OPTIMAL CROPPING PATTERN FOR THE BETTER UTILIZATION OF MINOR IRRIGATION SCHEMES

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree

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2000

DECLARATION

I here by declare that this thesis entitled **"Optimal cropping pattern for better utilization of minor irrigation schemes"** is a bonafide record of research work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Tavanur

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CERTIFICATE

Certified that this thesis entitled "**Optimal cropping pattern for the better utilization of minor irrigation schemes**" is a record of research work done independently by Mrs. Bindu.J under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Bindu, J.

Dedicated to My Husband and Son

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SYMBOLS AND ABBREVIATIONS

Agrl.	- agricultural
AN	- after noon
ASCE	- American Society of Civil Engineers
^oC	- degree celsius
Ch.	- Chapter
Dev.	- development
Div.	- division
Drain.	- drainage
et al.	- and others
Engg.	- engineering
ET	- evapo transpiration
ET crop	- Crop evapo transpiration
FN	- fore noon
ha.	- hectare
hp.	- horse power
hrs.	- hours
hrs/day	- hours per day
ht.	- height
IBM	- International Business machines
ICID	- International Commission on Irrigation and Drainage
Int.	- International
Jl.	- journal

KCAET	- Kelappaji College of Agricultural Engineering and Technology
Km/day	- Kilometre per day
LP	- Linear Programming
m bar	- millibar
m^3/ha	- metre cube per hectare
m^3/sec	- metre cube per second
Max	- maximum
Min	- minimum
mm	- milli metre
mm/day	- milli metre per day
Mm^3	- million metre cube
No.	- number
Proc.	- proceedings
Rs/ha	- rupees per hectare
Sci.	- science
Sl. No.	- serial number
Soc.	- society
viz.	- namely
vol.	- volume
%	- percent
&	- and

Introduction

INTRODUCTION

Water is the prime natural resource, a basic human need and precious national asset. Adequate supply of water is one of the most important factors affecting the agricultural development. In modern agriculture, water plays a vital role. The optimum use of land and water resources is, for this reason, essential. Due to the increasing demand of water for agricultural, domestic and industrial purposes greater emphasis has to be laid on the planned and optimum utilization of available water resources. Agro-climatically Kerala state situated on the southwest corner of India, is a humid region. Still the state experiences severe shortage of water for domestic, irrigation and hydropower generation during the summer months and thus the need for an assured supply of water for the summer months is most crucial for the development of the state.

Irrigation is an attempt by man to alter the hydrological cycle locally in order to make water available to the farmer with respect to time, location and quality as per the crop requirements. The importance of irrigation in increasing food supplies is well recognised and consequently, huge investments, world wide, are directed towards expanding the irrigated area. Building new physical systems rather than improving the performance of existing ones seems to have been the main concern of planners, practitioners, and decision makers in the past. However, emphasis is now being placed on the need to improve the performance of the existing systems.

Agricultural systems are characterised by interdependency and complexity of their components and by variability and risk involved in their management. Farmers today are facing both economic and environmental pressures. Farmers face fluctuating incomes from year to year primarily because of varying weather conditions, disease and pests and changes in prices and markets. The farmer, who irrigates continually obliged to change his production system (crop rotations and technical scheduling). The water utilized has to be considered not only as limited resource, but also as a factor in production and an important economic input, the unwise use of which can cause environmental problems.

In irrigated areas improvement of water management on farms is the first step towards the conservation of this diminishing natural resources and it is therefore important to find production systems that are able to exploit the full potential of irrigation. Even though this goal is well defined, it is difficult to outline a plan of action to achieve such a goal. Two situations are frequently found (1) when water availability is sufficient to guarantee irrigation of any crop, with only a very small risk of inadequate supply, and (2) when farms do not have enough water available to guarantee an adequate supply for all the crops throughout the entire cycle. In the first case, the selection of production systems (crop rotations) can be made by comparing gross profits for different crops to determine which of these will give the best economic results, taking into consideration other environmental conditions and the given limits of each farm. In the second case, defined as irrigation deficient, the problem is more complex. When water volume is limited two situations are feasible: (1) reducing the potential surface to be irrigated, giving more emphasis to crops with higher gross profit but needing more water, followed by allotting the rest of the irrigable land to dry lands or (2) increasing the irrigated area by introducing species which need little water in the crop rotation, and /or adopting eventually restrictive irrigation programmes.

The basic information needed to solve problems of optimum water management on farms consists in precise knowledge of the water consumption of each crop and its response to irrigation. In other words, we must know the production function in relation to water. The impact that the unequal distribution of water may have on production must be considered when determining optimum irrigation strategies and also when selecting a crop rotation that gives maximum economic benefits.

Several factors have to be considered in irrigation management, particularly for a mixed cropping. One of the key decisions to be made is, how water should be allocated to different cropped areas. The decision should be based on the availability of land and water resources, reliability of water supply and benefit from crop production. There are two possible strategies for the application of water to the crops. The first is to apply irrigation water at a level which gives maximum net income. This approach may be used when there is no constraint on irrigation supplies. However, when a constraint exists, it is useful to provide alternative levels of irrigation water and thus cover a larger area, which may result in higher returns. In spite of an acute water shortage, farmers may, in actual practice, irrigate more than required even for maximum production. This calls for optimum allocation and distribution of water along with scientific planning of cropping patterns.

In Kerala, an approximate area of 0.3 million hectares has been brought under irrigation and it is estimated that the area that can be ultimately brought under irrigation in the state is 1.6 million hectares. At present about 0.2 million hectares area is irrigated by major and medium irrigation schemes and the rest by minor irrigation schemes. Under minor irrigation schemes lift irrigation is mainly practiced in the state. In this scheme water is pumped from the rivers and tanks and then utilized for various purposes. Government owned and operated lift irrigation schemes in Kerala are confined to river basins. Depending on the water availability of the river, the command area in relation to the cropping pattern is determined. The feasibility of a lift irrigation scheme is usually fixed on the basis of the benefit-cost ratio. It is the ratio of annual cost of providing these additional benefits. The additional benefit is the difference between the value of agricultural produce after irrigation and that before irrigation. The annual cost is the cost of running a scheme, comprising fixed and operating costs. To estimate the value of agricultural produce before irrigation, it is necessary to know the existing cropping pattern. The value of the agricultural produce after irrigation can be determined from the cropping pattern adopted for the scheme and the net values of the produce, which may be anticipated.

Many of these schemes are unable to cater to the proposed command area under each due to unscientific crop and water management practices. Therefore, the present need of these irrigation schemes is the scientific approach in the crop and water resources planning to achieve the optimum use and conservation of available water resource.

The purpose of this study is to design a Linear Programming model for finding an optimum cropping pattern to ensure proper utilisation of the available land and water resources in an existing lift irrigation project.

The specific objectives of the study are:

1. To maximise the total profit from irrigation scheme.
2. To maximise the irrigated area using the available water resources of the scheme.

Review of Literature

REVIEW OF LITERATURE

Cropping activities go on all the year-round in India, provided water is available for crops. There are various ways of utilizing the land intensively. It is proposed to give a synoptic view of cropping patterns prevalent in the country. In any locality, the prevalent cropping systems are the cumulative results of past and present decisions by individuals, communities or governments and their agencies. These decisions are usually based on experience, tradition, expected profit, personal preferences and resources, social and political pressures and so on.

2.1. Cropping pattern

Optimal crop planning procedure means the selection of crop varieties from a number of feasible alternatives so as to satisfy the objectives of the planner under the limiting condition of available land and water resources, social requirements and other physical and technological constraints in the planning environment.

Following are some of important literature reviewed in the optimal cropping pattern studies.

Dudley *et al.* (1972) revealed a model to solve the long-run problem of determining the best area size for irrigation in case of regulated stream flow. The releases from the given reservoir of fixed capacity, the area to be planted and irrigation timing have been assumed to be controlled by a single decision-maker. The demand and supply of water have been considered as stochastic. The analysis indicates that the results are sensitive to the variation in the fixed costs of the alternatives in the system.

Anderson and Maass (1973) have developed a digital model to approximate the critical operating decision variables of an irrigation system for both short and long run problems. In the short run the model yields solution for the best way of water allocation for irrigation under water shortage conditions. The advantage of this model is its simple format of decision output which enables farmers and operators of irrigation systems to make decision on their own regarding the effects on cropping patterns, crop production and farm income of different water supply restrictions and different rules for delivering water. In case of long run problem, the model aids in comparing alternative programs or designs for the development of new supplies of irrigation water and new distribution systems.

Dudely and Burt (1973) have developed an integrated interseasonal stochastic dynamic programming model. The solutions from the model indicate the influence of developed irrigation area, distribution system capacity and reservoir capacity in optimizing design. A method has also been presented by them for incorporating the variance and expected value of net benefits in to the decision criteria for optimal developed crop area.

Sowell *et al.* (1976) have conducted studies on agricultural water demands in North Carolina. The objectives of their studies was to determine the following

i. total water requirement for a given level of agricultural activity in an area.

ii. the optimum level of agricultural activity for a given level of water available in a specified area.

iii. economically feasible irrigation water requirements for each crop grown in the area.

2.2. Linear Programming

Agricultural enterprises are faced with three major challenges, to reduce production cost, maintain the environment and adapt to present and future market.

The Linear Programming is an optimization technique. It is used to optimize (maximise or minimise) a linear function, called the objective function, of several variables subjected to a certain number of restrictions or constraints expressed by linear equalities or inequalities.

Blank (1975) has described a linear programming model for determining the mix of crops so as to take advantage of the limited resources to produce the maximum economic return. The total number of crop activity levels accounted in the model has been expressed as

No. of crop activities = No. of crops × No. of methods of growing for each crop

Water activity levels of the model considers time periods in the irrigation season.

Lakshminarayana and Rajagopalan(1977) have investigated the problem of optimal cropping pattern regarding conjunctive use and water release from canals and tubewells in the Bari Doab basin in India, using a linear programming model. The objective of the study was to determine the extent of allocation of irrigated area to alternative crops sources namely, canals and tubewells necessary for seasonal crop water requirements during one year period of operation such that the benefits from the system would be maximised. Their results showed that an increase in the available area for irrigation would give rise to increased benefits from irrigation activity.

Maji(1977) has established linear programming models in optimal allocation of land , water and other farm resources in the command area of the Mayurakshi project in West Bengal, India. The objective of the study was to envolve an optimal cropping pattern. For this purpose, the monthly gross irrigation requirement of each crop have been integrated with the monthly reservoir operations. The results indicate that the overall intensity of cropping in the command area can be increased from the existing level of 105 per cent to 155 per cent.

