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ENHANCING THE PRODUCTIVITY OF THE RICE-FISH/PRAWN FARMING SYSTEM IN *POKKALI* LANDS

BY

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "Enhancing the productivity of the rice-fish/prawn farming system in *Pokkali* lands" 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.

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CERTIFICATE

Certified that the thesis entitled "Enhancing the productivity of the rice-fish/prawn farming system in *Pokkali* lands" is a record of research work done independently by Sri.N.K.Sasidharan under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship, or associateship to him..

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We, the undersigned members of the Advisory Committee of Sri.N.K.Sasidharan, a candidate for the Degree of Philosophy in Agriculture with major in Agronomy agree that the thesis entitled "Enhancing the productivity of the rice-fish/prawn farming system in *Pokkali* lands" may be submitted by Sri.N.K.Sasidharan in partial fulfillment of the requirement of the degree.

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(N.K.SASIDHARAN)

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INTRODUCTION

INTRODUCTION

Pokkali lands, known after the renowned salt tolerant land race of rice "*Pokkali*" are acclaimed for the unique way of reclamation and management of soil salinity and also for the integrated farming system involving rice-fish/prawn. *Pokkali*, *Kaipad* and *Orumundakan* are the coastal saline soils of Kerala covering an extent of 30000 ha (Padmaja *et al.*, 1994) and are characterized by the accumulation of salts by tidal action over an underlying acidic soil. Thus, the rice crop grown here is subjected to two diametrically opposite cationic interferences in the production process. This results in excessive vegetative growth of the traditional tall '*Pokkali*' rice genotypes, which grow up to 2 m height. *Pokkali* in local language (Malayalam) means the one who stays tall (Pokkam = tall and Ali = that stays). But the rice grain yields are as low as 1000 to 1500 kg ha^{-1} resulting in very low harvest index.

Pokkali fields are tidal wetlands. The tides that occur twice a day play an important role on the fertility and productivity of this agro ecosystem. Tidal water contains high concentration of Na^+, K^+, Ca^{2+} and Mg^{2+} that are important for the physiological processes in plant cells (Kramer, 1984). The tidal influx, therefore, enriches the soils with these plant nutrients and removes the excess levels of cations like Fe^{2+} and Mn^{2+}, which otherwise can become toxic to the rice plant. In the rhizosphere the concentration of salt in the soil solution fluctuates because of the water supply, drainage, evaporation and transpiration. Na^+ *per se* and its interaction with K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Mn^{2+} and the anions Cl^-, CO_3^-, HCO_3^-, PO_4^{2-} and SO_4^{2-} make the *Pokkali* agro ecosystem very complex and the resulting excess/deficient nutrients influence the rice growth and rice grain yields considerably. The tidal influence on this soil-plant-productivity-environment has not been attempted so far and hence warrants detailed investigation.

The traditional varieties grow here luxuriantly from the very beginning to overcome the salinity, which interferes with the proper metabolic processes of the plant. However, the economic yield does not commensurate with the high biomass production. Identification of saline tolerant rice varieties that can convert at least half of the photosynthates to economic produce can substantially increase rice production from the *Pokkali* tract. Another theoretical alternative is the anionic amelioration of the excess cations in the soil and plant system. Such an effort is expected to reduce excess sodium, iron and manganese uptake as well as to neutralize them to a good extent in the plant, which will in turn help in a favourable partitioning between grain and straw. Such an improvement is expected to reduce lodging as well.

The farming system now followed in the *Pokkali* lands is internationally acclaimed as a sustainable system. The integration of rice and prawn rotationally with the change in the field water salinity augurs well with the rhythm of nature. It doesn't interfere with the natural flow of tidal water, unlike in Kuttanad - the rice bowl of Kerala – where the Thanneermukkom saltwater barrier prevents the entry of brackish water to facilitate the cultivation of rice during the post monsoon season. The retention of tidal flow during the post rice season causes inundation of brackish water into the *Pokkali* fields. Natural recruits of prawn larvae are trapped, grown and harvested after 2-4 months cultural period. The disintegrating paddy stubbles, intentionally left during rice harvest, release nutrients to the system invigourating photosynthetic activity, periphyton production and live feed generation (Purushan, 2002). The live feed thus generated forms the basis of perpetual renewable bio-energic resources for the alternate production of rice and prawn in *Pokkali* fields.

Simultaneous culture of fish with rice during kharif, in addition to the rotational prawn has been recommended based on the field experiments conducted at the Rice Research Station, Vyttila (Rajendran *et al.*, 1994). However, the leaf orientation and plant architecture of the present rice varieties do not allow light infiltration to the ground level which hinder the primary productivity and thus the live feed generation. The awfully low yield of the present popular varieties, also deter the farmers from rice cultivation, as evident from the present *Pokkali* rice area of 4994 ha (Balachandran *et al.*, 2002). An integrated farming system in which the components compliment each other and that can reduce the input cost by invigourating live feed generation, add or maintain soil fertility and in harmony with the nature, alone can be sustainable and increase the productivity and income from unit area of *Pokkali* lands.

It is in this background, the four experiments included in this study were taken up with the following objectives:

1) Characterise the tidal impact on the temporal and spatial changes on chemical characters of *Pokkali* soils.
2) Assess the tidal impact on growth, yield and elemental composition of rice.

3) Identify salt tolerance mechanisms operating in Vyttila-3 and locating the yield limiting factors.
4) Find out the effect of ameliorants on growth, yield and elemental composition of rice with emphasis on sodium uptake and transport.
5) Identify rice varieties and fish species, which are compatible for the simultaneous culture in *Pokkali* fields.
6) Assess the temporal changes in the chemical characters of water and soil consequent to the rice-fish integration in *Pokkali* fields.
7) Explore the feasibility of selective culture of tiger prawn during the high saline post rice season and
8) Economic analysis of the integrated farming system, involving rice-fish simultaneously and prawn rotationally.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The coastal areas in India, stretching over nearly 7000 km in length over the eastern and western border, pose serious problem from the point of view of agriculture productivity owing to various constraints in soil, climate and other natural resources. *Pokkali* soils are the coastal saline soils of Kerala, where a unique system of paddy cultivation is prevalent in an area of 26,400 ha. *Pokkali* tract, characterized by acid saline soils is subjected to tidal influence. Soil acidity, salt-water intrusion and flooding hinder the productivity of these soils. A farming system integrating rice-fish/prawn in harmony with the changing water salinity is desirable for increasing productivity of the *Pokkali* soils. Hence, works under the related topics of acid saline soils, their reclamation and management, salinity tolerance in rice and rice-fish/prawn integrated farming system are reviewed here.

2.1. Salinity

Soil salinity is defined as the presence of excessive concentration of soluble salts in the soil. A soil is saline when the electrical conductivity of the saturation extract is more than 4 dsm^{-1}, the exchangeable sodium percentage is less than 15, and the pH is lower than 8.5 (Yoshida, 1981). The most widely accepted definition of a saline soil is `the one that gives an electrical conductivity in the saturation extract exceeding 4 mmhos cm^{-1} at 25^{O}C'. FAO/UNESCO mapped soils with Ec$_e$'s exceeding 15 mmhos cm^{-1} as strongly saline soils (United States Laboratory Staff, 1954). A saline soil is formed when the influx of salt is greater than efflux. The balance depends on the climate, geomorphology, relief and hydrology (Ponnamperuma, 1984).

2.2. Saline soils of India

The salt affected soils in India are estimated to be 7 million ha (Abrol and Bhumbla, 1971). Saline and alkaline conditions reduce the value and productivity of these soils. Salt affected soils can be classified into saline soils, alkaline soils, saline-alkaline soils, Mg rich soils, gymniferous soils and acid sulphate soils (Szeboles, 1989). The coastal areas, mostly salt affected, are spread over 3.1 million ha comprising more than 30 per cent of the total salt affected soils in India. These include 0.26 million ha of acid sulphate soils in Kerala and Andaman and Nicobar group of islands (Singh, 1999).

2.3. Coastal saline soils of India

Salinity due to incursion of seawater is confined to areas bordering the seacoasts, situated below the high tide level and not artificially protected. In equatorial climate, the salt is easily washed away by the high precipitation, either by downward movement through the soil or by lateral surface drainage (Premachandran *et al.*, 2002). Van Breemen and Pons (1978) categorized the coastal saline soils as potential acid sulphate soils owing to the lowering of the soil pH on oxidation. Potential acid sulphate soils occur in tidal swamps. They have high levels of pyrites, low levels of bases and produce strongly acid sulphate soils when pyrite oxidises to sulphuric acid after drainage. Pyrite formation is favoured in brackish and saline mangrove swamps dissected by many tidal creeks where coastal aggradations are slow. The *Bhasabada* in West Bengal, *Pokkali* in Kerala, *Khazan* in Goa, *Gazani* in Karnataka and *Kharland* in Maharashtra are the coastal saline soils in India (Ghosh and Chakraborti, 1993).

2.3.1. Saline soils in Kerala

Three types of saline soils are recognized in Kerala, based on their location, extent and intensity of salinity and crop season (Padmaja *et al.*, 1994). The *Pokkali* soils are the predominant in this category and they account for 26400 ha. The *Kaipad* soils of Kannur district and *Orumundakan* lands of Alappuzha districts are the other saline soils of Kerala(Tomy *et al.*, 1984).

2.3.1.1. *Pokkali* soils

Pokkali lands are known after the renowned *Pokkali* rice cultivar, which is internationally accepted as gene donor for salt tolerance in rice (Sasidharan *et al.*, 2003). They comprise of low-lying marshes near streams, rivers and other water bodies. They are water logged, ill-drained and subjected to tidal waves (Tomy *et al.*, 1984). Padmaja *et al.* (1994) reviewed the work on soil characteristics of *Pokkali* lands. These soils are characterized by soluble salt accumulation, especially sodium, over an underlying acidic soil containing toxic levels of iron and manganese. These soils are deep, dark bluish black in colour, impervious and clayey in texture, which form hard mass with cracks on drying and turn sticky on wetting.

Sea and backwater tides make these soils saline. The soluble salts comprises mainly of chlorides and sulphates of Na, Mg and Ca. During monsoon season, when rainwater and fresh water from rivers enter the field, salinity is partially washed off.

Under such conditions the inherent acidity of these soils become more dominant. Nair and Money (1968) reported that most of the saline soils of Kerala are acidic with pH ranging from 3.0 to 6.8, in spite of high conductivity. A study on the mechanical composition revealed that they are either clayey or clay loam in texture. Most of these soils have EC values higher than 14 dsm^{-1} (Nair and Money, 1968; Varghese *et al.*, 1970 and Samikutty, 1977). The electrical conductivity of the soil during summer months varies from 12 to 24 dsm^{-1} and average salt content reaches up to 18 ppt. During rainy season, water becomes almost fresh, salt content reduces to traces and the EC ranges between 6 and 8 dsm^{-1} (Tomy *et al.*, 1984).

Detailed fertility investigations in these soils showed the extreme deficiency of phosphorus (Samikutty, 1977). Similar observations had been reported on other acid soils by Bloomfield and Coulter (1973), Ponnamperuma *et al.* (1973) and Bandyopadhyay and Rao, (2001). Surface soils of *Pokkali* lands are richer in potassium. Total sodium content ranges from 0.49 to 2.8 per cent. Samikutty (1977) reported the ranges of exchangeable sodium percentage and sodium absorption ratio values in the equilibrium solution as 13.7 to 83.3 and 11.7 to 34.8, respectively. The cationic and anionic composition indicated that these soils are of Na – Mg – Cl – SO_4 type.

2.4. Constraints for crop production in acid saline soils

Salinity hinders the growth of plants by limiting the moisture availability to the plant because of an increase in osmotic pressure of soil water and by the toxicity of the specific ions. Salinity causes poor vegetative growth, high sterility and ultimately results in low yields of grain and straw. Crop failure due to salinisation and acidification during drought and that due to intrusion of salt water or deep flooding are common. Low pH *per se*, toxicity from Al, Fe, hydrogen sulphide and carbon dioxide, salt injury, toxicity of organic acids and low pH, and deficiencies of P and micronutrients and poor nutrient status are the ill effects reported (Ponnamperuma *et al.*, 1973 and Premachandran, *et al.*, 2002). Regardless of the type of acid sulphate soil, such toxic levels detrimental for wetland rice occur in pH values below 4.5 to 5.0 for seedlings and below 3.5 to 4.2 for older plants. The low availability and fixation of phosphorus in acid sulphate soils may aggravate Al toxicity (Hesse, 1963). The average yield of rice in *Pokkali* soils reported by Tomy *et al.* (1984) is 1.5 t ha^{-1}. They further observed that the margin of profit is very narrow and often involves the risk of total crop failure due to the various adverse soil characters.

2.5. Tidal effect on acid saline soils

The effect of tides on wetlands has been described by various workers. James (2002) observed that the tides act as a stress by causing submergence, soil salinisation and soil anaerobiosis. It also removes excess salts, reestablish aerobic conditions and provide nutrients. They also shift and alter the sediment patterns in coastal wetlands. The action of water and sediments creates spatial heterogeneity, which opens up additional ecological niches.

Potential acid sulphate soils in tidal swamps will not acidify as long as the tidal effects are strong enough to prevent prolonged aeration. In most of such areas, soils are strongly saline and rice can only be grown along river banks where tides back up fresh water every day in the wet season (Van Breemen and Pons, 1978). Restoration of tidal influence leads to a rapid increase in pH and improves productivity when sufficient fresh water is available seasonally, presumably because acidity is inactivated by soil reduction within a few years and most dissolved Fe^{2+} is either removed by tidal flushing or precipitated as insoluble sulphide. Very acid shallow sulfaquepts in non-tidal swamps are highly toxic due to excess iron and aluminium.

The high tide and low tides occurring twice a day regulate the fertility and productivity of the *Pokkali* soils (Sasidharan *et al.*, 2003 and Tomy *et al.*, 1984). Tide brings nutrients to the *Pokkali* fields and removes toxic concentrations of heavy metals. The tidal influx is also helpful for the growth of a broad spectrum of beneficial microbes. Padmakumar *et al.* (2002) attributed the concentration of plant nutrients viz., nitrates and phosphates in the estuarine locations to the tidal influence. The de-acidifying effect of salt water especially in fishponds has been reported by Brinkman and Singh (1982).

2.6. Reclamation of acid saline soils

Saline lands can be converted to croplands by preventing the influx of saline water, leaching the salts out of the root zone, and correcting soil toxicities and nutrient deficiencies (Ponnamperuma, 1984). In areas with marine salinity, the most logical solution is protection by dikes. This practice may, however, be very hazardous in acid sulphate soils (Premachandran *et al.*, 2002). Blocking the entry of salt water will lower the water table during dry season and cause severe acidification. Reclamation of potentially acid saline swamps by dyking to prevent seawater intrusion at high tides often leads to strong acidification and abandonment of the land. This is illustrated by the reclamation efforts in Sierra Leone (Van Breemen and Pons, 1978). Similar experiences were reported from China (Huan-chi-Mao, 1958) and Bangladesh (Bloomfield and Coulter, 1973). After excluding tidal influence in potentially acid swamps in Philippines, salts were rapidly washed using irrigation water in addition to the abundant rainfall. The water table was never more than 10 cm below the surface and good rice yields were obtained during the two years of double cropping. These soils will remain productive only if such permanently wet conditions are maintained. Studies in Philippines have further shown that yields can be increased in saline lands by correcting the accessory growth limiting factors and by using short duration, salt tolerant rice varieties in dry season and intermediate statured salt tolerant rice varieties that have submergence tolerance in the wet season (Akber and Ponnamperuma, 1982).

The reclamation method of *Pokkali* soils is unique in several aspects. The high mobility of the water-soluble salts is made use of in the reclamation of these saline soils. *Pokkali* fields are drained and when the soil becomes dry, are heaped up to form mounds of about 1 m base and half a metre height. With the onset of monsoon the salt is washed off from the soil and water with the dissolved salt is drained off from the field and thus the salinity levels are brought to the below critical level for rice growth (Tomy *et al.*, 1984).

2. 7. Soil ameliorants

The high salt content coupled with very low pH and high concentration of iron and aluminium is responsible for the hazards encountered for rice production and several workers recommended reclamation measures. Several organic and inorganic amendments like pyrite, gypsum, saw dust, composted coir pith, casuarina needles, lime etc. have been attempted by Clarson *et al.* (1984) and Tiwari *et al.* (1984) depending upon the chemical characteristics of the soil.

2.7.1. Lime

Tomy *et al.* (1984) observed that wherever water was available in plenty, washing is the easiest and cheapest method for reclaiming saline soil. In order to expedite washing, they further recommended to throw open the field by forming mounds during the pre-monsoon period to increase the soil surface area for fast weathering action. Kuruvila (1974) recommended flushing the soil followed by application of lime in combination with manganese dioxide and nitrates to raise the pH to 6.5. Kabeerathumma and Money (1974) opined that lime precipitated toxic Al, dispersed dissolved iron concentration after flooding, lowered the peak concentration of hydrogen sulphide and presumably increased the availability of phosphorus.

Padmaja *et al.* (1994), while reviewing the work done on the problem soils of Kerala, reported the ameliorating effects of different levels of lime in the acid saline soils. Application of 1000 kg lime ha^{-1}, half at sowing and the rest at the time of dismantling of mounds, gave the maximum grain yield. Application of lime above 1000 kg lime ha^{-1} reduced the grain yield.

2.7.2. Sulphur

Use of sulphur in many forms as an ameliorant to saline soils had been reported by many (Padmaja *et al.*, 1984; Tiwari *et al.*, 1984 and Singaravel *et al.*, 1999). Lui *et al.* (1989) reported that application of sulphur retarded organic matter accumulation in paddy soil, increased available P and S, and released K from the clay crystal lattice. Sulphur application is known to reduce plant content of iron by reducing leaf sap pH and increasing chlorophyll content (Singh, 1970). Clarson and Ramaswamy (1992) found that rice plant removed 37 to 42 kg S ha^{-1} and that application of elemental S would not facilitate heavy absorption immediately. Singh *et al.* (1990) reported that steady supply of S ensured better growth.

2.7.3. Phosphorus

The role of phosphorus in plant nutrition is well known. However, little is known about its role as an anionic ameliorant in the P deficient acid saline soils. Such beneficial effect of P addition to sulphic tropaquepts had been described by Kawaguchi and Kymu (1969). Phosphorus is one of the three most important elements, along with N and K. However, the concentration of phosphate in soil solution is far lower than that of the other two and is less than 1 ppm in almost all the soils in the world.

Response to applied P varies with type of soil. De Detta *et al.* (1966) reported that only 8 to 27 per cent of the total P in an Indian variety of rice tested was derived from applied P, whereas Majumdar (1973) found that recovery of applied P was only 2 per cent. Kalam *et al.* (1966) reported that magnitude of response to P was much lower than that of N due to the high status of P in the soil, an opinion endorsed by Alexander *et al.* (1973). Mosi *et al.* (1973) concluded that low land rice was not likely to respond to addition of phosphatic fertilizers as upland rice crop, as the release of soil P in a flooded soil may be attributed to reduction of ferric phosphate to the more soluble ferrous phosphate and displacement of phosphate from ferric and aluminium phosphate by organic anions (Islam and Elahi, 1954; Ponnamperuma *et al.*, 1973 and Datta and Datta, 1963). However, the beneficial effects of flooding on phosphate availability depend on the intensity of reduction and on the iron content of the soil. Fujiwara and Ohira (1959) and Fujiwara *et al.* (1959) reported that the supply of large amount of Fe and Mn decreased P uptake. In a P deficient soil absorption of N and K decreased significantly and thus the yield. Reduction in P metabolism remarkably affected the redistribution of absorbed N to panicles (Yoshida, 1981). Gupta and Singh (1989) observed that the application of P decreased the toxic effect of Fe and Al. However, Alam and Azmi (1989) observed an increase in the content of N, P, K, Cu, Mn and Fe with P application and decreased Zn uptake. Phosphorus application decreased the transformation of applied Zn into water soluble and exchangeable form of Zn (Mandal and Mandal, 1990). Haque (1992) reported that P application increased S loss from flooded soil and resulted in a higher negative S balance for rice.

2.7.4. Silica

Rice plant is considered to be a typical siliciphilous plant (Takahashi, 1997). In soils low in silica, application of silica will increase yields of rice (De Datta, 1981). Application of silica up to 1000 kg ha^{-1} has shown increased yield in rice in laterite soils (Potty, 1965). Tadano (1976) attributed beneficial effects of silica to reduced absorption of iron and manganese. Lakshmikanthan (2000) observed that the application of Si ameliorates the limiting influences of Fe and Mn in laterite soils enabling increased rice productivity.

Wang *et al.* (1994) reported that application of silica increased the plant height, grain weight and yield, and decreased helminthosporium leaf spot and shoot blight of rice plant. Bridgit (1999) reported that application of silica kept the uptake of K at higher levels. It's application reduced weed infestation and lowered incidence of pests and diseases.

Application of silica promoted the utilization of P, reduced absorption of iron and manganese (Vora *et al.*, 1979) and stimulated photosynthesis through increased plant height, leaf area expansion resulting in increased carbon dioxide assimilation rate per plant and thus a substantial increase in grain yield (Subramaniam and Gopalaswamy, 1990). Increased grain and straw yields of rice, due to application of silica have been reported by many workers (Takahashi, 1968, 1997; Vyas and Motiramani, 1971; Su, 1982; Lee *et al.*, 1989 and Subramoniam and Gopalaswamy, 1990).

2.8. Crop production in coastal saline soils

Rice is the crop choice world wide for lowland ecologies of varied water regimes and saline-alkaline soils (Siddiq and Shivakumar, 1998). Coastal ecosystem is highly productive but fragile and vulnerable to weather aberrations. Year to year productivity is unpredictable due to various biotic and abiotic stresses. The yield limiting factors in these soils include influx of saline tidal water and submergence during rainy season. Rice is cultivated as a component of the integrated rice-fish production system in the coastal saline soils of West Bengal, Kerala, Goa, Karnataka and Maharashtra (Ghosh and Chakraborti, 1993). In *Pokkali* lands of Kerala, rice is cultivated during the rainy season that lasts from June to October. The fields those lie fallow after the harvest of rice is utilised for the traditional type of prawn culture (Tomy *et al.*, 1984). Purushan (2002) described *Pokkali* fields as an unfailing source of energy offering food security to a diversified group of aquatic plants and animal species and conversion of this energy for the production of a variety of edible crops of paddy, fish and shrimp. Natarajan (1985) described *Bherries* in West Bengal as a similar comparable system. The *Pokkali* fields produce about 1.5 t ha^{-1} of paddy during the low saline phase and an equal quantity of prawn and fish during the high saline phase (Purushan, 2002). Thus, the improvement in the productivity of the coastal saline soils lies with the integration of rice-fish/prawn.

2.9. Salt injury in rice

Rice is moderately susceptible to salinity (Mass and Hoffman, 1977). The degree of injury, however, depends on the nature and concentration of salts, soil pH, water regime, method of planting, age of seedling, growth stage of the plant, and duration of exposure to salt and temperature (Akbar and Ponnamperuma, 1982). Most rice cultivars are severely injured in submerged soil at an Ec_e of 8 to 10 dsm^{-1} at $25^{O}C$; sensitive ones are hurt even at 2 dsm^{-1}. However, Boyko (1966) stated that crop plants could stand much higher concentrations than generally supposed, if the solution consists of physiologically balanced salts as in seawater.

Rice is tolerant to salinity during germination, becomes very sensitive during the early seedling stage, gains tolerance during vegetative growth, again becomes sensitive during pollination and fertilization, and then becomes increasingly more tolerant at maturity. Salinity at the reproductive stage depresses grain yield much more than salinity at the vegetative stage (Akbar and Ponnamperuma, 1982). The symptoms of salt injury in rice are stunted growth, rolling of leaves, white leaf tips, white blotches in the laminae, drying of the older leaves, and poor root growth (Ponnamperuma, 1984).

There are marked interspecific differences in crop tolerance for salinity and within a species, ecotypes exist that can tolerate much higher salt concentration than normal population (Lauchli, 1976).

2.10. Salt tolerant rice varieties

Ponnamperuma (1973) recognized the potential of saline lands for rice production in the densely populated countries of South and South East Asia. For centuries farmers have grown salt tolerant cultivars on the saline soils of India, Burma, Thailand, Indonesia and Philippines. But because of lodging and susceptibility to disease and insect damage, yields are about 1 t ha^{-1}. Varietal screening for adverse soil conditions like salinity had been reported by Fernando (1949), Bhattacharya (1976) and Chandra (1979). An account of the yield potential and quality aspects of several salt tolerant lines developed at the Central Soil Salinity Research Institute, Karnal had been given by Mishra (1999). The dwarf high yielding CSR-10 had become popular among farmers. CSR-13 is fine grained and is suitable to salinity as well as alkalinity. The basmati type CSR-30 has the quality parameters comparable to the national check HBC-19. George *et al.* (1993) had identified *Pokkali, Chettivirippu, Kuruka, Anakodan, Eravappandy* and *Orppandy* as the popular salt tolerant rice cultivars of the coastal saline soils of Kerala. But these varieties are not preferable due to their poor yield potential. The Rice Research Station, Vyttila could release five high yielding rice varieties viz., Vyttila-1, Vyttila-2, Vyttila-3, Vyttila-4 and Vyttila-5 with built in tolerance to salinity (Siddique and Shivakumar, 1998) and to other abiotic stresses like deep water and soil acidity and an yield potential of 4.5 t ha^{-1} (Sasidharan *et al.*, 1997).

2.11. Mechanisms of salt tolerance in rice

Information on the physiological basis of salt tolerance is meager. Janardhanan and Murthy (1970) found higher water content in the shoots of two salt tolerant cultivars than in those of the two susceptible ones. Works done at IRRI revealed that salt tolerance is associated with high electrolyte content in the roots and low content in the shoots. The ability to accumulate potassium in the shoot correlated well with salt tolerance. The salt tolerant *Pokkali* accumulated 13 times more proline in the shoot than when grown in normal soil. Salt tolerance was also associated with tolerance for both high salt concentration and high sodium absorption ratio while chloride was not toxic (Ponnamperuma, 1984).

Shylaraj *et al.* (1995), while investigating on the ionic mechanism of salt tolerance in rice, found that the susceptibility of the high yielding strain Jaya to salinity was due to higher uptake and translocation of Na^+ and Ca^{2+} coupled with reduced uptake and translocation of K^+ in to aerial parts under saline condition. She also observed that the Na^+, K^+ and Ca^{+2} absorption as well as accumulation in different parts varied highly in the genotypes *Pokkali*, *Chettivirippu* and Jaya. She has established a very good compartmentalization of absorbed Na^+ in the lower part of the stem in the saline tolerant *Pokkali*. Mishra (1999) reported that the K^+ content exhibited strong positive correlation with grain yield and Na^+ content showed poor negative correlation. Shylaraj *et al.* (1995) observed negative correlation of Ca^{2+} content with rice yield. Mishra (1999) emphasized the importance of Na/K ratio, which had a significant negative correlation with grain yield.

Yeo and Flowers (1986) observed that the resistance to salinity is conferred not by any single attribute, but is the sum of a number of factors, all of which contribute to the overall resistance and all of which may vary within and between varieties.

2.12. Integrated farming in wetland ecosystem

Integrated farming involving rice and fish is an economically attractive and ecologically viable strategy most suited for the wetland ecosystem (Thampi, 1993). It is an age-old practice in India, China and some of the South East and Far East Asian countries (Iyengar, 1953; Iyengar, 1962 and Ghosh, 1981). Information on efficient rice-fish farming systems in wetland regions of Malayasia, Malawi in South Africa (Noble and Rashidi, 1990), China (Huashan *et al.*, 1992), Philippines (Dela Cruz, 1992) and India (Ghosh *et al.*, 1994) are available.

Aquaculture, especially fish and shrimp could be integrated with rice cultivation (Natarajan and Ghosh, 1982; Dela Cruz, 1989; Biswas, 1990; Light foot *et al.*, 1993 and Rajendran *et al.*, 1993). Rice cum brackish water aquaculture in coastal saline soils of India is an ideal and potential integrated farming system (Natarajan, 1983; Ghosh *et al.*, 1985 and Biswas *et al.*, 1990). Rice-prawn integration in the *Pokkali* fields of Kerala is a centuries old practice (Panikkar, 1937; Purushan, 1987 and Rajendran, 1993). Roy *et al.* (1990) suggested rice-fish culture with fruit crops and rice-fish-vegetable farming systems for deep water rice growing regions of West Bengal. Padmakumar *et al.* (2003) improved the rice-fish rotational system in to a multilevel integrated farming model involving rice and fish in the lowlands, and pig, poultry and cattle along with coconut, banana and pineapple on the dikes in Kuttanad, the rice bowl of Kerala. Deep-water rice cum fish culture was suggested by Das *et al.* (1990) and Das and Roy (1995). Inclusion of semi intensive aquaculture in integrated farming system was less risky because of their efficiency derived from synergism among enterprises, their diversity of produce and their environmental soundness (Lightfoot *et al.*, 1993). Combining aquaculture with rice production generated additional rice yield, additional income and reduced inputs due to the beneficial action of fish (Lazard and Cacot, 1997; Purushan, 2002; Rajendran *et al.*, 1993 and Padmakumar *et al.*, 2003).

Cultivation of rice and fish made good use of agricultural lands, produced fish for home consumption and generated additional income from fish sales (Fedoruck and Leelapatra, 1992). Li (1992) found that balanced ecosystem was obtained due to integration of rice and fish. Waibel *et al.* (1994) observed that the net profit in rice-cum-fish field was 2.5 times greater than fields in which rice alone was cultivated.

Integrated farming with fish culture was found to be ideal for better utilization of farm resources and conservation of the ecosystem in rain fed lowland farming (Sinhababu, 1994). Aquaculture as an integrated enterprise with rice not only yielded fish protein, but also additional income and employment (Mathew, 1991). Integrating aquaculture into crop based farming system played an important role in reversing environmental degradation, improving human nutrition and increasing farmers' purchasing power (Lightfoot, 1991).

2.13. Rice-fish integration

Although a large number of crops could be integrated with fish, the important ones are rice, coconut, banana, jute and vegetables (Thampi, 1993). Among these, the rice-fish combination was the most promising and had greater potential for development. Padmakumar *et al.* (2003) observed that the rice-fish integration was the most acceptable integrated farming system owing to its comparative advantage.

Hongx (1995) reported that rice fish farming was not only limited to the household economy and production for personal or family consumption but was a part of farmland improvement, soil improvement and environmental protection. The overall productivity of rice fields also increased. Luo-Guang-Aug (1995) observed that in the rice-fish system both the components developed harmoniously, each complementing the growth of the other and thus they could achieve their full production potential. He has further observed the reduced pesticide requirement owing to the pest control capability of the fish component. Mathur (1996) observed that the rice-fish system improved the linkage between rice and fish and resulted in better resource utilization and conservation of ecosystems besides increasing farm income. According to Ninawe (1997) integration of rice and fish could minimize the risk and helped to obtain a sustained production in low land areas. Rothius *et al.* (1998) opined that the contributions to environmental stability, bio-diversity, farm diversification and home nutrition are the main beneficial effects of rice-fish integration. Guttman (1999) observed that 65 to 75 per cent of the animal protein requirement of the poor rural households in Cambodia could be provided by the rice-fish integration.

In China, the pesticide consumption could be significantly reduced, since the populations of rice hoppers and leaf rollers were reduced by 2 to 6 times in rice – fish integration systems (Yinha, 2002). Composite culture of edible fish in rice fields in Cauvery delta of Tamil Nadu resulted in substantial reduction in the immature mosquito populations (Victor *et al.*, 1994). Yinha (2002) reported that the rice - fish system eradicated pathogens and parasites like hosts of malaria, encephalitis and filaria in China and this could improve the living standard and provide a better level of health to farmers. Luo-Guang-Aug (1995) also observed that, the rice-fish integration could eradicate mosquito larvae and snails thereby reduced malaria, filariasis and snail fever.

Pandiarajan (1995) reported that rice-fish integrated farming system increased the overall productivity of the system, lowered the cost of cultivation, increased the yield of rice and lowered the incidence of pests. Padmakumar *et al*, (2003) emphasized the economic and ecological superiority of integration of rice and fish over the other advantages.

2.14. Growth and yield of fish in rice-fish system

The survival and growth of fish in rice-fish integrated farming systems depends on a number of factors. Rajendran *et al.* (1993) identified prevention of light penetration by the leaf canopy, especially by the tall rice varieties and consequent low plankton production, submerged and floating aquatic weeds, algal scum formation, depletion of oxygen due to post harvest decay of stubbles, short cultural period, abnormal rise in salinity in the post rice period and invasion of undesirable species as the main problems affecting the survival of fish in rice-cum-fish system in coastal saline soils. Datta *et al.* (1984) reported 72 to 75 per cent recovery of fish while Yung-Sang-Kim (1990) reported more than 90 per cent of its survival. Sinhababu *et al.* (1992) found that recovery of fish in rice-fish system ranged from 38.1 to 63 per cent. Thampi *et al.* (1981) recorded a survival of 61.3 per cent for *Etroplus suratensis*. Mathew and George (1987) got an average survival rate of 11.6 per cent only for carps in the rice cum fish culture in *Pokkali* fields. However, the survival rate of *Mugil cephalus* and *Chanos chanos* ranged from 54 to 70 per cent. Padmakumar *et al.* (2003) pointed out the necessity to stock fingerlings of size beyond the pray-able size of predatory fishes.

Natarajan and Ghosh (1982) reported an yield of 100 to 400 kg fish ha^{-1} within a short span of 4 months under simultaneous system of rice-fish culture in West

Bengal. Rajendran *et al.* (1993) got an yield of 300 kg ha^{-1} with an average size of 153 g for *Oreochromis mossambicus* in Pokkali fields of Kerala while Thampi *et al.* (1981) reported an yield of 183 kg ha^{-1} for *E.suratensis.* Das *et al.* (1990) registered 575 kg ha^{-1} of fish yield from deep-water rice fields. As per Biswas *et al.* (1990), the fish yield was 304 kg ha^{-1} during wet season and 278 kg ha^{-1} during summer with brackish water rice - fish culture.

The fish yield in paddy culture with Catla, Rohu, Mrigal and Java punti was 230 kg ha^{-1} while, it was only 170 kg ha^{-1} under monoculture of Java punti (Ghosh *et al.* 1994). In the farmer participatory on farm field trial in an 8 ha polder, Padmakumar *et al.* (2003) recorded a fish production of 2500 kg ha^{-1} when the rice-fish culture was done on a rotational basis.

Rajendran *et al.* (1993) recorded an average prawn yield of 900 kg ha^{-1} from the conventional prawn filtration after rice. Pillai (1999) reported a yield range of 517 to 614 kg ha^{-1} for the traditional prawn filtration after rice, while for an improved traditional culture of *Penaeus monodon* accounted 261 kg ha^{-1} production. Yields of 370 kg ha^{-1} and 382 kg ha^{-1} (Jose *et al.*, 1987) were obtained for the selective stocking of *P.indicus.* Padmakumar *et al.* (2003) reported a prawn yield of 937 kg ha^{-1} from rice-prawn integration, where *Macrobrachium rosenbergii* was the dominant stocking component.

2.15. Rice-fish culture systems

The major forms of rice-fish culture systems widely prevalent are: the Synchronous or simultaneous system (Mathew and George, 1987 and Thampi, 1993), Alternate or rotational system (Panikker, 1937; Padmakumar *et al.*, 2003) and Inter phase system (Thampi, 1993 and Ghosh, 1981). Sequentio-synchronous system is a combination system prevalent in the coastal saline soils of West Bengal (Ghosh and Chakraborti, 1993).

In the synchronous system, fish is grown along with rice while in the sequential system, fish is stocked and grown after the harvest of rice. In the inter-phase system, fish culture is limited in between two rice crops. Synchronous system was commonly encountered in India to raise table size fish and fingerlings, along with paddy, particularly in monsoon months (Natarajan and Ghosh, 1982). The simultaneous system of rice-fish system is carried out in the eastern parts of India, while the sequential system is prevalent in most of the maritime states, where the sequential brackish water farming during the fallow period, after the harvest of rice is quite in vogue (Ghosh and Chakraborti, 1993). Similar integration of crustacean aquaculture with coastal rice is practised in some parts of the South East Asian countries like Vietnam, Indonesia and Java (Sanh *et al.*, 1993).

2.16. Simultaneous rice-fish culture

For simultaneous rice-fish culture several modifications were required to be made in the paddy field (Padmakumar *et al.*, 1988). Strengthening of bunds and providing peripheral or criss-cross channels were the major requirements. A sluice with shutters generally facilitated exchange of water and regulation of water level (Rajendran *et al.*, 1993). Ditch-pit method, ditch-ridge method and ditch-pond methods are also suggested. In ditch-pit method, ditches as wide as two rows of rice and 24 cm deep and pits of size 50 to 70 cm deep and one m^2 area were dug and the fishes were reared in ditches and pits. In ditch-ridge method, a semidry rice planted on raised ridges was combined with fish culture in the ditches. In the ditch and pond method, a small pond covering 6 to 8 per cent of the total area was dug at a corner of rice field and ditches of 30 to 50 cm deep and 30 cm wide, dug and connected to the pond were used for fish culture. Padmakumar *et al.* (2003) observed that the modifications required in the rice field for simultaneous rice-fish culture caused hindrances for its adoption in the large polders in Kuttanad the rice bowl of Kerala.

2.17. Rotational rice-fish culture

Rotation of crops and fish in the same field has many advantages. The package of practices of both the rice and fish can be followed without any compromise (Thampi, 1993). It allows the use of machinery and to a certain extent insecticides and pesticides for rice production and allow greater depth for fish culture. In large polders the rotational system of rice-fish culture was found to be more advantageous, as it permitted adoption of management practices more effectively for rice and fish (Padmakumar *et al.*, 2003). The *Bhasabada* in West Bengal, *Pokkali* in Kerala, *Khazan* in Goa, *Gazani* in Karnataka and *Kharland* in Maharashtra are the best examples of rotational rice-fish culture in India in which entrapping and culturing of tide borne prawn seeds within the impounded rice fields and the traditional culture of shrimps and estuarine fishes are done (Ghosh and Chakraborti, 1993).

2.18. Rice-fish/prawn integration in *Pokkali* fields.

The *Pokkali* rice-fish/prawn integration has been dealt with by several workers (Panikkar, 1937; 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 (Panikkar, 1952; Panikkar and Menon, 1956; Gopalan *et al.*, 1980; George *et al.*, 1993 and Pillai, 1999). 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 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 and grow (Rajendran, *et al.*, 1993). The decomposing paddy stubbles release nutrients to the shrimps and they grow (Purushan, 2002). The synergistic 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 (Purushan, 1996).

2.19. Fish species

The fish species generally selected for rice cum fish culture have characteristics to adapt to the rice ecosystem. Likangmin (1989) suggested that herbivorous and omnivorous fishes tolerant to high water temperatures and low night time dissolved oxygen levels were suited for simultaneous culture with rice. Rajendran *et al.* (1993) opined that the candidate species must be capable to withstand the 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 criteria endorsed by many (Rajendran *et al.*,1993 ; Rangaswamy *et al.*, 1995).

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. Species such as common carp and grass carp were found to be versatile species suitable for culture in paddy fields (Padmakumar *et al.*, 1993). Thampi (1993) identified *Cyprinus carpio, Oreochromis mossambicus, Trichogaster pectoralis, Chana striatus* and *Clarius batrachus* for the simultaneous rice-fish culture. Padmakumar *et al.* (1993) identified *Labeo rohita* as the most promising fish in terms of growth and performance. Since the rearing of fish is continued even after the rice harvest and when salinity rose to higher values in *Pokkali* fields, species, which are euryhaline are more preferable for rice cum fish culture (Rajendran *et al.*, 1993). *Punitus javanicus, Labeo bata, Catla catla, Labeo rohita, Cirrhinus mrigala, Cyprinus carpio, Chanos chanos*, and *Mugil cephalus* were the fish species with varying degree of salinity tolerance identified by him. Thampi (2002) identified the brackish water species *Etroplus suratensis, Chanos chanos, Mugil cephalus* and the fresh water prawn *Macrobrachium rosenbergii* for simultaneous culture during monsoon season. Kamal (1990) observed the composite culture of three exotic carps *viz.*, grass carp, silver carp and common carp were beneficial. The increased productivity of composite culture over monoculture was highlighted by Chandrasekharan *et al.* (1994) also. In China the fish species suited for rice-fish culture were identified as grass carp, common carp, Nile tilapia, silver crucian carp, local red carp and variegated carp (Wan-Banghuai and Zhang-Qianlong 1995). Rangasamy *et al.* (1995) reported that polyculture fingerlings were preferred to monoculture because the growth rate within a year was found to be economical in polyculture. Chinnusamy *et al.* (2001) indicated that polyculture, having the advantage of utilizing the nutrients available in the entire water column, maintained a higher productivity with lesser cost of production.

The utility of *Oreochromis mossambicus* as a suitable component of the rice-fish integrated farming system was amply illustrated by Rajendran *et al.* (1994). It's 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).

2.20. Rice varieties compatible for rice-fish integration

Culture of fish along with rice necessitates certain morphological characters for rice. Varieties either tall or semi-tall that can thrive under flooded condition were more desirable (Thampi, 2002). When traditional tall varieties like *Pokkali* are grown they prevented the light penetration and thus the plankton production in the rice field (Rajendran *et al.*, 1993). Padmakumar *et al.* (2003) used traditional *Chettivirippu* during the initial years but switched over to the high yielding semi tall *Pavizhom* for a simultaneous farming regime.

2.21. Effect of rice on fish/prawn

The complementary effects of rice on its aquatic components have been documented by a number of workers (Bahanot and Saha, 1981, Pillay and Wim, 1979; Mandal, 1981, Padmakumar *et al.*, 2003 and Rajendran *et al.*, 1993). Rice cultivation was practised almost universally under submerged field condition, which favoured fish culture by retaining standing water (Mandal, 1981). In low lands, water logging and impeded drainage favoured the cultivation of rice and these fields developed rich aquatic fauna and flora favouring aquaculture (Bahanot and Saha, 1981). Fish culture was more compatible with rice farming wherever rice fields retained water for three to eight months in a year (Pillay and Wim, 1979). Cultivation of rice continued to improve the biological potential of fields since the stubbles left after the harvest decomposed and provided shelter and feed for the growth of microorganisms, which formed ideal food for fish and shrimps (Purushan, 2002 and Bahanot, 1981). The Production of zoo and phytoplankton was high in the rice bottom, since the rice fields are fertile. Padmakumar *et al*, (2003) opined that the production cost of fish could be substantially reduced since the rice crop residues provided adequate detrital supplements to fishes. In the rotational rice-prawn system the shrimps took shelter in between the decaying paddy stalks. The decomposing paddy stubbles released nutrients to the system invigorating periphyton production and live feed generation, in addition to transforming itself as detritus (Purushan, 2002).

2.22. Effect of fish on rice

Integrated rice-fish systems offer possibilities of increasing rice yields as much as 15 per cent, as reported by several workers (Hora and Pillay, 1962, Lightfoot *et al.*, 1992 and Naegel, 1988). Dashu *et al.* (1985) reported better growth of rice and increase in yield by 8.0 to 47.3 per cent in fields with rice-fish culture. Manjappa *et al.* (1987) observed that although the rice area was reduced by 14 per cent, there was little difference in grain yield from plots with fish and those without fish. Rice yields increased in rice-fish system at an average of 9.08 per cent in irrigated and 9.54 per cent in rain fed farming in Thailand (Dela Cruz, 1989). Kim and Ree (1990) observed that the yield of rice in rice-fish farming was comparable with or even better than that of rice in monoculture.

Li-Xieping *et al.* (1995) and Wan-Banghuai and Zhang-Qianlong (1995) found that even with 10 per cent reduction in planting area due to fish trenches and ponds, the yield of rice with or without fish in the fields were about the same. Brazman and Das (2000) also reported, no significant decline in rice yields and in some cases even an increase due to rice-fish culture, even with loss of area due to fish ditches. Mathur (1996) reported increase in grain yield by 5 to 15 per cent and straw yield by 5 to 9 per cent, which he attributed to synergism between rice and fish, in a farmer participatory trial in Bangladesh. Padmakumar *et al.* (2003) observed perceptible increase in rice yield, which he attributed to the improvement in soil conditions. An increase in rice yield of 10 to 20 per cent (Lightfoot *et al.*, 1992 (a), Dela Cruz and Cagauan, 1992 and Dube, 1995) or even up to 30 per cent (Leelapatra *et al.*, 1992 and Ghosh *et al.*, 1994) was recorded when fish culture was practiced in rice fields. The increase in rice production and yield attributes in rice fish culture was attributed to the beneficial role on rice by aeration of the soil and subsequent release of soil nutrients (Sinhababu *et al.*, 1992 and Tiwari, 1993). The improved oxygen exchange on account of the movement of fish in rice field enhanced the dissolved nutrient mobilisation due to mechanical stirring of the impounded water (Sinhababu, 1994).

Wu-Langhu (1995) reported fish culture along with rice improved the number of panicles, grains panicle^{-1} and filled grains, and thus increased the yield. However, the test weight of rice grain was not significantly influenced by rice-fish culture. A 17.1 per cent increase in total dry weight of whole rice plant in rice-fish system was reported by Li-Duanfu *et al* (1995). Luo-Guang-Ang (1995) observed the removal of basal leaves of rice plant and morbid leaves by large grass carp, which allowed air and sun light to pass through the leaf canopy easily.

2.23. Effect of fish on soil fertility

Reports on the beneficial effect of rice-fish integration are plenty. FAO (1988) reported that the excreta of fish directly fertilized the water in rice fields. Likangmin (1989) and Fagi *et al.* (1989) found that the fish excretions in rice-fish system increased the concentrations of N, P, K, Ca and Mg in rice fields. The culture of Nile tilapia with rice contributed N accumulation through their faeces and decreased ammonia volatilization by reducing the biomass of micro algae that increased the floodwater pH (Lightfoot *et al.*, 1990 b and Dela-Cruz and Cagauan, 1992). Thampi (1993) reported that 50 kg of fish produced enough humus to fertilize 670 m^2 crop land. The utility of fish-excreta for enhancing the soil fertility has also been reported by Zon and Sanford (1999). Fagi *et al.* (1992) found that the inclusion of common carp in rice cultivation increased the P availability. Li-Xieping *et al.* (1995) reported an increase of P and K by 76.1 and 20.7 per cent respectively by rice-fish integration.

An increasing trend in organic carbon to the tune of 6.4 per cent was observed due to rice-fish culture with Catla and Rohu (Sinhababu *et al.*, 1992). Wu-Langhu (1995) observed that only about 30 per cent of the weeds and plankton eaten by fish was digested and absorbed and about 70 per cent was excreted, which increased the organic matter content and fertility of the soil. Sinhababu (1994) reported a 10 per cent increase in organic matter on account of rice-fish integration. Wu-Langhu (1995) observed an average organic carbon content of 3.52 per cent for soils in rice-fish culture against 3.29 per cent for the control. Wang-Zaide *et al.* (1995) found a soil organic matter content of 1.23 per cent in rice-fish system as compared to 1.09 per cent in a field with out fish. Li-Xieping *et al.* (1995) also observed an increase from 2.0 to 2.4 per cent in the organic matter content and 0.14 to 0.16 per cent in total N in the soil due to rice-fish culture.

Likangmin (1989) reported that in an integrated system with rice and fish, all most all the biomass *viz.*, aquatic weeds, phytoplankton and photosynthetic bacteria were consumed by fish, resulting in effective utilization of nutrients in the field. Integrating rice and fish in wetlands was found to improve the soil fertility through recycling of nutrient rich residues and better utilization of farm resources (Lightfoot *et al.*, 1990 a, Lightfoot *et al.*, 1993 and Sinhababu, 1994).

2.24. Ecological benefits

Liu-Chung-Chu (1995) stated that by rice-fish integration the recycling of nutrients, substances, and energies in the rice ecosystem was enhanced and the environment was improved in rice-fish farming system. Purushan (2002) observed that the rice-fish/prawn system in the *Pokkali* lands continuously replenished the nutrients, which in turn helped to yield paddy and fish sustainably. Padmakumar *et al.* (2003) concluded that rice-fish integration could not only make rice production attractive by increasing productivity and profitability but also render it more organic and environment friendly. Purushan (2002) further observed the rice-fish system in *Pokkali* lands as an economically viable, environmentally sound and socially acceptable enterprise.

2.25. Economic benefits

Lightfoot *et al.*, (1990 a) observed a substantial reduction in cost of rice production in rice-fish system on account of the reduction in pesticide use, fertilizer consumption and weeding cost. Padmakumar *et al.* (2003) reported that the integration helped to reduce cost of production of rice appreciably by 17.6 per cent, besides, increasing yield by 52 per cent. He further observed that indirect control of pests and diseases resulted in 54 per cent reduction in cost of plant protection and 27.2 per cent reduction in weeding cost and a saving of 100 per cent on weedicide. In the rice-fish/prawn system of *Pokkali* lands the farmers generally practised an organic rice culture devoid of fertilizers and plant protection chemicals, which significantly reduced the rice production cost (Tomy *et al.*, 1984).

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The experiments of the research project entitled "Enhancing the productivity of the rice-fish/prawn farming system in Pokkali lands" were conducted during 1999-2001 at the Rice Research Station, Vyttila under the Kerala Agricultural University. The details of materials used and methods adopted are given below.

Location

The Rice Research Station, Vyttila is the pioneer and the only institution in Kerala that investigates the various aspects of the rice based farming system of the salinity prone coastal tracts. Reclamation and management of *Pokkali* soils, breeding varieties suitable to the acid saline soils and developing sustainable production models suitable to the tract are the mandates of the station. It is located at 10^0N latitude and 76^015'E longitude at an altitude of 1.2 m above mean sea level.

Weather and climate

The area enjoys a typical humid tropical climate. The average annual rainfall is 3100 mm. The maximum day temperature varies from 27^0C to 34^0C and minimum temperature from 21^0 to 28^0C. Humidity is often high, exceeding 80 per cent. Heavy rains occurring continuously for a week result in flooding, which is usual during the South-West monsoon period. The mean weekly averages of important weather parameters observed during the experimental period are presented in Appendix-I and, Fig.1 (a) and (b).

Soil

The soil is clay loam in texture and belongs to the great soil group of tropaqualf under the hydromorphic saline type. These soils are basically acidic with an average pH range of 3.0 to 5.5. During summer months, the ingress of salt water makes them saline.

Fig. 1 (a)Weekly weather at Vyttila during June 1999 - May 2000

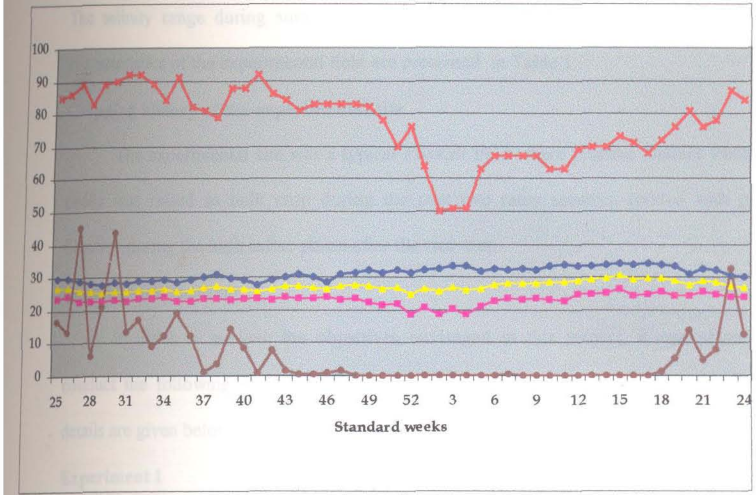
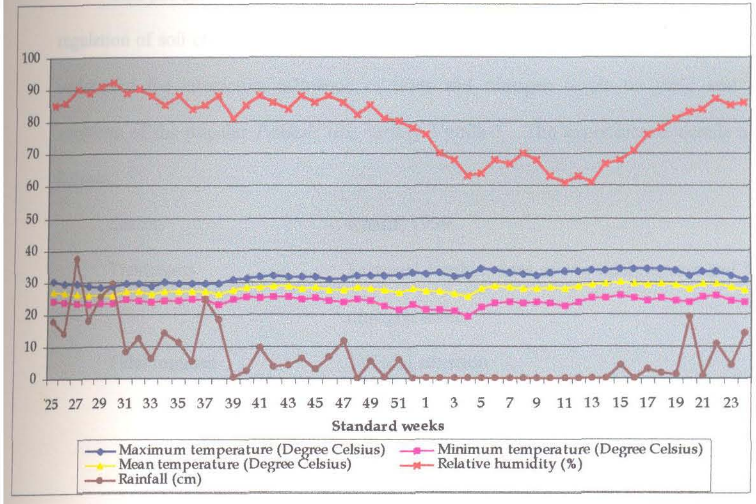


Fig. 1 (b) Weekly Weather at Vyttila during June 2000 - May 2001



The salinity range during summer months is 12 to 24 dsm^{-1}. The physico-chemical characteristics of the experimental field are presented in Table 1.

