CERTIFICATE

Certified that this thesis entitled "**Input optimization for medicinal rice (*Oryza sativa* L.) cv. Njavara.**" is a record of research work done independently by Shri N. Sriramkumar (2005-21-102) 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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Dedicated to my beloved parents Mrs. Rajeswari.N & Neelamegam.R

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N. Sri

N. SRIRAMKUMAR

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LIST OF ABBREVIATIONS

BCR	–	Benefit cost ratio
CD (0.05)	–	Critical difference at 5 % level
CEC	–	Cation exchange capacity
cfu g^{-1}	–	Colony forming units per gram
cm	–	Centimetre
cm^2	–	Square centimetre
cm^3	–	Cubic centimetre
CO_2	–	Carbon dioxide
cv	–	Cultivar
DAS	–	Days after sowing
day^{-1}	–	Per day
DMP	–	Dry matter partitioning
et al.	–	And others
Fe	–	Iron
Fig.	–	Figure
FYM		Farm yard manure
g	–	Gram
g cc^{-1}	–	Gram per cubic centimetre
g $hill^{-1}$	–	Gram per hill
HI	–	Harvest index
i.e.	–	That is
INM	–	Integrated nutrient management
K	–	Potassium
K_2O	–	Potassium
kg	–	Kilogram
kg^{-1}	–	Per kilogram
kg ha^{-1}	–	Kilogram per hectare
LAI	–	Leaf area index
m	–	Metre
m^{-2}	–	Per square metre
mg	–	Milligram
mm	–	Millimetre
Mn	–	Manganese
MRP	–	Mussorie Rock Phosphate

N	–	Nitrogen
NR activity	–	Nitrate reductase activity
NS	–	Non significant
P	–	Phosphorus
P_2O_5	–	Phosphate
PI stage	–	Panicle initiation stage
$Plant^{-1}$	–	Per plant
POP of KAU	–	Package of Practices Recommendations of Kerala Agricultural University
ppm	–	Parts per million
RDF	–	Recommended dose of fertilizers
RH	–	Relative humidity
Rs	–	Rupees
S	–	Sulphur / Significant
SE	–	Standard error of mean
t ha^{-1}	–	Tonnes per hectare
viz.	–	Namely
WHC	–	Water holding capacity
Zn	–	Zinc

LIST OF SYMBOLS

%	–	Per cent
μg	–	Micro gram
°C	–	Degree Celsius
@	–	At the rate of
&	–	And

INTRODUCTION

1. INTRODUCTION

Njavara, a unique short duration rice variety of Kerala is much famed for its use in Ayurveda. It is the main ingredient of the Ayurvedic treatment "Njavarakizhi", which is mainly used in the treatment of rheumatic ailments (Panchakarma). Being a high value unique land race of Kerala, it is imperative to intervene scientifically in the cultivation practices of Njavara for sustaining the productivity of this indigenous genetic resource of Kerala, which is fast shrinking to extinction.

'Ashtanga Hridaya' (Vagbhata, 500 B.C.) described two types of Njavara – black and white glumed, of which the latter is superior. However, the yield and quality of Njavara varies with the location. The 'Sushrutha Samhitha' (Sushruthacharya, 2500 B.C.) cited Njavara as a special cereal, having properties to rectify the basic ills affecting the circulatory, respiratory as well as the digestive system. However, it described black glumed Njavara as being the best.

Fu *et al.* (1991) reported anthocyanidin, flavanones and steroids as the medicinally active constituents of black glutinous rice. Elsy *et al.* (1992) reported that Njavara is having a duration of 69 days and has a productivity of 2 t ha^{-1} under lowland situations. Menon and Potty (1999) opined that black glumed Njavara had better quality compared to yellow glumed type.

The success of rice production depends on how best the crop can utilize the two basic inputs, nutrients and water. Nutrient management in rice is an important area to be investigated. Neglecting the importance of soil organic matter in crop production and prolonged over use of soluble chemical fertilizers with more emphasis to primary nutrients alone, apart from lowering the land productivity, have also increased pest and disease infestation, resulted in human health hazards and environmental pollution. Long-term fertilizer experiments in India have clearly demonstrated that in addition to fertilizers, the use of organic manures is essential to sustain crop productivity. At present, on an average, about 2 t ha^{-1} of organic manures are being used annually, which is far below the general recommendation of 10-20 t ha^{-1} (IFA, 2007).