Efforts have been made by Saksena and Satish Chandra(1978) to study the then existing and the future water balance in the command area of upper Ganga canal (Uttar pradesh , India) to plan the conjunctive use and to obtain an optimal cropping pattern using linear programming model. The objective of the problem was to maximise the annual aggregate benefits, considering the net benefits accrued from crops as well as the annual operating and maintenance costs of canals and tube wells system. Constraints considered include the limitations of

i. total land in kharif and rabi seasons
ii. total crop water requirements
iii. total release from surface storage and tubewells and
iv. the maximum and minimum area of each crop

They have considered ten crops and four decisions and solved the problem using IBM 360 computer. Their results indicate that the intensity of irrigation in the command area would increase from 98 per cent to 115 per cent.

Matanga and Marino (1979) have studied the irrigation programs generated for each of the selected three crops to be planted, using an area – allocation model to determine an optimal cropping pattern. The area-allocation model is a linear optimization model to maximize gross margine from yields of crops. The objective function has been formulated taking in to account the economic return from the cropped land, costs of production, water, and labour, which is subject the total water supply, maximum amount of water that can be delivered on any date of irrigation, yield limitation, and labour. The results obtained by them include the cropping pattern, gross margine, total irrigation depth on each date of irrigation, total irrigation labour, and crop yield sensitivity analysis has been performed to study the effect of changes in crop prices on the optimal results. Twenty seven combinations of crop prices between the three crops have been tested the model has been modified for drought conditions.

The development of the concept of optimal irrigation depth to select for a non-uniform irrigation system was presented by Peri *et al.* (1979). The authors showed from the cumulative distribution curve that whatever depth of irrigation was selected as the 'applied depth', some portion of the area received excess irrigation and the remainder was deficient.

It has already been stated that in the case of deficit irrigation the problem of planning the management of available water resources must be resolved by estimating the irrigation requirements of the various crop-soil units and by considering an appropriate crop pattern for the farm. Each alternative has differing capital costs, water, energy and labour requirements.

Kumar and Singh (1980) have studied the effect of interaction of irrigation and labour on optimal cropping pattern. A multi-crop optimization model has been formulated and applied for the canal command area of Sinsa branch of Western Jammuna Canal System in India, the optimal cropping plans have been determined with and without considering the labour constraints.

Venkatesan and Ramalingam (1980) have applied linear programming to plan the area under irrigation in the command of Bhadra-irrigation project, Gujarath, India, with the objective of optimising the benefits from irrigated crops.

Duggal and Khepar (1981) developed a linear programming model and it has been applied to a canal command region of Punjab in India to examine the capacity and operation of an irrigation system consisting of canals and tube wells. The objective of the model is to determine optimal cropping pattern,

i. the water availability constraint regarding surface water, ground water and total water

ii. the specification of the total land constraints, maximum and minimum crop land restrictions of certain crops grown specifically in the area, maintaining the rigid institutional frame work.

A deterministic model for a four-reservoir system on a monthly basis, using Linear Programming technique was developed by Vedula and Rogers (1981). This model has been applied to the Cauvery river basin in South India with the aim of finding optimum cropping patterns, subject to land water and downstream release constraints. In this model, while considering the two objectives, namely maximising net economic benefits and maximising irrigated crop area, they have analysed the resulting trade-offs in the context of multi-objective planning.

Kumar *et al.* (1982) have developed an optimal cropping pattern for Gandak command area of Utter pradesh in India using linear programming. The benefits to cultivars have been maximised in this study. Optimal cropping pattern (with adequate quantity of water) have been worked out for four different conditions for different limits of crop lands.

Khepar and Chadurvedi (1982) applied a linear programming formulation to make decisions on optimal cropping pattern and ground water management alternatives in a canal irrigated area. Various ground water management alternatives in conjunction with optimum cropping pattern and based on water production functions were compared. The model developed also ensured optimum utilization of surface water and poor quality groundwater and proper soil conditions for plant growth. But, the model did not consider the variability or reliability of water resources.

Mohile and Jagannathan (1983) have developed a linear programming model which determines allocation of land to irrigated as well as non-irrigated crops. The yields and benefits resulting from irrigated as well as non-irrigated crops have been considered in this model. The model also decides the reservoir releases, surface diversions, pumpings, and energy distribution. The benefits from different engineering designs effected by varying either the system parameters such as capacities of reservoirs, canals and pumping capacities or the system constraints like require flows and future conditions with and without the project have been investigated in the study.

Letey *et al.* (1984) presented a general method of evaluating the effects of non-uniform infiltration rates on optimal levels of water application. The results are critically influenced by the nature of the water yield relations postulated for the crops. For corn, where excessive water applications apparently have no effect on yield, non-uniform conditions reduce yield and profit. For cotton, non-uniformity leads to decrease in yields and profit that cannot be equalised by increased water applications. This is attribute to the apparent sensitivity of cotton yields to excessive applications of water. The results demonstrate that conventional economic analyses ignoring infiltration uniformities, under estimate optimal levels of applied water, often substantially.

Panda and Khepar (1985) also adopted linear programming techniques to maximise the net return from optimal irrigation planning. Both deterministic linear programming and chance-constrained linear programming were used.

Rao *et al.* (1988) conducted a study of irrigation scheduling under limited water supply. The problem of scheduling irrigation at weekly intervals for a single crop when water supply is limited is considered. The mathematical formulation is based on a dated water- production function, weekly soil-water balance, and a heuristic assumption that water stress in the early weeks of a crop growth stage leads to suboptimal yields. The allocation problem is solved at two levels, growth stages, and weeks. At the first level, the dated water production function is maximised by dynamic programming to obtain optimal allocations for growth stages. At the second, the water allocated to each growth stage is reallocated to satisfy weekly water deficits within the stage. Water delivery and soil-water storage constraints are included at both levels. The model is applied to a field problem to derive weekly irrigation programmes for cotton under various levels of seasonal water supply and initial soil moisture.

Ahmad and Heermann (1990) developed a model to simulate the irrigation scheduling of a water course command. The model was to predict cropping intensity, net farm returns, farm water use, percent water utilised, deep percolation at farm level, rainfall contribution, and extra tubewell-water pumped. Schedules for these selected farms on a water course command in Sargodha, Pakistan were simulated with three fixed-rotation strategies and compared to a demand strategy. The change of the fixed–rotation system to demand system will significantly increase the net farm return in addition to improved water allocation to various farms on a watercourse demand. The demand strategy will provide saving in energy due to scheduled pumping operations and effective utilization of canal water supplies.

Paudyal and Das (1990) solved the complex problem of irrigation management in a large heterogeneous basin by using a multilevel optimization technique. The real problem consisted of determining the optimal cropping patterns in various subareas of the basin, the optimal design capacities of irrigation facilities, including surface and ground water resources, and the optimal water allocation policies for conjunctive use. However, the effects of streamflow or resources uncertainty with the year-to-year variability of crop water requirements were not considered in the model.

A multi-objective linear programming based planning model for irrigation development, incorporating the integrated use of surface and ground water resources was developed by Onta *et al.* (1991). Evaluation of the objectives by Compromise Programming was carried out to indicate the optimal scale of development, cropping plans system design capacities and water allocation planning. These related studies need to be extended to incorporate the reliability of the resource to consider the uncertainty in the natural phenomena.

Matsukawa *et al.* (1992) presented a conjunctive-use model, that can be used to develop planning and operational strategies for a river basin. In contrast to previous investigations, the conjunctive use model explicitly incorporated.

(1) The hydraulics of the surface and ground water system;

(2) Water supply, hydropower, and ground water cost and benefit objectives.

The model was applied to the Mad River basin in Northern California. Optimal planning policies were developed for the water resource system. The optimisation model was solved using a large scale non-linear programming algorithm. The results indicated that conjunctive-use management is available tool for multi-objective water resources planning problems.

Mohan and Raipure(1992) developed a linear multi-objective programming model, the constraint technique was used to derive the optimal releases for various purposes from a large-scale multi reservoir system consisting of five reservoirs in India. Maximisation of irrigation releases and maximisation of hydro power production have been considered as the twin objectives in the model subjected to constraints on physical limitations, environmental restrictions, and storage continuity. The trade-of analysis between the conflicting objectives of irrigation and hydropower was also carried out and the transformation curve was plotted. The optimal point on this curve gives the best combination of the twin objectives considered in the model.

Onta *et al.* (1992) presented a three step modeling approach for comprehensive analysis of the planning problem involving integrated use of surface and ground water in irrigation. Applicability of the approach is illustrated by a case study of the Bagmati River basin, Nepal. In the first step, a stochastic dynamic programming model, which considers most of the interacting processes of the conjunctive use system, is used to derive the long term operation policy guidelines for alternative plans. Then, a lumped simulation model is used to evaluate the alternative plans and policies, considering a number of mutually related synthetic sequences of stream flow and rainfall. Various economic (cost and benefit) as well as risk related (reliability, vulnerability and resiliency) performance measures and their trade-offs are evaluated. Finally a multiple- criteria decision making method (compromise programming) is used to select the most satisfactory alternative plan for indicating the system design (pumping and diversion canal) capacities and water allocation policies.

Paul and Raman (1992) developed a linear programming model for obtaining an optimal cropping pattern from among the various alternatives for any command area by the conjunctive use of surface water and ground water, for getting maximum net returns from the command area as well as for maximising the area of cultivation.

Balasubramaniam *et al.* (1996) established LP analysis in a tank irrigation system for near real representation and optimal allocation of area of Aralikottai tank system in Tamilnadu State of India. The actual conditions are simulated at each sluice command level whereas the best operational policy is attempted for the entire system as a whole. The analysis is conducted separately for a drought year (1988) and a surplus year (1990) with the available five year data from 1988 to 1992. The major conclusions indicate that the late transplantations of the rice crop and the excess water application during the periods of water availability (leading to water stress during the last stages of crop maturity) are the causes of the meagre benefits in a drought year. Also, in a surplus year the excess water application over the entire cropping season resulted in under utilization of land resources and moderate benefits. The existing status of irrigation can be improved to obtain the maximum benefits from the tank command area based on the quantification done.

Juan *et al.* (1996) developed a model to determine optimal irrigation strategies for a single season. This has been achieved by using a simple relation between yield and amount of irrigation water which takes in to account the effect of uniformity of water application. The main objective of the model is to provide a procedure by which farms can evaluate and compare alternative assumptions on expected water regimes for the following year in order to optimise crop rotations, crop production and farm incomes and to attain the optimum use of irrigation works, farmland and other resources. The method require data that are readily available to the farmer.

Mainuddin *et al.* (1997) formulated a monthly irrigation planning model for determining the optimal cropping pattern and the ground water abstraction requirement in an existing ground water development project. Two objectives, maximisation of net economic benefit and maximisation of irrigated area aspired to by both the irrigation authority and the individual farmers in the Sukhothai Groundwater Development Project in Thailand are considered. To account the uncertainty in water resources availability the model is solved for three levels of reliability of rainfall and ground water resources (80, 50 and 20 per cent). The effects of deficit irrigation on the net benefit and cropping intensity as well as on the yield of crops are also assessed by considering three levels (no deficit, 25 per cent deficit and 50 per cent deficit) of water application to the crops. To select the best alternative plan, a multi-objective analysis is carried out using the Analysis Hierachy process considering the preference of the decision makers, including farmers and irrigation project managers.

