All furrow irrigaion	
	50 mm		75 mm	Alternate furrow alternately	
	50mm		75mm	Through surge irrigation	Visalakshi *et al.*, 2002

Sweet potato	50 mm 100% CPE	1.20	Once in 4 days at 10-30 DAP & 80-100 DAP	Sandy loam, summer rice fallow	Varghese *et al.* 1987 Nair, G.M. 1994
Amorphophallus	50 mm	0.90		Dec-Jan planted	Mathew et al., 1988
Tomato	40mm 0.9PE 0.6 PE	1.2	Daily Daily	Sandy clay loam -do- 150% POP fertigation	Nassar, A.M.K. 1995 Kingsley, R.D. 2002 -do-
Chilli	2 litres/plant		Daily	drip	Shirly, 1996
Water melon-		1.4		Surface	Ajith, C.B. 2000
Oriental Pickling Melon	30 mm 50mm 3 l/day/plant	0.40 1.2	25mm 125%PE	Summer fallow drip Drip, black polythene mulch	* Rao, S. 1989 Lakshmi, 1997 Oebremedhin, A.A., 2001
Ash gourd	30 mm 75% depletion of available water	0.70	Once in 5-7 days	With mulch	Visalakshi *et al.*, 1988 Lakshman, R., 1985
Bitter gourd.	30 mm 30mm 40 mm 75% PE	0.40 1.0	15 mm daily	Summer fallow Summer, laterite soil -do- Through KAU Micro sprinkler	Thomas, G Jacob. S. 1986 Thampatti *et al.*, 1993 Sreekumaran *et al.*, 1998
Snake gourd	15mm		5mm	drip	Syriac, K.E. 1998
Bhindi	60% PE 0.08Mpa SMT		Alternate days	Through KAU micro sprinkler (Fertigation) Furrow, LDPE mulch	* Sunilkumar, 1998
Pineapple	50 mm	0.60		With mulch 6 t/ha dry leaves	Varghese et al., 1988
Banana (Nendran)	10 mm 50 mm 20litres/plant 100% PEC	0.60	Alternate days (sandy loam soil) Daily Daily	Mulching with paddy straw Under scarcity of water Drip Drip	Pillai *et al.*, 1989 * Varghese, K., 1985 Thomas, D., 1999
Banana (Palayankodan)	40 mm		30 mm	With mulch	*

* Annual Reports, AICRP on Water Management, Agronomic Research Station, Chalakudy, KAU (1974-2003).

METHODS OF IRRIGATION

Surface irrigation

The principal cause of low productivity and unsustainable utilization of soil and water resources is the widespread adoption of inefficient water management practices. Irrigation water losses during application to the fields including deep percolation, tail water runoff, evaporation etc are substantial and account for 25 – 27% of water released at canal head.(Sharma and Sarkar, 1994). However, the surface irrigation is undoubtedly the most common method of applying water to crops, accounting for more than 95% of the 250 m ha of land irrigated world wide (Kay, 1990). Although many surface irrigation methods have been identified to meet a wide variety of operating conditions, they stem from the three basic methods: basin, border and furrow irrigation. Among them the check basin method of irrigation is the most popular one. The objective in each is to provide a uniform and adequate irrigation with minimum labour and capital requirements. The selection of the right method of irrigation is influenced by the soil type, land topography, crops to be grown, quality and quantity of water available for irrigation and other site specific variations. The furrow and border irrigation, the primary methods of water application usually achieve low uniformities because of unequal infiltration opportunity times and spatial variability in soil-water transport properties.

Automation of surface irrigation is possible through Cablegation. It is an advanced technique in which the design rates of flow are delivered into the irrigation furrows through gates or outlets positioned along a conveyance pipe laid on a certain gradient and a plug moves slowly through the pipe causing water to flow through the outlets into the furrows (Kemper *et al.*, 1985).

Surge flow irrigation

An innovative technology of surface irrigation namely, Surge irrigation, has been proved as a water conserving method of irrigation. Under the surge flow method water is applied intermittently in a cyclic manner into the furrows or border strips. Cycling the application of water makes it possible to complete the advance phase with less water than required by continuous application, thus increasing uniformity and application efficiency (Stringham and Keller, 1979). This method can achieve distribution efficiency as high as 96% and application efficiency, 90% (Visalakshi, 1995). Surge irrigation is suited to any shallow rooted row growing crops such as pulses, oil seeds, vegetables, tuber crops, sugar cane etc. The minimum water available during summer months can be best utilized through surge irrigation for raising the above crops in rice fallows with high water use efficiency.

Micro irrigation

Properly designed sprinkler and drip system commonly achieve a better uniformity because the amounts infiltrated depend primarily on application rates and the system design, rather than on soil infiltration properties. The pressurized method of irrigation gives many advantages over the gravity surface irrigation methods. Sprinkler system of irrigation is very well suited to all closely spaced crops, except rice, in coarse textured soils and undulated terrain where it is costly to level the land for surface irrigation.

Drip system can be adopted for irrigating with marginal/poor quality water. It is also possible to supply the nutrients to the crops through this system. Supplying liquid soluble fertilizers through a drip system leads to 40 – 60% savings in fertilizer without affecting the yield and a much higher application efficiency, compared to the conventional methods. This is in addition to the savings in water applied which could be from 50 – 70%. Sub surface application of drip irrigation conserves more water in the root zone than that by surface application (ARS, 2003). Sub surface application of drip irrigation in banana yielded a higher WUE of 440 kg/

ha mm, compared to 390 kg/ha mm in surface drip irrigation when irrigated at 100% Pan Evaporation Compensation (Deepa, 1999). But the high initial cost is considered to be the limitation for large scale adoption of these methods.

Mini/micro sprinklers that apply 30 to 120 litres per hour at heads varying from 0.5 – 25m with a wetting diameter of around 5m are available now. In addition, some special emitters called e-jets or j- jets, foggers/ misters etc. are also used for controlled irrigation in green houses, vegetables and floriculture nurseries, and for crops which require fine mist and spray. These are ideal for crops requiring humidity control under protected cultivation. **Porous pipe** and **drip tapes** are other water emission devices developed recently.

KAU Microsprinkler

An innovative microsprinkler irrigation system is designed, developed and evaluated at the Agronomic Research Station, Chalakudy, Kerala Agricultural University. The system is simple in design and user friendly as it can be easily fabricated and installed by the farmer himself using the locally available material. It is clog free and ensures complete wetting of the basin area of the crop. Trials on bittergourd indicated superiority of the system in increasing yield (19.5 %) over drip method of irrigation (Sreekumaran et al, 1998). This cost effective system is suited to a wide variety of commercial and horticultural crops of Kerala. The design criteria of the system is detailed below.(Visalakshi et al.,2002)

Table 4. Design criteria of micro sprinkler head

Diameter of sprinkler head	8mm	12mm
Length of sprinkler head	5cm	8cm
Nozzle size	1mm	1mm
Pressure required for working	0.3-1.0 kg/ cm^2	0.3-1.0 kg/ cm^2
Discharge rate	30-35 lph	40-45 lph
Wetting diameter	210-250 cm	200-230 cm
Height of riser pipe	30-90 cm	30-90 cm
Crops suitable	Leafy vegetables, ornamental plants, lawns etc.	Vegetable crops,banana, medicinal plants etc.

Agronomic practices for improved Water use Efficiency

Investigations on the improvement of irrigation water use efficiency has resulted in the formulation of some effective technologies such as mulching, changing cropping pattern , group farming, fertigation, land leveling, lining of irrigation channels etc.

Mulching

Experiments in amorphophallus indicated that mulching with organic wastes such as dried leaves (6t/ha), paddy waste (6t/ha) and coir pith (8t/ha) can significantly improve water use efficiency. Mulching Pineapple with dried leaves at 6t/ha was found to improve the efficiency of irrigation water use. Studies in Banana indicated that mulching the basins with poor quality paddy straw at 3.5 kg/plant appreciably improved WUE and bunch yields (ARS, 1984 – 1996). Ash gourd also showed beneficial effect of mulching (Table 5).

Table 5. Effect of mulching on water use efficiency

Treatments	Amorphophallus		Yield of Pineapple	Yield of banana
	Yield t/ha	WUE kg/hamm	t/ha	t/ha
No mulch	22.6	30.9	36.9	9.5
With Mulch	33.0	45.1	44.5	9.9

Cropping system

A study on the irrigation requirement of tapioca in sole and intercropping system indicated that a cropping system involving tapioca as the main crop and crops such as cowpea, black gram, green gram and groundnut as intercrops can be raised which give additional income without affecting the yield of tapioca or increasing the water consumption (Varghese *et al.*,1986).

Rice based cropping system

The following rice based cropping pattern is recommended for the sandy loam soils with high percolation rate for maximum water use efficiency and net return in the order of preference (KAU, 2002).

Kharif	Rabi	Summer
Rice(MD)	Rice(MD)	Groundnut
Rice (MD)	Rice (MD)	Sesamum-daincha
Rice (MD)	Rice (MD)	Vegetables
Rice (SD)	Rice (SD)	Tapioca

MD -Medium duration SD - short duration

Multiple cropping

Water requirement of crops in a multiple cropping system is less than the summation of the water requirement of crops grown singly. Moisture left in the profile after harvest of one crop is utilized for land preparation and sowing of the subsequent crops. Multiple cropping increases fertilizer and water use efficiency and brings more area under cultivation. During dry months, maximum area should be under short duration and low water requiring crops. No crop should suffer from scarcity of water during critical periods of growth.

System Management

Group management in rice farming

In rice, adopting channel to field rather than field to field irrigation and strict adherence to time schedule in various field operations through a collective approach (group farming) increases the rice productivity, water saving and WUE (Table 6)(Mohandas *et al.*,1989).

Table 6. Effect of group farming on yield and WUE.

Treatments	Grain yield (kg/ha)	Straw yield (kg/ha)	Irrigation Requirement (mm)	WUE (kg/hamm).	B:C ratio
Group farming	3069	3826	1259	2.50	1.11
No group farming	1810	2651	1660	0.93	1.38

Land levelling and lining

One of the major aspects in irrigated agriculture is the delivery system where a significant amount of water is lost in conveyance. These losses can contribute to environmental degradation and shrinkage of areas under irrigation. Lining of canals with suitable materials will control seepage losses. On farm water management aspect is also equally important where proper land levelling as one of the management components increases water application efficiency which leads to higher yield and increased water use efficiency.

Environmental Impacts of unscientific use of irrigation water

Some of the specific consequences incidental to irrigated agriculture are water logging and salinization, adoption of non sustainable cropping system, over exploitation of ground water and mismatch of canal water supply with crop water demands. The water logging is caused by over irrigation, wrong and defective method of irrigation, improper maintenance of natural channels, hydraulic pressures from saturated areas under higher elevation, heavy seepage losses from canals, absence of drainage canals in irrigated areas and silting of canals. About 24 % of the area irrigated by major and medium irrigation projects in India are threatened by water logging.

Unscientific water management in arid and semi arid regions of India results in salt accumulation which leads to unfavourable soil water relations and decreased crop production. The areas under water table depth range of 0 - 1.5m become salinised as a result of significant capillary rise.

Excessive pumping of ground water through tube wells leads to sea water intrusion and thereby the deterioration of water quality. Scientific regulation of the intensity of tube wells according to the local aquifer characteristics is essential to ensure proper water balance.

Improvement of on-farm water management including integrated judicious use of rain, surface and ground water and water distribution should receive highest priority to prevent occurrence of these problems

Future strategy

The country's renewable water resources are too finite to meet vital human needs. As population and domestic and industrial uses are rising, the per capita water availability will decrease. Thus the emerging shortage of water is a growing concern. Management of rain water particularly in high rainfall areas for preventing rain induced degradation and enhancing on-site and off-site agricultural productivity assumes high significance. Conjunctive use of surface and ground water, rehabilitation of degraded lands, diversified land use and cropping pattern, provision of adequate and effective drainage, capture of runoff water and its effective utilization etc. are the needs of the time. Creating public awareness on the judicious use of water and its conservation, and educating farmers about the adverse effects of over irrigation also form vital components of management strategies.

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III. SESSION ON EFFICIENCY IN AGRONOMIC PRACTICES

Organic Spice Production

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As natural foods consumers get more adventurous in their eating habits, the organic herb and spice trade is heating up. In the industrialised countries the market for organically grown products is increasing steadily. Concerning the most important markets in the European Union, the USA and Japan, annual rates of increase between 5% and 40% are being predicted for the future. However, at present, in many industrialised countries organically grown products occupy only small niche markets. Their share of the total turnover in food marketing amounts to approximately 1-4%. In Germany, the Government is striving for a market share of organic products comprising 20% in the next 10 years. Organically grown products have become an important factor on the international food markets. This unprecedented consumer preference is creating an opportunity for farmers to invest in sustainable agriculture programs.

Reasons for the **increasing acceptance of organic products on the market** are as follows:

- Consumer's increasing awareness of environmental and health issues
- Introduction of legal guidelines for production, commercialisation and import of organic products
- Increasing availability of high-quality organic products
- Involvement of supermarkets in the sales of organically grown food.

Spices constitute an important group of agricultural commodities, which are virtually indispensable in the culinary art. They are used in various forms viz; fresh, ripe, dried, broken, powdered etc. which contributes aroma, taste, flavour, colour and pungency to food, rather than a lone food seasoning factor. Spices may be either bark, buds, flowers, fruits, leaves, rhizomes, roots, seeds, stigmas and styles or the entire plant tops. They are well known as appetisers or preservatives and many of them have rich medicinal properties and are used in pharmaceutical, perfumery, cosmetic products, religious rituals etc.

The history and culture of Indian spices is probably as old as human civilization itself. The Vedas, the Bible and the Quran are all replete with references - direct or indirect - to Indian spices. The earliest literary record in India on spices is the Rig Veda (around 6000 BC), and the other three Vedas - Yajur, Sama and Atharva.

India grows over 50 different varieties of spices. Total production is around 2.7 million tonnes. Of this, about 0.25 million tonnes (8-10 per cent) is exported to more than 150 countries. The Indian share of the world trade in spices is 45-50 per cent by volume (25 per cent in value terms). Export of organic spices is showing marginal increase with the addition of more items every year ever since the country started exporting with organic pepper in 1998-99. During the fiscal 2001-02, total exports of organic spices stood at 98.65 tonne valued at Rs 2.67 crore as against 37.60 tonnes worth Rs 1.26 crore the previous year. The country during the current financial year is expecting an export of around 100 -150 tonnes of different varieties of organic spices ie 0.06% of the spice exports.

The major exporter of organic spices was Peerumade Development Society (PDS) in Kerala's Idukki district, which had exported 38.55 tonnes of organic white pepper valued at Rs 1.31 crore and 41.88 tonnes black pepper worth Rs 0.71 crore (2001-02). The average unit values of the white pepper and the black were Rs

340.25 and Rs 169.95 respectively per kg. The unit value of organic black pepper was more than double that of ordinary MG 1, the best quality pepper. Buyers of these products were Germany, Belgium, UK and Netherlands, while organic clove and thyme were exported to Switzerland. Clove fetched a unit value of Rs 673.53 per kg, while thyme Rs 124.78 per kg. Besides pepper, clove and thyme, chilli powder, dry ginger, turmeric (dry), mustard seed, tamarind (dry), nutmeg and mace were exported in 2001-02. Given the ever-growing shift towards chemical-free organic food items in western world the potential for export of Indian organic spices is increasing.

Organic farming/eco-farming/natural farming/biological farming is defined as **"an ecological production management system that promotes and enhances biodiversity, biological cycles and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that restore, maintain and enhance ecological harmony".** (National Organic Standards Board (NOSB)

Organic agriculture consciously avoids trying to maximise the yield per unit area. The total sustainable productivity of the farm optimally adapted to the site conditions is of prime importance. In contrast to the conventional agriculture, manure is used in organic farming systems to feed the soil and the organism living in it. SOIL is considered as the Source Of Infinite Life. The general guidelines for organic production of any agricultural commodity including spices remain the same.

Planting material

Selection of planting materials is a very important aspect in any planting programme. Emphasis should be given to varieties/species adapted to soil and environmental conditions prevailing in the respective areas selected for cultivation. These varieties respond well under moderate management. High yielding varieties of crop spices often bestowed with high sugar and relatively low fiber contents and these attributes make them vulnerable to various stresses. Further varieties having tender shoots, succulent leaves are considered to be more susceptible to pests and diseases. While selecting the planting materials of spice crops, varieties, which are sustainable under moderate management, may be preferred for organic system of cultivation. For instances in cardamom, a number of high yielding varieties/hybrids and land races have been reported. These selections will not bring about expected yield levels under moderate management, as they need high farm inputs including pesticides for realizing augmented yield levels. On the other hand the employment of traditional cardamom types (*Vazhukka/ Mysore*) under moderate management (organic system) will bring about sustainable yield.

Nursery management

For planting in the nursery, organically produced planting materials may be preferred. However, such materials if not available, planting materials may be procured from known sources preferably from certified firms. The general principles such as solarisation, crop rotation, shifting of sites etc followed in the nursery management need to be adhered to minimise pests and diseases problems. After solarsation, site(s) can be fortified with bioagents like *Trichoderma*, *VAM* and *Pseudomonas fluorescens* etc and organic manure such as neem cake, groundnut cake or farm yard manure. The appropriate technology developed for seed/planting material disinfecting and management practices of each crop for the nursery may be followed.

Nursery techniques such as bed nursery, polybag cuttings or rapid multiplication technique using bamboo splits can be used for the production of pepper planting materials. Instead of bamboo, serpentine system of vine multiplication using coconut husk filled with potting mixture could also be used. Potting mixtures can be inoculated with cultures of *VAM* and *Trichoderma* (250g mass multiplied media in 25kg compost). *Pseudomonas fluorescens* culture 10^9cfu @ 50ml/polybag flavours robust growth of cuttings.

Nursery diseases such as leaf rot caused by *Rhizoctonia solani* and basal wilt caused by *Sclerotium* *rolfsii* can be minimised in solarised soil inoculated with VAM and *Trichoderma* is used. Apart from FYM, neem cake and vermicompost can be applied in the polybag (50gm) at 40-45 days interval. Foliar application of vermiwash (5%) at frequent intervals favours rapid growth of cuttings.

In conventionally seed propagated crops like cardamom, higher rate of seed germination, earliness as well as uniformity in germination could be achieved with scarification and treatment with bioagents. The coating of seeds with bioagents like *Pseudomonas* and *Bacillus* (50ml spore suspension for 100kg seeds) and sowing seeds on beds inoculated with VAM gives better germination and growth. VAM or organic manure such as vermicompost, neem cake etc can be applied in the polybag (50gm) and also in trenches when sucker multiplication nursery is adopted.

Healthy plants with well-developed plump rhizomes free from pests and diseases are selected for ginger and turmeric seed multiplication. Seed rhizomes are stored in pits, the floor of which is generally plastered with a mixture of fresh cow dung and termitarium soil. The seeds are spread on leaves layer of medicinal plant *"Panal"* (*Glyconia pentaphylla*). Two weeks before planting the rhizomes are removed from pits and smoked. Rhizomes are kept over *panal* leaves on a bamboo mat should be subjected to smoking till 2 to 3 days before planting. The rhizomes dipped in cowdung slurry containing *Trichoderma* are used for planting.

Recently 'rhizome solarisation' technique has been developed at Indian Institute of Spices Research, Calicut to eliminate bacterial wilt pathogen. In this technique seed rhizomes are placed in transparent scaled polythene bags and exposed to sunlight for 30 minutes so as to maintain the temperature inside the bag in the range of 47 to 50°C. Temperature build up inside the polythene bag reduces bacterial inoculum level in the seed rhizomes. The treated rhizomes dipped in *Pseudomonas fluorescens* suspension was found effective in checking the bacterial wilt. Application of vermiwash (5-10%), humic acid (0.1%) and *Pseudomonas fluorescens* (0.1%) at frequent interval in vanilla nursery checks disease spread and promotes vine growth significantly.

Nursery practices may vary with crop species. However in the organic system of planting materials production, seed materials should be treated only with the biocontrol agents and not with any pesticides.

Field management

Agronomy practices are different in various spice crops. Some are shade loving (cardamom, vanilla etc) or some are annuals (ginger, turmeric, seed spices etc) or some are perennial trees (clove, nutmeg etc). The guidelines stipulated for organic farming have to be strictly followed.

Use of *Erythrina* sp. As a live standards for pepper or as a shade tree for cardamom should be minimised as the plant harbours root-knot nematode. *Glyricidia* is an ideal standard for vanilla as it filters the required amount of sunlight as well as is amenable for shade regulation. Some farmers strictly follow the traditional crop calendar for undertaking various agricultural operations such as *'Thiruvathira njattuvela'* or *Medam pathu* so on and so forth. Compost or well rotten cowdung mixed with rock-phosphate encourages early establishment and rooting. Inoculation of VAM along with organic manure helps in better rooting of most of the spice crops except vanilla.

For shade loving spices maintain 50% shade by retaining two-tier canopy in the plantations. Open areas invite fungal diseases such as *Chenthal* caused by *Colletrotricum Spp*, which can be managed by providing adequate shade in cardamom plantation. In areas where shade is less, plant suitable shade trees and avoid trees that may act as alternate hosts for pest and diseases of spices (*Jack tree* or *Erythrina* spp as they act as host for root grub beetles and nematodes). Install beehives at various locations in the plantation to encourage better pollination.

For annual crops such as ginger, turmeric or chilli, solarisation of soil beds using plastic sheets may be undertaken wherever feasible. Application of organic manure such as Neem cake and Farm yard Manure inoculated with bio-agents such as *Psuedomonas* or *Trichoderma* or *Bacillus* sp. is applied at the time of onset of Southwest and Northeast monsoon. Addition of bone meal or rock phosphate is done based on soil analysis. Application of *Azatobacter/Azospirillum* with phosphorus solubilising bacteria is found to be beneficial for plant growth. In many cases vermicompost was found to be better than FYM or compost. Mulching forms an integral part of every spice crop production.

In the organic farming time of planting and all other agronomic practises should be adjusted as per the crop calendar specified for each crop. This helps in the better establishment of crop and also to minimise the pest and disease infestation. Nutrient management in spices is carried out with the biofertilizers or manure or organic liquid foliar sprays. It includes Farm Yard Manure, vermicompost, vermiwash, traditional preparations such as *panchakavya*, fish amino acids and other agents of biological origin. The method of preparation of few of these agents is given as Annexure. Application of these in the soil as well as on the foliage in liquid form promotes speedy crop growth and augment production (yield). Further the soil health /productivity is improved. Panchakavya and fish amino acids are being extensively used in cardamom and chilli. Use of plant growth promoting agents such as Effective Micro-organism (EM) or sea weed extracts or humic acids or liquid manure (LM) and fermented plant extracts (FPE) are being increasingly used by farmers with varying degree of success.

After care

The cultural operations vary with crop. Operations like mulching, weeding, irrigation, nutrient management are common. In the shade loving plants like black pepper, cardamom and vanilla shade regulation is undertaken. Excess shade increases the disease and pest occurrence. Weeding is restricted to the plant base and only slash weeding between the plants is advocated. The weeded materials are used for mulching. Growing cover crops like *Calapagonium mucunoides*, *Mimosa invisa* is recommended to provide an effective soil cover to prevent soil erosion during rainy season and prevent weed growth as well as to enrich the soil.

Pest and diseases can be managed through integration of various agronomic strategies including the cultivation of resistant varieties or through the use of biocontrol agents and pesticides of biological origin. Use of fungal bioagents such as *Verticillium* or *Metarrhizium* or Entamo Pathogenic nematodes (EPN) for control of root grubs and borer, use of light or hormone traps or yellow sticky traps against white fly etc are extensively getting popular in commercial farms.

Spice crops require lot of organic matter and decomposed mulch, as they are the main source of nutrients for the plants. A thick layer of organic debris also helps to retain enough moisture and give a loose soil structure for the roots to spread. Hence it is very important that easily decomposable organic matter is applied around the plant base at least three to four times in a year. Any operation done in the plantation should not disturb the roots.

Use of spent lemongrass as mulch may reduce the pest and disease problem in crops like ginger and turmeric. Cow dung slurry or liquid manure may be poured on the bed after each mulching to enhance microbial activity and nutrient availability.

Pest and disease management

Use of disease tolerant varieties of crop spices is one of the desirable approaches to be followed. Phyto-sanitation is the most important essential operation to be undertaken while adopting pest management strategies. Use of biocontrol agents with specific colony strength and their timely application is important to obtain promising results in the field. Bio agents like *Trichoderma, Metarrhizium, Bacillus thuringensis, Verticillium* are generally employed.

The pest like pollu beetle (*Longitarsus nigripennis*) and leaf gall thrips (*Liothrips karnyi*) can be managed by spraying neem oil 400 ml/100litre water or other neem preparations as per the recommendations. Scale insects can be controlled by spraying of tobacco decoction and also through the management of shade. Application of neem cake and planting of trap plants like marigold (*Tagetis* sp.) would help to check the nematode problem. It is reported that for retaining the insecticidal properties of neem seed, mature fruits should be collected and shade dried for few days and immediately used.

Injection of *Bacillus thurigensis* (0.5ml /in 10ml water) to bore holes kills the stem borer (*Conogethes punctiferalis*) larvae and check its subsequent resurgence in cardamom. Planting of alternate host plant like castor may be useful in reducing the borer population. Use of yellow sticky traps and spraying neem oil with soft soap made out of minimum caustic soda (500ml neem oil and 500 g soft soap in 100 litre water) is found effective in the management of white flies.. Application of fish oil rosin soap is used for the management of thrips (*Sciothrips cardamoni*).

Harvest and post harvest

Harvesting and post harvest operations are very important in spice crops as the spices and spices products are the natural flavouring agents in various food preparations. Harvesting is to be done depending upon the guidelines given to each crop. Proper harvesting, processing, packing and storage will improve the quality and quality of the produce.

One important element in the processing of spices is sterilisation: non-organic spices are sterilised either by chemicals, such as ethylene oxide or methyl bromide, or by irradiation. But these methods have raised health concerns, for consumers and for staff working at treatment plants and unaccepted in organic spice trade. Instead, steaming can be an effective, safe way to sterilise non-leaf spices" like clove and nutmeg but less so for herbs, like tarragon, because steaming can strip herbs of flavour and essential oils. In that case, organic companies may fumigate herbs with carbon dioxide or freeze them. Importers are looking for dependable source of production to eliminate contamination at the farm source, minimising the need for sterilisation by ensuring that farmers sun-dry their spices in clean environments and by improving the sanitary conditions of the farms.

The transport, storage and processing systems must also be carefully monitored, to ensure the spices are not exposed to contamination of any. Such was the case for an herb and spice exporter in Guatemala, who was puzzled that certain herbs repeatedly failed the buyer's quality standards, despite thorough washing. Research revealed that when the herbs were harvested, the cut stems were placed on the ground, where they continued to absorb moisture and microorganisms that contaminated the final product. A similar situation of contamination of dried pepper with animal faecal was traced to the bamboo mats smeared with cowdung which were traditionally used for sun drying pepper by farmers. The marker ink used for stamping gunny bags also found its way to the products during packing.

'Sunning' the spice crop helps to reduce insect infestation. Solar dryers were found to substantially prevent aflatoxin and acrotoxin contamination in chilli, though practical problem on handling of huge volume is still to be overcome. Equally important are good storage methods. Strong plastic bags or sealed metal containers will protect a crop from beetles, moths and other insects far more effectively than traditional jute sacks.

The Spices Board, has come out with programmes for promotion of organic cultivation of ginger, turmeric, chillies, pepper vanilla and herbal spices. The farmers would have to ensure the minimum requirements for organic agriculture, "which must be fulfilled for certification programmes with regard to conversion, bio-diversity, seeds and planting materials, conversion period, cropping pattern, fertilisation policy, soil and water conservation, labelling, food processing and handling, packaging". To ensure the quality of the organic spice products there are seven accredited inspection and certification agencies operating in the country. They are the Association for Promotion of Organic Farming (APOF), SKAL International (India) and IMO Control Private Ltd all in Bangalore, Indian Organic Certification Agency (INDOCERT) at Aluva, Kerala, SGS India Pvt Ltd, Gurgaon, Haryana and Ecocert International and Lacon GMBH in Germany.

Conclusion

According to the trend in the European, US and Japanese markets, it is estimated that 10 per cent of the total demand of 5,70,000 tonnes for conventional spices could be shared by organic spices with in the next few years. With India's annual export of around 2.5 lakh tonnes of conventional spices, the 10 per cent of it would come to 25,000 tonnes. As against this, current exports were only at around 100 - 150 tonnes. Therefore, India was placed at an advantageous position being a major exporter of spices to the global market. The brand *Indian organic spices,* which goes beyond just flavouring; as natural preservative, colouring agent, anti oxidant and with all its diverse medicinal properties could set out another quest for healthy living.

Annexure

Panchakavya

Five products from Cow viz. cow milk, curd, ghee. dung and urine traditionally known as *Panchakavya.*
Requirement : Cow dung -5 kg., Cow's Urine -3 l., Sour curd -2 l., Milk -2 l, Ghee -500 ml to 1 litre, Jaggery ~ 1 kg, Tender Coconut -3-5 nos, Toddy -2 litres, Banana (Poovan) -: 10-12 nos, Water -5 litre

Method of preparation

Fresh cow dung and cow ghee may be mixed together and kept in a plastic bucket for 4 days. This may be kneaded (mixed), daily once. On 5th day add this mixture to the other items in a wide-mouthed mud pot or concrete tank or plastic can, mix thoroughly and stir well with hands or stick, twice daily cover with wire mesh and keep in shade.

Daily stir the mixture at least two times. The more it is stirred, more aeration is provided and therefore more micro-organisms are multiplied in the solution and therefore better results can be obtained. Continue this stirring daily for 15 days. Panchakavya is ready on the 16th day.

This Panchakavya can be kept for 6 months, for use, by stirring it daily. If the solution becomes very thick, add sufficient water and keep it loose enough. The more number of days the Panchakavya is stirred, the more potent it becomes.

This contains micro-organism, and plant growth nutrients in large quantity. This acts 75% as manure and 25% as pest repellant.

How to apply

Dilute 200 ml of mother solution in 10 litre of water (2 % strength) and use as a foliar spray or 5-10 litres per acre in irrigation water.

Effective microorganisms (EM)

Prof. Teruo Higa, developed the technology of EM (Effective Microorganisms) at the University of Ryukyus, Okinawa, Japan, in the early 1980s.

EM is a brown colour liquid concentrate containing a consortium of beneficial microbes and acts as soil conditioner as well as microbial inoculants. It is produced from cultivation of over 80 strains of beneficial microorganisms. EM mainly consists of Lacto bacillus, Photosynthetic bacteria, Yeast, Filamentous Fungi, Ray Fungi species of microorganisms. EM includes both aerobic and anaerobic species of microorganisms, which co-exist in an environment of less than 3.5 pH.

For using EM technology effectively, one needs to make a few products using EM. These are: Extended or Secondary EM, Compost, EM Bokashi, EM 5, EM FPE (Fermented Plant Extract) & EM Rice water.

Extended or Secondary EM

Mix Water: Molasses: EM in the ratio of 16 liters: 3 liters: 1 liters properly. Pour the mixture into a clean plastic container or drum and seal the container airtight, so that no air is left in the container. Keep the container in shade and at ambient temperature for a week (5-7 days). No refrigeration is required. After a week you will find a white layer on the top of the solution accompanied with a pleasant smell coming. The product is ready when pH drops below 4.0. Appearance of above characters indicates that Extended EM is ready and should be used with in 30 days.

Precaution: Secondary EM solution should never be multiplied again as if further extended, the microbial balance is altered and thus the efficacy of EM is lost.

Compost

First of all mix Extended EM and water in the ratio of 1: 50 by volume (e.g. 10 ltrs of water and 200 ml of Extended EM). Spray this solution on the ground where compost is to be made @ 2 lit/sq meters. Make a heap of organic matter like plant and animal waste about 12 inches in height. Spray the diluted Extended EM solution on the heap to make the moisture content of 70-80%. Another similar layer can be made on top of this layer and Extended EM solution sprayed. One can go on making the layers till a height of about 1.5 meters. Cover the heap with rice straw, gunny sacks or banana leaves. Do not cover it with plastic sheets. After some time, if moisture level drops in the heap then sprinkle some more water on the heap and cover again. The compost should ready for use with in 30 –45 days.

Application: To be applied @ 3-4 tones per acre to get good response.

EM Bokashi

Bokashi is rich fermented compost, which can be made as 'Aerobic' or 'Anaerobic', depending on the process used. Bokashi enhances the plant growth and work as a soil conditioning agent.

A typical Bokashi contains the following: Rice Bran: Oil cake: Fish/ Bone Meal: Water: Molasses: EM in the ratio of 10 kg: 2.5kg: 2.5kg: 150 ml: 150ml by volume. The quantity of water can be altered depending on the moisture content of the ingredients used. The material should be moist without drainage. It is recommended that at least 10-15% rice bran should be present in all Bokashi recipes.

Method for Anaerobic Bokashi

Mix rice-bran, oil cake and fish/bone meal thoroughly. Dissolve molasses in water (1:100). Add EM to the solution of molasses. Pour this mixture on the dry ingredients and mix well. Please ensure that no lumps are left after mixing. Place this mixture in a polythene bag and make it airtight. Release all air from the bag place the packed bag in another polythene bag and again make it airtight. Store in a dark place. Bokashi is ready in 4 - 5 days in summer and 7 - 8 days in winter. It has a sweet fermented smell when ready. A foul odor indicates that the process of fermentation is interrupted and the Bokashi is not fit for use.

Anaerobic Bokashi should be used soon after preparation. For storage, it should be spread on a concrete floor and dried under shade. After drying, it can be stored in polythene bags. Prevent the Bokashi from rodents and other pests.

Method for Aerobic Bokashi

The ingredients and method of mixing is similar to anaerobic Bokashi. Spread the mix on the concrete floor and cover it with gunny (jute) bags, straw, mat or similar matter preventing it from rain. The temperature rises rapidly but is controlled at 250-350 C by turning the mix upside down. This may have to be done 3 or 4 times. Bokashi is ready in 4 - 5 days. Storage is similar to that of anaerobic Bokashi.

EM 5

EM 5 is a non-toxic chemical free insect repellent used to repel pests and diseases in crops.

Mix Water: Molasses: Natural Vinegar: Distilled Spirit/Ethyl Alcohol/Whisky: EM in the ratio of 6:1:1:1:1. Seal the container. Release gas at regular intervals and re-seal till the formation of gas has subsided. Store in a cool and dark place.

EM FPE (Fermented Plant Extract)

FPE is also an organic bio pesticide

Mix freshly chopped weeds or leaves: water: molasses: EM in the ratio of 1lit: 1lit: 50ml: 50ml in a container. Place some weight on the liquid so that the leaves remain dipped in solution. Avoid any space between liquid and cover. Store the container in warm dark place for 5-10 days. Stir the liquid in container regularly to release gases.

FPE is ready when pH drops below 3.5. Filter the leaves and store the liquid in bottles. Leaves with strong flavours like neem, mint, stinging nettles and grasses having medicinal values are found to be more effective. One could also use garlic, ginger, green pepper etc to make good quality FPE.

Soil solarization – a novel technique for improving input use efficiency in agriculture

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Increasing agricultural production in India by increasing area is no longer possible as cultivable land left over is only marginal. Further a considerable cultivable land is being diverted year after year for industrial purpose and housing. Hence, self sufficiency in food lies in increasing the yield per unit area per unit time by enhancing the efficiency of input use through adoption of modern agricultural technology. Soil, water, labour, energy, machinery, nutrient sources, plant protection chemicals etc., are the major inputs under consideration in agriculture. Soil solarization, being a integrated system, aims mainly for weed management. Besides, it also targets soil borne disease control and also serves as a novel means to obtain higher yields with enhanced quality through better input use efficiency towards sustainable agriculture. Various terms used to describe the method of solarization are solar heating, plastic or polyethylene trapping, plastic or polyethylene mulching and solar pasteurization. Solarization is a technique, wherein the control of weeds is made through the use of traps for capturing solar energy by transparent polyethylene sheets. The use of plastic materials proved promising both on experimental and commercial basis. Hence, soil solarization, a preventive measure could be an efficient and non-hazardous option. Soil Solarization is a method of heating the surface soil by using plastic sheets placed on moist soil to trap solar radiation and there by increase the soil temperature. This method is nonhazardous to the user and the environment can be kept cleaner as it is dependent on renewable source of energy.

I. Effect of soil solarization on weed management

Weeds have become one of the major deterrents in the development of sustainable intensive agriculture systems. Weed menace in agricultural field is ever increasing in spite of constant efforts to get rid of it. Weeds by their manifold harmful effects on the growing crop plants and interference with land uses, ranked prime enemies in crop production. The annual global loss due to weeds has been estimated to be 1980 crore rupees and accounts for 33 per cent yield loss (Gautam and Mishra, 1995). Dormancy and longevity of weed seeds are natural mechanisms for the perpetuation of weed species on account of which it is impossible to deplete the soil weed seeds completely. There is a tendency to regard weeds as an unavoidable problem in the farming.

Weed control by mechanical and cultural means have some limitations as they are laborious, time consuming and expensive. Besides, these methods are employed only after the crop attained certain stage of growth, by this time the weed would have also grown sufficiently to cause damage to the crop plants by depriving them of nutrients, moisture and space. Chemical weed control although is one of the effective methods, there has been a growing apprehension among ecologists about the use of chemicals which have plagued with problems such as pollution of environment, development of weed resistance and above all is depend on fossil fuel. Hence, there is a need for developing eco-friendly alternate methods of weed control. Consequently, researchers in their search for new methods also took interest in some of the traditional practices with a hope of evolving a much efficient tool of weed management. The time demands that the new method besides, being efficient, economically viable, ecologically sound and acceptable to the users and environmental friendly. In this direction soil disinfection through soil solarization offers greater potentialities.

The possible mechanisms of weed control by soil solarization are direct killing of weed seeds by solar heat, indirect microbial killing of weed seeds weakened by sub-lethal heating, killing of seeds stimulated to germinate in the moist mulched soil and killing of germinating seeds whose dormancy is broken. Basically, all these are caused due to raising of soil temperature to lethal levels.

A. Solarization Material : Transparent polyethylene films are more efficient in trapping solar radiation (Horowitz *et al.*, 1983, Bhaskar *et al.*, 1998, Mudalagiriappa *et al.*, 1999) and residual weed control than colour or black films. Besides, clear transparent polyethylene sheets costs less and has high strength and allows maximum transmittances of solar radiation. Thinner films are more effective for solar heating than thicker films and are proportionately less expensive (Stapleton and De Vay, 1986). Patel *et al.* (1989) also observed that transparent polyethylene was more effective than black polyethylene in reducing weed density and dry weight in tobacco.

B. Solarization Technique : Soil solarization is recommended to be done for 4-6 weeks during warm months of the year. The soil to be solarized must be worked up to good seed-bed condition by cultivating the soil until it is loose and friable with no large clods or other debris in the soil surface as they create air pockets, which, reduces heating of the soil and keep the tarp from fitting tightly over the soil surface. A clean, flat surface will also prevent the accidental puncturing of the thin plastic mulch by debris. Adequate moisture level (up to field capacity) for working the soil before laying the plastic tarp is essential. If the soil is dry, irrigating the areas to be solarized is required before covering the sheet, since most weeds are more sensitive to high temperatures in wet soil than in dry soil. Results of the experiment conducted at UAS, Bangalore indicated that soil moisture upto FC was essential for achieving higher soil temperature and reduced weed infestation followed by irrigation upto 50 % FC. Then dig a shallow trenches all around the bed or plot at 6-8 inches deep. When the soil bed is ready for tarping two edges of polyethylene sheets of thickness 100-200 gauge or 0.025-0.05 mm should be inserted into the furrows and covered and tarped air tightly by maintaining minimum gap between polyethylene sheet and the soil surface. Soil solarization in nursery beds can be done manually. In the fields, soil solarization can be done either manually or by using improved machinery. Any damage to polyethylene sheets should be sealed at the earliest. Entry into plots covered with polyethylene sheet should be avoided to the extent possible. If entry is necessary, such as for sealing leaks, bare feet or smooth-soled shoes are preferable.

Mechanized mulching can be done either by separated beds (strip mulching) or by Continuous mulching. Most machines used for strip mulching operate on similar principles. Two discs (or flippers) open two trenches on either side of the strips. The plastic film is unrolled behind the machine, and its edges are deposited into the trenches by two guiding wheels. Which are also used to stretch the film outward and covering discs returns the soil to the trench. A whole field mulching requires a continuous mulching machine which is designed to unroll narrow film strips, each of which is anchored to the soil at one side and the other side connected to another plastic sheet laid on the previous pass. While traveling, a new sheet is unrolled. One edge of the newly unrolled sheet is embedded in the soil, while its other edge is glued or fused to the previously laid one.