Cropping history of the experimental site

The experimental site was a typical *Pokkali* field where a saline tolerant variety of paddy was raised as bulk crop during the past two rainy seasons, rotated with prawn filtration during the high saline phase after the rice crop.

Experimental methods

In order to achieve the objectives envisaged in this project, it was planned to conduct the following three experiments for two successive years. The experimental details are given below.

Experiment I

Response of rice to applied nitrogen in tidal and non-tidal situations

This pot culture experiment was laid out during 1999 to study the role of tides on regulation of soil chemical properties and enrichment of nutrients in *Pokkali* soils and to understand the interactive influence of tides and nitrogen levels on yield and yield attributes of the popular *Pokkali* rice variety Vyttila-3. The experimental details are as follows:

Season : Kharif, 1999

Treatments : Factorial combinations of two tidal regimes and five nitrogen levels

Tidal regimes : 1) Tidal situation
2) Non-tidal situation

Table 1. Physico-chemical properties of the experiment site during June, 1999

(a) Physical properties	
Apparent specific gravity	0.67
Absolute specific gravity	1.80
Water holding capacity	59.15
Porosity	40.00
Mechanical composition	
Coarse sand (%)	4.65
Find sand (%)	23.37
Silt (%)	17.98
Clay (%)	51.37
(b) Chemical properties	
Soil reaction (pH)	3.80 (yearly range 2.90 – 5.90)
Electrical conductivity (ds m^{-1})	3.00 (Range 2.00 to 12.20)
Organic carbon (%)	3.10
Available P (kg ha^{-1})	9.35
Available K (kg ha^{-1})	819
Neutral Normal Ammonium Acetate Extractable	
Ca (ppm)	15.18
Mg (ppm)	3.79
DTPA extractable	
Fe (ppm)	1727.00
Mn (ppm)	20.30
Zn (ppm)	11.30
Cu (ppm)	33.20

Nitrogen levels : 1) No nitrogen
2) 20 kg N ha^{-1}
3) 40 kg N ha^{-1}
4) 60 kg N ha^{-1}
5) 80 kg N ha^{-1}
Design : C.R.D.
Replications : 3
Variety : Vyttila-3

Pots of 30.0 cm dia. were filled with surface soil (0-15 cm) of typical *Pokkali* field at 20 kg pot^{-1}. The soil was puddled well and 25- day -old Vyttila-3 seedlings were planted in each pot at the rate of 4 hills pot^{-1}. Nitrogen as per the treatment schedule was applied at the time of planting. The pots with the treatments of factorial combinations of tidal situation and nitrogen levels were kept in *Pokkali* fields in such a way that the tidal flow could occur regularly through them without any hindrance. The remaining pots with the non-tidal treatments were kept on the field bund. The water level of these pots were regularly monitored and maintained at 5 cm depth.

Experiment II

Tidal effect on *Pokkali* soils and performance of rice

To evaluate the impact of tidal action on the soil and its consequence on the performance of *Pokkali* rice cultivars, field experiments were conducted during the kharif seasons of 1999 and 2000, separately under tidal and non – tidal situations.

The field experiments were laid out in two adjacent, identical fields. In one field tidal inundation as in any typical *Pokkali* field was allowed, while in the other, the entry and exchange of tidal water, was blocked by erecting an earthen bund. The same fields with the same design, lay out, plot size and spacing were used during both the years of the study (1999 and 2000).

The *Pokkali* varieties included in the study were Vyttila-3, a popular saline tolerant rice variety and two advanced pre-release cultures *viz.*, Cul. 1026 and *Chettivirippu* mutant. The Vyttila-3 is a tall variety that lodges towards reproductive phase Cul. 1026 is semitall and spreading while *Chettivirippu* mutant is dwarf and compact. The degree of salinity tolerance of all the three varieties is in the decreasing order with Vyttila-3 having the maximum tolerance followed by Cul. 1026 and *Chettivirippu* mutant. The experimental details are given below. The lay out of the experiment field is given in Fig. 2 (a) and (b).

Seasons : Kharif, 1999 and 2000
Treatments : 3 (Rice cultivars)
(1) Vyttila-3
(2) Cul. 1026
(3) *Chettivirippu* mutant
Design : R.B.D.
Replications : 7
Plot size : Gross - 20.25 m^2 (5 m x 4.05 m)
Net - 14.49 m^2 (4.2 m x 3.45 m)
Spacing : 20 cm x 15 cm

Experiment III

Impact of soil ameliorants on growth, yield and nutrient uptake of *Pokkali* rice

Impact of soil ameliorants on the growth and yield of *Pokkali* rice variety Vyttila-3 was studied for two successive kharif seasons starting from 1999. During the first season two levels each of lime, silica, phosphorus and sulphur were compared with an untreated

Fig. 2 (a) Layout of Experiment II (a) Tidal

4.05 m

5.00 m

V_3	V_1	V_2	V_1	V_3	V_2	V_3
V_1	V_2	V_3	V_2	V_1	V_3	V_1
V_2	V_3	V_1	V_3	V_2	V_1	V_2
R_1	R_2	R_3	R_4	R_5	R_6	R_7

Fig. 2 (b) Layout of experiment II (b) Non-tidal

4.05 m

5.0 m

V_3	V_2	V_3	V_1	V_2	V_1	V_3
V_1	V_3	V_1	V_2	V_3	V_2	V_1
V_2	V_1	V_2	V_3	V_1	V_3	V_2
R_1	R_2	R_3	R_4	R_5	R_6	R_7

V_1 - Vyttila-3
V_2 - Cul. 1026
V_3 - Chettivirippu mutant

control, while during the second season the promising level of these ameliorants alone and in combination were evaluated. The experiment details are given below.

Season 1 : Kharif, 1999

Treatments : 9

(1) Lime – 500 kg ha^{-1} (L 500)
(2) Lime – 1000 kg ha^{-1} (L1000)
(3) Fine silica – 250 kg ha^{-1} (Si 250)
(4) Fine silica – 500 kg ha^{-1} (Si 500)
(5) Phosphorus – 30 kg ha^{-1} (P 30)
(6) Phosphorus – 60 kg ha^{-1} (P 60)
(7) Sulphur – 300 kg ha^{-1} (S 300)
(8) Sulphur – 600 kg ha^{-1} (S 600)
(9) Control

Design : R.B.D.

Replications : 3

Plot size (m^2) : Gross - 20.25 m^2 (5 m x 4.05 m)
Net - 14.49 m^2 (4.2 m x 3.45 m)

Spacing : 20 cm x 15 cm

Season II : Kharif, 2000

Treatments : 10

(1) Lime – 1000 kg ha^{-1} (Ca)
(2) Fine silica – 125 kg ha^{-1} (Si)
(3) Phosphorus – 60 kg ha^{-1} (P)

(4) Sulphur – 600 kg ha^{-1} (S)

(5) Lime–1000 kg ha^{-1} + Fine silica–125 kg ha^{-1} (CaSi)

(6) Lime – 1000 kg ha^{-1} + Phosphorus 60 kg ha^{-1} (CaP)

(7) Lime – 1000 kg ha^{-1} + Sulphur – 600 kg ha^{-1} (CaS)

(8) Lime – 1000 kg ha^{-1} + Fine silica – 125 kg ha^{-1} + Phosphorus – 60 kg ha^{-1} (CaSiP)

(9) Lime – 1000 kg ha^{-1} + Fine silica – 125 kg ha^{-1} + Phosphorus–60 kg ha^{-1} + Sulphur - 600 kg ha^{-1} (CaSiPS)

(10)Control

Design : R.B.D.

Replications : 3

Plot size m2 : Gross - 20.25 m2 (5.00 m x 4.05 m)

Net - 14.49 m2 (4.20 m x 3.45 m)

Spacing : 20 cm x 15 cm

The lay out of the experiments are furnished in Fig. 3 (a) and (b) and the source of various ameliorants used in the experiment is given in Table 2.

Experiment IV

Plant ideotype suited to rice cum fish culture in Pokkali fields.

This experiment was conducted for two years during 1999 and 2000. Factorial combinations of three rice varieties differing in morphological characters and three fish

Fig. 3. (a) Layout of the Experiment III - Kharif, 1999

4.05 m

5.00m

Si250	S600	C	P60	Si500	L1000	L500	P60	S600
L500	S300	P60	P30	Si250	S300	S300	L1000	Si500
L1000	P30	Si500	C	L500	S600	P30	Si250	C

R_1 R_2 R_7

L500 – Lime 500 kg ha^{1},
Si 250 - Silica 250 kg ha^{1},
P30 – Phosphorus 30 kg ha^{1},
S 300 – Sulphur 300 kg ha^{1},
C - Control

L1000 – Lime 1000 kg ha^{1},
Si 500 - Silica 500 kg ha^{1},
P60 - Phosphorus 60 kg ha^{1},
S 600 - Sulphur 600 kg ha^{1},

Fig. 3.(b) Lay out of Experiment III - Kharif, 2000

4.05 m

5.0 m

LSiP	C	LP	Si	L.	C
L	LSiPS	LSiPS	LS	LP	LS
LS	LSi	LSi	P	LSiPS	LSiP
P	S	LSiP	S	P	LSi
LP	Si	C	L	S	Si

R_1 R_2 R_3

L1000 – Lime 1000 kg ha^{1},
P - Phosphorus 60 kg ha^{1},

Si - Silica 125 kg ha^{1},
S – Sulphur 600 kg ha^{1},

culture treatments were evaluated for their compatibility and yield in a simultaneous rice-fish integrated system. The experimental details are given below.

Seasons : Kharif, 1999 and 2000

Treatments : 9 (Factorial combinations of 3 rice varieties and 3 fish culture treatments)

Rice varieties

1) Vyttila-3
2) Cul. 1026
3) *Chettivirippu* mutant

Fish culture treatments

1) No fish
2) Male Tilapia (monosex culture)
3) Etroplus (during 1999)/
   Rohu (during 2000)

Design : R.B.D.

Replications : 3

Plot size :

	Rice	Fish
Gross -	72.00 m^2 (18.0 m x 4.0 m)	110 m^2 (22.0 m x 5.0 m)
Net -	55.68 m^2 (17.4 m x 3.2 m)	110 m^2 (22.0 m x 5.0 m)

Spacing : 20 cm x 15 cm

Rice plots having a length of 18.0 m were laid out across a paddy field by forming bunds at 4.0 m apart, thus giving a gross area of 18 m x 4 m for rice. On either side of the paddy field, peripheral ditches of 2.0 m width and 0.5 m depth were provided. These ditches were separated at 5.0 m interval with nylon nets, so as to give a ditch of 2.0 m x 0.5

Plate-1. Seedlings on mounds ready for dismantling and spreading

Plate-2. Experimental planting in progress

Plate-3. A view of the rice-fish dual culture field experiment

Plate-4. Pokkali rice during the panicle initiation stage m on either side of the rice plot. Thus the rice cum fish culture plot had a gross area of 22.0 m x 5.0 m (110 m^2). Two rows of rice were treated as boarder plants giving a net area of 17.4 m x 3.2 m (55.68 m^2). Along the 18.0 m length of the rice plot, marginal channels of 0.5 m width and 0.5 m depth, connecting the peripheral ditches were also provided to facilitate free movement of fish in the rice field. Thus, the total area exclusively for fish including the peripheral ditches and marginal channels was 38.0 m^2. The layout of the experiment field is given in Fig.4 (a) and the location and dimensions of the peripheral ditches are furnished in Fig.4 (b) and (c). Each plot was separated by nylon net connecting the outer bunds to contain the fish in their respective plot.

Crop culture

The management practices adopted for the *Pokkali* cultivation are different from that of the other systems of rice culture. When the field is dry during the summer months, mounds of 1 m^2 base and of 0.5 m height were formed at 4.0 m distance between the centre of the mounds to result 2500 mounds ha^{-1}. After the receipt of sufficient rains to wash off the soluble salts, the mound tops were raked and levelled, and sprouted seeds were sown at the rate of 100 kg ha^{-1}. No ameliorants/manures/fertilizers were applied for the crop except for the experiment entitled `Impact of ameliorants on growth, yield and nutrient uptake of *Pokkali* rice' where the ameliorants as per the treatments were used. When the seedlings attained 25-30 days growth, the mounds were dismantled and the seedlings were spread at the scheduled spacing (20 cm x 15 cm) with 2 to 3 seedlings per hill. Half the quantity of the ameliorants, as per the treatment schedule was applied on the mounds, two days prior to the sowing of the seed and the remaining at the time of dismantling of mounds and spreading of seedlings.

Fig. 4 (a) Layout of Experiment IV

22 m

5 m

F_0V_3	F_0V_3	F_0V_1
F_2V_3	F_2V_3	F_2V_1
F_1V_3	F_1V_3	F_1V_1
F_0V_1	F_1V_1	F_1V_3
F_2V_1	F_0V_1	F_0V_3
F_1V_1	F_2V_1	F_2V_3
F_2V_2	F_2V_2	F_2V_2
F_1V_2	F_1V_2	F_1V_2
F_0V_2	F_0V_2	F_0V_2
R_1	R_2	R_3

F_0 - No fish F_1 - Male Tilapia

F_2 - Etroplus during 1999 and Rohu during 2000

V_1 - Vyttila-3 V_2 - Cul.1026 V_3 - *Chettivirippu* mutant

Fig.4 (b) Plan of single rice-fish experiment plot

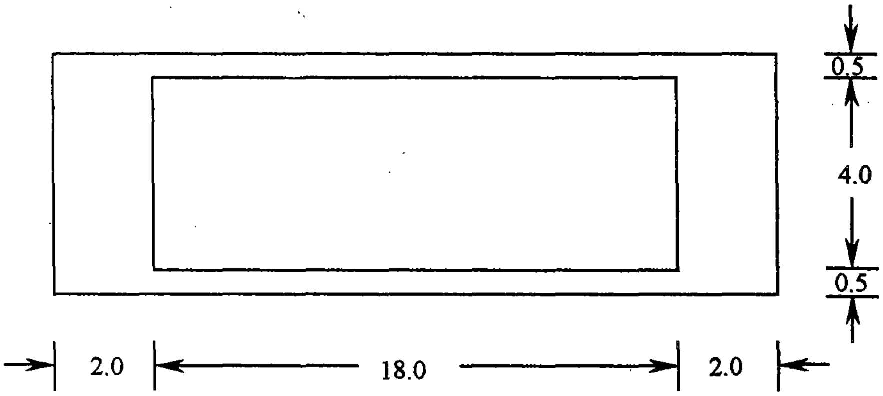
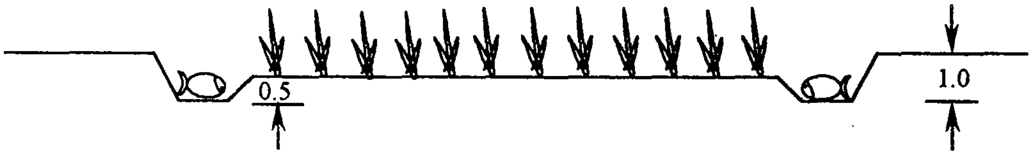


Fig. 4 (c) Cross sectional view of the rice-fish experiment plot



All dimensions in m

In the experiment IV, one week after the dismantling of mounds and spreading of seedlings, fish fingerlings at the rate of 5000 nos.ha^{-1} were stocked in the peripheral ditches and allowed to grow along with rice. A minimum water depth of 30 cm was maintained throughout the crop period in all the experiments. No fertilizers/plant protection chemicals were applied for the experiments during both the years. Date of sowing, dismantling of mounds and spreading of seedlings, and harvesting are given in Table 3.

Plants in two border rows on all sides of every plot were harvested and removed first. Net plots were harvested by cutting at the base. Threshing was done on the same day and wet yields were recorded. Moisture percentage of grain and straw were estimated. Dry weight of grain and straw were worked out and recorded at 14 per cent moisture content. In the simultaneous rice fish culture experiment, the fish culture was continued up to December, when the water quality has shifted to the saline phase. At this time the field was drained and the fishes were captured and observations were taken.

During the second year, after the harvest of the fish component, the fields were utilized for the culture of the Tiger prawn, *Penaeus monodon,* in order to assess the returns from rice-fish followed by prawn culture farming system. The fields were drained, weed fishes were removed and seeds of *P. monodon* were stocked at a density of 50,000 ha^{-1}. After $2^1/_2$ months growth, the fields were drained, the prawns were harvested and the weight was recorded and the average yield ha^{-1} was found out.

Observations

1. Rice plant

A. Biometric observations

i) Height of plants (cm) : At tillering, panicle initiation, flowering and at harvest stage.

Table 2. Sources of ameliorants and their content

Ameliorant	**Source**	**Content (%)**
Phosphorus	Super phosphate	16
Lime	Calcium oxide	85
Sulphur	Elemental sulphur	90
Silica	Fine silica	100

Table 3. Sowing and harvesting dates of crops in the experiments

Experi-ment	Year	Date of sowing	Date of Dismantling/ Spreading	Date of Harvest	Date of Stocking Of fish	Date of Fish Harvest
I	1999	21-06-99	19-07-99	22-10-99		
II	1999	21-06-99	22-07-99	28-10-99		
II	2000	15-06-00	15-07-00	25-10-00		
III	1999	17-06-99	12-07-99	05-10-99		
III	2000	15-06-00	14-07-00	09-10-00		
IV	1999	17-06-99	14-07-99	18-10-99	28-07-99	12-01-00
IV	2000	15-06-00	12-07-00	15-10-00	20-07-00	27-11-00

ii) Tiller count (no./hill) : -do-

iii) Dry matter production : -do-
(kg ha^{-1})

iv) Productive tillers (no./hill) : At harvest

v) Length of panicle (cm) : -do-

vi) No. of spike lets per panicle : -do-

vii) No. of filled grains per panicle : -do-

viii) No. of unfilled grains per panicle : -do-

ix) Grain yield (kg ha^{-1}) : -do-

x) Straw yield (kg ha^{-1}) : -do-

xi) Pest and disease incidence : As and when necessary

B. Physiological observations

i) Chlorophyll content : Chlorophyll content of index leaves was estimated calorimetrically in a Spectronic-20 spectrophotometer (Yoshida *et al.*, 1972).

ii) Plant sap pH : Plant sap pH was estimated at maximum tillering and panicle initiation stages using 1 : 2.5, leaf sample : water suspension and by measuring with a pH meter (Jackson, 1958).

C. Chemical analyses

Plant samples were dried in a hot air oven 60^{0}C + 5^{0}C, powdered well in a Wiley mill and analysed for nutrient contents by the methods given in Table 4.

Table 4. Methods used for plant bio-chemical analysis

Sl.No.	Nutrient	Method	Reference
1	Nitrogen	Microkjeldhal method	Jackson, 1958
2	Phosphorus	Diacid extract estimated calorimetrically in a spectronic-20 spectrophotometer by Vanadomolybdophosphoric yellow colour method	Jackson, 1958
3	Potassium	Diacid extract method using a flame photometer	Jackson, 1958
4	Sodium	Diacid extract method using a flame photometer	Jackson, 1958
5	Calcium	Diacid extract method using atomic absorption spectrophotometer	Jackson, 1958
6	Magnesium	Diacid extract method using atomic absorption spectrophotometer	Jackson, 1958
7	Sulphur	Turbidimetric method using spectronic-20 spectrophotometer	Hart, 1961
8	Iron	Diacid extract method using atomic absorption spectrophotometer	Jackson, 1958
9	Manganese	Diacid extract method using atomic absorption spectrophotometer	Jackson, 1958
10	Zinc	Diacid extract method using atomic absorption spectrophotometer	Jackson, 1958
11	Copper	Diacid extract method using atomic absorption spectrophotometer	Jackson, 1958
12	Silica	Gravimetric estimation on wet ashing in a muffle furnace	Yoshida *et al.*, 1972

D. Other observations

i) Light infiltration : Light intensity at noon at the top and bottom of the crop at maximum tillering and panicle initiation stages was measured using a lux meter.

ii) Percentage of filled grain : Computed from the number of filled grains and total number of grains per panicle.

iii) Grain : straw ratio : Computed from grain and straw yield.

iv) Nutrient uptake : Computed from nutrient content and dry matter accumulation.

II. Soil

Physico-chemical characteristics

The soil samples from the fields of experiment no.I was collected on all New moon days on which the tidal amplitude is the maximum, for one year (June 1999 to May 2000) from 10 sites each from the tidal and non-tidal fields, covering both the low saline and high saline phases (monsoon and post monsoon periods). Soil samples of the experiment II and III were collected after the harvest of the field experiments. The samples were dried in shade, powdered, passed through 2 mm sieve and analysed for the physico-chemical characteristics of the soil. The methods used for various analyses are given in Table 5.

III. Water

Water quality parameters with respect to the experiment no. IV were assessed as per APHA (1989). Water samples at weekly intervals were collected during the crop period from the peripheral channels. The methods used for various analyses are given in Table 6.

Table 5. Methods used for soil physical and chemical analysis

(a) Physical analysis

Sl.No.	Character	Method	Reference
1	Particle density	Keen-Raczkoski brass cup method	Piper, 1942
2	Bulk density	Keen-Raczkoski brass cup method	Piper, 1942
3	Pore space	Keen-Raczkoski brass cup method	Piper, 1942
4	Water holding capacity	Keen-Raczkoski brass cup method	Piper, 1942
5	Mechanical composition of soil	International pipette method	Piper, 1942
	(b) Chemical analysis		
1	Soil reaction	Soil water suspension 1 : 2.5 and read in a pH meter	Hesse, 1971
2	Electrical conductivity	Soil water suspension 1 : 2.5 and read in a conductivity meter	Jackson, 1958
3	Organic carbon	Walkely – Black method	Jackson, 1958
4	Total N	Microkjeldhal method	Jackson, 1958
5	Total P	Nitric-perchloric acid digest extract (2 : 1) estimated calorimetrically in a spectronic-20 spectrophotometer by yellow colour method	Hesse, 1971
6	Available N	Alkaline permanganate method	Subbaiah and Asija, 1956
7	Available P	Ascorbic acid reduced molybdophosphoric blue colour method	Watanabe and Olsen, 1965
8	Available K	Neutral normal ammonium acetate extract method using flame photometer	Jackson, 1958
9	Available Na	Neutral normal ammonium acetate extract method using flame photometer	Jackson, 1958
10	Exchangeable K	Turbidimetric method	Chesnin and Yien, 1951
11	Exchangeable Na	DTPA extract method using atomic absorption spectrophotometer	Lindsay and Vorvell, 1978
12	Available S	DTPA extract method using atomic absorption spectrophotometer	Lindsay and Vorvell, 1978

Table 5 contd.

13	Available Fe	DTPA extract method using atomic absorption spectrophotometer	Lindsay and Vorvell, 1978
14	Available Mn	DTPA extract method using atomic absorption spectrophotometer	Lindsay and Vorvell, 1978
15	Available Zn	DTPA extract method using atomic absorption spectrophotometer	Lindsay and Vorvell, 1978
16	Available Cu	DTPA extract method using atomic absorption spectrophotometer	Lindsay and Vorvell, 1978

Table 6. Methods of water analysis

Sl.No.	Character	Method	Reference
1	Salinity		APHA, 1989
2	PH		APHA, 1989
3	Electrical conductivity		APHA, 1989
4	Dissolved oxygen	Winkler method	APHA, 1989
5	Total alkalinity		APHA, 1989
6	Dissolved ammonia		APHA, 1989

IV. Statistical analysis

Sampling of plant samples was done as per Yoshida *et al.* (1972). Statistical analysis as per the design adopted in each experiment, was carried out using the analysis of variance technique (Panse and Sukhatme, 1978).

Yield and nutrient uptake were worked out on per hectare basis. Correlation and regression, and multiple regression analysis (Singh and Choudhary, 1977) were also done to work out the relationship between yield and yield attributes, nutrients and nutrient ratios and yield. The software Indostat was used for computations.

RESULTS

4. RESULTS

Productivity of *Pokkali* soils can be enhanced by identifying the various yield limiting factors and by their proper management. Four experiments at the Rice Research Station, Vyttila during 1999-2000 and 2000-2001 were conducted under the project entitled "Enhancing the productivity of the rice-fish/prawn farming system in *Pokkali* lands". The variabilities induced by the various treatments of the experiments in the physico-chemical properties of the soil and in the morphological, physiological and yield parameters of rice during various growth stages were observed and the relevant data are presented.

4.1. Experiment I.

Response of rice to applied nitrogen in tidal and non-tidal situations

The pot culture experiment entitled "Response of rice to applied nitrogen in tidal and non-tidal situations" studied the role of tides on regulation of soil chemical properties and enrichment of nutrients in *Pokkali* soils and its interactive influence with nitrogen levels on yield and yield attributes of *Pokkali* rice. The results obtained are presented in the tables 7 to 10.

4.1.1. Soil characters

4.1.1.1. pH

Soil subjected to tidal action exhibited higher values of pH than non - tidal soils (Table 7 a). Application of N up to 40 kg ha^{-1} resulted in an increase in pH, while further higher levels resulted in a decline that was at par with the N_0 level (Table 8). The interaction of tidal action and nitrogen levels did not result any significant change in pH.

Table 7 (a) Effect of tidal action on the soil characters and nutrient content of rice

Systems	PH	Organic carbon (%)	Available P (%)	Available potassium (%)	Straw content			Grain content		
					N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
Tidal	4.00	4.04	0.004	0.038	0.897	0.047	2.11	1.59	0.035	0.287
Non-tidal	3.61	3.31	0.003	0.021	0.369	0.044	1.45	0.59	0.026	0.287
C.D.(0.05)	**0.29**	**N.S.**	**N.S.**	**0.002**	**0.098**	**N.S.**	**0.30**	**0.20**	**0.005**	**N.S.**
S.Em	**0.10**	**0.27**	**0.0002**	**0.001**	**0.033**	**0.003**	**0.10**	**0.07**	**0.0050**	**0.006**

Table 7 (b) Effect of tidal action on yield and yield components of rice

Systems	Yield of grain (g pot^{-1})	Yield of straw (g pot-1)	Grain/ Straw ratio	Productive tillers (No. pot^{-1})	Panicle length (cm)	Filled grain (No. pot $^{-1}$)	No. of grain per panicle	Chaff (%)	Hundred grain weight (g)
Tidal	110.47	241.33	0.459	58.53	22.67	1121.13	48.70	52.69	2.76
Non-tidal	108.87	119.47	0.901	30.53	25.60	1720.13	76.75	24.18	2.99
C.D.(0.05)	**N.S.**	**16.64**	**0.060**	**5.54**	**2.18**	**44.32**	**12.87**	**9.40**	**N.S.**
S.Em	**3.16**	**5.60**	**0.02**	**1.26**	**0.74**	**14.95**	**4.33**	**3.16**	**0.10**

However, both tidal and non-tidal situations recorded higher pH values for 40 and 20 kg levels of N.

4.1.1.2. Organic carbon

Both tidal action and levels of N or their interaction did not bring about any change in the organic carbon content of the soil (Tables 7 a, 8 a and 9 a). However, the soils under tidal action recorded numerically higher values at all levels of nitrogen indicating the positive influence of the tidal action.

4.1.1.3. Available P content

No significant difference in the soil phosphorus content was noticed due to tidal action, N levels, or their interactions (Tables 7 a, 8 a and 9 a).

4.1.1.3. Available Potassium content

Tidal effect resulted in a significant increase in available K content of the soil. The available K content of soil was not influenced by N levels or by their interactions with tidal action (Tables 7 a, 8 a and 9 a).

4.1.2. Plant nutrient content

4.1.2.1. Nitrogen content of straw

Tidal influence was very much pronounced with respect to the straw nitrogen content (Tables 7 a, 8 a and 9 a). A two and a half fold increase in the nitrogen content of straw was observed in the rice plants under the tidal influence. The nitrogen levels also significantly increased the straw nitrogen content. The N_{40} level recorded the highest N content and was significantly superior to its lower and higher levels, which were at par

Table 8 (a) Effect of nitrogen levels on soil characters and nutrient content (%) of rice

N levels	pH	Soil Organic carbon (%)	Available soil P (%)	Available soil K (%)	Straw content of			Grain content of		
					N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
N_0	3.52	4.08	0.004	0.029	0.609	0.055	1.71	1.18	0.027	0.328
N_{20}	4.13	3.28	0.003	0.037	0.603	0.041	1.52	0.92	0.036	0.268
N_{40}	4.27	3.90	0.004	0.031	0.790	0.039	1.85	1.08	0.033	0.243
N_{60}	3.52	3.63	0.003	0.027	0.559	0.039	1.67	1.10	0.028	0.280
N_{80}	3.56	3.50	0.003	0.024	0.603	0.052	2.14	1.15	0.029	0.316
C.D.(0.05)	**0.46**	**N.S.**	**N.S.**	**0.008**	**0.155**	**0.013**	**N.S.**	**N.S.**	**N.S.**	**0.028**
S.Em	**0.16**	**0.43**	**0.0004**	**0.003**	**0.052**	**0.004**	**0.16**	**0.11**	**0.003**	**0.009**

Table 8 (b) Effect of nitrogen levels on yield and yield components of rice

N levels	Yield of grain (g pot^{-1})	Yield of straw (g pot^{-1})	Grain : Straw ratio	Productive tillers (no. pot^{-1})	Panicle length (cm)	Filled grain (no. pot $^{-1}$)	No. of grains panicle^{-1}	Chaff (%)	Hundred grain weight (g)
N_0	77.67	160.17	0.652	38.50	22.57	930.67	53.84	43.26	2.83
N_{20}	112.33	166.67	0.755	40.16	25.75	1340.17	67.63	36.85	3.03
N_{40}	103.00	163.50	0.708	43.33	26.28	1396.50	57.15	32.43	2.95
N_{60}	123.67	214.83	0.607	52.33	23.20	1608.83	66.75	42.39	2.65
N_{80}	125.17	196.83	0.676	48.33	23.88	1825.00	68.26	37.28	2.92
C.D.(0.05)	**14.83**	**26.03**	**0.095**	**8.76**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**4.99**	**8.85**	**0.03**	**2.94**	**1.16**	**236.45**	**6.85**	**5.00**	**0.15**

Table 9 (a) Interaction effects of tidal action and nitrogen levels on chemical characters of soil

N levels	pH		Soil organic carbon (%)		Soil available P (%)		Soil available K (%)	
	Tidal	Non-Tidal	Tidal	Non-tidal	Tidal	Non-tidal	Tidal	Non-Tidal
N_0	3.68	3.36	5.36	2.80	0.004	0.004	0.034	0.023
N_{20}	4.38	3.88	3.76	2.80	0.003	0.003	0.042	0.032
N_{40}	4.23	4.31	3.43	4.36	0.004	0.003	0.038	0.024
N_{60}	3.86	3.18	4.36	2.90	0.003	0.003	0.040	0.013
N_{80}	3.85	3.28	3.30	3.70	0.004	0.003	0.033	0.015
C.D.(0.05)	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**0.22**	**0.22**	**0.60**	**0.60**	**0.0005**	**0.0005**	**0.004**	**0.004**

Table 9 (b) Interaction effects of tidal action and nitrogen levels on nutrient content in rice

N levels	Content in straw						Content in grain					
	N		P		K		N		P		K	
	Tidal	Non-tidal	Tidal	Non-tidal	Tidal	Non-tidal	Tidal	Non-tidal	Tidal	Non-tidal	Tidal	Non-tidal
N_0	0.88	0.32	0.057	0.053	1.94	1.49	1.77	0.60	0.036	0.018	0.347	0.310
N_{20}	0.91	0.29	0.038	0.044	1.76	1.28	1.28	0.55	0.035	0.037	0.230	0.307
N_{40}	1.09	0.48	0.042	0.036	2.34	1.36	1.58	0.59	0.038	0.029	0.267	0.220
N_{60}	0.74	0.37	0.043	0.036	1.78	1.56	1.53	0.67	0.031	0.025	0.267	0.293
N_{80}	0.84	0.36	0.055	0.049	2.74	1.54	1.77	0.53	0.036	0.022	0.323	0.307
C.D. (0.05)	**N.S.**		**N.S.**		**N.S.**		**N.S.**		**N.S.**		**0.04**	
S.Em	**0.07**		**0.006**		**0.22**		**0.15**		**0.004**		**0.013**	

among themselves. The interaction effect between the tides and N levels, on the other hand, was not significant.

4.1.2.2. Phosphorus content of straw

No significant difference in the straw phosphorus content was noticed either due to tidal action or its interaction with N levels (Tables 7 a, 8 a and 9 a). However, the N levels revealed a significant effect on the straw phosphorus content, with the N_0 recording the highest value, which was at par with N_{80} and significantly superior to all the other levels.

4.1.2.3. Potassium content of straw

One and a half fold increase in straw potassium content was observed on account of tidal influence (Tables 7 a, 8 a and 9 a). Neither the N levels nor their interaction with the tidal regimes significantly influenced the potassium content.

4.1.2.4. Grain nitrogen content

The tidal action resulted almost three fold increase in the grain nitrogen content, while the interaction of nitrogen levels with tides didn't influence the grain nitrogen content (Tables 7 a, 8 a and 9 a).

4.1.2.5. Grain phosphorus content

The effect of tides on the grain phosphorus was quite evident (Tables 7 a, 8 a and 9 a). The tidal action significantly increased the grain phosphorus content by 35 per cent. Neither the nitrogen levels nor their interaction with tides resulted in significant difference in grain phosphorus content.

4.1.2.6. Grain potassium content

Unlike the straw potassium content, the grain potassium content didn't differ due to tidal influence (Tables 7 a, 8 a and 9 a). The nitrogen levels, however significantly influenced the potassium content of grain. The highest value for potassium content was recorded by N_O which was at par with N_{80} and significantly superior to all other N levels. The interaction of tides and nitrogen levels significantly affected the grain potassium content. Grain potassium content was the highest for the N_O level under the tidal influence, which was at par with N_{80} under tidal influence and N_O, N_{20} and N_{80} of non-tidal situation.

4.1.3. Yield and yield components

4.1.3.1. Grain yield

The effect of tidal action on grain yield was not significant (Tables 7 b, 8 b and 10). The nitrogen levels and their interactions with the tidal regimes, however, significantly affected the grain yield. N_{80} gave the highest grain yield, which was at par with N_{20} and was significantly superior to all other N levels of both the tidal regimes. N_{80} and N_{60} of both the tidal regimes and N_{40} of tidal regime were at par. Among the N levels N_{80} gave the maximum grain yield that was at par with N_{20} and was significantly superior to the others.

4.1.3.2. Straw yield

The tidal regimes significantly influenced the straw yield (Tables 7 b, 8 b and 10). Tidal action gave more than twice the straw yield as that of the non-tidal situation. The nitrogen levels also significantly increased the straw yield. The highest straw yield was recorded by N_{60} which was 32 per cent more than that of N_0, but was at par with N_{80}. N_0 gave the minimum straw which was at par with the next two nitrogen levels. The interaction of tidal regimes and nitrogen levels also differed the straw yield significantly. The nitrogen application under non-tidal regime differed the straw yield significantly. N_{60} under the non- tidal regime recorded the maximum straw yield that was at par with N_{80} but, superior to the other nitrogen levels.

4.1.3.3. Grain : straw ratio

Significant difference in grain : straw ratio was obtained due to tidal regimes, nitrogen levels and their interaction (Tables 7 b, 8 b and 10). At an average a 100 per cent lowering in the grain straw ratio was observed in tidal regime than the non-tidal. The nitrogen levels also significantly influenced the grain : straw ratio. The maximum grain straw ratio of 0.708 was noticed for N_{40} and the least for N_{60}. The non-tidal regime at N_0 gave the highest grain : straw ratio, which was significantly superior to all the others. Grain : straw ratio was the least (0.237) for N_0 at tidal regime.

4.1.3.4. Productive tillers

The tidal regimes and nitrogen levels significantly affected the number of productive tillers (Tables 7 b, 8 b and 10). Tidal situation gave 90 per cent more productive tillers than the non-tidal regime. Among the nitrogen levels, N_{60} gave the maximum number of productive tillers, which was at par with N_{80}. The lowest number of productive tillers was recorded by N_0, which was at par with the N_{20}, N_{40} and N_{80}. The interaction effect of the tidal regimes and nitrogen levels were not significant.

4.1.3.5. Panicle length

The effect of tidal regime on panicle length was significant, while either the nitrogen levels or their interaction with the tides didn't significantly differ it (Tables 7 b, 8 b and 10). Panicle length was more for the treatments governed by the non-tidal regime.

4.1.3.6. Filled grain number

Similar to the panicle length, the filed grain number was also altered by the tidal regimes (Tables 7 b, 8 b and 10). Maximum number of filled grain was recorded by the non-tidal regime, which was in general 100 per cent more than that of its counter part. The incremental levels of N increased the filled grain number even though the difference was not significant. The interaction effect of the tidal regimes and nitrogen levels was significant. The N_{80} of the non-tidal regime recorded the maximum number of filled grains, which was at par with N_{60} of the non-tidal regime and N_{20} of the tidal regime. Tidal regime at N_0 gave the least filled grain number.

4.1.3.7. Grain number per panicle

The effect of tidal regimes on the number of grains per panicle was significant, while that of nitrogen levels and it's interaction with tides were not significant (Tables 7 b, 8 b and 10). The non-tidal treatments recorded significantly more number of grains per panicle than the tidal counter part. The N levels didn't significantly differ the grain number panicle^{-1}. However, the grain number ranged from 34.34 for N_0 under the tidal regime to 91.10 for N_{60} under the non-tidal situation.

Table 10. Interaction effects of tidal action and nitrogen levels on yield and yield components of rice

N levels	Yield (g pot^{-1})				Grain : straw ratio		Productive tillers (no. pot^{-1})	
	Grain		Straw					
	Tidal	Non-Tidal	Tidal	Non-tidal	Tidal	Non-tidal	Tidal	Non-Tidal
N_0	56.00	89.33	238.33	82.00	0.237	1.067	54.33	22.67
N_{20}	155.66	69.00	257.33	76.00	0.603	0.907	60.33	20.00
N_{40}	110.33	96.66	222.33	104.67	0.500	0.917	56.33	30.33
N_{60}	114.66	132.66	253.33	176.33	0.457	0.757	65.67	39.00
N_{80}	116.66	134.67	235.33	158.33	0.497	0.857	56.00	40.67
C.D. (0.05)	**20.98**		**37.21**		**0.13**		**N.S.**	
S.Em	**7.06**		**12.52**		**0.04**		**4.17**	

(Table 10 contd.)

N levels	Panicle length (cm)		Filled grain (no. pot^{-1})		No. of grains per panicle		Chaff (%)		Hundred grain weight (g)	
	Tidal	Non-tidal	Tidal	Non-tidal	Tidal	Non-tidal	Tidal	Non-tidal	Tidal	Non-tidal
N_0	19.13	26.00	460.00	1401.33	34.34	73.33	69.11	17.40	2.66	3.00
N_{20}	27.10	24.40	1734.00	946.00	70.23	65.03	45.10	28.60	2.90	3.16
N_{40}	23.96	26.00	1261.67	1535.33	50.34	63.93	44.80	20.06	2.83	3.06
N_{60}	22.10	24.30	1104.00	2113.67	42.40	91.10	53.50	31.27	2.66	2.63
N_{80}	21.06	26.70	1045.00	2604.33	46.18	90.33	50.96	23.60	2.73	3.10
C.D. (0.05)	**N.S.**		**993.53**		**N.S.**		**N.S.**		**N.S.**	
S.Em	**1.64**		**334.39**		**9.69**		**7.07**		**0.23**	

4.1.3.8. Chaff per cent

The tidal effect on the chaff per cent was significant as revealed by the 117 per cent increase in the chaff compared to the non-tidal regime (Tables 7 b, 8 b and 10). The nitrogen levels as well as their interaction with the tidal regimes didn't show significant effect on the chaff per cent.

4.1.3.9. Hundred grain weight

The effect of tidal regimes, nitrogen levels or their interaction on the hundred grain weight of rice was not significant (Tables 7 b, 8 b and 10).

4.2. Experiment II

Tidal effect on *Pokkali* soils and performance of rice

The field experiment entitled 'Tidal effect on *Pokkali* soils and performance of rice' was conducted during kharif seasons of 1999 and 2000 with the objective of understanding the performance of the traditional tall saline tolerant *Pokkali* varieties in comparison with the new generation high yielding varieties of semi tall and dwarf stature, under the tidal and non-tidal situations. The data obtained on the soil chemical parameters, growth characters of the varieties involved, their morphological characters and yield parameters are presented in tables 11 to 29.

4.2.1. Growth characters

The performance of the varieties in terms of height revealed almost the same trend during both the years (Table 11). The variety Vyttile-3 recorded the maximum height at all the stages from active tillering to the harvest stage, under the tidal as well as the non-tidal situations during the kharif seasons of 1999 and 2000. This variety

Table 11. Tidal effects on height of rice varieties at different development stages (cm)

Treatments		1999				2000			
System	Cultivar/ Variety	Active tillering	Panicle initiation	Flower-ing	Harvest	Active tillering	Panicle initiation	Flower-ing	Harvest
Tidal	Vyttila-3	87.50	119.60	174.90	179.10	85.60	115.60	163.20	164.90
	Cul. 1026	54.90	85.80	132.70	140.70	60.00	76.30	125.30	135.40
	Chettivirippu mutant	55.00	80.60	110.70	119.50	59.50	75.20	100.80	107.20
	C.D. (0.05)	**2.72**	**7.01**	**8.70**	**6.20**	**4.00**	**6.10**	**5.01**	**5.84**
	S.Em	**0.81**	**2.27**	**2.42**	**2.01**	**1.80**	**1.97**	**1.63**	**1.90**
Non-tidal	Vyttila-3	93.60	115.90	168.60	169.60	70.90	113.30	137.40	148.40
	Cul. 1026	60.20	82.50	125.47	126.40	54.50	71.40	110.50	123.90
	Chettivirippu mutant	54.50	85.10	101.44	101.10	54.00	70.30	90.60	91.50
	C.D. (0.05)	**1.75**	**5.89**	**5.51**	**5.57**	**3.39**	**4.63**	**8.81**	**4.88**
	S.Em	**0.57**	**1.91**	**1.79**	**1.81**	**1.10**	**1.50**	**2.86**	**1.59**

Table 12. Tidal effects on inter nodal length of rice varieties (cm) - 2000

Treatments		1st node	2nd node	3rd node	4th node	5th node	6th node
System	Varieties						
Tidal	Vyttila-3	6.07	9.6	16.18	21.59	29.2	33.37
	Cul. 1026	2.17	3.22	6.44	11.89	17.19	25.66
	Chettivirippu mutant	2.88	3.88	7.26	12.54	18.24	26.67
	C.D. (0.05)	**0.54**	**0.74**	**1.08**	**1.55**	**1.85**	**2.81**
	S.Em	**0.25**	**0.35**	**0.33**	**0.52**	**0.86**	**1.02**
Non-tidal	Vyttila-3	3.84	7.90	16.41	22.36	27.8	33.65
	Cul. 1026	2.12	3.88	7.38	14.17	20.81	30.07
	Chettivirippu mutant	2.10	3.41	6.12	10.87	15.99	26.80
	C.D. (0.05)	**0.597**	**0.977**	**1.74**	**1.67**	**2.02**	**1.45**
	S.Em	**0.21**	**0.46**	**0.81**	**0.78**	**0.74**	**0.68**

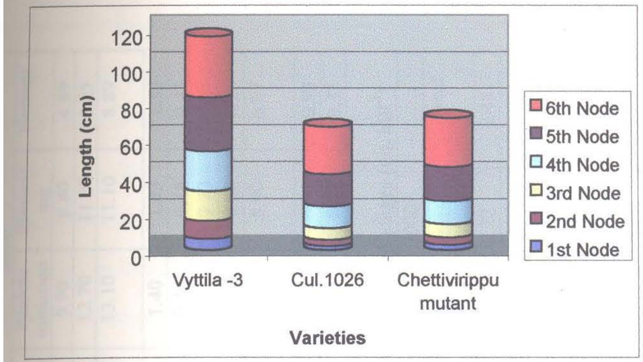
recorded its superiority in height, achieving 59 per cent more height than the dwarf *Chettivirippu* mutant at the active tillering stage during both the years and this lead was retained up to the harvest stage. However, the difference in height was only 21 per cent with the semitall variety Cul. 1026 at harvest stage. During both the years, the tidal regime recorded higher values for height in all the varieties, irrespective of the development stages.

The varietal variation in height was reflected on their inter-nodal length also (Table 12 and Figure 5). The varieties significantly differed in their inter-nodal length under both the tidal regimes. Vyttila-3 registered 179, 147, 123, 72, 60 and 25 per cent more length for the first, second, third, fourth, fifth and sixth internodes, respectively, than the *Chettivirippu* mutant under the tidal situation. Under the non-tidal situation, though Vyttila-3 retained its number one position, Cul. 1026 surpassed the *Chettivirippu* mutant. However, the difference in internodal length was less than the same under the tidal situation. The increase in the inter-nodal length of Vyttila-3 over Cul. 1026 was only 81.0, 103.6, 122.0, 57.7, 33.6 and 11.9 per cent, respectively for the first, second, third, fourth, fifth and sixth internodes, respectively. The difference in inter nodal length between the varieties under the non-tidal regime was less, especially for the first and second internodes.

The effect of the tidal regimes and varieties on the number of tillers of rice is presented in table 13. During the first year, the semi -tall variety Cul. 1026 recorded the maximum number of vegetative tillers at all the development stages under both the tidal and non-tidal regimes and enjoyed 29, 34, 56 and 37 per cent increase over Vyttila-3 at

Fig.5. Effect of tidal regimes on internodal length of rice varieties (cm)

Tidal



Non –tidal

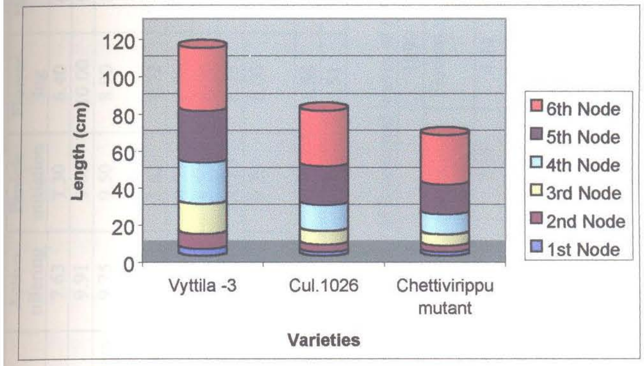


Table 13. Tidal effects on number of tillers at different growth phases in rice varieties (no. hill^{-1})

Treatments		1999				2000			
System	Cultivar/ Variety	Active tillering	Panicle initiation	Flower-Ing	Harvest	Active tillering	Panicle initiation	Flower-ing	Harvest
Tidal	Vyttila-3	7.63	7.30	6.40	6.90	9.75	9.90	8.80	4.69
	Cul. 1026	9.91	9.80	10.00	9.50	12.70	12.70	11.00	8.25
	Chettivirippu mutant	9.75	9.50	8.90	8.60	14.20	13.10	11.10	8.89
	C.D. (0.05)	**1.33**	**1.62**	**1.72**	**1.82**	**2.03**	**1.40**	**1.43**	**1.33**
	S.Em	**0.42**	**0.53**	**0.56**	**0.59**	**0.66**	**0.46**	**0.45**	**0.43**
Non-tidal	Vyttila-3	8.40	8.20	5.70	5.60	13.30	10.20	7.70	4.61
	Cul. 1026	11.30	10.20	8.33	8.00	11.00	10.40	8.50	6.26
	Chettivirippu mutant	10.60	9.20	8.00	8.10	10.80	9.60	8.90	6.07
	C.D. (0.05)	**N.S.**	**N.S.**	**1.56**	**1.00**	**1.64**	**1.57**	**0.81**	**0.98**
	S.Em	**0.72**	**0.53**	**0.51**	**0.32**	**0.53**	**0.51**	**0.26**	**0.32**

Table 14. Tidal effects on number of functional leaves of rice varieties at different growth stages (no. hill^{-1})

Treatments		1999			2000		
System	Cultivar/ Variety	Panicle initiation	Flowering	Harvest	Panicle initiation	Flowering	Harvest
Tidal	Vyttila-3	7.14	4.84	2.62	9.29	7.22	2.48
	Cul. 1026	9.62	8.76	5.49	13.09	12.67	6.24
	Chettivirippu mutant	9.02	6.92	4.44	11.60	8.82	5.11
	C.D. (0.05)	**N.S.**	**1.30**	**0.92**	**2.58**	**1.89**	**1.20**
	S.Em	**0.58**	**0.43**	**0.42**	**0.85**	**0.93**	**0.59**
Non-tidal	Vyttila-3	6.8	4.54	2.10	10.96	7.91	2.91
	Cul. 1026	9.76	6.02	4.64	10.37	10.70	5.60
	Chettivirippu mutant	8.54	6.66	4.89	8.69	9.77	2.61
	C.D. (0.05)	**1.27**	**1.09**	**0.48**	**1.20**	**1.50**	**0.72**
	S.Em	**0.41**	**0.35**	**0.16**	**0.58**	**0.74**	**0.35**

the active tillering, panicle initiation, flowering and harvest stages, respectively under the tidal regime. In the non-tidal situation, this was 34.0, 24.0, 45.6 and 42.9 per cent, at the respective development stages. The *Chettivirippu* mutant was at par with the Cul. 1026 at all the growth stages, under both the tidal regimes. In the second year the varietal effect on number of vegetative tillers was significant at all the growth stages under both the tidal regimes. The *Chettivirippu* mutant recorded the maximum vegetative tillers, at all the growth stages under the tidal regime but was at par with the Culture 1026.

Under the non-tidal regime, though, Vyttila-3 could establish a significant superiority over the others initially at the active tillering stage, it could not retain the trend subsequently. The varieties Cul. 1026 and *Chettivirippu* mutant recorded significantly more vegetative tillers than Vyttila-3 and were at par.

The climaxing of the tiller production up to the panicle initiation stage and a substantial decline subsequently (up to 65 per cent) was observed under both the tidal regimes of study where a 65 per cent decline in tiller number was observed. This phenomenon was more pronounced in Vyttila-3 during the second year under the non-tidal regime. The decline was 44.7 and 43.7 per cent, respectively, for the *Chettivirippu* mutant and Cul. 1026 under the same regime during 2000. The tidal regime during the same period recorded a tiller decline of 52, 37 and 36 per cent, respectively for Vyttila-3, *Chettivirippu* mutant and Cul. 1026.

The decline in the vegetative tillers was not so steep for the tidal regime during 1999 which recorded 4.0, 10.0 and 11.7 per cent decline in tiller numbers for Cul. 1026, Vyttila-3 and *Chettivirippu* mutant, respectively. However, under the non-tidal situation the same varieties recorded 29.0, 33.0 and 23.6 per cent decline in tiller number.

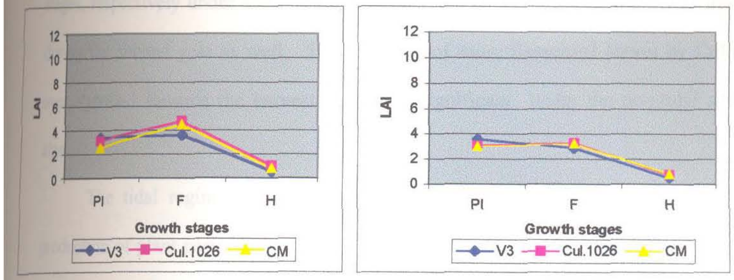
There was marked difference in the leaf area index among the varieties as well as the tidal regimes (Fig. 6). Initially Vyttila-3 recorded the maximum leaf area index at the panicle initiation stage under both the regimes during 1999 and at panicle initiation stage under non-tidal regime in 2000. Cul. 1026, on the other hand, recorded its superiority not only at the panicle initiation stage during 2000, but also at all the subsequent growth stages under the tidal regimes of 1999 and 2000. The mean leaf area index pooled over 1999 and 2000 clearly indicated the superiority of Cul. 1026 at all the growth stages under both the tidal regimes, except at panicle initiation stage under the non-tidal situation.

The leaf area index for all the varieties recorded the maximum values at the flowering stage and declined sharply towards harvest. The Cul. 1026, however, retained reasonable leaf area index values even at the harvest stage.