Sunantara *et al.* (1997) studied optimal seasonal multicrop irrigation water allocation and optimal stochastic intra-seasonal (daily) irrigation scheduling. They using a two-stage decomposition approach based on a stochastic dynamic programming methodology. In the first stage the optimal seasonal water and acreage allocation among several crops or fields is defined using deterministic dynamic programming with the objective of maximizing total benefits from all crops. The optimization is based on seasonal crop production functions. Seasonal crop production functions are obtained using single-crop stochastic dynamic programming, which incorporates the physics of soil moisture depletion and the stochastic properties of precipitation. In the second stage, optimal intra-seasonal irrigation scheduli performed using a single-crop stochastic dynamic programming algorithm, conditional on the optimal seasonal water allocation of stage one. Optimal daily irrigation decision functions are obtained as a function of root-zone soil moisture content and the currently available irrigation water. The methodology is applied to a case study characterized by four crops in which both the optimal irrigation applications and the optimal acreage for each crop are determined.

2.3. Crop water requirements

The original Penman (1948) equation predicted the loss of water by evaporation from an open surface is Eo. Experimentally determined crop coefficients ranging from 0.6 in winter months to 0.8 in summer months were suggested to relate Eo to evaporation for the climate in England. The Penman equation consists of two terms, namely the energy (radiation) term and the aerodynamic (wind &humidity) term. The relative importance of these two terms varies with the climatic conditions. An adoption of the Penman equation the direct prediction of ET crop by the use of appropriate reflection coefficient for incoming solar radiations, the effect of plant resistance to transpiration and by inclusion of appropriate wind function is taken into account the change in aerodynamic roughness with growth of crop.

This approach has not been used now and a slightly modified method is suggested the effect of climate on crop water requirements. The only variation to the original Penman method (1948) proposed that this involves a revised wind function term and an additional correction factor for day and night time weather conditions not representative of climates for which the wind function was determined.

Palaskar *et al.* (1985) in Maharashtra compared the pan evaporation and Modified Penman methods for the estimation of crop water requirements. For all the parameters in an average, the ratio of an estimate by pan evaporation methods to the estimate by Modified Penman method was 0.9.

Materials and Methods

MATERIALS AND METHODS

The detailed description of the model used and the methodology adopted for the evaluation of the model are presented in this chapter.

The model provides a procedure by which the planner and the designer can evaluate and compare alternative assumption on expected water regimes in the next year with the goal to optimize crop patterns, crop production and farm incomes and the optimal use of the available water resources and other resources. This model is intended to be used as a planning tool in the development, evaluation and selection of the best alternative on- farm irrigation system plan.

In this model, the use of linear programming technique is demonstrated for obtaining an optimal cropping pattern as well as the maximum net area sown by the conjunctive use of available surface water for an ayacut area of about 588 ha.

3.1. Location

For the present study, one of the lift irrigation schemes of Bharathapuzha river basin at Tavanur in Malappuram district, Kerala was taken. The total command area is about 588 ha . It is situated at $10^0 52'30''$ North latitude and $76\ ^0$ East longitude. Figure.1 shows the command area of the lift irrigation scheme.

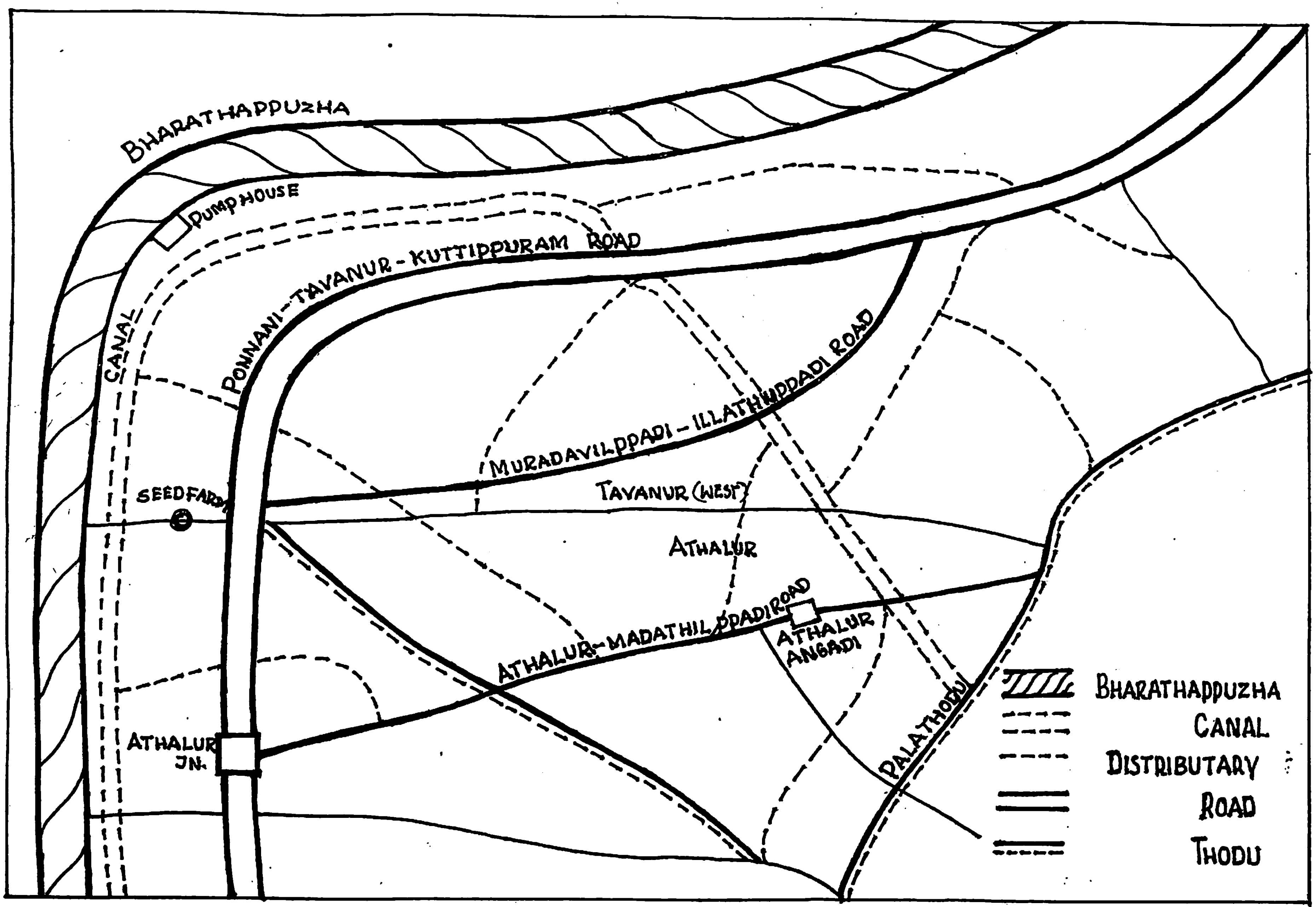

Figure 1. Command area of the lift irrigation scheme

3.2. Climate

Agro-climatically, the area falls within the border line of Northern zone, Central zone and Kole zone of Kerala. Climatologically, the area is in the rainfall zone with a rainfall of 2500 to 2900mm. The area receives rainfall mainly from the South-West monsoon and to a certain extent from the North- East monsoon.

The basic information regarding the water resource available, command area, existing cropping pattern, the various alternatives and bounds were collected from different agencies of the region.

Assumptions made in formulating the problem are,

i. Only principal crops such as three rice crops, banana (Nendran), garden crops like coconut, arecanut and mixed cropping, summer crops like vegetables, pulses, sesamum, ground nut, green manure are considered.

ii. All inputs other than water, viz. seeds, fertilizers, weedicides and pesticides of desired quality are available in adequate quantities.

iii. Virippu and Mundakan paddy cultivation is essential.

iv. Gross irrigation efficiency is taken as 57 per cent.

3.3. Crop water requirements

Crop water requirement of various crops is the water loss through evapotranspiration from these crops. The effect of climate on crop water requirement is given by the reference crop evapotranspiration (ETo). This has been worked out using Modified Penman's formula, which includes a revised wind function.

Climatological datas for 25 years (1974to1998) were collected from the nearest meteorological station at Pattambi. (Appendix.I)

The equation is

ET_O	=	$c[W. R_n + (1-W). f(u). (ea-ed)]$
where : ETo	--	reference crop evapotranspiration in mm/day
(ea –ed)	--	difference between the saturation vapour pressure at mean air temperature and the mean actual vapour pressure of the air, both in mbar
ed	=	(ea.Rh Mean)/100
Rh	--	relative humidity in per cent.
Rn	=	Rns – Rnl
Rns	=	$(1-\alpha)Rs$
Rs	=	(0.25 + 0.50 n/N)Ra
Rnl	=	f(T). f(ed).f(n/N)
Rs	--	solar radiation in mm/day
α	=	0.25(Rs must be corrected for the reflectiveness of the Crop surface)
Ra	--	extra –terrestrial radiation in mm/day
n/N	--	ratio of actual to maximum possible sunshine hours
Rns	--	net short wave radiation in mm/day
Rnl	--	net long wave radiation in mm/day
f(T)	--	effect of temperature on Rnl
f(ed)	--	effect of vapour pressure on Rnl

Table 1. ETo for different months (mm/day)

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo	5.99	6.49	6.70	6.67	5.93	3.67	3.47	4.02	4.64	4.50	4.60	5.37

Table 2. Water requirements of crops for different months (m^3/ha)

	Crops	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
X1	Coconut	1391.90	1362.20	1558.45	1500.98	1378.73	825.08	806.54	934.00	1044.90	1046.25	1034.30	1247.60
X2	Coconut mixedcrops	2041.23	1997.69	2885.70	2201.43	2022.13	1210.11	1182.93	1369.80	1532.52	1534.50	1517.01	1829.81
X3	Arecanut with pepper	2226.80	2179.30	2493.50	2401.56	2205.96	1320.12	1290.50	1494.32	1671.80	1674.00	1654.90	1996.20
X4	Banana	1670.09	1725.30	2077.93	2001.30	1838.30	1100.10	1075.40	1245.27		976.50	965.40	1247.60
X5	Paddy (Virippu)					1193.50	3489.58	3041.72	3341.18	660.72			
X6	Paddy (Mundakan)									2261.02	3704.50	35616.60	4816.50
X7	Paddy (Puncha)	87.80	5818.55	9147.17	8660.70	948.80							
X8	Pulses & Vegetables	598.60	1834.24	2223.40	880.57								
X9	Groundnut	1150.41	1671.60	2077.93	1000.60								
X10	Sesamum	989.48	1489.32	1890.00	802.23								
X11	Green manure	104.75	1107.80	603.27									