Solarization in orchards create discontinuities in the field so that application of continuous mulch can be done only manually. The procedure is to cut the sheet to surround the tree trunks or the poles. The film is held in place, where overlapped, with soil wind rows that are applied manually. An improved technique, without cutting the film, is also used. A trench is opened along the line of obstructions. One plastic sheet is unrolled to one side of the trees and a second sheet is placed from the opposite side, around the obstructions. One edge of each sheet is buried and the upper sheet is then opened.

C. Months of soil solarization: It is clearly understood that the success of soil solarization largely depends on the availability of intense radiation. Summer months with bright sunshine at least for one or two months are essential for effective soil solarization. In India, March – May in Southern parts and May – June in northern parts experiences the intense radiation and are best suited for solarization (Yaduraju, 1993). Systematic experimentation at UAS, Bangalore revealed that higher soil temperature, WCE with lower weed count with soil solarization during March & April attributing to the bright intense radiation.

D. Duration of soil solarization: Effectiveness of soil solarization depends actually on the cumulative heat accumulation which, inturn on the duration of solarization. The annual weeds are susceptible even at slightly lower cumulative heating but the perennials needs longer periods as they have several mechanism of escape. Solarization for a period of 10 weeks effectively control perennials (Rubin and Benjamin, 1983) In this regard, the experimental results revealed that soil solarization with TPE 0.05 mm for 45 days was beneficial in reducing the weeds and increasing the crop yields.

E. Extent of increase in soil temperature : The basic phenomenon helping weed control upon soil solarization is build up of lethally high temperature. Maximum temperature in upper soil layers under ideal condition are achieved in 3-4 days after solarization begins (Mahrer, 1979). The soil temperature goes up to 50-55 °C at 5 cm and 46-47 °C at 10 cm depth of soil where most of the dormant and viable seeds are present. Results of the field experiments indicated an increase in soil temperature to an extent of 10-12 °C more than the non-solarized control.

F. Effect on weed emergence : Due to elevated temperature in soil following solarization treatment it results in reduction in the population of weeds. The response to solarization in weeds varies with weed species. Soil solarization was most effective at controlling broad-leaved weeds than sedges and grasses (Reddy *et al.*, 1998).

G. Types of weeds controlled : The first sign of an effective soil solarization treatment could be seen by the amount of weeds grown in the treated plots. Soil solarization is effective in controlling most of the annual weeds however, the perennials, such as *Cynodon dactylon*, *Cyperus rotundus*, and *Convolvulus arvensis*, gradually recovered. Several studies over many years have revealed that many rainy and winter season annuals are susceptible to soil solarization. The dominant weeds viz, *Trianthema monogyna, Dactyloctenium aegyptium, Acrachne racemose, Digera arvensis, Echinochloa colona, Eleusine indica,* and *Commelina* spp. in rainy season and *Avena ludoviciana, Phalaris minor, Chenopodium album, Rumex dentatus Fumaria indica,* etc. of winter season were highly sensitive to solarization treatment. However, *Cyperus rotundus, Melilotus indica* and *Convolvulus arvensis,* were tolerant; though the seed-borne sedges were highly susceptible (Singh and Yaduraju, 2004). The survival of *Cyperus rotundus* tubers in the soil has been attributed to heat resistance of the tubers (Kumar *et al.*, 1993). Soil solarization controlled *Orobanche* by 90 % in Israel (Jacobsohn *et al.*, 1980).

The overall effect is best in crops, which form quick canopy cover. Otherwise, slow growth of crop plants may give way for weed seeds, which have escaped solarization treatment. Although the density of weeds is substantially reduced due to solarization, their increased biomass may seriously interfere with crop growth and yield. Under such circumstances, a low-energy input manual weeding or chemical would prove highly beneficial and cost-effective (Yaduraju, 1993).

H. Effect on weed seed bank : The reserves of dormant weeds in agricultural soils provide a source of seeds for persistent weed problems that often require repeated control measures. A reduction in the number of dormant weed seeds in the soil should also correspondingly reduce weed persistence and weed control requirements. Hence, soil solarization would be desirable as a means of reducing the dormant weed seed reserves in the soil. However, solarization was not effective in eliminating dormant weed seeds from the germination zone. The treatments killed non-dormant seeds and greatly reduced the number of weed seedlings that otherwise would have emerged (Egley, 1983).

II. Effect of soil solarization in improving crop productivity

As soil solarization has tremendous effect on soil-borne pathogens, nematodes and weeds, the treatment enables the crop to grow and yield better as compared to non-solarized field. The magnitude of increase depends upon the type of pest problem and the degree of control. Control of weeds alone due to solarization increased the yield of onion by 100-125 (Katan *et al.*, 1980), groundnut by 52% (Grinstein *et al.*, 1979), sesamum by 72% (Stapleton and Garza-Lopez, 1988) and 77-78% in soybean (Kumar *et al.*, 1993; Singh *et al.*, 2000). Solarization is very effective in controlling parasitic weed *Orobanche*, and yield of 78 t/ha of carrot was reported from solarized plot while the non-solarized plot did not yield at all. Similarly, there was a 20% increase in yield of bean due to *Orobanche* control by solarization (Jacobsohn, *et al.*, 1980). Many studies on solarization effect demonstrated the increased growth and yield of crop plants even in places where there is no infestation of either soil-borne pathogens, nematodes or weeds. This could be attributed to several chemical and biological changes in soil caused by solar radiation when covered by clear plastic films especially when the soil has a high moisture content (Yaduraju and Kamra, 1997). With adequate control of weeds and nematodes through chemical or mechanical methods, solarization still enhanced the yield of soybean (Yaduraju, 1993). There was significant reduction on weed growth with enhanced growth and yield of different crops and crop sequences. The results of the studies conducted at UAS, Bangalore indicated a significant improvement in yield of crops like sunflower, groundnut, potato, bell pepper, tomato etc attributing to the effective control of weeds and increased nutrient availability which favoured higher yields of crops.

III. Effect of soil solarization in improving the productivity of cropping sequences

Soil solarization is found to have residual effect on weeds, weed seeds and yields of succeeding crops. The increased yield of potato and tomato after groundnut (Anon., 2001), bell pepper after sunflower (Chandrakumar, 2002), ground nut after baby corn (Anon., 2004) were also reported. This was attributed mainly to the reduced incidence of weeds even in the succeeding crop and enhanced availability of nutrients owing to the rapid mineralization during soil solarization.

IV. Effect of soil solarization on soil chemical properties and nutrient use efficiency

Soil solarization was found beneficial in improving the chemical properties of soil, which intern enhanced the available nutrient status in the soil. The availability of nutrient in the soil was improved with respect to both primary and secondary nutrients. While, the organic carbon was reduced owing to the rapid decomposition of organic matter with increased temperature. Soils mulched with transparent plastic films have frequently been reported to contain higher levels of soluble mineral nutrients. Significant increases in ammonium-nitrogen, nitrate-nitrogen, Ca^{+2}, Mg^{+2} and electrical conductivity were consistently found (Chandrakumar, 2002). Phosphorus, K^{+} and Cl^{-} increased in some soils. Other micronutrients Fe, Mn, Zn and Cu were not increased (Stepleton and De Vay, 1986). At ICRISAT, Hyderabad Chauhan *et al.* (1988) demonstrated that solarization did not significantly affect pH, EC or available P levels. Soil NO -N concentration only to a depth of 30 cm was increased, specially where soil was irrigated before solarization. This increased availability of nutrients in the soil with improved soil chemical properties enhanced the nutrient uptake of crops and inturn the use efficiency of these nutrients (Chandrakumar, 2002). Improved efficiency of organic manures applied before solarization due to the rapid mineralization were observed. Application of poultry manure, FYM, vermicompost and compost before solarization resulted in increased nutrient status in the soil and inturn the uptake by maize, french bean and radish as compared to the application after solarization and non-solarized control (Anon., 2004).

V. Effect of soil solarization on soil enzymatic activity

Soil solarization increased the activity of soil enzymes such as ureases, acid and alkaline phosphatases. The highest activity of these enzymes was noticed with soil solarization with 0.05 mm TPE. But, the dehydrogenase activity was minimum with TPE 0.05 mm and was maximum with non-solarized control. This was attributed mainly for the warmer temperature as the enzyme activity known to double for every 10 ^{0}C rise in temperature. This increased activity of enzymes in the soil after solarization caused the faster mineralization and inturn the nutrient availability (Chandrakumar, 2002).

VI. Effect of soil solarization on pest control

The rise in soil temperature upon soil solarization caused the reduction in total disease incidence and soil arthropods. Soil solarization with 0.05 mm TPE for 45 days effectively checked the incidence of soil borne diseases like crown rot and collar rot in groundnut, Fusarium, Pseudomonas and Rhizactonia wilt in tomato (Anon, 2001). The effective control of soil borne diseases were attributed to the sub-lethal temperature by solarization, which is known to a break the viability of spore to greater extent. Effect of solarization on total parasitic nematode was significant and drastic. The population of all parasitic nematodes of chickpea including *Pratylenchus* spp, *Rotylenchulus reniformis*, *Tylenchorhynchus* Spp., and *Heterodera* larvae, was markedly affected by solarization Solarization also significantly reduced ant and earthworm numbers but had no effect on millipede population (Ricci *et al.*, 1999).

VII. Effect of soil solarization on microbial population

Due to solarization changes are reported to occur in the population of soil microorganisms. Solarization causes increase in temperature and at higher temperature only a few species are able to survive close to the upper limit of temperature for that group. At Sicily, Italy, it was observed that the total fungal population was decreased by 50 to 53 per cent due to solarization (Cartia, 1987). Bacterial counts were generally unaffected by soil solarization, but number in bare soil were usually lower for all bacterial types. Soil solarization with TPE 0.05 mm for 60 days significantly reduced the population of fungi and actinomycetes in soil but the effect was non-significant with respect to bacterial population (Chandrakumar, 2002).

Solarization had no effect on the association between *Rhizobium* and groundnut roots (Grinstein *et al.*, 1979). In Israel, Katan (1981) suggested that population of *Rhizobium* spp., sufficient to effect heavy nodulation of bean roots. Reduction of *Rhizobium* spp. and consequently of nodulation of broad bean, chickpea and cowpea was recorded in early stages of plant growth in solarized soils (Chauhan *et al.*, 1988). Later in the growing season, however, nodulation was improved and plant growth had recovered to normal levels. In the absence of inoculation, reduction in nodule number in soybean was observed (Chittapur, 1998).

VIII. Effect of soil solarization on residue recycling

Solarization can be combined with other management systems either during or after solarization. Adding suitable organic residues to the soil enhance the benefits of solarization (Katan, 1981). Katan *et al.* (1983) has suggested that pest suppressiveness in solarized soils. Which may result from shift in microbial population in favour of heat resistant antagonists could be enhanced when solarization is combined with residue management wherein chemical break down of products from green manure residues may provide even wider variety of additional interactions, leading, ultimately, to the better soil disinfestation and improved crop growth.

Phytophthora spp. were found very sensitive to nitrate and other nitrogeneous compounds in soil amended with various materials (Tsao and Oster, 1981). Chet *et al.* (1982) reported that combining the antagonist *Trichoderma harzianum* with solarization in *Rhizoctonia* infested soils improved disease and pathogen control. Combining soil amendments such as cabbage residues with solar heating of soil found to provide complete control of cabbage yellows caused by *Fusarium oxysporum* sp. *conglutinans* (Ramirez - Villapudua and Munnecke, 1987).

Not much information on solarization on nutrient release through residue management is available. However, Chittapur (1998) reported favourable changes in soil fertility. Residues under transparent polyethylene mineralized rapidly and released available form of nutrients. The EC, organic carbon, available P_2O_5 and available K_2O were higher with residues particularly with glyricidia and pigeon pea stalks. Wheat straw + cattle dung + *Phanerochaete chrysosporium* inoculation recorded higher soybean yield (3479 kg ha^{-1}) compared to residue-free solarized (2589 kg ha^{-1}) and non-solarized (2004 kg ha^{-1}) checks. Wheat straw + cattle dung (3621 kg ha^{-1}) and cotton stalks + dung + decomposer (3058 kg ha^{-1}) were next in order.

IX. Effect of soil solarization on labour use efficiency

Soil solarization is known to reduce the labour drudgery as the weeding is the major operation consuming labour to larger proportion and improves the labour use efficiency due to reduced weed menace caused by solarization. In such an ecosystem the use of intercultural implements, top dressing and plant protection becomes efficient with reduced labour requirement.

X. Effect of soil solarization on water use efficiency

Reduced weed menace by solarization would enhance the water use efficiency in irrigated agriculture since there is less competition for soil moisture and also nutrients. Weeds are known to be more efficient in using soil moisture and nutrients. Effective control of weeds by soil solarization directly contributes to the efficient use of water by the crops and its indirect effect through enhanced nutrient availability and inturn the crop yield would increase the water use efficiency considerably.

XI. Economics of soil solarization

The cost on transparent polyethylene sheet was comparatively higher, still the net returns are higher with soil solarization owing to increased yield of the crop. The results of the experiment on soil solarization in groundnut – tomato crop sequence revealed the highest gross and net return with soil solarization with 0.05 mm TPE for 45 days followed by chemical weed control through the application of alachlor @ 1.5 kg a.i. ha^{-1} and two hand weedings.

Conclusion

Innovative approaches to control the pests including weeds are in great demand around the world, particularly those which are cost effective and less harmful to environment. The search for such new control methods which are effective and economic and have minimal undesirable side effect is a continuous process. In recent years, with increased concern regarding the hazards of chemicals to the environment, interest in nonchemical approaches, which aim to reduce pesticide usage is growing. In this light harvesting of solar energy through soil solarization for controlling soil-borne pests including weeds, pathogens and nematodes will be the key preposition to reduce the dependency on chemicals, besides large number of side effects for improving the use efficiency of different input and reducing the labour drudgery and machineries.

Soil solarization is certainly not the "magic bullet" for which farmers have been hoping. However, it is a useful non-chemical and eco-friendly tool that can be integrated into the pest management program. Various researchers have recommended soil solarization for weed control besides improving the efficiencies of different inputs of crop production.

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Organic farming in rice with reference to input use efficiency

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Rice is the principal source of nourishment, providing about two thirds of the calories for more than two billion people in Asia and one third of the calorie intake of nearly one billion people of Africa and Latin America. Over the centuries the rice farmers have evolved a culture which is in tune with the different ecosystems. They have evolved varieties and systems of rice culture to suit every conceivable agronomic condition from totally dry to floating rice; under rainfed as well as irrigated conditions; in sandy to clayey soils and in saline to acidic soils. With the introduction of high yielding varieties, the traditional rice varieties evolved by natural selection and adapted to the different ecological situations were replaced. Modern agriculture, no doubt, has paved the way to 'Green Revolution'. But it has led to the application of heavy doses of chemical fertilizers and pesticides with the sole objective of maximizing the yield, totally disregarding the health of soil and balance of ecosystem. The fertilizer consumption of the country has steeply increased from 0.29 million tonnes in 1960-61 to 17 million tonnes in 1998-99. Use of herbicides for weed control has increased from 15 tonnes in 1970 to 7620 tonnes in 1995-96. The consumption of pesticides in India has increased from 154 metric tonnes in 1953-54 to 54135 metric tonnes in 1999 –2000

'Green Revolution' has come to be associated not only with higher production through enhanced productivity, but also with several negative ecological and social consequences.
Excessive use of chemical fertilizers and pesticides have caused damage to the soil and environment. Fertilizer fed soil cannot support microbial life resulting in less humus and fewer available nutrients in the soil. Indiscriminate use of chemical pesticides cause health hazards by accumulation of toxic chemicals in animals and human beings. Besides, the pesticides and fertilizers persist in the soil destroying the beneficial soil organisms and earthworms and thereby degrading soil fertility. Pesticide residue is the second largest agent causing cancer next to cigarettes. Further, in the wake of serious pollution problems and bio-magnification of toxic chemicals in the various biological systems, '**Organic Farming'** is the right approach in the present day agriculture.

'Organic cultivation' practiced in India from time immemorial, but largely given up in recent decades for agro chemicals deserves close attention of the scientific community. Most of the developed countries are now 'rediscovering' the virtues of chemical free, pro-nature kind of cultivation, through techniques that are friendly to the environment. Organic farming is a holistic system ensuring sustainability in crop production. It is a method of farming system which primarily aims at cultivating the land and raising crops in such a way as to keep the soil alive and in good health. Although the expanding organic movement is a positive development, in the final analysis, agricultural production will be maintained only if farms are designed in the image of natural ecosystems, combining the knowledge of science with the traditional wisdom. Organic farming aims at restoration of soil fertility and enhancement of the soil microbial activity by the use of organic manures, non chemical weed management and by biological pest and disease management. Then the important factor which would decide the fututre of organic farming is it's efficeiency in terms of production & productivey. is it a system whrein the inputs are used efficeiently? In this article we would be looking at the system of organic farming in rice, in general and also with reference to an experiment conducted at Regional Agricultural Research Station, Pattambi. Also an attempt is being made to assess the efficiency of the some of the inputs used.

Important regulations for Organic Farming

Materials permitted

1. Organic manures, soil conditioners and fertilizers of natural origin permitted (Plant and animal origin) FYM, Slurry, urine, vermi-compost, blood meal, meat meal, bone meal, hoof and horn meal, feather meal, fish and fish products, wool, fur, hair, dairy products
2. Soil conditioners and natural fertilisersBasic slag, lime, limestone, gypsum, calcarious and magnesium soil amendments, magnesium rock, kieserite, epsom salt, naturally occurring potassium minerals, natural phosphates, trace elements, sulphur
3. Micro biological materialsBio degradable processing by-products of microbial origin, biofertilisers

Materials not permitted

- Synthetic fertilisers
- Synthetic herbicides, fungicides, insecticides, growth regulators
- Genetically engineered organism or products

One of the tough tasks in organic farming is the challenge of meeting the nutrient requirement of rice as per the POP recommendations. The nutrient requirement of rice is quite high (5 t organic manure and NPK @ of 90:45:45 or 70:35:35 kg /ha). Some of the options for the same are given below.

Green manure: Green manuring is of two types – Green leaf manuring which is practice of growing leafy crops on the bunds or nearby waste lands, harvesting the leaves & tender twigs and incorporating the same into the filed at the time of land preparation. *In situ* green manuring refers to growing a green manure crop in same filed during the off season and incorporating the same at the time of land preparation. The amount of N contributed depends upon the species and vigor of the green manure, and ultimately on the duration of its growth cycle. Typically, a green manure crop will require approximately 50 to 60 days of growth to fix between 20 and 40 kg N per ha. Also the practice of broadcasting paddy & cowpea together also has been found useful in adding organic matter to the soil. Of these three systems insitu green manuring seems to be the most efficient.

Compost: Compost is a relatively cost-effective commercial organic source of N. Compost also provides P, K, Ca, Mg, S, and other minor nutrients in fairly well-balanced amounts. Although actual concentrations of P and K in compost are low, the total additions may be quite high due to the high volume of material applied. When applying compost, the challenges are to know and understand its composition and to determine how to use it most efficiently. The grower should understand the composting process used by the supplier and know the sources of raw material used. If the materials that are being composted are low in nutrients, the compost will have a low nutrient analysis. Poor-quality or immature compost may actually tie up nitrogen in the soil and decrease the availability of N to the growing crop. The carbon : nitrogen ratio (C:N) of a compost is one indication of the maturity and N availability. As the C:N ratio rises above 20:1, the tendency for N from the soil to get immobilized increases. A compost with a C:N ratio of less than 20:1 will generally release N to the succeeding crop.

Three types of composts are available to organic farmers viz., normal compost (NADEP), vermin-compost and biodynamic compost. The composition of these composts varies and should be considered before deciding the rate of application. Use of suitable microbial cultures may accelerate the process of composting and addition of Azotobacter can increase N content of the compost. Similarly, Addition of natural P sources such as rock phosphate can enrich the compost.

Animal Manure: Decomposed animal manure (FYM) can also be a balanced source of N and other major and minor nutrients. Fresh manure may be of limited use because of relatively high transport costs and the potential for pollution problems. Another potential limitation with manure is the availability of a consistent supply of a material that is uniform enough to be confidently incorporated into a production programme. A number of approved organic fertilizers or natural materials are available commercially. Many of these materials are by-products of fish, meat, and soybean processing industries. The commercial formulations and nutrient analyses of these materials vary considerably. In general, they range from 1 to 12 percent N and provide P, K or both along with N. Other simple fertilizer materials that offer only one macronutrient include blood mean (N), rock phosphate (P) and mined potassium sulfate (K).

Biofertilizers: Three types of biofertilizers are used viz., i) Symbiotic N_2 fixers such as *Rhizobium* culture for legumes, which could be used for effecting crop rotation ii) free living N_2 fixers (non-symbiotic bacteria) such as *Azotobacter* and *Azospirillum* sp., blue green algae and Azolla and iii) P solubilizers such as *Pseudomonas* sp. While symbiotic N fixers can fix substantial amount of atmospheric N to feed the host plant, free-living N fixers contribute much less, usually 10-30 kg/ha. P solubilizers enhance the availability of native inorganic P.[2]

Ecofriendly management of pests and diseases in rice

1. HOST PLANT RESISTANCE

Host plant resistance is the most effective, economical, practical and easiest means of encountering the pest problems and it is compatible with all other methods of pest control. Most of the modern varieties released and grown widely in pest prone areas possess resistance to at least one insect pest or disease. In Kerala most of the recently released rice varieties are resistant to pests & diseases.Many of these resistant varieties possess high yield and other desirable agronomic characters and are being extensively cultivated in the pest prone areas as a principal method of control or as a supplement to other methods of insect pest management.

2. CULTURAL CONTROL

Cultural practices are normal agronomic practices that are followed for increasing crop productivity and at the same time useful in pest suppression. Strategic manipulation of these practices can effectively suppress the multiplication or spread of insect pests. These include:

a) *Early and synchronous planting*

Wherever possible, altering the date of planting can often check the development of populations of insect pests like yellow stem borer, gall midge, BPH, WBPH and GLH. However, this needs community action and often depends on availability of water in command areas in irrigated rice situations.

b) *Balanced and judicious use of fertilizers*

Application of fertilizers, particularly nitrogen in right doses and at right time will help in enhancing the rice plants ability to compensate or withstand injury due to pests. Optimum dosage of nitrogen in 2-3 splits avoids buildup of gall midge, leaf folder, BPH and WBPH among insect pests.

c) *Cropping pattern or crop rotation*

These are important to break continuity in insect pest buildup or in disease cycle, which has been successfully attempted in Rice Tungro Disease endemic areas.

d) *Field sanitation*

Stubble destruction soon after harvesting effectively prevents are carry over of stem borer and gall midge.

e) *Water management*

Simple practices like draining of water from the fields when abundant plant hopper population or maintaining appropriate levels of water in case of pests like army worm and ease worm, etc., can be effective.

Use of botanical pesticides

Utilisation of botanical pesticides, mainly neem formulations is a novel approach as these are safe to humans and environment. Unlike traditional insecticides, neem formulations do not outrightly kill the insect pests but incapacitate them through repellency, growth retardant effect, feeding deterrency, reproductive inhibition and oviposition deterrence. However, in rice ecosystgems, neem formulations are only moderately effective against BPH, WBPH, GLH and leaf folder.

Biological control

Use of biological agents to manage crop pests is a key component of organic faming. The successful use of several entomophages and entomopathogens in the control of pests has projected biological control as a promising alternative to ecologically disruptive chemical control measures. In India, unlike in other crops, the scope of using biocontrol agents through inundative or inoculative releases in rice is restricted to the egg parasitoid, Trichogramma japonicum against yellow stem borer and T. chilonis against leaf folder. Five to six releases of the egg parasitoid @ 1,00,000 adult parasites/ha in a crop season is very useful and devoid of any side effects. Inundate release of Trichogramma spp. to control stem borers and leaf folders in rice fields is being done across the country by the Central IPM centers of the Directorate of Plant Protection, Quarantine and Storage, Government of India. Establishment of mass multiplication units by the State Agricultural Universities in different states has provided the impetus to the use of biocontrol agents in rice.

Conservation of native natural enemies & biological control in rice

Studies have indicated that native natural enemies can be used profitably in pest management. So, increased attention is now being given for the conservation of natural enemies. Several natural enemies identified from different rice ecosystems of the country have been documented. In case of yellow stem borer, the egg parasitism due to Tegrastichus, Telnomus and Trichogramma is very high in nature and needs to be conserved, while in case of gall midge, the parasitism due to Platygaster oryzaer has little impact on the pest in the field. The larval and pupal parasitism of leaf folder under natural conditions is also high and effective. In case of leaf and plant hoppers, the action of predatory spiders like Pardosa, Tetragnatha, Argiope, Araenus, Oxyopes, etc., and mirid bug, Cyrtorhinus lividipennis have been observed to be more common and dominant. the other general predators like dragon flies, damsel flies, ground beetles, staphylinids, and ear wigs have also been found effective in keeping the pest populations at lower levels.

Use of bio-pesticides

Use of microbial pesticides like Bt (*Bacillus thuringiensis*) formulations with endotoxins is another useful approach. They are specific to insect pests and quite safe to humans, natural enemies of insect pests and other non-target organisms. Evaluation of some of these formulations has revealed that they are effective against leaf folder and moderately effective against stem borer. Some of the fungal pathogens such as Beauveria bassiana against rice hispa and Pandora delphacis against BPH etc., have also been found promising. There is a need for a suitable mechanism to develop suitable formulation technology, proper marketing and commercialization of these products for possible use in organic faming in rice.

Use of insect sex pheromones

Sex pheromones have been found promising for management of yellow stem borer, in monitoring as well as direct control through male annihilation either by mass trapping or disrupting mating communication.

Eco-friendly disease management in rice farming

1. Varietal resistance

Cultivation of resistant / tolerant varieties in endemic areas is considered very important. For eg: Kairali, Athira and Aiswarya are comparatively tolerant to blast. So these varieties can be cultivated in blast endemic areas.

2. Cultural practices

The intensity of different diseases can be reduced to a great extent by suitably manipulating the cultural practices considering all major predisposing factors. Some of the practices are as follows:

- Burning of stubbles and straw
- Deep summer ploughing of the fields
- Collection of seeds from disease free fields and proper drying will help to reduce the seed borne inoculum.
- Optimum sowing or planting time is important. Altering the dates of sowing / transplanting preferably not coinciding the favorable climate for diseases like foliar blast.
- Application of rice hull ash @ 20 kg /cent will help to reduce the incidence of blast in the nursery.
- Controlling of disease harboring weeds
- Balanced fertilizer application.
  Excess of nitrogenous fertilizers favors the disease development. Nitrogenous fertilizers may be applied in split doses or delayed for 10-15 days in endemic areas. Mixing of neem cake along with urea (1:5) will help in slow release of nitrogen and also will get the benefit of neem cake. Application of organic manures like FYM & green manures favor the development of antagonistic micro organisms in the soil and thereby help in disease suppression. Optimum spacing
  Closer spacing favours the disease incidence and easy spread.
- Water management:
  Water logging favours the diseases like sheath blight. Draining the field for one or two days will help to reduce the spread of the disease.
- Avoid clipping of leaf tips at the time of transplanting in bacterial blight endemic areas.

3. Use of botanical formulations

Some of the botanical formulations are found to be effective against sheath blight. For example Azadiractin formulation, if applied at the initial stage itself, disease can be managed. .

4. Biological control agents

This strategy has gained considerable attention and appears to be promising as a viable supplement or alternative to chemical control. Antagonistic micro organisms that can grow in the rhizosphere are ideal biocontrol agents, as rhizosphere provides the frontline defence for roots against the attack of pathogens. *Pseudomonas fluorescens* strains of plant growth promoting rhizobacteria (PGPR) group have been successfully used in enhancing crop growth for suppressing plant pathogens. *P. fluorescens* is a potential biocontrol agent against major rice diseases. *P. fluorescens* is known to produce antibiotics, siderophores and also known to induce systemic resistance in plants. Because of these various modes of actions and effectiveness against fungal as well as bacterial pathogens of rice its potential as a biocontrol agent is very high.

Methods of application

1. Seed treatment @ 10 g/kg of seeds. Treat the seeds with powder formulation and soak in water for 24

hours and then keep for germination.

2. Seedling root dip. Dip the roots of seedlings in water containing powder formulation @ 20 g/l for 30 minutes and then transplant.
3. Soil application. Apply powder formulation at 2.5kg /ha at 30 DAT. The powder formulation can be mixed with FYM (2.5 kg + 50 kg FYM for 1 ha).
4. Foliar spray: @ 2 g / l 45 days after transplanting. Repeat the spraying15 days after the first spraying in disease prone areas.

Results of an NATP Experiment in organic farming conducted at RARS, Pattambi

The experiment was conducted in Split plot design with four replications. The plot size was 640 m^2 and the rice variety Kanchana was used in the study. The five systems studied were Rice + fish under organic system (FYM @ 3t ha^{-1} + Green manure@ 2t ha^{-1} + Vermi compost @ 5t ha^{-1}), Rice + fish under integrated system (FYM @ 3 t ha^{-1} + Green manure@ 2t ha^{-1} + Inorganic fertilizers @ 70:35:35 kg NPK ha^{-1}, Rice alone under organic system of management (FYM @ 3 t ha^{-1} + Green manure@ 2t ha^{-1} + Vermi compost @ 5t ha^{-1}). Rice alone under integrated system of management (FYM @ 3 t ha^{-1} + Green manure @ 2t ha^{-1} + Inorganic fertilizers @ 70:35:35 kg NPK ha^{-1} and Rice under inorganic system of management (Inorganic fertilizers @ 70:35:35 kg NPK ha^{-1}). In *rabi*, each of main plot was divided into two sub plots. The full dose of nutrients (as in the corresponding main field in *kharif*) was applied to one of the sub plots while the other sub plot received only half of the recommended dose of nutrients. In summer, cowpea was raised in the organic and integrated systems.

It was found that organic farming is very much feasible in rice and the incidences pests & diseases could be brought under control with eco - friendly management practices, avoiding the chemicals totally. The combination of organic manures used i.e., farm yard manure (3t/ha), green manure (2t/ha) & vermicompost (5t/ha) was found sufficient to meet the nutrient requirement of the rice as reflected by the yields. Also it could be seen that there was a steady increase in the yield indicating the sustainability of the system. However in all the years significantly high yields were obtained from the integrated system without fish and all other systems were at par. In the rabi season also, the integrated system gave the highest yield and the other systems were on par. Regarding the sub plot treatments, significant differences were not noticed between plots receiving full dose and half dose. It was also found that fish can be successfully integrated with both organic and integrated system. The varieties of fish used were Rohu, Catla and Mrigal. The total fish yield obtained ranged from 247 kg to 494 kg / ha. Vermicompost production is being done from straw also, available in plenty at the farm and it is being produced in large quantities now.

In both the organic and integrated system non chemical methods of pest and disease management were employed. The major pests recorded were case worm, stem borer, leaf folder and rice bug. Case worm control under rice fish system was difficult as draining the water completely could not be done. Hence mechanical collection & destruction were adopted. Against stem borer, pheremone traps and *Trichogramma japonicum* egg cards were effective. For the control of leaf folder T. *Chilonis* egg cards were used. Dusting of Tobacco powder & Chilli powder was found to be effective against the control of rice bug. The major diseases recorded were blast, sheath blight and bacterial blight. *Pseudomonas fluorescence* was used as seed treatment, soil application and as foliar spray for the management of diseases in general. Spraying of cowdung extract was done in organic & integrated nursery as well as in the main field for the management of bacterial blight. Application of lemon grass oil was found effective against blast disease. Application of ash & vermicompost has been found to bring down the thrips damage considerably in the nursery. With respect to natural enemies and neutrals, significant differences could not be noticed among all the systems during the entire period of experimentation. In summer a uniform crop of vegetable cowpea was raised without any additional inputs in both organic and integrated plots. The yield obtained varied from 547 to 1023 kg/ha. The main purpose of growing summer cowpea was to ensure the crop rotation component. The plant nutrient uptake of N, P, K, Ca & Mg was significantly higher under the integrated system without fish than all other systems.. The Ca & Mg uptake under the inorganic system was on par with that under integrated with fish but significantly superior to other systems.. The Peroxidase enzyme analysis of the leaf samples at various stages of growth showed no detectable difference in the isozyme pattern. Protein analysis of the grain revealed that the different management systems had no influence on the same

Soil chemical analysis revealed that in general the soil nutrient status was higher under the integrated system without fish. Organic C content was also highest in the integrated system followed by integrated rice + fish and Organic rice + fish. The pH as well as organic carbon was found to be lower under the inorganic system. However the available N & P content was found to be higher in the inorganic plots than under organic system.. With respect to exchangeable Ca. there were no significant differences. The soil enzymatic analysis (urease & dehydrogenase) has been carried out for the soil samples initially (before the experimentation). This will be again carried out at end of the experimentation.

In general the rhizosphere population of fungi, bacteria & actinomycetes were maximum under the organic system of management followed by integrated system. The inorganic system recorded the lowest population of these organisms. With respect to total pests, natural enemies and neutrals, significant differences could not be noticed among all the systems during the entire period of experimentation. From the point of view of pest population it could be an advantageous situation in the sense that pest population could be kept (naturally) below the threshold level in the organically managed plots. The phyllosphere micro flora was taken initially and will be assessed again at the end of experimentation. The residue analysis of the hazardous chemicals was done and it was found that there was no detectable pesticides residues in any of the systems including that raised under inorganic management.

Benefit cost ratio and input use efficiency

The cost of cultivation (Table 3 & 4) during Kharif ranged from Rs. 42,000/ ha in T_5 (Inorganic) to Rs. 75000/ha in T_1 (Organic with fish). Returns worked out between Rs. 44,000 in T_3 (Organic) and Rs. 58,000 in T_2 (Integrated with fish). The benefit cost analysis indicated that the inorganic system had B;C ratio of 1.05 and T_3 (organic) had 0.71. In rabi, cost pf cultivation ranged between Rs. 38,000/ha in T_5 (inorganic) to Rs. 55,000/ha in T_3 (organic alone) Highest returns (Rs. 46,000/ha) was recorded in T_4 (integrated) while T_3 continued with lowest (Rs. 35,000/ha).

It has been demonstrated beyond doubt that rice could be grown organically without any chemical inputs. However a total conversion of whole rice area into organic farming may not be feasible as it involves a large amount organic inputs which are not easily available. It is certainly possible to bring a small area under organic farming aiming a niche market. A premium price is very possible for organically grown rice. It is also true that there has been an indiscriminate use of fertilizers and plant protection chemicals, which has led to large scale pollution of the fragile rice eco-system. So it is essential that sufficient awareness is created for the need for a "safe food policy", which is the need of the hour.

When the Benefit – cost ratio was worked out it gives the wrong impression that the organic inputs are less efficient compared to the inorganic system. However in this case, the returns were not worked out taking the premium price available for organic rice. Also the labour costs were worked out at the Government rates which is much higher than prevailing local rates. Also in working out the efficiency of the system the ecological benefits associated with organic farming is not taken into consideration. Hence to work out the input use efficiency in an organic farming system, a separate methodology is to be evolved taking into consideration not only the inputs & outputs but also the associated ecological benefits.

Crop improvement for input use efficiency and ecosystem adaptability

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Dwindling natural resources extensively utilized in intensive agriculture focuses greater concerns on input use efficiency. Further increasing concerns on environmental safety and sustainable livelihood demands optional use of inputs in agriculture. Crop improvement is a major technological intervention to achieve this goal. Crop breeding had led to the development of varieties with better input use efficiency and adaptability to adverse cropping situations. This paper highlights crop breeding efforts in Kerala, for evolving efficient yield building varieties in major crops like rice, coconut, pepper and rubber.

Rice

Rice is world's most important food crop. The increased demand of rice in future will have to be meet under many constraints such as less land, less water, less labor, less pesticides and less nutrients (Kush, 1995). Increasing awareness about organic farming demands for varieties tolerant to insects pests and diseases. Rice varieties with more adaptation to organic fertilizers and nutrient use efficiency will be ideal under organic cultivation. So to meet the challenges of the future, in Kerala also, crop improvement efforts are in progress to identify/ develop rice varieties with better input use efficiency.

Rice improvement for water use efficiency

Scarcity of irrigation water for rice cultivation is a vital issue often leading to complete crop failure and even fights between nearby localities/ states. Lack of surface water leads to over exploitation of ground water resources. A major challenge in rice cultivation is to produce more with less water by increasing substantially the efficiency with which available water resources are used. To achieve this goal crop improvement efforts are made to incorporate high water productivity and drought tolerance in rice varieties.

Kerala is bestowed with an array of drought tolerant land races/ traditional varieties suited for cultivation in garden lands and uplands. PTB 28 (Kattamodan), PTB 29 (Karuthamodan) and PTB 30 (Chuvannamodan) are the major traditional varieties developed for upland cultivation (KAU,2002). These drought tolerant varieties are having a short growth duration of 100-105 days, early seedling vigor, efficient root system and red kernel color.

Navara is another medicinal rice cultivar of Kerala with an extra short growth duration of 69 days. This cultivar is highly suited for direct seeding in rainfed uplands. The reduced grain yield (2.5 t/ha) of this cultivar is compensated by the increased price (Rs. 30 – 40 /kg) of the produce viz. medicinal rice. This cultivar is traditionally raised under organic farming (Elsy *et al.*, 1992).

Intensive rice improvement programs to develop high yielding varieties with drought tolerance was initiated at Regional Agricultural Research Station, Pattambi during 1988 to develop rice varieties suitable for direct seedling during *virippu* season in the rainfed uplands. M210, a dwarf mutant of the traditional tall *indica* rice variety, Ptb 10, was crossed with the upland rice variety Ptb 28 to combine the drought tolerance of Ptb 28 with the high yielding ability of M210. Cul. A4-4-2 with an average yield of 4220 was released as Harsha (Ptb 55) (Rosamma *et al.*, 2003). The variety is non lodging, non shattering and is performing well under less water situations.

Rice improvement for low pesticide use

The major insect pests effecting rice crop are gall midge, brown plant hopper, stem borer and leaf folder whereas the minor pests are green leaf hopper, white backed plant hopper, rice hispa and blue beetle. Breeding programmes aimed for pest resistance in rice had led to the development of many traditional / high yielding rice varieties. Many of these varieties are identified and utilized as donors for pest resistance in international and national rice breeding programmes.

Rice improvement for gall fly resistance

Many of the traditional varieties released from Regional Agricultural Research Station, Pattambi are gene donors for gall fly resistance. Shastry *et al.* (1972) found that Ptb 18 and Ptb 21 were offering resistance to gall fly. Kalode *et al.* (1977) identified that traditional cultivars/varieties from Kerala like Chennellu, Vellathil cheera, Velutha cheera, Parakulam, Chitteni, Ptb 12 and Ptb 19 were resistant to gall midge. Heinrich and Pathak (1981) had reported that varieties like Ptb 10, Ptb 27, Ptb 28 and Ptb 32 were resistant to gall midge. Ptb 18 and Ptb 21 had contributed to the development of CR 94 series from CRRI, Cuttack and IR 36 from IRRI, Philippines. (Natarajan *et al.*, 1996) as sources of resistance to major insect pests.

Plant breeding programmes implemented at Rice Research Station, Mancombu had led to the release of many high yielding varieties resistant against gall fly, especially biotype 5. The details of these varieties are given in Table 1.

Table 1. High yielding rice vatieties from Kerala tolerant to gall fly.

No	Variety	Duration (days)	Grain type	Features
1	Pavithra (Mo-13)	115-120	Red, medium bold	Dwarf, medium tillering, resistant to BPH and GM biotypes
2	Panchami (Mo-14)	115-120	Red medium bold	Dwarf, medium tillering, resistant to BPH and GM Biotype 5.
3	Uma (MO-16)	115-120	Red,medium bold	Dwarf, medium tillering, non lodging, resistant to BPH and GM Biotype 5
4	Karishma (MO-18)	115-120	Red, medium bold	Dwarf, medium tillering, resistant to BPH and GM

Source: Package of Practices Recommendations: Crops KAU (2002).

Rice improvement for Brown Plant Hopper (BPH) resistance

Brown Plant Hopper (*Nilaparvatha lugens*) was first observed in severe form from Kerala in 1973. Subsequently reports from other states confirmed the devastating damage of this pest. Since then efforts to identify BPH resistance in rice and development of high yielding varieties with BPH resistance had gained attention to tackle the problem.