The number of functional leaves varied significantly between varieties at the different development stages (Table 14). Among the varieties, the Cul. 1026 recorded higher number of functional leaves under both the tidal regimes and at all the development stages except at flowering and at harvest under the non-tidal regime. The number of functional leaves, climaxed at the panicle initiation stage for all the varieties under both the tidal regimes except the *Chettivirippu* mutant and Cul. 1026 under the non-tidal regime of Kharif 2000. The increase in number of leaves for Cul. 1026 over Vyttila-3 was 34.7, 81.0 and 106.0 per cent at panicle initiation, flowering and harvest

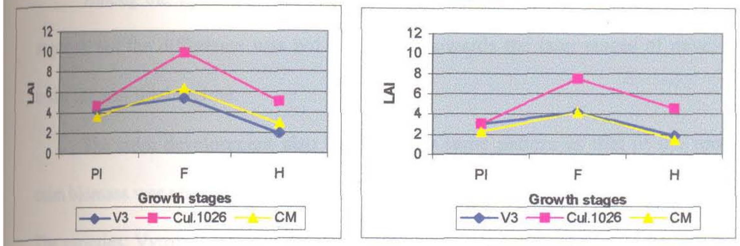
Fig. 6. Effect of tidal regimes on leaf area index of rice varieties.

1999



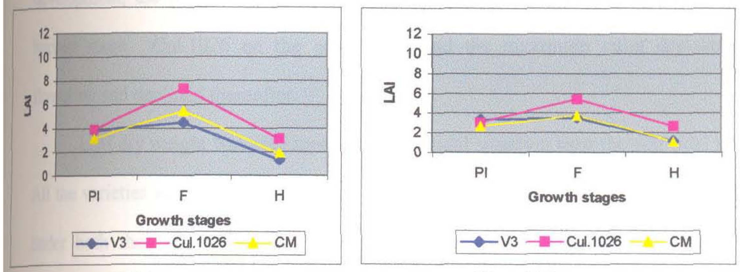
Tidal Non tidal

2000



Tidal Non tidal

Mean



Tidal Non tidal

PI- Panicle initiation, F- Flowering , H- harvest stages, respectively under the tidal regime during 1999. The same trend was observed during the second year as well. The retention of more functional leaves by Cul. 1026 over Vyttila-3 towards the harvest stage was significant under the non-tidal situation also.

The tidal regimes and the varieties had significant effect on the dry matter production of plant parts of rice during 2000 (Table 15 a and b). The root biomass was more under the tidal regime than the non-tidal situation.

Among the varieties, Vyttila-3 produced more root biomass under both the tidal regimes, but the difference was not significant towards the later stages of development under the non-tidal regime.

The culm development also followed the same pattern as that of the root. The culm biomass was also always higher under the tidal situation than the non-tidal situation. The varieties, Vyttila-3 and *Chettivirippu* mutant showed almost similar pattern of culm development, the progression was gradual and attained the maximum biomass at the harvest stage. Cul.1026 on the other hand had the maximum culm dry weight at flowering and declined thereafter.

Leaf dry weight was also more under the tidal situation than the non-tidal regime. All the varieties attained maximum leaf dry weight at flowering and declined thereafter under both the tidal regimes. Vyttila-3 produced more leaf biomass at the initial development phases, while the same was more in Cul.1026 towards the later stages.

The total biomass was also more under the tidal situation than the non-tidal. Vyttila-3 and *Chettivirippu* mutant had a linear progress in biomass build up while in

Table 15 (a) Tidal effects on root and culm dry weight of rice at different phases during 2000 (t ha^{-1})

Treatments		Root				Culm			
System	Cultivar/ Varieties	Active tillering	Panicle initiation	Flower-ing	Harvest	Active tillering	Panicle initiation	Flower-ing	Harvest
Tidal	Vyttila-3	0.56	0.68	1.49	1.52	1.27	2.07	6.91	7.37
	Cul. 1026	0.27	0.77	2.01	1.24	0.58	2.31	10.28	8.33
	Chettivirippu mutant	0.39	0.59	1.28	1.26	0.71	1.85	6.17	6.35
	C.D. (0.05)	**0.10**	**N.S.**	**0.39**	**0.20**	**0.16**	**N.S.**	**1.54**	**1.01**
	S.Em	**0.03**	**0.05**	**0.13**	**0.07**	**0.05**	**0.80**	**0.50**	**0.38**
Non-tidal	Vyttila-3	0.25	0.42	1.11	1.29	0.45	1.60	5.32	6.67
	Cul. 1026	0.19	0.41	1.37	1.02	0.35	1.11	7.20	5.72
	Chettivirippu mutant	0.11	0.29	1.28	0.84	0.31	0.97	3.91	3.90
	C.D. (0.05)	**0.07**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**0.36**	**1.01**	**1.07**
	S.Em	**0.02**	**0.06**	**0.18**	**0.12**	**0.04**	**0.12**	**0.33**	**0.35**

Table 15 (b) Tidal effects on leaf and total dry weight of rice at different phases during 2000 (t ha^{-1})

Treatments		Leaf				Total			
System	Cultivar/ Varieties	Active tillering	Panicle initiation	Flower-ing	Harvest	Active tillering	Panicle initiation	Flower-ing	Harvest
Tidal	Vyttila-3	1.22	1.32	2.07	0.85	2.95	4.62	10.48	12.27
	Cul. 1026	0.67	1.56	3.91	1.73	1.53	4.57	16.20	14.38
	Chettivirippu mutant	0.79	1.21	2.11	1.06	1.88	4.13	9.56	11.58
	C.D. (0.05)	**0.22**	**N.S.**	**0.91**	**0.31**	**0.47**	**N.S.**	**2.62**	**2.00**
	S.Em	**0.07**	**0.12**	**0.30**	**0.10**	**0.15**	**0.35**	**0.85**	**0.65**
Non-Tidal	Vyttila-3	0.55	1.18	1.61	0.79	1.29	3.20	8.05	11.85
	Cul. 1026	0.34	1.00	2.51	1.53	0.88	2.62	11.09	10.72
	Chettivirippu mutant	0.30	0.75	1.39	0.57	0.72	1.92	6.51	6.97
	C.D. (0.05)	**0.15**	**0.18**	**0.48**	**0.18**	**0.30**	**0.86**	**1.84**	**1.90**
	S.Em	**0.05**	**0.06**	**0.16**	**0.06**	**0.10**	**0.28**	**0.60**	**0.62**

Table 16. Tidal effects on dry matter accumulation in plant parts in rice varieties at harvest ($t\ ha^{-1}$)

Treatments		1999					2000				
System	Cultivar/ Varieties	Root	Culm	Leaf	Panicle	Total	Root	Culm	Leaf	Panicle	Total
Tidal	Vyttila-3	2.55	10.20	0.22	4.74	17.71	1.52	7.37	0.85	2.78	12.52
	Cul. 1026	2.25	8.81	0.34	4.90	16.30	1.24	8.33	1.73	2.70	14.00
	Chettivirippu mutant	1.59	6.34	0.26	6.05	14.24	1.26	6.35	1.06	3.07	11.74
	C.D. (0.05)	**0.55**	**2.21**	**0.09**	**0.82**	**N.S.**	**0.20**	**1.01**	**0.31**	**N.S.**	**2.01**
	S.Em	**0.16**	**0.91**	**0.03**	**0.27**	**1.01**	**0.07**	**0.38**	**0.10**	**0.10**	**0.65**
Non-tidal	Vyttila-3	1.80	7.22	0.20	5.41	14.63	1.29	6.67	0.79	3.20	11.95
	Cul. 1026	1.77	6.96	0.25	5.09	14.07	1.02	5.72	1.53	3.35	11.62
	Chettivirippu mutant	1.71	6.81	0.27	6.03	14.82	0.84	3.90	0.57	1.7	7.08
	C.D. (0.05)	**N.S.**	**N.S.**	**0.03**	**N.S.**	**N.S.**	**N.S.**	**1.07**	**0.18**	**0.95**	**1.90**
	S.Em	**0.12**	**0.40**	**0.01**	**0.29**	**0.68**	**0.12**	**0.35**	**0.06**	**0.18**	**0.62**

Cul. 1026 the same was sigmoid with the maximum build up at flowering and a subsequent decline, under both the tidal regimes.

The comparison of dry matter accumulation in different plant parts at harvest (Table 16) during 1999 and 2000 revealed that the dry matter production was more during 1999 and the tidal situation was more congenial than the non-tidal regime for dry matter production.

The varieties significantly varied with respect to the biomass production in various plant parts. Vyttila-3 had the maximum root and culm dry weight except under the tidal situation of 2000. The leaf dry weight, however, was more in Cul. 1026 which differed significantly with the others, except under the non-tidal regime of 1999. *Chettivirippu* mutant produced the maximum panicle weight on all occasions, except the non-tidal regime of 1999, where it was significantly inferior to the other two varieties.

4.2.2. Yield attributes and yield

Vyttila-3 had significantly lesser panicles hill^{-1} than the other two varieties under the tidal regime, during both the years (Table 17). However, the thousand- grain weight of this variety was the maximum, which was significantly superior to the others. Though the other characters were favourable for Cul. 1026, it recorded significantly higher chaff per cent than the other two varieties and this difference was very much pronounced during 2000. *Chettivirippu* mutant also had favourable yield attributes except for the lower thousand- grain weight, which was significantly lesser than the other two varieties.

The comparison between the tidal and non-tidal situations revealed that the chaff per cent was significantly lower in non-tidal situation in Vyttila-3 during both the years

Table 17. Tidal effects on yield attributes of rice varieties

Treatments		1999					2000				
System	Cultivar/ Variety	Panicles (no. hill^{-1})	Filled grains (no. panicle^{-1})	Panicle length (cm)	Chaff (%)	Thousand grain weight (g)	Panicles (no. hill^{-1})	Filled grains (no. panicle^{-})	Panicle length (cm)	Chaff (%)	Thousand grain weight (g)
Tidal	Vyttila-3	4.20	63.30	26.30	18.80	35.50	4.64	109.50	28.10	8.32	36.00
	Cul. 1026	7.70	37.50	23.40	32.10	28.87	8.13	90.70	26.70	36.70	29.90
	Chettivirippu mutant	7.20	68.00	19.00	16.70	25.70	8.84	80.10	19.30	9.55	25.50
	C.D. (0.05)	**1.57**	**10.43**	**1.29**	**6.93**	**0.97**	**1.33**	**15.07**	**1.54**	**4.39**	**1.80**
	S.Em	**0.51**	**3.60**	**0.52**	**1.67**	**0.31**	**0.45**	**4.89**	**0.50**	**2.01**	**0.60**
Non-Tidal	Vyttila-3	4.80	72.70	24.20	9.30	35.12	4.69	98.20	26.80	12.60	35.10
	Cul. 1026	7.10	59.10	23.00	21.90	29.81	6.19	94.70	26.20	32.65	31.10
	Chettivirippu mutant	7.50	81.60	18.80	10.70	26.20	6.00	74.40	20.00	9.33	27.80
	C.D. (0.05)	**0.96**	**11.97**	**3.96**	**11.50**	**4.81**	**0.97**	**9.50**	**0.92**	**5.18**	**2.30**
	S.Em	**0.31**	**4.82**	**1.45**	**1.17**	**1.58**	**0.37**	**3.08**	**0.30**	**1.32**	**0.73**

and in Cul. 1026 during 1999. However, a reverse effect was seen during 2000 in this regard. In general, the yield attributes were poor in all the varieties during 2000.

The grain yield (Table 18) was more under the tidal situation and the increased yield under this regime was conspicuous during 2000. Among the varieties Cul. 1026 gave significantly higher grain yield than the others. However, the difference in yield with *Chettivirippu* mutant was not significant during 1999. The ruling variety, Vyttila-3, gave the least yield during 1999, but performed better than the *Chettivirippu* mutant during 2000.

The straw yield and biomass production were also the highest in Cul. 1026, which was on par with Vyttila-3, under the non-tidal regime for these characters.

During 1999, *Chettivirippu* mutant registered higher ratio than the others, while, a reverse trend observed during the subsequent year.

The pooled data revealed the same trend where the Cul. 1026 recorded the highest yield of grain, straw and biomass under both the tidal situations (Table 19). The grain : straw ratio was higher in *Chettivirippu* mutant. The data further revealed that the grain, straw and biomass production were more under the tidal situation, but the grain : straw ratio did not vary significantly.

4.2.3. Elemental composition

The tidal effects on the elemental composition of the rice varieties are presented in the Tables 20 a to 27 b.

Table 18. Tidal effects on yield and yield attributes of rice varieties

Treatments		1999				2000			
System	Cultivar/ Variety	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Grain : straw ratio	Total biomass (kg ha^{-1})	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Grain : straw ratio	Total biomass (kg ha^{-1})
Tidal	Vyttila-3	4171.00	10214.00	0.42	14385.00	3443.00	7636.00	0.45	11079.00
	Cul. 1026	4903.00	13136.00	0.38	18039.00	4630.00	9293.00	0.48	13923.00
	Chettivirippu mutant	5440.00	7493.00	0.75	12933.00	3043.00	8650.00	0.35	11693.00
	C.D. (0.05)	**723.60**	**2353.00**	**0.10**	**3242.60**	**698.80**	**1451.70**	**0.04**	**2078.10**
	S.Em	**235.04**	**763.69**	**0.03**	**1010.00**	**226.80**	**471.15**	**0.01**	**674.50**
Non-tidal	Vyttila-3	4432.00	9750.00	0.47	14182.00	2250.00	6807.00	0.33	9057.00
	Cul. 1026	4977.00	9888.00	0.52	14865.00	3457.00	8650.00	0.40	12107.00
	Chettivirippu mutant	4630.00	5461.00	0.89	10091.00	1964.00	6507.00	0.30	8471.00
	C.D. (0.05)	**N.S.**	**1633.00**	**0.20**	**1700.50**	**335.20**	**1001.60**	**0.02**	**1331.30**
	S.Em	**142.83**	**528.81**	**0.06**	**580.00**	**108.80**	**325.07**	**0.01**	**432.06**

Table 19. Tidal effect on pooled yield (kg ha^{-1})

Treatments		Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Grain : Straw
System	Cultivar/ Variety			
Tidal	Vyttila-3	3807.00	8925.00	0.44
	Cul. 1026	4767.00	11215.00	0.43
	Chettivirippu mutant	4242.00	8072.00	0.55
C.D.(0.05)		**N.S.**	**N.S.**	**N.S.**
S.Em		**564.12**	**1240.48**	**0.05**
Non-tidal	Vyttila-3	3341.00	8279.00	0.40
	Cul. 1026	4217.00	9269.00	0.46
	Chettivirippu mutant	3297.00	5984.00	0.60
C.D.(0.05)		**N.S.**	**N.S.**	**N.S.**
S.Em		**240.58**	**1000.00**	**0.05**

4.2.3.1. Nitrogen

The nitrogen content of the rice varieties during 1999 didn't reveal any significant difference at the active tillering stage. During the subsequent year the shoot nitrogen content was the highest for Cul. 1026, which was superior to the other two varieties. Nitrogen content under the tidal situation was more than the non-tidal situation irrespective of the varieties, plant parts and the year of study.

At the panicle initiation stage there was no significant difference in nitrogen content of leaf and root under both the tidal regimes and culm under the non-tidal situation, during both the years of study. The culm nitrogen content under tidal influence, however, significantly differed among the varieties. The *Chettivirippu* mutant gave the maximum culm nitrogen content at the panicle initiation stage. Vyttila-3 recorded the lowest culm nitrogen content.

At the flowering stage, the leaf nitrogen content under the tidal situation, and culm nitrogen content under the non-tidal regime during 1999 and leaf nitrogen content under the non-tidal situation during 2000 varied among the varieties. The leaf, culm and root nitrogen content in *Chettivirippu* mutant under the non-tidal regime of 2000 was more than the other varieties and this was significantly higher in the leaf. Except for this variation, the nitrogen content in the various plant parts was more under the tidal regime.

The nitrogen content in root at harvest during 1999 and in culm during 2000 under the tidal situation alone differed significantly. The nitrogen content was more in Vyttila-3 than Cul. 1026. The culm nitrogen in Vyttila-3 under the tidal situation during the year 2000 was also more than that in Cul. 1026. Though not significant, the leaf

Table 20 (a) Tidal effect on nitrogen content (%) of rice varieties at active tillering phase

Treatments		1999		2000	
System	Cultivar/ Variety	Shoot	Root	Shoot	Root
Tidal	Vyttila-3	2.04	1.47	2.20	1.17
	Cul. 1026	2.04	1.38	3.11	1.10
	Chettivirippu mutant	2.08	1.38	2.94	1.20
C.D.(.05)		**N.S.**	**N.S.**	**0.07**	**N.S.**
S.Em		**0.09**	**0.08**	**0.08**	**0.07**
Non-tidal	Vyttila-3	1.68	1.35	2.12	1.30
	Cul. 1026	1.80	1.32	2.07	1.18
	Chettivirippu mutant	1.80	1.29	2.23	1.18
C.D.(.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.03**	**0.03**	**0.07**	**0.05**

Table 20 (b) Tidal effect on nitrogen content (%) of rice varieties at panicle initiation

Treatments		1999			2000		
System	Cultivar/ Varieties	Root	Culm	Leaf	Root	Culm	Leaf
Tidal	Vyttila-3	1.28	1.59	1.38	1.12	1.02	1.37
	Cul. 1026	1.38	1.71	1.53	1.10	1.26	1.54
	Chettivirippu mutant	1.25	1.98	1.41	1.12	1.35	1.51
C.D. (0.05)		**N.S.**	**0.24**	**N.S.**	**N.S.**	**0.12**	**N.S.**
S.Em		**0.04**	**0.07**	**0.06**	**0.04**	**0.04**	**0.18**
Non-tidal	Vyttila-3	1.10	1.35	1.35	1.21	1.16	1.52
	Cul. 1026	1.08	1.35	1.35	1.39	1.24	1.57
	Chettivirippu mutant	1.08	1.35	1.38	1.38	1.30	1.74
C.D.(.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.05**	**0.06**	**0.05**	**0.05**	**0.04**	**0.08**

Table 20 (c) Tidal effect on nitrogen content (%) of rice varieties at flowering

Treatments		1999			2000		
System	Cultivar/ Variety	Root	Culm	Leaf	Root	Culm	Leaf
Tidal	Vyttila-3	1.23	1.39	2.40	1.10	0.81	1.92
	Cul. 1026	1.35	1.54	2.08	1.21	0.76	2.20
	Chettivirippu mutant	1.39	1.59	2.00	1.18	0.90	2.19
C.D. (0.05)		**N.S.**	**N.S.**	**0.32**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.08**	**0.08**	**0.09**	**0.06**	**0.07**	**0.10**
Non-tidal	Vyttila-3	1.10	1.44	1.68	1.03	0.85	1.69
	Cul. 1026	1.10	1.47	1.84	1.12	0.74	1.70
	Chettivirippu mutant	1.24	1.29	1.80	1.31	1.05	2.68
C.D.(.05)		**N.S.**	**0.15**	**N.S.**	**N.S.**	**N.S.**	**0.04**
S.Em		**0.05**	**0.04**	**0.05**	**0.05**	**0.05**	**0.09**

Table 20 (d) Tidal effect on nitrogen content (%) of rice varieties at harvest

Treatments		1999				2000			
System	Cultivar/ Variety	Root	Culm	Leaf	Grain	Root	Culm	Leaf	Grain
Tidal	Vyttila-3	1.36	1.12	1.65	1.04	1.12	1.00	1.53	1.19
	Cul. 1026	1.12	1.18	1.55	1.00	1.09	0.83	1.52	1.16
	Chettivirippu mutant	1.16	1.32	1.53	1.14	1.30	0.96	1.34	1.25
C.D.(.05)		**0.15**	**N.S**	**N.S**	**N.S**	**N.S**	**0.06**	**N.S**	**N.S**
S.Em		**0.06**	**0.06**	**0.05**	**0.04**	**0.04**	**0.02**	**0.08**	**0.05**
Non-tidal	Vyttila-3	1.02	0.62	1.20	1.10	0.86	0.64	0.99	1.02
	Cul. 1026	1.06	0.62	1.15	1.02	0.99	0.58	1.01	0.94
	Chettivirippu mutant	1.02	0.58	1.23	1.10	1.06	0.74	1.24	1.09
C.D.(.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.03**	**0.02**	**0.08**	**0.02**	**0.05**	**0.03**	**0.05**	**0.03**

nitrogen under tidal situation of both the years was more in Vyttila-3 than the other varieties. The nitrogen content in leaf, root and culm under tidal regime and leaf and root under the non-tidal regime was always more than or equal to the nitrogen content in the grain. Though not significant, the nitrogen content in all the parts of the *Chettivirippu* mutant, under the non-tidal regime of 2000 was higher than the other varieties.

The nitrogen content was always higher under the tidal situation during both years, irrespective of the growth stage or the part of the plant.

Nitrogen uptake

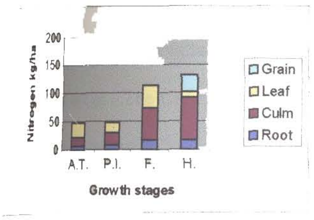
The uptake of nitrogen (Fig. 7) at the various growth stages during 2000 revealed that the tidal regimes as well as the varieties differed considerably on the nitrogen uptake and its utilization. The uptake of nitrogen at active tillering by Vyttila-3 under tidal situation was 40.8 kg ha^{-1} and increased to 46.8 kg ha^{-1} at panicle initiation, recorded a steep increase to 112.2 kg ha^{-1} at flowering and finally reached 130.6 kg ha^{-1} at harvest. Under the non-tidal regime the corresponding values were much lower, recording 26.0, 41.0, 83.0 and 93.0 kg ha^{-1}, respectively. Cul. 1026 recorded the maximum uptake of 179 kg nitrogen ha^{-1} under the tidal situation at flowering stage which declined to 137 kg nitrogen ha^{-1} at harvest. The *Chettivirippu* mutant recorded an uptake of 37.5 kg nitrogen ha^{-1} under tidal situation at active tillering phase, which gradually increased to 49.8 and 116.9 kg nitrogen ha^{-1} at the panicle initiation and flowering stages respectively and declined to 106.4 kg nitrogen ha^{-1} at harvest.

Under the non-tidal situation the uptake of nitrogen at active tillering stage was 45, 57 and 66 per cent lesser than that of the tidal situation for Vyttila-3, Cul.1026 and

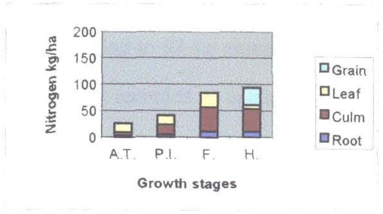
Fig 7 Effect of tidal regimes on partitioning of Nitrogen in rice varieties (kgha^{-1}) - 2000

Vyttila - 3

Tidal

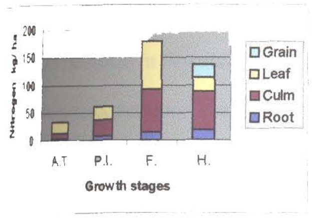


Non- tidal

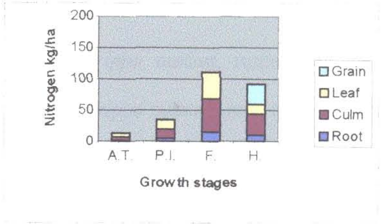


Cul. 1026

Tidal

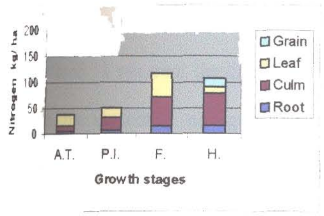


Non- tidal

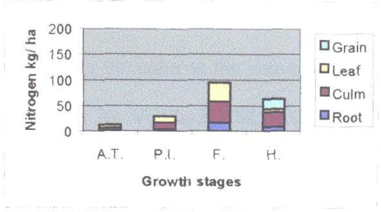


Chettivirippu mutant

Tidal



Non- tidal



AT- Active tillering , PI- Panicle initiation, F- Flowering , H- harvest

Chettivirippu mutant respectively. The same trend of decreased nitrogen uptake continued under the non-tidal situation at all the subsequent stages. The difference in uptake of nitrogen between the two tidal situations was as wide as 67 kg ha^{-1} for Cul.1026 at flowering stage. Vyttila-3 under the non-tidal regime registered a gradual increase in nitrogen uptake from 26 kg at active tillering to 93 kg nitrogen ha^{-1} at the harvest stage. The Cul. 1026 and *Chettivirippu* mutant recorded an uptake of 14.0 and 12.6 kg nitrogen ha^{-1} at active tillering and peaked to 111 and 95 kg nitrogen ha^{-1} at flowering and then declined to 82 and 63 kg nitrogen ha^{-1}, respectively at harvest.

A close perusal of the nitrogen uptake further revealed that the nitrogen uptake in leaf at harvest compared to the same at flowering, had substantially decreased by 75.7, 69.9 and 72.2 per cent under tidal situation and 74.3, 63.9 and 83.7 per cent under non-tidal situation in Vyttila-3, Cul.1026 and *Chettivirippu* mutant, respectively. The nitrogen accumulation in culm in Vyttila-3 and *Chettivirippu* mutant under tidal situation recorded 56 and 10 per cent increase at harvest from the flowering stage while all the varieties under the non-tidal regime registered a decline in nitrogen accumulation in culm at harvest stage. The decrease in nitrogen uptake in culm at harvest stage compared to flowering stage was 6.1, 37.6 and 30.1 per cent, respectively for Vyttila-3, Cul.1026 and *Chettivirippu* mutant under the non-tidal situation. Cul.1026 under tidal situation also registered 11 per cent decline of nitrogen accumulated in the culm at the above stage. Thus, the respective nitrogen accumulation in panicle by Vyttila-3, Cul. 1026 and *Chettivirippu* mutant was 30.0, 22.9 and 15.8 kg ha^{-1} under tidal regime and 32.6, 22.8 and 19.3 kg ha^{-1} under non-tidal situation. The translocation of nitrogen to the panicles was mainly from the leaves under the tidal regime and from both the leaves and culm under the non-tidal regime. The distribution of nitrogen in Vyttila-3 at harvest to root, culm, leaf and panicle was 13.0, 56.6, 7.4 and 23.0 per cent, respectively under tidal situation and 11.9, 45.4, 7.5 and 35.1, respectively under non-tidal situation.

A comparison over the different stages shows that (1) at all stages the N uptake was clearly higher in the tidal situation and (2) the translocation of N to the grain is mainly from the leaves in the tidal situation, whereas the translocation occurs from the leaves and culm in non-tidal condition. Comparing the N uptake in different varieties it was seen that the peak level was at flowering stage in Cul. 1026 and *Chettivirippu* mutant, whereas in Vyttila-3, the typical *Pokkali* variety, the uptake continued and the peak was reached at harvest stage.

4.2.3.2. Phosphorus

The phosphorus content in shoot and root at active tillering phase during 1999 under both the tidal regimes didn't record any significant varietal difference (Table 21 a, b, c and d). During the subsequent year, phosphorus content in shoot under the tidal situation was significantly more in Vyttila-3 than the other two varieties. The non-tidal regime didn't record any significant variation among the varieties in this regard. The root content of phosphorus, on the other hand significantly varied among the varieties under the non-tidal regime. Vyttila-3 recorded 12.7 per cent more phosphorus than Cul. 1026. Under the tidal situation, though the phosphorus content of root was high for Vyttila-3, the difference was not significant.

Table 21 (a) Tidal effect on phosphorus content (%) of rice varieties at active tillering phase

Treatments		1999		2000	
System	Cultivar/ Variety	Shoot	Root	Shoot	Root
Tidal	Vyttila-3	0.24	0.42	0.51	0.72
	Cul. 1026	0.25	0.45	0.26	0.50
	Chettivirippu Mutant	0.25	0.40	0.24	0.42
C.D.(0.05)		**N.S.**	**N.S.**	**0.08**	**N.S.**
S.Em		**0.01**	**0.04**	**0.03**	**0.09**
Non-tidal	Vyttila-3	0.26	0.38	0.44	0.71
	Cul. 1026	0.26	0.42	0.45	0.63
	Chettivirippu mutant	0.25	0.44	0.44	0.70
C.D.(0.05)		**N.S.**	**N.S.**	**N.S.**	**0.06**
S.Em		**0.01**	**0.02**	**0.03**	**0.02**

Table 21 (b) Tidal effect on phosphorus content (%) of rice varieties at panicle initiation

Treatments		1999			2000		
System	Cultivar/ Varieties	Root	Culm	Leaf	Root	Culm	Leaf
Tidal	Vyttila-3	0.47	0.26	0.18	0.51	0.32	0.25
	Cul. 1026	0.60	0.28	0.20	0.58	0.34	0.21
	Chettivirippu mutant	0.55	0.28	0.23	0.46	0.34	0.23
C.D.(.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S**	**N.S.**
S.Em		**0.03**	**0.01**	**0.01**	**0.06**	**0.03**	**0.02**
Non-tidal	Vyttila-3	0.56	0.30	0.21	0.65	0.37	0.36
	Cul. 1026	0.58	0.32	0.18	0.74	0.35	0.34
	Chettivirippu mutant	0.50	0.30	0.20	0.71	0.33	0.35
C.D.(.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**0.02**	**N.S.**
S.Em		**0.01**	**0.01**	**0.01**	**0.03**	**0.01**	**0.09**

Table 21 (c) Tidal effect on phosphorus content (%) of rice varieties at flowering

Treatments		1999			2000		
System	Cultivar/ Variety	Root	Culm	Leaf	Root	Culm	Leaf
Tidal	Vyttila-3	0.56	0.19	0.19	0.66	0.40	0.25
	Cul. 1026	0.44	0.20	0.16	0.45	0.29	0.23
	Chettivirippu mutant	0.49	0.22	0.23	0.46	0.31	0.27
C.D. (0.05)		**N.S.**	**0.01**	**0.02**	**0.17**	**0.06**	**0.02**
S.Em		**0.04**	**0.01**	**0.01**	**0.06**	**0.02**	**0.01**
Non-tidal	Vyttila-3	0.37	0.18	0.14	0.41	0.43	0.29
	Cul. 1026	0.32	0.18	0.12	0.39	0.37	0.32
	Chettivirippu mutant	0.35	0.22	0.18	0.43	0.40	0.31
C.D.(.05)		**N.S.**	**N.S.**	**0.03**	**N.S.**	**0.05**	**N.S.**
S.Em		**0.02**	**0.01**	**0.01**	**0.03**	**0.01**	**0.03**

Table 21 (d) Tidal effect on phosphorus content (%) of rice varieties at harvest

Treatments		1999				2000			
System	Cultivar/ Variety	Root	Culm	Leaf	Grain	Root	Culm	Leaf	Grain
Tidal	Vyttila-3	0.25	0.14	0.10	0.22	0.51	0.25	0.27	0.28
	Cul. 1026	0.18	0.11	0.14	0.22	0.52	0.28	0.18	0.29
	Chettivirippu mutant	0.22	0.10	0.14	0.21	0.40	0.28	0.24	0.31
C.D.(.05)		**N.S.**	**0.02**	**0.02**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.02**	**0.01**	**0.01**	**0.01**	**0.04**	**0.02**	**0.02**	**0.01**
Non-tidal	Vyttila-3	0.40	0.10	0.05	0.25	0.27	0.44	0.22	0.33
	Cul. 1026	0.24	0.10	0.08	0.25	0.30	0.44	0.25	0.34
	Chettivirippu mutant	0.27	0.08	0.07	0.26	0.31	0.46	0.28	0.34
C.D.(.05)		**0.05**	**N.S.**	**0.02**	**N.S.**	**N.S.**	**N.S.**	**0.02**	**N.S.**
S.Em		**0.02**	**0.01**	**0.01**	**0.01**	**0.02**	**0.02**	**0.01**	**0.01**

At the panicle initiation stage, the difference in phosphorus content in root, culm and leaf of rice was not significant during both the years except that in the culm under the non-tidal situation during 2000. Vyttila-3 recorded highest phosphorus content, which was 10.2 per cent more than that of *Chettivirippu* mutant. The P content was maximum in root followed by culm and the least in the leaf.

At flowering, during 1999, the phosphorus content in leaf and culm under tidal influence, and in leaf under the non-tidal regime in *Chettivirippu* mutant was significantly higher. The root phosphorus was higher in Vyttila-3. The phosphorus content in all the plant parts was least in Cul.1026.

Phosphorus content in culm and leaf was more under the tidal situation than the non-tidal while, the reverse was true with respect to the root and grain phosphorus during 1999. During the subsequent year, in contrast to the general rule of higher concentration of phosphorus in roots, under the non-tidal situation the culm and leaf phosphorus was $\geq$ root phosphorus. Though not significant, the *Chettivirippu* mutant had the maximum phosphorus content in root, culm, leaf and grain under the non-tidal regime during 2000.

Phosphorus uptake

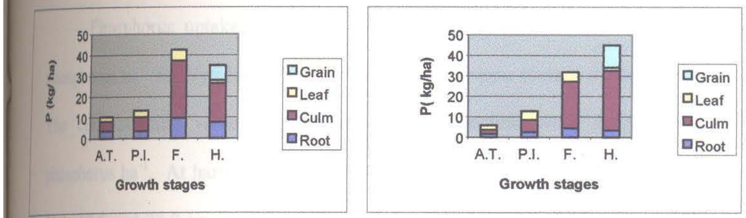
Phosphorus uptake pattern under the two tidal regimes was different (Fig. 8) from one another. The uptake pattern by the varieties also differed considerably. Among the varieties, Vyttila-3 had the maximum uptake of phosphorus at active tillering phase, under both the tidal regimes. The phosphorus uptake of Vyttila-3 under tidal regime at this phase was double that of Cul. 1026. The difference in uptake between these two was, however, lesser under the non-tidal situation. As the development stage advanced to

Fig.8. Effect of tidal regimes on partitioning of Phosphorus in rice varieties (kg ha^{-1}) -2000

Vyttila –3

Tidal

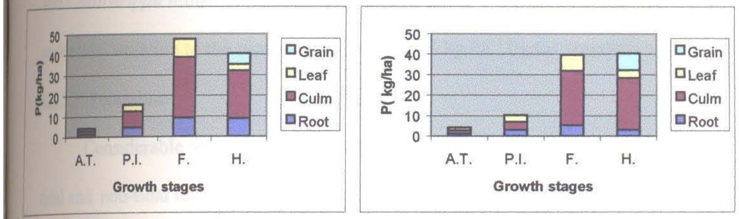
Non- tidal



Cul. 1026

Tidal

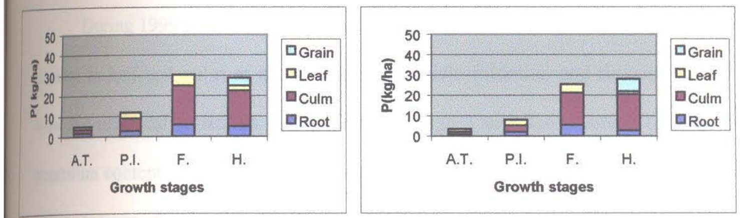
Non –tidal



Chttivirippu mutant

Tidal

Non –tidal



AT- Active tillering , PI- Panicle initiation, F- Flowering , H- harvest

panicle initiation, Cul. 1026 under tidal regime surpassed the phosphorus uptake of Vyttila-3, under the non-tidal regime.

Phosphorus uptake, under the tidal regime peaked at 42.5, 47.6 and 30.5 kg phosphorus ha^{-1} for Vyttila-3, Cul.1026 and *Chettivirippu* mutant at the flowering stage. The corresponding values under the non-tidal regime were 31.9, 39.9, 25.5 kg phosphorus ha^{-1}. At harvest, the phosphorus uptake under the tidal situation declined to 35.1, 40.5 and 28.0 kg phosphorus ha^{-1} while the non-tidal regime registered a gradual increase to 44.9, 40.5 and 28.0 kg phosphorus ha^{-1} for the varieties Vyttila-3, Cul.1026 and *Chettivirippu* mutant, respectively which indicated a decrease in phosphorus uptake under tidal situation to the tune of 7.4, 7.1 and 1.7 kg ha^{-1} by the respective varieties.

4.2.3.3. Potassium

Considerable variation in potassium content in various plant parts under both the tidal and non-tidal regimes could be observed during both the years (Table 22 a, b, c and d). Vyttila-3 had the maximum potassium content in the aerial parts irrespective of the tidal regimes up to the flowering stage.

During 1999 and 2000, Vyttila-3 followed by Cul.1026 recorded higher potassium content in leaf and culm at active tillering, panicle initiation and flowering under the tidal and non-tidal situations. At the harvest stage, Cul. 1026 recorded the highest leaf potassium content. No definite trend was visible with respect to the root potassium at the different stages of crop growth.

Table 22 (a) Tidal effect on potassium content (%) of rice varieties at active tillering phase

Treatments		1999		2000	
System	Cultivar/ Variety	Shoot	Root	Shoot	Root
Tidal	Vyttila-3	3.36	0.35	3.87	0.97
	Cul. 1026	2.96	0.38	2.97	1.01
	Chettivirippu mutant	2.52	0.30	2.78	0.78
C.D.(0.05)		**0.196**	**N.S.**	**0.32**	**N.S.**
S.Em		**0.06**	**0.03**	**0.10**	**0.06**
Non-tidal	Vyttila-3	3.84	0.57	3.46	1.42
	Cul. 1026	3.04	0.42	2.52	1.11
	Chettivirippu mutant	3.24	0.47	2.39	0.81
C.D.(0.05)		**0.26**	**0.10**	**0.41**	**0.22**
S.Em		**0.01**	**0.01**	**0.13**	**0.07**

Table 22 (b) Tidal effect on potassium content (%) of rice varieties at panicle initiation

Treatments		1999			2000		
System	Cultivar/ Varieties	Root	Culm	Leaf	Root	Culm	Leaf
Tidal	Vyttila-3	0.58	2.84	2.59	0.69	3.56	3.17
	Cul. 1026	0.60	2.57	2.55	0.59	2.55	2.88
	Chettivirippu mutant	0.74	2.34	2.36	0.71	1.83	2.60
C.D. (0.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**0.21**	**0.23**
S.Em		**0.05**	**0.16**	**0.09**	**0.06**	**0.07**	**0.07**
Non-tidal	Vyttila-3	0.50	3.40	3.59	1.12	2.85	2.93
	Cul. 1026	0.52	3.17	3.40	0.78	2.50	2.57
	Chettivirippu mutant	0.52	3.00	3.03	1.05	1.79	2.27
C.D.(.05)		**N.S.**	**N.S.**	**0.38**	**N.S.**	**0.30**	**0.22**
S.Em		**0.01**	**0.01**	**0.01**	**0.10**	**0.10**	**0.07**

Table 22 (c) Tidal effect on potassium content (%) of rice varieties at flowering

Treatments		1999			2000		
System	Cultivar/ Variety	Root	Culm	Leaf	Root	Culm	Leaf
Tidal	Vyttila-3	0.20	1.52	2.25	0.33	1.78	2.16
	Cul. 1026	0.22	1.28	1.99	0.36	1.54	2.06
	Chettivirippu mutant	0.21	1.22	2.06	0.40	1.22	1.71
C.D. (0.05)		**0.02**	**0.14**	**0.14**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.01**	**0.04**	**0.04**	**0.02**	**0.10**	**0.08**
Non-tidal	Vyttila-3	0.19	1.30	1.76	0.52	2.28	2.62
	Cul. 1026	0.23	1.05	1.68	0.33	1.61	2.07
	Chettivirippu mutant	0.22	1.07	1.67	0.58	1.35	1.83
C.D.(.05)		**0.03**	**N.S.**	**0.08**	**N.S.**	**0.35**	**0.17**
S.Em		**0.01**	**0.01**	**0.01**	**0.05**	**0.11**	**0.05**

Table 22 (d) Tidal effect on potassium content (%) of rice varieties at harvest

Treatments		1999				2000			
System	Cultivar/ Variety	Root	Culm	Leaf	Grain	Root	Culm	Leaf	Grain
Tidal	Vyttila-3	0.25	1.92	0.85	0.24	0.23	1.89	1.35	0.34
	Cul. 1026	0.23	2.02	1.15	0.23	0.33	1.71	1.55	0.40
	Chettivirippu Mutant	0.21	1.75	1.05	0.23	0.29	1.61	1.58	0.39
C.D.(.05)		**N.S.**	**N.S.**	**0.12**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.01**	**0.07**	**0.04**	**0.01**	**0.03**	**0.10**	**0.07**	**0.01**
Non-tidal	Vyttila-3	0.30	1.73	0.71	0.29	0.39	1.57	1.10	0.30
	Cul. 1026	0.25	1.48	1.09	0.29	0.35	1.72	1.63	0.36
	Chettivirippu Mutant	0.24	1.42	0.69	0.28	0.35	1.17	1.24	0.40
C.D.(.05)		**0.02**	**0.01**	**0.01**	**N.S.**	**N.S.**	**0.19**	**0.20**	**N.S.**
S.Em		**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.06**	**0.06**	**0.02**

Potassium uptake

Irrespective of the tidal regimes and varieties, the potassium uptake (Fig. 9) was linear up to the flowering stage and declined thereafter. The uptake was more under the tidal regime in all the varieties, though there were considerable variations among them in this regard.

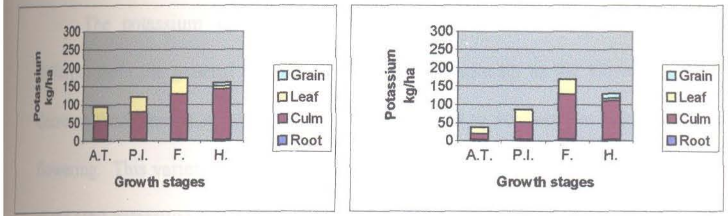
Vyttila-3 under the tidal situation accumulated as much as half of the maximum potassium uptake at active tillering stage, added 15.2 per cent more at panicle initiation and peaked at flowering by accumulating the remaining 30.8 per cent during the panicle initiation to flowering stage. Vyttila-3 shed 7.4 per cent of the total potassium accumulated by it, during the flowering to harvest stage. Under the non-tidal situation the uptake of potassium at flowering by Vyttila-3 was almost the same as that under the tidal regime, but was only 40 per cent at active tillering, 70 per cent at panicle initiation and 98 per cent at flowering as that of the Vyttila-3 under the tidal situation.

Cul.1026 had the maximum potassium uptake of 245.9 kg under the tidal situation. The phasic potassium uptake of this variety was 15.8 and 44.1 per cent of its maximum uptake at active tillering and panicle initiation stage. Cul.1026 shed 65.4 kg potassium ha^{-1} during the flowering to harvest stage to finally make a potassium uptake of 180.6 kg ha^{-1} under tidal situation. The potassium uptake of this variety under the non-tidal regime was only 175.6 kg ha^{-1}$\cdot$ which was the highest at the flowering stage. At the active tillering and panicle initiation stages only 11.1 and 32.3 per cent of its maximum potassium uptake was accumulated. The remaining 56.6 per cent potassium was accumulated during the period from panicle initiation to flowering stage. Cul.1026 under

Fig. 9. Effect of tidal regimes on partitioning of Potassium in rice varieties (kg ha^{-1}) -2000

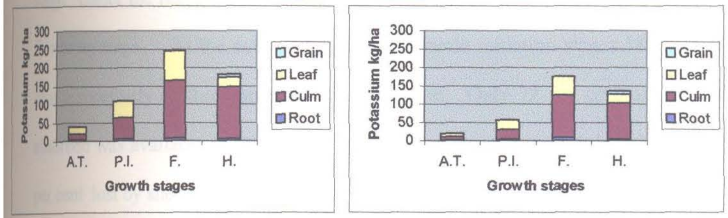
Vyttila –3

Tidal Non- tidal



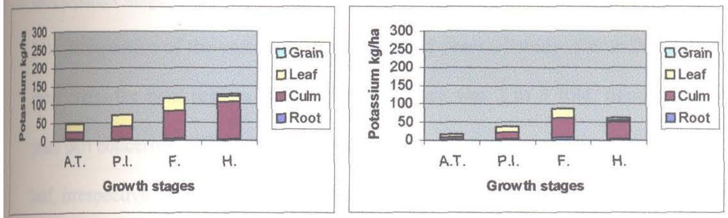
Cul. 1026

Tidal Non- tidal



Chettivirippu mutant

Tidal Non –tidal



AT- Active tillering , PI- Panicle initiation, F- Flowering , H- harvest

non-tidal regime during the flowering to harvest stage shed 22.9 per cent of the potassium accumulated by it during the growth period.

The potassium uptake of *Chettivirippu* mutant under the tidal regime was different from the general pattern of maximum uptake up to the flowering stage and a decrease thereafter. *Chettivirippu* mutant continued to accumulate potassium even after flowering. This variety under the tidal regime accumulated 35.7, 55.3 and 92.7 per cent of the total potassium uptake by it at the active tillering, panicle initiation and flowering stages, respectively and added the remaining 7.3 per cent during the flowering to harvest stage. Under the non-tidal regime the peak potassium uptake of 85.54 kg ha^{-1} was at the flowering stage. At the active tillering and panicle initiation stages 18.0 and 43.6 per cent respectively of this potassium was absorbed. Only 72 per cent of the potassium absorbed was available in the various plant parts at harvest, which left the remaining 28 per cent lost by shedding.

4.2.3.4. Sodium

Significant variation in sodium content in different plant parts at various development stages was observed on account of the varieties and tidal regimes (Table 23). Irrespective of the varieties, plant parts and years of study, the sodium content was more under the tidal regime, where the difference was 2 to 3 fold, depending upon the plant part concerned. The sodium content in plant parts was in the order of culm > root > leaf, irrespective of the stage, tidal regime and year of study. In general, Vyttila-3 and Cul. 1026 had lower sodium content than *Chettivirippu* mutant in all parts, especially under the tidal situation. *Chettivirippu* mutant recorded the maximum leaf sodium content

Table 23 (a) **Tidal effect on sodium content (%) of rice varieties at active tillering phase**

Treatments		1999		2000	
System	Cultivar/ Variety	Shoot	Root	Shoot	Root
Tidal	Vyttila-3	1.57	0.33	1.85	0.77
	Cul. 1026	1.60	0.38	1.98	1.29
	Chettivirippu mutant	1.85	0.33	2.41	0.96
C.D.(0.05)		**0.20**	**N.S.**	**0.31**	**N.S.**
S.Em		**0.06**	**0.03**	**0.10**	**0.12**
Non-tidal	Vyttila-3	0.83	0.18	0.37	0.20
	Cul. 1026	0.70	0.17	0.38	0.17
	Chettivirippu mutant	0.69	0.23	0.45	0.20
C.D.(0.05)		**N.S.**	**0.03**	**0.02**	**N.S.**
S.Em		**0.07**	**0.01**	**0.01**	**0.01**

Table 23 (b) **Tidal effect on sodium content (%) of rice varieties at panicle initiation**

Treatments		1999			2000		
System	Cultivar/ Varieties	Root	Culm	Leaf	Root	Culm	Leaf
Tidal	Vyttila-3	0.76	1.80	0.34	0.78	1.24	0.44
	Cul. 1026	0.83	1.61	0.33	0.66	1.00	0.44
	Chettivirippu mutant	0.87	1.93	0.45	0.67	0.97	0.93
C.D. (0.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**0.17**
S.Em		**0.06**	**0.11**	**0.06**	**0.06**	**0.10**	**0.06**
Non-tidal	Vyttila-3	0.23	0.43	0.19	0.17	0.30	0.09
	Cul. 1026	0.22	0.38	0.24	0.15	0.34	0.11
	Chettivirippu Mutant	0.25	0.46	0.18	0.20	0.36	0.15
C.D.(.05)		**N.S.**	**0.05**	**0.03**	**N.S.**	**N.S.**	**0.02**
S.Em		**0.01**	**0.02**	**0.01**	**0.02**	**0.02**	**0.01**

Table 23 (c) Tidal effect on sodium content (%) of rice varieties at flowering

Treatments		1999			2000		
System	Cultivar/ Variety	Root	Culm	Leaf	Root	Culm	Leaf
Tidal	Vyttila-3	0.31	0.85	0.18	0.45	1.25	0.30
	Cul. 1026	0.45	0.79	0.21	0.45	1.15	0.25
	Chettivirippu mutant	0.35	1.06	0.27	0.50	1.45	0.50
C.D. (0.05)		**0.07**	**0.11**	**0.03**	**N.S.**	**N.S.**	**0.05**
S.Em		**0.02**	**0.04**	**0.01**	**0.01**	**0.02**	**0.01**
Non-tidal	Vyttila-3	0.14	0.34	0.12	0.50	1.30	0.20
	Cul. 1026	0.21	0.33	0.10	0.45	0.95	0.20
	Chettivirippu mutant	0.18	0.42	0.17	0.50	1.40	0.45
C.D. (0.05)		**0.04**	**0.03**	**0.02**	**N.S.**	**0.20**	**0.10**
S.Em		**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**

Table 23 (d) Tidal effect on sodium content (%) of rice varieties at harvest

Treatments		1999				2000			
System	Cultivar/ Variety	Root	Culm	Leaf	Grain	Root	Culm	Leaf	Grain
Tidal	Vyttila-3	0.29	0.73	0.10	0.046	0.35	1.30	0.35	0.050
	Cul. 1026	0.34	0.45	0.10	0.054	0.45	1.20	0.25	0.065
	Chettivirippu mutant	0.53	1.01	0.26	0.058	0.40	1.40	0.65	0.065
C.D.(.05)		**0.11**	**0.26**	**0.03**	**N.S.**	**N.S.**	**N.S.**	**0.20**	**N.S.**
S.Em		**0.04**	**0.08**	**0.01**	**0.004**	**0.01**	**0.02**	**0.01**	**0.002**
Non-tidal	Vyttila-3	0.31	0.47	0.11	0.049	0.30	1.25	0.20	0.020
	Cul. 1026	0.23	0.37	0.07	0.047	0.50	1.00	0.15	0.025
	Chettivirippu Mutant	0.25	0.50	0.19	0.059	0.40	1.50	0.45	0.030
C.D.(.05)		**0.02**	**0.04**	**0.05**	**N.S.**	**0.10**	**0.20**	**0.02**	**N.S.**
S.Em		**0.01**	**0.01**	**0.02**	**0.003**	**0.01**	**0.01**	**0.01**	**0.001**

that significantly higher at the flowering and at the harvest stages. As the development stage progressed from panicle initiation to harvest the sodium content in plant parts decreased considerably in the tidal situation.

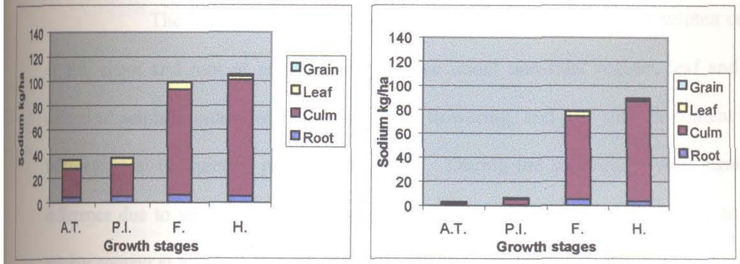
Sodium uptake

The sodium uptake (Fig. 10) by the varieties varied according to the growth phase and the tidal regime. Under tidal situation at the flowering stage Cul. 1026 and *Chettivirippu* mutant peaked the Na uptake at 137 and 106 kg ha^{-1}, respectively while Vyttila-3 had the maximum uptake at maturity (105 kg ha^{-1}). Under the non-tidal situation also Cul. 1026 and *Chettivirippu* mutant had the peak Na uptake at the flowering stage (79.6 and 67.4 kg ha^{-1}). Vyttila-3 had the maximum uptake at maturity stage (89.5 kg ha^{-1}).

The distribution pattern of sodium in different plant parts had little difference between the two tidal regimes at the various development stages. In Vyttila-3 at active tillering stage 20.7 per cent of the sodium absorbed was in the leaves and it decreased to 2.2 per cent at harvest. As the development stage progressed, the sodium retained in the culm also increased from 66.9 per cent at active tillering to 91.6 per cent at harvest. The root sodium uptake, on the contrary, decreased from 12.3 at the active tillering to 5.1 per cent at harvest. Under the non-tidal situation also a similar trend was observed. The distribution of sodium in plant parts of the other varieties also followed the same trend. Irrespective of the varieties and tidal regimes the sodium retained in panicle was 0.72 to 1.5 per cent of the total uptake.