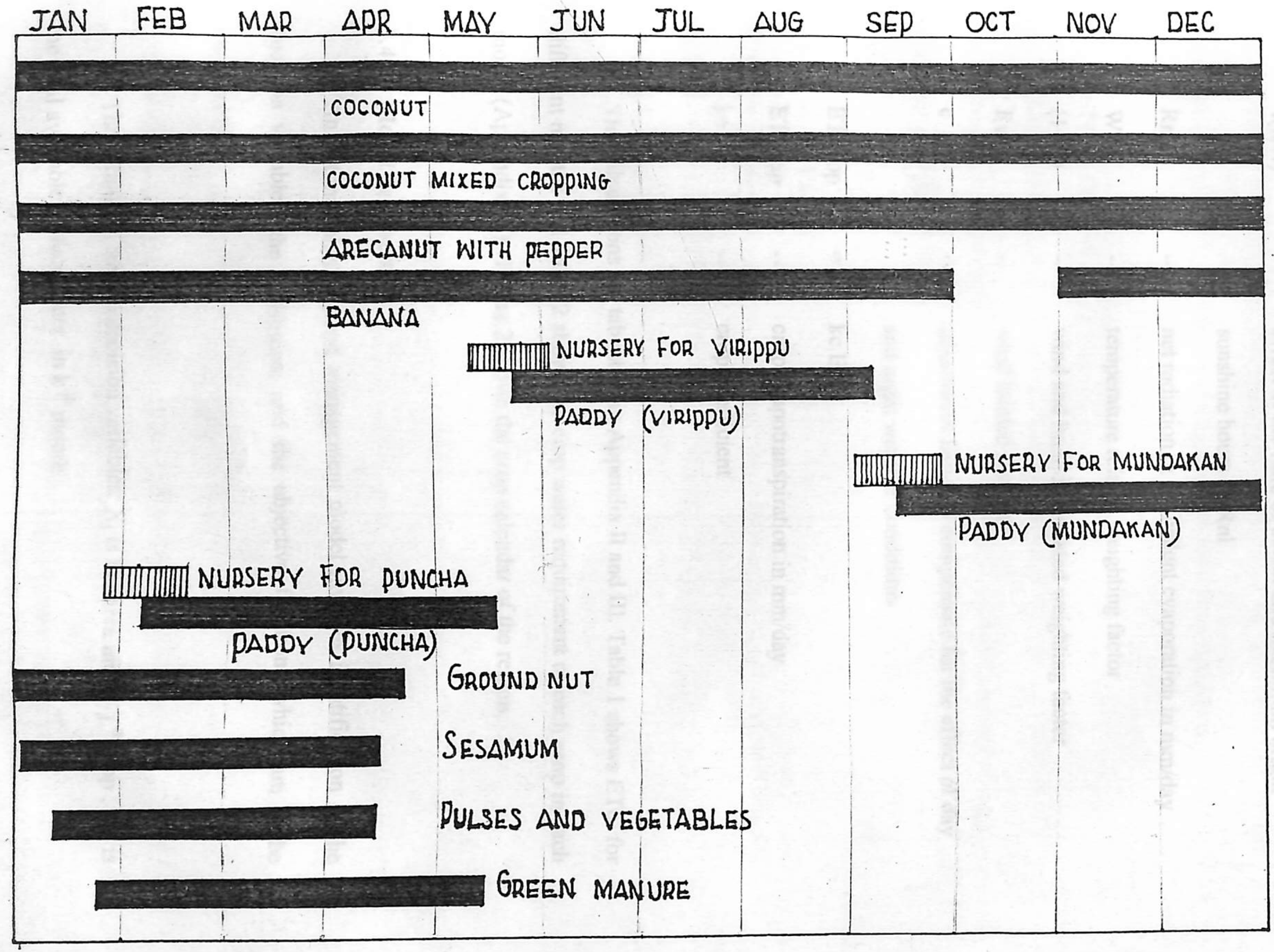

Figure 2. Crop calendar of region

f(n/N)	--	effect of the ratio of actual and maximum bright sunshine hours on Rnl
Rn	--	net radiation in equivalent evaporation in mm/day
W	--	temperature related weighting factor
(1-W)	--	wind and humidity related weighting factor
f(u)	--	wind related function
c	--	adjustment factor to compensate for the effect of day and night weather conditions
ET crop	=	kc.ETo
ET crop	--	crop evapotranspiration in mm/day
kc	--	crop coefficient

The calculations are tabulated in Appendix II and III. Table 1 shows ETo for different months and Table 2 shows the crop water requirement of each crop in each month (Appendix IV). Figure.2 shows the crop calendar of the region.

3.4. Model development

An optimal planning and management model involves identification of the decision variables, the constraints and the objective functions which are to be maximised.

The following are the decision variables: X_j is the area under j^{th} crop ; Qk is the total available surface water in k^{th} month.

The goal of the lift irrigation project is to obtain maximum economic and social benefit. Therefore, in this study two objectives, i.e. maximization of net economic benefit and maximization of irrigated area have been considered.

3.4.1. SITUATION-A

The optimization of cropping pattern is done using the existing facilities of the lift irrigation scheme with two pumps of capacities 90 hp and 40 hp delivering a total discharge of 0.71 m^3/sec.

3.4.1.1. Part I

In this part, the problem deals with the maximization of net economic benefit from the command area.

Mathematically this can be written as:

$$Max Z = \sum_{j=1}^{n} PjXj$$

where

- Z, net benefit from the command area to be maximised
- n, number of crop considered
- X_j, area under the j th crop
- P_j, net profit for the j th crop

The optimization of the net benefit is subject to the following constraints:

(i) The total water available for irrigation in k th month as shown in Table 3;

(ii) The total area available for cultivation in any particular month is 588 ha.

Table 3. Water requirement for each month and water availability(Mm^3)

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Water requirement (irrigation Efficiency 57%)	0.53	3.31	4.92	4.35	1.19	1.68	1.49	1.64	1.38	1.79	1.73	2.32
Available surface water (QK_1)	0.46	1.30	2.00	1.80	0.60	1.68	1.49	1.64	1.38	1.79	1.74	1.80
Available surface water (QK_2)	0.60	1.70	2.60	2.35	0.78	1.68	1.49	1.64	1.38	1.79	2.27	2.35
Water requirement (irrigation Efficiency 70%)	0.57	3.59	5.33	4.70	1.29	1.82	1.62	1.78	1.50	1.94	1.87	2.50
Available surface water (QK_3)	0.47	3.10	4.20	4.10	1.01	1.82	1.62	1.78	1.50	1.94	1.80	2.00

These constraints can be expressed as:

$$\sum_{j=1}^{n} XjQcj \leq Qk$$

$$\sum_{j=1}^{n} Xj \leq A$$

where

Qc_j, quantity of water required for irrigating j th crop in k th month

A, total area available for cultivation and

n, number crop in the area in a particular month.

In addition some other constraints are also considered, they are:

(i) Lower and upper bounds are given for any particular crop as desired by the decision makers; .

(ii) Bounds are also fixed for the total area for garden crops;

(iii) Lower and upper bounds are given for the total area under cultivation in each month.

Analysis by linear programming

The analysis was conducted using a software package called MSTAT –C, version-1, on an IBM compatible computer, which is a statistical and data management program. The package consists of an executable program that aids in experimental design, and managing, transforming and analysing data. The data was analysed using the Linear Programming model in the MSTAT package.

In order to make the best use of all the available water resources and to get the maximum benefit, different trials have been done with different crop combinations and constraints. Ten cases are studied as follows:

Case I

Crop grown: 1 to 8

Area constraints:

Coconut,	$X1 \geq 32$	1
Coconut mixed crops,	$X2 \geq 8$	2
Arecanut with pepper,	$X3 \geq 8$	3
Banana	$X4 \geq 8$	4
	$X4 \leq 40$	5
Paddy(Virippu)	$X5 \geq 141$	6
	$X5 \leq 382$	7
Paddy(Mundakan)	$X6 \geq 141$	8
	$X6 \leq 382$	9
Paddy (Puncha)	$X7 \geq 85$	10
	$X7 \leq 382$	11
Vegetables & pulses	$X8 \geq 8$	 12
	$X8 \leq 60$	13

Case II

Same as case I but no bounds were fixed for crop 1 and 2.

Case III

In case III crop 7,i.e.summer crop was substituted with crop 9,i.e.ground nut while all the other constraints mentioned above remain same.

Case IV

Same as case III but no bounds were fixed for crop 1 and 2

Case V

Crop 7 in case I was substituted with crop 10,i.e.sesamum.Constaints are same as case I

Case VI

Same as case V but no bounds fixed for crop1 and 2.

Case VII

Crop 7 in case I was substituted with crop 9,10 and 11 with the additional constraints as follows:

Groundnut	$X9 \geq 40$	 14
Sesamum	$X10 \geq 81$	 15
Green manure	$X11 \geq 24$	 16
	$X8 \geq 40$	 17

Case VIII

Same as case VII but no area constraints for crop 1and 2

Case IX

Crop 9, 10 and 11 were added to the crops in case I with the additional constraints mentioned in case VII.

Case X

Same as case IX but no bounds fixed for crop 1 and 2.

3.4.1.2. Part II

The second part, the problem was to maximise the net area in an year. In this profit variation is not considered. The objective function can be expressed as:

$$MaxA = \sum_{j=1}^{n} Xj$$

Where A, total area used for cultivation in an year.

The constraints were same as in the case of part I . All the ten cases were studied.

3.4.2. SITUATION-B

Installation of an additional pump of capacity 40 hp and discharge 0.22 m^3/sec.

The existing pumps in the lift irrigation scheme were of the capacity 90 hp and 40 hp respectively. Installing one more pump of 40 hp can increase the total discharge to 0.93 m^3/sec. Thereby total available water (Qk_2) per month is changed. With the same constraints the model was operated for achieving the objectives.

3.4.3. SITUATION-C

Improving canal

By improving the canal and structures for minimizing the conveyance losses and there by the irrigation efficiency can be increased to 70 per cent approximately. Now the total available water (QK_3) per month is increased to as shown in Table 3.

The model was run for the above ten cases with the same constraints to get the improved results.

Total quantity of water (Qk_1, Qk_2 and Qk_3) and profit from each crop collected from the farmers are shown in Table.3 and Table .4 respectively.

Table 4. Average profit from each crop in Rs/ha

	Crops	Profit Rs/ha
X1	Coconut	60050.00
X2	Coconut mixed crops	64050.00
X3	Arecanut with pepper	1043850.00
X4	Banana	125000.00
X5	Paddy (Virippu)	6600.00
X6	Paddy (Mundakan)	1100.00
X7	Paddy (Puncha)	4100.00
X8	Pulses & Vegetables	16553.00
X9	Groundnut	2570.00
X10	Sesamum	8875.00
X11	Green manure	1840.00

Results and Discussion

RESULTS AND DISCUSSIONS

In this chapter, the results obtained from the model are analysed and presented. The Linear Programming technique has been applied to get an optimal cropping pattern. The efficient utilization and management of lift irrigation water are achieved here through the selection of optimal cropping pattern. The study was aimed to obtain two objectives, viz.