Of the traditional rice varieties released in Kerala, Ptb 10, Ptb 18, Ptb 19, Ptb 21 and Ptb 33 are resistant to BPH (Kalode *et al.*, 1977; IRRI, 1978). Ptb 18, Ptb 21 and Ptb 33 are extensively used in breeding programmes for BPH resistance in India, Sri Lanka, Indonesia, Bangladesh, Thailand and IRRI, Philippines (Kalode, 1986). Ptb 33 and Ptb 21 are having digenic resistance to BPH. It is suggested that Ptb 33 is having Bph 3 and bph 4 genes (Natarajan, 1996). Along with BPH resistance, Ptb 33 also offered high level of resistance to White Blacked Plant

Hopper, leaf folder and thrips (Natarajan and Nair, 1983). Resistant genes from Ptb 33 had contributed to the development of IR varieties like IR 56, IR 58, IR 60, IR 62 and IR 65 (Natarajan *et al.*, 1996).

In Kerala, out break of BPH incidence is a regular menace in Kuttanad, the rice bowl of Kerala. Moreover tracts which were free of BPH outbreak are recently showing a regular incidence of this major pest. Hence high yielding varieties of rice resistant to this major pest had been developed using appropriate gene donors. High yielding varieties like Aswathy, Triveni, Jyothy, Bharathi, Bhadra (MO-4) and Asha (MO 5) are tolerant to this insect pest.

Hybridisation programme undertaken to incorporate high yield nature of IR 8 and resistance of *Karivennel* led to the development of the variety Pavizham. Later in 1976, hybridization programme was strengthened by introducing BPH resistance from resistant parents like Ptb 33 and ARC 6650 and this led to the evolution of Aruna. Remya, Kanakom and Ranjini are other high yielding rice varieties with tolerance to BPH. The details of these varieties are given in Table 2.

Table 2. High yielding rice varieties from Kerala tolerant to BPH.

No.	Variety	Parentage	Duration (days)	Grain type	Features
1	Pavizham (MO-6)	IR 8x Karivennel	115-120	Red, short bold.	Fairly resistant to BPH
2	Aruna (MO-8)	Jaya x Ptb 33	100-110	Red, medium bold.	Tolerant to BPH and stem borer, moderately resistant to gall midge sheath blight and sheath rot.
3	Remya (MO-10)	Jaya x Ptb 33	110-120	Red, long bold.	Moderately resistant to BPH, gall midge, sheath blight and sheath rot.
4	Kanakom (MO-11)	IR 1561 x Ptb 33	120-120	Red, medium bold	Resistant to BPH and moderately resistant to stem borer. Resistant to rice.tungro virus, blast and bacterial blight.
5	Ranjini (MO-12)	MO-5 x Improved Sona	115-120	Red, medium bold.	Dwarf, resistant to blast and BPH.

Source: Package of Practices Recommendations: Crops-2002.

Pavithra (MO-13), Panchami (MO-14), Uma(MO-16) and Karishma (MO-18) are tolerant to both BPH and Gall midge.

Rice improvement for salinity tolerance

The coastal belt of Kerala has a unique system of rice cultivation in saline soils locally known as '*Pokkali*'. The *Pokkali* soils are distinct from saline soils found elsewhere in India. During summer months due to ingress of salt water from the sea, the soil becomes saline. But with the onset of South West monsoon, the salts get washed off and the inherent acidity of the soil regenerates. Initial salinity, water logging and flooding, inherent acidity of the soil and saline water in the reproductive and ripening stages are the main problems of the area (George *et al.*, 1990).

Traditional varieties of *Pokkali* lands are known as *Pokkali* varieties and the special system of rice cultivation followed in *Pokkali* lands are known as *Pokkali* cultivation. Traditional varieties like *Pokkali, Cherivirippu, Karuka, Eravapandy, Orpandy* etc. are the varieties suited for *Pokkali* cultivation. Rice breeding efforts at Rice Research Station, Vyttila had led to the development of many HYVs of rice suited for the tract. Vyttila-1, Vyttila -2, Vytilla –3,Vytilla- 4 and Vytilla -5 are the varieties recommended for this tract (KAU, 2002). Rice cultivation in saline soils is also popular in Kollam district where it is known as *Orumundakan* lands. Sagara is a long duration variety suited for *Oorumundakan* lands. This variety is having a duration of 180-190 days, red kernel color and photosensitivity (KAU, 2002).

Rice improvement for nutrient use efficiency

Plant breeding efforts for the improvement of Mashuri was initiated at Regional Agricultural Research Station, Pattambi in 1987 to combine red kernel colour and nutrient use efficiency. The most promising culture from this programme viz. RM-1 was released as Mangala Mashuri (Ptb-53). This variety is capable of producing an average grain yield of 4.9 t/ha at a low fertilizer dose of 50:25:25 kg N, P_2O_5 and K_2O and is resistant to gall midge, stem borer, leaf folder, whorl maggot, rice hispa and iron toxicity. Total growth duration of the varieties is 140-145 days. Rice is red in colour and medium slender in shape. It is tolerant to water logging and had shown good response in low fertilizer regimes (KAU, 2002).

Rice is well known for its capability to thrive under a variety of agro ecological situations. Land races that evolved naturally in different agro ecological situations had developed morphological and physiological characteristics to survive in adverse conditions. Genes responsible for these specific features had contributed to the evolution of many high yielding varieties ideal for cultivation in different situations like drought, salinity, high incidence of pests and diseases etc. Further in recent era of genetic engineering varieties identified as gene donors for such specific features will be best utilized in rice improvement programmes.

Black Pepper

Black pepper is the most important and most widely used spice in the world. The black pepper of commerce is the dried mature fruit of the tropical, perennial climbing plant *Piper nigrum* L., belonging to the family Piperaceae. Kerala accounts for 96 per cent of the area and production of black pepper in India. Cultivar diversity is richest in Kerala. There are many black pepper cultivars that are specific to the major growing tracts of Kerala like the plains, higher altitude areas and valleys of hills as a pure crop, mixed crop or intercrop trailed on various trees. Cultivar variation exists in black pepper in relation to yield, morphological attributes, resistance or tolerance to biotic and abiotic stresses.

Pepper improvement for disease resistance/tolerance

Crop losses due to diseases and pests are the major causes of low productivity of pepper in India. This crop is affected by several diseases caused by fungi, bacteria, virus, mycoplasma and nutritional disorders. The foot rot of black pepper caused by *Phytophthora capsici* is the major one. Almost all the cultivated germplasm are susceptible to this disease. Among the cultivars, *Narayakodi, Kalluvally, Balankotta, Neelamundi, Mundi* and *Uthirankotta* have been identified as tolerant cultivars (Sarma and Anandaraj, 1997). Indigenous varieties like *Balankotta, Kalluvally, Uthirankotta, Arakulammunda* and *Arikotta* are more tolerant to the disease than the popular *Karimunda* and *Panniyur-1* (KAU, 2001). Among other taxa, *Piper colubrinum* is highly resistant to the fungus. In a study conducted by Indian Institute of Spices Research, Calicut, several open pollinated progenies of *Perambramundi, Kalluvally, Cholamundy* and hybrids involving *Panniyur-1* X *Karimunda* and *Narayakodi* X *Neelamundi* had recorded tolerant reaction (Sarma *et. al.*, 1994). A low ratio of total phenols to orthodihydroxy phenol (OD phenols) and a higher peroxidase activity in the cultivars imparts tolerance or resistance against this dreaded disease.

Pepper improvement for pest tolerance

Pollu beetle (*Longitarsus nigripennis*) is the most destructive pest of black pepper and its infestation is higher in plains of North Kerala, a major pepper growing tract of Kerala. Different cultivars show wide variation in resistance or susceptibility to pollu beetle. Shade intensity had a positive influence on pest incidence. In an experiment conducted at IISR, it was found that *Kalluvally* and *Karimunda* are less susceptible to the pest (Pillai and Abraham, 1979). The distribution pattern of the pest in the major pepper growing tracts of Kerala revealed that in northern Kerala, the cultivar *Kalluvally* was found to be least susceptible and *Arakkulammunda* was the most susceptible. In the southern regions of the state, the cultivar *Narayakodi* was more susceptible than *Karimunda* (KAU, 2001). There are several wild species that are resistant to the pest.

Pepper improvement for drought tolerance

Rainfall in the state is not distributed uniformly and black pepper suffers due to moisture stress for nearly six months. Cultivar variation exists in the tolerance level towards drought in black pepper. Stomatal resistance, transpiration rate, leaf water potential, proline accumulation and root to shoot ratio are the important traits used to screen such drought tolerant cultivars. The cultivars *Kottanadan, Arakulammunda* and *Kalluvally* showed high stomatal resistance, low transpiration rate and high leaf water potential indicating that these cultivars can tolerate drought. Accumulation of proline was higher and earlier in cultivars like *Neelamundi, Kottanadan* and *Aimpiriyan* indicating that these cultivars were also tolerant to drought. The root to shoot ratio was higher in *Kalluvally*, which is a drought tolerant cultivar (Vasantha *et al.*, 1990). Among the released varieties, *Panniyur-5* possessed superior morphological, physiological, biochemical and anatomical adaptations to tolerate water stress (Thankamani, 2000).

Pepper improvement for input use

The cultivar *Karimunda* is the most popular and widely adopted cultivar in all the major pepper growing regions of the state except in certain pockets of Idukki and Wayanad. The cultivars namely *Karimunda, Neelamundi, Vattamundi, Vadakkanmunda, Karuveli* and *Kotta* were identified as low input responsive varieties (KAU, 2001).

Rubber

Para rubber, *Hevea brasiliensis,* a forest tree indigenous to the tropical rain forests, is one of the most recently domesticated crop species in the world. It provides 99 per cent of the global natural rubber. The production and productivity indices of natural rubber, the versatile product from *Hevea brasiliensis* are the highest among the plantation crops in India. The rubber growing tracts receive majority of the rains from the South West monsoon and remaining portion from Northeast monsoons. Drought prevails in major tracts for more than six months that adversely affect the crop and pre disposes the crop to major diseases.

Rubber improvement for disease and pest resistance or tolerance

The most destructive disease of rubber in India is abnormal leaf fall which occurs during the South West monsoon period. All high yielding clones and clonal seedlings are susceptible to abnormal leaf fall disease under Indian conditions. The first report of this disease was from *Palappilly* in Trichur district of Kerala. Later the disease spread to all other rubber growing districts. Clones like RRII 105, PB 217, GT 1 and Gl 1 recorded to retain more leaves than many of the susceptible clones under similar prophylactic spraying.(Edathil *et. al.*, 2000)

The stem including the tapping panel region is also vulnerable to various diseases. Among the various stem diseases of rubber, pink disease is the most serious one affecting young rubber trees of two to seven years old. Different clones show variation in their susceptibility to this disease. Among the modern and widely planted clones PB 217, PB 311 and RRII 105 are highly susceptible to the disease in the traditional rubber growing areas but clones like PB 86, RRIM 513, Gl 1, PR 107, GT 1 and PB 260 are less susceptible (RRIM, 1992).

Unlike most crops, rubber is subject to pest attack only on a limited scale because of apparent aversion of insect and pests to the latex that is present in all parts of the plant. However a few pests do become serious at times. The predominant insect pests of rubber in India include white grub, bark feeding caterpillars, termites, scale insects and mealy bugs.

Rubber improvement for drought tolerance

Abiotic stresses individually or in combination constitute a major factor limiting the expression of genetic productivity potential of crop plants. Performance of the *Hevea* tree is highly influenced by water relation and has to confront conditions of soil moisture stress in many of the non-traditional areas. Even traditional areas, the wet season is followed by six months of dry period extending from October-November to March- April. The drought causes yield reduction, drying up and die back and early induction of wintering. The variety Gl 1 has low transpiration rate, high water potential and stomatal resistance, while GT 1 is characterised by lower transpiration rate and low reduction in photosynthetic rate indicating that both these clones are drought tolerant. Among yield components, high initial flow rate and low plugging index are important and in variety RRII 105 yield during drought is good.

Coconut

Coconut is one of the important cash crops grown in Kerala. It is the most important sources of vegetable oil in the world. Copra, the main product of the palm is the richest material for vegetable oil extraction. Apart from this, many commercially important bye products are obtained from the palm.

Coconut improvement for diseases tolerance

Of the several maladies that confront coconut production in the state, the coconut root wilt disease is of utmost concern. The palm is also affected by a number of other diseases like bud rot, stem bleeding, leaf rot etc. The root wilt disease first noticed in three isolated pockets of Kerala had spread to all the coconut growing tracts. Root wilt is reported to be caused by *Phytoplasma* and is spread by insects like lacewing bug and or plant hoppers. Symptoms of the disease include flaccidity, yellowing and marginal necrosis. So far no varietal resistance/ tolerance had been reported for this disease.However DXT hybrids are found to perform better with regard to yield in disease affected palms. That is the intensity of disease was low in hybrids. CPCRI has identified disease tolerant palms among CGD and local tall palm. Progenies of crosses involving CGD X WCT, Fiji X GB and GB X WCT are promising. The cultivars namely AO, SSG and Cochin China also showed fair degree of tolerance.

Coconut improvement for pest tolerance

Coconut palm is susceptible to the attack of a large number of pests of major and minor importance. The rhinoceros beetle and red palm weevil are the most serious pests that cause considerable damage to the palm in all coconut growing regions. The beetle attack is maximum during the summer months. The varieties vary in their tolerance level to this pest. In a study conducted at Regional Agricultural Research Station, Pilicode, it was revealed that the exotic varieties were more susceptible than WCTI and other cultivars. Among the hybrids, the lowest susceptibility was recorded by CDO X WCT hybrids, WCT X CDG hybrids and WCT X GB hybrids, whereas Cochin China X CDG was the most susceptible.

Relatively young palms are most affected by the red palm weevil. The leaf damage was lowest in WCT X CDG hybrids, CDO X WCT hybrids and WCT X LD hybrids.

Coconut improvement for drought tolerance

Coconut is a crop mainly cultivated under rainfed or limited water availability conditions. Hence drought is one of the major constraints affecting the coconut productivity. The traits that impart resistance or tolerance in different genotypes include accumulation of epicuticular wax on the leaf surface, low stomatal conductance and low transpiration rate. Biochemical characters that help in the maintenance of cell membrane integrity are stress sensitive enzymes like superoxidase dismutase, catalase and peroxidase. Coconut hybrids such as WCT X GB, LO X COD and WCT X COD and tall palms are relatively drought tolerant. The above cultivar or hybrid maintain higher dry matter production and higher partitioning of dry matter towards yield thus maintaining higher yield stability under stress condition (Rajagopal, 2002). The drought tolerant tall genotypes like WCT, FMS, Fiji, LO and the T X D and T X T hybrids exhibited high water use efficiency and enhanced fruit set with high harvest index (Rajagopal, 1998). The most sensitive stages to drought are seedling, initiation of inflorescence primordium, ovary development and post fertilization period.

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IV. SESSION ON EFFICENCY IN NUTRIENT USE

Improving nutrient use efficiency – challenges and opportunities

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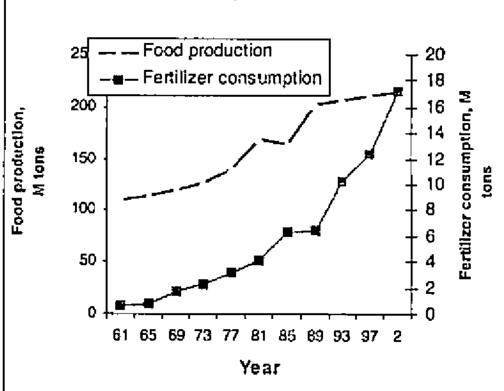
Use of fertilizers has become inevitable to increase agricultural productivity world over. There is a near linear relationship between Fertilizer Consumption and Food Production in most of the countries including India. The hope of meeting the food requirement of ever increasing population stands on this relationship. It is believed that our population stabilizes around 1.4 billion. To feed this 1.4 billion mouths we need to produce around 340 mt of food. For this the only hope is by increasing the fertilizer consumption from the current 18.4 mt to 30 to 35 mt of NPK fertilizers apart from 10 mt supplied through organic and bio-fertilizers. The increase in natural gas and other petroleum products costs has direct impact on the fertilizer cost. This trend would continue because of limited resources. Hence development of technologies and matching policy issues to increase nutrient use efficiency is receiving a great deal of attention to day. Activity has intensified in many sectors and at various scales. Last year the first formal meeting of the international nitrogen initiative was held in the Netherlands. This is a global effort with a primary focus on improving fertilizer nitrogen efficiency in order to optimize N's beneficial role and minimize negative environmental effect using both scientific and policy tools. Several farmers practices that improve nutrient use efficiency including fertilizers need to be assessed, fine-tuned and subsidized to popularize the practice. New fertilizer material that produce better yields with reduced nutrient loss by improving nutrient use efficiency must be developed and marketed to plug the loss of national revenue and to protect environment. While attempting to increase nutrient use efficiency one should consider the long-term impact of a nutrient management practice on the production system. This is because a practice may appear highly efficient in short term, but result in long-term negative impacts on the system or it may be inefficient in the short term but have positive long-term effects. Hence we must consider sustainable nutrient use efficiency rather than short term nutrient use efficiency.

Nutrient Use Scenario: As earlier stated there is a linear relationship between fertilizer consumption and food production in our country. Before Green Revolution our fertilizer consumption was hardly 0.5 mt with a production of about 50 mt of food (Fig.1). But to-day we reached a target of 210 mt of food production with a matching fertilizer consumption of 18.4 mt.

Fig 1. Food grain production and fertilizer consumption in India



Global fertilizer consumption has increased substantially since 1950. Between1960 and 1995 global use of N fertilizer increased seven fold and is expected to increase by another three fold by 2050 unless there is a substantial improvement in nitrogen use efficiency. In 1996, 82,906,340 metric tons of fertilizer N was applied in the world. Sixty per cent of this (49,743,80 metric tons) went to cereal production (Table 1). Out of that only 16572232 metric tons were estimated to have been removed in the grain (Dale, 1997).

Table 1. World consumption of fertilizer N (1996) for cereal production, N removed from cereal grain and estimated N use efficiency

Computation/Commodity	Production/N removed, mT
Total Consumption	82,906,340
Cereal Consumption	49,743,804
Cereal Production	2,056,637,800
Total N removed	33,144,465
Soil contribution	16,572,232
Estimated N use efficiency	33%
N saving for 1% increase in NUE	489,892
Value of fertilizer saving	$234,658,462

Source: FAO (1996)

The world cereal grain nitrogen use efficiency would therefore be estimated at 33%. This is far less than the 50% generally reported from research results. When we compare N use efficiency among different countries, developed countries have 42% while developing countries have 29% efficiency. An effort in this direction has not been made in this country for want of information on soil derived nitrogen in nutrient uptake.

Nutrient Harvest – Nutrient Addition Relationship: At the national level it is estimated for the year 1997 that annually 25.1 mt of nutrients are removed from the soil whereas only 15 mt are supplied from all sources including organics (IISS 1997) leaving a huge gap of 10.1 mt. Though required data is lacking, Biswas and Tewatia (1991) calculated this relationship on different Agro-climatic region basis, which showed the variability in nutrient gap between regions (Table 2).

Table 2. Agroclimatic region wise fertilizer use, nutrient removal and gap (kg/ha) (1989-90)

Region No.	Agroclimatic region	Fertilizer use	Nutrient removed	Gap
1	Western Himalayan region	51	97	46
2	Eastran Himalayan region	18	71	55
3	Lower gangetic plains	81	129	48
4	Middle gangetic plain	83	116	33
5	Upper gangetic plain	93	170	77
6	Trans gangetic plain	120	183	63
7	Eastern plateau hills	23	83	60
8	Central plateau hill region	30	118	88
9	Western plateau hills	38	94	57
10	Southern plateau hills	73	123	50
11	East coast plain & hill region	156	46	-
12	West coast plain & hill region	76	127	51
13	Gujarat plains & hills	66	87	21
14	Western dry region	6	33	27
15	The Islands	-	-	-
	All India	62	117	55

It varied from 21 kg/ha in Gujarat Plains and Western Hills to 88 kg/ha in Central Plateau Hills Region as against all India average of 55 kg/ha. The picture may be different if attempts are made in this direction according to Agro-ecological regions and Sub-Regions of the country. For example, the old Western Plateau Hill Region of Agro-climatic zone partly fall under Region-5 of the new Agro-ecological region covering parts of Rajasthan, Madhya Pradesh and Gujarat. The nutrient use - nutrient removed – nutrient gap for the Western Plateau Hill Region is 38 – 94 –57 kg/ha and that for Region-5 of Agro-ecological region is 50-86-28 kg/ha respectively. Hence, it is very important to generate this information on Agro-ecological region basis for developing management technologies to improve nutrient use efficiency. Since data on contribution of soil nutrients to total nutrient uptake is not available it is not possible to calculate the nutrient use efficiency either on Agro-climatic zone basis or Agro-ecological region basis. We must think seriously to generate this information to monitor shifts in NUE with time which has serious economic consequences to the country.

Why are Nutrient Use Efficiencies So Low? – Soil-water-plant atmosphere system is a very heterogeneous system. Bio-production depends upon the efficiency of this system. Nutrients are generally applied to soil. It then enters water (solution phase) and plant roots and then to plant top. The efficiency is influenced at each stage. They may be lost physically through erosion, surface run-off, leaching or fixation & adsorption and chemically through transformation into unavailable forms. Some nutrients like P may be temporarily lost and some may be lost permanently from the system like N through de-nitrification. The most serious step is the reaction and transformations of fertilizers when they enter soil system. Roughly the efficiency of N is estimated at 30-40%, P 15-20%, K 50-70%, S 8-10%, Micronutrients < 10 %.

Nitrogen: Low efficiency of nitrogen fertilizers is thought to be largely due to N losses from soil-water-plant-atmosphere system. Ammonia volatilization, de-nitrification, surface run-off and leaching are the major roots of N loss from the system. The efficiency hence is obviously influenced by the nature of N fertilizer, method of application, condition of the field.

N Loss from the Plant: Not until recently have scientists documented that plants release N from plant tissue, predominantly as NH_3 following anthesis (Harper *et al.*, 1987, Francis *et al.*, 1993). Plant N losses have accounted for 52 to 73% of the unaccounted N using ^{15}N in corn and between 21 and 41 % in wheat. Gaseous plant N loss to the extent of 45 kg N ha^{-1} yr^{-1} has also been documented in soybean (Fig. 2 and 3).

N Loss through Surface Run-off: Loss of N through surface run-off range between 1 % (Blevins *et al.*, 1996) and 13 % (Chichester and Richerdson, 1929) of the total N applied. These estimates are done in temperate

Fig. 2. Foliar N loss and transpiration rate over one solar day in soybean

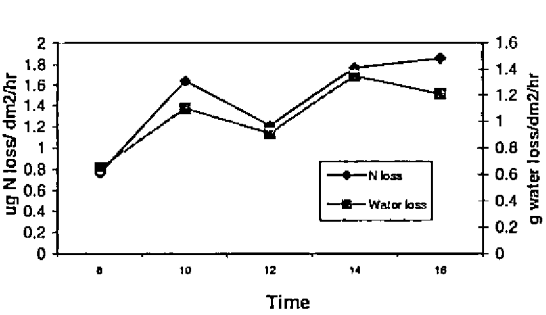
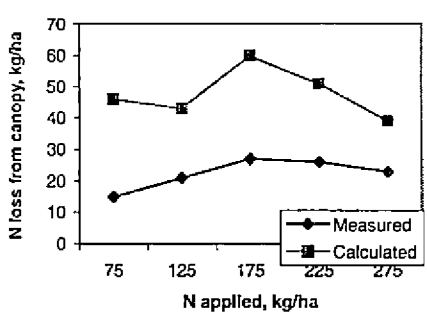


Fig. 3. Post anthesis N loss from corn



environment. But in tropics high intensify rains and over flow of water from rice fields cause much larger amounts of loss. Unfortunately no reliable estimates are available from tropical countries.

De-nitrification: Reported gaseous N loss due to de-nitrification from applied fertilizer N may go up to 22 % in corn (Hilton *et al.*, 1994), 10 % in low land rice (De Datta *et al.*, 1991) and 9.5 % in wheat (Aulakh *et al.*, 1982). Addition of decomposable plant material may substantially increase de-nitrification (Aulakh *et al.*, 1984).

Leaching: Losses of N through leaching can be significant when fertilizer N is applied at rates in excess of that needed for maximum yield. Under temperate environment nitrate losses through tile drainage may be as high as 26 kg N ha^{-1} yr^{-1} when 115 kg N ha^{-1} was applied (Drury *et al.*, 1996). This could be an over estimate as canopy N loss was not estimated and is accounted for leaching loss.

Volatilization: Loss of N through ammonia volatilization is a major loss mechanism that affects the efficiency of urea and other N fertilizers in irrigated low lands. The magnitude depends on wind speed, temperature, rainfall, NH_4- N concentration, pH and CEC. Depending upon mode of application and time of application the loss may range from 7 to 54 % (Table 3).

Table-3. Summary of Ammonia volatilization loss estimated using ^{15}N balance Technique

Method of Application	Site	Amount applied	NH_4 Volatilization	Total N Loss	Estimated De-nitrification
Basal incorporation	I	80	15	18	3
	II	60	13	26	13
	III	90	9	48	39
Broadcast at 10-21 DT	I	80	47	45	0
	II	60	27	60	33
	III	80	9	43	34
	IV	60	54	55	2
	V	40	7	39	32
Broadcast at 5-7 DBPI	I	40	11	13	0

Source: S.K.De Datta *et al.* (1991)

Aqueous ammonia in flood water increases about ten folds per unit increase in pH over the range 7.5 to 9.0. At constant total NH_4-N concentration and pH aqueous ammonia increases almost linearly with increasing temperature which results in nearly a 4-fold increase in the range from 10 to 40°C.

Phosphorus: Efficiency of phosphorus is generally lower than nitrogen. Low efficiency of P is thought to be largely due to fixation by the soil, chemical transformation to insoluble forms, erosion and surface run-off.

Fixation and Chemical Transformation: Loss of phosphorus through fixation and chemical transformation may range from 5 to 95 % depending upon soil type. Highly sandy neutral soils fix very low amounts of P whereas Oxisols having low pH may fix even the entire amounts of added phosphorus. In real sense this is not a loss as it becomes temporarily unavailable and becomes slowly available to subsequent crops.

Erosion and Surface run-off: Soluble P present in surface of soil is carried away in run-off water and is removed from the site of application and enters water bodies, which subsequently cause eutrification. The quantity of P lost through this means is highly variable.

Potassium: Among the major nutrients efficiency of potassium is much higher. It is generally above 50%. Loss of K from soil may occur through surface run-off and through leaching in highly sandy irrigated soils.

Secondary Nutrients: Among secondary nutrients the efficiency of Sulphur follow similar pattern of phosphorous or slightly less than that. Information on efficiency of Ca and Mg is not available but appears to follow similar to that of potassium.

Micronutrients: Generally micronutrients, which are applied in very small quantity undergoes transformation in soil and becomes unavailable with time. Specific work to evaluate the efficiency of applied micronutrients is very scanty. But the efficiency of soil- applied micronutrients is generally less than 10 %.

How can Nutrient Use Efficiency be increased? This question is very important because an unit increase in fertilizer use efficiency will have its direct impact on i) national economy, ii) it will reduce the adverse effects of fertilizers on environment, iii) it may improve the nutritive value of food produced.

Production practices that can increase nutrient efficiency when compared to conventional or standard practices are those that will counter conditions, or environments known to contribute to nutrient loss from soil-plant system.

Efforts to increase Nutrient Efficiency: There are several ways one can attempt to improve the nutrient use efficiency like i) source of nutrient, ii) method of application of nutrients, iii) time of application, iv) modified materials, v) arresting chemical transformations, vi) efficient crop rotations, vii) forage production systems, viii) nutrient use efficient varieties / hybrids, ix) conservation tillage, x) in-season and foliar application, xi) water management and xii) precision agriculture. Voluminous information is available on each of the above. But any effort to increase nutrient use efficiency will not be effective unless it is addressed in a holistic manner. It is out of purview of this paper to discuss each of the above means to improve nutrient use efficiency. But only those production practices that have resulted in increased nutrient use efficiencies when compared to conventional or standard practices thoroughly countering the conditions or environments known to contribute to nutrient loss from soil-plant system are discussed here.

i) Modified materials: Straight fertilizers that are added to soil come in direct contact with soil colloids and undergoes transformations. To increase efficiency of such fertilizers either the contact surface is reduced or contact period is reduced or such additives are added which suppress the rate of chemical reaction. Most of the work in this direction was directed towards N fertilizers mainly because N is lost through many channels and in the process removed from soil-plant system, whereas other nutrients temporarily become unavailable but remain within the system and become available in due course of time. Since urea is the chief source of N world over most of the efforts have gone in for reducing loss of N by modifying urea as i) urea super granule (USG) to reduce contact area and contact period and to have advantage of facilitating deep placement in rice fields which enhances N utilization (Table 4), ii) coated urea to reduce contact period and to suppress urease activity. Coatings are done with numerous material like coal tar, lac etc., to reduce physical contact period or coated with Sulphur, urease inhibitors or neem cake etc., to reduce rate of transformations (Table 5).

Coating of phosphatic fertilizers is also gaining momentum. Such work is limited in our country. Coating P fertilizers could limit the contact of applied P with soil possibly reducing its precipitation and or adsorption on soil colloids and increasing availability to plant roots. Experiments have demonstrated that polymer coating of monoammonium phosphate has increased the estimated fertilizer P use efficiency (Table 6) from 16 to 32.6% depending upon thickness of coating and has generally improved the response level (Malthi *et al.*, 2002).

Table 4. Effect of method of application of USG on NUE (kg grain / kg N) in rice

N LevelKg/ha	Prilled Urea	USGB&I	USGDP	UAB&I	UADP
30	35	45	45	34	36
60	28	32	36	28	31
90	22	25	28	23	24
120	20	21	23	21	21
Mean	26	31	33	27	28

US6 = Urea Super Ganules 1 g/pellet., UA = Urea Adduct (80% urea + 20% phospho gypsum)., B&I = Broadcast & Incorporation., DP = Deep Placement.

Source: Tahir Ali and T.A. Singh (1994)

Table 5. Apparent N recovery by rice as affected by urea management in different soils

Modified urea	*Vertisol*	*Inceptisol*	*Alfisol*	*Mean*
Prilled urea	52.1	18.5	43.9	38.1
Coal tar urea	51.7	23.4	60.4	45.2
Coal tar + Neem cake urea	53.7	24.8	65.5	48.0
Coal tar + Mustard cake	52.7	31.4	41.0	41.7
Urea + 6M	78.3	65.4	23.4	55.7
Urea + FYM	38.5	37.6	22.5	32.9

Source: T.J.Purakayastha, J.C.Katyal and N.N.Gowami (1997)

Table 6. Estimated P use efficiency in Barley from controlled release fertilizer

Treatment	*Dry matter yield (g/pot)*	*EPUE (%)*
Control	9.7	—
MAP	11.7	16.5
Thin coated MAP	12.6	32.6
Thick coated MAP	11.7	25.3

Source: S.S.Malhi, L.K. Harderbein, D.G.Panly and A.M.Johnstan (2002)

Chelated micronutrients are becoming common which prevents their reaction with soil colloids and makes them available to plants for extended period of time, thereby increasing their efficiencies.

Efficient Crop Rotations: A crop plant can be more nutrient efficient by absorbing more nutrients from the limited soil source or from applied source and/or by utilizing the absorbed nutrient more efficiently for seed or grain production (Ganeshamurthy,5 1998). The efficiency with which a crop produces a harvestable or economic product per unit of available plant nutrient varies with crop species. Rice, wheat, soybean, food legumes fall within the medium category with respect to their nutrient use efficiency. In these cases yields and total nutrient uptake increases with increase in soil fertility and rates of applied nutrients but utilization efficiency decreases with increasing rates of nutrient application as well as increasing soil fertility (Ganeshamurthy *et al.*,1998, Subba Rao *et al.*, 1997). Hence, while formulating an efficient rotation one must select such crops which feeds on both applied nutrients and the residues of nutrients applied to previous crops in rotation.

Evaluation of mung and urd bean cultivars (Ganeshamurthy *et al.*, 2004) for their ability to utilize applied fertilizer P have clearly shown cultivar differences (Table 7). It has also been demonstrated that for both phosphorous (Subba Rao *et al.*, 1997) (Table 8) and S (Ganeshamurthy, 1998) in soybean-wheat rotation (Table 9) that wheat crop which has relatively higher exploitation potential for residual nutrients may be able to grow at a relatively low level of available soil nutrients and may grow better than soybean. Whereas, soybean shows preference for direct applied nutrients. Hence, while working out nutrient requirement of a crop rotations, crops which have ability to utilize fertilizer nutrients better than residual nutrients should be followed by crops which have better ability to utilize residual nutrients and accordingly scheduling of fertilizer application should be planned.

Table 7. Phosphorus utilization from fertilizer source by mungbean cultivars

P levelKg/ha	PDM-11	PDM-54	NM-1	Samrat
0				
8.75	33.0	24.5	23.9	21.6
17.5	26.3	21.2	22.6	18.6
26.25	20.1	16.3	17.1	15.9
Lsd(0.05)	2.07	1.75	1.18	2.21

Source: Ganeshamurthy *et al.* (2004)

Table 8. Utilization of phosphorus by soybean and wheat from soil and fertilizer sources

Applied PKg/ha	Soil source (%)		Fertilizer source (%)	
	Soybean	Wheat	Soybean	Wheat
10	51.7	26.8	18.2	26.7
20	25.6	13.4	25.4	24.2
40	12.9	6.7	20.2	21.0
60	8.6	4.5	15.1	17.2
80	6.5	3.4	12.8	14.7
100	5.2	2.7	11.2	12.9
Lsd(0.05)	1.7	1.1	7.2	3.9

Source: Ganeshamurthy (1998)

Table 9. Utilization of sulphur by soybean and wheat from soil and fertilizer sources

Applied SKg/ha	Soil source (%)		Fertilizer source (%)	
	Soybean	Wheat	Soybean	Wheat
20	.39.3	39.5	9.0	13.4
40	19.7	18.7	10.4	11.3
60	12.5	12.5	9.0	9.5

Source: Ganeshamurthy (1998)

Forage Production Systems: Recent realization that plants release significant amounts of N from plant tissue, predominantly as NH_3 following anthesis has made us to think that if we can harvest the crop before reproduction stage it is possible to increase nitrogen use efficiency in the crop. But it cannot be done in most of the crops because economic edible part will be produced only in reproductive phase. Looking at the economic loss occurring from low N use efficiency (An increase in 20% use efficiency of N fertilizer brings a saving of about 2000 crore rupees annually) it is imperative to think of using biomass before attaining reproductive phase. Forage-only production systems which can be used to convert this biomass into meat and milk can be one way to prevent loss of this huge revenue (as plant is never allowed to approach flowering where N losses have been found to be great). Thomason (1998) has shown that N use efficiency in forage-only in wheat was 77% compared to 31 % for grain production system at 90 kg applied N. Similarly total N removed in forage production system was 104 against 59 kg N ha^{-1} in grain production system (Table-10). Such work has not been attempted in this country. However, it must be kept in mind that substitution of forage for grain will ultimately increase dependency on animal protein and decrease supply of starch for human diets.

Table 10. N removed and NUE in forage and grain production system at 90 kg N ha^{-1} in winter wheat

Production System	Total N removed (kg ha^{-1})	NUE (%)
Forage-only System	104	77
Grain Production System	59	31

Source: Thomason (1998)

Nutrient Use Efficient Cultivars/Hybrids: With the advancement of bio-technological tools, the interest in development of nutrient efficient cultivars and hybrids has increased. Considerable progress has been made in improving plants to grow and produce effectively on nutrient deficient soils. Gains have been rapid in some species. While progress has been slow in others. It is out of scope of this paper to go deep into science of this topic. But I must mention that soil scientists should work towards identification of traits for various nutrient efficiencies and to screen germplasm to identify donor parents which breeders can carry forward to achieve desired objectives. To mention a few, Ramani and Kannan (1986) used nitrate reductase activity as a screening trait to screen sorghum germplasm for N efficiency. They further observed heterosis of NR activity in Sorghum hybrids. Sreenivasa Rao and Ganeshamurthy (2004) have shown wide genotypic variability in P use efficiency of chickpea. Ganeshamurthy et al (2004) showed differences in P use efficiency in mung and urd bean cultivars. Takkar et al(1989) identified Mn efficient wheat lines. Of all these the most interesting and promising is the identification of iron efficient lines in crop plants because Fe deficiency chlorosis frequently occur with many plants grown on alkaline and calcareous soils. Ganeshamurthy (2003) screened 1100 chickpea lines. On the basis of visual scoring and Fe^{2+} / Fe^{3+} ratio identified BG-256 as one of the most efficient. Fe efficient cultivar which can be grown on these soils.

Conservation Tillage: Conservation tillage is becoming popular as they control erosion, prevent environmental pollution and lower operational cost. But recent reports suggests that conventional tillage causes organic carbon loss whereas conservation tillage conserves organic carbon. This in turn helps in improving nutrient use efficiency. Rao and Dao (1996) have shown that under a no-tillage production system, grain yield was improved 32% when 60 kg N ha was banded 8-10 cm below the seed row and 15% when banded between rows compared to surface broadcast urea. Adoption of sub-surface placement of N fertilizer for no-till winter wheat significantly improve N availability to plants and thereby improve NUE and reduce environmental and economic risks.

In-season and Foliar Applications: In-season application of nutrients either through soil application of nutrients as top dressing/split application or through foliar sprays is very common in this country. Split application of nitrogen fertilizer has been recommended for most of the field crops but P & K are generally applied as basal applications. Split application of N has been found to improve N use efficiency and reduces losses. It has also been found to increase protein content. More the number of splits better is the results. But economics of application comes in the way of increasing the number of splits. Since most crops receives one to two sprays of pesticides, it is always feasible to have two sprays of nutrients along with fertilizers as they are compatible.

Though food legumes fix atmospheric nitrogen and receives only a starter doze of nitrogen, it has been recently demonstrated that one spray of DAP at peak flowering has increased the yield levels of pulse crops (Table 11).

Table11. Effect of foliar application of DAP at flowering seed yield (kg ha^{-1}) on some pulse crops

Treatment	Mung	Urd	Pigeon Pea	Chick Pea	Lentil
Water Spray	11.0	10.9	24.6	22.3	14.0
DAP Spray (2%)	14.4	13.6	28.2	25.1	15.5

In case of micronutrients foliar applications have always been found superior to soil application. This is mainly because of the quantity of nutrient required to be pumped into plants.

Water Management: Moisture condition of the soil has a profound influence on nutrient availability to plants and losses through erosion and leaching. This is the basis on which fertigation has developed. Fertigation has a built-in mechanism of In-season application of nutrients. Hence efficiency of nutrient use is relatively higher in fertigation. However, extent of rainfed area in this country is so vast (>80 mha) that fertigation is not a practical preposition in dry lands. Here In-season application of nutrients matching with soil moisture condition will help in increasing nutrient use efficiency. A classical experiment on P use efficiency by simulating soil moisture fluctuation similar to monsoon fluctuations was conducted by Ganeshamurthy (1985). He has shown (Table 12) that P use efficiency drastically reduce with decrease in soil moisture and initial wet period followed by dry period later is better than initially dry followed wet period.

Table 12. Effect of P application at different moisture regimes on uptake of P from soil and fertilizer sources at 60 days of growth on low and medium P soils

	Low P soil		Medium P soil	
Moisture regime	P-20	P-40	P-20	P-40
Wet(100% FC)	22.2	23.1	23.9	24.8
Intermediate (60% FC)FC	15.4	15.8	17.9	17.9
Dry(40%FC)	7.7	8.1	9.4	9.8
Wet followed by dry	18.8	20.1	21.4	22.6
Intermediate followed by dry	12.8	14.1	14.5	15.8
Dry followed by wet	14.5	19.2	19.7	21.1

Source: Ganeshamurthy (1985)

Precision Agriculture: Current nutrient recommendations are based on soil testing. If a soil tests low in available nutrients then nutrients are added 25% above recommended level and if it tests high then 25% less is added. In any case it is a blanket recommendation for a large area. Natural and acquired variability in production capacity or potential within a field cause the average rate to be inadequate in some parts and excess in other areas. In precision agriculture, timely and precise applications are done to meet plant needs as they vary across the landscape. In order to capitalize on any potential fertilizer saving and increase nutrient utilization efficiency management decisions need to be made at the appropriate field element size (FES). FES is defined as that area or resolution which provide the most precise measure of the available nutrient where the level of that nutrient changes with distance. Random field variability in soil test and plant biomass has been documented at resolutions less than or equal to one square meter. When nutrient management decisions are made on areas of one square meter, variability present at that resolution can be detected using sensors, treated accordingly with foliar nutrient application thus increasing the nutrient use efficiency. It is however, important to note that soil testing irrespective of within field is a first approximation to refine nutrient rates. A combination of soil testing, fertilizer experience of the farmer and projected nutrient requirement (targeted yield) are the best management tools available for farmers to determine fertilizer requirements.