Fig.10. Effect of tidal regimes on partitioning of Sodium in rice varieties (kg ha^{-1}) -2000

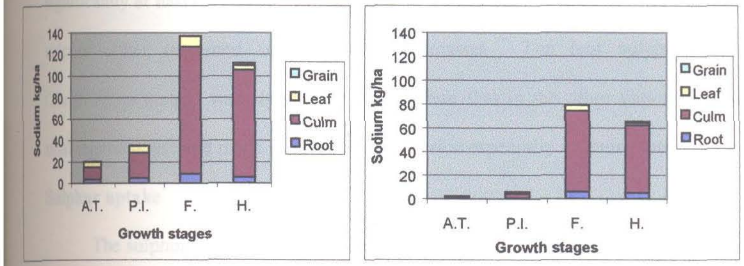
Vyttila –3



Tidal

Non- tidal

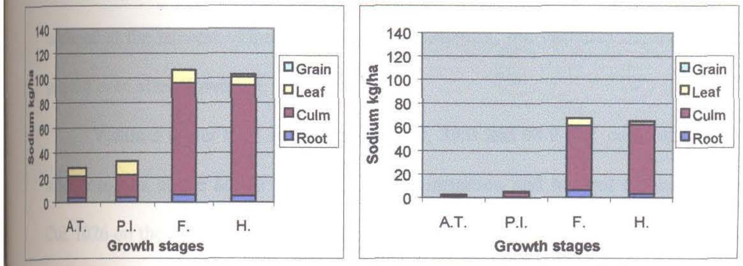
Cul.- 1026



Tidal

Non -tidal

Chettivirippu mutant



Tidal

Non –tidal

AT- Active tillering , PI- Panicle initiation, F- Flowering , H- harvest

4.2.3.5. Sulphur

The varieties revealed (Table 24) significant difference in sulphur content in their shoot and root at active tillering stage under non-tidal regime, leaf and culm content of sulphur under both the regimes at flowering, and leaf sulphur content under tidal regime at the harvest phase during 1999. During the subsequent year, significant difference due to varieties was observed in culm sulphur content at flowering and leaf sulphur content at harvest, under the non-tidal situation.

The leaf content of sulphur was more at the early stages which got reduced significantly at harvest stage. As the stage of development advanced, the root and culm sulphur either remained unchanged or increased. The leaf sulphur content in *Chettivirippu* mutant was significantly more than that in the other varieties. The non-tidal regime registered more sulphur content in rice especially in their roots.

Sulphur uptake

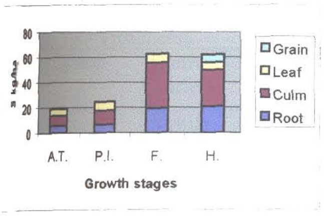
The sulphur uptake pattern followed by the varieties under both the tidal regimes was similar to that of the phosphorus uptake (Fig. 11). Under the tidal regime the uptake of sulphur peaked at the flowering stage except in the case of *Chettivirippu* mutant and declined at the harvest. Under the non-tidal situation, the varieties continued to absorb sulphur even after flowering.

Vyttila-3 under tidal situation had 30.0, 39.0 and 98.9 per cent of its maximum sulphur uptake at the active tillering, panicle initiation and harvest stages, respectively. Cul. 1026 on the other hand, recorded 9.3, 35.3 and 86.7 per cent of it's sulphur uptake at the above respective stages. The *Chettivirippu* mutant, had 17.2, 43.6 and 90.9 per cent

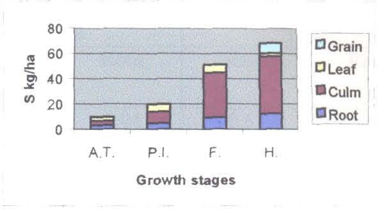
11. Effect of tidal regimes on partitioning of Sulphur in rice varieties (kg ha^{-1}) -2000

Vyttila -3

Tidal

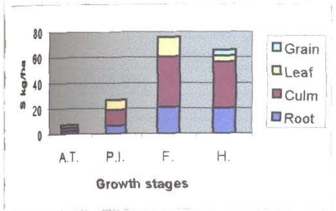


Non- tidal

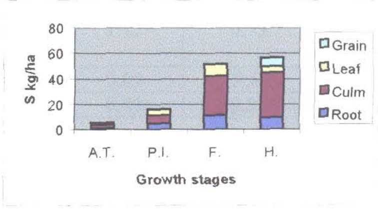


Cul.- 1026

Tidal

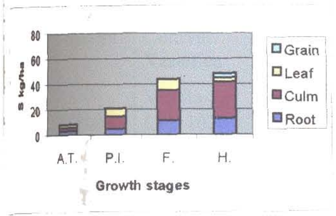


Non -tidal

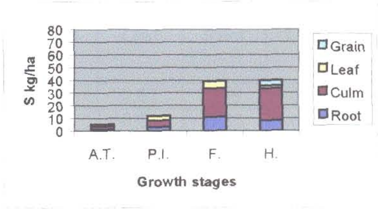


Chettivirippu mutant

Tidal



Non –tidal



AT- Active tillering , PI- Panicle initiation, F- Flowering , H- harvest

Table 24 (a) Tidal effect on sulphur content (%) of rice varieties at active tillering phase

Treatments		1999		2000	
System	Cultivar/ Variety	Shoot	Root	Shoot	Root
Tidal	Vyttila-3	0.63	1.04	0.61	1.03
	Cul. 1026	0.70	1.17	0.44	0.84
	Chettivirippu mutant	0.75	0.91	0.39	0.80
C.D.(0.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.05**	**0.10**	**0.05**	**0.04**
Non-tidal	Vyttila-3	0.65	1.20	0.77	1.30
	Cul. 1026	0.68	1.04	0.77	1.26
	Chettivirippu mutant	0.57	1.11	0.73	1.17
C.D.(0.05)		**0.06**	**0.09**	**N.S.**	**N.S.**
S.Em		**0.02**	**0.03**	**0.02**	**0.03**

Table 24 (b) Tidal effect on sulphur content (%) of rice varieties at panicle initiation

Treatments		1999			2000		
System	Cultivar/ Varieties	Root	Culm	Leaf	Root	Culm	Leaf
Tidal	Vyttila-3	1.28	0.66	0.62	0.99	0.52	0.53
	Cul. 1026	1.47	0.58	0.63	0.85	0.54	0.49
	Chettivirippu mutant	1.38	0.63	0.73	0.85	0.51	0.54
C.D. (0.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.08**	**0.05**	**0.04**	**0.04**	**0.02**	**0.04**
Non-tidal	Vyttila-3	1.42	0.64	0.63	1.15	0.57	0.48
	Cul. 1026	1.51	0.69	0.63	1.18	0.57	0.50
	Chettivirippu mutant	1.37	0.63	0.63	1.10	0.51	0.51
C.D.(.05)		N.S.	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.05**	**0.03**	**0.03**	**0.08**	**0.02**	**0.01**

Table 24 (c) Tidal effect on sulphur content (%) of rice varieties at flowering

Treatments		1999			2000		
System	Cultivar/ Variety	Root	Culm	Leaf	Root	Culm	Leaf
Tidal	Vyttila-3	2.04	0.41	0.69	1.31	0.52	0.34
	Cul. 1026	1.73	0.32	0.46	1.06	0.38	0.39
	Chettivirippu mutant	1.85	0.41	0.57	0.88	0.39	0.40
C.D. (0.05)		**N.S.**	**0.05**	**0.09**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.11**	**0.02**	**0.03**	**0.10**	**0.03**	**0.02**
Non-tidal	Vyttila-3	1.33	0.41	0.62	0.84	0.66	0.40
	Cul. 1026	1.32	0.30	0.36	0.83	0.43	0.37
	Chettivirippu mutant	1.06	0.36	0.55	0.88	0.57	0.43
C.D.(.05)		**N.S.**	**0.06**	**0.11**	**N.S.**	**0.09**	**N.S.**
S.Em		**0.09**	**0.02**	**0.04**	**0.05**	**0.03**	**0.02**

Table 24 (d) Tidal effect on sulphur content (%) of rice varieties at harvest

Treatments		1999				2000			
System	Cultivar/ Variety	Root	Culm	Leaf	Grain	Root	Culm	Leaf	Grain
Tidal	Vyttila-3	1.90	0.34	0.22	0.20	1.38	0.39	0.38	0.24
	Cul. 1026	2.20	0.31	0.27	0.24	1.20	0.43	0.29	0.24
	Chettivirippu mutant	1.89	0.40	0.33	0.25	1.02	0.45	0.34	0.25
C.D.(.05)		**N.S.**	**N.S.**	**0.05**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.16**	**0.03**	**0.02**	**0.02**	**0.07**	**0.05**	**0.03**	**0.03**
Non-tidal	Vyttila-3	1.51	0.43	0.26	0.16	0.98	0.68	0.32	0.25
	Cul. 1026	1.97	0.36	0.31	0.12	0.95	0.62	0.31	0.27
	Chettivirippu mutant	2.10	0.42	0.33	0.14	0.95	0.65	0.40	0.24
C.D.(.05)		**0.42**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**0.002**	**N.S.**
S.Em		**0.14**	**0.02**	**0.03**	**0.01**	**0.03**	**0.02**	**0.01**	**0.02**

of it's sulphur uptake at the active tillering, panicle initiation and flowering stages respectively.

Under the non-tidal situation, all the three varieties had the peak sulphur uptake at the harvest stage. The uptake by Vyttila-3 under non-tidal regime at active tillering, panicle initiation and flowering stages was 13.9, 28.8 and 74.7 per cent, respectively, of the total uptake. The corresponding percentages were 9.8, 28.6 and 91.4 for Cul. 1026 and 12.9, 30.0 and 99.7 for the *Chettivirippu* mutant.

4.2.3.6. Calcium

Leaf calcium content (Table 25) of Vyttila-3 under the tidal regime at harvest was significantly superior to the other varieties. The leaf calcium content at panicle initiation of both the regimes and under non-tidal regime at harvest didn't vary between the varieties. The culm and root calcium content at panicle initiation and culm, root and grain calcium content at harvest stages, under both the tidal regimes, also didn't vary significantly among the varieties.

Calcium uptake

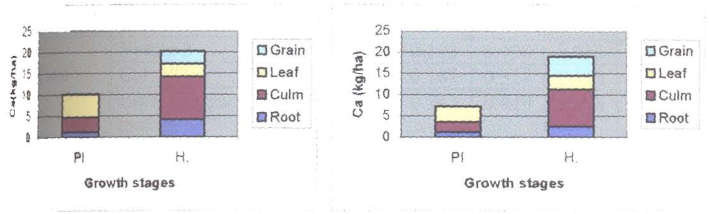
The uptake of calcium (Fig. 12) was maximum between the panicle initiation and harvest stages in all the varieties under both the tidal regimes. Vyttila-3 under tidal regime had 50.0 per cent of it's total calcium uptake at the panicle initiation stage while it was 42.5 per cent in Cul. 1026. The corresponding figure for *Chettivirippu* mutant was 38.2 per cent.

Under the non-tidal situation Vyttila-3 recorded the maximum calcium uptake of 18.95 kg ha^{-1}. At panicle initiation stage, 38.0 per cent of this was accumulated by

Fig 12 Effect of tidal regimes on partitioning of calcium in rice varieties (kgha^{-1}) -2000

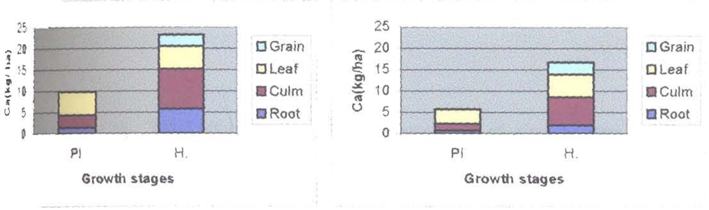
Vyttila -3

Tidal Non- tidal



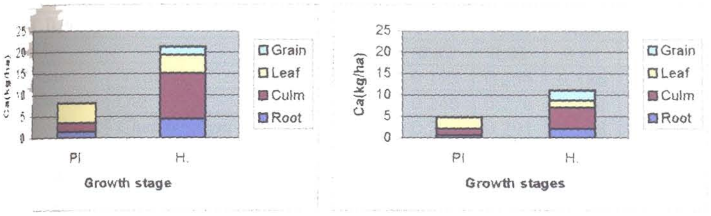
Cul.- 1026

Tidal Non -tidal



Chettivirippu mutant

Tidal Non -tidal



Panicle initiation, H- harvest

Table 25. Tidal effect on calcium content (%) of rice varieties in 2000

Treatments/stages		Panicle initiation			Harvest			
System	Cultivar/ Varieties	Leaf	Culm	Root	Leaf	Culm	Root	Grain
Tidal	Vyttila-3	0.409	0.164	0.182	0.496	0.136	0.272	0.112
	Cul. 1026	0.353	0.126	0.182	0.314	0.112	0.328	0.143
	Chettivirippu mutant	0.381	0.112	0.243	0.440	0.168	0.349	0.150
C.D.(0.05)		**N.S.**	**N.S.**	**N.S.**	**0.064**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.02**	**0.02**	**0.02**	**0.02**	**0.01**	**0.03**	**0.01**
Non-tidal	Vyttila-3	0.314	0.150	0.280	0.458	0.129	0.203	0.140
	Cul. 1026	0.339	0.147	0.175	0.349	0.115	0.196	0.115
	Chettivirippu mutant	0.356	0.157	0.224	0.370	0.126	0.245	0.129
C.D.(0.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.02**	**0.01**	**0.02**	**0.02**	**0.01**	**0.01**	**0.01**

Table 26. Tidal effect on magnesium content (%) of rice varieties in 2000

Treatments/stages		Panicle initiation			Harvest			
System	Cultivar/ Varieties	Leaf	Culm	Root	Leaf	Culm	Root	Grain
Tidal	Vyttila-3	0.230	0.215	0.369	0.311	0.168	0.340	0.090
	Cul. 1026	0.231	0.215	0.262	0.299	0.125	0.180	0.061
	Chettivirippu mutant	0.278	0.213	0.251	0.235	0.088	0.278	0.068
C.D.(0.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.02**	**0.02**	**0.02**	**0.02**	**0.01**	**0.04**	**0.01**
Non-tidal	Vyttila-3	0.317	0.153	0.193	0.254	0.186	0.360	0.080
	Cul. 1026	0.315	0.160	0.246	0.276	0.164	0.356	0.099
	Chettivirippu mutant	0.356	0.143	0.250	0.291	0.158	0.262	0.098
C.D.(.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**0.037**	**N.S.**
S.Em		**0.01**	**0.01**	**0.03**	**0.02**	**0.01**	**0.01**	**0.01**

Vyttila-3. The corresponding figures for Cul. 1026 and *Chettivirippu* mutant were 34.4 and 20.7 per cent respectively.

4.2.3.7. Magnesium

The difference in the magnesium content (Table 26) of rice varieties at panicle initiation in leaf, culm and root and that at harvest of leaf, culm and grain under both the tidal regimes and root at harvest under the tidal regime was not significant. The magnesium content of roots in Vyttila-3, under the non-tidal regime at harvest was significantly more than that of the *Chettivirippu* mutant.

Magnesium uptake

The magnesium uptake (Fig. 13) followed almost the same pattern as that of calcium. The uptake continued up to the harvest stage. Vyttila-3 under the tidal regime at the panicle initiation stage absorbed 45.7 per cent of it's total calcium uptake. The corresponding figures for Cul. 1026 and *Chettivirippu* mutant were 53.8 and 71.7 per cent. Under the non-tidal situation the magnesium uptake at panicle initiation stage was much lower and Vyttila-3, Cul. 1026 and *Chettivirippu* mutant absorbed 32.6, 30.2 and 41.2 per cent of the total magnesium uptake. However, the magnesium uptake continued up to the harvest stage in the non-tidal situation and the final quantity of magnesium uptake was almost same in both tidal and non-tidal situations.

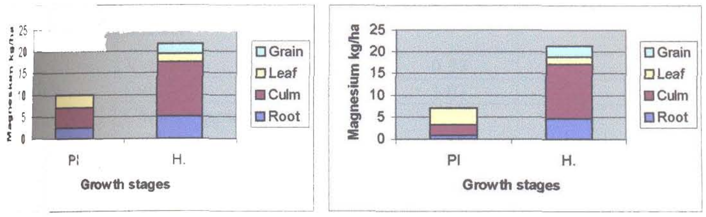
4.2.3.8. Sodium potassium ratio (Na : K)

The sodium : potassium ratio (Table 27 a, b, c and d) varied significantly between plant parts, varieties and tidal regimes during both the years of the study. The shoot Na : K at all stages under the tidal regime during both 1999 and 2000 was the narrowest for

Fig 13. Effect of tidal regimes on partitioningof Magnesium in rice varieties (kgha^{-1}) -2000

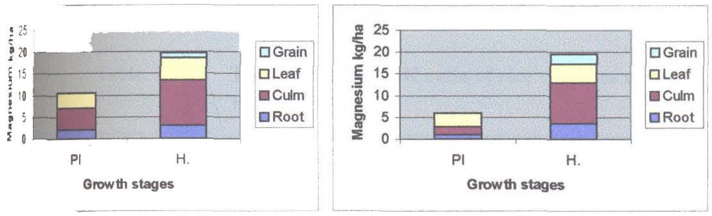
Vyttila –3

Tidal   Non- tidal



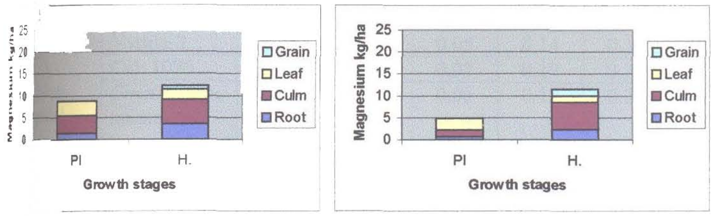
Cul. 1026

Tidal   Non-tidal



Chettivirippu mutant

Tidal   Non –tidal



Panicle initiation,   H- Harvest

Table 27 (a) Tidal effect on Na:K ratio of rice varieties at active tillering phase

Treatments		1999		2000	
System	Cultivar/ Variety	Shoot	Root	Shoot	Root
Tidal	Vyttila-3	0.47	0.93	0.46	0.85
	Cul. 1026	0.54	1.01	0.67	1.27
	Chettivirippu mutant	0.74	1.13	0.94	1.35
C.D.(0.05)		**0.08**	**0.11**	**0.14**	**N.S.**
S.Em		**0.03**	**0.04**	**0.04**	**0.11**
Non-tidal	Vyttila-3	0.22	0.33	0.12	0.15
	Cul. 1026	0.22	0.41	0.14	0.16
	Chettivirippu mutant	0.22	0.49	0.19	0.23
C.D.(0.05)		**N.S.**	**0.06**	**N.S.**	**N.S.**
S.Em		**0.02**	**0.02**	**0.01**	**0.02**

Table 27 (b) Tidal effect on Na:K ratio of rice varieties at panicle initiation

Treatments		1999			2000		
System	Cultivar/ Varieties	Root	Culm	Leaf	Root	Culm	Leaf
Tidal	Vyttila-3	1.32	0.63	0.13	1.21	0.44	0.14
	Cul. 1026	1.28	0.64	0.13	1.14	0.37	0.19
	Chettivirippu mutant	1.99	0.86	0.20	0.95	0.51	0.30
C.D. (0.05)		**0.21**	**0.16**	**0.07**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.07**	**0.05**	**0.02**	**0.11**	**0.05**	**0.04**
Non-tidal	Vyttila-3	0.46	0.13	0.05	0.14	0.10	0.03
	Cul. 1026	0.43	0.12	0.07	0.19	0.13	0.04
	Chettivirippu mutant	0.48	0.15	0.06	0.19	0.20	0.07
C.D.(.05)		0.04	**0.02**	**0.01**	**N.S.**	**0.04**	**0.01**
S.Em		**0.01**	**0.01**	**0.01**	**0.02**	**0.01**	**0.01**

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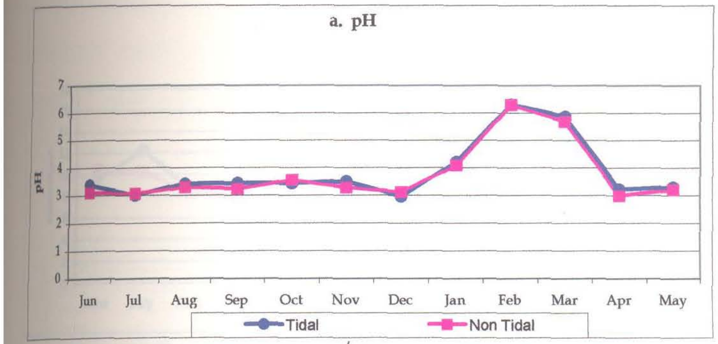
Table 27 (c) . Tidal effect on Na:K ratio of rice varieties at flowering

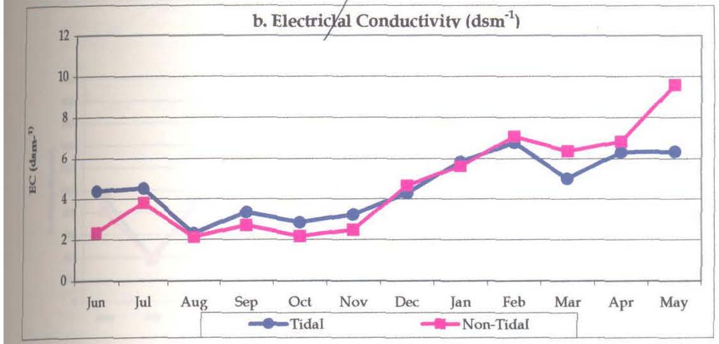
Treatments		1999			2000		
System	Cultivar/ Variety	Root	Culm	Leaf	Root	Culm	Leaf
Tidal	Vyttila-3	1.59	0.56	0.08	1.36	0.70	0.14
	Cul. 1026	2.05	0.63	0.11	1.25	0.75	0.12
	Chettivirippu mutant	1.68	0.88	0.13	1.25	1.19	0.29
C.D. (0.05)		**0.31**	**0.10**	**0.02**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.01**	**0.03**	**0.01**	**0.04**	**0.03**	**0.01**
Non-tidal	Vyttila-3	0.74	0.29	0.07	0.96	0.56	0.08
	Cul. 1026	0.92	0.31	0.06	1.36	0.59	0.10
	Chettivirippu mutant	0.82	0.39	0.11	0.86	1.04	0.25
C.D.(0.05)		**0.09**	**0.08**	**0.01**	**N.S.**	**N.S.**	**0.10**
S.Em		**0.03**	**0.02**	**0.01**	**0.02**	**0.02**	**0.01**

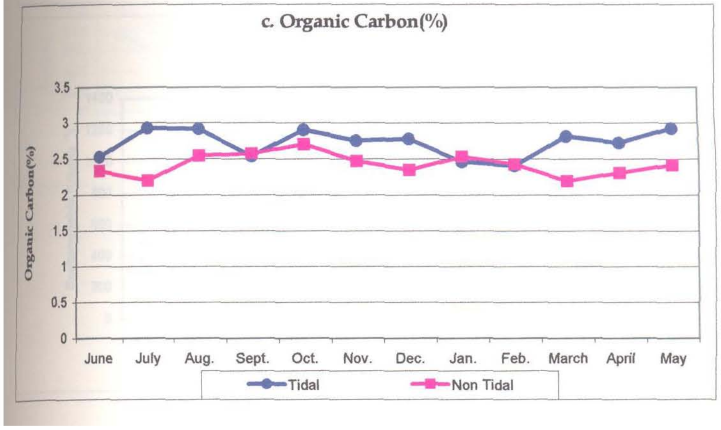
Table 27 (d) Tidal effect on Na:K ratio of rice varieties at harvest

Treatments		1999				2000			
System	Cultivar/ Variety	Root	Culm	Leaf	Grain	Root	Culm	Leaf	Grain
Tidal	Vyttila-3	2.92	0.15	0.12	0.19	1.52	0.69	0.26	0.15
	Cul. 1026	2.01	0.17	0.09	0.23	1.36	0.70	0.16	0.15
	Chettivirippu mutant	2.60	0.58	0.26	0.27	1.38	0.87	0.41	0.15
C.D.(.05)		**0.73**	**0.12**	**0.05**	**N.S.**	**N.S.**	**N.S.**	**0.10**	**N.S.**
S.Em		**0.24**	**0.04**	**0.02**	**0.03**	**0.05**	**0.02**	**0.01**	**0.01**
Non-tidal	Vyttila-3	1.04	0.27	0.15	0.17	0.77	0.80	0.18	0.07
	Cul. 1026	0.93	0.25	0.06	0.16	1.43	0.58	0.09	0.07
	Chettivirippu mutant	1.07	0.36	0.28	0.21	1.14	1.28	0.36	0.08
C.D.(.05)		**N.S.**	**0.04**	**0.07**	**0.04**	**0.25**	**0.20**	**0.05**	**N.S.**
S.Em		**0.05**	**0.01**	**0.02**	**0.01**	**0.02**	**0.01**	**0.01**	**0.01**

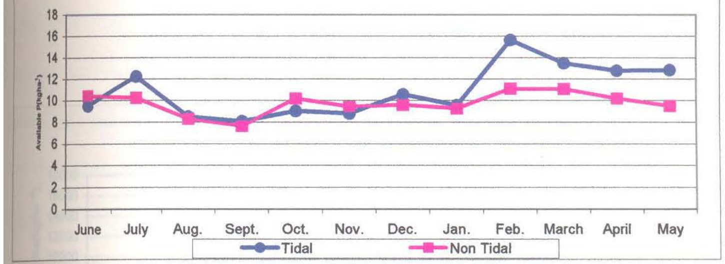
Fig. 14. Tidal effects on chemical characters of Pokkali soils



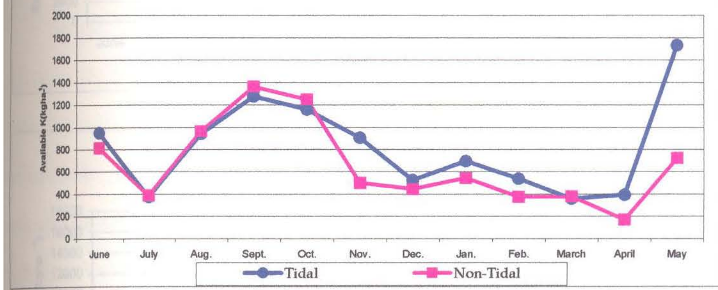




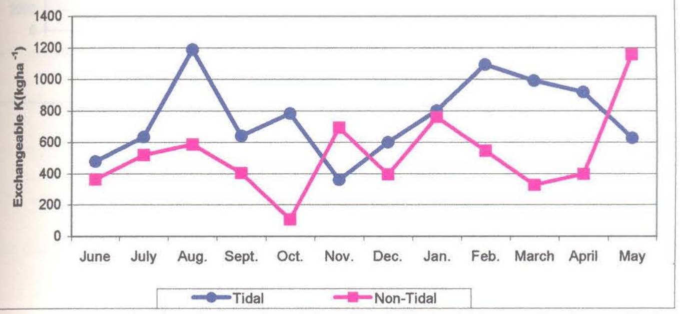
d. Available P(kgha^{-1})

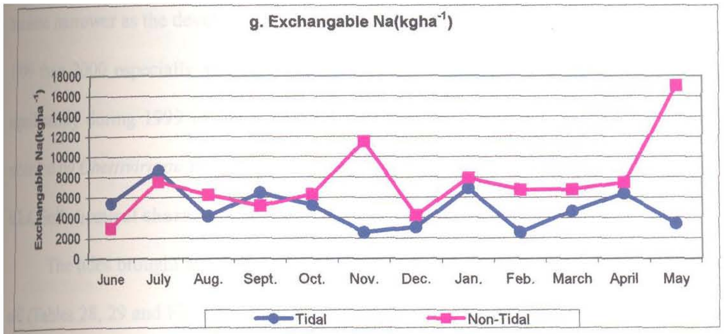


e. Available K(kgha^{-1})

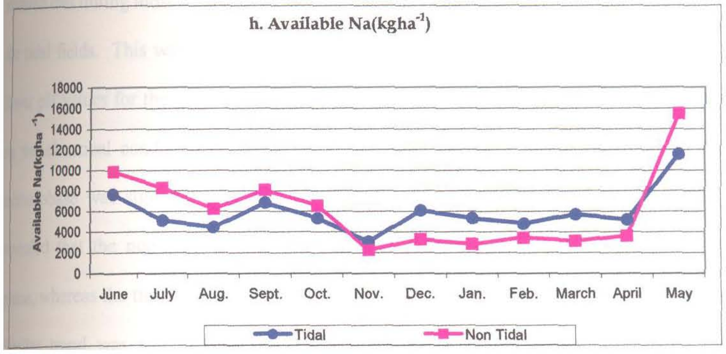


f. Exchangable K(kgha^{-1})





g. Exchangable Na(kgha^{-1})



h. Available Na(kgha^{-1})

Vyttila-3, which was significantly lower than the other two varieties. The root Na : K ratio was wider than that of the shoot and the difference between varieties was significant during 1999. The Na :K ratio followed the order of grain < leaves < culm < root. The ratio was narrower under the non-tidal situation than the tidal. The ratio in the culm became narrower as the development stage advanced to harvest. The ratio was wider in 1999 than 2000 especially at flowering and harvest stages. The grain Na : K differed significantly during 1999 in the non-tidal regime. The widest grain Na : K ratio was recorded by *Chettivirippu* mutant.

4.2.4. Soil chemical characters

The tides brought about significant changes in the chemical properties of *Pokkali* soil (Tables 28, 29 and Fig. 14 a to h). The month-wise data on the pH values of the soil showed that during most of the observations the non-tidal fields had lower pH values than the tidal fields. This was reflected on the mean values also, which showed significantly lower pH values for the non-tidal fields. Though the tidal influence was not pronounced on the electrical conductivity during the low saline phase, it's effect during the high saline phase was significant. Comparison between high saline and low saline phase revealed that the non-tidal regime had high electrical conductivity during low saline phase, whereas the tidal soil had high electrical conductivity during the high saline phase. Similar trend was reflected on the available sodium, exchangeable sodium and the available : exchangeable sodium ratio.

The values of organic carbon content were significantly higher in the tidal soil, though the difference was not significant when the low saline and high saline phases are

Table 28. Tidal effect on chemical characters of *Pokkali* soil in 2000-01

Soil chemical characters	Tidal	Non-tidal	C.D.(0.05)	S.Em
pH	3.83	3.74	0.08	0.03
E.C. (dsm^{-1})	4.64	4.59	N.S.	0.09
Organic carbon (%)	2.72	2.42	0.09	0.03
Available phosphorus (kg ha^{-1})	10.91	9.74	0.75	0.26
Available potassium (kg ha^{-1})	819.38	657.81	86.20	29.69
Available sodium (kg ha^{-1})	6879.50	6089.50	N.S.	299.36
Exchangeable potassium (kg ha^{-1})	718.00	563.70	93.99	32.39
Exchangeable sodium (kg ha^{-1})	6404.70	6011.00	N.S.	230.35

Table 29. Tidal effect on soil chemical characters during the low saline crop phase and high saline post crop phase - 2000-01

Soil chemical characters	Low saline crop phase		High saline post crop phase		C.D. (0.05)	S.Em
	Tidal	Non-tidal	Tidal	Non-tidal		
pH	3.36	3.25	4.31	4.22	N.S.	0.04
EC(dsm^{-1})	2.61	3.43	6.69	5.76	0.36	0.12
Organic carbon (%)	2.76	2.47	2.69	2.37	N.S.	0.04
Available phosphorus (kg ha^{-1})	9.35	9.36	12.47	10.11	1.06	0.36
Available potassium (kg ha^{-1})	934.20	878.05	704.60	437.60	121.85	41.99
Available sodium (kg ha^{-1})	5406.15	6891.20	8532.90	5287.90	1228.50	423.38
Exchangeable potassium (kg ha^{-1})	838.60	681.40	597.60	446.00	N.S.	45.81
Exchangeable sodium (kg ha^{-1})	4477.10	5406.43	8332.40	6615.60	945.30	230.25
Available:Exchangeable potassium ratio	1.11	1.29	1.18	0.98	N.S.	0.08
Available:Exchangeable Na ratio	1.30	1.32	1.02	0.81	N.S.	0.09

compared. Available phosphorus content was higher in the tidal soil and this was significantly pronounced during the high saline phase. However, in the case of potassium, the tidal soil had higher values of available and exchangeable potassium, even though the difference was significant only for the available potassium. High saline phase had lower values than the low saline phase. The difference between high saline and low saline phases was lesser in the non-tidal soil.

The correlation matrix of soil chemical characters under the tidal and non-tidal situations is presented in Table 30 a and b. Under the tidal situation the available soil phosphorus had significant positive correlation with soil pH and electrical conductivity. Under non-tidal situation also available phosphorus had positive correlation with pH and electrical conductivity, but the relation was not significant.

Available phosphorus had negative correlation with available potassium under tidal situation and the trend was the same under the non-tidal situation. However, with exchangeable potassium the relation was positive under the tidal situation but negative under the non-tidal regime.

The relation between organic carbon and pH was negative under both the tidal regimes. The electrical conductivity and organic carbon also had positive correlation under both the regimes. Available potassium had positive correlation with organic carbon under both the regimes and it was significant under the non-tidal situation while the relation with exchangeable potassium was negative under both the regimes.

Available sodium had positive correlation with available potassium under both the situations and it was significant under the tidal regime. The relation with exchangeable

Table 30 (a) Correlation matrix of soil characters under tidal situation

Soil characters	Avail. Phos-phorus	Organic carbon	Avail. sodium	Exch. Na	Avail. K	Exch. K	pH	EC
Available P	1.000	-0.067	-0.161	-0.154	-0.397	0.385	0.605*	0.807***
Organic carbon		1.000	0.108	0.001	0.148	-0.007	0.438	-0.382
Available Na			1.000	0.031	0.638*	-0.230	-0.191	0.348
Exchange-able Na				1.000	0.224	-0.039	-0.302	-0.007
Availabale K					1.000	-0.307	-0.340	-0.225
Exchange-able K						1.000	0.545	0.174
pH							1.000	0.428
EC								1.000

Table 30 (b) Correlation matrix of soil characters under non-tidal situation

Soil characters	Avail. Phos-phorus	Organic carbon	Avail. sodium	Exch. Na	Avail. K	Exch. K	pH	EC
Available P	1.000	-0.544	-0.190	-0.051	-0.606*	-0.239	0.547	0.367
Organic carbon		1.000	0.028	0.021	0.748**	-0.268	-0.138	-0.378
Available Na			1.000	0.409	0.420	0.410	-0.392	0.174
Exchange-able Na				1.000	-0.459	0.821**	-0.074	0.573
Availabale K					1.000	-0.196	-0.288	-0.542
Exchange-able K						1.000	-0.083	0.547
pH							1.000	0.379
EC								1.000

* Significant at 0.05 level
** Significant at 0.01 level
*** Significant at 0.005 level

potassium was negative under tidal situation whereas it enjoyed a positive correlation under the non-tidal situation.

Available potassium and electrical conductivity were negatively correlated under both the regimes, but the exchangeable potassium had significant positive correlation with exchangeable sodium under tidal situation and a negative relation under non-tidal regime. Under tidal situation, the available sodium and potassium had significant positive correlation whereas, under the non-tidal situation the exchangeable sodium and potassium had highly significant positive correlation.

4.2.5. Correlation of plant nutrient content with yield

Correlation studies on the nutrient content in root, culm, leaf at different growth stages and in grain of the three rice varieties could give a clear picture of the inter-relationship among the nutrients and their correlation with grain yield (Table 31 a, b and c). The high co-efficient values showed that the culm nitrogen content at panicle initiation and leaf nitrogen at harvest had significant positive correlation, irrespective of the varieties. The nitrogen in shoot at active tillering and in culm at harvest was found to have significant positive correlation with grain yield in Vyttila-3 and *Chettivirippu* mutant but not in Cul. 1026. In Vyttila-3, leaf content of nitrogen at flowering and harvesting also registered significant positive correlation with the yield.

The grain nitrogen content in Vyttila-3 and Cul. 1026 had negative relation with yield. The culm nitrogen at flowering for Vyttila-3 and root nitrogen at active tillering for Cul. 1026 also had negative correlation with yield. The *Chettivirippu* mutant, however, didn't reveal to have any excess content of nitrogen at any of the growth stages.

Table 31 (a) Correlation of nutrient content in plant tissues with grain yield in Vyttila-3

Growth stage and plant parts	N	P	K	Na	K : Na	S
Shoot at A.T.	0.632*	-0.461	0.925***	0.937***	0.904***	-0.627
Root at A.T.	0.581	0.343	0.921***	0.836***	0.937***	-0.092
Leaf at P.I.	0.146	-0.345	0.918***	0.899***	0.912***	0.115
Culm at P.I.	0.791**	-0.339	0.985***	0.976***	0.874***	0.236
Root at P.I.	0.455	0.507	0.853***	0.894***	0.829***	-0.408
Leaf at flowering	0.713*	0.746*	0.920***	0.927***	0.884***	0.231
Culm at flowering	-0.514	0.115	0.926***	0.941***	0.904***	0.112
Root at flowering	0.565	--	0.940***	0.877***	0.896***	0.693*
Leaf at harvest	0.799**	0.810***	0.868***	-0.123	0.862***	-0.331
Culm at harvest	0.834***	0.457	0.939***	-0.917***	0.944***	-0.667*
Root at harvest	0.765	-0.851***	0.920***	0.976***	0.825***	0.496
Grain	-0.072	-0.750*	0.904***	-0.079	0.878***	0.475

Table 31 (b) Correlation of nutrient content in plant parts with grain yield in Cul. 1026

Growth stage and plant parts	N	P	K	Na	K : Na	S
Shoot at A.T.	0.591	-0.253	0.685*	0.412	0.795**	-0.519
Root at A.T.	-0.124	0.551	0.794**	0.741*	0.769**	-0.307
Leaf at P.I.	0.247	-0.087	0.685*	0.519	0.645*	-0.293
Culm at P.I.	0.837**	-0.154	0.767**	0.707*	0.760*	-0.524
Root at P.I.	0.483	0.213	0.767**	0.791**	0.717*	0.091
Leaf at flowering	0.601	0.621	0.753*	0.775**	0.657*	0.451
Culm at flowering	0.363	0.425	0.695*	0.719*	0.670*	0.562
Root at flowering	0.162	--	0.663*	0.428	0.764*	0.710*
Leaf at harvest	0.729*	0.751*	0.741*	0.752*	0.692*	-0.048
Culm at harvest	0.589	0.097	0.755*	0.071	0.616	-0.013
Root at harvest	0.201	-0.266	0.787**	0.738*	0.733*	-0.124
Grain	-0.044	-0.743*	0.665*	-0.449	0.879***	0.461

* Significant at 0.05 level
** Significant at 0.01 level
*** Significant at 0.005 level

A.T. - Active Tillering
P.I. - Panicle Initiation

Table 31 (c) Correlation of nutrient content in plant parts with grain yield in *Chettivirippu* mutant

Growth stage and plant parts	N	P	K	Na	K : Na	S
Shoot at A.T.	0.701*	0.028	0.937***	0.891***	0.907***	0.479
Root at A.T.	0.186	0.022	0.900***	0.750**	0.938***	-0.462
Leaf at P.I.	0.063	0.432	0.925***	0.646*	0.714*	0.303
Culm at P.I.	0.717*	0.404	0.836***	0.922***	0.627	-0.005
Root at P.I.	0.475	0.331	0.979***	0.950***	0.952***	-0.221
Leaf at flowering	0.389	0.709*	0.962***	0.773**	0.912***	0.031
Culm at flowering	0.719*	0.162	0.959***	0.942***	0.933***	0.419
Root at flowering	0.479	--	0.956***	0.896***	0.920***	0.662*
Leaf at harvest	0.505	0.902***	0.957***	0.623	0.861**	-0.082
Culm at harvest	0.949***	0.341	0.933***	0.673*	0.856**	-0.008
Root at harvest	0.405	-0.312	0.928***	0.833**	0.852**	-0.054
Grain	0.083	-0.701*	0.956***	-0.236	0.928***	0.824***

* Significant at 0.05 level
** Significant at 0.01 level
*** Significant at 0.005 level

A.T. - Active Tillering
P.I. - Panicle Initiation

The leaf content of phosphorus at harvest had significant positive correlation with grain yield whereas a high phosphorus content in the grain was undesirable, as revealed by the significant negative correlation. High phosphorus content of leaf at flowering was also desirable for higher grain yields in all the three varieties. *Chettivirippu* mutant was insulated against higher content of phosphorus up to the flowering stage, while in Vyttila-3 and Cul. 1026 higher phosphorus during early stages had negative correlation with grain yield.

Potassium content in all plant parts at all stages had highly significant correlation with the yield especially for the *Chettivirippu* and Vyttila-3 varieties. The relation though significant and positive was less pronounced in Cul. 1026, as revealed by the lower coefficients compared to the other two varieties.

The sodium content in plant parts up to flowering in Vyttila-3 had significant positive correlation with grain yield while the content in leaf at harvest had significant negative correlation. The grain sodium as well as the leaf - sodium at harvest were also negatively related with yield. However, the root sodium at harvest had significant positive correlation with yield.

The other two varieties didn't show any significant negative correlation for sodium content in plant parts with the grain yield. However, the content of sodium in grain in all the three varieties had negative relation with yield. The potassium:sodium ratio in all plant parts at all stages had significant positive relation. The relation was more strong for Vyttila-3 and *Chettivirippu* mutant.

Sulphur content in root at flowering had significant positive correlation with yield. Sulphur content in shoot at active tillering was negatively correlated with yield in all the varieties. In Vyttila-3, the culm sulphur content had significant negative correlation. Cul. 1026 was observed to be more insulated against higher content of sulphur than the other two varieties.

The interrelationship of nutrients revealed that the relations varied with the plant parts and stages of growth of the plant. Nitrogen in general had positive relation with potassium and sodium, though the relation with culm sodium at harvest was negative. The phosphorus content in leaf at flowering and harvest and in culm at harvest had positive relation with nitrogen content, while the phosphorus content in root had negative relation. The sulphur content in shoot at active tillering and in culm at harvest also had negative relationship with nitrogen content.

The potassium content in plant parts had negative correlation with phosphorus content up to the flowering stage and also with grain phosphorus and root phosphorus at harvest. However, the potassium content had positive correlation with phosphorus content in aerial parts of rice. The sulphur content in root at flowering and harvest and in grain were positively correlated with potassium content and had negative correlation with that in the other plant parts.

Sodium content in plant parts had positive correlation with root and culm phosphorus at harvest and negative correlation with leaf phosphorus at active tillering and panicle initiation stages.

4.3. Experiment 3. Impact of Ameliorants on growth, yield and nutrient uptake of *Pokkali* rice

Impact of soil ameliorants on the growth, physiological characters, yield attributes, yield and content of important nutrients was studied for two successive years of 1999 and 2000. Two levels each of lime, silica and sulphur were compared with non-amelioranted control during the first year, while promising levels of these ameliorants individually and in combination with others were evaluated during the second year.

4.3.1. First year – Kharif 1999

Effect of lime (500 and 1000 kg ha^{-1}), fine silica (250 and 500 kg ha^{-1}), phosphorus (30 and 60 kg ha^{-1}) and sulphur (300 and 600 kg ha^{-1}) compared to the non-ameliorated control treatment on morphological characters, biomass production, physiological characters, yield attributes, yield, nutrient content and uptake, and soil characters at the end of the field experiment were studied during June to October, 1999. The data obtained on these characters are furnished in Tables 32 to 48 and Fig. 15.

4.3.1.1. Growth characters

The data on the effect of the ameliorants on height at the different growth stages (Table 32) didn't show any significant influence. However, at active tillering, the non-ameliorant control treatment recorded the maximum height of 135 cm, whereas the higher level of sulphur (S 600) recorded the lowest plant height of 119 cm. At flowering the higher level of silica (Si 500) and lower level of phosphorus (P 30) simultaneously recorded the tallest plants (207 cm) and the lower level of sulphur (S 300) the shortest

Table 32. Effect of ameliorants on plant height and vegetative tillers in 1999

Ameliorants	Plant height (cm)			Vegetative tillers (no. hill^{-1})		
	Active tillering	Flowering	Harvest	Active tillering	Flowering	Harvest
L 500	125.00	195.00	199.00	8.43	4.53	4.80
L 1000	121.00	201.00	203.00	7.17	4.67	4.50
Si 250	128.00	181.00	187.00	7.47	4.93	5.00
Si 500	122.00	207.00	208.00	6.57	4.07	4.90
P 30	131.00	207.00	209.00	8.17	4.40	5.40
P 60	124.00	187.00	191.00	7.87	4.07	4.50
S 300	123.00	180.00	188.00	8.43	3.67	4.80
S 600	119.00	192.00	195.00	7.27	3.67	5.20
Control	135.00	182.00	186.00	7.53	4.27	5.20
C.D. (.05)	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**3.06**	**3.86**	**3.06**	**0.72**	**0.81**	**0.54**

(180 cm). At harvest stage, P 30 recorded the maximum height of 209 cm and the control treatment gave the shortest (186 cm).

The number of tillers hill^{-1} (Table 32) at active tillering stage though varied between 6.57 and 8.43, the difference was not significant. S 300 and the lower level of lime (L 500) simultaneously recorded the maximum number of vegetative tillers hill^{-1} (8.43), while Si 500 recorded the least (6.57). At flowering stage also the treatment effect on number of tillers was not significant. However, a substantial decline in the number of tillers at this stage was noticed from that of the previous stage. The maximum tiller number was recorded by Si 250 and the minimum by the sulphur treatments. At the harvest stage also, the tiller number didn't significantly vary among the treatments, with P 30 recording the maximum number of 5.4 and L 500 and P 60 the least value of 4.5. In general, though the ameliorants didn't impart any significant variation in tiller count, a considerable decline in vegetative tillers was observed, irrespective of the treatment, as the growth stage advanced from active tillering to flowering.

There was no significant change in the biomass production due to the ameliorants at active tillering and maturity stages. However, at flowering stage, the control (non-ameliorated) plants produced significantly higher root, culm, leaf and total dry matter production.

At harvest (Table 33) the root biomass, though ranged between 1.31 and 2.61 t ha^{-1}, the difference among the treatments was not significant. The S 300 recorded the highest root biomass, while, P 60, the least. The culm and leaf biomass production were

Table 33 (a) Effect of ameliorants on biomass production (t ha^{-1}) at active tillering and flowering in 1999

	Active tillering				Flowering			
Amelio-rants	Root	Culm	Leaf	Total	Root	Culm	Leaf	Total
L 500	1.91	2.97	1.98	6.86	2.32	7.90	1.42	11.65
L 1000	1.31	2.22	1.53	5.05	2.80	9.41	1.52	13.73
Si 250	1.33	2.11	1.46	4.91	3.35	8.54	1.46	13.36
Si 500	1.55	2.32	1.56	5.39	2.05	5.49	1.26	8.80
P 30	2.09	2.98	1.83	6.88	2.59	9.49	1.74	13.78
P 60	1.64	1.96	1.20	4.80	3.10	7.72	1.20	12.03
S 300	1.75	2.51	1.66	5.92	1.76	6.78	1.25	9.78
S 600	1.66	2.18	1.41	5.25	2.04	7.27	1.41	10.72
Control	1.90	3.26	2.06	7.21	4.31	8.31	1.85	14.48
C.D.(.05)	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**0.99**	**2.20**	**0.41**	**3.29**
S.Em	**0.09**	**0.14**	**0.11**	**0.42**	**0.31**	**0.32**	**0.09**	**1.10**

Table 33 (b) Effect of ameliorants on biomass production (t ha^{-1}) at maturity in 1999

Ameliorants	Root	Culm	Leaf	Panicle	Total
L 500	1.73	9.33	0.36	4.44	15.86
L 1000	1.58	8.20	0.32	4.38	14.47
Si 250	1.59	8.56	0.35	4.92	15.41
Si 500	1.61	10.81	0.35	4.33	17.10
P 30	2.27	11.24	0.40	4.44	18.35
P 60	1.31	7.05	0.20	3.50	12.06
S 300	2.61	9.08	0.38	4.88	16.94
S 600	1.59	10.71	0.33	3.88	16.50
Control	1.34	9.13	0.40	4.69	15.56
C.D.(.05)	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**0.35**	**1.45**	**0.06**	**0.38**	**1.81**

also the least for P 60, while P 30 gave the maximum culm biomass. P 60 also recorded the minimum panicle dry weight. The total biomass production at harvest stage was also the least for P 60, while P 30 recorded the maximum total biomass.

The treatments didn't influence the leaf area index (Table 34) at both the panicle initiation and flowering stages. At panicle initiation L 500 recorded the highest leaf area index of 5.03 followed by the control treatment (4.62). At the flowering stage P 30 recorded the highest leaf area index followed by the control treatment.

The ameliorants significantly increased the specific leaf weight. The maximum specific leaf weight were recorded by S 600, which was superior to all other treatments. The control treatment was the second best treatment, which was on par with the others.

The chlorophyll b content was significantly influenced by the ameliorants (Table 34). L 500 gave the maximum chlorophyll b content which was significantly superior to S 600, L 1000 and the control treatment. Chlorophyll a and total chlorophyll also followed the same trend. S 600 followed by the control treatment recorded the lower content of total chlorophyll and chlorophyll a. The cell sap pH did not significantly differ among the ameliorants. However, the L 500 recorded the highest cell sap pH of 6.33, while S 300 the lowest.

4.3.1.2. Yield attributes and yield

The data on the effect of ameliorants on yield attributes (Table 35) didn't reveal any significant influence of the treatment. The number of panicles hill^{-1} was, however, higher for S 600 followed by P 30 and the control treatment. P 60 gave the maximum panicle length, while the control treatment the shortest panicle. The filled grain number

Table 34. Effect of ameliorants on physiological characters in 1999

Ameliorants	Leaf area index		Specific leaf weight (g cm$^{2-1}$)	Physiological characters			
	Panicle initiation	Flowering		Cell sap pH at P.I.	Chlorophyll content at P.I. (mg g^{-1})		
					Chlorophyll **a**	Chlorophyll **b**	Total
L 500	5.03	3.58	0.00394	6.33	1.06	0.64	1.70
L 1000	3.67	3.63	0.00417	6.27	0.91	0.52	1.43
Si 250	3.45	3.45	0.00424	6.27	0.92	0.54	1.47
Si 500	3.75	2.69	0.00416	6.28	1.04	0.60	1.65
P 30	4.45	4.27	0.00410	6.25	0.90	0.55	1.44
P 60	2.83	2.84	0.00424	6.28	1.02	0.61	1.62
S 300	3.85	1.62	0.00430	6.23	0.84	0.53	1.38
S 600	2.80	2.37	0.00503	6.30	0.77	0.47	1.24
Control	4.62	3.69	0.00440	6.28	0.79	0.50	1.29
C.D.(.05)	**N.S.**	**N.S.**	**0.00047**	**N.S.**	**N.S.**	**0.11**	**N.S.**
S.Em	**0.24**	**0.51**	**0.00002**	**0.03**	**0.08**	**0.04**	**0.12**

Table 35. Effect of ameliorants on yield attributes in 1999

Amelio-rants	No. of panicles hill^{-1}	Panicle length (cm)	Filled grain panicle^{-1}	Chaff (%)	Thousand grain weight (g)
L 500	4.60	28.60	78.53	23.23	35.79
L 1000	4.07	29.23	70.47	29.87	36.26
Si 250	4.80	29.20	76.60	25.17	36.61
Si 500	4.80	30.37	63.77	32.93	35.88
P 30	5.07	30.07	68.57	31.13	36.53
P 60	4.27	30.87	53.87	27.70	35.87
S 300	4.53	29.37	57.40	28.07	35.84
S 600	5.20	29.40	76.50	25.57	36.31
Control	5.07	28.20	59.80	23.53	36.37
C.D.(.05)	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**0.41**	**1.36**	**6.54**	**5.26**	**0.73**

Table 36. Effect of ameliorants on yield (kg ha^{-1}) and grain : straw ratio in 1999

Ameliorants	Grain	Straw	Biomass	Grain : straw ratio
L 500	3158	12085	15240	0.27
L 1000	4362	11565	15930	0.39
Si 250	3542	10385	13925	0.36
Si 500	2978	12985	15960	0.23
P 30	2870	11135	14005	0.26
P 60	3258	8100	11360	0.40
S 300	3125	11985	15110	0.26
S 600	4517	13915	18435	0.33
Control	3850	13015	17035	0.30
C.D. (.05)	**933**	**2972**	**2830**	**N.S.**
S.Em	**311.27**	**1000.45**	**3729.45**	**0.06**

hill^{-1} was maximum for L 500 followed by Si 250 and S 600. Si 500 recorded the maximum chaff per cent of 32.93 followed by P 30 (31.13). The chaff percentage was the least for L 500 (23.23) followed by the control treatment (23.53). Si 250 recorded the highest thousand- grain weight, while L 500 the least.