1. To get the maximum annual net benefit from the command area.
2. To get the maximum area of cultivation per year with the available water.

The Linear Programming model of MSTAT-C package was used to solve the optimization problem. The constraints considered in the model were land area, lift irrigation and crop water requirement.

Three types of total surface water situations were studied as explained in Chapter. III. Each consists of two parts, benefit maximisation and area maximisation. The results obtained from these studies are discussed as follows.

4.1. Benefit maximisation

All the ten cases in each situation (A, B and C) as stated before were tried with the model to get the optimal allocation of area for each crop with the objective of achieving maximum net benefit from the command area for an year. The results obtained are shown in Table.5, 6 and 7 respectively. To get an optimal feasible solution about 11 to 18 iterations were required when the model was run.

Table. 5 . Area under each crop in ha and net benefit for different cases of cropping pattern (Situation-A)

Crops / Cases	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII	Case IX	Case X
X1 Coconut	32.00	0.00	32.00	0.00	32.00	0.00	32.00	0.00	32.00	0.00
X2 Coconut mixed crops	8.00	0.00	8.00	0.00	8.00	0.00	8.00	0.00	8.00	0.00
X3 Arecanut with pepper	124.32	151.96	126.73	154.37	134.46	192.00	104.67	132.31	110.34	137.98
X4 Banana	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
X5 Paddy (Virippu)	141.00	141.00	203.65	203.65	189.49	382.00	244.10	244.10	166.42	166.42
X6 Paddy (Mundakan)	297.63	297.14	296.67	296.17	293.58	356.82	305.49	305.00	303.22	303.73
X7 Paddy (Puncha)	85.00	85.00							85.00	85.00
X8 Pulses & Vegetables	60.00	60.00	8.00	8.00	8.00	60.00	40.00	40.00	8.00	8.00
X9 Ground nut			85.00	85.00			40.00	40.00	40.00	40.00
X10 Sesamum					85.00	322.00	81.00	81.00	81.00	81.00
X11 Green manure							24.00	24.00	24.00	24.00
Benefit in Million Rs.	141.60	163.30	143.41	165.11	151.85	209.24	122.04	143.74	127.10	148.80

Table. 6 . Area under each crop in ha and net benefit for different cases of cropping pattern (Situation –B)

Crops / Cases	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII	Case IX	Case X
X1 Coconut	32.00	0.00	32.00	0.00	32.00	0.00	32.00	0.00	32.00	0.00
X2 Coconut mixed crops	8.00	0.00	8.00	0.00	8.00	0.00	8.00	0.00	8.00	0.00
X3 Arecanut with pepper	152.00	192.00	152.00	192.00	152.00	192.00	152.00	192.00	152.00	192.00
X4 Banana	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
X5 Paddy (Virippu)	240.25	217.59	307.33	284.67	307.33	284.67	307.00	284.67	240.04	217.38
X6 Paddy (Mundakan)	382.00	382.00	382.00	382.00	382.00	382.00	382.00	382.00	382.00	382.00
X7 Paddy (Puncha)	85.00	85.00							85.00	85.00
X8 Pulses & Vegetables	60.00	60.00	60.00	60.00	60.00	60.00	100.00	54.52	60.00	43.36
X9 Ground nut			129.43	106.77			40.00	40.00	40.00	40.00
X10 Sesamum					155.32	128.12	81.00	81.00	89.68	81.00
X11 Green manure							24.00	24.00	107.32	24.00
Benefit in Million Rs.	171.17	205.57	171.68	206.01	172.69	206.85	172.99	206.48	172.31	206.13

Table.7 . Area under each crop in ha and net benefit for different cases of cropping pattern (Situation-C)

Crops / Cases	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	CaseVIII	Case IX	Case X
X1 Coconut	32.00	0.00	32.00	0.00	32.00	0.00	32.00	0.00	32.00	0.00
X2 Coconut mixed crops	8.00	0.00	8.00	0.00	8.00	0.00	8.00	0.00	8.00	0.00
X3 Arecanut with pepper	152.00	192.00	131.28	158.92	139.01	166.64	109.22	136.85	114.89	142.52
X4 Banana	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
X5 Paddy (Virippu)	373.43	382.00	382.00	382.00	382.00	382.00	382.00	382.00	382.00	382.00
X6 Paddy (Mundakan)	326.56	321.12	334.85	334.35	331.76	331.26	343.67	343.18	341.41	340.91
X7 Paddy (Puncha)	159.12	119.54							85.00	85.00
X8 Pulses & Vegetables	60.00	39.31	8.00	8.00	8.00	8.00	40.00	40.00	8.00	8.00
X9 Ground nut			85.00	85.00			40.00	40.00	40.00	40.00
X10 Sesamum					85.00	85.00	81.00	81.00	81.00	81.00
X11 Green manure							24.00	24.00	24.00	24.00
Benefit in Million Rs.	172.35	206.38	149.43	171.13	157.97	179.67	127.78	149.48	133.38	155.08

In the case of situation-A, cropping pattern described in case VI was found to give the maximum net profit when compared with other cases. The pumping capacity of the existing lift irrigation project was one of the major constraints in the availability of water for the crops.

The results derived from situation-B show the cropping pattern in case VI was found to give the maximum benefit with respect to other cases.

In the case of situation-C the irrigation efficiency was increased to 70 per cent from 57 per cent by improving the conveyance system, and the maximum benefit was obtained from case II of the same situation.

For all the three situations, the benefit from case VI (situation-B) was less by 1.15 per cent than case VI in situation-A. And also comparing A and C situations, for case II in situation-C the benefit was less by1.37 per cent than that of case VI in situation-A. While comparing the benefits from B and C situations, it was observed that only a little reduction in benefit, i e. 0.23 per cent, occurred with situation-C than the ·other situation. The variation of profit occurred because of the change in cropping area of each crop, the quantity of water and efficiency. Hence the utilization of water for each crop varied and subsequently the benefit.

4.2. Area maximisation

For maximisation of area the study was conducted in all the ten cases for the above three situation of water availability. The results are tabulated in Table.8, 9 and 10 respectively.

Table. 8 . Area under each crop in ha and net area cultivated in an year for different cases of cropping pattern (Situation - A)

Crops / Cases	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII	Case IX	Case X
X1 Coconut	32.00	0.00	32.00	4.66	39.23	50.66	65.71	77.14	32.00	19.46
X2 Coconut mixed crops	8.00	0.00	8.00	0.00	8.00	0.00	8.00	0.00	8.00	0.00
X3 Arecanut with pepper	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
X4 Banana	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
X5 Paddy (Virippu)	279.39	322.06	382.00	382.00	382.00	382.00	382.00	382.00	354.04	382.00
X6 Paddy (Mundakan)	344.16	354.72	344.16	353.60	342.43	342.56	336.07	336.21	344.16	350.05
X7 Paddy (Puncha)	179.87	190.00							85.00	85.00
X8 Pulses & Vegetables	60.00	60.00	60.00	60.00	60.00	60.00	40.00	40.00	60.00	60.00
X9 Ground nut			276.77	322.00			172.53	40.00	132.00	132.00
X10 Sesamum					322.00	322.00	81.00	81.00	81.00	81.00
X11 Green manure							88.47	221.00	24.00	24.00
Net area sown ha.	919.42	942.78	1118.93	1138.26	1169.65	1173.22	1189.78	1193.35	1136.20	1149.51

Table. 9 . Area under each crop in ha and net area cultivated in an year for different cases of cropping pattern (Situation-B)

Crops / Cases	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII	Case IX	Case
X1 Coconut	43.34	43.52	32.00	11.80	46.37	57.80	176.00	184.00	176.00	184.0
X2 Coconut mixed crops	8.00	0.00	8.00	0.00	8.00	0.00	8.00	0.00	8.00	0.0
X3 Arecanut with pepper	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.0
X4 Banana	76.20	84.07	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.0
X5 Paddy (Virippu)	382.00	382.00	382.00	382.00	382.00	382.00	382.00	382.00	382.00	382.0
X6 Paddy (Mundakan)	363.71	364.50	382.00	382.00	380.71	380.85	349.60	350.56	349.60	350.5
X7 Paddy (Puncha)	322.00	322.00							229.00	229.0
X8 Pulses & Vegetables	60.00	60.00	60.00	60.00	60.00	60.00	40.00	40.00	8.00	8.0
X9 Ground nut			285.10	322.00			41.25	45.62	40.00	40.0
X10 Sesamum					322.00	322.00	81.00	81.00	81.00	81.0
X11 Green manure							219.75	215.38	24.00	24.0
Net area sown ha.	1263.24	1264.09	1165.10	1173.80	1215.08	1218.65	1313.60	1314.56	1313.60	1314.5

Table.10 . Area under each crop in ha and net area cultivated in an year for different cases of cropping pattern (Situation-C)

Crops / Cases	Case I	Case II	Case III	Case IV	Case V	Case VI	Case VII	Case VIII	Case IX	Case X
X1 Coconut	32.00	37.96	93.23	104.66	139.23	150.66	176.00	184.00	136.61	148.04
X2 Coconut mixed crops	8.00	0.00	8.00	0.00	8.00	0.00	8.00	0.00	8.00	0.00
X3 Arecanut with pepper	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
X4 Banana	8.00	10.70	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
X5 Paddy (Virippu)	380.14	382.00	382.00	382.00	382.00	382.00	382.00	382.00	382.00	382.00
X6 Paddy (Mundakan)	382.00	382.00	382.00	382.00	382.00	382.00	382.00	382.00	382.00	382.00
X7 Paddy (Puncha)	242.27	242.30							85.00	85.00
X8 Pulses & Vegetables	60.00	60.00	60.00	60.00	60.00	60.00	40.00	40.00	60.00	60.00
X9 Ground nut			322.00	322.00			159.44	163.80	132.00	132.00
X10 Sesamum					322.00	322.00	81.00	81.00	81.00	81.00
X11 Green manure							101.56	97.20	24.00	24.00
Net area sown ha.	1120.41	1122.96	1263.23	1266.66	1309.23	1312.66	1346.00	1346.00	1306.61	1310.04

Under the exercise of area maximisation, case VIII, in situation-A is found to give maximum area per year with the available water while in situation-B, cases VIII and X resulted in the best cropping pattern in area maximisation. But in situation-C, cases VII and VIII are found the best crop combinations. Comparing the three situations, the situation-C gave the maximum area for cultivation than the other situations, with change in irrigation efficiency and quantity of water. It is found that for situation-B the net area was more than that of the situation-A, by 10.16 per cent. The cultivated area is increased by 12.8 per cent in situation-C than situation-A. Nevertheless, comparing the situation-B and C, the situation-C resulted in greater net area than that of situation-B by 2.4 per cent.