Conclusions:

- The best hope for reducing nutrient loss and increase nutrient use efficiencies lies in finding efficient ways to fertilize crops and by developing better fertilizer materials.
- Nutrient use efficiency should be viewed differently for different nutrients depending upon the chemistry of the element in question and their residual effects.
- Efficiency studies should not be concluded on short term experimental basis as practices that appear efficient in short term may simply be mining soil nutrients causing imbalance.
- Soil test based fertilizer recommendations help in increasing fertilizer use efficiency.
- Manage soil moisture efficiently and apply nutrients when soils are moist.
- Balanced nutrition improves nutrient use efficiency as deficiency of one or more elements can reduce the use efficiency of others.
- Efforts must be made to develop ways and means to reduce canopy loss of N.
- Nutrient efficient donors for different nutrients should be identified and used in breeding work to develop nutrient efficient hybrids/varieties
- It is time that we should consider sustainable nutrient use efficiency rather than simple nutrient use efficiency in.

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Improving nutrient use efficiency in moisture stress environments

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In the absence of adequacy of water resources for irrigation, rainfed farming is practiced in nearly two third of the arable land (96 million hectares, mha) in India. The gross cropped area of the country is 182 mha. Out of an estimated 142 m ha of net cultivated area about 67% is rainfed. In this, 76 mha is under irrigation. The potential for additional production gains in these areas may lessen with time from inherent problems. It is in the rainfed belt where cultivation of coarse cereals (91%), pulses (91%), oilseeds (80%) and cotton (65%) predominates. About 44% of the total production is contributed by rainfed region. Rainfed agriculture supports 40% of country's population. Rainfed regions in India encompass a wide range of soil and rainfall conditions.

Rainfall varies with a large range in its temporal and spatial distribution. The rainfed area in the country can broadly be classified into three climatic regions– arid, semi-arid, and sub-humid. Among many factors contributing to sub-optimal and unsustainable yield levels, availability of excessive water in spells during rainy season, and water stress of varying degree and duration during post rainy season figure prominently. The crop yields, thus, largely or entirely depends on the growing season rainfall plus water stored in the soil profile. Due to this, rainfed regions are characterized by relatively low and unstable crop yields. Risk is high because rain is undependable in both timing and amount making the region prone to periodic short to long-term droughts.

Soils of these regions belong to alluvium (Entisols, Inceptisols and Alfisols), red soils (Alfisols), black soils (Vertic Inceptisols and Vertisols), submontane soils (Entisols, Inceptisols, and Mollisols) and sierozemic soils (Aridisols). Among these, red (132 mha) and black (72 mha) soils are largest in extent in the country. Red soils exhibit large variation in pore size distribution, and consequently in water retention, transmission and release characteristics. Black soils possess high water retention and unsaturated hydraulic conductivity, which make them suitable for rainfed crops in both the seasons. However, soils with high clays remain prone to oxygen stress because of poor internal drainage through micro-pores in rainy season (*kharif*). Black soils of northern India have mostly columnar structures, while prismatic in south India. In red sandy loams and loamy sands, the clogging of micro pores by amorphous hematite affects the water intake. Thus, there exists a wide range of water retention, its conductivity and availability to the growing plants. The length of water availability or growing period and growth depends on soil related constraints inherently.

Soils of rainfed region are universally deficient in nitrogen. Most of them are also deficient in available phosphorus, sulphur and some micro-nutrients (mainly Zn and Fe). The soils are highly degraded with a large number of physical and chemical constraints. Shallow depth is a familiar feature of rainfed soils. Research in this area has primarily focused on overcoming the textural problems posed by dryland soils, tillage and water intake properties, soil fertility management through use of chemical fertilizers, organics and bio fertilizers. Contrary to the past belief on excessive risks associated with the use of chemical fertilizers, research findings conclusively established that there is vast potential for increasing crop yields through fertilization, typically N fertilizers, across contrasting rainfed environments. Cost benefit ratio was highly favourable when crops were fertilized. A fertilized crop was able to withstand drought better than a non-fertilized one. A stressed crop could also recover faster if it was fertilized following relief from stress. Pest attack was low. Some fertilizer application strategies are given in Table 1.

Table 1. Fertilization strategies for improved management

Nutrient		Vertisols	Alfisols
Nitrogen	Short-term		
	Quantity:	About 80 kg N/ha in average rainfall seasons 80-120 kg N/ha in above average rainfall seasons 40 kg N/ha in below average rainfall seasons	About 60-80 kg N/ha in average rainfall seasons 80-120 kh N/ha in above average rainfall seasons 40 kg N/ha in below average rainfall seasons
	Form:	Any common form of fertilizer is suitable.	Ammonical form is preferred to nitrate or urea (amide)
	Method:	Banding is more effective than broadcast of broadcast incorporation.	Banding
	Time:	Basal dose + 1 or 2 split applications for top-dressing	Basal dose + 2 or more split applications of top dressing
	Long term	Buildup of organic source Use of FYM and crop residues Cereal/ legume intercrop or cereal-legume sequential cropping Crop or cropping system rotation involving ground cover/ green manure	Buildup of soil organic matter Use of FYM and crop residues Cereal/ legume intercropping and wherever possible legume-cereal sequential cropping Crop or cropping systems rotation involving ground cover, green manure, legume ley, or agro forestry applications.
Phosphorus	Quantity:	About 15 kg P/ha if soil has <5 ppm of Olsen-extractable P	About 10 kg/ha, if soil P is 5-10 ppm as Olsen-extractableAbout 15 kg/ha soil P is <5 ppm as Olsen-extractable
	Form:	Water-soluble P	Water-soluble P
	Method:	Band application	Band application
	Time:	Basal	Basal
Zinc		50 kg $ZnSO_4$ once in 3 or 4 seasons as basal	50 kg $ZnSO_4$ once in 3 to 4 seasons

Split application ensures against loss in nutrients and deep root system for reaching sub-surface stored moisture in aberrant weather (Table 2). More so against loss in nutrients with occurrence of above normal rainfall during crop growth period.

Table 2. Effect of rainfall on efficiency of split application of nitrogen fertilizer on pearl millet in Aridisols and rice in sub-humid Alfisols

No. of splits	Increase in yield with splitting over all basal application (%)			
	Pearl millet		Rice	
	Above normal rainfall	Below normal rainfall	Above normal rainfall	Below normal rainfall
2	8.2	45.1	-16.1	0.7
3	17.5	19.5	-	-
4	50.3	31.3	7.8	-11.8
10	-	-	27.6	58.8
Yield with all basal application (Mg/ha)	1.83	0.85	1.96	0.59

Optimal doses of N, P and K fertilizers for different crops in relation to diverse rainfall conditions and contrasting soil-moisture-holding characteristics have been worked out. Fertilizer application on any part of toposequence is profitable (Table 3).

Table 3. Fertilizer pays under different land capabilities

Fertilizer	Fingermillet (7 seasons) (Mg/ha)		
	Shallow (Class VI)	Medium (Class IV)	Deep (Class III)
0N:0P	0.96	1.16	1.39
20N:15 P	1.45	1.67	2.00
40N:30P	1.81	2.14	2.57
60N:45P	1.92	2.27	2.69

(AICRPDA, Bangalore)

Fertilizer ensures better returns in above normal rainfall (Table 4). However, even in below normal rainfall, the returns are economic.

Table 4. Fertilizer pays even in sub-normal seasons

Crop	Rainfall	kg grain/kg N (seasons)	
		20 – 40 N	60-80 N
Coarse cereals	Above normal	21.4 (3)	29.4(1)
	Below normal	8.7 (3)	7.4 (1)
Cereals	Above normal	12. 9 (5)	11.9 (5)
	Below normal	15.6 (5)	13.3(5)
Oilseeds	Above normal	12.2 (4)	11.1 (4)
	Below normal	8.3 (4)	6.0 (4)

Deep tillage (20-25 cm) not only assisted in increasing water intake and in controlling persistent weeds (a statement made earlier) but also helped in improving the efficiency of applied fertilizer-N. Fertilizer efficiency increased with placement of fertilizer in advance (Table 5) for post rainy season crop.

Table 5. Variation in efficiency of advancing fertilizer application over all basal application by about a month with rainfall for post-rainy season mustard on Aridisols

Rainfall during 36-38 standard weeks (mm)	% Efficiency of advanced fertilizer application techniques over application at the time of sowing (seasons)
0 – 10	5.6 (2)
10 – 20	8.7 (1)
20 – 30	22.2 (1)
30 - 40	19.9 (3)

(AICRPDA, Ballowal Saunkhri)

Integrated nutrient management studies have established the value of a number of naturally occurring nutrients containing (organic manures) and generating (biofertilizers) sources to augment overall nutrient turnovers for soil fertility management. Green manure was found to be a dependable source of several plant nutrients. Typically it could meet half the N requirements of a crop. Inclusion of legumes in a rotation produced benefit to the succeeding crop equivalent to 10-30 kg N ha^{-1}. Short-duration legumes such as cowpea produced greater benefit. An integration of FYM (10 t/ha) + recommended NPK at Bangalore has not only stabilized productivity and improved sustainability but also improved economics. The urease, phosphotase and dehydrogenise activity increased was more in integrated treatments. pH was reduced in continuously fertilized plots, the calcium in FYM helped in buffering capacity in soils. The phosphorus showed a built up, except control. The things status was above critical limit in FYM applied plots. The tendency in improving was also noticed in application of FYM. Integrated nutrient management in combination with in legume based crop is recommended for higher productivity. Integrated nutrient management systems, besides nutrient supplementation, enhanced soils' ability to hold additional water and produced more favourable soil biology. Schemes to generate green manure in a non-competitive way during the noncropping season and bund farming have been worked out. This has opened up a new vista to make green manuring a viable option. Long term integrated nutrient management trials are being conducted for more than 15 seasons at Akola, Anantapur, Bangalore, Ranchi, Solapur, Agra and Rakh Dhiansar while at 9 other centers the experiments on the same theme are nearing a decade. Fertilizer cost can be reduced by substitution of fertilizer with organics (Table 6).

Table 6. Fertilizer cost reduction by half with substitution of organic residues without yield reduction

Crop (seasons)	Grain yield (Mg/ha)	
	Recommended dose of fertilizer	50% inorganic + 50% organic
Post-rainy season sorghum (16)	1.19	1.16
Pearlmillet (17)	2.03	2.08
Fingermillet (22)	2.21	2.92
Groundnut (16)	1.06	1.05
Cotton (14)	0.76	0.82
Greengram (14)	0.52	0.56

In most of the situations, the sustainability of yield was higher when the recommended dose of fertilizer was applied. In case of cereals, higher sustainability was obtained when the recommended dose of nutrients was applied through chemical sources. In case of oilseeds, however, the recommended dose applied half through chemical fertilizer and the other half through organic source led to higher sustainability values. Available nitrogen, organic carbon and phosphorus content in soil were increased with organic fertilizer application. Application of crop residues in combination with chemical fertilizer resulted in higher sustainable yield and also maintained higher levels of nitrogen, phosphorus and organic carbon. Green leaf manure proved promising in increasing the sustainability in yield and improving the organic carbon, infiltration rate and hydraulic conductivity of the soil.

Thus, a recommendation mileu of integrated nutrient management thus should produce a low cost complex fertilizer with effective matching of pulses of crop requirement based on birch effect in rainfed agriculture of all essential elements that are needed for completing crop life cycle without any limitation resulting in hidden hunger. This can be done by a balanced mixture of inorganic, organics, neem etc. as nitrification inhibitors, VAM, biofertilizer, FYM, Blacksoil , and residues for soil acidity adjustment.

The steps in enhancing crop productivity in rainfed areas are as follows: Timely sowing of seed in rows in the moist zone with use of proper seed rate through a seed-cum-fertilizer drill to achieve adequate plant stand. Timely weeding creates soil mulch so that soil moisture is not lost through evaporation. Row place need based moderate levels of fertilizer (basal as well as top dressing) but not on blanket basis. Use complex fertilizers depending on the economic status of the farmer. Intercrop as a step towards risk distribution. Use a legume as a component in the cropping system, either in rotation, sequence, or intercropping for building soil resilience and quality. Land capability and system based fertilizer management practices are given in Table 7.

Table 7. Land capability, rainfall and soil order based integrated nutrient management practices

Land Capability Class	Rainfall 250-500 mm	
	Aridisols	Inceptisols
I	Pearlmillet 40:8:0 NPK Clusterbeans/ mothbean 0:13:0 NPK Horsegram/ blackgram/ cowpea/ pigeonpea 20:13:0 NPK	Pear millet 40:8:0 NPKHorsegram/ blackgram/ cowpea/ pigeonpea 20:13:0 NPKAgroforestry trees are not fertilized, however crop components are fertilized as per recommended doses.
II	Pastures are grown on native soil fertility.	Same as above
III	Pastures are grown on native soil fertility. Fertilizers are not recommended usually for silvicultural species. Horticultural species are recommended fertilizer doses as per the age and the species	Same as above. Pastures are grown on native soil fertility.
IV - V	No fertilizer for agroforestry species except for horticulture trees depending on age and type of species. Pastures are grown on native soil fertility.	
VI - VII	Generally fertilizers are not recommended in silvipasture system	
VIII	Fertilizer doses are not recommended	

	Rainfall 500-750 mm	
	Vertisols	Alfisols
I - IV	Pearl millet 75:11:0 NPK **Shallow to medium deep soils** Pearlmillet 50:25:0 NPK Post rainy season sorghum 50:0:0 NPK (9-10 t/ha Leucaena loppings can substitute 25 kg N/ha) Safflower 50:25:0 NPK Chickpea 15:25:0 NPK (placement at 10 cm depth near seed row) Fallow – post rainy season sorghum system: FYM or crop residue + leucaena and gliricidia loppings during fallow. 50%N through crop residue (sorghum/ leucaena) + 50% N through fertilizer for post-rainy season sorghum **Medium to deep soils** Greengram/ post-rainy season sorghum 25:50:0 NPK Sequence cropping 30:0:0 NPK Hybrid pearlmillet 40:40:40 NPK Post-rainy season sorghum 30:25:0 NPK Pulses 20:40:0 NPK (basal) Leucaena loppings @ 5 t/ha can be used. Chickpea 50 kg N/ ha and 5t/ha compost **Vertic to Vertisols** Maize 50:30:0 NPK Maize+pigeon pea 50: 30:0 NPK (50 %N can be given through organics) Sorghum 50:30:0 NPKGreengram/ blackgram/ cowpea 15:30:0 NPK Wheat/ barley/ safflower/ mustard 30:15:0 NPK (Reduce N by half in case previous crop was a legume) Chickpea/ lentil 15:30:0 NPK **Medium to deep Vertisols** Groundnut 12.5 :25:0 NPK (basal) Sorghum 90:30:0 NPK (N in 2 splits) Pearlmillet 80:40:0 NPK (N in 2 splits) Cotton (GAU-cot-10) 40:20:0 NPK (N in 2 splits) Cotton (V-797&CJ.73) 25:25:0 NPK Sesame 25:25:0 NPKCastor 50:50:0 NPK Greengram 20:40:0 NPK	Pearlmillet 75:11:0 NPK or 50:13:20 NPK; **Shallow soils** Groundnut 20:40:40 NPK Castor 40:40:40 NPK Pigeonpea 20:40:20 NPK Pearlmillet 40:40:40 NPK Setaria 40:40:40 NPK (for all crops N in 2 splits)

	Pigeonpea 20:40:0 NPK (all basal). FYM @ 6t/ha is also recommended. Among INM practices, application of 6:12:0 NPK + mulching with sunhemp in between rows + rhizobium and phosphorus solubulizing bacteria is recommended.	
V	No fertilizer for agroforestry species. For alley cropped millets and legumes doses as mentioned above. For bushes of aromatic and medicinal plants, standard doses are applied depending on the age, production capacity per bush and kind of species..	
VI	As above	Fertilizers are recommended based on kind and age of horticultural tree species.
VII	Generally fertilizers are not recommended in silvipasture system	As above for other crops. Fertilizer doses are not recommended. But for horticultural crops doses are recommended as per age and type of species.
VIII	Fertilizer doses are not recommended	
	Rainfall 750-1000 mm	
	Alfisols	**Inceptisols/Vertisols**
I - IV	Sorghum 40:13:0 NPK deep soils; 18:17:0 NPK shallow soils Fingermillet 50:22:25 NPK Maize 75:22:25 NPK **Medium deep soils** Sorghum 40:30:0 NPK Castor 50:30:0 NPK Pigeonpea 10:30:0 NPK Fingermillet 40:30:0 NPK Pearlmillet 40:30:0 NPK **Deep soils** Fingermillet 50:50:25 NPK (N in 3 equal splits). Or combination of organic (FYM 10t/ha) and inorganic (50:40:25 NPK). Maize 75:50:25 NPK (N in 2 splits) Groudnut 25:50:25 NPK (N basal)Pigeonpea/ cowpea/ horsegram 25:50:25 NPK (N basal) **Bundelkhand region** Clusterbean 15:60:0 NPK and inoculation with rhizobium is recommended. In order to improve the yields of post-rainy season crops, in-situ incorporation of sunnhemp at 45 days prior to post-rainy season crops to improve the yield.	Sorghum 40:13:0 deep soils; 18:17:0 NPK shallow soils Fingermillet 50:22:25 NPK Maize 75:22:25 NPK **Sub-montane Inceptisols/ Entisols** Maize and wheat (sandy loam-clay loam) 80:40:20 NPK (drill fertilizers at or before seeding)Maize and wheat (loamy sand-sand) 40:20:10 NPK (N in 2 splits to maize) **Deep Vertisols** Soybean –wheat: In case of soybean FYM@ 6t/ha+ 20:30:0 NPK. Substitute 50% of fertilizer N through FYM
V	Same as above	For horticulture trees, doses as per age and type of species. Others as above.

VI	For bushes of aromatic and medicinal plants, standard doses are applied depending on the age, production capacity per bush and kind of species.	For millets and legumes as mentioned above. No fertilizer for agro-forestry tree species. For horticulture trees (doses as per age and type of species)
VII	For horticultural crops, fertilizer doses are recommended as per age and type of species..	
VIII	Fertilizer doses are not recommended	
	Rainfall 1000 –1250 mm and more	
	Inceptisols/Entisols/Vertisols	**Oxisols**
I	Maize 40:9:10 NPK Upland rice 40:18:0 NPK Chick pea 10:11:0 NPK Oilseeds 10:11:0 NPK **Sub montane region** Pearlmillet 50:30:15 NPK (in 2 splits) Maize 75:40:30 NPK (placement 5cm below/ away from seed) Wheat 50:30:20 NPK (placement 10 cm deep) Barley 40:20:10 NPK (placement 10 cm deep) Cowpea 15:45:0 NPK Greengram/ blackgram 15:45:0 NPK Sarson 40:60:20 NPK (N in 2 splits) For maize + blackgram (mash) intercropping system, conjuctive use of organics (40 N) and inorganics (50 N) **Alluvial soils** Upland rice and Barley, 80 N, Wheat 60 N Chickpea 40 P Sesame/ mustard/ safflower 40 N Linseed 40:20:0 NPK (in 2 split doses in rainy season , while as basal in post-rainy season). **Baghelkhand plateau (Vertisol)** In case of chick pea use of biofertilizers such as Rhizobium + phosphate solubilising bacteria (PSB) is recommended **Eastern Maharastra plateau (Vertisol)** 5 t/ha FYM + 40 kg P/ha + microbial culture @1.5 kg/ha is recommended for pigeonpea.	**Chota Nagpur plateau region** Application of 30:20:0 NPK in upland rice (local).Hybrid rice 60:30:0 NPKFor medium land the doses can be increased. 75-90:60:40 NPK (apply N in 3 splits) Wheat 30:20:0 NPK (apply N in 3 splits) Barley 30:20:20 NPK (all basal). Safflower 20 N (N in 3-4 splits), Chickpea 0:20:0 NPK
II	Same as above	Application of 30:20:0 NPK in upland rice For medium land the doses can be increased. 75-90:60:40 NPK (apply N in 3 splits)

III	Same as above. Doses as per age and type of species for horticulture trees.	Same as above
IV	Same as above. Doses as per age and type of species for horticulture trees.	Same as above
V	Doses as per age and type of species for horticulture trees	Same as above
VI	Doses as per age and typė of species for horticulture trees	
VII	Fertilizer doses are not recommended. But doses are recommended as per age and type of species for horticultural crops	Fertilizer doses are not recommended.
VIII	Fertilizer doses are not recommended	

Note: P isP_2O_5; K is K_2O; NPK kg/ha

Legumes have an important role as intercrops and sequential crops in sustaining the productivity of different cropping systems. A holistic system approach is a must for maximizing the benefits from BNF in legumes. High N_2-fixing legumes and cultivars should be selected for inclusion in the cropping systems. Appropriate soil and water management practices are sowing on ridges or broad beds for protecting from water logging, using scoops for light textured soils to increase water storage. To ensure good nodulation and N_2-fixation by legumes in cropping systems, farmers must (a) use appropriate crop management practices, such as application of phosphatic fertilizers or other deficient plant nutrients; (b) control pests and disease that may affect plant canopy and in turn photosynthate supply to roots; (c) practice N-management in soil (e.g., use of slow releasing formulations, applying N to cereals only by placement, use of organic sources); and (d) use need – based inoculations with good quality rhizobial inoculants. If returned to the soil, plant residues would help in increasing the soil organic matter content, and thereby increase the soil fertility. Through such an approach, benefits from legumes BNF can be maximized for improving or sustaining productivity of cropping system (Table 8).

Table 8. Need based prioritization on research and development of pulses for sustainable production

Time scale	Post monsoon	Rainy season
Short term Research Issues		
Urgent	• Water management • Development and introduction of extra-short-duration (50-55 days) varieties • Management of crop residues • Multiple nutrient application based on soil needs Vis-à-vis sustainability • Poor crop establishment • Intercropping with winter legumes	• Weed control practices • Planting techniques and appropriate land configuration for proper crop establishment and vegetative growth • Weed flora changes qualitatively and quantitatively in various systems • Sustainability based on nutrient balance/ budgets in various systems • Meeting the demand for improved seed
Necessary	• Nutrient management of legumes in cropping systems • P Management	• True value of BNF • Benefits of mixed cropping • Forages

Desirable	• Development of high temperature tolerant legume cultivars • Control of diseases and pests through management practices • High harvest index on high biomass basis	• System based nutrient management • Integrated pest management (but urgent for pigoenpea) • Tangible and non-tangible benefits • P fertilization for better moisture use
Long term Research Issues		
Urgent	• Development of extra-short-duration (50-55 days), high-yielding, input responsive, heat-disease-, and pest-resistant varieties suitable for new niche cropping systems • Integrated nutrient, water & pest management. Crop modeling and post harvest technology. • Developing new plant types responsive to high inputs by introduction of gene pools of cultivars from abroad • Development of early maturing cultivars (green gram, black gram and pigeonpea) for multiple cropping • Developing plant types suitable for intercropping with cereals • Exploring avenues for horizontal expansion through short season pulses and cropping system manipulations • Genetic enhancement of yields and grain quality • Breeding varieties resistant to Ascochyt blight, Botrytis gray mold, wilt/root rot, pod borer and nematodes in chickpea; Sterility mosaic, Phytophthora blight, wilt Alternaria blight, pod fly and pod borers in pigeonpea; yellow mosaic virus, Cercospora leaf spots, powdery mildew, thrips, whitefly and stemfly in green gram/ black gram; rust and wilt/root rot in lentil, and powdery mildew and rust in fieldpea • Application of biotechnology to overcome the basic constraints of yield in stability i.e., biotic stresses	• Develop short-duration, high yielding (a minimum yield of 2 t ha^{-1}), water logging-, disease-, and pest-resistant legume genotypes suitable for sole and intercropping systems. • Bridging the yield gap between national demonstrations and farmer's field • Genetic enhancement of yields and grain quality • Breeding varieties resistant to Ascochyt blight, Botrytis gray mold, wilt/root rot, pod borer and nematodes in chickpea; Sterility mosaic, Phytophthora blight, wilt Alternaria blight, pod fly and pod borers in pigeonpea; yellow mosaic virus, Cercospora leaf spots, powdery mildew, thrips, whitefly and stemfly in black gram/ green gram; rust and wilt/ root rot in lentil, and powdery mildew and rust in fieldpea • Application of biotechnology to overcome the basic constraints of yield in stability i.e., biotic stresses • Developing new plant types responsive to high inputs by introduction of gene pools of cultivars from abroad • Development of early maturing cultivars (black gram, green gram and pigeonpea) for multiple cropping • Developing plant types suitable for intercropping with cereals • Integrated nutrient water and pest management. Crop modeling and post harvest technology.
Necessary	• Establish system-based integrated nutrient and weed management practices • Simulation modeling • Value addition • Germplasm resources – collection, evaluation and conservation	• Develop legume genotypes that produce reliable yields in high input systems • Establish integrated nutrient management practices • Develop integrated pest and disease management practices

		• Minimizing losses through efficient processing/ milling and development of safe storage procedure. • Germplasm resources – collection, evaluation and conservation
Desirable	• Develop legume cultivars with high BNF, capacity in high-input systems. • Initiate research to separate 'N' and 'non-N' benefits of legumes on the following crop • Development of cultivars with better amino acid profile in seeds, low in anti-nutritional and toxin factors	• Establish suitable planting patterns for intercropping systems • Develop equipment for efficient and economical harvesting and grain processing. • Development of cultivars with better amino acid profile in seeds, low in anti-nutritional and toxin factors
Developmental issues		
	• Ensure availability of canal water during summer for cultivation of summer legumes	• Ensure availability of quality seed and quality Rhizobium inoculant. • Seed processing • Make vigorous efforts to disseminate information on improved varieties and their management through extension agencies and on-farm demonstrations.

- In a pigeonpea breeding programme care should be taken to ensure that progenies are grown under conditions, i.e., on soils low in nitrogen and with a high population of effective rhizobia, that favor strong symbiotic development. There are many situations, such as at Gwalior (Madhya Pradesh state) and Hisar (Haryana state) in northern India where pigeonpea nodulation has been reported as poor despite vigorous plant growth and detailed investigations are needed to clarify this – is the poor nodulation due to lack of rhizobia, or because of stress factors such as high temperature and high levels of NO_3-N?

- In pigeonpea the recently developed, high yielding, extra short duration (about 3 months) genotypes are altogether a new plant type, and they should be examined for the adequacy of their symbiotic nitrogen fixation. There is a need to improve the nitrogen fixing ability of short duration pigeonpea as these genotypes respond to fertilizer nitrogen. This can probably be achieved either by extending the longevity of nodule activity into the pod filling stage and/or selecting genotypes with resistance to nodule damage by *Rivellia angulata.*

- Studies on the ecology of pigeonpea rhizobia deserve more attention. Because of cross reactivity among cowpea rhizobia, it has not been easy to distinguish inoculant strains of pigeonpea from native rhizobia. Unless improved methods of identification of inoculant strains are developed, ecological studies of pigeonpea rhizobia cannot make much progress.

- Because of the sensitivity of symbiotic activity to salinity, waterlogging and drought stress, or temperature stress, monitoring the symbiosis and understanding its response to particular stresses will be mandatory before selecting appropriate symbioses for stress conditions.

- Most of our knowledge on the effects of stress factors on BNF comes from studies on legumes other than chickpea and pigeonpea. Hence, more studies on how these two crop plants react to the stress factors are required. *Rhizobium* strains growing as saprophytes in the soil can tolerate stress environments much better than the host legumes and the symbiosis. Also, *Rhizobium* strains tolerant to some of these stress factors have been isolated; they can also be identified more easily than tolerant host plants.

- Plants depending on symbiotic nitrogen are more prone to the adverse effects of drought, soil temperature, high pH, and salts than are plants fertilized with nitrogen. This suggests that identification of genotypes tolerant of these stress factors should be a first step in over coming the adverse environmental effects. All the stress factors result in absence or distortion of root hairs, the site was rhizobia enter the host prior to establishment of the symbiosis. Hence, in selecting legume genotypes better able to tolerate stress factors, the ability to form normal root hairs should be a major consideration.
- A study as to why, and at which stage, the symbiosis breaks down under environmental stress is important from a practical point of view, and it may provide more information about the process itself. An important contribution may be expecied from a comparative study between genotypes that differ in their capacity to establish a symbiosis under stress conditions.

Unabated land degradation due to nutrient mining with a combination by topsoil loss by water erosion and climatic change towards adverse conditions are the twin problems affecting the future of dryland agriculture. In this connection, an early action is to be taken by controlling erosion, replenishing the soil with high biomass for revitalizing the various soil processes and congenial microenvironment creation. This will improve the soil resilience, quality and mitigates the drought affect Invariably. The practice that is most needed is the resource conservation and utilization based template created by using perennial, semi-perennial and annual plants. This knits the farmers to the land and generates employment through out the year. Use of cash returning species will improve the socio economic conditions of the farmers. Agroforestry is a relatively new name given to an approach to cultivation, which has been used by many people all over the world, in many different ways. It is a collective name for land use systems in which woody perennials are grown in association with herbaceous plants (crops, pastures etc.) or livestock, in a spatial arrangement, a rotation, or both. There are usually both ecological and economic interactions between the tree and other components of the system. The agroforestry model is unique as it focuses on assisting farmers in creating a situation where they are managing their own natural resources including livestock in a sustainable productive way, and making them less dependent on outside labour and forest areas. To prevent runoff and soil erosion and to meet all the requirements in terms of fodder resources and soil cover, efforts must be made to obtain them from integrated farming system only. The cropping system must permit limited grazing. Sufficient lopping should be available from the farmstead. Micro level farming systems are practicable only in rainfed lands due to resilience in adoption of diversification from crop through tree to animal.

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Nutrient use efficiency in humid tropics with special reference to Kerala

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The tropics, comprising 40% of the land surface of the earth, lie between 23 1/2 °N and 23 1/2 °S latitudes and are characterized by the absence of a cold season. A mean temperature of 18 °C prevails during the coldest month of the year. The humid tropics experience high rainfall and humidity and many parts of India come under this class.

Kerala state comes under the perhumid and humid climatic types, except in the southern most pockets and the eastern part of Palakkadu region, which experience moist sub humid climate. The state as a whole experience megathermal climate, which indicates that crop growth, is not much inhibited by temperature, but is governed mainly by rainfall. The mean monthly humidity varies from 85 to 95 per cent during June - September, and is about 70% in January over different parts of Kerala. The high rainfall has led to the evolution of characteristic soil types in the state, deficient in bases and rich in iron and aluminium.

Crop productivity is largely dependent on the use of critical inputs like improved seeds, fertilisers and water. Considerable improvement in the use of these inputs has greatly contributed in making our country self sufficient in food. Efficiency of any crop production unit is primarily decided by the system characteristics where it is operating. The geographical position and layout thus becomes important. Kerala is unique in its diversity and richness in land and water resources. It is one of the smallest states in India with an area of 38.86 lakh ha. The state is a narrow coastal strip having a sea coast of nearly 590 km length. The state is broader is the central area, but not more than 120 km, and narrows down to 30 km at northern and southern extremities. Within a distance of 50 km the altitude ranges from -3m to 4500m. The sea coast, midland and low altitude region endowed with humid tropical climate is spread over the entire length of the state.

Water, the most important decisive factor which controls other production factors, *prima facie* cannot be classified as a negator of efficient crop production in Kerala. Receiving more than twice the mean annual rainfall of India, Kerala is bestowed with sufficient water for taking three wet land puddled rice crops in one year. However the natural distribution of rainfall and the unique geography of Kerala brings a flood and a drought almost every year, the situation being aggravated by managerial inadequacies.

The soil which holds the plant is the basic unit of agricultural production. It is the factor which primarily decides the water and nutrient use efficiencies. In general, Kerala soils experience stress due to deficiencies or excesses of mineral elements involved in crop production. The main soil types of Kerala are laterite (with or without B horizon), sandy loam (Onattukara or coastal sandy), alluvium, red loam, peat (*Kari*) and black soil. The extent and characteristics are given in Table 1.

Table 1. Important soils of Kerala

Soil type	Extent (%)	Important characteristics
Laterite	67.0	Low soil depth, low organic matter, Fe and Mn toxicity, pH 5.0- 6.5, low WHC
Sandy loam	10.0	Very low organic matter and mineral nutrients, very low WHC, acidic, soil salinity in coastal sandy area
Red loam	14.0	Low organic matter, medium mineral nutrients, acidic
Alluvium	8.5	Medium in mineral nutrients and organic matter, acidic.
Peat	0.4	Very high organic matter, Fe and Al toxicity, salinity intrusion, very acidic, pH 3-5.5
Black soil	0.1	Low organic matter content, alkaline in reaction, medium in mineral nutrients, alkaline, pH 8.5

Traditional wisdom has succeeded in the selection of crops with pH 7-8.5 and cropping system with higher productivity suited to different soil types. Shyam Sundaran Nair and Saifudeen (2004) have listed the 13 agro-climatic zones classified based on altitude, rainfall pattern and soil type along with the primarily crops grown. The topography, soil types, water situations and crops have resulted in heterogeneous agronomic zones where use efficiency of production inputs vary considerably.

Nutrient use efficiency

Use efficiency of nutrients is generally expressed as agronomic efficiency, uptake efficiency (also termed as chemical efficiency or apparent recovery) and physiological efficiency. Agronomic efficiency is the product of uptake efficiency and physiological efficiency. The unit of agronomic efficiency is kg grain per kg nutrient while that of physiological efficiency in kg grain per kg nutrient taken up by the crop. Uptake efficiency is expressed as percentage of applied nutrient taken up by crop.

Habeeburahman (1983) has reported an agronomic efficiency of 10.82 to 19.04 for applied N in rice grown in the laterite soil (Table 2.). Agronomic efficiency was found to increase at higher levels of N when the soil was amended with lime at 600 kg/ha (Table 2).

Table 2. N use efficiency in rice as influenced by time of application

Treatment	Agronomic efficiency (kg grain/ kg N)	
	Without lime	With lime
N_{45}	16.08	10.82
N_{675}	16.36	19.04
N_{90}	13.84	18.74

Changing the form and method of application of N fertilizers has been found to improve nutrient use efficiency over usual method of urea broadcasting in alluvial soils of Kuttanadu, Kerala (Table 3).

Table 3. Nutrient use efficiency as influenced by form and method of application of N in rice

Rate of N application kg/ha	Method of application	AE (kg grain/ kg N)		References
		Urea broad casted	Applied as per treatment	
70	Urea + powdered neem cake (5:1) mixing and keeping overnight and broadcasting	18.5	28.8	RRSM, 1982
56	Urea super granules- deep placement	21.5	48.6	RRSM, 1982
90	Neem coated urea and broadcasting	20.5	24.8	RRSM, 1982
90	N- serve 1% coating and broadcasting	22.8	27.5	RRSM, 1983
70	Urea paper packets- deep placement	21.5	36.5	RRSM, 1983
70	Urea mud balls- deep placement	21.5	38.8	RRSM, 1982

Jayakumaran (1981) studied the influence of N levels and azolla incorporation at 5 t/ha on yield and nutrient use efficiency (Table 4). The nutrient use efficiency was found to be increased in the presence of incorporated azolla.

Table 4. Yield (kg/ha) and agronomic efficiency in the presence and absence of azolla incorporation

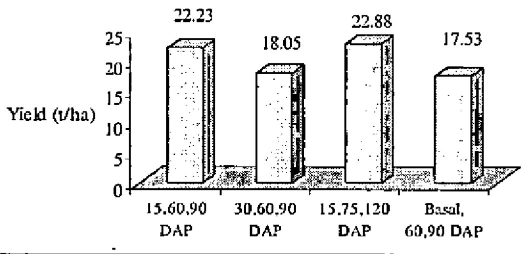
N levels (kg/ha)	Without Azolla Grain yield (kg/ha)	AE	With Azolla Grain yield (kg/ha)	AE
0.0	1819		1880	
45.0	2300	10.7	2551	14.9
67.5	2599	11.5	2982	16.4
90.0	2798	10.8	2689	9.0

Balachandran (1979) reported decreasing P use efficiency in black gram grown in laterite soil with increasing P doses. The P use efficiencies were 24.4, 19.5 and 14.2 at 10, 20 and 30 kg P_2O_5/ha. Joseph (1982) observed nutrient use efficiency of 13.4, 15.3 and 9.9 for N at 37.5, 75.0 and 112.5 kg for chilli crop grown in laterite soil. The P use efficiency at 20, 40 and 60 kg P_2O_5/ha were 5.15, 5.08 and 3.81, respectively. The K use efficiency was 32.2, 19.8 and 17.7 for K_2O applied at 10, 20 and 30 kg/ha respectively.

The time of fertilizer application could also influence nutrient use efficiency. A shift in 15 days for application of basal fertiliser dose in a 10 months duration tapioca crop grown in laterite soil resulted in higher use efficiency of fertilizer and consequently considerable yield variation (Bridgit, 1985) (Fig. 1.).

An agronomic efficiency of 2.32 was reported for seasum grown in sandy loam of Kerala (Paul, 1995) when 30 kg N was applied in two splits. The use efficiency of N for the aromatic grass palmarosa was 0.42 and 0.33 t herbage yield at 20 and 40 kg N, respectively (Regimol, 1996).

Fig. 1. Yield of tapioca (t/ha) as influenced by time of fertiliser application



Nutrient balance

Crop productivity can only be sustained if soil fertility levels (supply of nutrients in proportions matching the crop's need) are maintained. In order to attain this balance, it is essential to know the nutrient demand of a crop to produce a target yield and the amount removed from the soil is to be replaced scores sooner or later.

Imbalanced application of N increases neither the yield nor the profit in the long run. But it may result in acceleration of deficiency of other nutrients in soil. Soil nutrient depletion in the case of potash is particularly alarming. This is because many crops remove as much or more than K than they absorb N, but potash application is far less than that of N.

The removal of primary nutrients by major crops grown in Kerala and the nutrients added to the soil through fertilisers are given in Table 5.

Table 5. Nutrient balance sheet for Kerala

	Added through fertilisers (t)	Removed by crops (t)	Balance (t)
N	88638	113562	-24924
P	47252	34168	+ 13084
K	76564	128751	- 52187
Total	**212454**	**276481**	**- 64027**
S	11258	35857	-24599
G. Total	**223712**	**312338**	**-88626**

The N and K removal is 24924 and 51187 tonnes more than the addition, however P is added in excess, i.e., 13084 tonnes than the removal. Sulfur which is identified to be deficient in most Kerala soils (John, 2004) is also removed in higher quantities to the tune of 24599 tonnes more than that of addition. A detailed district- wise analysis showed that only in Palakkadu district there is a positive balance for N and only in Trivandrum, Kollam, Malappuram and Kasaragode there is negative balance for P. In Kottayam, Pathanamthitta and Kozhikode, the P addition is remarkably higher than the removal. In Kottayam, Idukki and Kozhikode, addition of K through fertilizers is more than the crop removal, but in all other districts the removal is more than the addition.

Measures to augment the nutrient supply

The wide gap between the quantity of nutrients removed by crops and supplied through fertilizers can be bridged by exploiting the enormous potential of organic manure sources. In areas where rice based cropping system is predominant, introduction or intensification of grain legumes in the cropping system may add nitrogen and other nutrients through organic matter addition apart from increasing pulse production. Intercropping grain legumes and alley cropping with leguminous fodder trees will enrich the soil by fixing atmospheric N. *Tephrosia purpurea Crotalaria juncea* and *Indigofera spp* are suitable green manures in coconut garden. *Sesbania aculeata* and *Crotalaria juncea* are good for irrigated paddy lands and *Sesbania rostrata* for low lying paddy lands.

Green manures can be substituted by a suitable dual purpose grain legume in irrigated rice areas. John *et al.* (1989) received equal or more benefit from a soil incorporated with grain legume residue apart from about one tonne grain production per ha compared to growing a green manure crop. Dual purpose grain legumes like cowpea, mungbean, green gram, etc. suitable for this zone can be identified by screening of available varieties.

Leguminous and non- leguminous trees and plants grown on bunds, wastelands, road sides etc. can be used for green leaf manuring. In rubber and coconut plantations in coastal hilly sub- regions and midland sub- regions, cover cropping with *Calapagonium mucunoides, Peuraria phaseoloides, Centrosema pubescens, Mucuna bractetea and Mimosa invisa* are highly essential. Besides other benefits these will add a large quantity of organic matter and N into the soil (John and George, 1990).