The grain, straw and biomass yield (Table 36) had significant effect of the treatments. S 600 recorded the highest grain yield of 4517 kg ha^{-1} which was superior to Si 250, P 60, L 500, S 300, S 500 and P 30. L 1000 and the control treatment were on par with S 600. The yields in L 1000 and control treatments were 4362 and 3850 kg ha^{-1} respectively, which were higher by 52 and 34 per cent, respectively, than P 30, which recorded the least grain yield.

The straw and biomass yield was also higher for S 600 as in the case of grain yield. The yield of straw for S 600 was significantly higher than Si 250 and P 60. The biomass yield for the control, Si 500 and L 1000 were on par with S 600. Significant variation in grain : straw ratio was not noticed . P 60 recorded the highest ratio of 0.40 closely followed by L 1000. Si 500 recorded the least grain : straw ratio.

4.3.1.3. Elemental composition

4.3.1.3.1. Nitrogen

The nitrogen content in leaf, culm and root at active tillering, flowering and harvest, and in grain are depicted in Table 37. The effect of the ameliorants on nitrogen content was significant only for root at flowering stage. The leaf nitrogen content was high for P 30 at active tillering, while the control treatment followed by P 30 gave higher leaf nitrogen content at flowering. It was simultaneously high for the control, L 1000 and

Table 37. Effect of ameliorants on nitrogen content (%) of Vyttila-3

Ameliorents	Active tillering			Flowering			Harvest			
	Leaf	Culm	Root	Leaf	Culm	Root	Leaf	Culm	Root	Grain
Lime 500	2.52	1.49	1.59	2.05	1.49	1.47	1.61	1.63	1.31	1.31
Lime 1000	1.96	1.87	1.49	1.96	1.87	1.96	2.03	1.42	1.16	1.21
Silica 250	2.07	1.68	1.68	1.77	1.87	2.03	2.03	1.58	1.37	1.31
Silica 500	2.32	1.40	1.68	1.68	1.59	2.24	1.75	1.42	1.26	1.40
Phosphorus 30	2.71	1.87	2.09	2.15	1.49	2.18	1.89	1.52	1.31	1.31
Phosphorus 60	2.02	1.40	1.55	1.68	1.68	1.47	1.96	1.31	1.37	1.37
Sulphur 300	2.33	1.87	1.27	1.96	1.49	1.89	1.89	1.58	1.42	1.37
Sulphur 600	2.52	1.55	1.31	1.87	1.68	1.68	1.82	1.42	1.21	1.31
Control	2.43	1.49	1.68	2.33	1.59	1.89	2.03	1.63	1.31	1.16
C.D. (.05)	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**0.66**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**0.21**	**0.12**	**0.13**	**0.16**	**0.11**	**0.22**	**0.15**	**0.11**	**0.12**	**0.06**

Si 250 at harvest stage. The leaf nitrogen didn't substantially decrease as the growth stage advanced to harvest, as usually noticed in rice grown in normal soil conditions.

The culm nitrogen content at active tillering was high for L 1000, P 30 and S 300 simultaneously and low for Si 500 and P 60. It remained almost the same during the flowering stage and registered slightly lower numerical values at harvest for all the treatments.

The root nitrogen content at active tillering was the highest for P 30 and the sulphur treatments recorded lower numerical values. A substantial increase in root nitrogen content was observed at the flowering stage and the variation was significant. All the treatments other than P 60 and L 500 were superior and at par. At the harvest stage, the root nitrogen content decreased from that at the flowering stage and registered almost equal values to as that of the grain nitrogen content. The grain nitrogen content was the highest for Si 500, while the lowest was for the non-ameliorant control treatment. The nitrogen uptake (Fig. 15 a) was as high as 267 kg ha^{-1} for P 30, while the least was for P 60, which registered a nitrogen uptake of 162 kg ha^{-1}.

4.3.1.3.2. Phosphorus

The treatments including the two levels of phosphorus didn't significantly differ in the phosphorus content of the plant parts of rice at various growth stages (Table 38). The phosphorus content was higher at active tillering stage in all the plant parts and the content was more in root than culm or leaf.

The phosphorus content in all the plant parts decreased at the flowering stage. At this stage the culm phosphorus of P 60 and P 30 were less than that of their

Table 38. Effect of ameliorants on phosphorus content (%) of Vyttila-3 in 1999

Ameliorents	Active tillering			Flowering			Harvest			
	Leaf	Culm	Root	Leaf	Culm	Root	Leaf	Culm	Root	Grain
Lime 500	0.24	0.32	0.38	0.19	0.22	0.22	0.08	0.09	0.18	0.23
Lime 1000	0.27	0.32	0.44	0.19	0.20	0.37	0.08	0.12	0.19	0.20
Silica 250	0.22	0.34	0.41	0.19	0.20	0.26	0.10	0.10	0.22	0.23
Silica 500	0.25	0.30	0.58	0.20	0.20	0.22	0.09	0.10	0.20	0.25
Phosphorus 30	0.23	0.32	0.47	0.18	0.20	0.31	0.11	0.09	0.15	0.24
Phosphorus 60	0.23	0.33	0.44	0.20	0.18	0.23	0.06	0.09	0.19	0.25
Sulphur 300	0.21	0.33	0.41	0.18	0.21	0.29	0.10	0.11	0.12	0.22
Sulphur 600	0.25	0.33	0.37	0.20	0.23	0.26	0.07	0.11	0.16	0.24
Control	0.21	0.32	0.47	0.21	0.20	0.31	0.05	0.10	0.15	0.23
C.D. (.05)	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**0.02**	**0.02**	**0.06**	**0.02**	**0.02**	**0.04**	**0.03**	**0.02**	**0.05**	**0.01**

corresponding leaf phosphorus content at active tillering, while in all the other treatments the reverse was true.

Considerable decrease in leaf and culm phosphorus content was observed during the harvest stage. The leaf phosphorus was high for P 30 followed by S 300 and Si 250 at this stage. The control, P 60, S 600 and lime treatments recorded lower leaf phosphorus values. The grain phosphorus content was higher for P 60 and Si 500, while the S 300 recorded the lowest value. The phosphorus uptake (Fig. 15 b) was higher at flowering than at harvest. The control treatment recorded the maximum uptake of 33.9 kg ha^{-1} of which only 22.1 kg ha^{-1} was retained at maturity. The phosphorus uptake at flowering and maturity were almost the same for S 600.

4.3.3.3. Potassium

The treatments had significant effect on the potassium content of leaf at flowering and maturity (Table 39). The variation in other plant parts at different growth stages was not significant. The leaf potassium content was more at the active tillering stage than the subsequent stages. The leaf potassium at this stage was the highest for Si 500 followed by P 60. The leaf potassium at the flowering stage differed significantly among the treatments. P 30 registered the highest leaf potassium content, which was superior to S 600, S 300 and L 500. At harvest stage S 300 gave significantly more potassium which was superior to P 60 but on par with the others. Though, the potassium content in leaf registered a gradual decrease with the advancement of growth, the culm and root potassium decreased at the flowering stage only. The culm and root potassium content at maturity were higher than that of the same at flowering. The root potassium at maturity

Fig. 15. Effect of ameliorants on nutrient uptake of rice 1999

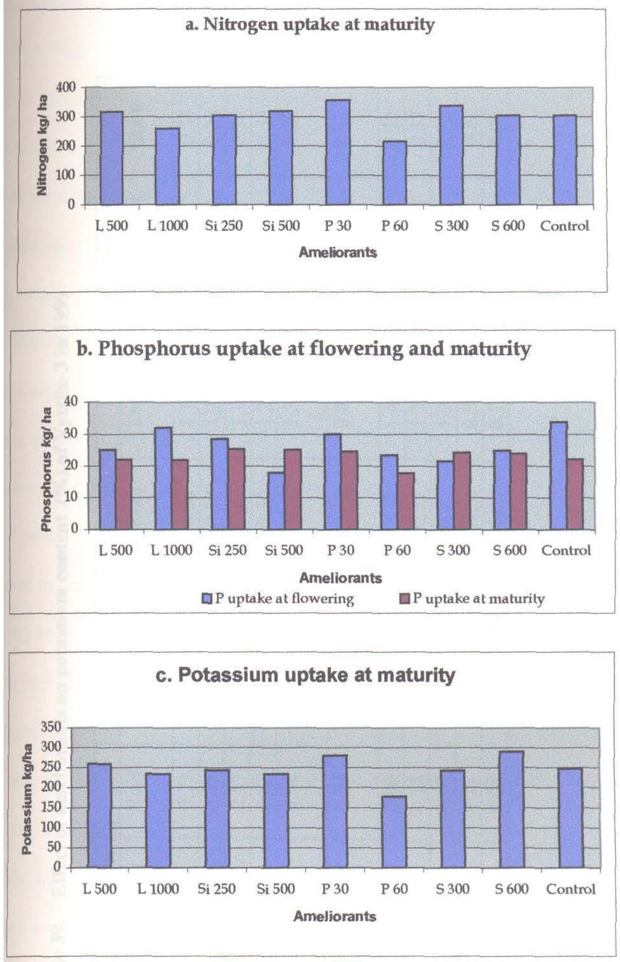


Table 39. Effect of ameliorants on potassium content (%) of Vyttila-3 in 1999

Ameliorents	Active tillering			Flowering			Harvest			
	Leaf	Culm	Root	Leaf	Culm	Root	Leaf	Culm	Root	Grain
Lime 500	2.63	3.08	0.73	1.93	1.98	0.30	1.15	2.52	0.27	0.35
Lime 1000	2.63	2.95	0.77	2.13	1.95	0.22	1.25	2.55	0.33	0.35
Silica 250	2.40	3.17	0.87	1.97	2.03	0.28	1.12	2.58	0.30	0.30
Silica 500	2.98	3.02	0.87	2.00	2.10	0.30	1.28	2.12	0.35	0.33
Phosphorus 30	2.89	3.53	0.92	2.32	2.25	0.32	1.35	2.27	0.33	0.28
Phosphorus 60	2.95	3.30	0.85	2.02	1.78	0.27	0.85	2.27	0.27	0.33
Sulphur 300	2.63	3.05	0.90	1.85	1.93	0.32	1.40	2.35	0.32	0.32
Sulphur 600	2.83	2.97	0.78	1.63	1.88	0.32	1.22	2.48	0.38	0.37
Control	2.70	3.12	0.63	1.97	1.93	0.25	1.07	2.42	0.33	0.32
C.D. (.05)	**N.S.**	**N.S.**	**N.S.**	**0.38**	**N.S.**	**N.S.**	**0.35**	**N.S.**	**N.S.**	**N.S.**
S.Em	**0.16**	**0.23**	**0.08**	**0.12**	**0.12**	**0.03**	**0.11**	**0.10**	**0.04**	**0.02**

for P 30, however, registered lower values while the same for S 300 remained the same as that at flowering. The potassium uptake (Fig. 15 c) was highest (290 kg ha^{-1}) for S 600, while P 60 recorded the least value (177 kg ha^{-1}).

4.3.1.3.4. Sodium

A significant variation in the sodium content was observed only in leaf at flowering stage (Table 40). Sodium in different plant parts was higher during the active tillering stage. The leaf sodium at active tillering was the lowest for the control treatment and the highest for S 600. At flowering Si 250 recorded significantly higher leaf sodium content than L 500, L 1000, P 30 and S 300. The leaf sodium content at harvest registered higher values than that of the flowering stage. However, the values were slightly less for P 60 and the control treatment.

The culm sodium content decreased at flowering and harvest stages and the values were least at maturity. The root sodium content also registered a declining trend at flowering, which ended up with higher values at maturity. P 60, however, reacted in the opposite way registering root potassium values of 0.28 and 0.23 per cent at flowering and harvest stages, respectively. The grain sodium content also didn't vary significantly. The lime levels, Si 250 and P 30 recorded higher grain sodium content than the others.

The uptake of sodium differed widely (Fig. 15 d) among the treatments. Si 500 and S 300 had the maximum uptake of sodium at active tillering stage. All the other treatments had their peak uptake of sodium at flowering. P 30 registered the maximum accumulation of 93.2 kg ha^{-1} of sodium and S 300 the least quantity of 60.1 kg ha^{-1}. The sodium retained at maturity ranged between 42.2 for L 1000 and 73.3 kg ha^{-1} for P 30.

Table 40. Effect of ameliorants on sodium content (%) of Vyttila-3 in 1999

Ameliorents	Active tillering			Flowering			Harvest			
	Leaf	Culm	Root	Leaf	Culm	Root	Leaf	Culm	Root	Grain
Lime 500	0.34	1.87	0.53	0.187	0.83	0.26	0.26	0.40	0.30	0.05
Lime 1000	0.35	1.88	0.55	0.195	0.73	0.31	0.22	0.41	0.36	0.05
Silica 250	0.33	1.75	0.62	0.227	0.84	0.28	0.24	0.52	0.36	0.05
Silica 500	0.35	1.87	0.75	0.203	0.61	0.26	0.22	0.36	0.30	0.04
Phosphorus 30	0.38	1.89	0.60	0.195	0.89	0.22	0.29	0.56	0.31	0.05
Phosphorus 60	0.37	1.80	0.62	0.213	0.70	0.28	0.21	0.56	0.23	0.04
Sulphur 300	0.35	1.8	0.65	0.200	0.78	0.27	0.26	0.40	0.35	0.04
Sulphur 600	0.39	1.76	0.68	0.224	0.93	0.26	0.24	0.37	0.36	0.04
Control	0.31	1.79	0.57	0.224	0.79	0.29	0.22	0.41	0.35	0.04
C.D. (.05)	**N.S.**	**N.S.**	**N.S.**	**0.016**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**0.02**	**0.11**	**0.06**	**0.005**	**0.09**	**0.02**	**0.04**	**0.09**	**0.04**	**0.003**

Thus, 14.3 to 38.1 kg ha^{-1} of the accumulated sodium in the plant tissues was reduced from the rice plant either by leaf or tiller shedding.

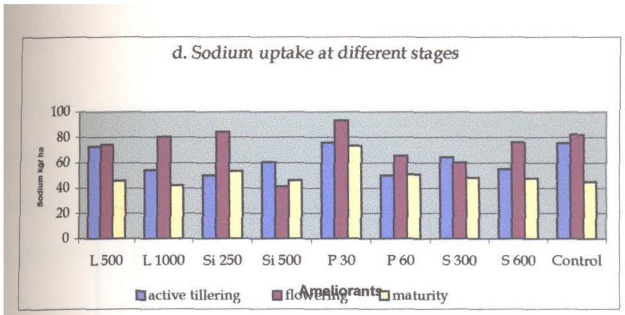
4.3.1.3.5. Calcium

The ameliorants significantly influenced the calcium content of culm and root at flowering and the grain calcium content (Table 41). The leaf calcium content at none of the growth stages, differed significantly. Considerable increase in leaf calcium content was noticed at flowering compared to the active tillering stage. At maturity also the leaf calcium content was higher than the previous stage except that for L 1000 and S 300.

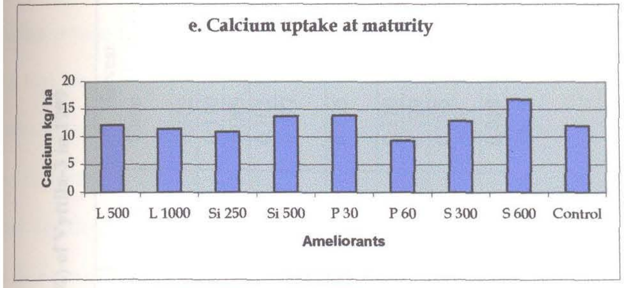
The culm calcium content at flowering was higher than that at the active tillering phase. At maturity also the same trend was observed with the exceptions of L 500, Si 250 and P 30. The culm calcium content was significantly higher for P 30, which was superior to S 300, S 500 and L 1000.

The root calcium content at tillering, though didn't differ significantly, the higher levels of the ameliorants considerably decreased the root calcium content in comparison to their lower levels. At flowering the root calcium was significantly higher for S 300, which was superior to the others except the control treatment. Root calcium content for L 500, Si 250 and P 30 were higher than L 1000, Si 500 and P 60. The root calcium content at maturity didn't differ significantly. The values at this stage were higher than their corresponding values at flowering. S 600 and L 1000 simultaneously recorded the highest leaf calcium at harvest.

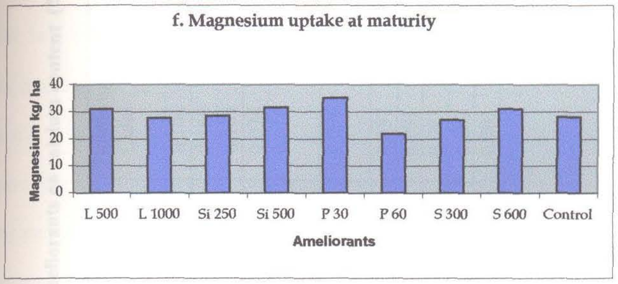
The grain calcium content was significantly higher for S 600 which was superior to all the other ameliorants but at par with the control treatment. In general, the lime



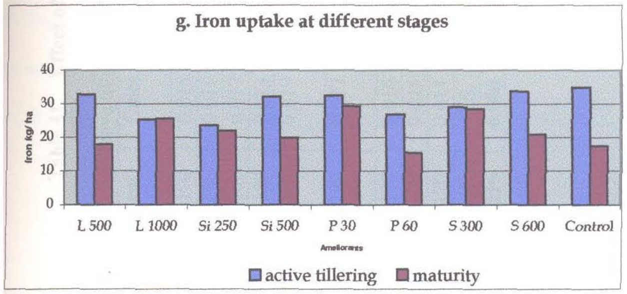
d. Sodium uptake at different stages



e. Calcium uptake at maturity



f. Magnesium uptake at maturity



g. Iron uptake at different stages

Table 41. Effect of ameliorants on calcium content (%) of Vyttila-3 in 1999

Ameliorents	Active tillering			Flowering			Harvest			
	Leaf	Culm	Root	Leaf	Culm	Root	Leaf	Culm	Root	Grain
Lime 500	0.190	0.015	0.024	0.226	0.106	0.0063	0.230	0.102	0.009	0.037
Lime 1000	0.180	0.016	0.018	0.271	0.069	0.0047	0.265	0.110	0.009	0.032
Silica 250	0.160	0.017	0.029	0.242	0.109	0.0046	0.247	0.089	0.031	0.039
Silica 500	0.180	0.023	0.016	0.216	0.074	0.0038	0.240	0.101	0.008	0.041
Phosphorus 30	0.180	0.019	0.051	0.221	0.110	0.0073	0.25	0.097	0.017	0.033
Phosphorus 60	0.180	0.027	0.024	0.210	0.094	0.0038	0.225	0.105	0.010	0.038
Sulphur 300	0.180	0.016	0.018	0.260	0.057	0.0116	0.240	0.110	0.017	0.032
Sulphur 600	0.140	0.025	0.014	0.239	0.091	0.0067	0.265	0.129	0.007	0.051
Control	0.170	0.014	0.028	0.215	0.093	0.0098	0.249	0.095	0.015	0.045
C.D. (.05)	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**0.032**	**0.0028**	**N.S.**	**N.S.**	**N.S.**	**0.010**
S.Em	**0.016**	**0.006**	**0.008**	**0.008**	**0.001**	**0.0017**	**0.016**	**0.010**	**0.003**	**0.003**

application didn't increase the calcium content in plant parts compared to the other ameliorants.

4.3.1.3.6. Magnesium

Significant variation in magnesium content in plant parts (Table 42) was observed only in the culm at flowering, while the same didn't express any appreciable difference in other plant parts at various growth stages. The leaf magnesium content was more at flowering than active tillering and the content was the least at maturity. The culm magnesium content on the other hand had a linear increase registering the peak content at maturity. In contrast to the above, P 60 at flowering had lower culm magnesium content, which was significantly lower than that of the other ameliorants. At this stage P 30 recorded the highest culm magnesium content.

The root magnesium content, though didn't vary significantly among the treatments, recorded higher content at active tillering and lower content at flowering and harvest stages. P 60 at flowering, however, recorded higher root magnesium content than that at active tillering or at maturity. The control treatment, S 600, S 300, Si 250 and P 30 also registered higher numerical values of root magnesium content at maturity than that at flowering. The grain magnesium though didn't vary significantly, Si 500 recorded the highest value of 0.1 per cent and S 600 the lowest value of 0.085 per cent. The magnesium uptake (Fig. 15 f) recorded by P 30 was the highest (35.1 kg ha^{-1}) and by P 60 the lowest (22.0 kg ha^{-1}).

Table 42. Effect of ameliorants on magnesium content (%) of Vyttila-3 in 1999

Ameliorents	Active tillering			Flowering			Harvest			
	Leaf	Culm	Root	Leaf	Culm	Root	Leaf	Culm	Root	Grain
Lime 500	0.246	0.110	0.118	0.322	0.181	0.090	0.221	0.265	0.065	0.099
Lime 1000	0.255	0.102	0.115	0.299	0.167	0.108	0.208	0.257	0.103	0.098
Silica 250	0.239	0.090	0.131	0.308	0.160	0.080	0.196	0.228	0.107	0.095
Silica 500	0.251	0.124	0.125	0.261	0.183	0.111	0.201	0.233	0.085	0.100
Phosphorus 30	0.279	0.079	0.126	0.297	0.185	0.076	0.251	0.245	0.101	0.096
Phosphorus 60	0.260	0.116	0.122	0.303	0.120	0.128	0.158	0.247	0.066	0.096
Sulphur 300	0.238	0.113	0.125	0.283	0.162	0.077	0.240	0.216	0.084	0.094
Sulphur 600	0.220	0.122	0.123	0.291	0.160	0.063	0.185	0.238	0.108	0.085
Control	0.229	0.102	0.119	0.281	0.141	0.055	0.195	0.233	0.115	0.096
C.D. (.05)	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**0.034**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**0.020**	**0.008**	**0.015**	**0.016**	**0.014**	**0.021**	**0.023**	**0.082**	**0.014**	**0.004**

4.3.1.3.7. Iron

The iron content (Table 43) in root, culm and leaf at different stages and in grain didn't significantly vary with the treatments. The content of iron in leaves at the tillering stage ranged between 5623 and 6608 ppm. At flowering and harvest stages the leaf iron content decreased substantially to such an extent that at harvest it ranged from 424 to 798 ppm. The culm iron was also more at active tillering than at flowering. The culm iron at harvest was almost equal to that at flowering. The content of iron was more in root than in leaf or culm at all the stages. L 500, P 60, S 600 and the control treatment gradually diluted their root iron content towards maturity, while other treatments increased the root iron content at harvest. The iron uptake (Fig. 15 g) at active tillering ranged between 26.8 and 34.9 kg ha^{-1} among the treatments. At harvest the uptake range was only 15.4 to 28.5, thus suggesting the loss of the remaining iron by shedding of plant parts.

4.3.1.3.8. Manganese

The treatments didn't significantly differ the manganese content (Table 44) of the plant parts at any of the growth stages. The manganese content in culm was more than leaf, while the root manganese shifted either way at active tillering. At flowering the root manganese content was less than the leaf content. At harvest S 600 recorded the highest leaf manganese content while P 60 had higher concentration of culm manganese, the variation however, was not significant. The highest grain manganese content, was recorded by P 60, whereas S 600 and L 1000 also had almost same numerical values.

Table 43. Effect of ameliorants on iron content (ppm) of Vyttila-3 in 1999

Ameliorents	Active tillering			Flowering			Harvest			
	Leaf	Culm	Root	Leaf	Culm	Root	Leaf	Culm	Root	Grain
Lime 500	5623	1017	9805	462	673	9689	424	651	6707	25
Lime 1000	6608	1646	8863	781	536	8015	682	583	12989	16
Silica 250	5757	1165	9656	837	629	6433	798	706	10449	19
Silica 500	5752	1260	13073	464	786	7979	398	498	8916	13
Phosphorus 30	6204	1582	7908	537	620	7702	526	781	8950	18
Phosphorus 60	6604	1093	10176	477	661	9960	457	596	8475	18
Sulphur 300	5761	1192	10258	594	574	5039	564	598	8765	16
Sulphur 600	5784	1242	9398	667	615	6781	628	645	8619	18
Control	5377	1064	10696	539	640	5951	548	758	7596	16
C.D. (.05)	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**589.89**	**217.99**	**1823.27**	**16.28**	**65.01**	**1618.88**	**41.22**	**58.69**	**1216.92**	**1.78**

Table 44. Effect of ameliorants on manganese content (ppm) of Vyttila-3 in 1999

Ameliorents	Active tillering			Flowering			Harvest			
	Leaf	Culm	Root	Leaf	Culm	Root	Leaf	Culm	Root	Grain
Lime 500	88.07	49.30	48.37	54.27	74.67	27.60	69.20	58.20	27.07	18.03
Lime 1000	99.40	58.43	61.10	56.07	62.97	15.87	164.70	97.47	40.40	22.30
Silica 250	103.47	55.27	33.07	51.00	58.83	18.23	65.37	64.13	32.77	19.33
Silica 500	124.60	65.50	59.37	52.23	56.87	26.93	50.20	53.7	32.33	15.23
Phosphorus 30	118.60	64.23	41.27	47.37	65.00	21.40	62.53	73.13	36.93	19.23
Phosphorus 60	85.10	62.83	48.63	52.90	54.90	31.57	171.33	112.20	27.60	23.50
Sulphur 300	94.77	49.73	44.73	53.50	70.13	33.20	50.27	48.67	27.93	15.73
Sulphur 600	81.93	48.20	49.80	53.33	69.83	23.03	171.63	69.00	38.10	22.70
Control	77.10	45.20	47.37	58.97	72.63	16.20	123.17	81.00	46.83	20.33
C.D. (.05)	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**6.16**	**13.88**	**8.61**	**5.87**	**9.90**	**9.23**	**4.31**	**14.78**	**4.63**	**2.67**

Table 45. Effect of ameliorants on copper content (ppm) of Vyttila-3 in 1999

Ameliorents	Active tillering			Flowering			Harvest			
	Leaf	Culm	Root	Leaf	Culm	Root	Leaf	Culm	Root	Grain
Lime 500	7.73	7.10	29.17	11.97	10.33	18.60	24.03	12.07	43.00	10.80
Lime 1000	8.00	8.43	23.73	28.57	8.10	56.53	16.07	16.50	43.17	11.73
Silica 250	7.67	10.80	48.73	18.57	8.63	18.90	24.57	16.43	41.33	9.90
Silica 500	10.37	12.17	52.60	17.77	7.70	18.37	16.97	13.33	45.23	9.40
Phosphorus 30	12.27	21.57	37.63	14.13	8.53	96.50	19.57	10.63	67.77	9.10
Phosphorus 60	13.00	8.97	48.93	12.27	8.70	23.80	20.43	10.60	32.93	8.97
Sulphur 300	8.43	10.17	34.73	14.77	10.43	11.50	14.67	17.00	51.27	12.13
Sulphur 600	13.33	11.63	59.27	11.23	8.37	14.73	23.73	13.80	53.87	17.17
Control	5.63	8.83	39.43	13.40	10.17	15.67	25.03	17.00	47.20	24.30
C.D. (.05)	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**1.86**	**2.84**	**8.73**	**6.06**	**1.54**	**1.78**	**4.99**	**2.64**	**11.33**	**0.50**

Table 46. Effect of ameliorants on zinc content (ppm) of Vyttila-3 in 1999

Ameliorents	Active tillering			Flowering			Harvest			
	Leaf	Culm	Root	Leaf	Culm	Root	Leaf	Culm	Root	Grain
Lime 500	104.77	103.90	86.17	102.43	108.63	31.40	28.60	27.50	27.90	26.63
Lime 1000	103.63	96.80	104.03	113.43	73.18	24.03	27.73	37.97	43.00	22.00
Silica 250	99.73	105.73	100.87	116.37	80.47	32.57	31.13	35.37	39.63	19.63
Silica 500	106.77	129.53	112.60	104.67	116.67	31.63	27.77	34.13	38.20	30.93
Phosphorus 30	105.63	107.03	90.03	107.47	110.00	24.57	36.63	26.10	42.27	21.87
Phosphorus 60	106.47	101.70	127.33	118.97	100.07	46.77	25.67	35.07	28.33	28.43
Sulphur 300	102.13	105.07	106.33	103.93	114.57	18.93	24.40	26.83	34.57	20.27
Sulphur 600	100.24	101.73	123.20	111.23	114.57	40.50	32.17	28.47	36.27	32.13
Control	101.57	107.30	153.30	106.20	101.77	23.53	35.27	29.97	41.13	29.53
C.D. (.05)	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**1.94**	**8.80**	**19.19**	**6.70**	**11.02**	**7.65**	**3.65**	**4.86**	**4.92**	**4.20**

4.3.1.3.9. Copper

The data on the effect of the ameliorants on copper content in plant parts of rice are depicted in Table 45. The copper content in plant parts increased with the advancement of the growth. Its content in plant parts followed the order of root > leaf > culm. The copper content of grain ranged between 8.97 and 24.3 ppm. The maximum grain copper content was recorded by the control treatment (24.3 ppm) followed by S 600 (17.17 ppm).

4.3.1.3.10. Zinc

The treatments didn't reveal any significant effect on zinc content in plant parts (Table 46). The zinc content in leaf, culm and root was almost uniform at active tillering stage. At the flowering stage, the root zinc content was decreased considerably, while the leaf and culm content were maintained at almost the same level as that of the first stage. At harvest stage the leaf and culm zinc content registered lower values, while the root zinc content recorded higher values.

4.3.1.4. Soil chemical characters

The content of the major soil nutrients as well as the important micronutrients at the end of the field experiment didn't vary significantly. The organic carbon content (Table 47 a) was uniformly higher which ranged between 2.58 and 2.96 per cent. The total nitrogen content of the soil also registered higher values ranging between 0.251 and 0.448 per cent. The available nitrogen was also uniformly higher in all the treatments. The available phosphorus on the other hand registered medium rated values ranging from 10.9 to16.00 kg ha^{-1}.P 30 recorded the highest available phosphorus of 16.00 $kgha^{-1}$,

Table 47 (a) Effect of ameliorants on major soil nutrients after the experiment in 1999

Ameliorants	Organic carbon (%)	Total N (%)	Available N (%)	Total P (%)	Available P (kg ha^{-1})	Available K (%)
Lime 500	2.88	0.251	0.023	0.079	11.2	0.079
Lime 1000	2.96	0.401	0.015	0.106	10.9	0.08
Silica 250	2.58	0.448	0.014	0.042	11.2	0.079
Silica 500	2.59	0.336	0.018	0.083	13.2	0.107
Phosphorus 30	2.80	0.467	0.016	0.095	16.0	0.073
Phosphorus 60	2.84	0.383	0.016	0.036	13.4	0.078
Sulphur 300	2.89	0.345	0.020	0.072	11.8	0.094
Sulphur 600	2.83	0.392	0.014	0.087	12.7	0.101
Control	2.78	0.299	0.019	0.095	13.1	0.111
C.D. (.05)	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**0.400**	**0.105**	**0.003**	**0.011**	**2.160**	**0.010**

Table 47 (b) Effect of ameliorants on important soil micro nutrients after the experiment in 1999

Ameliorants	Available Na (%)	Available Ca (ppm)	Available Mg (ppm)	Available Cu (ppm)	Available Zn (ppm)	Available Fe (ppm)	Available Mn (ppm)
Lime 500	0.109	9.67	360.33	29.43	9.03	1631.33	20.97
Lime 1000	0.104	15.33	345.00	31.50	8.17	1622.33	21.50
Silica 250	0.129	20.33	368.00	25.80	7.80	1683.00	19.07
Silica 500	0.150	15.67	391.33	27.60	9.10	1726.67	20.93
Phosphorus 30	0.102	13.67	326.67	56.50	11.93	1482.00	17.63
Phosphorus 60	0.109	19.00	378.33	26.47	8.33	1604.67	19.13
Sulphur 300	0.104	15.00	374.67	30.93	8.67	1634.00	19.83
Sulphur 600	0.125	18.33	418.00	33.13	10.87	1788.33	23.83
Control	0.171	9.67	457.67	37.53	12.70	2105.67	20.90
C.D. (.05)	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**0.02**	**0.48**	**35.81**	**8.69**	**1.66**	**162.04**	**1.32**

followed by P 60 (13.4 kg ha^{-1}). The available potassium and available sodium, though not significant, gave clear indications on the effect of application of ameliorants on *Pokkali* soils. All the higher levels of ameliorants *viz.*, L 1000, Si 500 and P 60 gave higher available potassium than their lower levels. Similarly, the higher levels of ameliorants *viz.*, L 1000, Si 500, P 60 and S600 gave higher available sodium than their corresponding lower levels.

The important micronutrients (Table 47 b) also didn't vary significantly with the treatments. The available sodium was fairly high (0.17%) for the control treatment followed by Si 500 and S 600. Available magnesium, available copper, available zinc and available iron were also higher for the non-ameliorated control treatment. The available manganese ranged between 17.63 and 23.83 ppm. P 30 recorded the lowest value, while the S 600 registered the highest manganese content.

4.3.1.5. Correlation studies

The correlation studies on the soil chemical characters revealed that the organic carbon content related negatively with available phosphorus, sodium, calcium, magnesium and iron, and positively with available zinc, copper and manganese (Appendix-II). Available nitrogen had significant negative correlation with available calcium. It's relation with grain yield was also negative. Available phosphorus had significant positive correlation with available copper and zinc but negatively correlated with available manganese and grain yield.

Available potassium had significant positive correlation with available sodium, magnesium and iron. Available potassium also had positive correlation with available

Table 48. Correlation matrix on plant nutrient content, available soil nutrients and grain yield of rice in 1999

	RNH	CKAT	GK	LCaAT	LCaH	LMnH	GMn	Av.N	Av.P	Av.K	Av.Mn	Sp.leaf weight	Grain Yield
RNH	1.000	0.403	-0.562	0.237	-0.701*	-0.491	-0.364	0.329	0.087	-0.154	-0.645	-0.271	-0.652
CKAT		1.000	-0.780*	0.242	-0.320	-0.209	0.088	-0.117	0.767*	-0.527	-0.832**	-0.340	-0.576
GK			1.000	-0.254	0.204	0.575	0.318	0.082	-0.526	0.298	0.903***	0.652	0.625
LCaAT				1.000	-0.599	-0.389	-0.401	0.641	0.029	-0.345	-0.510	-0.906***	-0.657
LCaH					1.000	0.349	0.318	0.426	-0.056	0.192	0.475	0.551	0.760*
LMnH						1.000	0.921***	-0.471	-0.087	0.017	0.484	0.526	0.756*
GMn							1.000	-0.578	0.026	-0.260	0.224	0.417	0.656
Av.N								1.000	0.160	0.160	-0.029	-0.478	-0.484
Av.P									1.000	-0.005	-0.436	0.031	-0.408
Av.K										1.000	0.565	0.503	0.241
Av.Mn											1.000	0.652	0.744*
Sp.leaf weight												1.000	0.679
Grain yield													1.000

RNH - Root N at harvest
CKAT - Culm K at active tillering
GK - Grain K
LCaAT - Leaf Ca at active tillering
LCaH - Leaf Ca at harvest
LMnH - Leaf Mn at harvest
GMn - Grain Mn
Av.N - Available N
Av.P - Available P
Av.K - Available K
Av.Mn - Available Mn

manganese and grain yield. Available sodium had significant positive correlation with available magnesium and iron. Available calcium had negative correlation with available nitrogen, zinc, iron and copper and the relation was significant for nitrogen. Available magnesium had significant positive correlation with iron.

Available manganese had positive correlation with available potassium, magnesium, iron and sodium. The available phosphorus and copper registered negative relation. The available manganese, however, had a significant positive correlation with grain yield.

The critical parameters that were identified to have direct bearing with the grain yield were systematically evaluated for their interrelationship. It was revealed that the leaf content of calcium and manganese at harvest and available soil manganese and specific leaf weight had significant positive correlation with the grain yield (Table 48). The root nitrogen at harvest, leaf calcium and culm potassium at active tillering had negative influence on grain yield, while grain potassium had the opposite effect.

Among the soil characters available nitrogen and phosphorus had negative relation with grain, yield while the available potassium favoured the grain yield. The root nitrogen at harvest had negative relation with all the parameters except culm potassium at active tillering, available nitrogen and phosphorus, and it was significantly negative with leaf calcium at harvest, grain potassium, available phosphorus, available manganese and specific leaf weight. The grain potassium on the contrary, had significant positive relation with available manganese. Grain manganese and leaf manganese at harvest had highly significant positive correlation with the grain yield.

4.3.2. Impact of Ameliorants on growth, yield and nutrient uptake of *Pokkali* rice – Kharif 2000

The levels of ameliorants found promising in the trials during 1999 (L500, P 30, Si 125 and S 600) were evaluated alone and in selected combinations during the second year (2000). The results obtained are presented in Tables 49 to 66.

4.3.2.1. Growth characters

Among the growth characters studied the plant height at all stages except at flowering, and vegetative tillers at all stages (Table 49) didn't differ significantly due to the effect of the treatments. However, silica at active tillering phase, lime along with sulphur at panicle initiation and flowering, and lime along with silica at harvest produced taller rice plants. Sulphur application reduced the height of plants especially during the active tillering to flowering stage. At harvest the control treatment without any ameliorant produced the shortest rice plants.

All the treatments in general had the maximum vegetative tillers hill^{-1}at panicle initiation and the number decreased considerably at the subsequent stages.

Though the leaf area index (Table 50) at different growth stages varied widely among the treatments, the difference was significant only at the panicle initiation stage. In general, the control treatment without any ameliorant gave much higher leaf area index than other treatments at all the stages. At the panicle initiation stage the control treatment was significantly superior to all others.

Table 49. Effect of ameliorants on growth characters of Vyttila-3 in 2000

Ameliorants	Plant height (cm)				Tillers (nos.)			
	Active tillering	Panicle initiation	Flowering	Harvest	Active tillering	Panicle initiation	Flowering	Harvest
Ca	73.93	96.00	161.70	170.30	8.30	9.37	6.90	4.93
Si	78.67	104.00	157.80	171.70	8.27	10.40	8.63	5.41
P	76.53	103.00	157.20	170.50	9.80	11.47	8.67	4.88
S	71.53	94.00	155.30	169.40	9.07	9.73	7.73	5.09
CaSi	76.97	105.00	162.90	174.10	9.10	10.77	8.07	5.17
CaP	71.90	104.70	162.40	172.30	7.80	9.83	8.03	6.08
CaS	77.73	110.00	168.90	172.30	10.83	11.37	9.57	5.00
CaSiP	74.27	100:00	164.30	167.80	8.93	10.17	8.27	5.90
CaSiPS	72.03	97.00	166.00	173.90	8.00	9.20	6.67	5.68
Control	76.20	103.70	158.20	165.10	9.17	10.73	8.93	4.98
C.D.(.05)	**N.S.**	**N.S.**	**7.72**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**3.36**	**3.93**	**2.60**	**3.05**	**0.81**	**0.82**	**0.75**	**0.74**

Table 50. Effect of ameliorants on leaf area index of Vyttila-3 at various growth stages in 2000

Ameliorants	Active tillering	Panicle initiation	Flowering	Harvest
Ca	1.28	2.45	4.95	1.81
Si	1.14	2.39	5.50	1.55
P	1.34	2.94	4.35	1.38
S	1.26	1.91	4.72	1.53
CaSi	1.59	2.83	4.29	1.56
CaP	1.09	2.37	5.03	1,61
CaS	0.84	3.00	5.38	1.44
CaSiP	1.27	2.52	4.60	1.73
CaSiPS	1.37	2.26	5.03	1.50
Control	1.56	3.91	6.22	2.45
C.D.(.05)	**N.S.**	**0.85**	**N.S.**	**N.S.**
S.Em	**0.25**	**0.29**	**1.01**	**0.34**

The treatment effect on the root dry weight (Table 51) was significant at the panicle initiation stage only, where the lime and sulphur combination gave the highest root biomass followed by calcium and silica. At flowering and harvest stages the control treatment recorded more root dry matter than most of the other treatments. The culm weight was more for the control treatment at all growth stages except at the active tillering stage.

The leaf dry weight and total dry weight (Table 52) were significantly more for the control treatment at the panicle initiation stage and it retained the top position at the subsequent stages also, though the difference was not significant. Phosphorus application recorded the least leaf weight values at the flowering and harvest stages.

In general, the dry matter accumulation was higher under a no-ameliorant situation rather than under an ameliorant applied situation. Combined application of lime and silica also positively influenced the total dry matter production.

Though the treatments didn't significantly differ in the cell sap pH, (Table 53) chlorophyll b content was significantly more for the combination treatment of lime, silica, phosphorus and sulphur. Chlorophyll a content also was the highest for the above treatment.

4.3.2.2. Yield attributes and yield

Variation due to the treatments on yield attributes (Table 54) was significant with respect to the number of grains per panicle and panicle weight. The maximum number of grains panicle^{-1} was recorded by the lime treatment which was at par with the other treatments, except silica, and combination of lime with silica, and lime with sulphur.

Table 51. Effect of ameliorants on dry weight (t ha^{-1}) of root and culm of Vyttila-3 in 2000

Ameliorants	Root				Culm			
	Active tillering	Panicle initiation	Flowering	Harvest	Active tillering	Panicle initiation	Flowering	Harvest
Ca	0.40	0.78	1.41	1.18	0.66	1.11	6.54	6.36
Si	0.34	0.77	0.88	1.30	0.64	1.20	5.68	5.71
P	0.47	0.76	1.03	1.43	0.53	1.31	5.04	5.11
S	0.39	0.61	1.13	1.32	0.62	0.97	5.43	6.46
CaSi	0.57	1.00	1.39	0.88	0.77	1.46	6.92	5.20
CaP	0.38	0.88	1.28	1.66	0.57	1.12	5.42	7.02
CaS	0.43	1.15	1.52	1.28	0.61	1.66	6.06	5.72
CaSiP	0.49	0.88	1.19	1.83	0.69	1.22	5.90	7.18
CaSiPS	0.43	0.67	1.10	0.92	0.67	1.17	5.40	6.57
Control	0.46	0.81	1.52	1.64	0.74	1.72	7.74	7.57
C.D.(.05)	**N.S.**	**0.24**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**0.10**	**0.08**	**0.21**	**0.22**	**0.09**	**0.16**	**0.81**	**0.82**

Table 52. Effect of ameliorants on dry weight (t ha^{-1}) of leaf and total dry weight of Vyttila-3 in 2000

Ameliorants	Leaf				Total			
	Active Tillering	Panicle Initiation	Flowering	Harvest	Active Tillering	Panicle Initiation	Flowering	Harvest
Ca	0.50	0.95	1.91	0.70	1.55	2.83	9.87	11.22
Si	0.46	0.92	2.12	0.60	1.44	2.89	8.68	9.62
P	0.52	1.14	1.68	0.53	1.52	3.20	7.76	9.21
S	0.49	0.74	1.82	0.59	1.50	2.32	8.39	10.50
CaSi	0.62	1.09	2.16	0.60	1.95	3.55	10.47	8.24
CaP	0.42	0.92	1.94	0.62	1.37	2.92	8.64	12.42
CaS	0.45	1.16	2.08	0.56	1.49	3.96	9.66	9.33
CaSiP	0.49	0.97	1.78	0.67	1.67	3.10	8.87	12.00
CaSiPS	0.53	0.87	1.94	0.58	1.63	2.70	8.44	10.47
Control	0.55	1.51	2.40	0.94	1.75	4.04	11.67	13.47
C.D.(.05)	**N.S.**	**0.33**	**N.S.**	**N.S.**	**N.S.**	**0.88**	**N.S.**	**N.S.**
S.Em	**0.08**	**0.11**	**0.07**	**0.13**	**0.25**	**0.30**	**1.23**	**1.26**

Table 53. Effect of ameliorants on physiological characters of Vyttila-3 in 2000

Ameliorants	Cell sap pH		Chlorophyll content at P.I.	
	Panicle initiation	Flowering	Chlorophyll a (mg g^{-1})	Chlorophyll b (mg g^{-1})
Ca	6.43	6.47	1.87	0.92
Si	6.42	6.47	1.69	0.79
P	6.45	6.35	1.91	0.86
S	6.45	6.45	1.70	0.82
CaSi	6.43	6.33	1.67	0.61
CaP	6.33	6.48	1.99	0.94
CaS	6.30	6.43	1.95	0.92
CaSiP	6.40	6.37	1.55	0.71
CaSiPS	6.43	6.40	2.01	0.95
Control	6.43	6.38	1.73	0.81
C.D.(.05)	**N.S.**	**N.S.**	**N.S.**	**0.16**
S.Em	**0.06**	**0.03**	**0.11**	**0.05**

Table 54. Effect of ameliorants on yield attributes of Vyttila-3 in 2000

Ameliorants	Panicle length (cm)	No. of grains per panicle	Chaff (%)	Thousand grain weight (g)	Panicles per hill (no.)	Panicle weight (g)
Ca	28.70	126.60	4.62	35.10	4.83	43.47
Si	26.20	81.10	6.25	36.20	5.40	27.83
P	28.40	104.40	5.03	35.40	4.80	35.50
S	27.97	111.30	3.19	36.70	5.00	39.17
CaSi	26.43	95.20	6.69	34.40	5.07	29.83
CaP	28.60	114.50	4.17	34.90	6.00	41.17
CaS	27.77	94.90	5.48	35.50	4.87	32.13
CaSiP	27.20	113.30	5.75	35.50	5.40	39.67
CaSiPS	28.30	108.20	5.31	34.80	5.60	34.83
Control	28.20	114.20	4.66	36.60	4.87	40.17
C.D.(.05)	**N.S.**	**22.91**	**N.S.**	**N.S.**	**N.S.**	**7.42**
S.Em	**0.96**	**7.71**	**0.89**	**0.63**	**0.53**	**2.41**

Panicle weight was also the highest for the lime treatment which was superior to silica, its combination with lime, lime + sulphur combination, lime + silica + phosphorus + sulphur combination, and phosphorus alone treatment. The number of panicles hill^{-1}, panicle length, chaff per cent and thousand grain weight didn't differ significantly. The control treatment resulted in higher values for panicle length, grain panicle^{-1}, thousand - grain weight and panicle weight than most of the other treatments. It's chaff per cent was also lower.

The grain yield (Table 55) didn't vary significantly due to the treatments. However, the highest grain and significantly more straw yield and biomass production were recorded by the control followed by sulphur treatment. The grain : straw ratio didn't differ significantly. However, the highest ratio was recorded by the combination treatment of calcium and silica.

4.3.2.3. Elemental composition

4.3.2.3.1. Nitrogen

The ameliorants didn't significantly influence the nitrogen content (Table 56 a and b) of the plant parts except that of the grain and culm at flowering. Silica application gave maximum culm nitrogen content at flowering. The combination treatments of calcium + silica + phosphorus, and calcium + silica + phosphorus + sulphur, resulted in the maximum but similar grain nitrogen content.

The leaf nitrogen content at active tillering varied from 1.50 to 2.11 per cent, which decreased to 1.17 to 1.52 per cent at harvest. The nitrogen content in the plant parts followed the order of leaf > roots > culm at all the stages except at active tillering.

Table 55. Effect of ameliorants on yield and yield attributes of Vyttila-3 in 2000

Ameliorants	Yield (kg ha^{-1})			Grain : Straw ratio
	Grain	Straw	Biomass	
Ca	2633	7066	9700	0.37
Si	2683	6950	9633	0.39
P	2650	5800	8450	0.46
S	3000	7050	10050	0.43
CaSi	2767	5800	8567	0.47
CaP	2867	6950	9817	0.41
CaS	2600	5650	8250	0.46
CaSiP	2533	5650	8183	0.46
CaSiPS	2683	6950	9633	0.38
Control	3333	8200	11533	0.43
C.D.(.05)	**N.S.**	**1278**	**1747**	**N.S.**
S.Em	**207.72**	**430.21**	**587.88**	**0.03**

Table 56 (a) Effect of ameliorants on nitrogen content (%) of Vyttila-3 in 2000

Ameliorants	Active tillering			Panicle initiation		
	Leaf	Culm	Root	Leaf	Culm	Root
Ca	1.92	1.93	1.02	1.30	0.94	0.96
Si	1.85	1.27	1.26	1.32	0.88	0.09
P	1.61	1.03	1.09	1.39	0.88	1.04
S	1.55	0.98	1.16	1.14	0.81	0.98
CaSi	1.58	1.06	1.03	1.06	0.88	1.01
CaP	1.75	1.06	1.17	1.52	0.92	1.00
CaS	1.50	1.04	1.04	1.14	0.84	0.93
CaSiP	1.52	1.11	1.03	1.12	0.90	0.95
CaSiPS	1.78	1.06	1.13	1.08	0.85	1.16
Control	2.11	1.00	1.20	1.11	0.81	1.10
C.D.(.05)	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**0.16**	**0.08**	**0.10**	**0.14**	**0.05**	**0.06**

Table 56 (b) Effect of ameliorants on nitrogen content (%) of Vyttila-3 in 2000

Ameliorants	Flowering			Harvest			
	Leaf	Culm	Root	Leaf	Culm	Root	Grain
Ca	1.95	0.75	0.88	1.23	0.57	0.85	1.10
Si	1.96	0.90	0.82	1.29	0.85	0.97	1.09
P	1.86	0.71	0.94	1.34	0.81	0.91	1.11
S	1.85	0.80	1.00	1.23	0.72	0.87	1.07
CaSi	1.65	0.74	0.89	1.52	0.83	1.05	1.12
CaP	2.04	0.84	0.91	1.33	0.80	0.95	1.13
CaS	2.04	0.79	0.97	1.24	0.84	0.96	1.10
CaSiP	1.76	0.70	0.87	1.29	0.81	0.86	1.20
CaSiPS	2.04	0.83	0.92	1.17	0.73	0.95	1.20
Control	1.80	0.74	1.07	1.30	0.84	0.93	1.17
C.D.(.05)	**N.S.**	**0.12**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**0.08**
S.Em	**0.09**	**0.04**	**0.05**	**0.12**	**0.07**	**0.05**	**0.03**

The maximum nitrogen uptake (Fig. 16) of 130 kg ha^{-1} was registered by the non-ameliorant control treatment followed by the lime + phosphorus combination.

4.3.2.3.2. Phosphorus

The ameliorants significantly varied the phosphorus content (Table 57 a and b) of culm at active tillering, leaf at panicle initiation stage and root at flowering. The culm phosphorus at active tillering and root phosphorus at flowering were significantly higher for the non-ameliorant control treatment. At panicle initiation stage the leaf phosphorus for the above treatment was the least. At harvest stage the phosphorus content of the culm, root and grain was also less in the control treatment than the others. The phosphorus content in the plant parts generally followed the order of root > culm > leaf ≥ grain in almost all the growth stages. However, at the panicle initiation stage the phosphorus content in leaf ≥ culm in most of the treatments receiving the ameliorants.

Application of lime, sulphur and lime- silica- phosphorus- sulphur combination enhanced the uptake (Fig. 17) of phosphorus than the application of phosphorus alone. Phosphorus uptake by the control treatment was less, even though the biomass production was the highest in this treatment.