4.3. Sensitivity analysis

Sensitivity analysis was performed to study the effect on the optimal solution when the different variables are either altered or changed. Four trials were conducted with various returns of the summer crop in each situation as mentioned earlier. The returns considered for the four trials are as follows.

Summer crops	Returns from crops (Rs/ha)			
	Trial 1	Trial 2	Trial 3	Trial 4
Paddy (Punch)	4100	3000	5000	3500
Vegetables &pulses	16553	14000	18000	10000
Ground nut	2570	2000	3000	1000
Sesame	8875	6000	10000	5000
Green manure	1840	1500	2000	1900

Table. 11 Area under each crop in ha when the returns from summer crop varies.

(Situation-A)

Crops/ Cases	Trial 1	Trial 2	Trial 3	Trial 4
Coconut	32.00	32.00	32.00	32.00
Coconut mixed crops	8.00	8.00	8.00	8.00
Arecanut with pepper	110.34	110.34	110.34	110.34
Banana	8.00	8.00	8.00	8.00
Paddy (Virippu)	166.42	166.42	166.42	166.42
Paddy (Mundakan)	303.22	303.22	303.22	303.22
Paddy (Puncha)	85.00	85.00	85.00	85.00
Vegetables & pulses	8.00	8.00	8.00	8.00
Ground nut	40.00	40.00	40.00	40.00
Sesamum	81.00	81.00	81.00	81.00
Green manure	24.00	24.00	24.00	24.00
Benefit million Rs	127.10	126.66	127.24	126.56

Table. 12 Area under each crop in ha when the returns from summer crop varies.

(Situation-B)

Crops/ Cases	Trial 1	Trial 2	Trial 3	Trial 4
Coconut	32.00	32.00	32.00	32.00
Coconut mixed crops	8.00	8.00	8.00	8.00
Arecanut with pepper	152.00	152.00	152.00	152.00
Banana	8.00	8.00	8.00	8.00
Paddy (Virippu)	240.04	240.04	240.04	240.04
Paddy (Mundakan)	382.00	382.00	382.00	382.00
Paddy (.Puncha)	85.00	85.00	85.00	85.00
Vegetables & pulses	60.00	60.00	60.00	60.00
Ground nut	40.00	40.00	40.00	40.00
Sesamum	89.68	89.68	89.68	89.68
Green manure	107.32	107.32	107.32	107.32
Benefit million Rs	172.31	171.50	172.36	171.21

Table. 13 Area under each crop in ha when the returns from summer crop varies.

(Situation-C)

Crops/ Cases	Trial 1	Trial 2	Trial 3	Trial 4
Coconut	32.00	32.00	32.00	32.00
Coconut mixed crops	8.00	8.00	8.00	8.00
Arecanut with pepper	114.89	114.89	114.89	114.89
Banana	8.00	8.00	8.00	8.00
Paddy (Virippu)	382.00	382.00	382.00	382.00
Paddy (Mundakan)	341.41	341.41	341.41	341.41
Paddy (Puncha)	85.00	85.00	85.00	85.00
Vegetables & pulses	8.00	8.00	8.00	8.00
Ground nut	40.00	40.00	40.00	40.00
Sesamum	81.00	81.00	81.00	81.00
Green manure	24.00	24.00	24.00	24.00
Benefit million Rs	133.38	132.94	133.52	132.84

The results given in Table 11, 12 and 13 shows that the optimal allocation of the area for each crop changes with respect to the changes in the net returns from each cropping pattern. When the return from a crop is reduced to certain level the model gave zero values of area for that crop or in other words the cultivation of that particular crop was not recommended.

Summary & Conclusion

SUMMARY AND CONCLUSION

This study is concerned with the economic optimization of irrigation practices. Optimization in this context means maximising the net benefit from cultivation and area put under cultivation achieved per unit of available water used.

A procedure was developed for the optimal utilization of lift irrigation scheme subjected to different constraints. Three conditions were considered in the model formulation based on Linear Programming analysis. Constraints and bounds were fixed by interacting with the farmers and concerned departments of the region. In order to make the best use of the available water resource and to get the maximum benefits and maximum area put under cultivation, different trials were conducted with different crop combinations subjected to the constraints identified, using the model. The maximum benefit was obtained in case II and VI, where as the maximum area was found to be for case VII, VIII and X where, paddy crop was given prime importance for both the methods.

The procedure developed here can be used to identify alternative cropping patterns for maximising the net benefit and/ or maximising the irrigated area. The area allocation model is a valuable tool in planning an optimal cropping pattern for an area with the available water for irrigation. The model is very much flexible to adopt any timely changes made by the decision makers. Area maximisation was found useful to provide more labour opportunities to the region even with a limited supply of water. By using the developed model runs for area and benefit maximisation, the decision makers can recommend a better cropping pattern which will satisfy both the objectives to the desired levels to the farmers in advance.

The model is very useful for policy makers such as State Agricultural Departments and Agricultural Universities to suggest a proper cropping pattern to different agricultural zones of the state before the start of each season. The only uncertainty involved in this sort of suggestion is that of the dependability of the predictions made for the availability of water.

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Appendices

APPENDIX-I
MONTHLY AVERAGE OF MAXIMUM TEMPERATURE

YEAR/MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1974	33	35.6	37.3	34.8	33.2	32.3	28.1	28.7	30.1	30.1	32.2	32.5
1975	33.3	34.9	36.1	36	33	28.9	28.9	28.5	30.1	29.2	31.5	32.8
1976	32	35.2	36.8	34.3	33.5	32	28.9	29.2	30.9	32.1	32.1	33
1977	33.5	35.3	36.7	35.9	32.8	30	28.5	29.9	30.9	32	31.2	32.3
1978	33.5	35.2	36.4	35.8	33.4	28.8	28.8	28.7	31.7	32.1	31.9	32.8
1979	33.7	35.1	36.2	35.7	34.1	31.1	28.6	29.5	31.2	32.7	31.9	33.2
1980	33.5	35.7	36.2	34.4	35.3	30.7	29	29.1	31	32.1	33.1	33.3
1981	33.7	35.9	37	35.2	35.3	28.6	39.6	29	28.9	31.2	32.4	33.3
1982	33.7	36.2	36.6	36.4	34.9	30.8	29.7	29.1	31	33	33	32.9
1983	34.2	35.5	36.7	37	35.5	32.1	29.9	29.1	29.4	31.3	32.4	32.5
1984	33.2	35.2	35.8	34.7	35.7	29.1	28.4	28.9	30.1	30.1	32.4	32.6
1985	32.8	34.8	36.5	35.7	34.5	28.5	28.1	29.2	30.5	31	32.4	32.7
1986	32.7	34.2	36.4	36	34.6	30.7	29.7	29.2	30.7	31.7	31.7	33.9
1987	34	35.2	36.7	36.9	35.7	30.8	29.5	29.8	31.6	32.5	32.1	32.4
1988	33.1	35.6	36.1	35.7	34.1	30.1	28.9	29.1	29.9	31.5	33.4	33.9
1989	34.3	36.3	37.1	35.9	34.2	29.9	29.8	29.7	30.1	31.3	32.5	33.1
1990	33.5	35	36.2	36.1	32.5	30.1	29	29.3	31.4	32.4	31.7	32.5
1991	33.5	35.6	37.8	35.6	34.8	29.9	29.5	29.2	31.7	31.1	31.7	32.2
1992	32.8	34.6	37	36.6	34.1	30.6	29	29	30.4	30.8	31.7	31.5
1993	32.8	34.5	35.5	36.4	34.8	30.5	29.1	29.7	31.1	31.2	31.6	31.6
1994	33.3	34.9	36.8	34.4	34.5	29.4	28.6	29.7	31.3	31.6	31.9	32.3
1995	32.9	34.9	36.8	36.3	32.8	30.9	29.1	29.6	30.5	32.1	31.6	32.5
1996	33.4	35.2	36.7	34.6	34.1	31.3	29.4	29.6	30	30.7	32.3	31.7
1997	32.8	34.7	36.6	34.9	34.9	31.7	28.8	29.2	31.5	32.4	32.1	32.3
1998	33.5	34.4	36.3	36.4	34.9	30.6	29.3	29.9	29.4	29.6	31.5	31.2

* Source : Meterological station, Pattambi.

MONTHLY AVERAGE OF MINIMUM TEMPERATURE

YEAR/MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1974	18.3	19.3	22.7	24.4	24.1	22.7	22	22.3	22.7	21.9	21.1	20.6
1975	19.2	22	23.3	24.5	24.2	22.5	22.7	22.6	22.9	22.8	22.3	20.9
1976	20	19.7	22.4	23.9	24.5	23.1	22.5	23	23	22.8	22.7	21.5
1977	19.6	21.3	23.9	24.9	23.7	22.9	22.6	23.2	23.2	22.2	22.4	20.1
1978	19.6	22.2	23.1	24.2	24.3	22.1	22.3	22.6	22.8	22.8	22.4	22.2
1979	21.5	22.1	23.6	24.5	24.5	23.3	22.6	22.5	23.1	22.9	23	21.8
1980	19.4	20.8	23.2	24.3	25	23.5	23	23.1	23	23.3	22.8	21.9
1981	21.2	20.3	23.5	25.3	24.6	23.3	23.5	23.3	22.9	23.4	22.3	21.3
1982	20.4	21.1	23.5	25.2	24.8	23.6	23.3	22.5	23	23	23.5	21.8
1983	20.1	21.9	23.4	24.7	25.7	24.7	23.5	23.8	23.3	23	21.7	22.9
1984	22	23.8	23.8	24.6	25.6	22.9	23	23.2	23.1	22	22.5	19.5
1985	21.9	21.4	23.8	25.2	25	22.9	22.7	23.1	23	22.7	21.9	21.5
1986	20.9	21	23.8	24.9	24.8	23.3	23.3	22.6	2.8	23	20.7	21.7
1987	20.7	20.9	21.4	24.7	23.5	22.9	22.8	22.5	22.7	22.7	21.4	21.3
1988	19.1	20.7	22.8	22.8	23.7	21.4	19.7	20.4	20.2	20.9	19.3	17.8
1989	19.2	18.5	22.3	25	24.6	22.4	23.2	22.8	22.8	23.1	21.6	20.9
1990	17.1	17.5	19	20.9	20.4	19.2	20	22.7	23.4	23.3	22.2	21.9
1991	20.3	20.2	24.4	24.8	25.4	23.4	22.5	22.3	23.1	22.9	21.8	19.6
1992	18.6	20.8	21.9	23.7	24	22.7	23.2	22.4	22.3	21.8	21.5	19.5
1993	18.7	20.5	22.8	24	23.9	22.9	22	22.4	22	22.3	21.3	19.9
1994	19.8	19.9	21.3	22.1	22.7	21.2	20.3	20.9	20.5	20.7	20.1	19.4
1995	20.7	22.3	22.9	24.3	23.7	23.3	22.3	22.7	22.4	22.1	21.4	17.7
1996	18.5	19.6	21.2	23.5	24.1	23.1	22.3	22.4	22.5	21.7	21.5	19.6
1997	19	18.8	21.6	22.3	24.6	23.6	23	23.3	23.5	23.3	23.4	23.1
1998	21.9	22.4	23.2	26.1	25.7	23.7	23.4	23.8	23.4	23	22.8	21.2

* Source : Meterological station, Pattambi.