Use of biofertilizers should be enhanced. Rhizobium inoculation in legumes, use of azolla and blue green algae in rice fields, inoculation of upland crops with AMF and PSB to enhance nutrient solubilisation especially P and inoculation of aerobic N fixing bacteria in cereals and oilseed crops like gingelly are important non- monetary means to supply nitrogen into the soil. Enhancing production of rural and urban compost, efficient use of farmyard manure, ash and slaughter waste, utilisation of aquatic weeds like *Eichhornia crassipes* which is abundant in Kerala, for compost making are supplemental sources of nutrients. The efficiency of added inorganic fertilizer is to be increased to the maximum possible by way of suitable agronomic measures such as placement, soil incorporation, coating, split application etc.

Constraints in increasing nutrient addition through fertilizers

The relatively high cost of fertilisers, low benefit - cost ratio, lack of awareness of nutrient recommendation for specific crops, etc. discourage the farmers from using more quantity of fertilizers. The expected response from fertilizers may not be reflected in the yield due to various controllable and uncontrollable loss mechanisms and non -response of certain cultivars used. In certain areas farmers are not willing to apply fertilizers for rainfed crops fearing inadequate returns. Non- availability of fertilizers in certain interior regions is observed due to limited number of sale points. Lack of organized efforts to enhance the production of rural and urban compost, difficulty in getting seeds of green manure and cover crops, inadequate agricultural extension services and government policies result in poor use of organic source of nutrients in the soil.

Narrowing down the deficit of nutrients due to high crop removal and low supply will have a definite influence in bridging the wide gap between the actual and potential yields. Agricultural extension and fertiliser promotion programmes should be strengthened and sale points of fertilizers should be increased to enhance fertiliser use. Group farming activities in rice and coconut adopted by the Government of Kerala, efforts of scientific and other voluntary organisations can stimulate the farmers to adopt better management practices of applied fertilisers and for mobilizing organic sources of nutrients.

Balanced fertilisation

In recent years, great interest in LISA (Low Input Sustainable Agriculture) has become the focus of many environmentalists, but the innovations and management techniques suitable for one set of soils, climates and cropping conditions may be entirely unsatisfactory for another situation and Low Input Sustainable Agriculture is not the solution for achieving higher yields and meeting the higher food demand. Site specific management with balanced fertilisation as the main tool is the correct alternative. Balanced fertilization is the rational use of fertilisers and manures for optimum supply of all essential nutrients taking into account the availability of nutrients already present in soil which simultaneously ensures efficiency of fertiliser use, promotes synergistic interactions and keeps antagonistic interactions out of crop production systems. It enhances crop yield, crop quality and farm profits, corrects inherent soil nutrient deficiencies, maintains or improves soil fertility, avoids damage to the environment and restores fertility and productivity of the land that has been degraded by wrong and exploitative activities in the past.

Maximising fertiliser use efficiency

Fertilizer use efficiency refers to the proportion of applied nutrient recovered by the crop. It is commonly expressed as a percentage of fertilisers used by the crop or alternatively in terms of crop yield per unit of fertilisers.

Evolving site specific best management practices (SSBMP) is the possible solution for higher yields, conserving natural resources and maximising fertiliser use efficiency. Best management practices are specific for individual farms, fields, soils and climate. They should aim at maximum crop responsiveness to fertiliser and reduced environmental impacts of the fertiliser, balancing production inputs at appropriate levels, utilisation of site specific soil and water conservation techniques to maximize soil retention and minimize losses to ground water.

Knowing the soil, both the health and ill health, is the basic requirement for evolving best management practices. Ameliorating soil with lime or gypsum to correct soil reaction and addition of optimum quantity of organic manures are the pre-requisites for enhancing fertiliser use efficiency. Research results are available for varying nutrient use efficiency in the presence and absence of lime application, in the presence and absence of organic manure, pre - rice legume crops etc. in Kerala soils.

Choice of the correct fertiliser material has been proved to improve fertiliser use efficiency of individual nutrients. Use of ammonium sulfate against urea to supply N has improved the nitrogen use efficiency probably due to the benefit of maintaining an appropriate N:S ratio in soil and plant (RRSM, 1982). Use of Ammonium phosphate sulfate (Factomphos) has resulted in enhanced uptake, use efficiency of both N and P against the recommended practices of using urea and rock phosphorus as nutrient sources in Kuttanadu alluvium in Kerala (RRSM, 1983) due to its soluble P content, N balance and S content.

Proper timing of fertiliser application can considerably improve nutrient use efficiency in Kerala soils where soil as well as rainfall characters favour high leaching losses of nutrients. Application of soluble nutrients in splits at growth stages when requirements are high, is a ruling principle in fertilizer programmes. Fertiliser application in 3 to 4 splits for rice, 6 to 7 for banana and pine apple, 2 to 4 splits for coconut are being recommended for Kerala in order to improve the nutrient use efficiency. Basal application of fertilisers is varied depending on the mode of plant introduction. In direct sown wet and dry rice it is recommended at 10-15 days after sowing against basal application before planting in transplanted rice.

Soil incorporation of ammoniacal N fertilisers, rock phosphorus and potassium has resulted in higher use efficiencies than broadcast application in Kerala soils Deep placement of amoniacal N fertilizers either as mud balls, paper packets or as USG have resulted in improving efficiency from 25 to 55 percentage. Use of nitrification inhibitors and slow release N fertilisers have resulted in improved use efficiencies. Incorporation of urea with powered non-edible oil cakes such as *neem, marotti* and *mahuva* cakes have resulted in higher use efficiencies. Application of urea mixed with powdered *neem* cake in 5:1 ratio in rice is a common practice in Kerala.

Correction of nutrient deficiencies and toxicities

Identifying the deficiencies and toxicities which create stress in soil through soil and plant analyses is an important step of balanced fertilisers. Deficiencies of N, K and S and toxicity of Fe, Mn and Al are commonly reported from several agronomic zones of Kerala. Takkar *et al.* (1997) reported that 34, 31 and 4 percentage of the soil samples collected from Kerala were deficient in Zn, Cu and Mn.

Synergistic and antagonistic nutrient interaction affects the fertiliser use efficiency. Potassium has been found to influence the use efficiency of other nutrients. The ill effects of Fe can be reduced by K fertilization. High level of K is reported to decrease Fe uptake and helps maintain K/Fe ration in plants. Higher rate of K application increased efficiency of N, P and Z in laterite soils of Kerala (Bridgit, 1999; Mathew, 2002; Thomas, 2002).

Interaction of nutrient elements, both in the plant and in the soil, play a significant role in affecting nutrient availability, and consequently, crop growth and yield. Experiments in rice revealed that yield cannot be related to any single element, but rather to the net effect of all the elements. The effect of an element on yield can be direct or indirect, by its effect through other elements. In laterite soils it was observed that Ca application could effectively check iron content, which is the main yield limiting factor, but it could not contain the adverse effects of Mn and Zn which directly interfered with N metabolism. Instead, S was found to restrict Mn and Zn uptake more effectively at later stages of growth (Bridgit, 1999).

John (2004) has observed significant N and S interaction in rice crop grown in laterite soil of Palakkadu (Table 6).

Table 6. Yield of rice as influenced by N and S levels

S kg/ha	N kg/ha				Mean
	N_0	N_{40}	N_{80}	N_{120}	
S0	3.85	4.65	5.21	5.30	4.74
S15	3.71	5.40	5.85	6.40	5.34
S30	4.15	5.51	6.05	6.48	5.54
Mean	3.90	5.19	5.70	6.06	
CD (0.05)	N- 0.49	S- 0.52	N x S - 0.784		

Environmental consequences of fertiliser use

Nitrogen, phosphorus and potassium fertilisers after their application undergo various transformation processes. A series of physical, chemical and biological processes are involved in such a turnover. Dynamics of N in the soil - plant- atmosphere system include various soil processes such as mineralisation, immobilization, urea hydrolysis, nitrification, volatilization, denitrification and N movement in soil. Phosphorus, after its application in soil, is either removed by crop or gets converted into various insoluble forms (Fe and Al phosphates in acid soil and Ca-phosphate in alkaline soils) and gets fixed in soil clays or organic matter. Loss of K is a waste but carries no environmental concern.

The excessive use of fertilisers can result in the environmental problems like ground water contamination, eutrophication, nitrate poisoning, diseases like methenoglobinemia and cancer, acid rain, ammonia evolution, stratospheric ozone depletion and global warming. Thomas (2001) observed leaching of 42% N and 16% K, but no phosphorus to a depth of more than 60cm from the surface applied fertilisers through irrigation water in laterite soils of Kerala. However this may not pose any environmental concern since deep rooted perennial trees, a common feature all over Kerala, act as nutrient pumps which take up the leached

Table 7. Fertiliser consumption (kg/ha usable land)

Country/ state	Consumption
Republic of Korea	458
Japan	290
China	257
Netherlands	494
UK	330
USA	111
Bangladesh	141
Pakistan	112
India	99
Kerala	79
Punjab	250
Tamil Nadu	110

nutrients. Moreover the fertiliser use in Kerala is far less than those reported for several other countries and states in India (Table 7).

Conclusion

Kerala, most of its area being in the humid tropics, enjoys the benefit of high rainfall, ample sunlight and temperature. However, the geo- physiography and the undistributed high rainfall make the soil susceptible to undesirable weaknesses in the crop production system. The high temperature results in the fast decline of organic carbon from unprotected soil. The use efficiency of agricultural inputs is either declining or in stagnation. Through it is essential to review and improve the management strategy of all inputs, it is high time to pay serious attention to nutrient management in particular. It should aim at reducing the present depletion of soil nutrient reserves. Improvement of soil fertility by efficient use of plant nutrients besides increasing productivity also leads to better environment. The balanced fertilisation through the right nutrients, fertilisation at the right time, right quantity and through right methods of application only will result in high efficiency. Integrated nutrient supply with combined use of fertilisers, organic manures and biofertilisers in conjunction with checking erosion of soil fertility by efficient and better soil water conservation and management practices, enhancing native mineral nutrients availability by felicitating soil microbial population, exploiting the benefit of synergistic nutrient interactions in the soil etc will play a great role in maintaining the nutrient balance and crop productivity at higher levels.

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Precision agriculture with reference to nutrient management – An Indian perspective

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Approaches to increasing productivity in India, has seen a major shift over the last few decades. India is in some way self-sufficient as far as the food sector is concerned. The priority now is towards crop diversification and management systems that would enable economic stability and reduce the risks related to the vagaries of climate and market. In the Indian a sustainable practice would translate as creating opportunities for livelihood while increasing the productivity of the land, which are also embedded in the Millennium Development Goals of the United Nations.

Different approaches have been adopted in developing sustainable agriculture practices such as, ecoagriculture, integrated farming system, low input agriculture, organic farming, to name a few. Each one these are examples of site-specific farming methods and a combination of these methods would result in development of new models. Such diverse approaches in farming practice provide opportunities for developing and determining the appropriate techniques for efficient use of natural resources. Such a holistic production management systems relevant to region specific with a focus on enhancement of the ecosystem health would be on the lines of organic agriculture as defined by Codex Alimentarius.

In India, organic farming is gaining support, especially in the context of the export potential it offers. However, in order to make a conscious effort for bringing about an organic cultivation practices among the farming community, efforts are needed to provide the necessary know-how and inputs. An alternative strategy that could be adopted in place of going for certified organic products is "green" products, which are produced with fewer chemicals, this would not only address the environmental concerns but would ensure profitable productivity for the farmers.

In the context of globalisation, it is imperative to increase the production efficiency primarily to meet the global competitiveness. Precision agriculture techniques such as variable rate fertiliser application could provide the impetus for making Indian agriculture competitive in the global market.

Available literatures on the application of precision farming technique mostly deal with the technicality and its potential and the components of which are computers, Geographic Information System (GIS), Global Positioning System (GPS) and Remote Sensing (RS), which are far beyond the reach of the average farmers. However, many institutions in India have taken up the field application trials along with the community. Precision agriculture, as practised in the western countries is not suitable in the Indian context, our priorities are entirely different. We have to look at the issue from an overall perspective and match it with our priorities in meeting the goals of food, nutrient and livelihood security. The National Consultative Meet on Critical Issues Confronting Farmers at Hyderabad organised by NABARD (8-9 August 2004) did bring out the need for a holistic approach for mitigating the problems facing the Indian farmers.

Nutrient management under precision agriculture approach.would require precise information on soil properties, which mean reliable methods of soil sampling and laboratory analysis. One of the instrument now available for soil analysis the visible-near-infrared reflectance spectroscopy, which reduces the time and labour required for soil analysis. Studies using such technique is being carried out in India, such as National Bureau of Soil Survey & Land Use Planning, Nagpur. Such inputs could be shared with the farmers and correlated with the cultivation practices adopted by the farmer and suggest management technique which would facilitate proper application of fertilizer, this would also call for a participatory research approach between the farmer and the researcher.

MSSRF experience have shown that by varying the fertilizer application across the field, based on a grid sampling method, it is possible to reduce the fertiliser (phosphorus) application by 39% in chickpea compared to the conventional method, with no loss in yield. A collaborative study along with the team at Space Application Centre (ISRO), Ahmedabad on the correlations between the soil properties (macro nutrients, organic carbon and pH) and spectral values derived from satellite imageries were found to be significant for available phosphorus and the pattern of soil nutrients were closely related to spectral index.

The constraint faced in effectively utilising precision agriculture technique is the non-availability of reliable map based information. Only when adequate information is made available in desired scale, informed decisions for planning purpose can be made. Precision agriculture coupled with Information and Communication Technology (ICT), provides a means for effectively addressing the issues confronting the agriculture sector. Information available with the various institutions could be shared and made available from a single source, an information-clearing centre, which could integrate the information that would support decision-making and planning.

Institutions such as Regional Remote Sensing Service Centre (ISRO), Bangalore, with their programme on "Agro-climate Planning and Information Bank", Tata Chemicals Limited with their "Tata Kisan Kendra" and many other industries have developed GIS based decision support systems to help their farmers. Such institutional supported programmes are desirable for making available the tools associated with precision agriculture affordable to the average farmer. Another initiative taken by the Government of India, is the support for agricultural graduates in setting up Agriclinics & Agribusiness Centres which would facilitate the availability of professional support nearer to the farmers.

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V. SESSION ON EFFICIENCY IN THE USE OF AGRO-CHEMICALS

Pesticides use– issues and strategies

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Pesticides are important inputs in agricultural production and have played crucial booster roles in ushering in green revolution across the country on varied crops. The present consumption of pesticides in India is over 90,000 t, being spread across 100 m ha. The big question is then: Is India over-using pesticides? In one sense the answer would be no, as per unit consumption of pesticides in India is only 600g/ha. Compare this with USA, Europe and Japan whose consumptions (g/ha) are 2500, 3000 and 12000, respectively. Yet in another sense the answer may be yes; for certain pockets of agro-ecosystems in India are hotspots of pesticide use. These would be the cotton, rice, and wheat ecosystems where nearly 70% of the pesticides are used. Certain crops like grapes, for example also receive a heavy dose of pesticides [on an average one spray for every 3-5 days]. Thus, states, which support these crops, are mainly, the major consumers of pesticides, viz. Andhra Pradesh, Punjab, Karnataka, and Gujarat.

Thanks to awareness and green movements, the use of pesticides is being viewed from a need-based point of view. But the reality is that pesticide consumption has not seriously been retarded. In spite of the Insecticides Act 1968 to regulate insecticide production, India is a major player in manufacture and production of pesticides; in fact there are nearly 150 products registered and over 60 technical grade manufacturers. The industry is a Rs 3000 crore business, and big volume of spurious pesticides are in circulation [www.ficci.com indiachem]. In this paper, therefore, the issue of minimizing pesticide use without affecting the desired efficacy is discussed drawing examples from horticultural systems.

There was a time when prophylactic sprays were given emphasis to ensure absolutely no pest situation. The concept changed to economic threshold levels as a decider for treatments. When this became tedious for farmers, entomologists thought of sequential sampling plans in roving surveys. This also did not succeed well, so prediction models under forecasting and surveillance was recommended and by and large is being accepted as ideal for deciding pesticidal applications. The decision is drawn from either experience of farmers/scientists or from weather/crop models. This helped farmers and pest managers to identify either crop phenological status or crucial weather situations that would cause pest outbreak/incidence sufficient to cause loss, if sprays were not taken up.

In mango, for example, it was found that attack of hoppers at bloom, causes loss to fruit set. So the critical stage of spray is pre-bloom or panicle emergence, a phenological stage prior to bloom stage. Mango sprays will not control hoppers if it is taken up before pre-panicle stage though this is still in vogue. Invariably the farmer has to give a second/third spray to affect the desired control level. On the other hand, if spray is given at full bloom pollinators are affected resulting in poor fruit–set. If, spray is given after full bloom, much of hopper damage would have taken place. Therefore, in a situation like this, the pesticidal efficiency is maximized at pre-panicle stage by a single spray. This is just to highlight the importance of crucial stages to spray to optimize on pesticide use.

In case of fruit flies, *Bactrocera dorsalis* it was always felt that temperature is an important abiotic factor with reasonably good prediction quotient. In a long term study at IIHR, it was found that wind speed had much more of a say in predicting fruit flies than any other factors either alone or regressed in combination. It was found that polynomial model of order 3 ($y = -1.2779x^3 + 30.859x^2 - 208.17x + 455.55$) could satisfactorily predict the fruit fly (t-test not significant between observed and predicted, $p = 0.05$). Based on this one can decide whether spray or IPM is needed and if so, when it is to be timed. Such an approach avoids the wastage of chemicals.

In case of grape scolytid, it has been found that pesticidal (dichlorvos) application at the first sight (sealing hole with a drop or two of dichlorvos solution) of infestation prevents further multiplication of the beetles. It is crucial here that through supervised monitoring pest attack should be nipped in the bud. If application is done after the infestation progresses it requires at least two sprays of the insecticidal solution on the trunk @ one liter at each spray. What could be done with two drops requires two liters of spray mixture later. Thus, a huge volume of pesticidal input is reduced if infestation is detected early and controlled. It has been found that vines treated at first sight of infestation were statistically on par with the healthy vine in terms of growth parameters and yield.

In case of seriously scolytid infested vines swabbing [with used brush or soft broom] the pesticide on the trunk as compared to spraying was found more effective. The chemicals had longer residual efficacy on the trunk when swabbed and had no problem of spray drift in the basin of the plant. So, the mode of pesticidal application also helps in increasing the pesticidal input efficiency and avoidance of drift means minimizing damage to non target organisms.

In case of the mango stone weevil, it was found that junctions of the branches on the tree trunks where leaf litter gathers are ideal hibernating niche for the weevil. By regularly sweeping such junctions during the off seasons weevils can be destroyed up to 95%. Fallen fruit sampling models (1996 – 97) have shown that sprays should be timed at the first sight of infestation in the fallen fruits. Subsequently it has been found that fruits, with a size between 2.5 and 3.0 cm diameter, had maximum correlation with infestation incidences. So, if a spray treatment is warranted the timing should be at this size of the fruit for maximum efficacy. This enhances the input efficiency of the pesticidal application.

In view of the green influence, a lot of hype on botanicals is going on. While they work in some cases, they definitely do not work in many others. The use of neem soap has been found to be more efficient than neem seed kernel extract. This is an excellent example of how a change in formulation enhances efficacy. Likewise, neem seed powder in a ready to mix shelf-availability has increased the appeal of botanicals, which otherwise farmers avoid due to pungent smell during preparation of the neem seed extracts. However, the efficacy of botanicals varies with insects and needs to be tested on each case, otherwise the problem will only be compounded with farmer eventually resorting to commercial synthetic pesticidal sprays in addition to investment on botanicals.

Another blunder made is an assumption of compatibility between insecticides and fungicides. It has been found in many situations (especially non-systemic pesticides) such mixing reduces the efficacy in insect and disease controls. Instead of two birds at one shot the farmer ends up spraying several rounds to control both disease and insects. Experiences have shown that a second spurt in pests and diseases, due to previous partial controls are more virulent and widespread. Compatibility of insecticides and fungicides for different pest-disease combinations are needed. These are practicable only if worked out on specific crop-insect-disease matrix.

Spray application equipments in India do not conform to a set of standards including safety aspects except for some recognized manufacturers. Many times progressive farmers modify their equipment to suit their needs. In general, dose-transfer to biological target needs to be very efficient to avoid pesticidal loss. However, one can easily notice that drift, run-off, leaky tankers, etc., waste a lot of pesticides. These enhance the volume of pesticide use and cost.

One way of overcoming loss due to dose-transfer has been with a use of narrow angle cone nozzles. It has been found at the International Pesticide Application Research Centre [UK] that angled spray cones (<35°) achieved three-fold better dose-transfer resulting in also better coverage when tested with a fungicide for control of diseases in cocoa. Run-off can be avoided if the drop-let size is made smaller.

One area of study that needs standardization for improved pesticide application is the pressure management of delivery through improved and adjustable valves. There is a need to have a pressure gauge that can read the wind speed and direction to help farmers optimize on pressure management.

A code of standards for pesticide applicators [including safety aspects for the applicator], therefore, is to be widely circulated. Tinkering with pesticide applicators by non-specialist should be discouraged and may be legislatively looked into.

Attempts to synergise the biocontrol impacts with a pre or post spray of pesticide should also be explored and can also be need-based. An interesting example is the *Entomophthora aphidis* Hoffman infesting *Aphis punicae* Passerinin in pomegranate. This pathogen controls aphids to more than 90% and subsequently if there is no new flush on the plant there is no need to spray. But if new flush promotes aphid spurt, a single spray will suffice. Likewise the onset of this pathogen can be predicted based on humidity and temperature models. So a pre pathogen spray of fungicide to control any disease is desirable as fungicidal spray during *E. aphidis* infection will kill the pathogen and cause aphid numbers to increase alarmingly. This is a clear case of temporally diversifying pesticide application for maximum management of disease and pest while taking advantage of a naturally occurring bio-agent.

One sure way of reducing the intake of pesticides is to promote biocontrol availability in a commercial form for farmers.

A lot has been said about resistance to insecticides in insects and insect resistance management is one area of minimizing pesticide use. In such situations enhancing insecticidal efficacy is by use of synergists. The use of piperonyl butoxide is already known but limited due to its cost. Indian farmers will appreciate cheaper synergists. Recently it has been found that seed oils of cotton, neem, pongamia, mahua and sesamum can be exploited as effective synergists in the DBM, *Plutella xylostella* control. This enhances the efficacy of the pesticide use and in turn reducing the frequencies of sprays.

Misuse of pesticides takes place mostly under the following circumstances: excess frequency of application and/or dose; often in case of high value crops where farmers spray as a routine; there is also a belief that excess dose improves efficacy and cuts down pest risk. Incorrect pesticides: an outcome of quackery; non-specialists become plant-health experts. Use of pesticides in wrong places: chemicals used in homesteads when mere cleanliness could avert pestilence. Avoidable use: farmers perceive a threat and press into panic spray. Pesticides preferred over IPM; because farmers desire quick results and so IPM or biocontrol are thrown to winds.

Pesticides use in India is skewed and wherever it is less used the *status quo* should be maintained; our north-east is deemed naturally organic and may augur well for up-market exports. Where the use is on higher unit consumption, IPM efforts [including transgenics] are going on and let us optimistically hope for lower pesticidal pollution without limiting productivity.

Management of problem weeds in the humid tropical regions

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Introduction

Tropical ecosystems provide ideal conditions for the luxurient growth of a wide variety of weeds. Weeds invade agricultural and non-agricultural areas including the aquatic areas, competing with the crops for various resources and creating problems for human activities. The history of weed competition is as old as the history of human civilization. When man started settled life he began raising crops and experienced the competition from the native flora, which he designated as weeds.

Weed flora of tropical ecosystem

The water bodies of the tropical areas are heavily infested with a variety of aquatic weeds. Most troublesome among them are the alien weeds, which got introduced from the neotropical regions. *Eichhornia crassipes* and *Salvinia molesta* have invaded almost all lakes, canals and ponds, creating difficulties for inland navigation (Joy, 1978), irrigation systems, aquaculture and health of people living near the water bodies. *Ipomoea carnea, Ipomoea aquatica* and *Typha angustata* are common problem in shallow water areas. *Limnocharis flava* and *Alternanthera philloxeroides* are the comparatively new addition to the introduced weeds in India.

Weeds of rice fields

Rice is the major crop of the low land areas in the tropical region. Grass weeds which mimic the rice plant and create problem to farmers include various species of *Echinochloa* (*E. colona, E. crusgalli, E. stagnina* and *E. glabrescence*) and wild rice (*Oryza rufipogon*), *Diplachne fusca* is typical of areas where incrustation of sea water is common whereas *Sacciolepis interrupta* is a problem in the dry sown rice. Many sedges (*Cyperus iria, Fimbristylis miliacea, Cyperus difformis* etc.) and broad leaf weeds (*Ludwigia parviflora, Monochoria vaginalis, Lindernia* sp. etc.) are also common in rice crop (Abraham *et al.*, 1990 and Vidya *et al.*, 2004).

Terrestrial weeds

As in the aquatic areas, alien weeds are more problematic than the native weeds in the terrestrial ecosystem. They include *Chromolaena odorata, Mimosa pudica, Mimosa invisa, Lantana camara* and *Mikania micrantha*. As they were introduced free of their natural enemies, these weeds could establish and spread fast in the new areas, creating problems to the crops like vegetables, banana and plantation crops common in the tropical areas (Sudheesh *et al.*, 1998, Abraham and Abraham, 1998 and Abraham and Abraham, 1999).

Management of problem alien weeds

a. AQUATIC WEEDS

For controlling *Salvinia molesta* spraying paraquat @ 0.4 – 0.8 kg ai/ha is found to be very effective. The herbicide could kill the weeds within a few days after the application. However, against *Eichornia crassipes* paraquat could result only a temporary control and by 30 days regrowth occurred. Glyphosate @ 1.2 – 1.6 kg ai/ha and 2,4 – D @ 2.0 kg ai/ha were effective in controlling the water hyacinth. Against *Ipomoea carnea* and *I. aquatica* also 2,4 – D was effective, where as against *Typha sp* and other perennial grasses glyphosate was very effective.

b. UPLAND WEEDS

Spraying 2,4 – D @ 2.5 kg ai/ha, glyphosate @ 1.6 kg ai/ha or paraquat @ 1.0 kg ai/ha have resulted in good control of *Chromolaena odorata*. The systemic herbicides were more effective when sprayed on the regrowth emerging after a slashing than when applied on the normal growth. The physical methods like sickle weeding and digging were not very effective against *Mikania micrantha*, as the weed has the capacity to regrow from the pieces of the stem. Among the herbicides, 2,4 – D @ 1.0 kg ai/ha or glyphosate @ 1.2 kg ai/ha were the promising ones. Paraquat resulted in immediate scorching and drying of the weeds. However new sprouts occured subsequently and the effect of the herbicide could not last for longer period (Abraham and Abraham, 1999).

Against the spiny alien weeds *Mimosa invisa* and *M. pudica* the best control was obtained when sprayed with glyphosate @ 1.6 – 2.0 kg ai/ha. Paraquat was effective if sprayed at the seedling stage. On well-grown *Mimosa* paraquat was not very effective as regrowth occurred by one month after spraying. 2,4 – D also was ineffective against *Mimosa spp*.

Weed management in major crops

Rice

Manual and mechanical methods of weed control are the most common practice of the farmers. Due to the increase in the labour charges and non availability of enough labourers, there is increased adoption of chemical methods for weed control. For controlling the aquatic weeds, before the land preparation for raising rice, spraying paraquat (0.4 kg/ha) or glyphosate (0.8 kg/ha) is found to be very much cheaper and more effective than the manual removal of weeds. Many farmers in Kerala practice stale seed bed technique for managing weeds in rice field. They keep the field drained for some time to allow the weed seeds in the soil to germinate. Once germinated, the seedlings will be killed by maintaining flooded condition for a about two weeks. In dry sown rice, stale seed bed technique is found to be effective for controlling *Sacciolepis interepta* (Renu *et al*., 2000)

Application of pre-emergence herbicides oxyfluorfen (0.1 kg/ha) or pretilachlor (0.5 kg/ha) was found to be effective in semi-dry rice. However, in wet sown (puddle sown) conditions pre-emergence herbicides are not widely used, due to phytotoxicity to rice seedlings. New combinations of herbicide with safeners like the 'sofit' are likely to get the acceptance of farmers. 2,4-D (1.0 kg/ha) is widely used for post emergence control of broad leaf weeds and sedges in rice. The new herbicide Almix (Metsulfuron methyl 10% + Chlorimuran ethyl 10%) is also found effective for this purpose. For selective control of *Echinochloa* in rice fields Clincher (Cyhalofop butyl) is promising (Abraham *et al*; 1999). However, its tank mix with 2,4-D to broaden the spectrum of weed control was not successful as efficiency of cyhalofop was adversely affected.

Fruit crops

In banana and pineapple, raising a crop of cowpea in between the rows of the crop was found effective to smother the weeds (Nybe *et al*., 1991 and Savithry *et al*., 1994). Alternatively, pre-emergence application of Diuron (1 to 3 kg/ha) also gave selective weed control. For post emergence weed control, directed spraying of non-selective herbicides paraquat (gramoxone 5 ml/litre water) or glyphosate (roundup 8 ml/litre water) was effective. Care should be taken to avoid spraying on the leaves of the crop.

Plantation crops

Plantation crops like coconut, rubber, arecanut and cashew are the important crops in the terrestrial areas in the coastal belt. As the crops are planted wide apart, weed problems are very severe, especially during the seedling stages of the crop. Non-selective herbicides paraquat or glyphosate can be sprayed in interspaces of the crop plants for weed control. Wherever broad leaf weeds are common, 2,4-D @ 1.00 kg can be sprayed (Salam *et al*,. 1993).

In rubber gardens cover crops like *Pureria*, *Mimosa* or *Centrosema* are grown for smothering weeds during the pre-tapping stages. Weeds in the tapping stage can be controlled by spraying paraquat or glyphosate. Rubber being a tall growing and wide spaced, phytotoxicity to crop plant is not common.

Soil solarisation and polythene mulching for weed control

Solarisation, the technique of covering the soil with transparent polythene sheets to trap the solar radiation and thereby increasing the soil temperature is a promising method for weed control in home gardens and is ideal for high value crops. Due to increase in soil temperature the seeds in the soil bank will be killed. This method is effective against annual weeds, which are propagated by seeds (Sainudheen and Abraham, 2001).

Covering the seedbeds with black polythene sheets will cut off sunlight and hence no weeds can get established in the crop. This method is ideal for high value crops grown in rows.

Biological methods

Biological control of weeds with natural enemies from the original home of the weed has been successfully practiced against many alien weeds in the coastal area. Salvinia could be effectively controlled in the lakes of Kerala using the weevils *Cirtobagous singularis* and *C. salvinia* (Joy *et al.*, 1985). However, similar attempt against Eichhornia by releasing *Neochetina eichhorniae* and *N. bruchi* was not very successful, though suppression in the growth of the weed was noticed. In terrestrial weeds, lantana could be controlled by releasing various insects. Attempts are being made to control introduced weeds like *Mikania micrantha*, *Mimosa pudica* and *M. invisa* by this method.

A new development in this area is the use of bioherbicides using the fungi which cause diseases on weeds. Phytophagous fungi, which are host specific to the weeds, will be cultured in the laboratories and the spores collected from them can be processed, stored and sprayed on the weed to control them.

Conclusion

A large number of weeds are of concern for the tropical agriculture. The main problem weeds are the alien weeds, both in aquatic and terrestrial situations. Broad-spectrum herbicides like paraquat, glyphosate and 2,4 – D are effective against these weeds. However their efficiency varies with species of the weed. Continuous use of some herbicide has resulted in development of herbicide resistance in same weeds. By following herbicide rotation and integrated approach for weed control, this problem can be avoided or delayed. People should be concerned about residue problems from herbicides and should restrict the use of slow degrading herbicides. Biological methods maybe the ideal against the alien weeds, as this approach is eco-friendly and sustainable.

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Enhancing insecticide effectiveness and reducing their input in the Indian context- Opportunities and challenges

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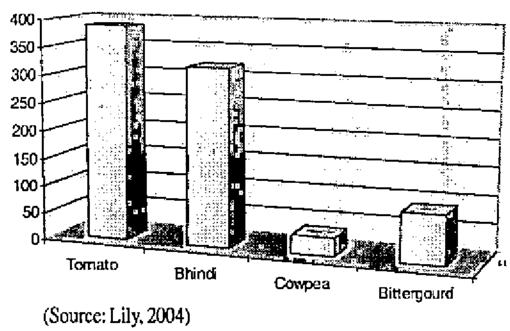
Insecticides will be an unwelcome yet indispensable input for intensive agriculture in the foreseeable future. In the third world context of India, where majority of the farmers are illiterate, or under-educated, both per unit insecticide use and use efficiency are low. Even though lower use is a welcome sign for the environment, there is widespread misuse in places where it is used. Cotton is one agro ecosystem where more than 50 per cent of the insecticides are offloaded, and the cotton farmers throughout the country pay very little heed to scientific advice by qualified people. In this, they also burn their fingers very badly. It is no secret that mismanagement of insecticide use and a little adventurism on the part of the farmers have caused problems like resistance to insecticides, resurgence, and secondary pest outbreak. Hence, it is imperative that urgent interventions are made to enhance the effectiveness of insecticide application and reduce the total input of insecticides in the Indian environment.

Various strategies that can be incorporated towards this end include
- Incorporating the right crop mix for the right end result
- The right insecticide at the right spot
- Developing precision predictions and application
- Utilising synergism
- Precision placement
- Anti drift agents
- Spray adjuvants
- Improving spray quality
- Earmarking sprayers and reducing rinse water

a) Incorporating the right crop mix for the right end result

In any cropping system, it is important to identify the key insect pests. In the cotton, vegetable and pulse cropping system, the borer *Helicoverpa armigera* is a key pest. In fact, the fortunes of the cotton farmer were badly hit by this pest during the past 3-4 years (Fig. 1). Managing the pest involves a strategy to add natural enemy promoting crops like cowpea and bitter gourd in the concurrent crop mix, and to avoid pest promoter crops like bhindi and tomato. Mixing should be always for a natural enemy promoting crop like cowpea and bitter gourd with a pest promoter crop (Lily, 2004). The availability and proper exploitation of native natural enemies reduces the pesticide pressure on the pest and the environment, reducing the development of resistance. This also reduces the number of sprays for effective management, and also ensures a reduced pest population. Ultimately this results in a lower contamination to the environment and a better yield for the farmer.

Fig.1. Population of *Helicoverpa armigera* in different crops



(Source: Lily, 2004)

b) The right insecticide at the right target

In the coconut mite complex scenario, it is recommended to use targeted pesticide use on bunches 3-5 that is the mite abundance habitats and desist from using high volume sprays and spraying on older bunches. Older bunches function as refuges for minimal mite population that can serve as food for the predators. (Ranjith *et al.*, 2000). It is also necessary to develop precision prediction models for pest abundance, considering the biology of the pest and influence of weather on the different life stages. For the coconut mite, the maximum influence on current population was obtained based on weather prevalent at current week (negative with wind speed, and direct influence with minimum temperature and morning humidity), current fortnight, one-week lead-time, and two-weeks lead-time. Maximum temperature at two weeks lead-time positively influenced the mite population.

Table 1. Correlation of mean coconut mite population (bunches 3 and 4) with weather of different weeks

	Wind speed	Maximum temp.	Minimum temp.	Morning humidity
Current week	-.442*		0.386*	
current fortnight	-0.479*		0.492**	0.466*
-1 fortnight (one week lead time)	-0.465*		0.521**	0.461*
-2 fortnight (two weeks lead time)	-0.458*	0.447*	0.490**	0.398*

* significant at 5% level **significant at 10% level

(Source: Vidya, 2001)

Among the many acaricides, it was found that Neem triterpenoids at 10000 ppm @ 4ml/litre, and neem-garlic- soap emulsion at 20-20-5 proportion per litre gave very good results

With aphids, whitefly eggs and thrips that aggregate on the new flushes it is very important to apply the insecticide at the initial population flux This flux should be monitored regularly at the target sites and the right insecticides for the specific pest applied immediately. The case of the brown plant hopper in rice, *Nilaparvata lugens* is also too familiar. The hoppers congregate on the underside of the hills at the base, and hence the pesticide targeting must be at this point. Regular monitoring of the pest build up can identify the first sites of yellowing that subsequently develop into hopper burn. Targeting the pesticide at this point and its surroundings saves the crop and also enhances predator activity.

c) Developing precision predictions and application

Prediction equations were developed for the mite coconut eriophyid mite *Aceria guerreronis* (Keifer)

$Y= -9097.16+76.22X_1+117.49X_2+54.11X+133.02X_4$, where

Y=Mite population,

X_1=Maximum temperature, X_2= Minimum temperature,

X_3=Morning humidity and X_4= Wind speed.

(Vidya, 2001).

Introducing current data and enhancing the resource base, thus improving prediction accuracy, can perfect predictions further. These are to be used regularly to increase sampling at vulnerable periods and to monitor the population. A rising population can then be managed with minimal insecticidal application and increased pest suppression efficiency.

d) Utilising synergism

Synergistic influences exist between different insecticides, botanicals and microbials. In the case of *H.armigera,* a combination involving the extract of the plant *Vitex nigundo* with the fungi *Nomuraea rileyi, Metarhizium anisopliae, and Beauveria bazziana* enhanced the mortality substantially. These fungi also fared well with Spinosad, an actinomycete derived synthetic neonicotinoid insecticide. The bacteria *Bacillus thuringiensis* also exhibited synergism in combination with extracts of *V.nigundo,* essential oils of *Cymbopogan flexuosus, C.martini,* and *C.winterianus* and also with Spinosad. Microbials including the nuclear polyhedrosis virus and insecticides could reduce dosages by half and also synergise to produce near total mortality of the pest (Lily, 2004).

e) Precision placement

Precision placement can reduce doses and improve efficiency. Field studies in Georgia in 1999-2001 have shown that precision placement of aldicarb with cotton seed in hill planting reduced dosages to half with in-furrow placements. There were no significant differences in yield and control of thrips, *Frankliniella fusca.* Residue analysis confirmed the presence of as much as or more of aldicarb or its metabolites in the plants than conventional treatments (Lohmeyer *et l.,* 2003).

In the Indian context, the following possibilities exist.

- Seed treatment with imidacloprid in cotton and bhindi
- Seed mix with granular insecticides in mechanical seeders
- Slurry dip of setts in sugarcane
- Slurry dipped mat nursery in rice transplanters
- Seedling dip of rice overnight in chlorpyriphos

All of these gives blanket pest cover for extended periods, minimises insecticide doses and improves crop stand, vigour and yield.

f) Anti-drift agents

These are materials that are added to the spray fluid to reduce the drift of the spray to non –target sites.

- They improve the efficiency of control in adverse weather
- They improve reach on the target and safety to non –target sites like waterways, and non-cropped area.

Products that can be used include lemongrass oil, Kacholam oil and neem oil. They function as anti drift agents, while retaining their antifungal and insecticidal properties. Synthetic latex also is an anti-drift agent. Their use reduce the percentage of very fine drift keeping the droplet size between 200 and 400 microns for maximum spray efficiency. Wind tunnel tests have shown that under identical conditions, droplets of 200 microns drifted 0.28m while droplets of 100 microns drifted 5.1 m (The Tibre hand book,2004)

g) Spray adjuvants

- Spray adjuvants improve the chemical performance in adverse conditions
- Improve the target reach and improve efficiency in inclement weather by enhancing the sticking and /or spreading and improved penetration on plants
- This can lead to reduced dosage, less cost of chemical and improve the crop yield.
- By low biological activity, and better sticking properties, they also reduce mortality of non-target organisms.

Organosilicones and soya phospholipids are used abroad as spray adjuvants. In India, coconut water from copra units, starch solution (Rice broth) and soap solution are some of the candidate spray adjuvants especially for use on difficult pests like mealy bugs, scales, leaf and plant hoppers, thrips, mites and aphids.

h) Improving spray quality

Improving spray quality also requires regular nozzle cleaning, and calibrating for correct pressure. Even in knapsack sprayers, installation of inexpensive low /high pressure cut off devises and pressure gauges ensure a correct spray of 200-400μ droplet size, reducing drift and runoff. Air assisted spraying reduces water needs and ensures low volume application for improved penetration, target reach and reduced dosage. In screen houses and green houses, vacuum cleaners modified for spraying is a simple substitute. Air pressure regulation can help achieve correct droplet size. This also dislodges small insects like aphids and thrips and improves spray efficiency.

i) Reducing rinse water after application

Reducing rinse water after application requires immediate rinsing after every spray operation and that sprayers be earmarked for herbicides or insecticides or fungicides. Cleaning drills on specified dates improves efficiency and knocks out breakdown wastage of man-hours and spray fluid. Specialist spray groups can be professionally managed for the good of the farmers and for their own good.