4.3.2.3.3. Potassium

The ameliorants didn't significantly differ the potassium content of the plant parts at any of the growth stages of rice (Table 58 a and b). Potassium content was higher in culm at active tillering stage and the variation ranged between 3.57 and 3.95 per cent. The values were less in roots at the harvest stage and the potassium content ranged

Fig.16. Effect of ameliorants on partitioning of N at maturity - 2000

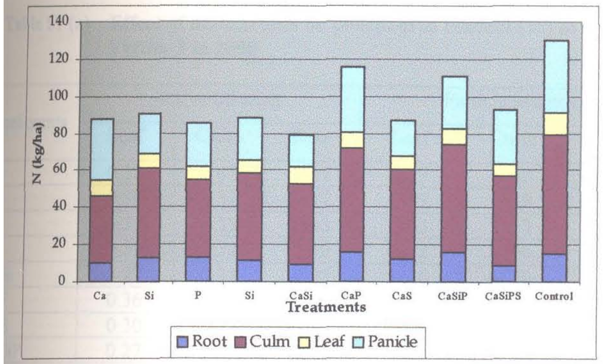


Fig.17. Effect of ameliorants on partitioning of P at maturity - 2000

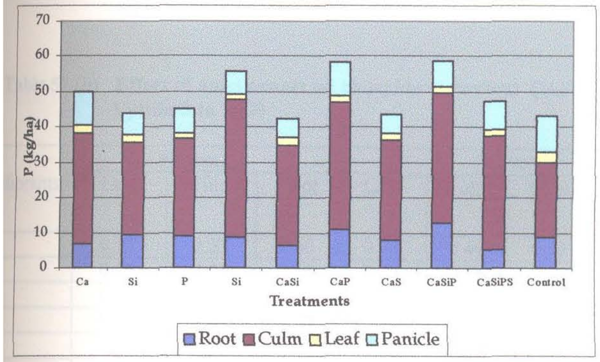


Table 57 (a) Effect of ameliorants on phosphorus content (%) of Vyttila-3 in 2000

Ameliorants	Active tillering			Panicle initiation		
	Leaf	Culm	Root	Leaf	Culm	Root
Ca	0.32	0.42	0.87	0.47	0.40	0.79
Si	0.30	0.32	0.77	0.39	0.38	0.67
P	0.31	0.35	0.83	0.43	0.43	0.80
S	0.29	0.32	0.70	0.42	0.36	0.80
CaSi	0.27	0.35	0.97	0.36	0.40	0.87
CaP	0.36	0.38	0.75	0.45	0.42	0.87
CaS	0.30	0.43	0.76	0.36	0.43	0.72
CaSiP	0.27	0.45	0.81	0.37	0.39	0.76
CaSiPS	0.28	0.35	0.95	0.40	0.40	0.83
Control	0.31	0.56	0.87	0.29	0.39	0.67
C.D.(.05)	**N.S.**	**0.12**	**N.S.**	**0.09**	**N.S.**	**N.S.**
S.Em	**0.02**	**0.04**	**0.09**	**0.03**	**0.03**	**0.06**

Table 57 (b) Effect of ameliorants on phosphorus content (%) of Vyttila-3 in 2000

Ameliorants	Flowering			Harvest			
	Leaf	Culm	Root	Leaf	Culm	Root	Grain
Ca	0.27	0.37	0.60	0.33	0.49	0.59	0.32
Si	0.28	0.35	0.59	0.34	0.46	0.72	0.31
P	0.34	0.39	0.55	0.29	0.54	0.64	0.32
S	0.29	0.41	0.53	0.29	0.60	0.67	0.30
CaSi	0.27	0.39	0.63	0.36	0.55	0.73	0.33
CaP	0.27	0.38	0.66	0.35	0.51	0.66	0.30
CaS	0.28	0.40	0.74	0.32	0.50	0.61	0.31
CaSiP	0.29	0.41	0.58	0.31	0.51	0.70	0.30
CaSiPS	0.29	0.38	0.62	0.35	0.49	0.58	0.32
Control	0.25	0.40	0.82	0.34	0.28	0.53	0.30
C.D.(.05)	**N.S.**	**N.S.**	**0.17**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**0.02**	**0.02**	**0.06**	**0.03**	**0.07**	**0.06**	**0.02**

Table 58 (a) Effect of ameliorants on potassium content (%) of Vyttila-3 in 2000

Ameliorants	Active tillering			Panicle initiation		
	Leaf	Culm	Root	Leaf	Culm	Root
Ca	3.48	3.93	1.05	2.85	3.53	0.73
Si	3.43	3.95	1.15	3.09	3.62	0.93
P	3.20	3.78	1.08	2.92	3.00	0.77
S	3.38	3.72	1.15	2.75	3.40	0.85
CaSi	3.37	3.88	1.02	2.75	3.40	0.73
CaP	3.47	3.92	1.08	3.03	3.62	0.80
CaS	3.43	3.75	1.08	2.83	3.42	0.70
CaSiP	3.18	3.57	1.12	2.88	3.40	0.82
CaSiPS	3.42	3.68	1.13	2.82	3.23	0.97
Control	3.38	3.75	1.13	2.82	3.23	0.97
C.D.(.05)	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**0.09**	**0.12**	**0.08**	**0.08**	**0.14**	**0.12**

Table 58 (b) Effect of ameliorants on potassium content (%) of Vyttila-3 in 2000

Ameliorants	Flowering			Harvest			
	Leaf	Culm	Root	Leaf	Culm	Root	Grain
Ca	2.23	1.85	0.23	0.97	1.62	0.18	0.37
Si	2.18	2.06	0.17	0.87	1.33	0.20	0.30
P	2.23	1.97	0.22	1.05	1.53	0.17	0.33
S	2.22	1.73	0.22	0.62	1.47	0.17	0.32
CaSi	2.10	1.67	0.28	0.68	1.08	0.13	0.33
CaP	2.20	2.08	0.32	0.97	1.60	0.22	0.35
CaS	2.15	2.03	0.23	1.02	1.57	0.17	0.32
CaSiP	2.12	1.92	0.28	0.95	1.57	0.13	0.33
CaSiPS	2.08	1.72	0.23	0.75	1.68	0.17	0.32
Control	2.37	1.72	0.27	1.08	1.83	0.15	0.32
C.D.(.05)	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**0.07**	**0.14**	**0.04**	**0.12**	**0.18**	**0.03**	**0.02**

between 0.13 and 0.22 per cent. Differing from the general pattern of culm > leaf > root the potassium content at flowering stage followed the order leaf > culm > root.

The uptake of potassium (Fig. 18 a and b) was maximum at the flowering stage irrespective of the treatments. The maximum uptake of potassium was registered by the non-ameliorated control treatment (194.1 kg ha^{-1}) which retained only 83.3 per cent of it at the harvest stage, shedding the remaining quantity during the flowering to harvest stage. The per cent of shedding of potassium during the flowering to harvest stage was the highest for lime + silica combination (59.6%), followed by silica alone (45.4%) and combination of lime and sulphur (39.6%).

4.3.2.3.4. Sodium

The data (Table 59 a and b) didn't reveal any significant effect of ameliorants on the sodium content in the root, culm and leaf of rice at the active tillering and panicle initiation stages. At flowering the culm sodium content was significantly less for the control treatment. The root sodium content at flowering and leaf and root sodium content at harvest were also less for the above treatment though the difference with that of the ameliorants was not significant. At flowering the treatment receiving silica recorded the maximum culm sodium content, which was at par with the combination of silica with lime, phosphorus and sulphur. In general, a higher concentration of sodium was observed in culm than the root. The root sodium was higher than the leaf sodium content.

The peak uptake of sodium (Fig. 19 a and b) varied according to the ameliorants. Peak of sodium uptake was at flowering for the treatments viz., lime, silica, lime + silica combination, lime + sulphur combination and lime + silica + phosphorus + sulphur

Fig.18 (a) Effect of ameliorants on partitioning of K at flowering - 2000

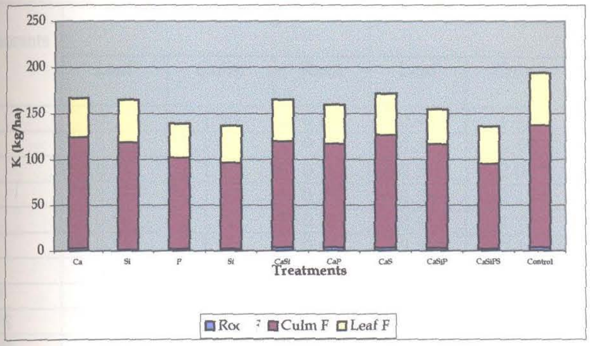


Fig.18(b). Effect of ameliorants on partitioning of K at harvest - 2000

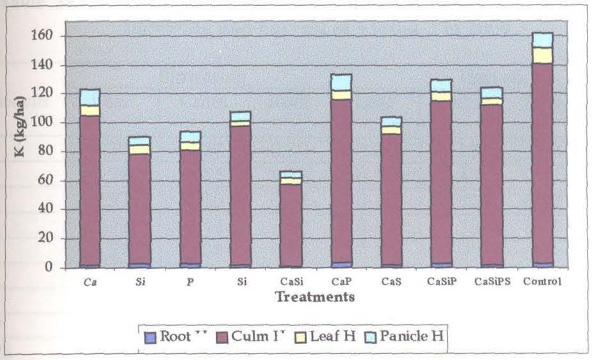


Table 59 (a) Effect of ameliorants on sodium content (%) at active tillering and panicle initiation of Vyttila-3 in 2000

Ameliorants	Active tillering			Panicle initiation		
	Leaf	Culm	Root	Leaf	Culm	Root
Ca	0.53	1.80	0.87	0.47	1.88	0.80
Si	0.50	1.68	0.88	0.57	2.17	1.07
P	0.57	1.85	0.82	0.55	2.05	1.02
S	0.45	1.85	0.80	0.50	2.12	0.93
CaSi	0.50	1.80	0.80	0.48	1.78	0.83
CaP	0.58	1.72	0.68	0.55	2.10	1.28
CaS	0.50	1.72	0.82	0.48	1.97	0.98
CaSiP	0.52	1.73	0.83	0.57	1.90	0.83
CaSiPS	0.57	1.88	0.90	0.57	1.70	0.97
Control	0.53	1.57	0.77	0.55	2.02	0.90
C.D.(.05)	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**0.05**	**0.08**	**0.05**	**0.05**	**0.15**	**0.13**

Table 59 (b) Effect of ameliorants on sodium content (%) at flowering and harvest of Vyttila-3 in 2000

Ameliorants	Flowering			Harvest			
	Leaf	Culm	Root	Leaf	Culm	Root	Grain
Ca	0.30	1.27	0.30	0.22	1.12	0.52	0.07
Si	0.28	1.87	0.32	0.13	1.43	0.53	0.10
P	0.37	1.10	0.32	0.17	1.42	0.53	0.13
S	0.32	1.43	0.22	0.15	1.30	0.55	0.08
CaSi	0.27	1.08	0.28	0.25	0.97	0.48	0.08
CaP	0.33	1.32	0.45	0.08	1.45	0.48	0.17
CaS	0.30	1.23	0.28	0.17	1.28	0.50	0.10
CaSiP	0.30	1.47	0.33	0.12	1.25	0.47	0.10
CaSiPS	0.30	1.83	0.40	0.15	1.22	0.52	0.07
Control	0.37	0.82	0.20	0.07	1.23	0.33	0.15
C.D.(.05)	**N.S.**	**0.34**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**0.03**	**0.13**	**0.10**	**0.04**	**0.15**	**0.06**	**0.04**

Fig. 19 (a).Effects of ameliorants on partitioning of Na at flowering - 2000

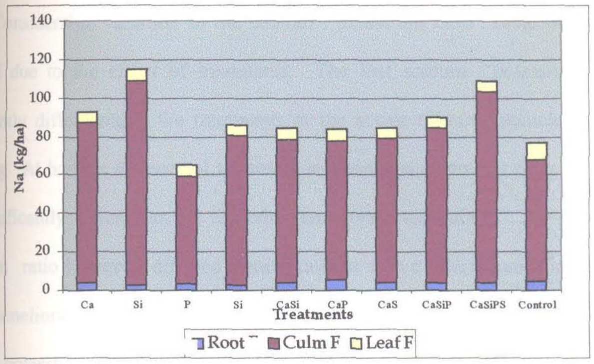
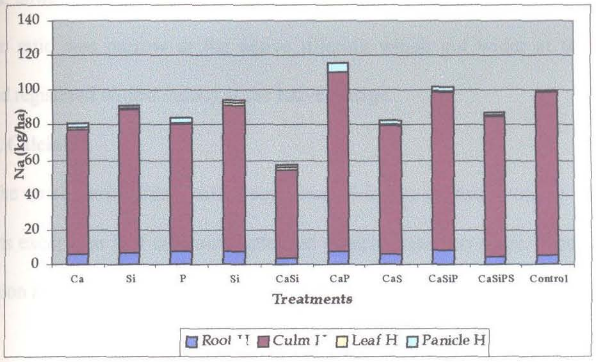


Fig. 19(b). Effect of ameliorants on partitioning of Na at harvest – 2000



combinations. The peak uptake of sodium for the other treatments was at the harvest stage. The treatments which peaked the sodium uptake at flowering, shedded 2.78 to 27 kg ha^{-1} of sodium during the subsequent period.

4.3.2.3.5. Sodium : Potassium ratio

Considerable variation in the sodium : potassium ratio (Table 60 a and b) was observed due to the effect of treatments. The leaf sodium : potassium ratio didn't significantly differ among the treatments at the active tillering, panicle initiation and flowering. At harvest the control treatment recorded the narrowest ratio for leaf which was significantly lower than all the other ameliorant treatments. The culm sodium : potassium ratio however, differed significantly at active tillering and flowering, where the non-ameliorated control treatment registered the lower ratio. The culm and leaf sodium : potassium ratios of the control treatment gave lower values at the harvest and flowering stages, while the ratios for the same was higher at the pre-flowering stages. The root sodium : potassium ratio didn't significantly differ among the treatments. The ratio was, however, the least for the control treatment at flowering. The root sodium : potassium ratio was narrow at the active tillering which got wider at the subsequent stages and registered widest values at the harvest stage.

4.3.2.3.6. Calcium

The ameliorants didn't differ significantly in the calcium content (Table 61) in plant parts except for leaf calcium content at panicle initiation stage. The lime + silica combination and phosphorus alone recorded a similar but the highest leaf calcium content

Table 60 (a) Effect of ameliorants on Na : K ratio of Vyttila-3 at active tillering and panicle initiation in 2000

Ameliorants	Active Tillering			Panicle initiation		
	Leaf	Culm	Root	Leaf	Culm	Root
Ca	0.15	0.46	0.82	0.16	0.53	1.14
Si	0.15	0.43	0.79	0.18	0.60	1.16
P	0.18	0.49	0.75	0.19	0.58	1.26
S	0.13	0.51	0.72	0.18	0.62	1.14
CaSi	0.15	0.46	0.79	0.17	0.53	1.21
CaP	0.17	0.44	0.66	0.18	0.58	1.62
CaS	0.15	0.46	0.76	0.17	0.58	1.44
CaSiP	0.16	0.49	0.77	0.20	0.56	1.11
CaSiPS	0.17	0.51	0.80	0.20	0.53	1.03
Control	0.16	0.42	0.78	0.19	0.57	1.19
C.D.(.05)	**N.S.**	**0.09**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**0.01**	**0.03**	**0.06**	**0.02**	**0.04**	**0.15**

Table 60 (b) Effect of ameliorants on Na : K ratio of Vyttila-3 at flowering in 2000

Ameliorants	Flowering			Harvest			
	Leaf	Culm	Root	Leaf	Culm	Root	Grain
Ca	0.14	0.70	1.30	0.23	0.74	2.97	0.21
Si	0.13	0.56	1.88	0.16	1.07	2.77	0.33
P	0.16	0.56	1.67	0.17	0.93	2.31	0.43
S	0.14	0.83	1.09	0.23	1.00	3.02	0.26
CaSi	0.13	0.67	1.01	0.36	0.90	3.90	0.23
CaP	0.15	0.62	1.30	0.13	0.96	2.40	0.50
CaS	0.14	0.63	1.31	0.20	0.83	3.10	0.35
CaSiP	0.14	0.76	1.10	0.12	0.78	3.66	0.31
CaSiPS	0.14	0.70	1.39	0.20	0.72	3.18	0.21
Control	0.15	0.47	0.73	0.06	0.69	2.39	0.47
C.D.(.05)	**N.S.**	**0.24**	**N.S.**	**0.16**	**N.S.**	**N.S.**	**N.S.**
S.Em	**0.01**	**0.08**	**0.42**	**0.05**	**0.14**	**0.56**	**0.11**

Table 61 Effect of ameliorants on calcium content (%) of Vyttila-3 in 2000

Ameliorants	Panicle initiation			Harvest			
	Leaf	Culm	Root	Leaf	Culm	Root	Grain
Ca	0.33	0.16	0.21	0.55	0.13	0.18	0.05
Si	0.36	0.15	0.15	0.55	0.11	0.26	0.07
P	0.51	0.17	0.16	0.54	0.12	0.19	0.03
S	0.37	0.11	0.15	0.51	0.10	0.18	0.08
CaSi	0.51	0.17	0.16	0.47	0.11	0.26	0.07
CaP	0.39	0.16	0.28	0.50	0.12	0.21	0.07
CaS	0.44	0.13	0.15	0.49	0.11	0.16	0.04
CaSiP	0.31	0.13	0.13	0.60	0.09	0.29	0.07
CaSiPS	0.36	0.13	0.20	0.52	0.14	0.18	0.08
Control	0.37	0.15	0.21	0.58	0.13	0.18	0.07
C.D.(.05)	**0.13**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**0.04**	**0.02**	**0.04**	**0.05**	**0.02**	**0.04**	**0.01**

Table 62. Effect of ameliorants on magnesium content (%) of Vyttila-3 in 2000

Ameliorants	Panicle initiation			Harvest			
	Leaf	Culm	Root	Leaf	Culm	Root	Grain
Ca	0.42	0.14	0.44	0.22	0.17	0.33	0.12
Si	0.27	0.18	0.41	0.21	0.20	0.18	0.11
P	0.20	0.18	0.37	0.25	0.17	0.33	0.14
S	0.31	0.19	0.33	0.27	0.18	0.28	0.09
CaSi	0.26	0.20	0.36	0.21	0.20	0.22	0.11
CaP	0.27	0.20	0.36	0.29	0.19	0.18	0.11
CaS	0.30	0.19	0.38	0.24	0.18	0.33	0.14
CaSiP	0.20	0.19	0.38	0.21	0.20	0.40	0.11
CaSiPS	0.26	0.18	0.38	0.25	0.18	0.30	0.13
Control	0.27	0.19	0.40	0.23	0.22	0.51	0.13
C.D.(.05)	**0.01**	**N.S.**	**N.S.**	**0.05**	**N.S.**	**0.14**	**N.S.**
S.Em	**0.04**	**0.02**	**0.05**	**0.02**	**0.02**	**0.05**	**0.02**

which was significantly superior to the other ameliorants and control treatment except the combinations of lime with sulphur and phosphorus.

4.3.2.3.7. Magnesium

The magnesium content (Table 62) was significantly higher in leaf at panicle initiation and harvest stages. Lime application resulted in significantly higher leaf magnesium in the former and lime + phosphorus combination in the latter. The root content of magnesium at harvest was significantly higher for the control treatment which was superior to all others except lime + silica + phosphorus combination.

4.3.2.3.8. Sulphur

The ameliorants had a significant effect on the sulphur content (Table 63 a and b) of leaf. Sulphur application either alone or in combination with lime increased the leaf and culm sulphur content at active tillering, panicle initiation, flowering and harvest stages and this increase was significant for leaf sulphur content at panicle initiation and flowering. Though the difference was not significant, the root sulphur content was the highest for the control treatment at active tillering and flowering stages, and the lowest at panicle initiation and harvest stages. The grain sulphur content was the highest for the control treatment. At active tillering, flowering and harvest stages the sulphur content was in the order of root > culm > leaf, while at the panicle initiation stage the leaf sulphur content exceeded the culm sulphur for all the ameliorant treatments. However, the leaf sulphur content of the control treatment was lower than the culm sulphur content at the panicle initiation stage. The control treatment gave lower values for sulphur content of culm and root at harvest than that at the flowering stage, while these values of

Fig. 20. Effect of ameliorants on partitioning of S at maturity - 2000

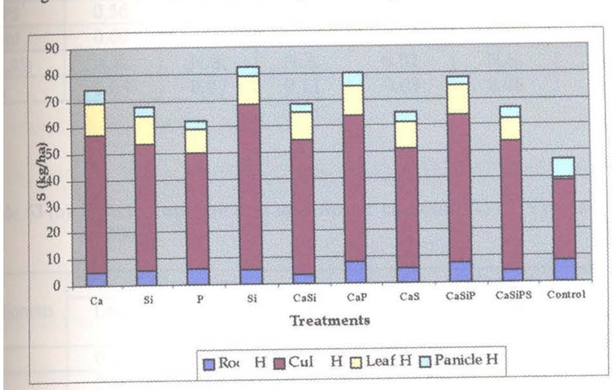


Table 63 (a) Effect of ameliorants on sulphur content (%) of Vyttila-3 in 2000

Ameliorants	Active tillering			Panicle initiation		
	Leaf	Culm	Root	Leaf	Culm	Root
Ca	0.54	0.69	1.26	0.62	0.57	1.27
Si	0.60	0.69	1.11	0.61	0.50	1.24
P	0.61	0.70	1.15	0.73	0.54	1.30
S	0.73	0.74	1.00	0.82	0.66	1.34
CaSi	0.54	0.57	1.26	0.60	0.59	1.22
CaP	0.66	0.70	1.01	0.61	0.57	1.26
CaS	0.68	0.87	1.04	0.72	0.57	1.43
CaSiP	0.59	0.68	1.27	0.62	0.59	1.23
CaSiPS	0.56	0.60	1.13	0.68	0.59	1.44
Control	0.60	0.83	1.34	0.47	0.57	1.19
C.D.(.05)	**N.S.**	**N.S.**	**N.S.**	**0.01**	**N.S.**	**N.S.**
S.Em	**0.05**	**0.07**	**0.11**	**0.03**	**0.06**	**0.08**

Table 63 (b) Effect of ameliorants on sulphur content (%) of Vyttila-3 in 2000

Ameliorants	Flowering			Harvest			
	Leaf	Culm	Root	Leaf	Culm	Root	Grain
Ca	0.29	0.51	1.40	0.45	0.82	1.72	0.17
Si	0.28	0.47	1.31	0.45	0.83	1.85	0.17
P	0.29	0.50	1.43	0.42	0.86	1.69	0.15
S	0.39	0.58	1.36	0.42	0.98	1.76	0.15
CaSi	0.29	0.46	1.26	0.41	0.98	1.84	0.20
CaP	0.27	0.54	1.45	0.50	0.79	1.82	0.17
CaS	0.44	0.60	1.55	0.45	0.79	1.85	0.18
CaSiP	0.30	0.48	1.35	0.41	0.79	1.66	0.14
CaSiPS	0.35	0.54	1.51	0.52	0.74	1.53	0.17
Control	0.29	0.55	1.72	0.49	0.40	1.51	0.21
C.D.(.05)	**0.08**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em	**0.03**	**0.03**	**0.12**	**0.04**	**0.11**	**0.09**	**0.02**

the ameliorant treatments at harvest were higher than their corresponding values at the flowering stage.

The sulphur uptake (Fig. 20) was the highest (82.1 kg ha^{-1}) when sulphur alone was applied. The combination treatment of sulphur with lime or with lime + silica + phosphorus didn't increase the sulphur uptake. The sulphur uptake was the least for the control treatment receiving no ameliorants.

4.3.2.3.9. Silica

The ameliorants had significant effect on the silica content of grain, leaf at flowering and root at flowering and harvest (Table 64). The leaf silica at flowering was more for the silica alone treatment. The combination of silica with other ameliorants didn't increase the leaf silica content at flowering. The root silica was highest for the combination treatment of silica and lime at flowering stage and for the lime + silica + phosphorus + sulphur combination at harvest. The grain silica content was also highest for the above combination.

Grain and root silica content at harvest was the least for the control treatment.

4.3.2.4. Soil chemical characters

The ameliorants brought about significant changes in the soil chemical characters (Table 65). The changes in pH values, though not significant were the least for sulphur (2.8), while the lime treatment gave the highest value of 4.3. The electrical conductivity was significantly higher for the ameliorant treatment combination of lime and sulphur which gave significantly higher EC values than the control and phosphorus treatments. The organic carbon values ranged from 2.05 to 2.57 which didn't carry the effect of the

Table 64. Effect of ameliorants on silica content (%) of Vyttila-3 in 2000

Ameliorants	Flowering			Harvest			
	Leaf	Culm	Root	Leaf	Culm	Root	Grain
Ca	2.92	3.45	14.54	7.83	4.68	16.32	2.20
Si	4.82	3.99	19.82	8.02	6.15	19.07	2.12
P	4.07	4.29	16.67	6.64	6.43	16.51	1.81
S	2.61	4.49	14.27	8.39	5.73	17.55	1.44
CaSi	2.49	4.83	19.83	8.81	5.40	17.03	1.92
CaP	3.91	3.62	19.43	5.86	4.73	11.85	1.95
CaS	3.43	4.70	16.03	6.74	5.41	19.19	1.57
CaSiP	2.20	4.21	19.03	7.69	7.14	18.53	2.15
CaSiPS	3.28	3.48	18.95	8.87	6.00	19.38	2.58
Control	2.57	3.65	12.15	9.70	5.82	12.37	0.96
C.D.(.05)	**1.44**	**N.S.**	**3.64**	**N.S.**	**N.S.**	**4.55**	**0.47**
S.Em	**0.48**	**0.42**	**1.22**	**0.80**	**0.50**	**1.53**	**0.16**

Table 65. Effect of ameliorants on chemical characters of *Pokkali* soils after crop harvest in 2000

Ameliorents	pH	EC (ds m^{-1})	Organic carbon (%)	Available P (kg ha^{-1})	Available K(kg ha^{-1})	Exchangeable K (kg ha^{-1})	Available Na (kg ha^{-1})	Exchangeable Na (kg ha^{-1})
Ca	4.30	2.00	2.14	10.23	1627	761	7018	4106
Si	3.50	2.13	2.27	10.93	1418	717	5376	3315
P	3.70	1.53	2.15	15.57	1254	597	5376	2075
S	2.80	2.43	2.21	14.88	731	223	4928	2747
CaSi	3.70	2.03	2.17	11.07	1135	537	5973	5002
CaP	4.20	1.93	2.05	12.90	1180	911	5824	7586
CaS	3.60	2.53	2.57	10.47	1542	627	5376	5107
CaSiP	4.00	1.93	2.36	13.57	1015	582	5226	2882
CaSiPS	3.40	2.07	2.25	14.50	1194	672	6720	3345
Control	4.00	1.67	2.17	10.77	1254	567	4763	2956
C.D. (0.05)	**N.S.**	**0.61**	**N.S.**	**N.S.**	**N.S.**	**248.32**	**N.S.**	**N.S.**
S.Em	**0.32**	**0.21**	**0.18**	**2.00**	**221.97**	**83.58**	**992.62**	**1222.47**

treatments. The available phosphorus on the other hand was high for the phosphorus and sulphur treatments; the variation, however, was not significant.

The ameliorants had pronounced influence on the available and exchangeable forms of potassium and sodium. Lime application gave the highest values of available potassium and sodium while, the lime-phosphorus combination registered higher exchangeable potassium and sodium. The available and exchangeable potassium were the least for the sulphur treatment, while the least values of available sodium and exchangeable sodium were registered by the control and phosphorus treatments, respectively.

4.3.2.5. Correlation studies

The intensity of inter- relationship among plant nutrient contents that revealed to have significant effect on the grain yield are depicted in Table 66. Phosphorus content in root at harvest and potassium content in culm at panicle initiation and leaf at flowering were the parameters having significant positive correlation with grain yield. Sodium in leaf and root at harvest, sodium:potassium ratio in culm at flowering and in the leaf at harvest, grain silica and available sodium in soil at planting were the negative factors influencing the grain yield. Phosphorus content in root at harvest had significant positive correlation with leaf potassium at flowering and highly significant negative correlation with sodium in leaf and root at harvest, sodium:potassium ratio in culm at flowering and leaf at harvest. It had significant negative relation with grain silica and available soil sodium at planting of rice. Potassium in culm at panicle initiation and in leaf at flowering also had negative effect on the above parameters. On the contrary the inter relationship

Table 66. Inter-relationship among nutrient content and their relation with yield

	PRH	KCPI	KLF	NaLH	NaRH	Na:KCF	Na:KLH	SiG	Av. Na at planting	GY
PRH	1.000	0.338	0.459*	-0.426*	-0.602***	-0.425*	-0.549**	-0.531**	-0.678***	0.561***
KCPI		1.000	0.156	0.249	-0.342	-0.412*	-0.244	-0.136	-0.512***	0.363**
KLF			1.000	-0.437*	-0.331	-0.264	-0.529**	-0.289	-0.329	0.419*
NaLH				1.000	0.167	0.394*	0.902****	0.155	0.391*	-0.549***
NaRH					1.000	0.469**	0.253	0.377*	0.431*	-0.442*
Na:KCF						1.000	0.419	0.223	0.343	-0.396*
Na:KLH							1.000	0.156	0.490**	-0.514***
SiG								1.000	0.289	-0.427*
Av. Na at planting									1.000	-0.374*
GY										1.000

PRH – P in root at harvest
NaLH – Na in leaf at harvest
Na:KLH - Na:K ratio in leaf at harvest
KCPI – K in culm at P.I.
NaRH – Na in root at harvest
SiG - Si in grain
KLF – K in leaf at flowering
Na:KCF - Na:K ratio in culm at flowering
GY - Grain yield

* - Significant at 0.05 level
** - Significant at 0.01 level
*** - Significant at 0.005 level

among nutrient content *viz.*, sodium in leaf at harvest and culm at flowering, their ratio with potassium content in the respective plant parts, grain silica and available soil sodium at planting were positive and most of the co-efficient were highly significant.

4.4 Experiment 4

Plant ideotype suited to rice cum fish culture in *Pokkali* fields

Three rice varieties with varying plant architecture were evaluated for their compatibility with three fish treatments for two successive years. The interactive influence of the rice and fish components of this integrated farming system on their growth and yield, together with the soil, water and environmental parameters were studied and the data are presented in Table 67 to 74.

4.4.1. Growth characters of rice

The varietal difference in the growth characters of rice as expressed by the vegetative tillers and the height was pronounced. During 1999, the interaction effect of rice varieties and fish treatments on the vegetative tillers was significant (Table 67). Cul. 1026 without fish recorded the maximum number of vegetative tillers, which was superior to the same variety combined with male tilapia. However, this interaction effect was not significant during the subsequent year. The varietal difference, however, was significant during both the years and when pooled. Over the years Cul. 1026 was significantly superior to Vyttila-3. The fish treatments, however, didn't have any effect on the vegetative tillers.

The interaction effects of the rice and fish components on height at vegetative and reproductive stages were not significant. The varietal effect on plant height, however,

Table 67. Effect of rice-fish integration on growth characters of rice

Treatments		Vegetative tillers (no. hill^{-1})			Height at vegetative phase (cm)			Height at maturity (cm)		
Fish	Rice	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
Without Fish	Vyttila-3	9.3	9.2	8.3	150.4	141.8	146.1	186.7	159.3	173.0
	Cul. 1026	13.1	13.6	13.4	97.4	83.6	90.5	121.7	126.8	124.3
	Chettivirippu mutant	10.3	11.3	10.8	87.5	82.3	84.9	115.3	112.3	113.8
Male tilapia	Vyttila-3	7.8	7.8	7.8	150.0	140.1	145.1	201.1	180.3	190.7
	Cul. 1026	10.4	10.7	10.6	99.6	100.4	100.0	135.8	133.1	134.5
	Chettivirippu mutant	11.6	12.1	11.9	91.6	87.0	89.3	125.7	128.8	127.3
Etroplus/ Rohu	Vyttila-3	9.5	8.3	8.9	155.2	158.8	157.0	207.7	167.1	187.4
	Cul. 1026	11.5	15.1	13.3	111.9	89.6	100.8	129.7	133.1	131.4
	Chettivirippu mutant	10.4	11.9	11.2	98.9	85.3	92.1	112.7	109.3	111.0
C.D. (0.05)		**2.1**	**N.S.**	**N.S.**	**N.S.**	**12.1**	**N.S.**	**12.3**	**N.S.**	**N.S.**
S.Em		**0.70**	**0.91**	**1.01**	**4.11**	**4.19**	**4.25**	**4.00**	**4.01**	**4.41**
Sub table for rice varieties										
	Vyttila-3	8.2	8.4	8.3	151.8	146.9	152.4	145.4	168.9	182.2
	Cul. 1026	11.7	13.1	12.4	102.9	91.2	97.1	129.1	131.0	130.1
	Chettivirippu mutant	10.8	11.8	11.3	92.4	84.8	88.6	117.9	116.8	117.4
C.D. (0.05)		**1.2**	**1.6**	**1.8**	**8.2**	**9.2**	**9.5**	**9.6**	**6.9**	**7.2**
S.Em		**0.40**	**0.53**	**0.60**	**2.71**	**3.07**	**3.17**	**3.18**	**2.30**	**2.40**
Sub table for fish treatments										
	Without fish	10.3	11.4	10.9	111.7	102.6	107.2	141.5	132.8	137.2
	Male tilapia	9.9	10.2	10.1	121.7	109.2	115.5	154.2	147.4	150.8
	Etroplus/rohu	10.5	11.8	11.2	113.7	111.2	112.5	150.0	136.5	143.3
C.D. (0.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.40**	**0.53**	**0.60**	**2.71**	**3.07**	**3.17**	**3.18**	**2.30**	**2.40**

Table 68. Effect of rice-fish integration on leaf angle and light infiltration to the lower canopy layer of rice

Treatments		Leaf angle at flowering (^{0})			Light intensity (lux)					
					Active tillering			Flowering		
Fish	Rice	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
Without fish	Vyttila-3	33.0	36.0	35.0	1000	1050	1025	975	933	954
	Cul. 1026	14.0	14.0	14.0	1917	1500	1709	1875	1333	1604
	Chettivirippu mutant	5.0	7.0	6.0	1875	1633	1688	1500	1367	1634
Male tilapia	Vyttila-3	36.0	35.0	36.0	917	700	809	925	1017	971
	Cul. 1026	16.0	16.0	16.0	1417	1567	1492	1500	1766	1633
	Chettivirippu mutant	7.0	6.0	7.0	1917	1383	1650	1875	1500	1688
Etroplus/ rohu	Vyttila-3	34.0	36.0	36.0	792	783	788	875	1017	946
	Cul. 1026	15.0	14.0	15.0	1500	1766	1633	1500	1517	1509
	Chettivirippu mutant	9.0	6.0	8.0	1500.	1533	1517	1417	1667	1542
C.D. (0.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**089**	**1.01**	**1.44**	**87.21**	**82.58**	**92.89**	**101.87**	**103.64**	**109.32**
Sub table for rice varieties										
	Vyttila-3	34.0	36.0	35.0	903	844	874	925	989	957
	Cul. 1026	15.0	15.0	15.0	1611	1611	1611	1625	1539	1582
	Chettivirippu mutant	7.0	6.0	7.0	1764	1517	1641	1597	1511	1554
C.D. (0.05)		**2.1**	**2.4**	**2.8**	**161**	**157**	**192**	**185**	**191**	**201**
S.Em		**0.71**	**0.82**	**0.98**	**52.25**	**53.44**	**62.76**	**61.25**	**62.22**	**71.02**
Sub table for fish treatments										
	Without fish	17.0	19.0	18.0	1597	1394	1496	1450	1211	1331
	Male Tilapia	20.0	19.0	20.0	1417	1216	1317	1433	1428	1431
	Etroplus/rohu	19.0	19.0	19.0	1264	1361	1313	1264	1400	1432
C.D. (0.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.71**	**0.82**	**0.98**	**52.25**	**53.44**	**62.76**	**61.25**	**62.22**	**71.02**

was significant. The mean height of the varieties at vegetative phase ranged between 88.6 and 152.4 cm. The maximum height was recorded by Vyttila-3, which was superior to Cul. 1026 and *Chettivirippu* mutant. At maturity also Vyttila-3 recorded the maximum height of 182.2 cm and was taller than the other two varieties. The fish treatments didn't have any effect on the height of rice.

The influence of the plant architecture on the light infiltration to the lower canopy of the rice plant was significant. Though, no interactive effects of the components of this integrated farming system was evident, the rice varieties significantly varied for the light infiltration (Table 68) to the lower canopy. At active tillering stage the mean light intensity varied from 874 to 1641 lux. *Chettivirippu* mutant in its lower canopy had the maximum light intensity and was superior to the tall variety Vyttila-3. At the flowering phase also the varietal effect on the light infiltration was significant and the same trend as that at the active tillering stage was observed. The fish treatments didn't have any significant effect on light infiltration.

The varietal difference on the leaf angle (Table 68) was significantly evident. The leaf angle of Vyttila-3 was significantly higher than the others. The leaf angle of *Chettivirippu* mutant was the least (7^0) denoting the erect leaf character of the variety.

4.4.2. Yield attributes and yield of rice

The varieties significantly differed in the yield attributes (Table 69 a and b) of rice. The rice variety, Cul. 1026 registered significantly more productive tillers hill^{-1} during both the years. The pooled mean value was also the highest for Cul. 1026, which

Table 69 (a) Effect of rice-fish integration on yield attributes of rice (a)Panicles hill^{-1}, panicle length and filled grains panicle^{-1}

Treatments		Panicles (no. hill^{-1})			Panicle length (cm)			Filled grains panicle^{-1} (no. panicle^{-1})		
Fish	Rice	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
Without fish	Vyttila-3	4.6	7.3	6.0	26.5	26.2	26.4	73.3	84.5	78.9
	Cul. 1026	8.2	11.9	10.1	23.8	25.2	24.5	69.1	84.5	76.8
	Chettivirippu mutant	7.3	7.4	7.4	19.6	20.0	19.8	81.6	81.0	81.3
Male tilapia	Vyttila-3	4.8	8.4	6.6	26.8	27.0	26.9	72.2	92.1	82.2
	Cul. 1026	8.6	9.9	9.3	24.7	25.1	24.9	60.1	71.5	65.8
	Chettivirippu mutant	6.9	6.2	6.6	20.1	19.5	19.8	80.2	101.9	91.1
Etroplus/ rohu	Vyttila-3	4.7	8.6	6.7	27.0	28.7	27.9	75.2	84.7	80.0
	Cul. 1026	7.8	11.1	10.0	25.2	24.4	24.8	63.7	65.3	73.9
	Chettivirippu mutant	7.1	6.6	6.9	19.8	18.1	19.0	63.1	84.1	83.6
C.D. (0.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.81**	**0.71**	**1.17**	**0.85**	**0.74**	**0.81**	**0.61**	**7.88**	**7.35**
Sub table for rice varieties										
	Vyttila-3	4.7	8.1	6.4	26.8	27.3	27.1	73.6	97.7	85.7
	Cul. 1026	8.5	11.0	9.8	24.6	24.9	24.8	69.8	90.4	80.1
	Chettivirippu mutant	7.1	6.7	6.9	19.8	19.2	19.5	81.6	99.4	90.5
C.D. (0.05)		**1.6**	**1.2**	**2.1**	**1.6**	**1.3**	**1.6**	**1.09**	**N.S.**	**N.S.**
S.Em		**0.48**	**0.42**	**0.69**	**0.52**	**0.43**	**0.52**	**0.36**	**4.55**	**4.32**
Sub table for fish treatments										
	Without fish	6.7	8.9	7.8	23.3	23.8	23.6	74.7	83.4	79.1
	Male Tilapia	6.8	8.2	7.5	23.9	23.9	23.9	70.8	88.5	79.7
	Etroplus/rohu	6.9	8.8	7.9	24.0	23.8	23.9	74.0	78.0	76.0
C.D. (0.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.48**	**0.42**	**0.69**	**0.52**	**0.43**	**0.52**	**0.36**	**4.55**	**4.32**

Table 69 (b) Effect of rice-fish integration on yield attributes of rice (b) chaff per cent and thousand grain weight

Treatments		Chaff (%)			Thousand grain weight (g)		
Fish	Rice	1999	2000	Mean	1999	2000	Mean
Without fish	Vyttila-3	11.2	7.7	9.5	35.5	35.7	35.6
	Cul. 1026	26.7	21.9	24.3	28.9	28.3	28.6
	Chettivirippu mutant	9.2	7.9	8.6	25.8	26.5	26.2
Male tilapia	Vyttila-3	13.1	7.7	10.4	35.9	36.3	36.1
	Cul. 1026	25.2	19.4	22.3	28.6	29.4	29.0
	Chettivirippu mutant	8.3	6.6	7.5	25.1	25.0	25.1
Etroplus/ rohu	Vyttila-3	12.8	9.7	11.3	36.1	34.7	35.4
	Cul. 1026	26.4	24.7	25.6	28.4	29.0	28.7
	Chettivirippu mutant	8.5	5.7	7.1	25.4	25.7	25.6
C.D. (0.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**2.11**	**3.22**	**2.52**	**0.33**	**0.49**	**0.40**
Sub table for rice varieties							
	Vyttila-3	12.4	8.4	10.4	35.8	35.5	35.7
	Cul. 1026	26.1	22.0	24.1	28.6	28.9	28.8
	Chettivirippu mutant	8.7	6.7	7.7	25.4	25.7	25.6
C.D. (0.05)		**4.2**	**5.6**	**4.9**	**1.1**	**0.9**	**1.2**
S.Em		**1.48**	**1.82**	**1.61**	**0.23**	**0.28**	**0.23**
Sub table for fish treatments							
	Without fish	15.7	12.5	14.1	30.1	30.2	30.2
	Male tilapia	15.5	11.2	13.4	29.9	30.2	30.1
	Etroplus/rohu	15.9	13.4	14.7	29.9	29.7	29.8
C.D. (0.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**1.48**	**1.82**	**1.61**	**0.23**	**0.28**	**0.23**

was superior to Vyttila-3. The interaction effect as well as the effect due to the fish treatment was not significant.

The varietal difference on the panicle length was also significant. The highest panicle length was noticed for Vyttila-3, which was superior to the others during both the years. The interaction effect of the two components and the effect of the fish treatments were not significant. The number of filled grains panicle^{-1} was also not influenced either by the fish component or by its combinations with the rice varieties. The rice varieties, however, differed significantly during the first year, while the difference was not significant during the next year. Though the pooled mean also was not significant the highest filled grain panicle^{-1} was recorded by the *Chettivirippu* mutant.

The varietal difference on chaff per cent was also significant during both the years. Cul. 1026 had the maximum chaff per cent which was distinctly more than the other two varieties. *Chettivirippu* mutant had the least chaff per cent during both the years. Vyttila-3 was at par with the *Chettivirippu* mutant. The thousand- grain weight, however, was significantly more for Vyttila-3 followed by Cul. 1026 during both the years. *Chettivirippu* mutant had the least thousand- grain weight. Neither the fish treatments nor its interaction with the rice varieties had significant effect on the thousand-grain weight.

The data on the effect of the rice fish integration on yield of rice (Table 70) revealed no significant influence of the fish treatments. The interaction effect of the fish treatments with the rice varieties was also not significant. The rice varieties, however, differed significantly with respect to the grain yield. During 1999, *Chettivirippu* mutant

Table 70. Effect of rice-fish integration on yield of rice

Treatments		Grain (kg ha^{-1})			Straw (kg ha^{-1})			Biomass (kg ha^{-1})			Grain : straw ratio		
Fish	Rice	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
Without fish	Vyttila-3	3061	1697	2379	7891	2554	5223	10956	4252	7604	0.39	0.67	0.53
	Cul. 1026	3621	2645	3133	5139	3445	4292	8670	6091	7381	0.72	0.82	0.77
	Chettivirippu mutant	4461	2509	3485	5124	2775	3950	9585	5285	7435	0.87	0.91	0.89
Male Tilapia	Vyttila-3	3045	2006	2526	7221	2624	4923	10267	4630	7449	0.43	0.77	0.60
	Cul. 1026	3591	3115	3353	4909	4018	4464	8500	7133	7817	0.74	0.78	0.76
	Chettivirippu mutant	4409	2594	3502	5045	3048	4047	9455	5642	7549	0.88	0.86	0.87
Etroplus/ Rohu	Vyttila-3	3061	1733	2397	6445	2390	4418	9506	4124	6815	0.44	0.74	0.59
	Cul. 1026	3967	3430	3699	4124	4709	4417	8182	9139	8161	0.80	0.73	0.77
	Chettivirippu mutant	4318	2639	3479	5476	2227	3852	9794	4867	7331	0.85	1.19	1.02
C.D. (0.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**137.27**	**129.42**	**142.63**	**418.05**	**304.03**	**421.32**	**452.76**	**378.19**	**422.11**	**0.04**	**0.07**	**0.08**
Sub table for rice varieties													
	Vyttila-3	3056	1812	2434	7186	2523	4855	10241	4335	7258	0.44	0.73	0.59
	Cul. 1026	3726	3063	3395	4724	4057	4391	8451	7121	7756	0.80	0.78	0.79
	Chettivirippu mutant	4396	2580	3488	5215	2684	3950	9611	5265	7438	0.85	0.99	0.92
C.D. (0.05)		**238**	**224**	**N.S.**	**724**	**526**	**N.S.**	**1357**	**655**	**N.S.**	**0.13**	**0.13**	**0.15**
S.Em		**79.25**	**74.82**	**93.26**	**241.36**	**175.53**	**256.72**	**261.40**	**218.30**	**316.76**	**0.02**	**0.04**	**0.04**
Sub table for fish treatments													
	Without fish	3714	2283	2999	6021	2925	4473	9735	5209	7472	0.66	0.80	0.73
	Male Tilapia	3682	2572	3127	5725	3230	4478	9407	5802	7605	0.68	0.80	0.74
	Etroplus/Rohu	3782	2601	3192	5379	3109	4244	9161	5710	7436	0.74	0.88	0.81
C.D. (0.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**79.25**	**74.82**	**93.26**	**241.36**	**175.53**	**256.72**	**261.40**	**218.30**	**316.76**	**0.02**	**0.04**	**0.04**

recorded the highest grain yield of 4396 kg ha^{-1} which was significantly superior to the other two varieties. During the second year, Cul. 1026 gave the maximum grain yield of 3063 kg ha^{-1} which was superior to both *Chettivirippu* mutant and Vyttila-3. The pooled mean, however, was more for the *Chettivirippu* mutant.

The influence of the fish treatments and its interaction with the rice varieties was not significant on the straw yield of rice. However, the varietal effect on straw yield was significantly evident during both the years. Vyttila-3 was superior to the others with the maximum straw yield of 7186 kg ha^{-1} followed by *Chettivirippu* mutant with 5215 kg ha^{-1}. During the subsequent year, Cul. 1026 produced the highest straw yield of 4057 kg ha^{-1} and was superior to the others. The pooled mean was the highest for Vyttila-3 (4855 kg ha^{-1}) followed by Cul. 1026 (4391 kg ha^{-1}).

The biomass yield also was not influenced either by the fish treatments or by its combinations with the rice varieties. The rice varieties significantly varied the biomass yield. During the first year, Vyttila-3 (10241 kg ha^{-1}) was significantly superior to *Chettivirippu* mutant (8451 kg ha^{-1}) but was at par with Cul. 1026 (9611 kg ha^{-1}). During 2000, Cul. 1026 recorded the highest biomass of 7121 kg ha^{-1} followed by *Chettivirippu* mutant with 5265 kg ha^{-1}. Vyttila-3 registered the least biomass yield of 4335 kg ha^{-1}. The pooled mean didn't reveal any significant difference among the varieties. Cul.1026, however, registered the highest biomass yield.

The interaction effect of the fish treatments and rice varieties and the influence of the fish treatments were not significant with respect to the grain : straw ratio also. The effect of the varieties on this character, however, was quite significant. The grain : straw ratio during both 1999 and 2000 and also for the pooled mean, were the highest for *Chettivirippu* mutant followed by Cul. 1026. The ratio for Vyttila-3 during 1999 was quite low, while during 2000 it was considerably high.

4.4.3. Yield characters and yield of fish

The yield characters and yield of fish as influenced by the rice fish integration are presented in Table 71. Neither the direct effect of the rice varieties nor the interaction effects of the rice varieties with the fish treatments were significant for the yield and yield characters during both the years of the study.

The survival of fish significantly varied with the fish species. During 1999 the male tilapia registered 36.2 per cent survival, while etroplus registered 0.0 per cent survival. Though the etroplus was replaced with rohu during 2000, the survival was only 16 per cent, while the male tilapia maintained 38.9 per cent survival. The pooled mean for male tilapia was 37.6 per cent.

The mean length of male tilapia at harvest was 20.4 cm during 1999 and 21.3 cm during 2000. During 2000 rohu at harvest had a mean length of 10.7 cm. The mean weight for male tilapia was 140 g during 1999 and 138.2 g during 2000 with a pooled mean weight of 139.1 g. The rohu during 2000 registered a mean weight of 79.7 g.

The rice varieties and their interactive influence with the fish treatments had no significant effect on the yield of fish. During 1999 all male tilapia treatment registered a yield of 209.1 kg ha^{-1} while etroplus failed to give any yield. During the second year also the all male population of male tilapia recorded the highest yield of 224.2 kg ha^{-1} while

Table 71. Effect of rice varieties on survival, yield and yield characters of fish

Treatments		Survival (%)			Fish yield (kg ha^{-1})			Mean length (cm)			Mean weight (g)		
Fish	Rice	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean	1999	2000	Mean
Male Tilapia	Vyttila-3	33.9	42.7	38.3	200.0	215.2	207.6	20.8	20.3	20.6	138.0	135.7	136.8
	Cul. 1026	37.0	38.9	38.0	230.3	212.1	221.2	19.7	22.0	20.9	133.0	138.5	135.8
	Chettivirippu mutant	37.6	35.1	36.4	197.0	245.5	221.3	20.7	21.4	21.1	149.0	140.5	144.8
Etroplus/ Rohu	Vyttila-3	0.0	11.5	5.8	0.0	18.2	9.1	0.0	10.4	5.2	0.0	31.7	15.9
	Cul. 1026	0.0	19.4	9.7	0.0	29.7	14.9	0.0	10.9	5.5	0.0	31.5	15.9
	Chettivirippu mutant	0.0	17.0	8.5	0.0	28.2	14.1	0.0	10.7	5.4	0.0	31.7	15.9
C.D. (0.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**1.13**	**1.88**	**2.01**	**10.18**	**10.81**	**11.21**	**0.55**	**0.37**	**042**	**5.57**	**7.49**	**8.60**
Sub table for fish treatments													
	Without fish	--	--	--	--	--	--	--	--	--	--	--	--
	Male Tilapia	36.2	38.9	37.6	209.1	224.2	216.7	20.4	21.3	20.9	140.0	138.2	139.1
	Etroplus/Rohu	0.0	16.0	8.0	0.0	25.4	12.7	0.0	10.7	5.4	0.0	79.7	39.9
C.D. (0.05)		**2.5**	**3.2**	**3.8**	**18.2**	**19.3**	**21.8**	**0.8**	**0.5**	**0.6**	**12.4**	**16.2**	**16.8**
S.Em		**0.80**	**1.10**	**1.30**	**6.21**	**6.20**	**7.10**	**0.30**	**0.25**	**0.25**	**4.30**	**4.60**	**5.10**

the yield from rohu was only 25.4 kg ha^{-1}. The pooled mean yield for male tilapia was 216.7 kg ha^{-1}.

4.4.5. Water quality parameters

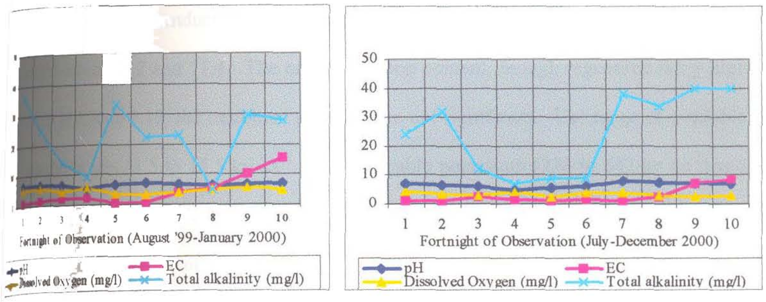
The water quality parameters of the field water during the five months period from the stocking of the fish fingerlings are presented in Fig. 21. The pH varied from 5.20 to 7.05 during 1999 and between 5.50 and 7.70 during 2000, and this pH range was conducive for fish growth. The electrical conductivity was below 4 ds m^{-1} up to November and rose to 15.3 ds m^{-1} in the first week of January during the first year. During the second year the peak EC registered was 8.5 ds m^{-1} during the last week of December. Similarly initial salinity was less during both the years and it rose to 12.2 ppt during 1999, but remained below 1 ppt during 2000.

The dissolved oxygen levels during the rice fish integration period were satisfactory. It ranged between 3 and 5.89 mg l^{-1} in 1999 and from 2.4 to 4 mg l^{-1} in 2000. The total alkalinity levels which indirectly refer to the carbon dioxide content and hence photosynthesis and phytoplankton growth had significant variation between the years of study. During 1999 the alkalinity ranged between 4.8 and 33 mg l^{-1}, while the range was 7.00 to 40.00 mg l^{-1} during 2000.

Dissolved ammonia that is detrimental to fish growth at high levels, coupled with low levels of oxygen was more or less under tolerable levels during both the years. However, during 1999 the dissolved ammonia level rose to 2.3 ppm during the post harvest rice phase. During 2000 the dissolved ammonia levels kept a range of 0.03 to 0.74 during the rice-fish dual culture.