MONTHLY AVERAGE OF RELATIVE HUMIDITY (%) - HOUR -I

YEAR/MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1974	82	84	90	93	93	96	97	97	97	96	96	75
1975	81	87	94	91	95	97	97	97	95	95	93	85
1976	76	82	91	90	90	93	95	95	93	94	93	83
1977	77	83	84	87	93	95	96	94	94	95	94	88
1978	84	84	84	88	95	97	97	96	95	96	89	82
1979	76	88	86	85	87	93	96	95	95	94	93	85
1980	82	87	89	88	90	96	97	96	95	96	90	85
1981	82	83	87	90	91	97	96	96	96	95	92	84
1982	81	92	91	89	91	96	96	96	95	95	87	76
1983	75	89	90	86	85	2	97	98	98	97	91	85
1984	81	82	88	92	90	94	95	94	94	92	90	87
1985	85	90	92	88	91	96	95	96	95	94	88	83
1986	82	83	87	90	90	91	95	91	95	97	93	84
1987	77	78	85	89	90	95	97	97	96	95	96	93
1988	88	93	93	92	94	97	96	97	96	96	92	91
1989	83	87	86	85	91	95	93	93	94	94	88	82
1990	86	85	89	88	93	94	94	94	94	93	92	83
1991	85	86	90	88	88	93	94	94	93	94	89	84
1992	76	91	90	89	91	92	94	94	93	93	91	78
1993	80	83	89	86	89	93	93	93	94	92	88	83
1994	80	85	85	90	88	93	94	92	93	93	83	77
1995	78	84	86	85	91	94	94	94	94	94	94	78
1996	76	76	85	90	90	92	95	93	95	95	92	87
1997	85	90	86	84	89	92	96	96	94	93	93	89
1998	82	83	90	86	90	95	95	95	95	95	93	87

* Source : Meterological station, Pattambi.

MONTHLY AVERAGE OF RELATIVE HUMIDITY (%) - HOUR -II

YEAR/MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1974	32	24	29	56	62	72	86	79	73	70	53	39
1975	34	38	41	51	63	82	81	86	75	77	62	43
1976	34	26	42	51	54	64	79	74	66	65	62	43
1977	35	33	35	51	66	81	86	82	70	70	72	54
1978	39	38	45	51	63	81	83	83	65	65	59	51
1979	41	51	46	50	55	76	82	73	70	61	6	52
1980	37	33	42	50	55	80	82	79	68	68	59	51
1981	41	32	39	51	57	83	77	77	73	71	59	44
1982	39	31	43	48	56	77	77	77	65	65	58	41
1983	36	40	41	44	53	73	80	83	81	68	57	55
1984	46	41	46	60	55	88	78	73	70	68	55	50
1985	56	47	47	53	59	86	80	77	71	68	59	50
1986	48	40	43	54	55	76	76	75	69	68	62	48
1987	44	38	38	50	55	80	74	80	71	71	67	63
1988	49	44	46	57	64	81	81	79	77	66	52	50
1989	46	33	32	49	56	76	76	73	73	72	54	47
1990	50	40	43	49	68	77	79	76	60	63	64	50
1991	46	30	40	51	54	78	76	74	60	69	58	46
1992	33	35	33	44	59	73	77	77	71	67	65	47
1993	36	35	40	46	56	77	77	72	64	67	58	53
1994	39	37	37	58	52	78	82	71	64	64	58	43
1995	42	42	34	47	60	76	78	77	70	62	63	55
1996	43	37	36	55	55	70	71	77	74	69	61	52
1997	45	38	39	45	51	67	81	78	69	62	64	56
1998	41	42	42	50	57	76	78	73	75	73	61	53

* Source : Meterological Station, Pattambi.

MONTHLY AVERAGE OF SUNSHINE (in hours)

YEAR/MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1974	10.1	10.1	9.8	8.5	7.2	5	1	4.3	5.3	6.5	7.7	9.9
1975	9.4	9	9	8.9	6.3	1.9	2.2	2	4.4	4.8	7.6	8.4
1976	9.3	9.8	9.9	9.2	8.7	6.8	2.9	4.9	7.2	5.9	6.6	9.1
1977	10.3	9.7	8.8	8.5	5.6	3	2.7	5.2	6.4	5.7	6.1	9.9
1978	9.7	10.1	9.7	9	7.6	2.1	3.4	3.1	7.2	7.3	7.1	7.7
1979	10.3	8.9	9.3	8.8	8.3	4.4	2	5	6.1	7.8	6.1	9.3
1980	10.1	9.8	9.3	8.5	8.5	2.5	2.7	4.3	7.4	6	7.6	8.5
1981	9.7	9.9	9.4	8.8	7.9	1.3	4.4	3.3	4.7	5.6	7.1	8.9
1982	10	9.9	9.3	9.1	7.4	2.7	3.4	3.9	7.2	7.2	7.3	8.6
1983	9.5	9.5	9.6	9.4	8.3	4.4	3.7	2.4	3.6	6.8	8.4	7.6s
1984	8	8.3	7.4	7.3	9.3	2.1	3.1	5.3	6.4	6	7.2	9
1985	8.7	9.1	9	8.5	7	1.9	3.1	4.3	6.1	6.3	6.8	8.4
1986	7.6	8.9	7.6	8.9	7.5	3.8	5.1	6.1	6.1	6.4	7.3	9.1
1987	9.5	9.9	9.3	8.3	9.1	4.2	5.3	4.7	7.3	6.9	7.1	8.3
1988	10.2	9.9	8.6	8.6	7.2	4	3.4	4	5.3	8	7.6	9.1
1989	8	9.3	9.1	8	8	2.8	4.4	6.1	5.3	6.2	8.4	9.4
1990	8.7	10	8.9	8.1	4.8	2.8	2.3	3.9	5.3	6.1	5	8
1991	8.4	9.8	8.7	8	8	2.2	2.2	2.6	7.7	4.1	6.7	8.3
1992	9.1	8.9	8.9	8.5	7.6	4.9	2.5	4.1	5.1	5.3	6	9.2
1993	8.4	9.5	8.4	8.9	6.7	3.6	2.5	5.1	6.3	4.9	6.1	7.3
1994	8.7	8.8	8.5	7.5	7.9	2.7	1.4	3.9	6.8	6.3	7.6	9
1995	8.6	9.5	9	9.2	7.1	4.2	2.1	5.1	6.4	6.9	6.5	9.8
1996	9.9	9.9	9.1	8.2	8.1	3.8	2.6	4.3	4.5	6.1	7.5	7.4
1997	9.4	9.1	9.2	9.2	7.8	5.9	2.2	3.5	7	6.9	6.8	7.9
1998	9.1	9.2	9.4	8.7	7.7	3.2	3.6	4.3	4	4.5	6.8	6.5

* Source : Materological Station, Pattambi.

MONTHLY AVERAGE OF WIND SPEED (in Km/hour)

YEAR/MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1974	4.9	4.6	4.2	4.5	3.9	4	4	4.8	4.3	3	2.7	3.3
1975	5.6	4.8	4.36	5	4.8	4.1	3.6	5.6	3.7	3.5	2.6	1.9
1976	6.6	5.3	4.3	4.3	5.3	3.8	3.9	4.4	3.8	2.4	2.6	4.6
1977	4.5	4.5	4.3	3.9	3	3.1	3.9	4	3.7	2.7	2.8	4.8
1978	3.9	4.6	4.1	4.1	3.9	2.7	3.9	4.5	3.8	2.9	2.6	5
1979	5.1	3.5	3.9	4	4.2	3.4	3.2	3.7	2.6	2.8	3.2	3.7
1980	4.2	3.9	4	3.7	3.8	2.8	3.4	3.1	3.7	2.4	2.3	2.8
1981	4	3.4	3.9	3.6	3.5	2	3.4	3.9	2.5	2.1	1.7	4.1
1982	4.6	3.2	3.6	4.2	3	2.1	2	3.1	2.9	1.	3.2	5.8
1983	4.8	3.6	3.7	4.1	3.8	3.4	1.9	2	2.3	2.2	1.7	4.2
1984	4.3	4.6	3.	2.9	3.9	10.9	2.8	3.8	2.7	1.6	1.9	2.3
1985	4.3	3.2	4	3.6	3.	2.3	2.6	3.7	2.9	2.1	2.1	3.7
1986	3.7	3.1	3.7	3.6	3.7	2.3	3.7	4.9	3.3	2.3	2.5	4.6
1987	5.3	4.2	4.3	4.4	4	3.2	3.6	3.4	3:1	2.2	1.9	4.4
1988	4.9	3.6	3.9	3.7	3.6	2.	3	4.1	3.8	2.	2.	4.5
1989	5	4.2	5	5.4	5	3.9	5.6	5.3	3.6	2.8	4.5	7.9
1990	6.3	6.3	4.9	5	4.2	3.7	3.4	5.3	4.3	3.1	2.8	7.2
1991	5.8	5.3	4.6	4.3	.7	3.7	4.2	4.1	4.3	2.8	4.1	5.8
1992	8	4.1	4.4	4.7	4.1	4.4	4	3.6	3.3	.8	3	8.5
1993	6.1	.5	4.5	4.2	4.4	3.4	4	4.8	3.7	2.4	3.3	5.7
1994	7.5	4.3	4.9	3.6	4.6	4	3.6	4.2	3.7	2.3	5.5	4.5
1995	7.5	6	4.6	4.3	3.9	3.5	3.6	.8	4.1	2.7	0.9	5.9
1996	5.4	5.6	4.1	3.7	4	3.9	3.3	4.4	3.4	2.1	2.5	4.7
1997	5.1	3.7	4.3	4.1	4.3	2.4	2	N.A.	2.9	2.7	2.6	4.5
1998	6.6	5.6	4.2	4.5	4	3.3	4.2	3.6	3	2.5	2.4	4.6

* Source : Materological Station, Pattambi.