Conclusion

Application of pesticides in India is still a semi manual operation for the best part, involving the human operator and a small sprayer. Large-scale mechanisation is both untenable and impractical in the current Indian context. A little amount of care, advise and perseverance on the part of the government and non-governmental agencies are bound to produce wonderful outcome on increased efficiency, reduced application of insecticides and a better, safer and ecologically sound and balanced Indian agro ecosystem. The above discussion is towards achieving this objective.

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Herbicide residues - detection and management

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Introduction

Weed management is an integral component of any crop production programme. Among the different methods of weed control, use of chemicals is the most efficient one in terms of energy as well as and labour and thus reduces the cost of cultivation considerably. In addition, herbicide application helps the farmers to remove weeds at the right time, before critical period of crop weed competition is over. Proper application of herbicides can improve irrigation, navigation and fishery and thereby play a key role in the economy of the country. According to the classification recommended by World Health Organization as shown in Table 1, no herbicide is coming under extremely hazardous category.

Table 1. Categories of pesticide hazard based on acute toxicity limits established by World Health Organization

Category	Toxicity classification	Acute toxicity limit for the rat (mg/kg body weight)			
		Oral LD_{50}		Dermal LD_{50}	
		Solids	Liquids	Solids	Liquids
A	Extremely hazardous	≤ 5	≤ 20	≤ 10	≤ 40
B	Highly hazardous	5-50	20-200	10-100	40-100
I	Moderately hazardous	50-500	200-2000	100-1000	400-4000
II	Slightly hazardous	≥ 501	≥ 2001	≥ 1001	≥ 4001

However, erratic and continuous application of herbicides create problems such as phytotoxicity to crop plants, residual effect on susceptible inter crops and succeeding crops in the rotation and health hazards due to accumulation of residues in crop produce and ground water. Even though herbicides are less toxic substances compared to insecticides (Table 1) they are also capable of polluting the environment. Since herbicides are sprayed rather early in the crop season, where the plant cover is little, major portion of the chemical enters in to the soil where it becomes a part of the life cycle. Hence these chemicals are supposed to be the major ground water pesticides. There are many reports published on ground water contamination due to herbicides all over the world. Ali and Jain (1998) reported that concentration of atrazine, alachlor, simazine, metolechlor and prometryn in ground water were much higher than the permissible health value given by United States Environmental Protection Agency (Vettorazzi, 1979). Therefore, regular monitoring of herbicide residues in soil, plant, and water systems has become a necessity of the day.

Detection

Herbicide residues in the soil can be estimated either by chemical methods or biological methods.

Bioassay

Biological methods commonly termed, as bioassays are the simplest techniques for quantitative determination of herbicide residues in soil. These methods do not require sophisticated equipments and expensive chemicals for estimating the residues. An attempt was made to standardize and identify suitable bioassay system for detection of residues of the commonly used herbicides viz., butachlor, 2,4-D and oxyfluorfen in rice soils of Kerala. Results of the studies indicated that shoot length of amaranthus at 35 and 14 days after sowing are the sensitive bioassays for the detection of residues of butachlor and oxyfluorfen respectively in soil. For 2,4-D, dry weight of cowpea at 35 DAS was the most sensitive parameter for bioassay of its residue in soil. The concentrations of these herbicides, at which 50% reduction in growth of the sensitive plants occurGR_{50} for butachlor and 2,4-D were 2.9 and 1.9 ppm respectively and for oxyfluorfen the value was just above 0.4ppm.(Devi and Abraham; 2001)

Bioassays were used to assess potential hazards from the rice herbicides viz: oxyfluorfen, thiobencarb, butachlor, anilophos, pendimethalin, pretilachlor (with safener) and cyhalofop butyl, under two methods of application viz: spray and sand mix in puddle rice. Post harvest soil samples were collected from the treated plots in the experimental field and the residual effect of the seven herbicides was estimated by conducting bioassay using the indicator plants. During 1994-95, butachlor and pendimethalin showed residual effect by inhibiting the germination and growth of indicator plant, ragi under both methods of application (spray/sand mix) whereas anilophos had residual effect only when it was applied as sand mix indicating that more quantity of herbicide is retained by soil due to adsorption. During 1995-96 when Jyothi, a longer duration variety of rice was grown, no residual phytotoxicity of these herbicides on ragi was noticed. This variation in response of ragi seedlings can be attributed to the duration of rice variety. The difference of about 25 days in the harvesting of rice resulted in dissipation of these herbicides to non-toxic levels (Devi and Abraham, 2000).

There are many limitations for bioassay. Some of them are listed below.

a. Bioassays are not suitable for determination of compounds in biological materials.
b. Response of bioassay does not differentiate between the original compound and bioactive derivatives.
c. Very low concentration of the herbicide cannot be tested
d. Bioassay measures the quantity of herbicide available to the organism, but not the total quantity actually present in the medium.

Chemical methods

Herbicide residue analysis significantly differs from macro analysis. As the quantity of residues present in the substrate would be at ultra micro levels, the analysis consists of chain of procedures involving large number of extractions with organic solvents, clean up, concentration and final estimation using the instruments like spectrophotometer, gas chromatograph (GC) or high performance liquid chromatograph (HPLC) . In the case of water-soluble herbicides like glyphosate, paraquat and 2,4-D, an additional step viz; derivatization is also required before determination by gas chromatography. Therefore, choice of analytical procedures for herbicide residues depends on properties of the chemical as well as the type of instrument available in the laboratory.

Colorimetry

Colorimetric methods were among the earliest instrumental techniques used for the estimation of 2,4-D residues and even today it continuous to be a useful technique wherever costlier modern facilities like gas chromatograph are not readily available Freed (1948) developed a qualitative method in which 2,4-D was heated with chromotropic acid in concentrated sulfuric acid at 150 °C and the development of wine purple colour was taken as a measure of 2,4-D concentration. Subsquent modifications of Freed's procedure by Marquardt and Luce (1951 and 1955) helped in the quantification of2, 4-D residues in milk, seeds grain and in soil.

In order to develop a simple colorimetric technique for the estimation of of2,4-D residues in soil an investigation was carried out at college of Horticulture, KAU(*Devi et al.* 2001). Soil samples were fortified with standard 2,4-D acid and the recovery of 2,4-D from soil was worked out by shaking with seven solvents at soil solvent ratios of 1: 2 and 1: 4.The solvent mixture viz., acetonitrile: distilled water: glacial acetic acid(80:20:2.5) with at soil solvent ratio of 1: 4 and an equilibrium period of 30 min was best suited for the extraction of 2,4-D residues from soil. Recovery of 2,4-D at different fortification levels in fifteen soil samples under study proposed the suitability of the method irrespective of the soil type.

Colorimetry could be employed for determining behaviour of herbicides (persistence adsorption and leaching) in the soils of Kerala. The studies were mostly concentrated on 2,4-D because of the reason that it is the most popular herbicide in Kerala. Rice growers of Kuttanad region have been using this herbicide continuously during the last two decades. Being a chlorinated organic compound, its persistence in soil and water would have adverse effects in the ecosystem. The major rice growing areas viz, Kuttanad and Kole are low laying areas (below mean sea level) where rice is grown under submerged condition. Many reports from different parts of the world are indicative of the accumulation of 2,4-D residues in aquatic environments. Considering the seriousness of this issue, studies on assessment of 2,4- D residues in the rice ecosystem were initiated in Kerala since 1996. Both laboratory and field experiments were conducted to find out the fate of 2,4-D in the major rice soils of Kerala viz; Palakkad, Kole and Kuttanad.

Adsorption and persistence of 2,4-D in the soils

The importance of adsorption in herbicidal action is that it determines the availability of herbicide in the soil for plant uptake, its persistence in soil and also its movement to lower soil layers and to ground water. The degree of adsorption of a pesticide depends upon the nature and properties of the chemical, the kind and amount of adsorbents in the soil and the physico-chemical environment existing in the soil. There are conflicting reports in the literature regarding the reversible nature of adsorption (Khan, 1974). Complete adsorption of a pesticide on organic surfaces (Nearpass, 1965), partial adsorption (Hance, 1967) as well as nearly complete irreversibility (Coffee and Warren, 1969) have been observed.

Studies conducted under AICRP on Weed Control, Thrissur Centre revealed that half-life of 2,4-D in the rice soils of Kerala vary from 3.44 to 10.76 days indicating rapid degradation of the chemical. Degree of adsorption of 2,4-D in the soils in terms of Freundlich isotherm constant, K varied from 3.55 to 9.02 (Devi, 2002).

Leaching pattern of 2,4-D in soils of Kerala

Movement of herbicide within the soil profile is influenced by many factors like chemical nature of herbicide, the adsorptive capacity of soil and the amount of water available for downward movement through the soil. The same factors of adsorption work in reverse for leaching (Coffee and Warren, 1969). As early as 1964, Hartley (1964) reported that percolating water appeared to be the principal means of movement of water-soluble compounds. Sodium salt of 2,4-D is the most common herbicide in paddy fields and it is highly soluble in water (4.5 g per 100 ml at 25°C). In Kerala, rice is grown mostly under submerged condition and percolation of water is a continuous process in these soils. Report of Lavy *et al.* (1973) had shown that 2,4-D was leached down as deeply as 90 cm. If so, there is a potential danger of surface and ground water contamination with this herbicide. In order to understand the leaching behaviour of 2,4-D in rice soils of Kerala, column-leaching study was conducted by taking soil columns from paddy fields of the 15 representative locations (five each from Kole, Palakkad and Kuttanad). 2,4-D was applied on the top of the soil columns and water was added to pass through the soil columns of 20 cm length. Leachate (50ml) was collected in a beaker kept below the soil column. Columns were cut at 10 cm and 20 cm length, and residue content in the 0-10 cm and 10-20 cm layers and in the leachate was estimated by colorimetry.

Based on the data obtained on the leaching behaviour of 2,4-D in the rice soils of Kerala, graphical interpretations were made and summarized below.

Major portion of 2,4-D (58.3, 64.5 and 66.4 % of the applied herbicide in Kole,Kuttanad and Palakkad respectively) remained in the first 10 cm soil layer (Fig 1). Soils from Palakkad region recorded the maximum quantity of 2,4-D in the upper soil layer which was followed by Kuttanad and Kole. Less than 30 percent of the applied chemical was found in the 10 to 20 cm soil column and only 5 to 15 % was registered by the leachate. Soil columns collected from the Kole region showed higher quantity of 2,4-D in the leachate, which is attributed to the higher percolation rate of water through the soil column. It was clear that at the present recommended rate of 1.00 kg ha^{-1}, the risk of ground water contamination with 2,4-D residues is negligible. Maximum residue limit of 2,4-D for drinking water is 0.1ìg l^{-1} (0.0001 mg per milliliter) and hence 2,4-D application at rates higher than 1.00 kg ha^1 (particularly in areas where movement of water through the soil column is greater than 0.01ml min^{-1}) should be restricted (Devi, 2002).

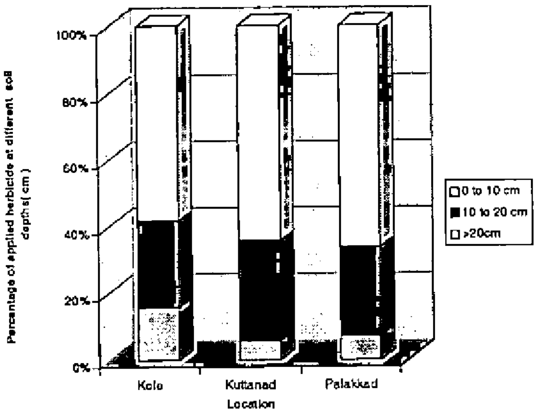

Fig. 1. Average recovery of applied 2,4-D (%) at different depths

Colorimetric techniques can be used for the detection of many herbicides in soil. Carbamates, phenyl amides and substituted ureas can be hydrolysed to yield aniline, which may be diazotized and suitably coupled to produce an azo dye (Sankaran et al., 1993). However, popularity of colorimetric methods has declined considerably because it lacks the sensitivity of advanced techniques particularly gas chromatography.

Gas chromatography

Gas chromatographic methods have definite advantage over other methods because of the capability of the instrument to resolve complex herbicide mixtures and to provide qualitative identification and precise quantitative analysis of the compounds. Separation is achieved due to the difference in the equilibrium distribution of sample components between two phases namely stationary (non volatile liquid in the column) and mobile phase (gas). The introduction of very narrow bore capillary columns (0.25 mm or less) and highly sensitive detectors facilitated the estimation of herbicide residues present in water and tissue samples at nanogram or picogram levels.

Using gas chromatograph, studies on persistence of herbicides in rice plant, grain and straw were conducted under AICRP on Weed Control, Thrissur Centre. Results revealed that residues of 2,4-D in the rice plant (Table 2) are very low even when applied at 4.00 kg ha^{-1} (0.40 and 0.70 ppb at 2.00 and 4.00 $kgha^{-1}$ respectively). In the rice grain and straw samples, the residues were very much lower than the maximum residue limits. (Devi, 2002).. It is very clear that little translocation of 2,4-D to the grain occurred even at higher rates of application of 2,4-D

Table 2. Residues of 2,4-D in the rice crop, at different levels of application (ìg g^{-1})

Dose of 2, 4-D (kg ha^{-1})	At 30 days after spraying	At harvest	
		Grain	Straw
0.0	ND	ND	ND
0.5	ND	ND	ND
1.0	ND	ND	ND
2.0	0.0004	0.00015	ND
4.0	0.0007	0.00017	0.0025

Studies conducted with recommended levels of butachlor and pretilachlor (1.25 and 0.75 kg ha^{-1} respectively) in the rice-rice system also gave similar results(Kannan,2003)..

Gas chromatography – Mass spectrometer(GC –MS)

All the GC techniques can be coupled with a mass spectrometer using various interfacial systems. The mass spectrometer itself can be operated in different ways. The most widely used technique is that of electro impact ionization (EI). In this mode, the sample is introduced into the ion source, after purification by means of a suitable GC method and ionized by an electron beam of high-energy electrons usually of 70 eV. The EI mass spectrum yields more structural information, which is usually considered as a fingerprint of the compound. Therefore, the method is suitable for elucidation of molecular structure of unknown compounds e.g. metabolites of herbicides not yet reported in the tissue samples of plants and animals.

High performance liquid chromatography

Many of the limitations of GC could be avoided by the use of liquid rather than gas as the mobile phase. The nature of mobile phase can be altered in HPLC and thus improving separations. Estimation of nonvolatile and polar compounds becomes easier by this technique. The major disadvantage is that the detection systems are not so sensitive as in gas chromatography. Suzuki and Wtanabe (1991) developed a method to screen phenoxy acid herbicides in ground water samples. The phenoxy acid herbicides viz; 2,4-D, MCPA and MCPB were reacted with 9- anthryl diazomethane (ADAM)under mild conditions and were converted into the corresponding fluorescent derivatives The ADAM derivatives were separated by reverse phased HPLC and determined using a fluorescent detector..The detection limits were about 500 pg per injection.

Radioassay

Radioisotopes have offered excellent tool for estimating behaviour of herbicides in aquatic systems (KAU, 2003). The most common label used for this purpose is ^{14}C, which is a soft beta emitter and can easily be detected in biological samples by liquid scintillation counting.

Management of herbicide residues

In order to minimize herbicide residue hazards in soil, following management techniques can be adopted.

1. Use of optimum dose of herbicide
2. Application of farm yard manure
3. Ploughing the land
4. Crop rotation / herbicide rotation
5. Use of activated carbon
6. Use of safeners / antidotes

As a part of residue management programme, a long-term herbicide trial was initiated in 2001 under AICRP on Weed Contol, College of Horticulture, Kerala Agricultural University. The experiment consisted of six treatments, namely, (T1) hand weeding twice (25 and 40 DAS); (T2) butachlor fb 2,4-D (with 100% NPK as inorganic fertilizer) in the first and second crop seasons of 2001 and 2002; (T3) butachlor fb 2,4-D(with 100% NPK as inorganic fertilizer) in the first crop season of 2001 and 2002, pretilachlor fb 2,4-D(with 100% NPK as inorganic fertilizer) in the second crop season of 2001 and 2002; (T4) butachlor fb 2,4-D(with 75% NPK as inorganic fertilizer and 25% through FYM) in the first crop season of 2001 and 2002, pretilachlor fb 2,4-D(with 100% NPK as inorganic fertilizer) in the second crop season of 2001 and 2002; (T5) butachlor fb 2,4-D(with 100% NPK as inorganic fertilizer) in the first and second crop of 2001, pretilachlor fb 2,4-D(with 100% NPK as inorganic fertilizer) in the first and second crop of 2002;(T6) butachlor fb 2,4-D in the first and second crop of 2001(with 75% NPK as inorganic fertilizer and 25% through FYM in the first crop and100% NPK as inorganic fertilizer in the second crop), pretilachlor fb 2,4-D the first and second crop of 2002 (with 75% NPK as inorganic fertilizer and 25% through FYM in the first crop and100% NPK as inorganic fertilizer in the second crop).

It was found that all the three herbicides namely, butachlor, pretilachlor and 2,4-D had been dissipated from the soil to non-detectable level by the time of harvest.
The effect of continuous application of butachlor, butachlor alternated with pretilachlor between seasons, butachlor alternated with pretilachlor between years, effect of organic matter and difference in the dissipation pattern between herbicides are furnished below.

(i) Continuous application of butachlor

Irrespective of the seasons and treatments, dissipation of butachlor was at a faster rate and the residues were not detected at the time of harvest. Even though butachlor was sprayed continuously in the four crop seasons without addition of organic matter, more than 96.20 per cent of the applied herbicide had been disappeared from the soil by 30DAS. Slightly higher rate of dissipation (97.66 per cent) observed during the second crop season might be due to higher temperature and optimum moisture content of the soil.

(ii) Butachlor alternated with pretilachlor between seasons

Since butachlor had been completely dissipated before the harvest of first crop, its application during the preceding season could not exert any influence on the persistence of pretilachlor sprayed in the succeeding season. Compared to butachlor, dissipation of pretilachlor took place at a slower rate. Only 94.16 per cent of the applied pretilachlor had been disappeared from the soil by 30DAS.

(iii) Butachlor alternated with pretilachlor between years

When butachlor was replaced with pretilachlor (after the application of butachlor for two seasons of the previous year), extent of disappearance of residue from the soil by 30DAS was 96.01 per cent in the first crop and 95.14 per cent during the second crop season respectively. The results indicate that lag phase of pretilachlor is comparatively higher than that of pretilachlor. However at the time of harvest no detectable amount of pretilachlor residues was recorded in this treatment even after its application for two seasons.

(iv) Effect of organic matter

Application of FYM enhanced the rate of degradation of butachlor, pretilachlor and 2,4-D in the soil. In the first crop season, percent dissipation of butachlor within a period of 30DAS from the plots with and without FYM was 97.66 and 96.20 per cent respectively. The corresponding values for pretilachlor were 97.47 and 96.01 per cent respectively and that of 2,4-D were 98.17 and 96.59 per cent respectively.

Herbicide pollution in aquatic environment

Kerala has a coastal line of 580 km with 3,55,000 ha of inland water bodies under lakes, backwaters and the contamination of water bodies with herbicides pose serious threat to the whole ecosystem. Potential sources of pollution of aquatic system with herbicides are the following

1.Herbicides applied for weed control in rice
2. Chemicals applied for aquatic weed control
3.Herbicides applied to plantations in hilly areas

A study on herbicide residues in the aquatic system was initiated in 1996 at Regional Agrl. Research Station, Kumarakom under the ICAR adhoc project on "Evaluation of Kuttanad ecosystem for possible contamination by pesticides, herbicides and heavy metals". The major herbicide under consideration was 2,4-D and its residues were detected in 17%of the field water samples at a concentration range of 0.26-8.7 μg/l. Samples taken during January showed higher values and July showed lower values. This is due to the use of the chemical for rice cultivation in November-March period. Residues of 2,4-D were detected in 13% river water samples in the range of 0.5-5.4 μg/l. The residues were high during January and trace in July. Eighty percent samples of ground water showed the presence of residues of 2,4-D up to a concentration of 0.09 μg/l and the residues were high during May which indicated that the maximum residue level of 2,4-D in ground water of Kuttanad is well below the permissible limits of 0.1 μg per litre (KAU, 2000).

An investigation using labeled 2,4-D was taken up as a part of adhoc project on "Persistence of herbicides in water bodies and its impact on aquatic life "under AICRP on Weed Control, College of Horticulture, KAU, Thrissur during the period from 2001 to 2004. The results obtained during 2002 and 2003 revealed that 2,4-D persisted in water even up to 1 year after application in glass aquarium tanks at levels higher than the maximum residue limits (0.1μg/l). There was accumulation of 2,4-D residues in the fish samples up to 30 or 60 days after spraying depending on the quantity of 2,4-D applied over salvinia. The above results are from laboratory studies conducted under closed conditions. Field studies are yet to be completed for confirmatory results (KAU, 2003).

Studies on herbicide residues in the aquatic environment in the state as well as in the country are very few mainly because of the complexity of analysis and lack of proper analytical facilities. Results obtained from the experiments conducted in the other countries revealed that there is a potential danger with herbicides in the aquatic system. Studies on the dissipation of 2,4-D Glyphosate and Paraquat in river water (Wang *et al.*, 1995) using ^{14}C indicated that half of the radio activity disappeared from water samples containing 2, 4-D but more than 80% of Paraquat remained in water samples after 56 days of incubation. Determination of Octanol-water partition coefficient (K) showed a large difference in amounts of 2,4-D partitioned in water phase at different pH values, 97.4% at the higher pH of ionic state and 5.2% at the lower pH of molecular state, implying that pH value of water might affect the bioaccumulation process of 2,4-D. The results showed that 95.0% of glyphosate present in water phase in ionic form (higher pH) and 82.3% in molecular form (lower pH), indicating that glyphosate might have no effect on the biomagnification, since most of the glyphosate could be excreted with water by organisms.

Need for future research

Proper use of herbicides has immense benefits in agriculture by reducing cost of cultivation. At recommended levels of application, these chemicals are quickly dissipated from soil. However, erratic and continuous application of water-soluble herbicides may contaminate water bodies. In order to avoid the risk of contamination of low land ecosystems, it is necessary to monitor herbicide residues in the aquatic environments and suggest appropriate management practices.

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VI. SESSSION ON CROPPING PATTERNS AND FARMING SYSTEMS FOR IMPROVED RESOURCE USE EFFICIENCY

Diversification of farming enterprises in the context of new WTO regime

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Introduction

The debate on the benefits and effects of trade liberalization continues till this day, even after nearing a decade since the signing of WTO. The signing of the agreement is in reality, a testimony of consensus by signatory countries that free trade is beneficial to everybody. However, despite the consensus, the debate on the advantages and disadvantages of trade liberalization not only continues but is also gaining momentum. This is especially so for liberalization in the agricultural sector, which is deemed strategic by many countries in both the developing and the developed worlds.

In the present day economic order, agricultural diversification has assumed prime importance from micro as well as macro point of view. It has become an integral part of the structural adjustments and transformation program of the agriculture sector in India to derive potential benefits of globalization. The unfolding globalization of agriculture, however, has thrown new challenges and opportunities to the agrarian sector. While there are apprehensions on the one hand, that the influx of subsidized cheap imports from the developed countries would adversely affect the agricultural sector, on the other hand, there is evidence that these countries are able to raise their agricultural export especially of high value and labour intensive commodities. This seems to open up a window of opportunities especially when Indian agriculture is experiencing shrinking size of its holdings, decelerating technological advances in staple crops, declining investment in agriculture and increasing degradation of natural resources.

Diversification of agriculture is to overcome many of these emerging challenges, if carried out appropriately, agricultural diversification ensures stability in the farm incomes by minimizing risk because the low return from one crop is compensated by the high return from others. Agricultural diversification also reduces peaks and depressions in demand for resources and ensures reduction in seasonal unemployment. It helps in maintaining the soil health because sequencing different crops in a rotation is one way to maintain soil fertility. This creates enterprise symbiosis, meaning the positive biological interaction among various enterprises in the production system. The diversification also brings the advantages of complementarities and supplementarities because of multidimensional and intensive use of space, time, capital, labor and enterprise symbiosis. Several micro level studies support the above proposition (Pingali and Rosegrant, 1995; Ramesh Chand, 1996 and Ryan and Spencer, 2001).

In the agriculture sector, diversification is considered a shift from one crop to another crop, or from one enterprise to another enterprise (Vyas, 1996). Diversification of agriculture may also come as an additional complementary enterprise to the main enterprise. Based on these concepts, Vyas (1996) proposed three situations of diversification:

- Shift from less profitable crops or enterprise to more profitable crop or enterprise within agriculture (horizontal diversification)

- Shift from farm to non-farm activities (vertical diversification)
- Use of resources in diverse activities (due to both horizontal and vertical diversification)

However, takes the macro approach of diversification where it extends well beyond the farm level encouragement of farmers to grow non-staple crops. According to this approach, diversification is not merely a production oriented question of what additional crops can be grown, neither it is merely an economic question of how to make them profitable. It relates to providing wider opportunities to farmers, both on the farm as well as non-farm, to use their resources including family labor and management skill with increasing efficiency. The issue is, therefore, tightly knitted with the broader agricultural development strategies, especially the interplay between short-run policies designed to meet immediate government objectives for the sector and the longer-run relationship of agriculture to the rest of the economy during the process of structural change (World Bank, 1990). This type of agricultural diversification includes diversification in production, marketing, and processing activities among different sub-sectors, and can contribute significantly to both growth and equity.

In a subsistence agricultural system, diversification is considered as a strategy to minimize farm risk, which arises as a result of fluctuations in output prices, weather uncertainties, and insect-pest incidences, among others. In an era of commercial and market-led agriculture, however, diversification is a growth strategy which replaces the subsistence enterprises with the high value ones. In the process, it reduces risk in agricultural production.

In a competitive environment, when the food grain prices slide down, the urban consumers and the landless poor gain but it may result in net income loss to food grain producers, especially those located in unfavorable environments (David and Otsuka, 1993). The livelihood of the poor in these environments critically depends on incomes from diverse sources including the production of commercial crops. In the course of development, diversification of agricultural resources to production of commercial crops nd livestock products with high-income elasticities becomes necessary to increase incomes in agriculture as well as to earn foreign exchange.

Under the free trade regime of the World Trade Organization (WTO), diversification of agriculture not only has an economic appeal but also a necessary condition for growth. In free trade, different countries have to decide what commodities or products should be produced and exported based on the competitive advantage. Failing to do this, they will progressively lose the ability to protect their production from global competition and making imports inevitable. The international trade is also likely to move from a mere comparative advantage to competitive advantage involving highly segmented markets, differentiated products, technology differences, economies of scale, etc. The traditional price-cum-cost comparisons will rather be only a preliminary indicator of competitiveness.

As per the Agreement on Agriculture (AoA), the member countries, both developed and developing, are required to slowly open up their agriculture sectors to world trade by removing all trade restrictions. As a signatory to the General Agreement on Tariff and Trade (GATT) and founder member of WTO, India is committed to implement various agreements and provisions encompassed in AoA. Many studies have brought out that Aggregate Measures of Support (AMS) would not affect Indian agriculture as the total Indian AMS is far below the upper limit (Gulati and Sharma, 1994). Gulati's argument is mainly based on the assumption that Indian agriculture is reasonably efficient and would emerge even more so once the domestic support to agriculture in developed countries is reduced to the agreed level. The global competitiveness of Indian agriculture, both on quality and price account, is another factor (Gill and Brar, 1996) which limits the gains for India from free trade. TRIPs, oligopolization of agricultural research, sanitary and phyto-sanitary measures, food security, oligopolization of global agricultural trade, falling trend in global agricultural commodity prices etc. are the other concerns of Indian agriculture.

India has removed quantitative restrictions (QRs) for 1,429 items on 31 March 2001. Out of these, 825 relate to agriculture and dairy (Ghuman, 2001). In other words, Indian producers of all these commodities would have to face global competition in their own domestic market. The removal of Non-Tariff Barriers would substantially increase the import of those items into the Indian market. There is a clear message that in order to survive in international competition, India must identify diversification options for agriculture. Diversification would require the promotion of alternative crops at a return higher than the traditional crops. Besides, it needs region-specific research and planning for various crops. Carefully planned agro-processing and agro-forestry can also help in diversification. That would further require research and development, price support and production-clearing-market network.

A sound understanding of the patterns of agricultural diversification and the constraints it faces would help in shaping up appropriate policies regarding institutional arrangements and creation of adequate infrastructure, which could benefit a large mass of small and marginal farmers. This paper is an attempt in this direction and intends to (i) examine the extent, nature and speed of agricultural diversification in India (ii) assess implications of agricultural diversification on food security, and employment.

Measuring Diversification

There are quite a few methods, which explain either concentration (i.e) specialization or diversification of commodities or activities in a given time and space by a single indicator. Important ones include (i) index of maximum proportion, (ii) Herfindal index, (iii) Simpson index, iv) Ogive index, (v) Entropy index (vi) Modified Entropy index, and (vii) Composite Entropy Index (Kelley Ryan and Patel 1995; Pandey and Sharma 1996; Ramesh Chand 1996). Each method has some limitation and or superiority over the other. Considering our objective of assessing the extent of diversity in crop, livestock and fisheries activities, Simpson index was used. The index provides a clear dispersion of commodities in a geographical region. The index ranges between 0 and 1. If there exists complete specialization, the index moves towards 0. The index is easy to compute and interpret, as follows:

$$SID = 1 - £p_j^2$$

Where SID is the Simpson index of Diversity, and Pj is the proportionate area (or value) of ith crop / livestock / fishery activity in the gross cropped area (or total value) of output.

The nature and patterns of diversification were examined by looking into temporal changes in area, production and value of different crops, and quantity (and or value) of livestock and fisheries activities. To estimate the speed of diversification in favour of high value commodities, annual compound growth rates of area, production and yield of different crop / livestock activities were computed. The analysis is based on time series information for the period 1985-86 to 2002-03. The period was divided into three viz., pre-liberalisation period (1985-86 to 1990-1991); Pre WTO period (1991-1992 to 1995-1996) and Post WTO period (1996-1997 to 2002-2003) respectively to examine the effects of WTO agreements.

Results

The macro-level data of value of agriculture and allied sector (at 1993-94, constant prices) showed that changes in the relative shares of the crop, livestock and fisheries sub-sectors have taken place in the different WTO regimes (Table 1).

The Simpson index of Diversity (SID) for Agricultural Allied activities was 0.78 in post WTO period, up from 0.66 in per liberalization period. This shows that India gradually diversifying crop sector.

The share of livestock increased from 23.09 percent in pre liberalization period to 25 percent in pre WTO period and 25.98 percent in post WTO period. In the livestock sector, milk and eggs started contributing more in the pre and post WTO periods than in the pre liberalization period. Milk production has increased to 60 million tonnes and 78 million tonnes during pre WTO and Post WTO periods as against 44 million tonnes in pre liberalisation period. Share of fisheries sub-sector in gross value of output also rose during this periods reflecting the emergence of structural change in favor of livestock and fisheries sectors.

Table 1. Share of agriculture and allied sectors in GDP in different WTO regimes

Sectors	Pre liberalization (1985-86 to 90-91)	Pre WTO period (1991-92to 95-96)	Post WTO period 1996-97 to 02-03
Agriculture and Livestock	34.17(0.66)	28.09(0.72)	22.37(0.78)
Forestry	2.33(0.98)	1.55(0.98)	1.08(0.99)
Fishing	0.75(0.99)	0.96(0.99)	0.97(0.99)

Figures in parentheses indicates simpson index

Crop sub sector

The share of crop sub sector is steadily declining in India, the share of crop sector in the value of agricultural sector in constant prices (Table 2) was declining from pre liberalisation period (76.91 percent) to post WTO period (74.02 percent).

Table 2. Share of agriculture and live stock sectors in value of agriculture and allied activities in different WTO regimes

Sector	Pre liberalization (1985-86 to 90-91)	Pre WTO period (1991-92to 95-96)	Post WTO period 1996-97 to 02-03
Agriculture	76.91	74.52	74.02
Livestock	23.09	24.56	25.98

The share of different crop sectors to total value of agriculture in different WTO regimes are presented in Table 3. The SID index of different crop sector showed that, the SID for cereals slowly increased from 0.64 in pre liberalization period to 0.66 in the post WTO period. Similar pattern of SID movement also exhibited in the pulses also. But in the case of fruits and vegetables SID movement is in the opposite i.e., SID for fruits and vegetables decreased from 0.82 in pre liberalization period to 0.77 post WTO period and similar opposite movement of SID also noticed in the case of oilseeds also. The trend showed that the non food grain have gradually replaced food grain crops. When comparing pre liberalisation period with post WTO periods value of cereals in the total value of output was declined from 36.42 to 34.08 percent.

Table 3. Share of different crop sectors to total value of agriculture in different WTO regimes

Crops	Pre liberalization (1985-86 to 90-91)	Pre WTO period (1991-92to 95-96)	Post WTO period 1996-97 to2002-03
Cereals	36.42 (0.64)	35.78 (0.64)	34.08 (0.66)
Pulses	6.78 (0.93)	5.80.(0.94)	5.11 (0.95)
Oilseeds	9.47 (0.91)	11.58 (0.88)	10.22 (0.90)
Sugars	7.49 (0..93)	7.83 (0.92)	7.83 (0.92)
Fibers	4.18 (0.96)	4.62 (0.95)	4.03 (0.96)
Drugs and Narcotics	2.05 (0.98)	1.96 (0.98)	2.11 (0.98)
Condiments and Spices	3.20 (0.97)	9.44 (0.91)	3.54 (0.96)
Fruits and Vegetables	17.98 (0.82)	18.74 (0.81)	23.47 (0.77)
Other Crops	2.87 (0.87)	2.67 (0.97)	2.64 (0.97)
Byproducts	8.75 (0.91)	7.03 (0.93)	6.30 (0.94)

Figures in parentheses indicates Simpson index

Similarly for the pulses also declined from 6.78 to 5.11 percent in the post WTO period. But fruits and vegetable crops gained from 17.98 to 23.47 percent in post WTO period. Similarly for the oil seeds and spices and condiments also. There fore non food grain crops like fruits and vegetables, oil seeds and spices have mainly substituted coarse cereals and pulses while in search for higher income.

Table 4. Annual compound growth rate (percent) of area production and yield of major crops in India

Crops	1981-90			1991-2003		
	Area (ha)	Production (mt)	Yield (kg/ha)	Area (ha)	Production (mt)	Yield (kg/ha)
Cereals	-0.24	3.36	3.61	-0.21	1.34	1.55
Pulses	0.06	1.55	1.49	-0.79	-0.51	0.28
Oil Crops	1.76	5.08	3.27	-0.45	-0.72	-0.27
Vegetables	-0.62	1.31	1.93	1.96	5.06	3.04
Fruits	5.39	5.63	0.23	4.06	5.87	1.74
Spices	1.23	7.53	6.23	9.49	10.16	0.61
Cotton	-1.24	2.80	4.10	1.23	-0.41	-1.61
Sugarcane	1.47	2.71	1.23	1.92	2.11	0.18

However, despite negative growth in cereals, its production is contributed by higher productivity growth of 1.55 percent per annum (Table 4). Pulses and Oil crops exhibited negative growth necessitating large imports during 90's. A substantial increase of 2.00 percent in area during 90's as against negative growth was observed in vegetables and 50.00 percent of yield increase contributed for higher growth. An eightfold increase in area war observed during 1990s in spices as against 1.23 percent in 80's.

The proportion of different cereals crops to total value of cereals production in different WTO regimes are presented in Table 5. Among the cereals, Wheat and Maize have replaced coarse cereals like Jowar, and Ragi. Favorable government pricing policies, assured procurement, high yielding technology, assured irrigation have encouraged north Indian Farmers to allocate more area in favor of wheat crop. During the post WTO period, maize picking up fast to meet the demand for poultry feed industry.

Table 5. Proportion of different cereals crops to total value of cereals production in different WTO regimes

Crop	Pre liberalization (1985-86 to 90-91)	Pre WTO period (1991-92 to 95-96)	Post WTO period (1996-97 to 02-03)
Paddy	55.52	55.82	55.00
Wheat	29.44	31.03	32.87
Jowar	5.39	4.24	3.16
Bajra	2.75	2.80	2.80
Barley	1.02	0.81	0.71
Maize	3.88	3.95	4.30
Ragi	1.10	0.96	0.78
Small Millets & Other cereals	0.57	0.35	0.37

The analysis of the area under different crops for the last three decades (1986 -2003) show that absolute area under wheat increased from 23 million ha in 1986 to 27.50 million ha in 1999 However, the relative proportion of area witnessed a little change, i.e., from 12.89 to near about 14.6 percent. Similarly, the absolute area under rice, oilseed, cotton and sugarcane, though increased, but no drastic shift in the relative share of area was observed during this period. The only significant shift observed was the sharp decline in the area under coarse cereals. Except maize and wheat area under course cereals decline during 1990's (Table 6).

Table 6. Annual compound growth rate of area of major cereals in India (percent)

Crop	1981-82to 1999-91	1991-92 to 2000-01
Rice	0.57	0.81
Jowar	-1.82	-3.18
Bajra	-0.71	-0.99
Maize	0.13	1.33
Ragi	-1.49	-1.88
Wheat	0.40	1.39
Barley	-5.63	-2.11
Other Cereals and Small Millets	-5.16	-3.55
Total Area of Crops	**0.48**	**0.38**

The proportion of different pulses crops to total value of pulse in different WTO regimes are presented in Table 7 and from this table it is concluded that among pulses crops, black gram, green gram and pigeon pea had increased share in total value of pulses output in post WTO period when compared to pre liberalization pulses output in above said periods. A positive growth rate of 0.50 percent was experienced in gram area during 90's as against negative growth rate of 1.26 percent in 80's (Table 8). Over all, i.e., share of pulses in the total value of agricultural output was also declined between the pre liberalization and post WTO periods.

The proportion of different oil seed crops to total value of oil seeds in different WTO regimes are presented in Table 9. Within oilseeds, soybean and sunflower gained during post WTO period. Specifically, the percent share of soybean in the value of oilseed output was tripled when comparing pre liberalisation and post WTO periods. Similarly there is an jump in share of the sunflower also in this period. But groundnut and mustard major looser; ie. 10 percent decline in share of oilseed by groundnut alone during the post WTO period. There was about three percent decline in the mustard in value of oilseed output. Groundnut and mustard are under serious threat in the wake of import liberalisation of edible oils at the cost of imported oils especially palm oil is much lower than the domestic price prevailing in the economy.

Table 7. Proportion of different pulse crops to total value of pulses in different WTO regimes

Crop	Pre liberalization (1985-86 to 90-91)	Pre WTO period (1991-92to 95-96)	Post WTO period (1996-97 to 02-03)
Gram	41.52	43.47	45.33
Arhar	20.05	18.75	18.96
Urd	9.97	9.46	9.54
Moong	11.09	10.62	8.68
Masoor	5.14	5.57	6.58
Horse Gram	2.25	1.70	1.14
Others	9.53	10.02	9.76

Table 8. Annual compound growth rate (%) of area of major pulses in India

Crop	1981-82to 1999-91	1991-92 to 2000-01
Gram	-1.26	0.50
Tur or Arhar	2.40	-0.16
Other Pulses	0.18	-1.20

Table 9. Proportion of different oil seed crops to total value of oilseeds in different WTO regimes

Crop	Pre liberalization (1985-86 to 90-91)	Pre WTO period (1991-92to 95-96)	Post WTO period (1996-97 to 02-03)
LinSeed	2.32	1.34	0.98
Sesam	4.59	3.40	2.97
Ground nut	40.10	32.02	29.28
Rape seed and Mustard	22.12	23.88	19.31
Castor	2.22	2.86	5.25
Coconut	15.08	16.01	14.54
Niger Seed	1.07	0.77	0.61
Saflower	1.97	1.27	1.10
Sun Flower	3.21	5.14	5.89
Soybean	6.09	12.49	16.34
Others	0.76	0.55	1.02

Except castor seed and coconut all the major oilseed witnessed a negative growth during Pre and Post WTO periods (Table 10).