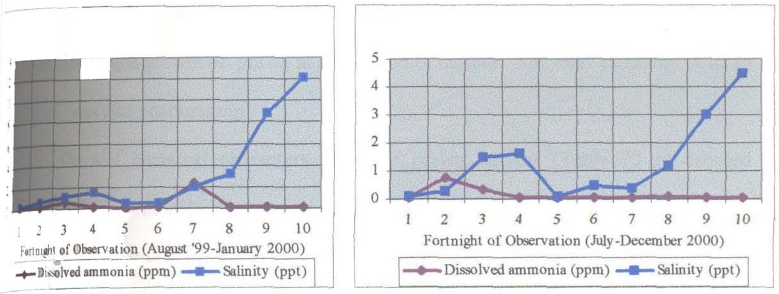
21 Quality parameters of field water of rice-fish culture experiment

1999-00 2000-01



22 Salinity and dissolved ammonia profile of field water of rice –fish culture experiment

1999-00 2000-01



4.4.6. Soil chemical characters

The rice fish integration didn't result in any significant variation in soil chemical characters (Table 72) after the harvest of rice. The pH of the soil ranged between 3.4 and 4.3. The electrical conductivity values also did not significantly vary. The EC values ranged between 7.2 and 11.4. The organic carbon content, though registered fairly high values of 2.36 to 3.19, the treatment effects were not significant. The range of available phosphorus was 11.5 to 15.5 kg ha^{-1}. The available potassium (224 to 582 kg ha^{-1}) and available sodium (2867 to 4032 kg ha^{-1}) were high irrespective of the treatments.

4.4.7. Selective culture of Tiger prawn

During the year 2000, after the harvest of fish, the fields were utilised for the culture of tiger prawn (*Penaeus monodon*) to assess the returns from the integrated farming with rice-fish followed by selective culture of prawn. The water quality parameters, growth parameters and yield of prawn are presented in Tables 73 (a) and (b). The field water pH, electrical conductivity and salinity were conducive for the growth and development of tiger prawn. The dissolved ammonia did not rise to levels detrimental for the growth of prawn at any period of culture. The total alkalinity of 32 to 48 mg l^{-1} was also encouraging.

The soil chemical characters after the prawn harvest (Table 73 c) denoted desirable changes in pH, organic carbon, available P and available K. However, the electrical conductivity and the available sodium registered considerable increase compared to the soil characters after the fish harvest.

Table 72. Effect of rice-fish integration on soil chemical characters during post fish harvest stage of 2000

Treatments		Soil chemical characters					
Fish	Rice	pH	EC (ds m^{-1})	Organic carbon (%)	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Available Na (kg ha^{-1})
Without fish	Vyttila-3	4.3	7.9	2.6	11.7	582	4032
	Cul. 1026	3.5	9.1	2.4	15.1	224	3360
	Chettivirippu mutant	3.6	8.2	2.9	12.8	314	3315
Male tilapia	Vyttila-3	3.5	7.4	2.4	11.5	314	2867
	Cul. 1026	3.5	7.7	3.2	11.7	479	3360
	Chettivirippu mutant	3.4	10.7	2.8	14.1	434	3449
Etroplus/ rohu	Vyttila-3	4.0	7.2	3.0	15.5	582	3064
	Cul. 1026	3.5	8.0	3.2	12.9	524	3225
	Chettivirippu mutant	3.4	11.4	3.1	13.1	579	3270
C.D. (0.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S**	**N.S.**
S.Em		**0.04**	**0.08**	**0.03**	**0.18**	**43.70**	**292.00**
Sub table for rice varieties							
	Vyttila-3	3.9	7.5	2.7	12.9	493	3321
	Cul. 1026	3.5	8.3	2.9	13.2	409	3315
	Chettivirippu mutant	3.5	10.1	2.9	13.3	442	3345
C.D. (0.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.03**	**0.06**	**0.02**	**0.12**	**73.70**	**498.00**
Sub table for fish treatments							
	Without fish	3.8	8.4	2.6	13.2	373	3569
	Male tilapia	3.5	8.6	2.8	12.4	409	3225
	Etroplus/rohu	3.6	8.9	3.6	13.8	562	3186
C.D. (0.05)		**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**	**N.S.**
S.Em		**0.03**	**0.06**	**0.02**	**0.12**	**73.70**	**498.00**

Table 73 (a) Water quality parameters of the selective culture of Tiger prawn in *Pokkali* fields during summer 2001

Quality parameters	Range	Mean
Field water pH	7 – 9	7.10
Dissolved oxygen (mg l^{-1})	5 – 8	5.30
Dissolved ammonia (ppm)	0.1 – 0.61	0.29
Total alkalinity (mg l^{-1})	32.0 – 48.0	38.60
Salinity (ppt)	4.1 - 12.2	7.90
Electrical conductivity (ds m^{-1})	8.6 – 15.8	11.70

Table 73 (b) Growth parameters of Tiger prawn from selective culture in *Pokkali* fields during summer 2001

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

Table 73 (c) Soil chemical characters after prawn harvest in *Pokkali* fields during summer 2001

Soil chemical characters	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

Even without any supplementary feeding, the prawn achieved a growth rate of 15.9 g in 50 days and 20 g in 74 days. The survival per cent of prawn was 49 at harvest. The yield finally obtained was 425 kg ha^{-1}.

4.4.8. Economic analysis of rice-fish-prawn integrated farming system

The economics of rice cultivation in *Pokkali* fields when integrated with fish and prawn is presented in Table 74. When rice was cultivated alone, the variety decided the net returns and the benefit : cost ratio. The traditional tall variety Vyttila-3 gave the minimum net returns and B : C ratio. The high yielding genotypes Cul. 1026 and *Chettivirippu* mutant gave considerably higher B:C ratio of 1.93 and 1.98, respectively. The net returns and B:C ratio decreased when rohu was integrated with rice, while the integration of male tilapia with rice increased the net returns and B:C ratio. The net return was the highest (Rs.48,390/-) when tiger prawn was included in this integrated farming system. The B:C ratio was 1.98 for the rice alone treatment with *Chettivirippu* mutant and 1.93 with Cul. 1026. Rice-fish-prawn integration also resulted a higher B:C ratio of 2.03. The rice-fish/prawn integration also generated additional employment. The *Pokkali* rice cultivation required 83 mandays, while integration of fish and prawn enhanced the manpower requirement to 113 and 149 days ha^{-1}, respectively. The latter integration thus generated 70 per cent more manpower than the traditional single crop of *Pokkali* rice.

Table 74. Economic analysis of rice-fish-prawn integration in *Pokkali* fields

Farming system	Cultivation expenditure (Rs. ha^{-1})				Returns (Rs ha^{-1})				Net returns (Rs ha^{-1})	Benefit : cost ratio	Additional employment generated (mandays ha^{-1})
	Main crop	Subsidiary crop			Main crop	Subsidiary crop					
	Rice	Fish	Prawn	Total	Rice	Fish	Prawn	Total			
Rice alone											
Vyttila-3	11450	--	--	11450	15821	--	--	15821	4371	1.38	83
Cul. 1026	11450	--	--	11450	22068	--	--	22068	10618	1.93	83
Chettivirippu mutant	11450	--	--	11450	22672	--	--	22672	11222	1.98	83
Rice-fish dual culture											
Rice + Rohu	11450	6250	--	17700	22672	1016	--	23688	5988	1.34	113
Rice + Male Tilapia	11450	6250	--	17700	22672	8668	--	31346	13646	1.77	113
Rice-fish-prawn integration											
Rice + Tilapia followed by prawn	11450	6250	29000	46700	22672	8668	63750	95090	48390	2.03	149

Rice @ Rs. 6500 t^{-1} Fish @ Rs.40 kg^{-1} Prawn @ Rs.150 kg^{-1}

Labour @ Rs.125 manday^{-1}

DISCUSSION

5. DISCUSSION

Pokkali agro-ecosystem has two distinct phases based primarily on the salinity of the field water. The low saline phase corresponds to the monsoon season from June to November and the high saline phase to the post-monsoon period from December to May. Though the salinity is less during the low saline phase its dilution depends on the fresh water discharge from the upstream side. The tidal water which has its realm on the *Pokkali* fields, ingress and egress twice a day and during these process the underlying soils develop the characters brought to them by the tides. The tidal water during low saline phase is a mix of seawater and fresh water and the chemical characters of the tidal water is governed by the proportion of this mix. A break of rain or a dry spell during the low saline phase increases the proportion of seawater and thus the salinity of both the tidal water and the underlying soils are increased. In addition to salts that may have deleterious effects on plant growth, the tidal water contains plant nutrients and their content are governed by the proportion of the seawater – fresh water mix. Thus the *Pokkali* soils must have an imprint of the tidal water quality. The results obtained from these experiments are therefore discussed on this background.

The variations brought about to the soil, water and environment parameters of *Pokkali* fields and the growth and yield attributes of rice, fish and prawn components of the integrated farming system practised in this tract were systematically studied for two years, in four experiments and the results are discussed one by one.

Plate–5. Luxuriant Pokkali rice during the low saline phase

Plate-6. Prawn culture in Pokkali fields during the high saline phase

Experiment I

5.1. Response of rice to applied nitrogen in tidal and non-tidal situations

The role of tides on regulation of soil chemical characters of *Pokkali* soil and its effect on the yield and yield attributes of *Pokkali* rice was studied in a pot culture experiment and the results are discussed below.

Soil characters

The tidal action had significant effect on the soil pH and available potassium content. Tidal action that occurs twice a day regularly washes the underlying soils and removes the leachates and thus increases the pH of the soil. Thampatti and Padmakumar (1999) reported low soil pH values consequent to the curtailed tidal waters in kari soils of lower *Kuttanad* in Kerala. The tidal waters are rich in potassium, calcium, magnesium and other plant nutrients like phosphates and nitrates. Hence the increase in available potassium, phosphorus and organic carbon is quite natural. Padmakumar (2002) reported higher concentration of plant nutrients like phosphates and nitrates in estuarine locations than the riverine zones.

Nitrogen application up to 40 kg ha^{-1} significantly enhanced the pH and the subsequent incremental doses decreased the soil pH. The soil pH depends on acidification process such as nitrification, carbon-dioxide release *viz.*, plant and microbial respiration, mineralisation of organic matter and disassociation of organic acids in soil solution (Marykutty, 1986). The exact reason responsible for the change in soil pH to applied inputs can not be explained with the available data due to the complexity of the system and hence require further investigation.

The grain yield between the tidal and non-tidal regimes didn't reveal any significant difference. However, the straw and productive tillers were more under the tidal situation. This implies that the tidal situation favoured the vegetative growth of the rice plant consequent to the favourable changes in the chemical characters like increased pH, higher organic carbon, available phosphorus and available potassium. The increased vegetative growth under tidal situation helps to dilute the salt content within the plant system. While analysing the various salt tolerance mechanisms in rice, Yeo and Flowers (1986) attributed the lower shoot sodium content in the salt tolerant *Pokkali* genotype to the diluting effect by the rapid vegetative growth. The higher vegetative growth neutralises the salinity, which, however, adversely affects the yield attributes. However, if the tidal action could be regulated during the reproductive phase, the ill-effects of the higher salt content could be alleviated and an yield proportionate to the vegetative growth would be attained.

Yield attributes and yield

The content of nutrients in the plant parts differed significantly between the tidal regimes. The nitrogen content in straw under tidal regime was more than twice that of the non-tidal regime, which indicated that there was continous absorption of nitrogen even at the ripening phase under the tidal situation. The nitrogen content in the grain under tidal regime was almost three times as that of the non-tidal regime, implying the continued utilization of carbohydrate for protein synthesis and its accumulation in grain. The phosphorus content in straw didn't reveal any significant difference between the tidal regimes. However, the grain content of phosphorus under the tidal regime was 34.6 per cent more than that under the non-tidal situation. The increased grain phosphorus content may be due to the higher content of phosphorus in the tidal water. However, the 45.9 per cent increase in the content of potassium in the straw under the tidal situation didn't cause any proportionate increase in its grain content. This may be due to the functional difference of these nutrients in which the nitrogen and phosphorus has structural role, while the main function of potassium is as a facilitator. The increased content of nutrients under the tidal situation may be due to their continued presence in the tidal waters. Padmakumar *et al.* (2002) reported higher concentration of plant nutrients in the estuarine locations. The presence of nodal roots of rice plants under the tidal situation was another indication of absorption of nutrients from the tidal water.

The pot culture experiment thus indicated that the tidal action favoured vegetative growth of the rice plant. Incremental doses of nitrogen up to 80 kg ha^{-1} failed to give biomass yield equivalent to the biomass contributed by the tidal action. Tidal action though favoured vegetative growth, increased the plant nutrient content and productive tillers, failed to optimize the other yield attributes *viz.*, chaff per cent and hundred grain weight, which is attributed to the continued absorption of nutrients and consequent extension of vegetative growth resulting in protracted flowering. A timely curtailing of tidal waters would have arrested the vegetative growth and caused full fledged switching over to the reproductive phase and benefited the grain yield.

Experiment II

5.2. Tidal effect on *Pokkali* soils and performance of rice

The performance of the traditional tall saline tolerant rice variety Vyttila-3 was compared to the new generation high yielding semi-tall varieties under tidal and non-tidal situation for their biomass production, yield potential and content and uptake of important plant nutrients including sodium during two successive years from June 1999. The results obtained are discussed under the following heads.

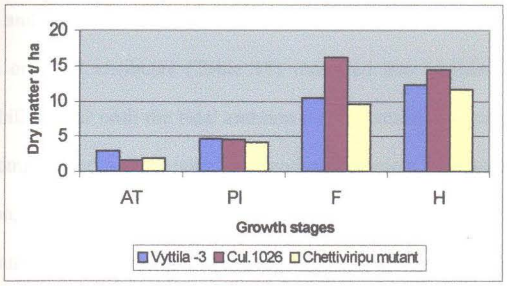
Growth characters

Comparison of the growth of the rice varieties under the tidal and non-tidal regimes revealed that the growth was more under the tidal regime rather than the non-tidal, in terms of height (Table 11) as well as tiller number (Table 13). The height at the active tillering was more than 50 cm for all the varieties. This increased height at the active tillering phase is necessary to withstand the possible flood during the initial stage of development. Among the varieties Vyttila-3 had the maximum height at all the stages. The first and second internodes had a significant role in increasing the height of the plants, especially under the tidal regime (Table 12 and Fig. 5). The tendency of the plant to elongate internodes with the rising tides, may be the reason for the taller plants under the tidal situation.

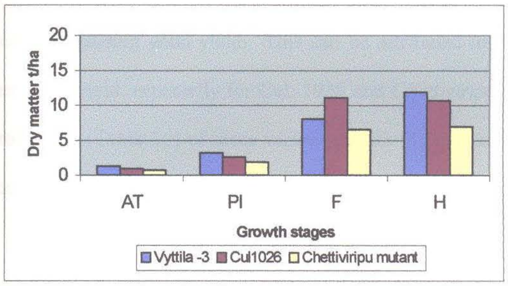
The vegetative tillers at the initial stages up to the panicle initiation were higher than that at the flowering and harvest stages. A heavy decline in vegetative tiller number was observed at the flowering and harvest stages which may be similar to the tiller decline reported by Musthafa (1995), where he found heavy declines of non productive tillers, to shed the excess iron accumulated by the plant. The number of functional leaves and the leaf area index were more under the tidal situation than under non-tidal situation and the maximum values of both the functional leaves and the leaf area index were at the flowering stage, beyond which both declined sharply. The drastic reduction in the leaf area is due to the shedding of older leaves. Yeo and Flowers (1984) reported higher content of sodium in older leaves of rice and identified shedding of them as a mechanism of salt tolerance.

The root, culm and leaf dry weight were more under the tidal regime than the non-tidal situation. A higher biomass production under the tidal regime is necessary to dilute the higher content of sodium noticed in rice grown under the tidal wetlands. Vidya (2003) observed higher biomass production in weeds grown in the coastal saline soils compared to their counter parts in the normal rice ecosystem. The biomass production in the present studies was the highest for Vyttila-3 during the vegetative phase. The higher biomass production, especially during the seedling establishment stage is a salinity diluting mechanism of *Pokkali* genotypes (Tomy *et al.*, 1984). The most important feature of the biomass production was the steep decline in leaf biomass in between the flowering and harvest stages. This reduction in leaf biomass was reflected on the leaf area index as well as on the number of functional leaves. A decline in total biomass after flowering was observed for Cul. 1026 under both the tidal regimes (Table 15 b). It can also be seen that (Table 16 and Fig. 23) under non-tidal situation the conversion of dry matter to the panicles is more or less the same for all the varieties while in tidal condition Cul. 1026 and Vyttila-3, it was considerably less than that in the *Chettivirippu* ig 23. Effect of tidal regimes on dry matter production of rice varieties in 2000

Tidal



Non- tidal



AT-Active tillering, PI –Panicle initiation, F-Flowering, H-Harvest mutant. In other words, these two varieties responded differentially to the tidal regimes and have physiological adaptations to thrive under the tidal situation, compared to *Chettivirippu* mutant.

Yield attributes and yield

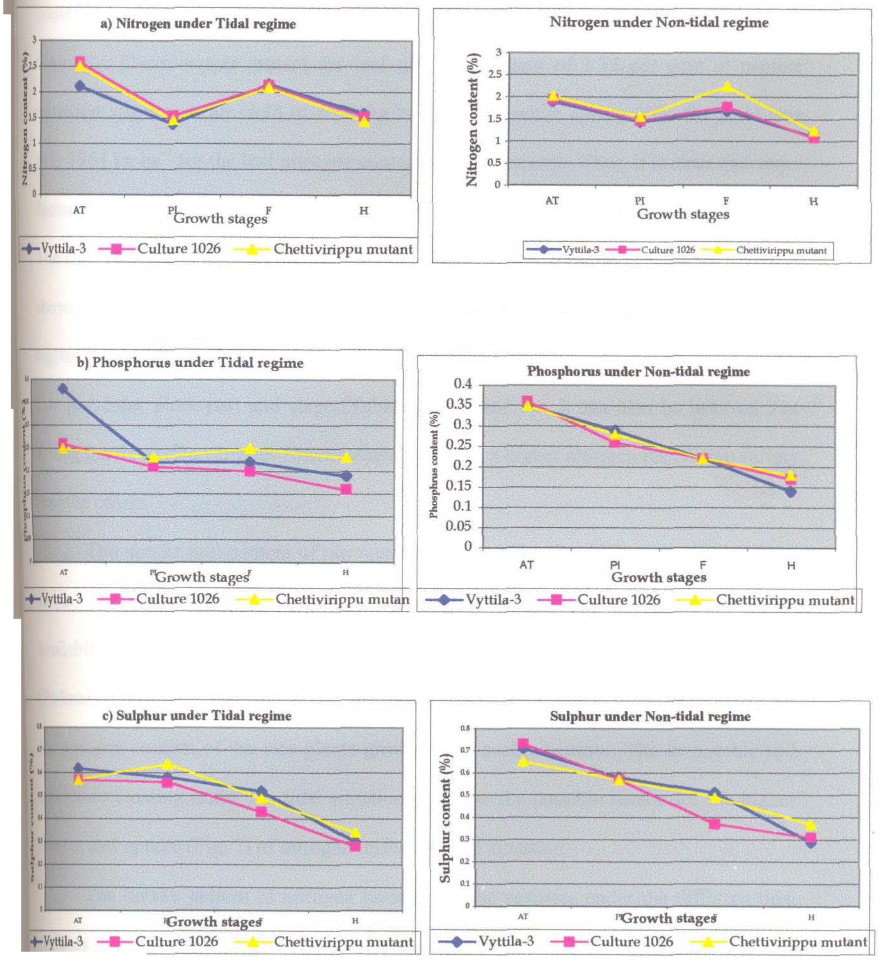
The data on yield attributes (Table 17) indicated that Vyttila-3 had the least panicle number hill^{-1} under both the tidal and non-tidal situation. But this draw back of Vyttila-3 was compensated by its higher thousand grain weight. Between the tidal and non-tidal situation, the varieties had almost similar yield attributes during 1999. During 2000, the yield attributes were not ideal under the non-tidal situation, where the panicle number hill^{-1} was less for both Cul. 1026 and *Chettivirippu* mutant. The number of grains panicle^{-1} under non-tidal regime was less for Vyttila-3 and *Chettivirippu* mutant than under the tidal situation. The chaff per cent for Vyttila-3 was more under non-tidal situation. Thus, it can be seen that the yield attributes under the non-tidal situation during 2000 was not ideal for realising good yield. This can be attributed to the insufficient biomass for higher grain yield, especially for Cul. 1026 and *Chettivirippu* mutant. The lesser biomass production (Table 16) of these varieties under the non-tidal regime must be due to unfavourable soil factors which is discussed in the section on soil chemical characters.

The grain yield showed significant variation under both the tidal regimes during 2000, while significant difference was confined only to the tidal situation during 1999. When the first year yields are considered *Chettivirippu* mutant recorded the highest yield of 5440 kg ha^{-1} which was at par with the 4903 kg ha^{-1} of Cul. 1026. Under the non-tidal situation, though there was no significant difference in yield among the varieties, the highest yield was recorded by Cul. 1026. However, during the second year, under both the tidal situations, Cul. 1026 recorded the highest grain yield. Considering the over all performance of biomass production, leaf area index, retention of more functional leaves and stability of the variety, Cul. 1026 is a better rice variety suited to the tidal wetlands compared to Vyttila-3 and *Chettivirippu* mutant The comparative yield trial at the Rice Research Station, Vyttila also confirms the superiority of Cul.1026 (KAU, 2003).

Elemental composition

The nitrogen content and uptake differed significantly between the tidal regimes and among the varieties. Irrespective of the stage of growth, Vyttila-3 had higher content of nitrogen than the other varieties. The nitrogen content at flowering in the culm during 2000 was less than that during 1999. The culm nitrogen at harvest during 2000 was also less than the grain content of nitrogen. Except for this aberration, the nitrogen content was fairly high in all the plant parts. The leaf nitrogen content for the *Chettivirippu* mutant during 2000 at flowering and harvest was also higher than the general average. So at any stage of the growth nitrogen was not a limiting factor for producing yields more than 5 t ha^{-1}. In the studies on the relation of leaf nitrogen to yield in the laterite rice soils of Kerala, the minimum leaf nitrogen to produce rice grain yields more than 7000 kg ha^{-1} was found to be 1.66 per cent at panicle initiation stage (Bridgit, 1999). In the present investigation, the leaf nitrogen at active tillering, flowering and harvest stages were fairly high (Fig. 24). The leaf nitrogen content of 1.35 per cent at panicle initiation stage during 1999 was capable to produce a yield of 4977 kg ha^{-1}, while the leaf nitrogen

Fig.24 Effect of tidal regimes on N, P and S content in leaves at growth stages of rice varieties



content of 1.57 per cent for the same variety during 2000 could yield only 3457 kg ha^{-1}. Similarly, *Chettivirippu* mutant for leaf nitrogen content of 1.35 per cent at panicle initiation stage gave an yield of 4630 kg ha^{-1} in 1999 while during 2000 the yield was only 1964 kg ha^{-1} for the leaf nitrogen content of 1.74 per cent. Thus, it is clear that some factor other than nitrogen is the limiting factor for higher grain yields in *Pokkali* fields. The correlation co-efficients for nitrogen in culm at panicle initiation for all the varieties showed strong positive correlation with grain yield, while Vyttila-3 and Cul.1026 registered negative influence of nitrogen, which indicated that nitrogen was in excess for that particular plant part and stage (Table 31 a, b and c). It can also be inferred that among the three rice varieties *Chettivirippu* mutant is a higher nitrogen responsive variety than the others.

The uptake and content of nitrogen was more under the tidal situation in *Pokkali* fields. The tidal influence enhanced the soil pH, organic carbon and increased the available phosphorus and potassium of the soil (Table 28). The increased nitrates (Padmakumar *et al.*, 2002) and dissolved ammonia in tidal water may also have enhanced the nitrogen content of the rice plants grown under such situation. The favourable soil conditions existing under the tidal situation might be the possible reason for the higher content and uptake (Fig. 7) of nitrogen under the tidal situation.

The uptake pattern of nitrogen revealed by the varieties under the different tidal regimes were different. Cul. 1026 under the tidal regime had the maximum uptake of nitrogen (179 kg ha^{-1}) at the flowering stage, which at the time of harvest declined to 137 kg ha^{-1}. Under the non-tidal regime also Cul. 1026 had the maximum uptake of 111 kg ha^{-1} which declined to 83 kg ha^{-1} at harvest. Thus, the Cul. 1026 at harvest retained 28 and 42 kg less N ha^{-1} than what it had accumulated at the flowering stage. This phenomenon can be attributed to the decline in dry matter production (Table 12 b) at harvest in the variety Cul. 1026. The decrease in biomass of Cul. 1026 was mainly on account of a significant reduction in culm and root biomass during the growth stage from flowering to harvest.

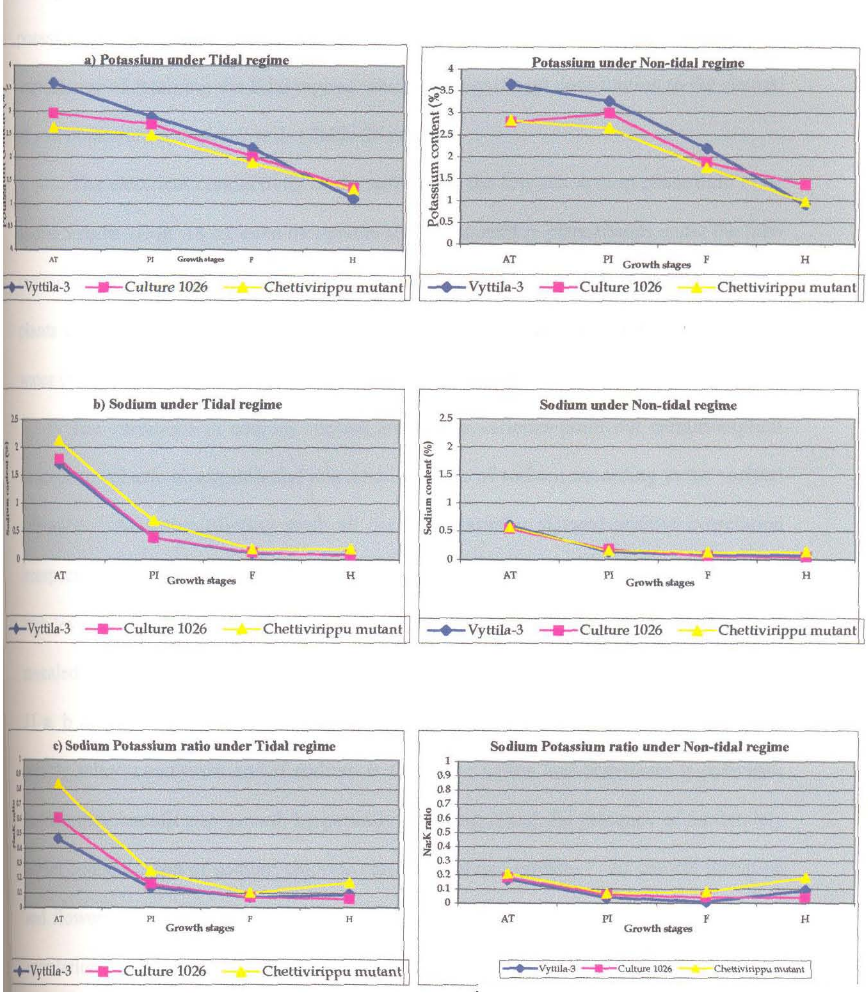
The phosphorus content and uptake were distinctly different in 1999 and 2000. The content in shoot and root at active tillering and in root, culm and leaf at the panicle initiation and flowering were distinctly more during 2000 than in 1999. The high content of phosphorus in 2000 was due to the low biomass production during 2000 compared to 1999. The higher concentration of phosphorus in culm and leaf at harvest under the non-tidal regime of 2000 may be attributed to the lesser biomass production. The phosphorus content at harvest was the highest for *Chettivirippu* mutant under the non-tidal regime, where the root, culm and leaf biomass were the least. The low grain yield during 2000 for *Chettivirippu* mutant under the non-tidal situation can also be attributed to the non-dilution of nutrients due to low biomass production. Nutritionally, high yield is considered to be the capacity of the plant to dilute nutrients (Wilcox, 1937).

The phosphorus content of root and shoot of Vyttila-3 at active tillering phase was higher than the others. The biomass production of Vyttila-3 up to the panicle initiation stage was significantly higher than the other varieties (Table 12 b). Hence, a high content of phosphorus is highly helpful for the early development of more root, culm and leaf biomass. De Geus (1954) has also emphasised the role of phosphorus in root development and tillering.

The potassium content and uptake were significantly different among the varieties. Up to the flowering stage Vyttila-3 had the highest potassium content. The potassium content in plant parts, especially in saline soils are of paramount importance since the ability to accumulate potassium in shoot correlated well with salt tolerance (Yeo and Flowers, 1984). A comparison between Cul. 1026 and *Chettivirippu* mutant revealed that the former had higher potassium content than the latter (Fig. 25). It is also seen that Vyttila-3 and Cul.1026 had low sodium content than the *Chettivirippu* mutant. So it can be inferred that the preference and selectivity for potassium over sodium was the highest for Vyttila-3 followed by Cul. 1026.

The higher level of potassium in Cul. 1026 shows that this variety, though the highest yielder among the varieties tried is capable of attaining much more yield or in short the realised yield is much less than the potential yield. On the contrary potassium content in Vyttiula-3 at harvest is very less probably because most of the leaves have been shed and resulted in a lower availability of potassium to support the reproductive phase of the plant (Table 14). The low leaf potassium content at harvest in Vyttila-3 is deleterious, since a consequent high sodium : potassium ratio may adversely affect the saline tolerance mechanism at this stage. On the other hand the higher potassium content in leaf enjoyed by Cul. 1026 at maturity is a boon by way of narrowing down of the sodium : potassium ratio. Thus the higher leaf and culm potassium content at harvest in Cul. 1026 must be one of the reasons for higher grain yield in this variety, especially

25. Effect of tidal regimes on K, Na content (%) and Na: K ratio in leaves at growth stages of rice varieties



during the non-tidal regime of 2000. The highly significant positive correlation of potassium content with grain yield (Table 31 a, b and c), therefore, emphasises the importance of retaining the tidal regime which had significant contribution to the accrual of soil potassium in *Pokkali* soils (Table 28 and 29).

The electrical conductivity of the soil during the low saline crop phase didn't rise above 5 ds m^{-1} (Fig. 18 b), even though the sodium content in plant tissues under the tidal regime was 2 to 3 fold more than that under the non-tidal regime. It is possible that the plants under the tidal situation had absorbed the higher sodium available from the tidal water through the nodal roots and contributed to the higher sodium content.

The variations in sodium content among the varieties point out certain explicit concepts of phasic absorption and allocation patterns of sodium according to the varietal tolerance. At active tillering stage all the three varieties showed positive correlation irrespective of the tissues, which means that at this stage all the plant parts can withstand high levels of sodium. At this stage Cul. 1026 had preferential allocation of sodium as revealed by the higher root content (Table 23 a) and its strong positive correlation (Table 31 a, b and c) with grain yield. Yoshida and Castaneda (1969) observed that under weakly saline conditions and if sodium is the major cation and potassium is deficient, sodium may benefit rice growth by partially replacing it and the presence of moderately higher concentration of sodium chloride can promote rice growth. At panicle initiation and flowering yield of *Chettivirippu* mutant and Vyttila-3 registered stronger level of correlation with sodium content which is very explicit with respect to Vyttila-3 at flowering. At panicle initiation and flowering stages this variety expressed maximum level of positive correlation between yield and content of sodium in culm and leaf tissues. On the other hand at maturity Vyttila-3 had negative correlation with leaf and culm sodium and the latter was highly significant while the sodium in root tissue registered significant positive correlation with yield. All these point to the level of tolerance to salinity at the genetic level. At the flowering stage the leaf tissues of Vyttila-3 had higher concentration of sodium; that too necessarily in older leaves. Such leaf to leaf gradient of sodium concentration in leaves of *Pokkali* – an internationally acclaimed saline tolerant rice cultivar – which is a parent of Vyttila-3, had been reported by Yeo and Flowers (1984).

A decrease in leaf and culm sodium content at maturity is desirable for Vyttila-3 as it revealed to have negative impact on grain yield. In Vyttila-3 a sharp decline in leaf sodium content is manipulated by the shedding of older leaves as revealed by the lesser number of leaves (Table 14), lesser leaf weight (Table 15 b) and lesser leaf area index (Fig. 6). The sodium thus excreted by leaf shedding in the present study was 16.3, 12.5 and 12.9 kg ha^{-1} for Vyttila-3, Cul. 1026 and *Chettivirippu* mutant, respectively. Shedding of leaves has been identified as a common strategy in monocot halophytes (Albert, 1975) and gradients in salt content from leaf to leaf are often reported for non-halophytes exposed to salinity (Flowers *et al*., 1981). The high rate of leaf shedding and consequent low leaf number at harvest should be the reason for the low productivity of Vyttila-3, though it is the most saline resistant.

In comparison, Cul. 1026 and *Chettivirippu* mutant retained more leaves at harvest and the content of sodium showed weak positive correlation compared to Vyttila-

3. However, the higher content of sodium in tissues were not detrimental for Cul. 1026. The leaf and culm sodium content in Cul. 1026 was almost equal or less than that in Vyttila-3 at almost all growth stages from panicle initiation. A selective preferential absorption of potassium over sodium might be working in these two varieties compared to *Chettivirippu* mutant in which higher content of sodium is observed. At maturity, leaf sodium content in Cul. 1026 was higher than that of Vyttila-3. Therefore, the probable mechanism of containing higher sodium in Cul. 1026 may be the balancing of sodium : potassium ratio by a higher potassium content. Mishra (1999) reported strong positive correlation of potassium content and significant negative correlation of sodium : potassium ratio with grain yield of rice. The significantly narrow leaf sodium : potassium ratio (Table 27 d) of Cul. 1026, especially towards the harvest stage explains the better performance of this variety during both the years, in spite of salinity variations.

The sulphur content in shoot and root was fairly high at the active tilering stage (Table 24 a). Thereafter the leaf content gradually decreased to 50 per cent at flowering and to 30 per cent at maturity. On the contrary the root content of sulphur registered a gradual increase up to the harvest stage. The correlation studies (Table 31 a, b and c) revealed that it has negative influence on grain yield except during the flowering stage, where its content in root has significant positive correlation with yield. This points out that a higher concentration of sulphur in leaf would have negative effect. The positive relation of sulphur content in root at harvest in Vyttila-3 further denotes that this variety has specific adaptations to thrive in acid sulphate soils.

Leaf calcium content at harvest (Table 25) was more in Vyttila-3, and the difference with the others was significant under the tidal regime. The higher leaf calcium content in Vyttila-3 can be seen as a salinity tolerance mechanism by which the divalent calcium ions protect the leaf membranes against the toxic effect of higher concentration of salt. Leopold and Willing (1984) reported such protective role of calcium against the organic solute leakiness induced by sodium chloride.

Another mechanism operating in the saline tolerant Vyttila-3 is the narrow Na:K ratio for aerial parts and wider ratios for the root tissues. In Vyttila-3 – a designated saline tolerant rice variety – the leaf and culm Na:K ratio at all stages under the tidal regime was narrow, and the difference with the other varieties was significant (Table 27 a, b, c and d). The correlation studies (Table 31 a) amply point out the strong positive correlation of K:Na ratio with grain yield. It is also worth mentioning that the correlation with the other two varieties (Table 31 b and c) is not so strong as that of the Vyttila-3. Yeo and Flowers (1984) also observed that saline sensitive varieties showed poor selectivity for potassium ions.

Soil chemical characters

The soil chemical characters of the *Pokkali* soils are governed by the tidal action. The tides ingress and egress *Pokkali* fields twice a day and during this action the tidal waters bring in and remove nutrients. The tidal waters are a mixture of fresh water from the upstream side and seawater from down stream. The water quality is governed by salinity, which will be low during the monsoon months and high during the summer months. So the soil characters of the *Pokkali* fields are associated with the tidal water quality which changes with the climatic parameters especially rainfall.

The tides brought about significant changes in the chemical properties in the present case. The tidal action significantly enhanced the soil pH. *Pokkali* soils are inherently acidic and the ingress of seawater makes them saline. Apart from that, the regular saturation and washing of *Pokkali* fields with tidal water is instrumental in enhancing the pH of the soil. Table 30 a and b reveals a positive correlation with electrical conductivity and pH. The favourable role of tides on regulating the soil pH is also clear from Table 7 a where the tidal action had significantly increased the soil pH. Similar observations were reported by Thampatti and Padmakumar (1999). A comparison between tidal and non-tidal situation on electrical conductivity revealed that the tidal regime has an edge over non-tidal regime. A close perusal of the same between the low saline and high saline phase (Table 29) revealed that during the low saline phase electrical conductivity is significantly less in the tidal situation than that under the non-tidal regime while during the high saline phase the non-tidal regime had the lesser electrical conductivity. During the low saline phase the tidal waters has more proportion of fresh water and the soil exposed to it will undergo frequent washing and hence the possibility of removal of soluble salts are more, while the non-tidal fields retains the inherent salt load with it and hence the high electrical conductivity of the non-tidal soils during the low saline phase. During the high saline phase the proportion of seawater is more in the tidal waters and hence the high electrical conductivity of the tidal fields during the high saline phase compared to the non-tidal situation. The variations in available sodium, exchangeable sodium and available : exchangeable sodium ratio under tidal and non-tidal situation can also be explained on this basis. Thus it is clear that the tidal paddy fields during low saline phase are better equipped to wash off of soluble salts than non-tidal fields which are devoid of salt removing facilities. This also emphasises the need for regulating the entry of tidal waters in to the *Pokkali* fields towards the reproductive stage of the crop when the tidal waters have a higher proportion of seawater.

Marginal increase in organic carbon content was noticed under tidal situation than the non-tidal regime. The data on organic carbon content under tidal and non-tidal situation from the pot culture experiment (Table 7 a) also corroborate this observation. The conducive ecological environment (optimum pH, water temperature, dissolved oxygen and organic productivity) prevailing under the estuarine conditions enhances the primary production (Purushan, 2002). The *Pokkali* fields under tidal situation are inhabited by innumerable biota. The beneficial role of tides in providing habitats for nitrogen fixing microbes and the effect of salinity variation in decomposition of photosynthetic aquatic biomass in *Pokkali* fields and their impact on fertility build up have been reported by Sasidharan *et al.* (2003). Thus the conducive environment for the biomass production and decomposition would have contributed to the increased organic carbon.

The increased availability of phosphorus under tidal situation can be related to the changes brought about in the pH and electrical conductivity. The variation in the availability of phosphorus between the tidal and non-tidal situation is wider towards the high saline phase (Fig. 14). It was observed that the tidal soils enjoyed higher pH and electrical conductivity. Availability of phosphorus is positively correlated with pH and electrical conductivity (Table 30 a and b). So a higher electrical conductivity and pH might have increased the availability of phosphorus. The beneficial effects of increasing the pH of acid soils, on availability of phosphorus had been reported by Ponnamperuma (1972). The availability of potassium, though was more under the tidal situation, its availability was significantly more during the low saline crop phase. The enhanced availability of potassium in tidal fields can be attributed to the presence of higher concentration of potassium in tidal waters (Padmakumar *et al.*, 2002).

Thus, it is evident from the above that the soil chemical characters under the tidal situation during low saline phase are more conducive for rice growth than the same under the non-tidal situation. Purushan (2002) further observed that this conducive environment and associated habitats are abode for innumerable natural habitants and thus the *Pokkali* fields provide feeding and breeding ground not only for the rice crop but also for many migratory shrimp and fish species.

These observations may provide certain practical implications on the management of Kuttanad soils also where free exchange of tidal water is regulated by the Thanneermukkom salt water barrier.

Experiment III

5.3. Impact of ameliorants on growth, yield and nutrient uptake of *Pokkali* rice

The ameliorants tried independently during the first year and in combination during the second year caused considerable variations in growth, physiological characters, yield and yield attributes of rice. Significant changes in the soil chemical characters could also be observed. The results thus obtained are discussed below.

Growth characters

The growth of rice expressed in terms of height and number of tillers did not reveal any significant difference between the treatments during both the years (Table 32 and 49). At maturity, though the difference was not significant the non-ameliorated control treatment recorded the least height, which implies that the chemical amelioration had stimulated the growth in terms of height. Though the ameliorants had no significant effect on the number of tillers progressive declining of tillers was observed which was 29 per cent during 1999 and 48 per cent during 2000. De Datta (1981) observed that wider range in tiller production accompanied by over 80 per cent of their conversion to productive tillers would appear as a response of favourable additive inputs, whereas a limited conversion to productive tillers appears to be the expression of domination of unfavourable factors. The decrease in leaf area index and leaf weight at harvest can also be explained in this way.

Among the physiological characters studied, the specific leaf weight and chlorophyll b content had significant effects of the treatments (Tables 34 and 53). The chlorophyll b content, though was higher for L 500 during 1999 and for combination treatments with lime during 2000, didn't result any positive effect on grain yield. Chlorophyll a is the photosynthetic unit and Chlorophyll b is the receptor pigment and the latter is formed from the former. Hence, an increase in Chlorophyll b is not expected to give increased photosynthetic efficiency.

A high chlorophyll content may necessarily result in higher rate of carbohydrate synthesis and its accumulation in cells. For the synthesis of protein essential elements like N, S etc. are to be adequately available. Dearth of any such element can result in the non-utilisation of synthesized carbohydrate (Tisdale *et al.*, 1995). This may probably result in an enhanced biomass but not the grain production.

S 600 also resulted in favourably influencing most of the characters, even though the difference was not significant in comparison with the control. However, contrary to the expectations application of silica and phosphorus could not give any benefit and in fact adversely affected the yield. For example P 30 and Si 500 resulted in yields lower than the control.

The data also showed that S 600, L 500 and control which were comparatively better in performance had more specific leaf weight indicating that the leaves were thicker, helping them to stand erect leading to better photosynthetic efficiency. Correlation studies (Table 48) pointed out its stronger positive correlation with the grain yield.

The study during the second year with single as well as combination of different ameliorants also couldn't result any significant increase in growth and yield of rice. The higher grain yield as well as the total biomass was recorded by the control treatment followed by amelioration by sulphur. Most of the yield attributes were also better in the control treatment. Absence of response of rice to ameliorants like lime and to fertilizer inputs in *Pokkali* soils had been reported earlier (KAU, 2003). Results of the permanent manurial experiment in *Pokkali* soils being conducted from 1974 at the Rice Research

Station, Vyttila also conclusively proved the superiority of the control treatment (receiving no organic or inorganic inputs) over the treatments receiving organic manures, inorganic fertilizers or lime (KAU, 2003).

Elemental composition

The nutrient content in plant parts as influenced by the ameliorants didn't reveal any direct link with the yield variation. However, correlation studies could bring to light some of the explicit relations among the nutrients themselves and with the grain yield.

Nitrogen content in plant parts was fairly high and was not a limiting factor as revealed by the negative relation of the root nitrogen at harvest and grain nitrogen content. Considering the high nitrogen content of the soil (Table 47 a) and the comparatively low nitrogen requirement of the test variety (Vyttila-3) nitrogen was not a limiting factor in *Pokkali* soils for crop production. On the contrary, the correlation studies revealed negative influence of available nitrogen with the grain yield (Table 48). This must be due to the negative relationship of root nitrogen at harvest with the yield promoting factors *viz.*, leaf calcium at harvest, leaf manganese at harvest, grain manganese and the specific leaf weight.

The leaf phosphorus at harvest, though, had a negative influence on yield, the culm phosphorus at harvest revealed to have positive influence. Except for culm potassium content at active tillering potassium had positive influence on grain yield. Potassium content was also fairly high and such high concentrations were required to contain the ill-effects of sodium, which however, was not a threat to the grain yield during 1999 owing to the comparatively low concentrations, especially at the post

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flowering stage (Table 40). The sodium content in plant parts were considerably higher during the subsequent year (Table 59 b).

Pokkali soils contain fairly high content of magnesium but lower calcium content in spite of the tidal inundation. However, the leaf calcium was in excess at the active tillering stage as revealed by the negative correlation it had with the grain yield. It is positively correlated with leaf zinc at active tillering and grain magnesium, which are negatively related with grain yield. Leaf calcium at harvest on the contrary had significant positive correlation with yield. This is mainly because of its positive influence on the specific leaf weight as well as on the leaf and root manganese at harvest, which are favourably associated with the grain yield. The leaf calcium content was simultaneously highest for S 600 and L 1000 and the high leaf calcium content may be the reason for their higher grain yields. Higher grain and straw yields with higher leaf calcium content had been reported by Bridgit (1999) also.

The most striking revelation on yield limiting nutrients in *Pokkali* situation is on the possible role of manganese. The available manganese ranged from 17.63 to 23.83 ppm. The manganese content in plant parts at harvest had a strong positive influence on grain yield. The influence of leaf manganese at harvest was revealed to be significantly positive. In the present experiment S 600, P 60, L 1000 and control treatments registered higher values of leaf and root manganese at harvest and grain manganese content while, the soil content of this nutrient was also high for these treatments (Table 47 b). Though not significant the grain yields were higher for the above treatments except in P 60, which had other already explained reasons for the low grain yields. Manganese is considered to be a factor in oxidation -reduction process. It is an activator of several enzymes, such as oxidase, peroxidase, decarboxylase and kinase (De Datta, 1981). Manganese along with iron and copper take part in an indispensable role in electron transport system (Hariguchi and Kitagishi, 1976). Thus the higher grain yields in S 600, L 1000 and control treatment might also be due to the above beneficial effect of manganese. Tadano and Yoshida (1978) also suggested that a high manganese content in rice tissues was frequently associated with high yields.

A higher content of available manganese for S 600, L 1000 and the control treatment (Table 47 b) and the significant positive correlation with grain yield also add strength to this argument. The highest manganese content in plant parts in this study was only 171.63 ppm and the fact that it can be toxic to rice only at levels above 2500 ppm (Yoshida, 1981) points out to the insufficient manganese content in plant parts. Based on these observations it can be concluded that manganese has a definite role in limiting grain yields in rice in *Pokkali* fields, on which detailed probe is warranted.

During the second year, it can be seen that the sodium content in plant parts are considerably higher than 1999 (Tables 40 and 59 b) especially at the post flowering stage. The tidal water with their varying proportion of fresh water from upstream side and seawater from downstream decides the salinity of the *Pokkali* soils. Since the tidal water contain different plant nutrients (Padmakumar *et al.*, 2002) the soil nutrients of *Pokkali* soils are in a dynamic stage and it changes with the tidal accretion and depletion. The relatively lesser rainfall received during post flowering stage (Appendix I) and consequent higher available sodium (Fig. 14 h) during September 2000 must have increased the sodium content in plant parts during the flowering and harvest stages. The influence of the higher sodium content had its impact on the grain yield of rice in this field experiment.

The sodium content and sodium : potassium ratio were lower in leaf and culm in the control in most of the stages. The *Pokkali* soils are saturated with sodium as revealed by the mean exchangeable and available sodium of 6404 and 6879 kg ha^{-1}, respectively (Table 28 Fig. 14 g and h). Under such sodium saturated condition of the exchange complex, addition of a chemical ameliorant may enhance the sodium availability (Table 65) and increases its absorption by the plant. Also the correlation studies (Table 66) revealed a significant negative correlation of available sodium on grain yield of rice. The increase in available sodium for the higher levels of all the ameliorants tried (L 1000, Si 500, P 60 and S 600) adds strength to this argument (Table 47 b). This increased availability of sodium thus increased the sodium absorption of the plant and hence the decreased grain yield of the ameliorated treatments as revealed by the significant negative correlation of sodium in plant parts with the grain yield (Table 66). The data on the potassium content in plant parts showed no significant difference between the treatments including the control. Thus, it is evident that the lower values of sodium:potassium ratio in the control treatment was due to the lower concentration of sodium in the control treatment plants than that in the ameliorated treatment plants. However, the sodium : potassium ratio (Table 60 a and b) in culm at active tillering, flowering and harvest and in leaf at harvest for the control treatment was the lowest and these ratios had significant negative correlation with the grain yield. Thus, it is inferred that the ameliorants significantly increased the sodium : potassium ratio of culm at flowering and leaf at harvest which had negative influence on the grain yield. Yeo and Flowers (1984) and Shylaraj *et al.* (1995) had pointed out the favourable role of low sodium : potassium ratio on imparting tolerance for salinity in rice.

Yield prediction models

The stepwise multiple regression analysis of content of plant nutrients in leaf, culm and grain identified seven out of the 71 parameters having direct bearing on grain yield based on which three independent yield prediction models are proposed for the three varieties (Table 75) evaluated under the tidal and non-tidal situation. The favourable influence of potassium in culm at panicle initiation, phosphorus in leaf at flowering and sulphur in culm at flowering were the positive factors while, unfavourable effect of nitrogen in culm at panicle initiation, leaf at flowering and sodium in shoot at active tillering and culm at harvest were the negative factors considered for the model for Vyttila-3.

The model proposed for Vyttila-3 is the following:

$$Y = 7.2635 - 5.2685\ \mathrm{NCPI} - 2.9895\ \mathrm{NLF} + 1.5901\ \mathrm{KCPI} - 0.1330\ \mathrm{NaSAT} - 6.9376\ \mathrm{NaCH} + 3.8923\ \mathrm{PLF} + 7.4281\ \mathrm{SCF},$$ where

Y = Grain Yield

NCPI = Nitrogen in culm at panicle initiation

NLF = Nitrogen in leaf at flowering

KCPI = Potassium in culm at panicle initiation

NaSAT = Sodium in shoot at active tillering

Table 75. Parameters selected for expression of grain yield models

Parameters	R.square	Reg.coeff.	Std.error	Probability
(a) Vyttila-3				
Nitrogen culm P.I.	-0.0992	-5.2685	-0.0387	0.0001***
Nitrogen Leaf flowering	-0.1127	-2,9895	0.0109	0.000***
Potassium culm P.I.	0.8839	1.5901	0.0027	0.000***
Sodium in shoot at active tillering	-0.0226	-0.1330	0.0071	0.0028***
Sodium in culm at harvest	0.2854	-6.9376	0.0315	0.000***
Phosphorus leaf flowering	0.0448	3.8923	0.0485	0.0002***
Sulphur in culm at flowering	0.0205	7.4281	0.0160	0.000***
(b) *Chettivirippu* mutant				
Root K at P.I.	0.7973	9.2251	0.0133	0.000***
Root P at Active tillering	-0.0033	-8.7701	0.0193	0.000***
Culm P at flowering	0.02	-20.7505	0.0593	0.000***
Leaf P at harvest	0.1942	22.4864	0.1424	0.000***
Leaf sulphur at P.I.	-0.0039	-0.2758	0.0105	0.0014***
Leaf sulphur at harvest	-0.0056	3.6454	0.0323	0.001***
Root sulphur at harvest	0.0013	-0.1844	0.0028	0.0002***
(C) Cul. 1026				
Nitrogen in leaf at flowering	0.0207	1.5935	0.5035	0.0870
Nitrogen leaf at harvest	-0.2054	-6.5136	0.4612	0.0050**
Potassium in culm at P.I.	-0.2065	-0.4667	0.0620	0.0172*
Potassium:sodium in leaf at A.T.	0.3304	1.0465	0.0396	0.0014**
Potassium:sodium in grain	0.8355	0.7299	0.0134	0.0003***
Sulphur in root at flowering	0.2569	1.6475	0.0790	0.0023**
Sulphur in grain	-0.0316	-2.1379	0.9633	0.1541

* - Significant at 0.05 level
** - Significant at 0.01 level
*** - Significant at 0.005 level

NaCH = Sodium in culm at harvest

PLF = Phosphorus in leaf at flowering and

SCF = Sulphur in culm at flowering

In *Chettivirippu* mutant the positive effect of potassium in root at panicle initiation, phosphorus and sulphur in leaf at harvest and negative effect of phosphorus in root at active tillering, culm at flowering and sulphur in root at harvest were taken in to consideration and the model proposed is:

$$Y = 9.5864 + 9.2251\ KRPI - 8.7701\ PRAT - 20.7505\ PCF + 22.4864\ PLH - 0.2758\ SLPI + 3.6454\ SLH - 0.1844\ SRH$$ where

Y = Grain Yield

KRPI = Potassium in root at panicle initiation

PRAT = Phosphorus in root at active tillering

PCF = Phosphorus in culm at flowering

PLH = Phosphorus in leaf at harvest

SLPI = Sulphur in leaf at panicle initiation

SLH = Sulphur in leaf at harvest and

SRH = Sulphur in root at harvest

The grain yield in Cul.1026 was decided positively by the leaf nitrogen at flowering, potassium : sodium ratio in leaf at active tillering and grain, and the sulphur content in root at flowering. On the contrary leaf nitrogen at harvest, potassium content in culm at panicle initiation and the sulphur content in grain had negative effect on grain yield. Thus the yield prediction model suggested for Cul. 1026 is:

$$Y = 6.1341 + 1.5935\ NLF - 6.5136\ NLH - 0.467\ KCPI + 1.0465\ K{:}NaLAT + 0.7299\ K{:}NaGH + 1.6475\ SRF - 2.1379\ SGH$$ where

Y = Grain Yield

NLF = Nitrogen in leaf at flowering

NLH = Nitrogen in leaf at harvest

KCPI = Potassium in culm at panicle initiation

K:NaLAT = Potassium : sodium ratio in leaf at active tillering

K:NaGH = Potassium : sodium ratio in grain

SRF = Sulphur content in root at flowering and

SGH = Sulphur content in grain

The stepwise multiple regression analysis was also exercised to evaluate the relationship of grain yield and plant nutrient contents of the field experiment-3. The relationship of grain yield with content of various plant nutrients in root, culm, leaf at active tillering, flowering and harvest stages and grain identified nitrogen in root at harvest and potassium in leaf at active tillering and culm at flowering as the negative factors and calcium content in leaf at harvest and copper content in leaf at flowering and harvest as the positive factors. Based on this, the following yield prediction model is proposed.

$$Y = 3375 - 1589.14\ RNH - 194.73\ LKAT - 2541.93\ CKF + 28494.09\ LCaH + 8.5675\ LCuF + 31.358\ LCuH$$ where

Y = Yield,

RNH = Root Nitrogen at harvest,

LKAT = Leaf Potassium at Active Tillering,

CKF = Culm Potassium at Flowering,

LCaH = Leaf Calcium at Harvest,

LCuF = Leaf Copper at Flowering and

LCuH = Leaf Copper at Harvest

This model was further improved by incorporating the soil parameters *viz.*, organic carbon content, available phosphorus and the yield attribute, number of panicles $hill^{-1}$. The improved yield prediction model is :

$$Y = -1313.3056 + 301.8685\ PH + 19733.445\ LCaH + 6.5191\ LMnH + 9.01144\ GCuH - 71.155\ OC - 160.6965\ Av.P$$ where

Y = Yield

PH = Panicles $hill^{-1}$,

LCaH = Leaf Calcium at harvest

LMnH = Leaf Manganese at harvest,

GCuH = Grain Copper at harvest

OC = Organic Carbon content of soil and

Av.P = Available Phosphorus of the soil

The adjusted R^2 of the first model is 0.9999 and the second 1.000. These two models were tested using the yield data obtained during 1999 (Table 36). No variation is noticed between the actual yield and the predicted yield as per model I and model II.