APPENDIX-II

Month-wise details of climatological parameters for 25 years from 1974-1998

Average for 25 years taken together

Month	Relative humidity (%)			Temperature (°C)			Mean sunshine (hrs/day)	Wind speed at 2m ht. km/day
	FN	AN	Mean	Max	Min	Mean		
January	80.80	41.28	61.04	33.31	19.91	26.61	9.23	128.64
February	85.40	37.00	61.20	35.19	20.76	27.97	9.47	107.23
March	88.28	39.96	64.12	35.12	22.75	28.94	9.01	101.38
April	88.36	50.84	69.60	35.67	24.19	29.93	8.58	99.26
May	90.60	57.60	74.10	34.29	24.28	29.29	7.58	96.29
June	94.32	77.12	85.72	30.38	22.83	26.60	3.45	76.61
July	95.36	79.08	87.22	29.05	22.43	25.74	2.97	83.33
August	94.92	77.00	85.96	29.28	22.66	25.97	4.23	94.18
September	94.72	69.76	82.24	30.62	22.70	26.66	5.96	81.98
October	94.52	67.56	81.04	31.43	22.54	26.99	6.18	59.33
November	91.20	60.32	75.76	32.09	21.90	27.00	7.00	65.57
December	83.76	49.94	66.85	32.60	20.78	26.69	8.58	113.66

* Source : Meterological station, Pattambi.

APPENDIX- III

Computation of reference evapotranspiration values

Month	ea mbar	ed=ea x Rhmean/100	(ea-ed)	f(u)	(1-W)	W	Ra	N hrs
1	2	3	4	5	6	7	8	9
Jan.	34.88	21.29	13.59	0.62	0.24	0.76	13.06	11.56
Feb.	37.75	23.10	14.65	0.56	0.24	0.76	14.10	11.77
March	39.96	25.62	14.34	0.54	0.23	0.77	15.23	12.00
April	42.24	29.40	12.84	0.54	0.23	0.77	15.70	12.33
May	40.76	30.20	10.56	0.53	0.23	0.77	15.57	12.63
June	34.87	29.89	4.98	0.48	0.24	0.76	15.37	12.74
July	33.10	28.87	4.23	0.49	0.26	0.74	15.37	12.64
Aug.	33.54	28.83	4.71	0.52	0.26	0.74	15.54	12.43
Sept.	34.99	28.77	6.21	0.49	0.24	0.76	15.27	12.11
Oct.	35.68	28.91	6.76	0.43	0.24	0.76	14.60	11.80
Nov.	35.7	27.04	8.65	0.45	0.24	0.76	13.50	11.57
Dec.	35.05	23.43	11.62	0.58	0.24	0.76	12.76	11.46

Continued

n/N	Rns	f(T)	f(ed)	f(n/N)	Rnl	Rn	c	ET_0
10	11	12	13	14	15	16	17	18
0.80	6.36	16.02	0.14	0.82	1.80	4.56	1.09	5.99
0.81	6.90	16.11	0.13	0.83	1.71	5.18	1.10	6.49
0.75	7.15	16.49	0.12	0.78	1.54	5.60	1.10	6.70
0.70	7.04	16.51	0.10	0.73	1.21	5.83	1.10	6.67
0.60	6.43	16.64	0.10	0.64	1.04	5.38	1.09	5.93
0.27	4.44	16.02	0.11	0.34	0.58	3.87	1.05	3.67
0.24	4.24	15.72	0.11	0.31	0.52	3.72	1.05	3.47
0.34	4.89	15.66	0.11	0.41	0.67	4.22	1.07	4.02
0.49	5.68	16.03	0.11	0.54	0.91	4.77	1.07	4.64
0.52	5.60	16.10	0.11	0.57	0.97	4.64	1.07	4.50
0.61	5.59	16.10	0.11	0.65	1.14	4.45	1.07	4.60
0.75	5.98	16.04	0.12	0.77	1.52	4.46	1.07	5.37

* Source : Meterological station, Pattambi
* : FAO, Irrigation& Drainage paper : No. **24**

APPENDIX IV

Water requirement of coconut

Month	Kc	ET_0	ETcrop mm/day	ETcrop for the month mm
Jan.	0.75	5.99	4.49	139.19
Feb.	0.75	6.49	4.87	136.22
March	0.75	6.70	5.03	155.85
April	0.75	6.67	5.00	150.10
May	0.75	5.93	4.45	137.87
June	0.75	3.67	2.75	82.51
July	0.75	3.47	2.60	80.65
Aug.	0.75	4.02	3.01	93.40
Sept.	0.75	4.64	3.48	104.49
Oct.	0.75	4.50	3.38	104.63
Nove.	0.75	4.60	3.45	103.43
Dec.	0.75	5.37	4.03	124.76

Water requirement of coconut mixed crops

Months	Kc	ET_0	ETcrop mm/day	ETcrop for the month mm
Jan.	1.10	5.99	6.59	204.12
Feb.	1.10	6.49	7.14	199.77
March	1.10	6.70	7.37	228.57
April	1.10	6.67	7.34	220.14
May	1.10	5.93	6.52	202.21
June	1.10	3.67	4.03	121.01
July	1.10	3.47	3.82	118.29
Aug.	1.10	4.02	4.42	136.98
Sept.	1.10	4.64	5.11	153.25
Oct.	1.10	4.50	4.95	153.45
Nov.	1.10	4.60	5.06	151.70
Dec.	1.10	5.37	5.90	182.98

Water requirement of arecanut with pepper

Months	Kc	ETo mm/day	ETcrop for the month mm
Jan.	1.20	5.99	222.68
Feb.	1.20	6.49	217.93
March	1.20	6.70	249.35
April	1.20	6.67	240.16
May	1.20	5.93	220.60
June	1.20	3.67	132.01
July	1.20	3.47	129.05
Aug.	1.20	4.02	149.43
Sept.	1.20	4.64	167.18
Oct.	1.20	4.50	167.40
Nove.	1.20	4.60	165.49
Dec.	1.20	5.37	199.62

Water requirement of banana planting in october

Months	Kc	ETo mm/day	ETcrop for the month mm
Oct.	0.70	4.50	97.65
Nov.	0.70	4.60	96.54
Dec.	0.75	5.37	124.76
Jan.	0.90	5.99	167.009
Feb.	0.95	6.49	172.53
March	1.00	6.70	207.793
April	1.00	6.67	200.13
May	1.00	5.93	183.83
June	1.00	3.67	110.01
July	1.00	3.47	107.54
Aug.	1.00	4.02	124.527

Water requirement of sesamum planting in January 3[rd]

Stage of Crop	Length of stage (days)	kc value
Initial stage	20	0.5
Crop development	25	0.5 to 0.95
Mid season	35	0.95
Late season	20	0.95 to 0.9

Months	kc	ETo	ETc-month
Jan.	0.57	5.99	98.95
Feb.	0.82	6.49	148.93
March	0.94	6.70	189.00
April	0.93	6.67	223.00

Water requirement of pulses and vegetables planting in January 12[th]

Stage of crop	Length of stage days	kc
Initial stage	20	0.5
Development stage	25	0.5 to 1.05
Mid season	30	1.05
Late season	20	1.5 to 0.9

Month	kc	ETo	ETc crop month
January	0.50	5.99	59.86
February	1.01	6.49	183.42
March	1.07	6.70	222.34
April	1.20	6.67	88.06

Water requirement for ground nut planting in January 1 st

Stage of crop	Length of stage	kc
Initial stage	10	0.3 to 0.4
Development stage	30	0.7 to 0.8
Mid season	50	0.9 to 1.1
Maturity	20	0.7 to 1:8

Month	kc	ETo	ETc crop month
January	0.62	5.99	115.04
February	0.92	6.49	167.16
March	1.00	6.70	207.79
April	0.75	6.67	100.06

Water requirement of green manure planting in January 26 th

Stages of crop	Length of stage	kc
Initial stage	15	0.3 to 0.4
Development stage	30	0.7 to 0.8

Month	kc	ETo	ETc crop month
January	0.35	5.99	10.48
February	0.61	6.49	110.78
March	0.75	6.70	60.33

Water requirement of paddy (nursery)

	Virippu		Mundakan	Puncha	
	May 10 th to June 3 rd		Sept. 2 nd to 26 th	Jan. 27 th to Feb.15 th	
	May	June	Sept.	Jan.	Feb.
	22 days	3 days	25 days	5 days	15 days
Kc	1.1	1.1	1.10	1.1	1.1
ETo	5.93	3.67	4.64	5.99	6.49
ETc	6.52	4.03	5.11	6.59	7.14
Percolation mm/day		7.1	6.60	10.97	19.20
Total water mm/day	6.52	11.13	11.71	17.56	26.34
Total water mm/month	143.51	33.40	292.70	87.80	395.03
1/10 of total water	14.35	3.40	29.27	8.78	39.50

Water requirement for puddling

Season	Month	Water requirement
Virippu	May 25 th to June 3 rd	150
Mundakan	Sept. 17 th to 26 th	150
Puncha	Feb.15 th to 24 th	200

Duration of growth stage of paddy by season (transplanted crop)

Stage of crop	Virippu 95 days		Mundakan 95 days		Puncha 90 days	
	L.S	kc	L.S	kc	L.S	kc
Initial stage	15	1.10	15	1.10	15	1.10
Development stage	25	1.10	25	1.10	25	1.10
Mid season	30	1.05	30	1.05	30	1.25
Late stage	25	0.95	25	0.95	20	1.00

Water requirement of paddy (main field)

	Virippu planting 4 th June				Mundakan planting 27 th Sept.				Puncha planting 16 th Feb.			
	June 27 days	July 31 days	Aug. 31 days	Sept. 6 days	Sept. 4 days	Oct. 31 days	Nov. 31 days	Dec. 30 days	Feb. 13 days	March 31 days	April 30 days	May 16 days
Kc	1.10	1.07	0.99	0.95	1.10	1.01	1.06	0.97	1.10	1.12	1.22	1
ETo	3.67	3.47	4.02	4.64	4.64	4.50	4.60	5.37	6.49	6.70	6.67	5.93
ETc	4.03	3.71	3.98	4.41	5.11	4.95	4.87	5.21	7.14	7.51	8.14	5.93
Percolation mm/day	7.10	6.10	6.80	6.60	6.60	7.00	7.00	1085.00	19.20	22.00	20.73	
Total water mm/day	11.13	9.81	10.78	11.01	11.71	11.95	11.87	16.06	26.34	29.51	28.87	5.93
Total water/month	300.62	304.17	334.12	66.07	46.83	370.45	356.16	481.65	342.36	914.72	866.07	94.88

OPTIMAL CROPPING PATTERN FOR THE BETTER UTILIZATION OF MINOR IRRIGATION SCHEMES

By

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ABSTRACT OF A THESIS

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

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ABSTRACT

A monthly irrigation planning model was formulated for determining the optimal cropping pattern in an existing lift irrigation scheme. The study deals with the use of Linear Programming technique which is a powerful tool in systems analysis for obtaining an optimal cropping pattern from various alternatives for a command area by the conjunctive use of surface water. The optimal cropping pattern was selected for two purposes, i e. to maximise the net economic benefit from the command area for an year and to maximise the net area put under cultivation in an year. Appropriate constraints were also included while formulating the model on total cropping area of each month, cropping area of each crop, surface water availability and monthly crop water requirement etc. The model is found very flexible to alter the constraints or add any more constraints according to the policy makers decisions from time to time based on socio-economic considerations.