There was no or little change in the sugar, or fiber and drugs and narcotic crops share in the value of agricultural output in the different WTO regimes. Within crop sector, fruits and vegetables gained during post WTO period. Specifically, the percent share of fruits and vegetables in the value of agricultural output when comparing pre liberalization and post WTO periods. Due to the data limitation, it is very difficult bring out the extent of diversification with in the fruits and vegetable crops.

Table 10. Annual compound growth rate (%) of area of major oil seeds in India

Crop	1981-82 to 1999-91	1991-92 to 2000-01
Ground nut	2.12	-2.73
Castor seed	2.79	2.92
Sesame	2.61	-3.98
Rape Seed and Mustard	7.85	-0.86
Linseed	-3.14	-3.49
Coconut	3.31	2.26
Other Oilseeds	10.08	3.02
Total Oilseeds	10.08	-0.25

Livestock sector

The livestock sector is growing at a faster rate and there fore its share in the total value of output is progressively raising from pre liberalisation to post WTO period (Table 11). But diversification within the livestock sector is modest mainly due to large share of milk group (66 percent). The remaining share of livestock products (34 percent) distributed to several items like meat, egg, wool, etc. Meat and poultry sub sectors have also registered good performance during the post WTO period.

Table 11. Proportion of different livestock sectors to total value of livestock in different WTO regimes

Details	Pre liberalization (1985-86 to 90-91)	Pre WTO period (1991-92to 95-96)	Post WTO period (1996-97 to 02-03)
Milk Group	64.39	65.55	67.28
Meat Group	16.04	17.80	17.06
Eggs	3.14	3.41	3.65
Wool and Hair	0.31	0.26	0.26
Dung	12.51	9.41	7.99
Silkworm cocoons and Honey	1.39	1.42	1.29
Increment in Stock	3.58	2.19	2.47

Contrary to crop diversification, diversification towards allied sectors, i.e., dairy, poultry and fish production, is fairly good. The production of milk increased by 253 percent, eggs by 367 percent and fish by 243 percent during 1980-81 to 2002-2003. The growth of milk production was much higher (5.01 percent) during 1981-90 than 1991-2003 (4.20 percent) (Table 12). However, there is still a large gap between the availability and requirement of these commodities.

Livestock production brought out revolutionary changes inn the country during pre liberalization period and these continued during Post WTO period also at a slower pace. In dairy sector break through is ascribed to the implementation of Operation Flood Programme. Realizing the success of the programme. The Integrated Dairy Development Programme was launched in non operation flood, hilly and backward areas in 1992-93 to enhance production and procurement and marketing of milk and to generate employment opportunities in those areas.

Table 12. Growth performance of livestock activities and fish in India

Details	Products	1981-90			1991-2003		
		Nos	Production	Yield	Nos	Production	Yield
Milk	Cow Milk	0.74	5.20	2.97	0.86	4.06	2.18
	Buffalo Milk	1.83	4.74	0.94	1.29	4.63	2.18
	Total Milk		5.01			4.20	
Poultry	Chickens	5.21	11.78	0.00	9.77	11.32	0.00
	Hen Eggs	5.21	7.96	2.87	9.77	4.59	0.61
Total Meat			3.74			3.17	
Total Fish Catch				5.06			3.77

Forestry sector

The proportion of different forestry sectors to total value of forestry in different WTO regimes are presented in Table 13. The share of fire wood in total value of forestry sector was increased from 67 percent in pre liberalization period to 78 percent in post WTO period where as share of industrial wood declined sharply.

Table 13. Proportion of different forestry sectors to total value of forestry in different WTO regimes

Forestry sectors	Pre liberalization (1985-86 to 90-91)	Pre WTO period (1991-92to 95-96)	Post WTO period 1996-97 to 02-03
Industrial Wood	21.75	14.97	12.13
Fire wood	66.96	71.96	77.67
Minor forest products	12.30	12.87	10.20

Fisheries sector

Fisheries sub sector has also diversified over the years. The percent share of marine and in land fisheries to the total value of fisheries (Table 14) clearly indicated that, a gradual shift from marine to inland fisheries during post WTO period when compared to pre liberalisation period. Traditionally the marine fisheries used to dominate the fish production in the country which was more than 75 percent in 1960-61 and has fallen to 47 percent in post WTO period while that of inland fisheries has arisen about to 53 percent in post WTO period from less than 25 percent in 1960-61.

Table 14. Proportion of different fishery sectors to total value of fishery in different WTO regimes

Sectors	Pre liberalization (1985-86 to 90-91)	Pre WTO period (1991-92to 95-96)	Post WTO period (1996-97 to 02-03)
Inland Fish	47.34	48.39	52.59
Marine Fish	53.82	52.07	47.41

The higher growth in inland fisheries was mainly attributed by progress in the aquaculture. The share of culture fisheries in inland sector went up to 84 percent in 1994-95 (Kumar *et al.,* 2001). A bulk of growth in culture of fisheries has come from the fresh water of aquaculture (Krishnan *et al.*, 2000).

Implications of diversification

Food Security

Food security at the national and household level is an important issue in the context of agricultural diversification. Producing additional food is a major challenge when population and incomes are rising, and natural resources degrading. There are apprehensions that shift in crop portfolio from food to non-food crops may lead to food insecurity. Incidentally, the diversification in majority of the states in India was coming as a result of expansion in cropping intensity. The crop substitution was also taking place, which was diverting area in favour of high-yielding cereals from low-yielding inferior cereals. Wheat and maize gained while sorghum, ragi and millets lost the area. The high-yielding nature of foodgrain crops has improved their availability. The production trends reveal that the per capita daily availability of foodgrains has increased from 448.56 grams in 1981-82 to 475.4 grams in 1999-2000. Similarly, the per capita daily availability of milk has substantially gone up from 128 grams in 1980-81 to 214 grams in 1999-2000 [Government of India, 2002].

Interestingly, the consumption basket is changing over time. The food consumption is shifting from cereals to non-cereals in both rural and urban areas (Table 15). The per capita cereal consumption in rural and urban areas has declined, while those of milk, milk products, vegetables and fruits have increased significantly [Kumar 2002]. Most remarkable increment in consumption was witnessed in case of fruits and vegetables. The available evidence clearly reveals that diversification of crop and livestock sectors has not only increased production of non-cereal commodities, but also raised their consumption pattern.

Table 15. Per capita consumption pattern of food items

(kgs / person / annum)

Item	Rural				Urban			
	1977	1987	1993	1999	1977	1987	1993	1999
Rice	86.5	88.1	85.4	81.0	67.6	66.1	64.2	62.5
Wheat	49.4	61.6	53.5	53.9	64.6	60.4	57.4	55.4
Coarse cereals	56.7	29.8	24.1	17.7	14.8	10.6	7.7	7.1
Total cereals	192.6	179.5	163.0	152.6	147.0	139.14	129.3	125.00
Pulses	8.7	11.5	9.2	10.1	11.7	12.2	10.5	12.00
Milk and Milk products	24.6	58.0	51.4	50.5	39.7	64.9	68.3	72.0
Edible oils	2.7	4.3	4.6	6.0	4.8	6.8	6.6	8.6
Vegetables	24.7	50.8	53.2	66.0	39.7	66.4	63.1	70.0
Fruits	2.6	10.3	9.8	17.00	5.9	18.8	20.1	19.0
Meal, eggs, fish	2.7	3.3	4.1	5.0	4.8	4.9	6.3	6.8
Sugar, and Gur	13.5	11.0	9.2	10.1	17.1	12.3	11.8	12.0

Source: Kumar (2002)

The impact of structural shift in dietary pattern through diversification is expected to show a marginal improvement in nutrition, especially energy (Table 16). The share of horticultural crops in total energy will improve from 5.2 percent in 1995 to 7.8 percent in 2030, from 7.5 to 12.3 percent for livestock and fisheries products, while there will be marginal improvement for "other" food items during this period(Paroda and Kumar, 2000). These changes will bring improvement in food security in terms of enhanced availability of micronutrients, such as iron and vitamin A. Despite these diversification led structural changes in demand and their impact on food security, however, food grains will continue to dominate and maintain their share of 61 percent in total energy even in 2030.

Table16. Source of energy by major food groups in india during 1995 and 2030

S.No	Food group	Year	Per capita GDP growth	Total energy Consumed (percent)
1	Food grain	1995	3.5	68.6
		2030*	3.5	64
		2030	5.5	60.6
2	Horticultural products	1995	3.5	5.8
		2030	3.5	7.6
		2030	5.5	8.9
3	Livestock & Fisheries Products	1995	3.5	7.3
		2030	3.5	9.8
		2030	5.5	11.7
4	Other food Items	1995	3.5	18.2
		2030	3.5	18.6
		2030	5.5	18.8
5	Daily per capita energy(kcal)	1995	3.5	2,188
		2030	3.5	2,294
		2030	5.5	2,389

Source: Paroda and Kumar, 2000.

Note: * Projections for 2030 were done for two different growth rates (i.e., 3.5 and 5.5 percent).

Employment

In order to maximize the labor absorbing capacity of the rural sector, it is critically important to add extra farm production activities to traditional cereal production by means of developing more intensive crop rotations and crop-livestock combination. Agricultural diversification can act as a powerful force in this direction and can counteract the population pressure which otherwise results in growing poverty and inequality. In this context, the trends in agricultural diversification in India are welcoming. Generating employment avenues in rural areas is critical. The question is how diversification of crop sector can generate additional employment opportunities in the rural areas. Some information was collated from labour use in production of different crop activities from the publications of Cost of Cultivation Principal Crops (Table 17). It may be noted that labour use for cultivation of non-cereals is substantially higher than cereals (except rice).

Area shift from cereals to vegetables would generate substantial employment opportunities in rural areas. Rough estimates suggest that 1 ha shift in area from wheat to potato would generate 145 additional man-days. Similarly, 1 ha area shift from coarse cereals (sorghum and pearl millet) to onion would generate 70 man-days more employment opportunities in rural areas. In case of substitution from coarse cereals to other vegetables (for example, cabbage, cauliflower, egg plant, tomato, lady finger), it is expected to generate 70 man-days/ha additional employment. A marginal shift in area from wheat and coarse cereals in favour of high-value crops can thus generate enhanced employment opportunities. Generating additional employment in rural areas has welfare and equity implications.

Table17. Average labour use in vegetables, cereal and non-cereal crops

(Man-days per ha)

Vegetables		**Cereals and Non-Cereals**	
Crop	Labour Use	Crop	Labour Use
Potato	200	Rice	110
Onion	125	Wheat	55
Cabbage	110	Sorghum	51
Cauliflower	120	Pearl millet	63
Eggplant	70	Cotton	96
Tomato	195	Sugarcane	228
	-	Maize	77

Source: Derived from several sources (i) Subramanian et al (2000) and Government of India (2003)

There are several micro level evidences, which demonstrate that diversification of agriculture in favor of commercial crops augments income, generates more employment opportunities, and alleviates rural poverty. The diversification as a result of competitive environment is a outcome of economic reform. The empirical evidences reveal that economic reforms have generated more employment opportunities. For example, Dev (2000) had shown that the employment growth during 1983-88 was slow which improved during 1987-94 because of the economic reforms during the later period. Similarly, incidence of poverty in agriculture sector among rural households also declined marginally from 37 percent in 1987-88 to 36 percent in 1993-94 (Bhalla, 2000). Recent estimates from the Planning Commission (2001) showed that these positive trends have further strengthened, and population below poverty line has come down to 26 percent in 2000. These trends in poverty alleviation can be related to agricultural diversification as well. Such kind of diversification must be encouraged and sustained through continuous monitoring of policies and institutions responsible for the change.

Challenges of Agricultural Diversification

Different countries have different potential to implement the WTO regulation, thus diversify their production and consumption systems. The concern for food security remains a sensitive issue. Related to this is agricultural and food subsidies and would require more attention in the new economic regime. Considering the social objectives of various forms of subsidies in agriculture and their political sensitivity, reforms in input sector in terms of withdrawal of these subsidies are going to be the real challenge for the policy-makers. The extent of diversification in India will depend upon how efficiently the WTO issues are implemented and free markets are allowed to work both in the input and output markets.

As noted before, cereal grains will continue to be a dominant source of energy in India. Therefore, in the competitive environment, no country can afford to dilute efforts in sustaining production growth of food grain crops. This growth must come through raising productivity levels because the scope for area expansion is now limited in the event of diversification towards high value crops and more competition of land for non-agricultural uses. The available estimates reveal that the yield levels of all food grain crops need to be stepped up substantially, failing that would create food security threats and jeopardize the diversification drive in developing countries. Having said that, producing balanced food is also the major challenge in the fast changing economic paradigm especially when resources are limited and degrading. Concentration of efforts on cereals and demand shift to other food may create an imbalance in the supplies of the cereals and the non-cereals commodities. For example, the concentrated efforts on the diffusion of modern cereal production technologies enabled Indonesia to move from being the largest importer in the world to self-sufficiency in rice within the decade ending in the mid-1980s, while the self-sufficiency ratio of soybean (a major source of protein foods) declined from 100 to almost 50 percent, partly because of rising demand for high-protein foods and partly because of significant diversion of land from soybean to rice (Hayami and Otsuka, 1994). Similar imbalance in demand and supply can be observed in pulses and oilseed in Pakistan and Bangladesh, and pulses in India. As a result, either the consumption of these commodities has reduced, or the import bill on account of these commodities has surged. The reduced consumption of especially pulses has serious implication for the balanced diet, especially for the poor income group. Therefore, keeping a balance between cereals and non-cereals in the policy arena is an important challenge of diversification programs.

Lastly, building infrastructure and institution for diversification is an expensive and daunting task. Appropriate fiscal incentives for alternative crops and enterprises, based on their competitive advantage, will be required to build on favorable environment for diversification.

Conclusion

The study diagnosed the status of agricultural diversification in India , during different WTO regimes .The results of the study revealed that agricultural sector in India is gradually diversifying in favour of high-value commodities, namely, fruits, vegetables, livestock and fish products. Much of the diversification came, if at all, with only little support from the governments. It was because food security issues are still critical in the subcontinent and government policy is still obsessed with self-sufficiency in cereals, which presumably contributes to a large share of area still being allocated to cereal crops. Despite focusing efforts towards food grain production, a silent revolution is witnessed in high-value commodities. Production of fruits, vegetables, livestock and fish products have increased remarkably in India. Due to their low share in gross value of agricultural output, the silent revolution was unnoticed.

The success of any diversification program involves the development of crop- or enterprise-specific technologies, creation or identification of market, and provision of economic incentives. The free trade regime envisages the movement from command to market economies and leaves it on the market, domestic or international, to judge the competitive advantage of any product.

As a signatory of GATT and member of WTO, India is committed to implement the various agreements and provisions of AoA. This creates the fears that traditional agricultural products will face a stiff competition from imports. The diversification of agricultural production in favor of the commodities in which India enjoys the competitive advantage can help to meet this challenge. Various studies show that due to diverse agro-climatic conditions, India has the advantage of producing a number of commodities. Particularly it enjoys the competitive advantage in those commodities and enterprises where the labor requirements are relatively high. Following types of diversification options have been suggested:

1. Items of mass production and consumption such as dairy, poultry, pulses, oilseeds, forestry, etc.;

2. Area-specific enterprises of moderately high value commodities in different agro-climatic regions and sub-regions, e.g., cotton, vegetables, fruits, sugarcane, basmati rice, durum wheat; etc.

3. Limited site-specific diversification through introduction of high value crops for the consumption of elite, e.g., floriculture, exotic vegetables, etc.

In the scenario of higher economic growth and population pressure, the production environment and dietary patterns in India are rapidly changing. To meet the demand in the competitive environment, the crop-mix is changing in favor of more non food crops and low-elasticity commodities to high-elasticity commodities. However, producing balanced food is the major challenge in the fast changing paradigm shift when resources are limited and degrading. To meet the challenge, the production strategy should be more diversified towards commercial crops without sacrificing the basic objective of ensuring food security.

To encourage diversification of agriculture a multi-prone strategy needs to be designed. However to put the diversification policy into practice demands the gradual restructuring of diversification hindering market, institutions, and credit and fiscal setup into a diversification encouraging ones. It demands revamping of the agricultural financial system and human resource development programs. It requires heavy investments on technological improvements and creating supporting marketing and postharvest infrastructure. The improvement and fine-tuning of technologies and their dissemination is fairly a long-term process and may take 7-10 years of gestation period. Decrease in the cost of production either through productivity improvement or enhancing the efficiency of resource use or both can go a long way in providing the competitive edge to specified Indian agricultural products.

Global competitiveness also requires the strict adherence to the quality standards. Hence the research and institutional agenda drawn for the future agricultural development and diversification must strive on enhancing productivity, reducing costs, and improving quality. The National Agricultural Policy addresses these vital issues but does not specify any time-bound action plan. However, the National Export-Import Policy gives the clear directions for diversification.

The lack of product-specific data on cost of production and government support that various products enjoy in various countries and regions of the world is a major constraint in identifying the comparative advantage and the diversification options. Therefore, it should be made mandatory, in the clauses of WTO, for the member countries to be transparent in sharing this information. Once this is done, different countries will be able to judge the competitive advantage of their products in a better way and identify the options for diversification.

Certain cautions should also be taken while going for diversification. First, the long-run food security of the country must be kept in mind. Secondly, since the world agricultural trade is likely to witness many ups and downs especially in the initial years, an element of flexibility must be injected in diversification plans. Thirdly degree of risk in the transition from traditional products to new products and enterprises is quite high and may prove detrimental to marginal and small farmers. Therefore, some income insurance schemes must be evolved to safeguard the interests of the marginal and small farms. The research institutions are also required to evolve a suitable farming system for these categories of the farmers. The overall objective of the policy should be to maximize the gains from diversification and minimize the pains of transition.

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Farming system research for improving resource use efficiency in rice: Recent advances

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India would need to produce additional food grains of 100 and 160 million tonnes by 2030 and 2050 AD, respectively, to feed its projected population. In India more than 85 million out of 105 million operational holdings are with less than two hectares of farm size, necessitate intensive cultivation involving the modern concept of time and space by adopting heavy dose of chemical fertilizers leading to accumulation of chemical residues in the soil. Hence, it is imperative to go for integrated farming system approach which is not only a reliable way of obtaining fairly high productivity with substantial fertilizer economy but also a concept of ecological soundness leading to sustainable agriculture. A judicious mix of one or more enterprises with cropping complements each enterprise through effective recycling of wastes/ residues.

An effort has been made for a holistic integration of different farming enterprises with cropping with the objectives of increasing income and recycling of farm wastes and by-products to sustain the soil productivity. Studies on integrated farming system involving various components were carried out at different agro-ecological zones of Tamil Nadu since 1985. The identified technologies emanated from the research programme on integrated farming systems for the last three decades are enormous.

Lowland farming system

Field Experiments were conducted at TNAU, Coimbatore in lowland involving cropping, poultry, piggery, duck, goat, pigeon, fishery and mushroom enterprises in all possible combinations with a view to recycle the residue and by products of one component over the other. The recycling process could reduce the cost of production per unit of grain, meat, milk, egg, edible mushroom, biogas etc and there by widen the gap between the production cost and net return.

Crop + poultry/ pigeon + fish + mushroom.

Experiment on enterprise linkage for low land farming systems was conducted at Tamil Nadu Agricultural University during September, 1993 through August 1995. The components of integrated farming systems in lowland involves crop + fish + mushroom, crop + poultry + fish + mushroom and crop + pigeon + fish + mushroom. The efficiency of the component linkages was evaluated predominantly on the basis of productivity, its income and employment generation with the possibility of utilizing recycled organic wastes as nutrient to enrich the soil fertility.

In one-hectare farm, an area of 0.90 ha assigned for crop activity and the remaining area of 0.10 ha to fishpond. 1000 polyculture fingerlings were reared in 0.10 ha fishpond. Fifty numbers of babkok layers / hundred productive pairs of pigeon were linked to supplement the feed requirement of 1,000 fingerlings. Mushroom unit with an average production of 5 kg day^{-1} was included. The recycled pond silt obtained from fish ponds fed with poultry/pigeon droppings were applied as organic source to first crop in the crop sequence.

The results revealed that crop + pigeon + fish + mushroom integration was found to be superior in obtaining the highest net return to the tune of Rs.90,105 ha^{-1}(Tables 1 and 2). Integration of cropping with poultry + fish + mushroom generated the highest employment of 798 man days / ha / year with 1.16 man days from the allied enterprises linked with equidistribution through out the year. Integration of poultry + fish + mushroom + cropping applied with recycled poultry manure sustained the productivity of soil though the addition of bioresource residue with better NPK nutrient supply potential.

To enhance and sustain the productivity, economic returns, employment generation for the family labour round the year and soil fertility with environmental protection, integration of rice-gingelly-maize and rice-soybean-sunflower cropping each in 0.45 ha with recycled poultry manure as fish pond silt to rice and 75 per cent of the recommended NPK to each crop in the system + poultry (50 layers) + fish (1000 polyculture fingerlings in 0.10 ha of ponded water) comprising catla (20 per cent), silver carp (20 per cent) rohu (20 per cent) mirgal (15 per cent), common carp (15 per cent) and grass carp (10 per cent) fed with poultry dropping + Oyster mushroom(5kg/day) for the lowland farmers having one hectare farm.

Feed for poultry, fish and pigeon, substrate for mushroom production, organic manure from the wastes can be secured at the least cost through proper integration. Stability of egg production could be achieved with a productivity of 75 per cent by attaining an average egg production of 274 eggs per layer in a year by procuring 17 weeks old bird after completing preliminary preventive measures instead of going for day old chick to the poultry unit. Cost of production per bird was Rs.109.55/year in commercial venture as against the production cost of Rs.30.65/year through IFS.

Fish growth obtained through feeding of droppings of 50 babkok layers and 100 pairs of pigeon was similar. Since, the feed cost involved for pigeon rearing was least due to open grazing, the net profit under pigeon linked system was higher than in poultry linked system.

About 10 kg of rice straw, maize sheath or crop wastes could be effectively utilised as substrate for producing 5 kg of edible mushroom per day. Cost of production per kg of mushroom was Rs.20/- in commercial venture as against the production cost of Rs.12 through IFS. With an annual production of 1,460 kg of edible mushroom, an additional net income of Rs.11,680 could be obtained in IFS over commercial mushroom units. It also helps in supplementing high value organic manure to the tune of 3.0 t to the crop activity. Employment opportunity was also enhanced at the rate of 1/2 mandays everyday to the family labourer and thus could increased to 182 mandays for the whole year.

With regard to water requirement, cultivation of rice-greengram-maize and rice-sunhemp-maize cropping alone consumed 182 ha cm of water, 201 ha cm of water was needed for rice-soybean-sunflower and rice-gingelly-maize cropping systems in 0.90 ha included in integrated farming systems. Poultry, pigeon, fish and mushroom utilized, respectively, 0.02, 0.04, 15.84 and 1.37 ha cm of water for their production in a year. Integration of cropping with pigeon + fish + mushroom utilized 218.25 ha cm as against 182.00 ha cm of water with cropping alone. Integration of poultry and pigeon required very little quantity of water and total requirement of water in integration of cropping with fish + mushroom + poultry/ pigeon was lesser than the total water requirement of cropping alone in a hectare area.

Cropping + poultry / pigeon / goat +fishery

Field experiments on Integrated Farming Systems were conducted at the Tamil Nadu Agricultural University, Coimbatore during 1998-2001 involving cropping, poultry, pigeon, goat and fishery enterprises in all possible combinations, with a view to recycle the residue and by-products of one component over the other. In one hectare farm, an area of 0.75ha was assigned for crop activity, 0.10ha for growing fodder grass to feed the goat unit (20+1), 0.03 ha allotted to goat shed and the remaining 0.12ha alloted to 3 fish ponds. Three integrated farming systems *viz.,* crop + fish + poultry (20 Bapkok layer birds), crop + fish +pigeon (40 pairs) and crop + fish + goat (Tellicherry breed of 20 female and 1 male maintained in 0.03ha deep litter system) were tried for 2 years. Polyculture fingerlings of 400 numbers (catla, rohu, mrigal/ common carp and grass carp) in the ratio of 40:20:30:10, respectively, reared in 3 ponds of size 0.04ha (depth of 1.5 m) each. Fishes were fed with poultry, pigeon (700 kg poultry/pigeon droppings obtained from 20 Bapkok layers/40 productive pairs of pigeon) sheltered over two fish ponds and goat droppings (3 animals - 800kg droppings) to assess the feasibility of rearing fish by using different manures as feed. Under Integrated Farming System, cropping sequence includes (i) sugarcane (Planted) –sugarcane (Ratoon) – banana (3 years) (ii) banana - turmeric – rice – banana (3 years) and (iii) maize – rice – sesame – sunnhemp (annual) each in 0.25ha and bajra- napier grass + desmanthus (perennial) in 0.10ha. In another one hectare, conventional cropping system as practiced by the farmers was taken up.

Table 1.Component and System Productivity (rice grain equivalent yield) of different Integrated Farming Systems (Mean over three years 1998– 2001)

Farming systems	Component Productivity (kg)					System productivity (kg ha^{-1})	Per cent increased over CCS
	Crop	Poultry	Pigeon	Fish	Goat		
Cropping alone	12995	-	-	--	12995	-	
Crop + Fish + Poultry	26352 (89.0)	1205 (4.1)	-	2052 (6.9)	-	29609	128
Crop + Fish + Pigeon	24854 (85.2)	-	2545 (8.7)	1774 (6.1)	-	29173	124
Crop + Fish + Goat	25725 (68.3)	-	-	1975 (5.2)	9979 (26.5)	37679	190

*** Figures in the parenthesis indicate per cent contribution of each component**

Table2. Economic analysis of Integrated Farming Systems (1998 –2001)

Farming Systems	Net return (Rs./ha)			
	I year	II Year	III year	Mean
Cropping alone	31921	40460	39077	37153
.Crop + Fish + Poultry	123066	92869	77260	97731
Crop + Fish + Pigeon	134516	89013	72805	98778
Crop + Fish + Goat	147889	126662	118804	131118

Research results on integrated farming system for three years revealed that integration of crop with fish, poultry, pigeon and goat resulted in higher productivity than cropping alone under lowland. Crop+ fish + goat integration recorded higher rice grain equivalent yield of 37, 679 kg/ha than other systems (Table1). The goat unit (20+1) could provide 11.0t of valuable manure apart from supplementing the feed requirement of 400 numbers of fish. While assessing the feasibility of rearing fish by using poultry, pigeon and goat droppings as feed, the fish fed with poultry droppings resulted in higher fish yield (289 kg /0.04ha ponded water) than the other two sources of feed.

The highest net return of Rs. 131118 and per day return of Rs.511/ha were obtained by integrating goat+ fish+ improved cropping applied with recycled fish pond silt enriched with goat droppings (Table 2). Higher BCR of Rs.3.36 was obtained by integration of pigeon + fish + cropping applied with recycled fish pond silt enriched with pigeon droppings.

The employment opportunity was also increased to 576 man days/ha/year by integrating fish + goat in the cropping as against cropping alone (369 mandays/ha/year). Combining cropping with other allied enterprises would increase labour requirement and thus provide scope to employ family labour round the year.

Twenty fowls in the poultry unit and 40 productive pairs in the pigeon unit voided 700kg of droppings with the nutrient potential of 22.5, 17.5 and 7.4kg and 12.7, 3.9 and 6.9kg of N, P_2O_5 and K_2O, respectively, but when recycled through fish pond, nutrient contents were enhanced. Similarly, three goats produced 810kg of voiding contributing 11.3, 6.9 and 5.7kg of N, P_2O_5 and K_2O nutrients, which were further enhanced through recycling. The additional nutrients gained by recycling were the highest with poultry manure 65.7, 28.4 and 25.0kg N, P_2O_5, and K_2O, respectively) than with goat/pigeon manure.

The system as a whole provided opportunity to make use of produce/waste material of one component as input on another at the least cost/no cost at farm level.

Rice – Fish + Azolla Farming system

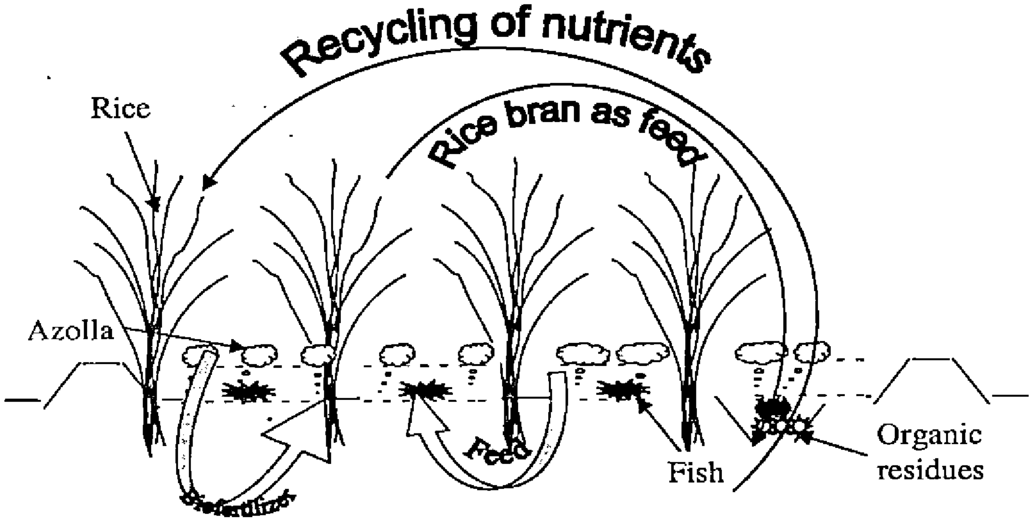

Fig.1. Fish – Azolla integration in rice field

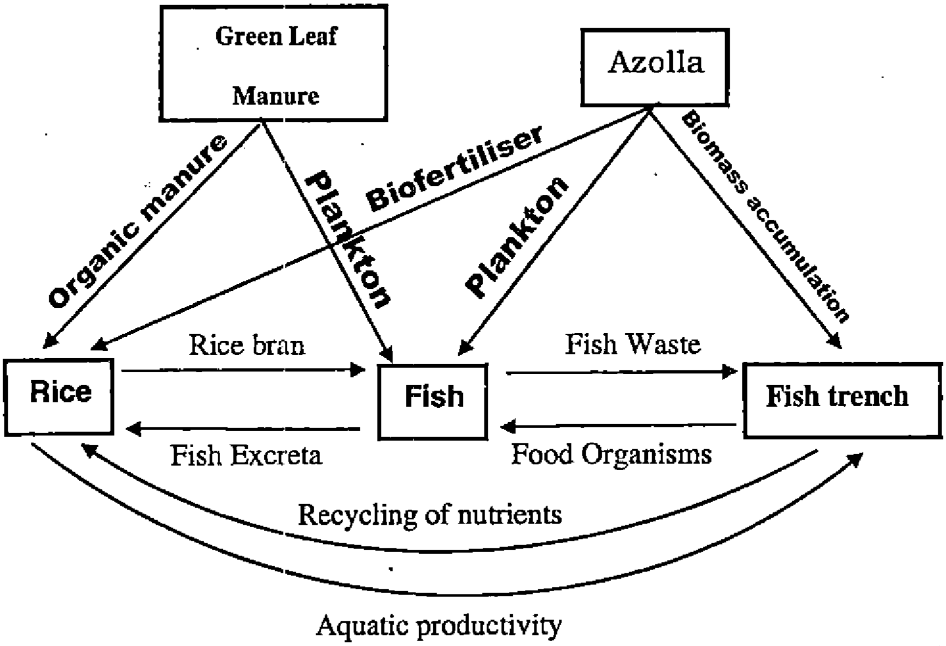

Fig.2. Bio-resource flow model of Rice-Fish -Azolla integrated farming system

Field experiment was conducted at ARS, Bhavanisagar to develop an integrated N management practices for rice-fish- azolla farming in wetland. Farming systems consisted of rice – rice + fish and rice – rice + azolla + fish and two levels of N (100 and 75 per cent recommended) with and without green leaf manure (*Sesbania rostrata*) applications. In the rice – fish system, rice and fish crops were raised together in rice field. Field trenches were provided with 1.0 m depth and 1.5 m width occupying 10 per cent of the rice area, for sheltering the fish. *Azolla microphylla* was grown in rice field throughout the cropping period. The dual culture method of growing azolla with rice has gained widespread adoptability because standing water is available in rice field from seedling to panicle maturity in lowland rice fields and is effectively used as biofertilizer for rice. Azolla cultivation in rice field can improve the fish food organisms. Fish culture in rice fields loosens the soil as a result of their swimming and thus aerating the soil, enhance the decomposition of organic matter and promotes release of nutrients from soil. The excerta of fish directly fertilize the water in rice fields leading to increase in utlizable source of N to the rice crop. Integration of allied components like azolla + fish with rice in lowland farming could provide wider scope for bioresources recycling (Fig. 1 and 2).

Rice- rice – azolla + fish farming with 75 per cent recommended N as well as incorporation of green leaf manure resulted in higher productivity with increased economic returns and improved the soil fertility through recycling of organic residues. The quantum of organic residue addition and N added through recycling were higher in rice- rice- azolla + fish farming with *Sesbania rostrata* incorporation. The unutilized fish feed, decayed azolla and fish excreta settled at the fish trench bottom had a higher nutrient value, which can be recycled to enrich the soil.

Rice – fish integration for improving input use efficiency in rice farming in humid tropics

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Kerala has a very long tradition of integration of rice and fish in its coastal wetlands. The *Pokkali* farming system, which has been acclaimed as a sustainable model, is time tested and unique in several respects especially in its high efficiency standards in utilizing the natural resources and the exogenous inputs. The live feed generation by the disintegrating paddy stubbles intentionally left during the harvest of rice forms the basis of perpetual renewable bio-energic resources for the alternative production of rice and prawn in these fields. The *Pokkali* rice farming system of centuries old owes it origin to the traditional wisdom of our forefathers, while the scientific and systematic rice- fish integration in *Kuttanad*- the rice bowl of Kerala - is of recent origin. The present paper is an attempt to analyse the strength and weakness of the *Pokkali* rice fish prawn system *vis a vis* the rice fish rotational system in *Kuttanad.*

Pokkali and *Kuttanad* are contiguous and together they constitute 75,000 ha of the coastal wetlands. They are interconnected low lying network of back waters, canals and streams, and are the basins of the rivers; *Periyar, Chalakudy, Muvattupuzha, Meenachil, Pampa, Achencoil* and *Manimala.* These two rice ecosystems can be considered as the two sides of the same coin separated by the *Thanneermukkom* salt-water barrier constructed to prevent the entry of salt water into the Kuttanad rice fields.

With the cessation of monsoon the sea water inundates the *Pokkali* fields resulting a gradual change in water quality to saline, the intensity of which depends on the fresh water discharge from the up streams side. At the very same time, the *Thanneermukkom* barrier prevents the entry of salt water into *Kuttanad* and hence, the water quality in either side of the barrier will be different, which necessitates cropping / farming system appropriate to the prevailing soil and water characteristics. The rice – fish / prawn farming system of the *Pokkali* fields is well tuned to the changing water quality .The soil chemical parameters as influenced by a simulated tidal and non- tidal situation as exist on either side of the *Thanneermukkom* barrier is given in Table 1 (Sasidharan, 2004). It can be seen that during the high saline phase under the tidal situation the electrical conductivity and available sodium of soil are quite high, which do not allow a second crop of rice during the high saline phase in *Pokkali* soils. On the contrary, the blocking of tidal water entry could decrease the electrical conductivity and available sodium to some extent, which may permit a rice crop, for the success of which washing with abundant fresh water is necessary as is done in *Kuttanad* during the *puncha* season.

Crops and crop season of these two rice tracts are tailored to these soil conditions. In *Pokkali* fields cultivation of rice is restricted to the low saline phase and as the field water shifts to the saline phase, prawn/ fishes are grown. In *Kuttanad* two rice crops are taken: the main season during October-March (*puncha*) and an additional crop subsequently. Rice cultivation in the beginning of the last century was done only once in two years, which became annual cultivation during 1940's and the intensification into double cropping began in the 1950's with the series of development interventions *viz.* spillways to drain off flood waters and barrage to ward off salinity incursion (Padmaja, et *al.*,1994).

Table 1. Tidal effect on soil chemical characters during the low saline crop phase and high saline post crop phase in *Pokkali* soils

Soil chemical characters	Low saline crop phase		High saline post crop phase	
	Tidal	Non-tidal	Tidal	Non-tidal
pH	3.36	3.25	4.31	4.22
EC(dsm^{-1})	2.61	3.43	6.69	5.76
Organic carbon (%)	2.76	2.47	2.69	2.37
Available phosphorus(kg ha^{-1})	9.35	9.36	12.47	10.11
Available potassium(kg ha^{-1})	934.20	878.05	704.60	437.60
Available sodium(kg ha^{-1})	5406.15	6891.20	8532.90	5287.90
Exchangeable potas-sium(kg ha^{-1})	838.60	681.40	597.60	446.00
Exchangeable sodium(kg ha^{-1})	4477.10	5406.43	8332.40	6615.60
Available:Exchangeable potassium ratio	1.11	1.29	1.18	0.98
Available:Exchangeable Na ratio	1.30	1.32	1.02	0.81

Rice-fish/prawn integration in *Pokkali* fields.

The *Pokkali* rice-fish/prawn integration has been dealt with by several workers (Purushan, 1987 and Rajendran *et al.*, 1993). Most of the workers have described the different aspects of the prawn filtration system, in which seed shrimps and fishes are allowed to enter into the post harvest *Pokkali* fields through tidal water and then trapped for short term culture. Prospects of simultaneous culture of fish species *viz*., *Etroplus suratensis, Oreochromis mossambicus, Cyprinus carpio, Labeo rohita, Chanos chanos* and *Mugil cephalus* with the *Pokkali* rice genotypes have been reported by Thampi (1993) and Rajendran *et al.* (1993). However the simultaneous rice-fish culture in *Pokkali* fields did not get the popularity as that of the sequential rice-prawn culture.

Prawn filtration in *Pokkali* fields starts after the harvest of rice with the strengthening of outer bunds and installation of sluice gates. Removal of weeds and desilting of canals, wherever necessary, are carried out for increasing the water holding potential (Rajendran, *et al.*, 1993). Brackish water carrying the shrimp seed ingresses and egresses regularly at desired levels during high and low tides respectively. While regulating the entry and exit of tidal flow, a large mesh conical bag net or closely packed bamboo screen is suitably installed in the sluice gate. This process being repeated cautiously during each tide enables the shrimp and fish seed to get concentrated in the field (Purushan, 1986). The species auto stocked includes commercially important shrimps such as *Metapenaeus dobsoni, M.monoceros, Penaeus indicus* and *P.monodon*. These shrimps take shelter in between the decaying paddy stalks (Rajendran, *et al.*,1993), which release nutrients to the shrimps and they grow. The syriergistic effect of all these and the congenial conditions prevailing devolve to form a rich niche of forage organisms to the growing shrimps that attain a marketable size within 3 to 4 months period

The actual harvesting of prawn starts by the middle of January coinciding with the lunar phase. When the water is let out of the fields, during low tide the prawn and fishes carried along with water and are collected in the prawn filtration net. Luring in of prawns continues simultaneously along with fishing until the end of March, when the fields are finally drained for taking up rice cultivation. The yield is about 800-to1000 kg ha^{-1}. Prawns constitute about 80 per cent of the catch. The spp. being *Metapenaeus dobsoni* (65 %), *M. monoceros* (10%), *Penaeus indicus* (22%) and P. *monodon*(3%) depending up on the season. Fishes comprises 20 percent of the harvest. The main spp. are *Oreochromis mossambicus, Etroplus suratensis, Mystus sp.,Lates calcarifer, Anabas testudineus, Megalops cyprinoides, Mugil sp.* etc. The species diversity is the strength of prawn filtration as it adds to the sustainability of this farming system. However, a higher volume of low value species dilutes the percentage of quality prawn like *Penaeus indicus* and *P. monodon* and the returns from prawn filtration under such circumstances will be less.

It is in this context that the supplementary stocking of quality prawn seeds along with prawn filtration and monoculture of fast growing selected species get set their roots in *Pokkali* fields.

Selective culture of quality prawn

Selective culture of tiger/white prawn after preparing the field is an improvement over this traditional practice of prawn filtration (Pillai,1999). The native fish population in the fields is completely eradicated. Stocking with desirable prawn seed at desired stocking density and other cultural operations are done to get higher yields. Farmers opt for fast growing species and artificial feeds, which enhances the prawn yield and the production cost. The risk of crop failure is also high when the intensive farming techniques like higher stocking density and feeding with commercial feed formulations are resorted to. Perennial prawn culture system with out rotational rice is also being practised by many. Monoculture of prawn with out rotational rice can erode the sustainability base of this system, since the live feed generation, which enhances the species diversity of this agro-eco system is totally ignored.