Experiment IV

5.4. Plant ideotype suited to rice cum fish culture in *Pokkali* fields

Growth characters of rice

The results indicated that the growth characters of rice *viz.*, height and vegetative tillers were governed mainly by their genetic make up rather than the fish treatment associated with. However, during 1999 *Chettivirippu* mutant without fish recorded higher vegetative tillers than that under the male tilapia. It seems that the water depth maintained for the fish treatment might have some unfavourable effect on tiller production. The high tillering nature of Cul. 1026 and *Chettivirippu* mutant (11.7, 10.8) compared to Vyttila-3 (8.2) is quite natural as the former two varieties belong to the new generation high yielding group and the latter to the traditional tall category. All the three varieties had more than 80 cm height from the active tillering phase. The height factor decided their suitability to thrive under a water regime suitable to the rice-fish culture. Rajendran *et al.* (1994) observed that the new high yielding dwarf rice varieties may not be suitable to deep water conditions and hence are not suitable for rice-fish integration. The new rice varieties used in this experiment, however, are suitable for a water regime appropriate to rice cum fish culture.

The photosynthetic efficiency of the new generation rice varieties is well known. The *Chettivirippu* mutant was capable of intercepting 88 per cent more sun light than the traditional tall Vyttila-3. The leaf angle of *Chettivirippu* mutant and Cul. 1026 explains the variations on this behalf. Vyttila-3 has a closed canopy with a leaf angle of 35^0 while the canopy of *Chettivirippu* mutant and Cul. 1026 are relatively open as expressed by their respective leaf angles of 7^0 and 15^0 which permit sufficient sun light to reach the floor. So a plant ideotype with open leaf canopy allowed possibilities of higher primary production of live feed (phytoplankton, zooplankton) in a rice cum fish dual culture system.

The rice varieties varied significantly with respect to the yield attributes and yield (Table 69 a and b). The maximum panicles hill^{-1} were recorded by Cul. 1026, which had 35 per cent more panicles than Vyttila-3. However, the number of filled grains per panicle was less for this variety due to higher chaff percentage of 26.1 compared to 8.7 in *Chettivirippu* mutant. Thus, the number of filled grain panicle^{-1} was highest in *Chettivirippu* mutant followed by Vyttila-3 and Cul. 1026. However, the thousand grain weight was maximum for Vyttila-3 which was 19 per cent more than Cul. 1026 and 39 per cent more than the *Chettivirippu* mutant.

The comparatively higher panicle number hill^{-1}, low chaff per cent and relatively higher thousand grain weight were the good yield attributes of *Chettivirippu* mutant. Thus, the grain yield was higher for this variety during the first year. However, the yields were comparatively less for all the varieties during the second year, and this decline was more pronounced in *Chettivirippu* mutant. The Cul. 1026 was a more stable variety with less variation in yield between the first and second year. The pooled mean yield didn't give any significant difference among the varieties. The straw yield also showed pronounced variation between the years. Vyttila-3 recorded the highest straw yield during 1999, while during 2000, it had the least straw yield. The same trend was seen in *Chettivirippu* mutant also. However, the Cul. 1026 gave almost similar straw yield during the second year as well. The stability of Cul. 1026 was also noticed for the biomass yield. The biomass yield of Vyttila-3 and *Chettivirippu* mutant widely varied between 10241 and 4335 kg ha^{-1}, during 1999 and 2000. Cul. 1026 recorded stable biomass yield of 8451 and 7121 kg ha^{-1} during the above two years. The grain : straw ratio of both 1999 and 2000 also gave almost the same trend for *Chettivirippu* mutant and Cul. 1026, while Vyttila-3 had a lower ratio during the first year and a higher one for the second year. A lower grain yield and higher grain : straw ratio suggested a poor vegetative development combined with reduced photosynthetic capability during the second year. However, Cul. 1026 could produce sufficient vegetative structure during the second year as well and hence a stable grain, straw and biomass yield and almost equal grain : straw ratio during both the years. Differential response of the *Pokkali* varieties to variations in the environment has been reported by George *et al.* (1993).

The integration of fish with rice didn't bring about any reduction in grain, straw and biomass production in rice. Several workers (Hara and Pillay, 1962, Lightfoot *et al.*, 1992 and Naegel, 1988) reported increase in grain yield to the tune of 15 per cent by rice-fish integration. In the present investigation, however, there was no significant increase in grain, straw and biomass yield, Manjappa *et al.* (1987) observed little difference in grain yield from plots with and without fish.

Yield characters and yield of fish

The survival of the fish (Table 71) depended mainly on the species under culture. During 1999 male tilapia and etroplus were the species tried. Tilapia recorded 36.2 per cent survival while etroplus registered zero per cent. During the subsequent year also survival by tilapia was 38.9 per cent while rohu recorded only 16.0. Such variations in survival of fishes under rice-fish synchronous production systems has been reported by several workers (Rajendran *et al.*, 1994 and Padmakumar *et al.*, 1993). The hydrographic parameters has a profound influence on the survival and growth of fish. The water depth other than that of the periphery channels was less than 30 cm. Though the pH range of 5.5 to 7.7 and dissolved oxygen level of 3.0 to 5.89 were conducive for fish growth the toxic gases like hydrogen sulphide produced during post rice harvest decay of paddy stubbles were deleterious for most of the cultured species (Rajendran *et al.*, 1994). The sharp rise in electrical conductivity and salinity during the post paddy phase is another decisive factor. So all these factors *viz.*, the lower water depth, increased dissolved ammonia of 2.3 ppm during the post harvest paddy phase and the toxic gases produced by the decaying paddy stubbles might have brought about the low survival percentage of etroplus and rohu. The capability of tilapia (*Oreochromis mossambicus*) to tolerate high levels of carbondioxide, ammonia and hydrogen sulphide that originate from the decomposition of organic matter had been reported by Pullin and Mc Connell, (1982). Hence, the mean survival of 37.6 per cent registered by male tilapia is reasonable.

The average stocking weight of etroplus, rohu and tilapia were 5.0, 3.0 and 45.0 g, respectively. The mean weight of 140 g in 169 days during 1999 and 138.2 g in 131 days during 2000 attained by the male tilapia was satisfactory. The other survived fish species *viz.*, rohu recorded a mean weight of 79.7 g in 131 days while, the recovery from etroplus was nil. The mean size of rohu was only 3 g at stocking and a much higher stocking size would have registered encouraging survival and growth rate. In rice fish dual culture, Padmakumar *et al.* (1993) obtained 74 per cent survival and an average mean weight of 328 g at harvest for rohu with an average stocking size of 15 g.

The fish yield obtained during the first and second years varied both in kind and quantity. The rice varieties with varying leaf architecture did not influence the fish yield which imply that the existing space of periphery channels alone was sufficient to achieve the present level yield of 250 kg ha^{-1}. During the first year the yield of 209.1 kg ha^{-1} was obtained from male tilapia while no survival could be obtained from etroplus. Such poor performance of *Etroplus suratensis* were reported by Padmakumar *et al.* (1993). During the second year *Labeo rohita* gave a yield of 25.4 kg ha^{-1}, which was not at all encouraging compared to the 224.2 kg ha^{-1} fish yield recorded by male tilapia. The relatively small stocking size (3 g) and absence of any supplementary feeding may be the reason for the non-performance of rohu in the present study. On the other hand tilapia are macrophagous, feeding either on plankton or on detritus, that are available in plenty in *Pokkali* fields. Swingle (1961) has reported that this species tolerated pH fluctuations in the range of 4 to 11. Rajendran *et al.* (1994) has also identified tilapia as an ideal species for integrated agriculture-aquaculture farming systems in the tropics. Rearing an all male population is the management strategy proposed by him to combat the prolific breeding habit of tilapia.

The rice varieties with varying leaf architecture, though significantly influenced the light intensity at the floor of the rice field, didn't influence the fish yield. The fish shelter provided in the periphery of the rice area might be sufficient to get the present yield levels of 250 kg ha^{-1} in 5 to 6 months. Additional foraging ground for the fish is

Plate-7. Tiger Prawn (*Penaeus monodon*)

Plate-8. Tilapia (*Oreochromis mosambicuss*) required only when still higher yield levels are targeted. Under such circumstances the stocking size of the fingerlings are to be enhanced by which the survival, growth rate and finally the yield can be substantially enhanced.

Rotational prawn culture

Prawn filtration is the natural choice of cropping activity in *Pokkali* fields during the high saline phase. Selective culture of tiger/white prawn is an improvement over the traditional practice of prawn filtration. In the present study during the short culture period of 74 days from 15-01-2001 a prawn yield of 425 kg ha^{-1} could be obtained without any supplementary feeding. The hydrographic parameters (Table 73 a) were conducive for the growth and development of prawn as evidenced by the growth parameters (Table 73 b). In the traditional prawn filtration, often the percentage of quality prawn is very low due to the natural stocking. The selective stocking of tiger prawn in *Pokkali* fields prevented the entry of undesirable species and facilitated the selective culture of the desired prawn species. In the present selective culture of tiger prawn a survival per cent of 49 could be obtained which finally gave an yield of 425 kg ha^{-1} of prawn. Pillai (1999) reported a survival per cent of 31.4 and prawn yield 261 kg ha^{-1} by the adoption of the improved traditional culture of tiger prawn where the operations were similar to that of the selective culture of tiger prawn. The prospects of the culture of tiger prawn have been demonstrated by Gopalan *et al.* (1980), Verghese *et al.* (1982) and Purushan (1988), and the present findings agree well with these reports..

Change in soil chemical characters

The changes brought about in the soil chemical characters after fish harvest in November 2000 and prawn harvest in April 2001 are presented in Tables 72 and 73 (c). The effect of the rice varieties, fish treatments as well as their interactions were not significant on the soil chemical characters. Pokkali soils are inherently fertile (Table 72). Any marginal changes that occurred in the chemical characters of these soils by fish introduction are masked by a much higher magnitude of changes brought about by the tides. The sub table for fish treatments of table 72 revealed a low soil pH of 3.5 to 3.8 and high electrical conductivity of 8.4 to 8.9. *Pokkali* soils are basically acidic and low pH values are typical of these potential acid sulphate soils. Nair and Money (1968) reported that the saline soils of Kerala are acidic with pH ranging from 3.0 to 6.8 in spite of high conductivity. The present findings are in conformity with this report.

The organic carbon content of the soil after fish harvest recorded a range of 2.6 to 3.6 per cent, which showed a remarkable high degree of soil fertility. The organic carbon status remained to be the same after the prawn harvest also. Samikutty (1977) had reported that the Pokkali soils are extremely deficient in phosphorus. In the present studies the available phosphorus after the fish harvest varied between 11.5 and 15.5 kg ha^{-1}, which is rated as medium. Either the fish treatments or its interaction with rice varieties did not have any significant effect on the available soil phosphorus. The available phosphorus after the prawn harvest was (Table 73 c) 10.6 to 15.1 kg ha^{-1} which did not vary much from the figures after the harvest of fish (Table 72). The available potassium after the fish harvest also did not reveal any treatment effect. However, the values after the prawn harvest gave a higher and wider range (314.0 to 1299.0 kg ha^{-1}) compared to that of the 224 to 582 kg ha^{-1} range after the fish harvest. The available sodium also did not have any effect of the treatments. The available sodium range of 2867 to 3032 kg ha^{-1} at the fish harvest rose to 3564.0 to 13440 kg ha^{-1} after the harvest of prawn. This clearly indicated the dynamic nature of of cations in the *Pokkali* soils. The increase in available potassium and sodium content of the soil may be attributed to the saline water incursion.

So an integrated farming system involving rice-fish dual culture followed by prawn during summer evokes positive changes in soil characters *viz.*, pH, organic carbon, available phosphorus and available potassium. The unfavourable changes like increase in EC and sodium content are reversible and hence will not affect the sustainability of the system.

Economic analysis

The economic analysis (Table 74) of the integrated farming system point to 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 and pesticides are nil in *Pokkali* fields. The expenditure on weed management that usually costs 50 per cent of the production cost, is also low in *Pokkali* area. The production cost was Rs.11,450/- ha^{-1} while the returns depended on the yield. The net return was only Rs.4371 ha^{-1} from Vyttila-3, while it was higher from the Cul. 1026 (Rs. 10,618/-) and *Chettivirippu* mutant (Rs.11,222/-). The benefit : cost ratio were 1.38, 1.93 and 1.98, respectively for Vyttila-3, Cul. 1026 and *Chettivirippu* mutant. The increased yield from Cul. 1026 and *Chettivirippu* mutant gave higher net returns and thus the higher benefit : cost ratios.

Introduction of the fish component to the rice cultivation increased the production cost only marginally. The *pokkali* fields generally have deeper inner channels, which require renovation before stocking. Removal of weed fishes, cost of fingerlings and harvest operations are the other important items which require major expenditure. A low yield as in the case of rohu can substantially decrease the net returns and benefit : cost ratio. In the present studies, yields are less, even with male tilapia which gave a net return of only Rs.13,646/- ha^{-1}. Many of the beneficial effects of rice-fish integration that have a direct bearing on the cost of production were not visible in P*okkali* fields. The direct effects of the fishes on reducing the cost on weeding and lowering of the cost on fertilizers were conspicuous by their absence in *Pokkali* fields. The tidal regulation of water depth, generally makes the *Pokkali* fields weed-free. Similarly, the *Pokkali* fields are basically fertile and fertility accretion rather than depletion is the general rule. In Kuttanad where high input cultivation practices are the general rule, rice-fish integration has significantly reduced the cost of rice cultivation. While analyzing the economic benefit of rice-fish farming system in Kuttanad, Shanat (2000) found that the rice-fish integration could reduce the cost of cultivation of rice by 29 per cent, of which the reduction in labour cost alone accounted for 19.77 per cent.

The economic analysis, thus, confirms that the integration of prawn rather than fishes is the key for increasing the net returns and benefit : cost ratio of *Pokkali* fields. In the present study, stocking of tiger prawn at 50,000 ha^{-1} gave an yield of 425 kg ha^{-1}

without any supplementary feeding. The prawn grows well feeding on the live feed generated by the decaying paddy stubbles left in the field. The live feed generation capacity of the paddy stalks in *Pokkali* fields has been reported by Purushan (2002). Feeding with artificial feeds would have increased the production cost sky high. Dependence on the live feed generated , restricted the production cost to Rs. 29,000 ha^{-1} and the net returns were Rs. 48,390/- ha^{-1}. Pillai (1999) reported a net return of Rs. 24,000/- ha^{-1} from an improved traditional prawn culture field.

The rice-fish-prawn integration in P*okkali* fields gave the maximum benefit cost ratio of 2.03. The additional employment generation to the tune of 66 man days ha^{-1} is another advantage of this integration. Thus, additional employment generation of 13 lakh man days can be annually made by the integration of rice and fish/prawn from the 20,000 plus ha of *Pokkali* fields.

SUMMARY

6. SUMMARY AND CONCLUSIONS

The research project entitled "Enhancing productivity of the rice-fish/prawn farming system in *Pokkali* lands" was conducted at the Rice Research Station, Vyttila under the Kerala Agricultural University, during the period from June 1999 to May 2002. The main objective of the project was to evolve a sustainable integrated farming system with rice, fish and prawn as the major components. Three field experiments and a pot culture experiment were conducted. Growth analysis of rice, fish and prawn was done and yield data were collected. Field water samples, soil samples and plant samples were periodically collected and analysed for major and minor nutrient contents. The important research results obtained are furnished below:

1. Tidal action significantly increased the soil pH and available K. The content of organic carbon and available phosphorus were also higher under the tidal situation.
2. In the pot culture studies tidal action significantly increased the straw yield, number of productive tillers and chaff per cent, while decreased grain:straw ratio, panicle length, filled grains and number of grains panicle^{-1}.
3. Soil pH had positive correlation with available potassium and available phosphorus and the relation was significant with the former.
4. Tidal regime significantly increased the straw yield and lowered the grain:straw ratio by 50 per cent.
5. Number of tillers was more for Cul.1026 and *Chettivirippu* mutant than Vyttila-3.

6. During 2000, tiller decline to the tune of 43.7, 44.7 and 65.0 per cent were observed under the non-tidal regime for Cul.1026, *Chettivirippu* mutant and Vyttila-3, respectively while the decline was 36.0, 37.0 and 52.0 per cent for the same varieties under the tidal regime. The decline was marginal during 1999 where the decline under tidal regime was 4.0, 11.7 and 10.0 and under non-tidal regime was 29.0, 23.6 and 33.0 for Cul.1026, *Chettivirippu* mutant and Vyttila-3, respectively.
7. Vyttila-3 had the maximum leaf area index and number of functional leaves at the vegetative phase, which sharply declined towards the flowering stage. Cul.1026 had the maximum leaf area index and number of functional leaves at maturity.
8. The tidal regime had considerably higher leaf area index and leaf weight than the non-tidal regime during both the years of the study.
9. The root, culm, leaf and total biomass were higher under the tidal situation than under the non-tidal regime.
10. The biomass production was linear for Vyttila-3 and *Chettivirippu* mutant while it was sigmoid for Cul.1026, under both the tidal regimes.
11. Tidal situation favoured higher grain, straw and total biomass production while non-tidal regime favoured a higher grain:straw ratio.
12. N content was always higher under the tidal situation during both the years irrespective of the growth stage or plant tissue.
13. The tidal regimes varied considerably for N uptake. The N uptake under tidal regime was 130.6, 179.0 and 116.9 kg ha^{-1} while it was 93.0, 111.0 and 95.0

kg ha^{-1} under the non-tidal regime for Vyttila-3, Cul.1026 and *Chettivirippu* mutant, respectively.

14. Translocation of N to the panicle was mainly from leaves under the tidal situation whereas both the culm and leaves functioned as source under the non-tidal situation.
15. The growth stage of peak nitrogen uptake varied between varieties. Cul. 1026 and *Chettivirippu* mutant had the peak N uptake at flowering while Vyttila-3 had the peak uptake at maturity.
16. P uptake patterns under the tidal and non-tidal regimes were different. The P uptake pattern under the tidal regime peaked at flowering and declined at maturity whereas under the non-tidal regime, the uptake registered a gradual increase and peaked at maturity. The P uptake at maturity under the tidal regime and the non-tidal regime was 35.1, 40.5 and 28.0 kg ha^{-1} and, 44.9, 40.5 and 28.0 kg ha^{-1} for Vyttila-3, Cul.1026 and *Chettivirippu* mutant, respectively.
17. The pot culture studies revealed a significantly higher content of K in plant tissues under the tidal regime whereas in the field experiment both the tidal and non-tidal regimes gave more or less same K content, possibly because of the curtailing of subsurface influence in the pot culture trials.
18. The uptake of K was linear up to flowering and declined at maturity. Cul.1026 recorded the maximum uptake of 245.9 kg ha^{-1} at flowering, out of which 65.4 kg ha^{-1} was shed subsequently by way of leaf shedding/tiller declining.

19. The Na content in plant tissues was two to three fold higher under the tidal regime than under the non-tidal situation up to the flowering stage and both the regimes had almost same content subsequently. Vyttila-3 and Cul.1026 had lesser sodium content than *Chettivirippu* mutant.
20. The pattern of Na uptake differed between the tidal regimes with the tidal situation registering the peak uptake for Cul.1026 and *Chettivirippu* mutant at flowering and for Vyttila-3 at maturity. The peak stages of Na uptake were the same under the non-tidal regime also, but the uptake under the tidal regime was 30 to 35 percent more than the non-tidal situation.
21. Under the tidal situation, Vyttila-3, Cul.1026 and *Chettivirippu* mutant registered a Na uptake of 105, 137 and 106 kg ha^{-1}, respectively.
22. The Na distribution at maturity revealed that the panicles retained only 0.72 to 1.50 per cent of the total Na uptake, while the culm and root had 91.6 and 5.1 per cent, respectively, and the leaves retained the rest.
23. The S uptake patterns under tidal and non-tidal regimes were different irrespective of the varieties. The tidal regime recorded the peak sulphur uptake at flowering while the non-tidal regime continued to absorb S even after flowering and had the peak value at maturity.
24. Vyttila-3 under the tidal regime had significantly higher leaf Ca content at harvest than the non-tidal regime. The uptake patterns of Ca and Mg were similar.

25. The Na:K ratio differed significantly between the tidal and non-tidal regime with the former recording wider ratios than the latter at the pre-flowering stage. Vyttila-3 recorded significantly narrower shoot Na:K ratio than the other varieties.
26. The tidal influx brought about significant changes in the chemical properties of *Pokkali* soils. Tidal action significantly enhanced the soil pH, organic carbon, available P and available and exchangeable K. Available and exchangeable Na, and electrical conductivity were higher under the tidal situation, though the difference was not significant
27. The available soil P had significant positive correlation with soil pH and electrical conductivity under both the tidal regimes and the relation among them was significant under the tidal regime. Available P had significant negative correlation with available K. With exchangeable K, available P was negatively correlated under the non-tidal regime while the relation was positive under the tidal regime.
28. The relation between organic carbon and pH was negative under both the tidal regimes and the relation was stronger under the tidal situation.
29. Available Na had positive correlation with available K under both the regimes and it was significant under tidal situation. The exchangeable Na and K had highly significant positive correlation with available Na under non-tidal situation.

30. Ameliorants didn't impart any significant variation in vegetative tillers. However, a considerable decline in tillers was observed irrespective of the treatment as the growth stage advanced from active tillering to flowering.
31. Ameliorants had no significant influence on the biomass production during both the years of the study. The non-ameliorant control plants produced significantly higher root, culm, leaf and total biomass during certain stages of crop growth.
32. During both the years of the study ameliorants had a negative influence on the leaf area index while the S application at 600 kg ha^{-1} significantly increased the specific leaf weight.
33. Lime at 500 kg ha^{-1} gave higher chlorophyll a, chlorophyll b and total chlorophyll in the leaf at panicle initiation stage. The chlorophyll b content for L 500 was significantly more than that of the control treatment, S 600 and L 1000.
34. None of the ameliorants tried except, S 600 and L 1000 had a favourable influence on the grain yield of rice compared to the non-ameliorant control treatment.
35. S 600 recorded the highest panicle number $hill^{-1}$, grain, straw and biomass yield. The grain yield was at par with L 1000 and the control treatment. P 60 followed by L 1000 recorded higher grain:straw ratios (0.40 and 0.39).
36. Content and uptake of P were lesser for non-ameliorant control treatment than the ameliorant treatments.
37. Application of lime, S and combination of lime, Si, P and S enhanced the uptake of P.

38. S 600 gave significantly higher grain Ca content and higher leaf Ca content at harvest.
39. Fe content in leaf was the highest at active tillering stage (5623 to 6608 ppm) and the lowest at harvest (424 to 798 ppm). L 500, P 60, S 600 and the control treatment gradually diluted their root Fe content towards maturity while the other treatments increased the root Fe content at harvest. The range of shedding of Fe was 6.4 to 11.4 kg ha^{-1}.
40. Amelioration significantly increased the culm Na content at flowering compared to the non-ameliorant control treatment. Ameliorant treatments also enhanced leaf and root Na at harvest and root Na at flowering considerably.
41. Ameliorants significantly enhanced the Na:K ratio of leaf at harvest, culm at active tillering and flowering compared to lower Na:K ratios in the respective plant tissues for the non-ameliorant control treatment.
42. S application either alone or in combination with lime increased the leaf and culm S content at active tillering, panicle initiation, flowering and harvest stages. This increase was significant for leaf S content at panicle initiation and flowering. All the ameliorant treatments registered considerably higher culm and root S content than the non-ameliorant control treatment.
43. Ameliorants, especially Si, significantly increased the root Si at flowering and harvest and grain Si content compared to the control treatment.
44. The ameliorants significantly increased the electrical conductivity and exchangeable K of the soil. The changes in pH values, though not significant,

were the least for S 600 while lime treatment gave the highest pH value. Ameliorants influenced the quantity of available and exchangeable forms of P, K and Na. Lime application increased availability of K and Na while lime-P combination increased the exchangeable K and Na. S 600 registered the least values of available and exchangeable K while the control treatment recorded least value of available Na. The higher levels of ameliorants of the 1999 experiment, increased the availability of Na considerably compared to the control treatment and lower levels of ameliorants.

45. S 600 recorded highest numerical value for leaf Mn content at harvest.
46. All the ameliorants decreased the availability of Fe and Zn compared to the non-ameliorant control treatment while S application increased the Mn availability.
47. The organic carbon content related negatively with available P, K, Na, Ca, Mg and Fe and positively with Zn, Cu and Mn. Available N had significant negative correlation with available Ca. Available P had significant positive correlation with available Cu and Zn, but negatively correlated with available Mn. Available K had significant positive correlation with available Na, Mg, Fe and Mn. Available Na had significant positive correlation with available Mg and available Fe. Available Ca had significant negative relation with available N. Available K and Mn had significant positive correlation with grain yield.
48. Leaf Ca and Mn at harvest had significant positive correlation with grain yield while the root N at harvest and culm K and leaf Ca at active tillering had negative relation with the grain yield.

49. Available Mn had significant positive correlation with grain K content and grain yield.

50. P content in root at harvest, K content in culm at panicle initiation and leaf at flowering had significant positive correlation with grain yield, while Na in leaf and root at harvest, Na:K ratio in culm at flowering and leaf at harvest, grain Si and available Na in soil at planting had significant negative relation with the grain yield.

51. The yield prediction models developed independently based on nutrient content in plant tissues at various growth stages for Vyttila-3, Cul. 1026 and *Chettivirippu* mutant were observed to be cent per cent fit.

52. The three rice varieties with varying leaf orientation and plant architecture revealed to have significant variation on the light infiltration to the ground level. Cul. 1026 and *Chettivirippu* mutant allowed significantly more light to reach the ground level.

53. Rice-fish integration on rice yield didn't reveal any significant effect of the fish treatments. The rice varieties significantly differed in grain yield with *Chettivirippu* mutant recording the highest yield during the first year (4396 kg ha^{-1}) and Cul. 1026 (3063 $kgha^{-1}$) during the subsequent year. There was no significant difference between them when the data were pooled (3488 and 3395 kg ha^{-1}) for *Chettivirippu* mutant and Cul. 1026, respectively. The biomass yield during the first year was significantly higher for Vyttila-3 (10241 $kgha^{-1}$) while Cul.1026 recorded the highest yield during the subsequent year (7121 $kgha^{-1}$).

54. The simultaneous rice-fish integrated farming system registered a fish survival of 36.2 to 38.9 per cent for the male tilapia against 0.0 and 16.0 per cent for Etroplus and Rohu, respectively. The corresponding fish yields were 209.1 to 224.2 $kgha^{-1}$ for male tilapia and 0.0 $kgha^{-1}$ and 25.4 $kgha^{-1}$ for Etroplus and Rohu, respectively. The rice varieties didn't exert any influence on the fish yield.
55. The rice-fish integration didn't significantly vary the soil chemical characters after the fish harvest.
56. Selective culture of Tiger prawn (*Penaeus monodon*) recorded a survival of 49 per cent and growth rate of 20 g in 74 days and gave an yield of 425 kg ha^{-1} without any supplementary feeding.
57. The soil chemical characters after the prawn harvest denoted desirable changes in pH, organic carbon and available P and K. The electrical conductivity and available Na recorded considerable increase compared to the same after the fish harvest.
58. Among the three rice varieties tried the high yielding genotypes Cul. 1026 and *Chettivirippu* mutant gave considerably higher B:C ratio of 1.93 and 1.98 respectively. Integration of male tilapia (*Oreochromis mosambicus*) with rice increased the net returns and B:C ratio. The net return was the highest (Rs.48,390/-) when tiger prawn was also included in the system. Rice-fish-prawn integration resulted in the highest B:C ratio of 2.03.

59. A comprehensive analysis of the results of the experiments brought about the following conclusions.

Tidal influx is necessary for the regulation of pH and salinity in *Pokkali* soils that has favourable influence on the growth and yield of rice. Tidal ingress is instrumental for the maintenance of soil fertility of *Pokkali* soils. Phasic regulation of tidal water by curtailing it with provision for freshwater influx during the reproductive phase can ward off Na absorption during this critical phase and thus can increase rice grain yield.

Rice grain yields higher than 4.5 t ha^{-1} is realisable without the application of either organic manure or inorganic fertilizers under the tidal situation from Cul. 1026, which is as good as Vyttila-3 in terms of salinity tolerance.

Soil application of amendments *viz.*, lime, silica and phosphorus doesn't have any favourable effect on the soil exchange complex and on the contrary triggers the release of Na to soil solution, increases the plant absorption of Na and topples down the Na: K ratio which eventually leads to decreased grain yield.

Management practices which have bearing on lesser content of Na and P in leaf at harvest and higher Ca and Mn in leaf at harvest can increase the grain yield as revealed by the significant positive correlation of these factors with the grain yield.

An integrated farming system of simultaneous culture of a high yielding saline tolerant rice cultivar like Cul. 1026 and fish species *viz.*, all male population of Tilapia (*Oreochromis mosambicus*) followed by the selective culture of Tiger

prawn (*Penaeus indicus*) is well suited to the *Pokkali*-agro-eco system. The components of this system well mingled with the nature and the produce diversity ensured reasonable economic returns. Hence, the simultaneous culture of the high yielding Cul. 1026 and male tilapia during the low saline phase and subsequent prawn culture are socially acceptable, economically viable and ecologically sound.

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* Originals not seen

APPENDIX

Appendix-I

Weekly weather at Vyttila during the experiment period from 21-06-1999 to 30-06-2001

Standard week	Maximum temperature (^0C)	Minimum temperature (^0C)	Mean temperature (^0C)	Relative humidity (%)	Rainfall (mm)
1999 25	29.8	23.7	26.8	85	168.1
26	29.6	24.4	27.0	86	133.5
27	28.9	22.9	25.9	89	452.7
28	28.2	22.8	25.5	83	60.6
29	27.6	22.7	25.2	89	213.0
30	28.5	23.1	25.8	90	434.4
31	28.1	22.9	25.5	92	135.8
32	28.8	23.5	26.2	92	169.1
33	28.7	23.6	26.2	89	89.8
34	29.2	23.9	26.6	84	120.1
35	28.5	22.9	25.7	91	192.2
36	29.1	22.9	26.0	82	120.8
37	29.9	23.5	26.7	81	11.0
38	30.7	23.4	27.1	79	38.0
39	29.5	23.3	26.4	88	144.2
40	29.1	23.4	26.3	88	86.7
41	27.7	23.5	25.6	92	7.6
42	29.3	23.3	26.3	86	76.8
43	30.0	24.1	27.1	84	16.4
44	30.8	23.7	27.3	81	6.0
45	30.1	23.5	26.8	83	5.5
46	28.4	24.1	26.3	83	6.5
47	30.9	23.3	27.1	83	16.5
48	31.3	23.7	27.5	83	0
49	32.0	22.4	27.2	82	0
50	31.5	21.7	26.6	78	0
51	32.2	21.8	27.0	70	0
52	31.2	18.5	24.9	76	0
2000 1	32.3	20.9	26.6	64	0
2	32.6	18.8	25.7	50	0
3	33.5	20.3	26.9	51	0
4	33.3	18.6	26.0	51	0
5	31.9	21.2	26.6	63	0
6	32.7	22.8	27.8	67	0
7	32.2	23.7	28.0	67	4.4
8	32.4	23.3	27.9	67	0

9	32.3	23.6	28.0	67	0
10	33.4	23.2	28.3	63	0
11	33.7	22.8	28.3	63	0
12	33.4	24.6	29.0	69	0
13	33.5	25.0	29.3	70	0
14	33.8	25.1	29.5	70	0
15	34.1	26.5	30.3	73	0
16	33.8	24.5	29.2	71	0
17	34.1	24.8	29.5	68	1.6
18	33.7	25.5	29.6	72	12.5
19	33.4	24.2	28.8	76	53.8
20	30.9	24.3	27.6	81	138.0
21	32.5	25.5	29.0	76	48.5
22	32.3	24.8	28.6	78	82.9
23	30.5	23.8	27.2	87	324.2
24	30.2	23.8	27.0	84	124.0
25	30.1	23.9	27.0	85	178.3
26	29.5	23.8	26.7	86	140.3
27	29.3	23.1	26.2	90	373.5
28	28.6	23.0	25.8	89	179.4
29	28.3	23.4	25.9	91	253.4
30	28.6	23.2	25.9	92	296.2
31	29.6	24.4	27.0	89	83.4
32	29.5	24.2	26.9	90	123.4
33	28.8	23.7	26.3	88	60.7
34	29.8	23.9	26.9	85	140.4
35	29.4	24.1	26.8	88	110.2
36	29.6	24.4	27.0	84	53.2
37	29.6	24.5	27.1	85	243.1
38	29.3	22.7	26.0	88	183.4
39	30.5	24.3	27.4	81	4.8
40	31.3	25.5	28.4	85	25.4
41	31.6	25.1	28.4	88	95.4
42	31.8	25.3	28.6	86	39.4
43	31.4	25.5	28.5	84	41.2
44	31.4	24.3	27.9	88	62.9
45	31.5	24.9	28.2	86	29.8
46	30.7	24.1	27.4	88	64.8
47	31.3	23.5	27.4	86	115.0
48	31.9	24.3	28.1	82	0
49	31.9	24.0	28.0	85	55.2
50	32.0	22.6	27.3	81	3.0
51	31.9	21.3	26.6	80	58.4

	52	32.7	22.9	27.8	78	0
2001	1	32.4	21.2	26.8	76	0
	2	32.7	21.0	26.9	70	0
	3	31:7	20.7	26.2	68	0
	4	32.1	18.9	25.5	63	0
	5	33.9	22.1	28.0	64	0
	6	33.6	23.4	28.5	68	0
	7	32.6	23.5	28.1	67	0
	8	32.3	23.2	27.8	70	0
	9	32.1	23.5	27.8	68	0
	10	32.9	23.3	28.1	63	0
	11	33.3	22.4	27.9	61	0
	12	33.2	23.8	28.5	63	0
	13	33.5	24.8	29.2	61	0
	14	33.8	24.7	29.3	67	0
	15	34.0	25.9	30.0	68	40.8
	16	34.2	25.0	29.6	71	0
	17	33.9	24.1	29.0	76	29.8
	18	33.9	25.1	29.5	78	18.0
	19	33.8	23.9	28.9	81	14.4
	20	32.0	23.6	27.8	83	190.4
	21	33.1	25.4	29.3	84	9.0
	22	33.1	25.8	29.5	87	107.2
	23	32.1	24.1	28.1	85	40.2
	24	30.8	23.7	27.3	86	143.0
	25	30.3	23.4	26.9	87	152.1
	26	30.2	23.5	26.9	89	331.0

Appendix II - Correlation matrix of the different parameters of the field experiment "Impact of ameliorants on growth, yield and nutrient uptake of *Pokkali* rice – 1999"

CORRELATION MATRIX

	BIOMASSF	Specific leaf wei (g	Chlorophyl	No. of panicles	Panicle length (cm)	Filled grain panicle-1	Chaff (%)	Thousand grain we (g)	CNF	RNH
BIOMASSF	1.00000	-0.15947	-0.28872	0.00961	-0.38421	0.13282	-0.32040	0.69403	0.34340	-0.10037
Specific leaf weight (		1.00000	-0.74438	0.48370	-0.07095	0.08974	-0.23302	0.26296	0.18636	-0.27126
Chlorophyl			1.00000	-0.45522	0.38917	-0.00927	0.21474	-0.58212	-0.15037	0.18179
No. of panicles				1.00000	-0.22155	0.26109	-0.19610	0.47110	-0.34275	0.00742
Panicle length (cm)					1.00000	-0.40076	0.71363	-0.23504	0.00987	0.10062
Filled grain panicle-1						1.00000	-0.29744	0.37448	0.26213	-0.43064
Chaff (%)							1.00000	-0.08909	-0.03010	-0.22575
Thousand grain weight								1.00000	0.44757	-0.19767
CNF									1.00000	-0.36830
RNH										1.00000

CORRELATION MATRIX

	GNH	CKAT	GKH	LCaAT	LCaH	CCaH	LMgAT	GMgH	LFeF	LMnH
BIOMASSF	-0.79151	0.40992	-0.36090	-0.00888	0.28595	-0.43886	0.20935	0.10109	0.35740	0.28820
Specific leaf weight (	-0.09882	-0.33998	0.44651	-0.90626	0.55170	0.70449	-0.68428	-0.92714	0.27374	0.52671
Chlorophyl	0.51534	0.15032	-0.03509	0.69111	-0.74909	-0.37657	0.50904	0.72454	-0.47462	-0.33274
No. of panicles	-0.08078	0.20708	-0.21453	-0.56749	0.26926	-0.00780	-0.32936	-0.47788	-0.11376	-0.23155
Panicle length (cm)	0.72109	0.39451	-0.18011	0.12633	-0.30078	0.10202	0.57455	0.06122	-0.26420	0.06461
Filled grain panicle-1	-0.16287	-0.20692	0.24643	-0.33863	0.41091	0.09984	-0.18294	-0.20537	0.43956	-0.08033
Chaff (%)	0.42669	0.17812	-0.26168	0.29228	0.09828	0.02295	0.63158	0.30375	-0.11124	-0.19414
Thousand grain weight	-0.52301	0.31407	-0.43354	-0.53867	0.65115	-0.25456	-0.00928	-0.31181	0.63624	0.09506
CNF	-0.28660	-0.29965	0.17574	-0.40204	0.44412	0.00160	-0.14963	-0.10760	0.80704	0.48685
RNH	0.40297	0.43577	-0.56200	0.23721	-0.70157	-0.45115	0.04891	0.09827	-0.23326	-0.49177
GNH	1.00000	0.13318	-0.07059	0.13321	-0.53236	0.12759	0.22814	0.00660	-0.34042	-0.38995
CKAT		1.00000	-0.78009	0.24212	-0.32022	-0.48823	0.70149	0.14692	-0.27955	-0.20987
GKH			1.00000	-0.25452	0.20412	0.75996	-0.53297	-0.31625	0.00518	0.57522
LCaAT				1.00000	-0.59931	-0.44527	0.65000	0.87242	-0.50936	-0.38910
LCaH					1.00000	0.40336	-0.27090	-0.48642	0.66465	0.34901
CCaH						1.00000	-0.38150	-0.68751	0.05708	0.54718
LMgAT							1.00000	0.56885	-0.26470	-0.20153
GMgH								1.00000	-0.32701	-0.42441
LFeF									1.00000	0.19917
LMnH										1.00000

CORRELATION MATRIX

	GMnH	GCuH	LZnAT	CZnAT	Organic carbon (%)	Total N (%)	Available N (%)	Total P (%)	Available P (kg ha-1)	Available K (%)
BIOMASSF	0.53252	0.29520	-0.22711	-0.54018	0.16431	0.30771	-0.26318	0.14968	0.10699	-0.37272
Specific leaf weight (	0.41706	0.54650	-0.59796	-0.18521	0.03078	0.16260	-0.47829	0.08109	0.03102	0.50346
Chlorophyl	-0.30741	-0.69793	0.73283	0.36365	-0.18833	-0.29213	0.40877	-0.37400	-0.08312	-0.38572
No. of panicles	-0.14956	0.45964	-0.35313	0.32015	-0.44401	0.07672	-0.08373	0.21154	0.49733	0.44849
Panicle length (cm)	0.06765	-0.66714	0.62284	0.29980	-0.19099	0.45732	-0.37680	-0.39600	0.48065	-0.25534
Filled grain panicle-1	0.05790	-0.09145	-0.37055	-0.17808	-0.09581	0.10767	-0.13879	0.20107	-0.32593	-0.26462
Chaff (%)	-0.27126	-0.54265	0.59800	0.48473	-0.14504	0.42515	-0.26950	0.21320	0.42522	-0.06579
Thousand grain weight	0.33743	0.25571	-0.53110	-0.22489	-0.28205	0.68157	-0.66073	0.16631	0.23378	-0.12723
CNF	0.53325	-0.05622	-0.38267	-0.31106	-0.15994	0.46624	-0.72742	-0.21093	-0.47545	-0.18455
RNH	-0.36480	-0.17993	-0.03459	0.04815	-0.20865	-0.05530	0.32968	-0.68630	0.08792	-0.15491
GNH	-0.42418	-0.70470	0.40647	0.44795	-0.30309	0.08769	0.06352	-0.53009	0.15211	-0.12869
CKAT	0.08873	-0.31446	0.36295	-0.03124	-0.12251	0.46830	-0.11778	-0.24344	0.76699	-0.52743
GKH	0.31820	0.24740	-0.11081	-0.21520	0.41542	-0.47329	0.08226	0.20043	-0.52607	0.29875
LCaAT	-0.40104	-0.43323	0.73666	0.15733	0.24784	-0.35912	0.64126	0.05352	0.02967	-0.34587
LCaH	0.31847	0.38712	-0.53082	-0.25428	0.13363	0.42672	-0.58196	0.62974	-0.05629	0.19204
CCaH	0.33357	0.16147	-0.16029	-0.29844	0.52077	-0.04226	-0.18376	0.25749	-0.12263	0.22334
LMgAT	-0.03700	-0.68228	0.76466	0.08124	0.07372	0.39028	-0.04616	0.00874	0.51939	-0.66179
GMgH	-0.41733	-0.37658	0.64079	0.37649	-0.13176	-0.29299	0.46412	0.02894	-0.05841	-0.21538
LFeF	0.29575	0.02655	-0.71015	-0.44137	-0.05636	0.56677	-0.64932	-0.02334	-0.48683	-0.20630
LMnH	0.92181	0.34084	-0.12170	-0.57259	0.46593	0.10578	-0.47150	0.04890	-0.08776	0.01747
GMnH	1.00000	0.22519	-0.16565	-0.69082	0.38179	0.32355	-0.57886	-0.07942	0.02659	-0.26016
GCuH		1.00000	-0.53863	-0.14646	0.13277	-0.36495	0.09145	0.40440	-0.03511	0.69282
LZnAT			1.00000	0.39157	0.07200	-0.14236	0.29230	0.02785	0.43510	-0.23918
CZnAT				1.00000	-0.71979	-0.19075	0.20097	0.03335	0.28993	0.50533
Organic carbon (%)					1.00000	-0.19892	0.22865	0.36653	-0.15007	-0.26125
Total N (%)						1.00000	-0.85752	-0.15111	0.35431	-0.45600
Available N (%)							1.00000	0.13565	-0.15856	0.16085
Total P (%)								1.00000	0.14104	0.30428
Available P (kg ha-1)									1.00000	-0.00501
Available K (%)										1.00000

CORRELATION MATRIX

	Available Na (%)	Available Ca (ppm)	Available Mg (ppm)	Available Cu (ppm)	Available Zn (ppm)	Available Fe (ppm)	Available Mn (ppm)	Grain
BIOMASSF	0.03902	-0.20547	-0.07363	0.42502	0.32680	0.15605	-0.30948	0.27490
Specific leaf weight (	0.24739	0.36696	0.59359	-0.04592	0.32682	0.43297	0.65211	0.67897
Chlorophyl	-0.21059	-0.05869	-0.44020	-0.33755	-0.52771	-0.46134	-0.33201	-0.63600
No. of panicles	0.50383	-0.14000	0.44912	0.47200	0.75568	0.41743	0.12665	0.00759
Panicle length (cm)	-0.32145	0.59223	-0.36587	-0.00101	-0.28964	-0.57130	-0.35074	-0.39329
Filled grain panicle-1	-0.14305	0.01326	-0.25021	0.01832	-0.06443	-0.14538	0.33160	0.32237
Chaff (%)	-0.21030	0.24914	0.46061	0.24896	-0.13686	-0.49262	-0.27200	-0.32729
Thousand grain weight	0.18175	0.20068	-0.00326	0.48213	0.39091	0.15441	-0.15482	0.36501
CNF	0.03022	0.62101	-0.04366	-0.42921	-0.46828	0.04365	0.18595	0.62162
RNH	-0.08251	0.06324	-0.02039	-0.08947	-0.14880	-0.11054	-0.64579	-0.65244
GNH	-0.32795	0.46037	-0.31280	-0.26096	-0.45665	-0.55970	-0.22531	-0.59897
CKAT	-0.24527	0.00205	-0.39158	0.65820	0.31781	-0.39870	-0.83269	-0.57690
GKH	-0.00169	-0.00386	0.31976	-0.52113	-0.18913	0.22436	0.90366	0.62508
LCaAT	-0.29340	-0.50406	-0.48015	0.06204	-0.23656	-0.38489	-0.51000	-0.65747
LCaH	0.07993	0.12340	0.08788	0.30159	0.29913	0.20027	0.47582	0.76010
CCaH	-0.27885	0.21441	0.15674	-0.11345	0.01045	-0.03447	0.73055	0.55827
LMgAT	-0.49768	-0.02900	-0.76853	0.47379	-0.08862	-0.71703	-0.72374	-0.57804
GMgH	0.04263	-0.40692	-0.35099	-0.07379	-0.27191	-0.17840	-0.47018	-0.56220
LFeF	-0.12794	0.50471	-0.15223	-0.15974	-0.31996	-0.02738	0.13593	0.60604
LMnH	-0.03360	0.25242	0.28738	-0.14775	0.05601	0.22203	0.48417	0.75626
GMnH	-0.14296	0.30784	0.10685	0.02092	0.08860	0.07769	0.22463	0.65619
GCuH	0.66052	-0.41976	0.84593	0.10565	0.66650	0.90905	0.50098	0.55210
LZnAT	-0.22433	-0.20039	-0.40109	0.14580	-0.09094	-0.45191	-0.35670	-0.60660
CZnAT	0.53546	-0.06497	0.18333	-0.06490	0.07899	0.14710	-0.07212	-0.51322
Organic carbon (%)	-0.57343	-0.33345	-0.19355	0.16967	0.03771	-0.19294	0.21382	0.30729
Total N (%)	-0.33786	0.67746	-0.45424	0.36970	-0.06062	-0.45635	-0.39429	0.09423
Available N (%)	0.05467	-0.78132	0.08397	-0.07477	0.06614	0.11484	-0.02931	-0.48495
Total P (%)	0.11951	-0.60189	0.04644	0.52740	0.54665	0.20553	0.38668	0.31918
Available P (kg ha-1)	0.05403	-0.07959	-0.05045	0.77217	0.65650	-0.12778	-0.43689	-0.40796
Available K (%)	0.80448	-0.21075	0.85975	-0.17524	0.41081	0.81087	0.56561	0.24173
Available Na (%)	1.00000	-0.21737	0.82711	-0.14003	0.43767	0.88690	0.27871	0.14904
Available Ca (ppm)		1.00000	-0.15748	-0.36681	-0.52150	-0.31887	-0.03880	0.18408
Available Mg (ppm)			1.00000	-0.24559	0.45043	0.94194	0.52994	0.38310
Available Cu (ppm)				1.00000	0.74038	-0.16391	-0.37178	-0.18317
Available Zn (ppm)					1.00000	0.48993	0.07260	0.08351
Available Fe (ppm)						1.00000	0.47520	0.42735
Available Mn (ppm)							1.00000	0.74436
Grain								1.00000

Significance Levels	*0.05*	*0.01*	*0.005*	*0.001*
If correlation r =>	*0.66638*	*0.79767*	*0.83588*	*0.89825*

ENHANCING THE PRODUCTIVITY OF THE RICE-FISH/PRAWN FARMING SYSTEM IN *POKKALI* LANDS

By

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ABSTRACT OF THE THESIS

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ABSTRACT

A research project entitled "Enhancing the productivity of the rice-fish/prawn farming system in *Pokkali* lands" was carried out from 1999 to 2001 at the Rice Research Station, Vyttila under the Kerala Agricultural University. The objective of the research project was to characterise the *Pokkali* rice-fish/prawn system through critical analysis of the component factors, so as to evolve an ideal technology to have higher productivity from *Pokkali* lands.

Four experiments were conducted to achieve the above objective. The first experiment entitled "Response of rice to applied N in tidal and non-tidal situations studied the role of tides on regulation of soil chemical properties and enrichment of plant nutrients in *Pokkali* soils. This pot culture study revealed the significant contribution of tides on increasing the soil pH, available K, straw yield and productive tillers. The soil pH showed significant positive correlation with available K.

The field experiment entitled "Tidal effect on *Pokkali* soils and performance of rice" compared the performance of three rice cultivars under the tidal and non-tidal situations and studied the influence of tides on the chemical properties of *Pokkali* soil during the low saline rice crop phase and high saline post rice phase. The tidal influx brought about significant changes in the chemical properties of the soil. It significantly increased the soil pH, organic carbon, available P and, available and exchangeable K. Though the difference was not significant, the electrical conductivity and, available and exchangeable Na were higher under the tidal situation. Tidal regime favoured higher

grain, straw and biomass production while non-tidal situation favoured a higher grain : straw ratio.

The Na content in plant tissues were two to three fold higher under the tidal regime than the non-tidal situation up to the flowering stage and both the regimes had almost same Na content subsequently. N content was always higher under the tidal situation irrespective of the plant tissue, varieties and year of study. Among the varieties Vyttila-3 and Cul. 1026 had the lower Na content and Na : K ratio which implied the effective saline tolerant mechanism operating within them.

Two levels each of lime, silica, phosphorus and sulphur, tried individually during the first year and in combination subsequently, caused considerable variation in soil chemical characters and, growth, physiological characters and yield of rice. The ameliorants significantly increased the electrical conductivity and exchangeable K of the soil. The sulphur application decreased the soil pH while lime increased it. Lime application increased the availability of K and Na, while lime + phosphorus combination increased the exchangeable K and Na. Higher levels of ameliorants considerably increased the availability of Na compared to the lower levels and the non-ameliorated control treatment. Sulphur at 600 kg ha^{-1} had the highest grain Mn, leaf Mn and Ca at harvest, specific leaf weight and, significantly higher grain, straw and biomass production.

The field experiment entitled "Plant ideotype suited to rice-cum-fish culture in *Pokkali* fields" evaluated the compatibility of three rice varieties of varying plant architecture with three fish treatments. The rice varieties revealed to have significant variation for light infiltration, growth characters, yield, yield attributes and biomass production. Considering the light infiltration, grain yield, biomass production and B:C ratio Cul. 1026 was more suitable for rice-fish culture in *Pokkali* fields. Among the fish species tried male Tilapia (*Oreochromis mosambicuss*) gave higher survival rate (38.9%) and fish yield (224.2 kg ha^{-1}). Selective culture of Tiger prawn (*Penaeus monodon*) after the rice-fish dual culture recorded a survival rate of 49.00 per cent, growth rate of 20 g in 74 days and an yield of 425 kg ha^{-1}. The integrated farming system involving rice-fish dual culture during the low saline phase and selective culture of Tiger prawn subsequently is capable of increasing the productivity and income from *Pokkali* lands.