Selective culture of prawn with out supplementary feeding is seldom practiced. A yield of 425 kg ha^{-1} of prawn under selective culture, when fed with the live feed generated in the Pokkali fields is reported (Sasidharan, 2004). Average weight gain of 15.9 g in 50 days and 20 g at harvest in 74 days after stocking could be observed as given in the Table 2.

Table 2. Performance of tiger prawn under selective culture in *Pokkali* fields

Growth parameters	Range	Mean
Length after 50 days (cm)	10.2 – 15.0	10.9
Weight after 50 days (g)	10.0 – 22.0	15.9
Length at harvest (cm)	15.8 – 19.3	18.2
Weight at harvest (g)	17.0 - 35.0	20.0

Rice cum fish culture

Integrated fish culture along with rice is feasible in *Pokkali* fields. Most of the Pokkali fields have peripheral channels, which are invariably required for the rice- fish dual culture. The depth of the channel may vary from 50 – 75 cm and the width from 100-200cm. The channels provide a safe habitat for fishes particularly during the low tide. A sluice with shutters facilitate exchange of water and regulation of water level, a removable net screen is provided in the sluice to prevent the escape of cultured fishes and the entry of undesirable organisms. The eradication of weed and undesirable fish can be achieved by applying bio-pesticides like mahua oil cake. Rice varieties and fish species with in the allowable tolerance limit for salinity alone are selected for culture in *Pokkali* fields. Rice varieties either tall or semi tall that can thrive under flooded condition are more desirable (Thampi, 2002). When traditional tall varieties like *Pokkali* are grown they prevented light penetration and thus the plankton production in the rice field . (Rajendran *et al.*,1993). Rice varieties of varying morphological characters were evaluated for their compatibility with fish species under simultaneous rice-fish regime. Semi tall compact varieties permitted significantly more light to reach the floor of the *Pokkali* fields. These varieties could give significantly higher grain yield than the traditional tall varieties (Table 3). However, the straw yield for such varieties is significantly less compared to the traditional tall varieties like Vytilla-3.

Table 3. Performance of rice cultivars in simultaneous rice – fish dual culture

Cultivars	Height (cm)	Light intensity (lux)	Yield (kg ha^{-1})		
			Grain	Straw	Biomass
Vyttila-3	182.2	925	3056	7186	10241
Cul-1026	130.1	1625	3726	4724	8451
Chettivirippu mutant	117.4	1597	4396	5215	9611
C D (.05)	7.2	185	238	724	1357

The fish fingerlings are stocked immediately after the dismantling of mounds and spreading of seedlings in *Pokkali* fields. Fish culture is continued even after the rice harvest, when the salinity may rise to higher values, in which case it is necessary to select species, which are euryhaline. Several attempts were made to identify species capable to withstand the harsh conditions existing in *Pokkali* fields. Rajendran et al. (1993) opined that the candidate species must be capable to withstand anoxic condition in field water during the post harvest decay of rice stubbles. Fast growth rate to get marketable size within the short cultural period was another criterion. Thampi (1993) identified *Cyprinus carpio, Oreochromis mossambicus, Trichogaster pectoralis, Chana striata and Clarius bratachus* as suitable species for the simultaneous culture. Among the three species, tried Sasidharan (2004) identified *Oreochromis mossambicus* as the most suitable species (Table 4).

Table 4. Performance of fish species in simultaneous rice – fish culture.

Fish spp.	Survival (%)	Fish yield (kg ha^{-1})	Mean length (cm)	Mean weight (g)
Etroplus	0.0	0.0	0.0	0.0
Rohu	16.0	25.4	10.7	79.7
Male tilapia	37.6	216.7	20.9	139.1
C D (0.05)	3.8	21.8	0.6	16.8

The utility of *Oreochromis mossambicus* as a suitable component of the rice-fish integrated farming system was amply illustrated by Rajendran *et al.* (1994). Its profuse occurrence, prolific breeding and shadowing effect on other species were dealt by Purushan (2002), while the possibilities of hormonal sex reversal and mono sex culture as a remedial measure have been reported by Roy (1998).

Sustainable farming system

The integrated farming system involving rice, fish and/or prawn followed in *Pokkali* fields is considered as a sustainable system. It in no way interferes with the l rhythm of seasonal changes and the components of this farming system well mingle with the nature. The tides regulate the salinity and pH of the soils and contribute to the fertility and productivity of the *Pokkali* soils. Thus, the components of the system compliment each other by organic recycling and generation of live feed. The organic matter addition by rice stubbles is also significant since the total biomass production by rice in *Pokkali* fields is reported to be 12 to 18 t ha^{-1}out of which only three to five tons alone are taken away by way of grain (Sasidharan, 2004). Even after the removal of substantial quantities of plant nutrients for the production this much biomass, no depletion of nutrients rather than accretion was observed in *Pokkali* soils. This is evident from the soil chemical characteristics of the *Pokkali* soil after the prawn harvest as given in the following Table 5.

Table 5. Soil chemical characters after fish and prawn harvest in *Pokkali* fields

Soil chemical characters	After prawn harvest	
	Range	Mean
PH	5.70 – 6.20	5.80
Electrical conductivity (ds m^{-1})	6.10 – 8.90	8.00
Organic carbon (%)	2.43 – 3.17	2.78
Available P (kg ha^{-1})	10.60 –15.10	11.90
Available K (kg ha^{-1})	314 – 1299	463
Available Na (kg ha^{-1})	3564 – 13440	5484

The soil chemical characters after the prawn harvest denoted desirable changes in pH, organic carbon, available P and available K. The electrical conductivity and the available sodium however, registered considerable increase compared to the soil characters after the rice harvest.

The economic analysis of this integrated farming system brought forth its economic superiority also. The production cost of rice under the Pokkali system of cultivation is comparatively lesser than the other rice ecosystems of the state. Input costs on fertilizer, pesticides and herbicides are nil in *Pokkali* fields. The expenditure on weed management, which usually costs 50 per cent of the production cost, is also lesser in *Pokkali* farming system. The integration of prawn and fishes with rice is the key for increasing the net returns and benefit: cost ratio of Pokkali fields. Hence, the simultaneous culture of high yielding *Pokkali* rice varieties and male tilapia during the low saline phase and subsequent prawn culture is a sustainable farming system, which is socially acceptable, economically viable and ecologically sound.

Rice-fish integration in *Kuttanad*

The impact of the developmental activities to intensify rice cultivation in *Kuttanad* is to be examined in this background. The environmental consequences because of the rice centric developmental interventions were not marginal. Emergence and proliferation of new aquatic weeds, fall in fertility status of soil, resurgence of pests and diseases, indiscipline in rice cultivation practices and non-judicious use of agro-chemicals resulting environmental hazards, which arose out of the increased rice intensification etc. were the new problems surfaced(Padmakumar *et al.*,2003). They further observed that all the economic interventions intended to boost the rice production were becoming not only ineffective but also positively counter productive, which resulted in waning of interest of farmers in rice cultivation.

In this context, a farming system approach that integrated fish along with rice was initiated and models suited to the *Kuttanad* rice ecosystem were developed. In the laboratory model developed at the Regional Agricultural Research Station, Kumarakom the possibility of integrating fresh water fish and prawns along with rice was evaluated under a simultaneous farming regime, initially. The development of these models, their evaluation at the on station and on farm levels, its transformation from simultaneous to rotational system and its lateral diffusion from scientist managed to farmer managed trials over a period of two decades are illustrated in Table 6.

The results indicated that integration of fish culture along with rice is quite feasible in *Kuttanad.* In addition to rice productions ranging from 1.7-to 4.2 t ha^{-1}, fish production of 383 to 600kg ha^{-1} over a period of 210 to 220 days could be obtained under a simultaneous farming regime. As observed from the subsequent studies, rice - fish rotational farming model was found more advantageous as it permitted adoption of management practices more effectively for rice and fish.

The general species mix and stocking model evolved comprised 20 per cent surface feeders, 30 per cent column feeders, 40 per cent bottom feeders, and 10 per cent macro vegetation feeders. Common carp and grass carp were found to be versatile species suitable for culture in paddy fields along with other carps. Multi size stocking of each species of fish was also found useful. The kuttanadan konchu *Macrobrachium rosenbergii* was demonstrated to be the most promising species suited to rice field and was found to attain size up to 180 to 200 g in 6 to 7 months.

Table 6. Changes in cost and returns and production in rice based fish farming models in Kuttanad (Padmakumar *et al.*, 2003)

Year	Farming System	Yield (kg/ha)		Cost of Production (Rs./ha)		Net returns (Rs./ha)			Total return (Rs./ha)
		Rice	Fish	Rice	Fish	Rice	Fish	Others	
On Station Research									
1986-87	-do-	1757-4208	383-600	4715	3535	990	6065	—	7155
1987-88	Rice-Fish rotational	2100-4208	538-1000	4715	3535	2910	12465	—	15375
On farm participatory trial									
1996-97	Rice-Fish rotational	2625	1140	8073	22896	5216	7878	4419	17513*
1997-98	-do-	3219	1289	10211	20966	6091	12234	5732	24057**
Farmer managed trials									
1995-96	Rice monocropping	2338	—	12013	—	859	—	—	859
1996-97	Rice-fish rotational	3563	347	10925	3350	8716	6453	—	15169
1997-98	-do-	4105	673	11780	11403	13350	8460	—	21810
1998-99	-do-	4178	1643	8563	21683	17915	18610	—	36525
1999-00	-do-	3988	1265	10463	21995	15090	13270	—	28360
2000-01	-do-	4058	815	9638	14823	17443	7898	—	25341

* includes net returns from rice, fish, pig and cattle

** includes net returns from rice, fish, pig, poultry, banana and pineapple

Complementary effects

Cultivation of rice improved the biological potential of rice fields since the stubbles left after harvest decomposed and provided shelter and feed for the growth and development of live feed. which formed ideal food for fish. In an on farm trial rice fish rotation yielded fish production as high as 2500 kg ha^{-1}. This observation indicated that fish could attain much higher growth when left to grow in larger impoundments even under an extensive farming system (Padmakumar *et al.*, 2003). The complementary effect of fish on rotational rice is quite evident on land preparation, manuring, pest incidence and weed control (Table 7). The sustainable rice yields obtained during the later years in the farmer managed trial (Table 6) point out the complementary effect of fish on rice yield.

Economic benefits

The effect of fish integration on cost of production of rice in farmers participatory trials is illustrated in Table 7. The integration helped to reduce cost of production of rice appreciably by 17.6 percent during the first year besides increasing yield by 52 per cent. Although varying levels of yield in rice have been reported by fish integration the average increase in such cases was always over 15 per cent. Indirect control of pest and diseases resulted in substantial reduction in cost on plant protection. A perceptible reduction in weeding cost by 32.7 per cent and a saving of 100 per cent on weedicide was also observed. It is evident that the integration not only helped to reverse the up trend in cost of production of rice but also contributed to increase in yield of both fish and rice.

Ecological benefits

The ecological effect of rice fish integration is more convincing due to the reduction in agricultural chemicals, especially in weedicide and other hazardous plant protection chemicals (Table 7). The perceptible improvement in the soil condition had favuorable effect by the recycling of the nutrients and energies, which render the rice ecosystem more organic and environment friendly.

Table 7. Effect of rice-fish integration on cost of production of paddy in Kuttanad (Padmakumar *et al.*, 2003)

Item	Before fish integration				After fish integration			
	1995 (Puncha) Cost (Rs.)		1995 (Virippu) Cost (Rs.)		1995 (Puncha) Cost (Rs.)		1995 (Virippu) Cost (Rs.)	
	Material	Labour	Material	Labour	Material	Labour	Material	Labour
Expenses								
Land preparation	0	1483	0	2238	0	634	0	486
Bunding	0	472	0	575	0	606	0	790
Seeds & sowing	808	101	842	108	876	108	1021	115
Weeding	76	3198	76	3631	0	1460	0	3013
Plant protection	381	270	393	324	232	229	66	103
Manuring/Liming	2008	298	2376	342	2200	319	2581	510
Other inputs	346	894	371	1050	393	1062	0	1465
Harvesting	0	427	0	674	0	685	0	642
Total	3619	7143	4058	8942	3701	5103	3668	7124
Income	Quintals	(Rs.)	Quintals	(Rs.)	Quintals	(Rs.)	Quintals	(Rs.)
Paddy	19	8967	28	14812	34	17144	35	17938
Straw	0	371	0	449	0	225	0	309
Total	19	9338	28	15261	34	17369	35	18247
Profit	(-) 1405	2289	8599	7490				

Conclusion

Rice-fish/prawn integration rather than monocropping of rice or fish/prawn is more suited to the coastal wetlands of Kerala comprising of *Kuttanad, Pokkali* and *Kole* lands. The ecological and environmental impacts of rice- fish integration are instrumental in broadening the spp. diversity base of these ecosystems. The seasonal difference in chemical and biological properties of the soil and water of the *Kuttanad* and *Pokkali* tracts make it imperative to develop individual production models for the different coastal wetlands. Information on the beneficial effects of the components of the system and their complementary interaction can substantially lower the input use and enhance its efficiency. Achieving higher production targets for rice utilising the favourable soil conditions and minimising the use of commercial feed formulations for fast growing prawn species in *Pokkali* tract and exploring the utility of increased organic matter accumulation as a result of fish integration, for reducing the inorganic fertilizer use in *Kuttanad* are some of the unexplored area requiring immediate research attention.

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Resource use efficiency in farming systems research in Kerala

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Exploitative agriculture offers great possibilities if carried out scientifically, but posses a great danger if carried out with only an immediate profit motive. India is now experiencing this problem in many of our agricultural systems. The yield levels remain stagnant even with the addition of more and more inputs like fertilizers, irrigation and plant protection chemicals. The ever increasing population is exerting high pressure on agricultural lands and it is from small fragmented holdings that we have to derive sustained output. The only practical approach to achieve this is integrated farming.

Farming systems represent an integration of farm enterprises such as cropping systems, animal husbandry, fisheries, forestry and the resources available to the farmer to raise them profitably and sustainably. Higher profitability without altering ecological balance is emphasized in farming systems. A judicious mix of cropping systems with associated enterprises like dairy, poultry, piggery, fishery, sericulture and apiculture suited to the given agro climatic conditions and socio-economic status of farmers would bring prosperity to the farmer. Farming system as a concept, takes into account the components of soil, water, crops, livestock, labour, capital, energy and other resources of the farm with the farm family at the centre managing agricultural and related activities. The area and production of major crops of Kerala are given below (Table 1).

Table 1. Area and production of major crops of Kerala

Major crops	Area ('000 ha)	Production ('000 tonnes)
Coconut	906	5479*
Rubber	475	580
Rice	322	704
Pepper	204	58
Tapioca	111	2456
Banana & other Plantain	106	769
Arecanut	93	85
Coffee	85	67
Cardamom	41	8
Tea	37	66
Ginger	11	40

* million nuts (Farm guide, 2004)

1. Rice based farming systems

In Kerala, rice is cultivated in 3.2 lakh ha with an annual production of 7 lakh tonnes and it is the most important staple food crop. It is cultivated under various situations like upland, lowland and deep water conditions. The cropping systems also vary based on the ecosystem and soil chemical reactions. In uplands, the systems most prevalent are rice-rice-fallow, rice-rice-vegetables, rice-rice-sesamum, rice-rice-groundnut, rice-rice-pulses, rice-rice-green manure crops, rice-tapioca etc. In low lands most of the times a single crop of rice is taken.

During the rest of the period either it is left fallow or fish/prawn culture is the practice.

Rice cultivation in Kerala is on the decline mainly because of the escalating labour charge, which can be tackled by introduction of chemical control of weeds and machineries like mechanical transplanter and combine harvester. To save chemical fertilizers, the use of organic manures like green manuring and azolla culture are in vogue. The use of leguminous green manure crops raised either as fallow crops or along with rice crop is also becoming popular. Beena Jacob *et al.*, (1999) have reported that groundnut-rice system and sesbania-rice system were comparable in retaining a higher level of soil fertility but returns per rupee invested was the highest for cowpea-rice system. They have also reported that the mean yield increase for the application of 35 kg N ha^{-1} was 15 kg grain per kg of N over control whereas it was only 6.6 kg grain for the next 35 kg and further declined to 4.5 kg grain for the last 35 kg N (Table 2)

Table 2. Yield of rice as influenced by preceding crops and N levels (kg ha^{-1})

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
Preceeding crops (C)		
Cowpea	3.23	3.42
Groundnut	2.82	2.84
Sesbania	3.24	3.29
Fallow	2.57	2.94
N levels, kg ha^{-1}		
035	2.39	2.47
7	2.95	3.11
0	3.18	3.42
105	3.34	3.49
SEm for C	0.12	0.11
SEm for N	0.09	0.09
CD(0.05) for C	0.34	0.32
CD(0.05) for N	0.26	0.26

Source: (Beena Jacob *et al.* 1999)

1.1. Rice-fish culture

Low lands are fragile ecosystems and are important in surface as well as ground water movement and storage. Pokkali, Kuttanad, Kole and Kaipad are the important low land tracts in Kerala. To maintain the balanced ecology of lowlands, it is important to protect these low lands as 'low lands' itself which can be attained by evolving strategies for sustaining the rice based farming systems in these areas. Substantial area under paddy has been converted into residential areas.

Assured water availability in coastal and adjacent areas throughout the year gives the opportunity for the inclusion of aquaculture component in the farming systems. It was an age old practice prevalent in low lands, which got neglected after the introduction of high yielding rice varieties. But over dependence on chemical fertilizers for years resulted in drastic reduction in its productivity. It also caused aquatic pollution and depletion of organic base in soils. This made farmers to go back to the old practice of rice-fish integrated farming system to make lowland farming economically feasible (Siddiq, 1999). But it has got its own advantages and disadvantages.

Advantages:

- Controls insect pests and weed infestation in rice fields and brings down pesticide use.
- Fish excreta and left over feed contributes to soil fertility and rice yield.
- Movement of fish aerates the field.

Disadvantages:

- Increased use of fertilizers and plant protection chemicals in lowlands is harmful to the aquaculture component.
- If the aquaculture component is not cautiously introduced, it can act as an environmental pollutant due to accumulation of fish wastes. Fish component should be selected so as to utilize the agricultural or livestock wastes and the fish waste (pond silt) in turn should be properly recycled in crop fields.

Along with rice and fish, several livestock components like cattle, pig, duck and poultry can also be integrated into the lowland farming system in order to increase the efficiency of the system.

1.1.1. Pokkali model for rice-fish farming system

Out of the various fish farming practices followed in low lands, a successful example is 'Pokkali' cultivation. It is originally a rice-fish rotation (sequential) system. The main rice crop season is from May-June to September-October when the monsoon rains wash off the excessive salinity. After rice, field bunds are strengthened and fishes are allowed to naturally infiltrate into field during high tide till January. Harvesting is done towards end of March by draining the field. This system provides a fish yield of 300-1600 kg ha^{-1} per season in addition to increased rice yield. 80 percent of the fish catch will be prawns, out of which 65 percent will be *Metapenaeus dobsoni*, 22 percent *Penaeus indicus*, 10 percent *Metapanaeus monoceros* and 3 percent *Penaeus monodon*. Thilapia, Pearl spot and Milk fish are the important fish species in the catch (Rajendran et *al.*, 1993).

In order to increase the total returns from prawn cultivation, selective stocking of large sized prawns having high market preference is done. Selective stocking of *P. indicus* in pokkali fields gave a prawn yield of 382 kg ha^{-1} in 90 days and when supplemental feeding was done, an yield of 552 kg ha^{-1} in 83 days was obtained (Jose *et al.*, 1987)

Simultaneous rice-fish culture in pokkali fields with fishes like Milk fish, Mullets and Pearl spot is also in practice but their performance was reported to be poor. Rotational rice-fish/prawn culture was found to be the most suited one in terms of fish yield, effective pest and weed control and fertility improvement of the field. Field preparation requirements are also less in such farming systems. The saline waters of Pokkali offer great opportunities for crab fattening and mussel farming. These resources remain totally untapped. Kole lands of Thrissur and Malappuram also have similar aquatic environments as that of Pokkali.

1.1.2. Kuttanad model for rice-fish farming system

Ecology of Kuttanad was influenced by a combination of flood water and sea water entering the Vembanad lake. The wide spectrum of salinity divergence enabled the sustenance of a range of aquatic life especially brackish water fish. Till the commissioning of Thannirmukkom salt exclusion barrier, farmers used to get prawn catch of 300-400 t per season. In addition, edible clams like *Villorita sp* and lime shells were abundant in Kuttanad. Drastic decrease in breeding, growth and development of fishes, prawns and clams resulted due to prevention of saline water intrusion and extinction of mangroves, which used to provide shelter ground for prawns and other estuarine fishes. Due to these constraints, fish production in Kuttanad had suffered a serious set back. But nowadays due to increased awareness of people about the disturbed ecological balance, purposeful integration of aquaculture component in wet lands of Kuttanad is undertaken by the farmers themselves. The field lay out of a single plot is shown in Fig. 1.

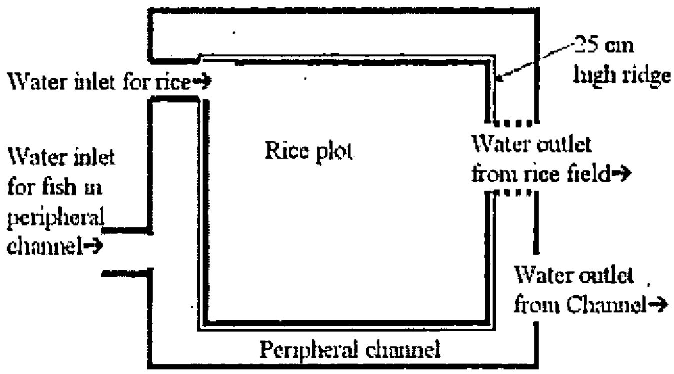

Fig. 1. Rice-fish culture: field layout

Plant protection chemicals are applied to rice after draining the field so that fishes can retrieve to the canals through breaches in the dyke separating field and canal. Carps except grass carp and fresh water prawns are suited for this system. Size of fingerlings at the time of stocking is important in determining their survival rate. At Kumarakam, Padmakumar and Nair (1988) found that common carp attained the highest individual size in simultaneous culture system, but percentage of survival and contribution to yield was maximum for Indian carp as given in Table 3 and 4

Table 3. Aquaculture components for Kuttanad

Common name	Scientific name	Feeding habit
Catla	*Catla catla*	Surface feeder (Zoo plankton)
Rohu	*Labeo rohita*	Columns/filter feeder
Mrigal	*Cirrhinus mrigala*	Bottom feeder
Common carp	*Cyprinus carpio*	Omnivorous
Grass carp	*Ctenopharyngodon idella*	Macro vegetation feeder
Silver carp	*Hypothamichthys molitrix*	Surface feeder
Indian carp	*Labeo fibriatus*	Bottom feeder
Thilapia	*Oreochromis mossambicus*	Omnivorous
Pearl spot	*Entroplus suratensis*	Omnivorous
Giant fresh water prawn	*Macrobrachium rosenbergii*	Bottom feeder

Source: (Padmakumar *et al.*, 1993)

Table 4. Survival and yield of fish species under rice-fish culture

Species	No. Stocked	No. Recovered	Yield/ 1500m^2 (kg)
Catla	139	8	3.0
Rohu	280	232	24.5
Mrigal	215	138	18.5
Indian carp	178	174	36.5
Common carp	218	17	7.5

Source: (Padmakumar and Nair, 1988)

To avoid competition among fishes for space and feed they are selected according to feeding habits and composition of the stock is fixed as 25 percent surface feeders, 30 percent column feeders and 45 percent bottom feeders. Apart from additional income from fish, rice yield was also found boosted by simultaneous fish culture under rice-fish farming system as shown in Table 5. Brown plant hopper (BPH) which is one of the major pests in Kuttanad is also reduced by this system.

Table 5. Comparative performance of paddy monocrop with rice-fish culture

Component	Yield in kg ha^{-1} during Punja season	
	With fish	Without fish
Rice (var: pavizham)		
Grain	2500.00	1835.94
Straw	1389.83	1132.81
Fish	600.00	-

Source: (Padmakumar and Nair, 1988)

1.2. Rice-fish-livestock farming system

Additional feeding using rice bran, cassava, coconut oil cake, clam meat, prawn shell wastes from marine processing industry and mollusk meat from back waters improves the fish yield. This additional feeding cost (about 50 percent of the total cost) can be avoided by incorporating some livestock component like duck and pig etc in the farming system (Padmakumar, 1987). A batch of 250-300 ducks provides enough manure to feed 1.0 ha of fishpond yielding 3.5-4.0 t ha^{-1} of fish meat. The expenditure on duck is met by the sale of eggs alone. Housing for duck is constructed over the field to facilitate the droppings to directly fall in the field itself. Pigsties are constructed on the field or pond bunds so that the dung and shed washings are easily drained into the field. Carps feed directly on pig dung which contains 70 percent of the digestible food for fishes. Pig manure also fertilizes the pond and increases its productivity by enhancing plankton production. Sale of pig meat will meet the entire expenditure in the system. Two batches (each kept for 6 months) of 30-40 piglets each can support 1.0 ha of fish pond in a year without additional feeding. Fodder for grass carp can be grown on field or pond bunds. The material flow in this system is shown in Fig. 2.

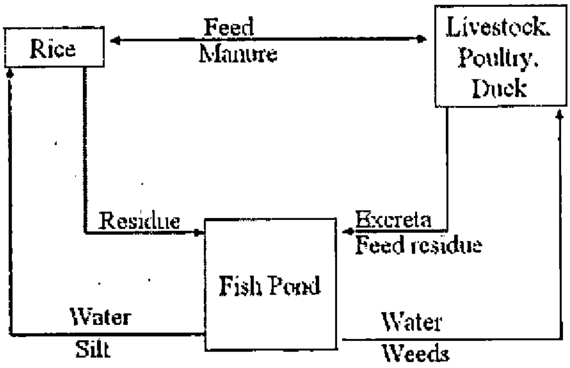

Fig. 2. Material flow in rice-fish-livestock system

Fodder integration facilitates livestock rearing and in turn biogas production. There is also scope for rearing small ruminants like goats in low lands, as the land requirements to support small ruminants are meagre.

1.3. Rice-azolla-fish farming system

The use of azolla has a tremendous impact on rice production systems, not only as a cheap substitute to nitrogenous fertilizer, but also for other nutrients. Azolla also utilizes fish excreta in metabolic process as its nutrition. Azolla contains a high amount of arginine, which is important for fish growth. Since azolla grows rapidly and produces small individual plants, it is ideal for fish to feed. Continuous manuaring is desirable in rice-fish culture to ensure availability of natural fish food. Application of green leaf manure and azolla and addition of fish excreta and the remains of fish feed together could enhance the soil fertility to a greater extent than application of inorganic nutrients alone.

Advantages of the rice-azolla-fish farming system over traditional rice cropping systems include increased fish production, decrease in inorganic fertilizer and pesticide requirements, reduction in incidence of insect pests and weeds, improvement of soil fertility and higher economic benefits.

2. Coconut based farming system

Coconut is the major crop in Kerala. Due to availability of sufficient interspaces in coconut garden, a variety of crops are grown as intercrops. The intercrops are banana, tapioca and other tubers, clove, nutmug, pepper, ginger, turmeric, curryleaf, sapota, guava, annona, lovilovi, pineapple, roseapple, papaya, bilimbi, coffee, fodder, vegetables, betelvine, glyricidia and medicinal plants (John and Nair, 2001). The livestock is reared entirely on household waste. Crop selection is based on dietary and socioeconomic preferences of farmers. Tuber crops and fuit trees find a place in homegarden. Enterprises like floriculture, apiculture and mushroom culture also find a place in coconut gardens. Floriculture component include shade tolerant bush jasmine, orchid, anthurium etc.

With the integration of livestock component in coconut garden, it became a necessity to raise quality fodder crops. Scientific investigations showed that the grass-legume mixtures viz. guinea grass/ congosignal+stylosanthes was most suited for coconut gardens in Kerala (Lakshmi *et al.*, 1989). Inclusion of livestock component in homestead farming improves the quality of life by providing nutritious food (milk and meat) and ensuring the food security of farm family. In addition to this, there is nutrient recycling in the system by the addition of cattle manure or biogas slurry, thus improving the productivity of land. The biogas plant can readily meet the energy requirement of the farm family and slurry obtained after the biogas production is having a high content of available plant nutrients.

The by-products from coconut palms are sufficient to meet the fuel requirements of a farm family. It is estimated that a coconut tree produces 76-136 kg of by-products (dried petioles, fronds, stipules, spadix, husk, shell etc per year which can be used as a cooking fuel. About 35-40 coconut trees are enough to meet the fuel requirements of a small farm family (Meerabai *et al.*, 1991).

In coastal areas, where coir industry predominates, coir pith forms the waste which is a potential pollutant due to tannins oozing out of the dump yards especially during monsoon. In such areas, the coconut based farming can be more sustainable by composting the coir pith using *Pleurotus sp.* of fungi. Studies at CPCRI, Kasargod proved the advantage of using coir pith as bedding material in poultry farms. The toxicants in coir pith get reduced and it gets enriched with nutrients from poultry droppings by this practice. The enriched coir is a highly acceptable organic manure. 150 kg dried coir pith used as bedding material for deep litter poultry unit of 100 birds gives 225 kg of enriched coir pith in 55 days (Maheswarappa *et al.*, 2000). The higher microbial activity in enriched coir pith hastened the decomposition process leading to reduced lignin and cellulose contents and increased nutrient contents. Acidic pH of the medium was brought to neutral range. Increased microbial activity lowered the C:N, thus increasing plant nutrient availability. Thus efficient nutrient cycling can be achieved in coconut based farming system involving a poultry component. Technique to produce biogas from coir pith was developed by CPCRI, Kasargod (Mathew *et al.*, 2000)

Coconut based model for uplands of Kerala was developed by CPCRI, integrating grasses, dairy, poultry, rabbitry and fish culture with coconut. Pepper was trailed on palms and banana all along the border. Other components of the system were fodder grasses viz guinea and hybrid napier grown in interspaces of coconut, dairy unit, a biogas unit, broiler chicks, Russian Chinchilla rabbits, Japanese quails. Aquaculture unit consisted of rohu, mrigal and grass carp. Soil organic carbon and available N, P and K status were improved by organic recycling in coconut garden and soil pH was brought to near neutral levels (Maheswarappa *et al.*, 1998). Soil physio-chemical properties and nutrient uptake by coconut palms were improved by grass intercropping and organic manure recycling. Nut yield of coconut was also improved by integrated farming system

Coconut is a plant which responds well to irrigation and nutrient application. Around 11.2 mt crop waste is available from coconut excluding coir pith. The nutrient recycling is not praticable in many cases since all the crop residues are being taken away mainly for coir industry and for fuel purpose, thatching etc. hence green manure/FYM incorporation becomes a must for improving productivity of coconut gardens. A study conducted at Department of Agronomy, College of Horticulture, Kerala Agricultural University showed that the neglected waste land weed *Crotalaria striata* and popular cover crop ***Peurarea phaseoloides*** could produce enough biomass to satisfy the organic manure requirement of coconut (Table 6). They accumulated 159-202 g N, 15g P_2O_5 and 76-101g K_2O per basin and considerable quantities of secondary and micronutrients when grown in the basins of coconut (Tanie Thomas *et al.*, 2001).

Table 6. Biomass and nutrient accumulation of basin raised green manures in coconut

Green manures	Biomass (kg basin^{-1})		Primary nutrients (g basin^{-1})		
	Fresh weight	Dry weight	N	P	K
Sesbania aculeata	13.66	2.73	92.92	10.39	87.46
Sesbania speciosa	6.91	1.72	55.26	5.18	48.36
Crotalaria juncea	5.50	1.10	23.10	3.52	19.80
Crotalaria striata	15.08	3.77	158.47	15.09	75.46
Cassia tora	18.50	3.07	76.75	13.20	98.24
Pueraria phaseoloides	23.00	4.60	202.40	15.18	101.20
Calapagonium mucanoides	16.50	3.30	132.00	9.90	99.00
Mimosa invisa	18.25	3.65	135.05	10.22	76.65

(Tanie Thomas *et al.*, 2001)

Cocoa is an important intercrop of coconut in Kerala. The litter fall in cocoa is estimated to be 5.3 t ha^{1}, which can supply 66.9, 4.9, 59.7, 84.9, and 40.3 kg ha^{-1} of N, P_2O_5, K_2O, Ca and Mg year^{-1} (Mercy George *et al.*, 2001). They have also reported that 95 percent of the litter is getting decomposed within 4 months. The maximum litter fall is in the hot months which will add to soil fertility with the onset of monsoon by increasing the organic carbon content of the soil and the nutrient supplying capacity and reducing the level of fertilizer application and reducing soil and water erosion.

Drip irrigation practices in coconut has improved the productivity of the main and component crops. Drip irrigation increases the water use efficiency not only at field level but also at plant and leaf level (Kumar *et al.*, 2000). Based on irrigation levels a soil-plant water relationship in coconut has been worked out (Table 7)

Table 7. Soil-plant water relationship in coconut

Irrigation levels (IW/CPE)	Available soil water mm (0-120 cm depth)	Stomatal resistance	Leaf water potential (Mpa)	Nut yield nos.
1.00	51.0	3.07	-0.90	144
0.75	43.7	5.10	-1.20	125
0.50	14.2	7.60	-1.30	110
0.00	9.5	14.9	-1.45	87

Source: Rajagopal *et al.*, 2002

3. Rubber based farming system

The introduction of rubber completely altered the existing cropping systems in Kerala. Two distinct rubber based systems evolved viz. the small holdings with monocrop of rubber and larger homesteads with rubber as a component of the system. High intensity of vertical and horizontal space utilization in home gardens had stimulated a natural forest ecosystem, but when rubber was introduced into the system, it dominated over other species (Jose, 1992), which affected the species diversity, food security and made the system more prone to risks.

On the other hand rubber when introduced into larger homesteads as a component, fitted well into the system. In initial years of rubber crop establishment, intercrops like banana, pineapple, ginger and turmeric can be successfully raised and the diversified products obtained give economic stability to the farm family before the rubber starts yielding. Insufficiency of filtered light through the rubber canopy limits the scope of intercropping beyond the third year of growth of rubber (Joseph, 1999). The extent of litter recycling is higher in rubber plantations resulting in accumulation of considerable amounts of organic matter and nutrients in soil.

4. Tapioca based farming system

Tapioca is the most important tuber crop of Kerala and a number of varieties have been evolved by Central Tuber Crops research Institute (CTCRI) Sreekaryam and Kerala Agricultural University (KAU), Thrissur. It can be raised as an intercrop in coconut or can form as the main crop where intercrops like colocasia, amorphophallus, yams, banana, coleus, sweet potato etc are grown. Varieties having a duration of 6 months to 11 months make it a very diverse crop and can be fitted into many types of farming/cropping systems. The tubers are relished by man and animals and the stem is also fed to cattle. The starch can be utilized in a number of industries like beverages, cotton industry etc.

Since very short duration varieties (6 months) are available, it is becoming a very important crop in rice based cropping systems and is very suitable in rice fallows. The average yield varies from 20-30 t ha^{-1}. For majority of people in Kerala, it takes the status of a staple food crop. It is a crop which responds well to fertilizer and land management practices.

5. Homestead farming system

Kerala home gardens are considered as the most popular and successful integrated farming systems in the world. The Kerala homesteads are technically called as 'tropical homegarden agroforestry' (Jose, 1992). A homegarden/homestead is a functional/operative and self sustaining farm unit which consists of a collection/ assembly/conglomeration of crops and multipurpose trees, planted arbitrarily with or without animals/poultry/

apiculture, owned and primarily managed by the dwelling farm family with the objectives of satisfying the basic family needs (food, fuel and timber) and producing some marketable surplus for the purchase of non-producible items (John and Nair, 2001) Typical multistoried cropping system can be seen in these holdings with a cropping intensity greater than 200 in most cases. Wide spaced perennials like coconut and arecunut grown in Kerala have greater scope for multiple/multistoreyed/multispecies cropping and mixed farming systems which provides opportunity for better horizontal and vertical utilization of same resources of land, time and solar energy and gives increased production and income.

The selection of components for the home garden is based on the need, perception and centuries of experience of farmers. Crop components are selected so as to harvest the maximum solar radiation (based on their canopy characteristics). Differential distribution of canopies of component crops in homestead ranging from ground level to more than 25 m is shown in Table 8.

The presence of wide variety of crops, especially tubers like tapioca and fruit trees like mango and jack helped a lot to maintain the food security of small farm families. Pepper is the most abundant spice crop in Kerala. The abundance of tree species in homesteads is an asset as it serves the function of a standard for trailing pepper. Apart from functioning as pepper standard, they have other uses like medicinal, ornamental, green manure, live fence, masticatory, fruit/nut yielding, oil yielding, timber or soft wood yielding, cotton yielding, forage yielding etc. In addition to pepper, other species like turmeric, ginger, curry leaf, tamarind, nutmeg, clove and garcinia form integral part of Kerala home gardens (Shehana *et al.*, 1992)

Table 8. Canopy distribution of crop components in homegardens

Canopy Height	Components
>25m	Coconut, arecanut, jack, albizzia, teak, cocoa, rubber.
10-25m	Tamarind, mango, cashew, mahogany, gooseberry, ailanthus, nutmeg.
3-10m	Breadfruit, bilimbi, annona, pepper, neem, cinnamon, sapota, moringa, guava, moringa, papaya, clove.
1-3m	Banana, cassava, dioscorea, teak, amorphophallus, colocasia, curry leaf.
<1m	Pineapple, turmeric, arrowroot, vegetables, fodder.

Source: John, 1997

The successful breeds of poultry suited for the backyard system of rearing in small homesteads of Kerala are Gramalakshmi, Gramasree, White leghorn, Minorca etc. Giriraja type of poultry is an ideal dual purpose type for homesteads.

The balanced input-output channelisation in a well planned homestead makes it highly productive and viable as evidenced in fig 3, showing the material flow in homestead farming system.

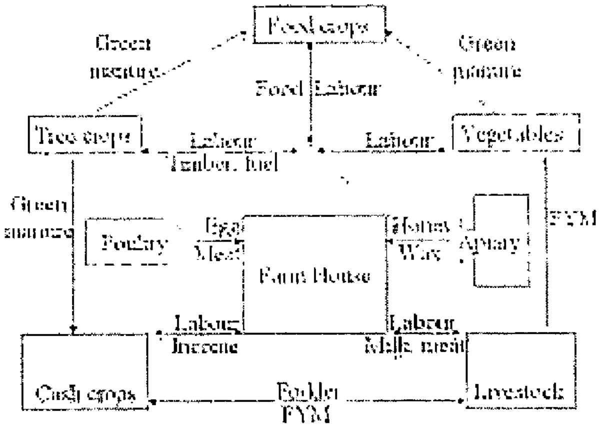

Fig. 3. Material flow in homestead farming system

6. Other cropping systems

Plantation crops and spices are cultivated in Kerala. Tea and coffee require cooler climate. Tea is grown in high altitude followed by coffee and pepper along hill slopes and cardamom in the valleys of mountainous terrain. Cashew is generally grown on the hills and hill slopes of coastal belt followed by arecanut and cocoa in the valley. Oil palm cultivation has been restricted to the command areas of major irrigation projects. Ginger and turmeric are also commercially important crops in the midlands along with nutmeg and other spices and medicinal plants. Arecanut finds a place in all religious, social and cultural functions. It is popular as a masticatory consumed wither raw or as a value added product like scented supari, pan masala, pan parag etc. Though arecanut has uses in ayurvedic and veterinary medicines, it has not been exploited due to lack of concentrated research efforts.

Conclusion

Nearly 95 percent of the farm holdings in Kerala are small or marginal and most of the farmers have no sustainable livelihood from their small holdings. A judicious mix of two or more interactive farm enterprises in the same unit of land alone can make these small farmsteads productive enough to support a family. Designing of suitable farming systems should be done on a location specific basis. Phasic research over an extensive period of time is needed for the identification of constraints and potentials of a region, selection of suitable components, attaining the technical know-how for the management of the system, formulation of a design where there is balanced distribution of components, implementation and monitoring of the performance of the system and finally extension of the results to the ultimate users viz. Farmers.

A paradigm shift from the crop centred agriculture concept of green revolution to a farming system centred approach is the need of the day as a primary step towards sustainability in future. This system can be regarded as 'ecotechnology based precision farming' and is the only practical way to meet the challenges of enhancing productivity while maintaining environmental soundness.

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