The continuing energy crisis, higher fertilizer price, increasing concern over soil pollution due to indiscriminate use of chemical fertilizers and imbalanced use of nutrients have thrown light over specific integrated nutrient management practices for rice. Integrated nutrient management is defined as a system approach wherein, all the possible components such as on-site resource generation, mobilization of off-site nutrient resources, resource integration and management are given equal importance (Agrawal, 2006).

Integrated use of organics with inorganics enables to conserve the nutrients, release nutrients at a slower rate and improve the physico-chemical and biological conditions of the soil. However, the variations in the quantity and proportion of N, P and K limit the efficiency of organic manures. Hence, the challenge is to combine organic manures of different quality with chemical fertilizers to optimize nutrient availability (Palm *et al.*, 1997). Organic farming is reported to have favourable effects on rice qualities under long term application.

With increasing scarcity of available fresh water for agriculture, rice cultures in the future have to compete with other cropping options in consuming less water. Under this circumstance "more rice with less water" would become the agenda of the rice research. Drought tolerant nature of Njavara can be exploited for studying the response of the crop to moisture regime other than submergence. So far no such study has been taken up to identify an ideal moisture regime for Njavara cultivation.

Keeping all the above in view, an assessment of the effect of input optimization for medicinal rice (*Oryza sativa* L.) cv. Njavara under different moisture regimes, will be useful for evolving an economically viable and environmentally safe management strategy for sustaining the productivity of Njavara. With this background, the present investigation entitled "Input optimization for medicinal rice (*Oryza sativa* L.) cv. Njavara." was undertaken with the following objectives.

- To evolve an ideal nutrient schedule for two moisture regimes for sustaining the productivity of Njavara
- To investigate the effect of nutrient regimes and nutrient sources on the physical, chemical and biological properties of soil under two moisture regimes
- To work out the economics of Njavara cultivation under two moisture regimes

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Research evidences proved beyond doubt that the practice of integrated nutrient management and organic agriculture was evinced during the last twenty five years and has generated world wide debate on the possibility of sustainable systems, which can be viable alternatives to conventional agriculture (USDA, 1980; Bezdicek and Power, 1984). Chemical residues were a major problem in modern agriculture and could be minimized by resorting to organic agriculture (Sharma and Mittra, 1990). Because of looming water scarcity, there is need to develop alternative systems of rice production that require less water for more rice. The research work done in these aspects on rice under the investigation "Input optimization for medicinal rice *(Oryza sativa* L.*)* cv. Njavara" is reviewed in this chapter. Since the research work done on input optimization for medicinal rice with special reference to njavara is very limited, relevant literature on integrated nutrient supply systems in non-njavara rice was also reviewed, with emphasis on the effect of levels and sources of organics.

The literature relevant to the investigation is reviewed under the following captions.

2.1. Effect of organic manures on growth, yield attributes, yield and quality of rice

2.2. Effect of organic manures on nutrient uptake

2.3. Effect of organic manures on the available nutrient status of the soil

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2.1. Effect of organic manures on growth, yield attributes, yield and quality of rice

Farm yard manure is the most commonly used organic manure by the farmers of Kerala. Farm yard manure (FYM) is a good source of both macro and micronutrients and has both direct and residual effect in plant nutrition. Use of organic materials improved the physical, chemical and biological properties of soil leading to betterment of soil quality and also increases the fertilizer use efficiency (Dick and Gregorich, 2004).

Application of FYM significantly increased tiller number of rice (Satyanarayana *et al.*, 2002). Application of FYM @ 10 t ha^{-1} produced better growth of rice in terms of taller plants and more dry matter accumulation (Singh *et al.*, 2002). Favourable effect of organic manures in improving the growth attributes of rice has also been reported by Kumar *et al.* (2002) and Mahavishnan *et al.* (2004). Highest LAI and DMP were obtained in FYM treated plots and it was significantly different from other treatments (Tamal and Sinha, 2006).

Deepa (1998) found that number of panicles and thousand grain weight of rice variety Kanchana was better in plots which received organic manure, when compared to treatments which received 100 per cent recommended NPK through chemical fertilizers. Sudha (1999) observed that organic manure application at different levels and through different sources could not produce any significant impact on the total and filled grains panicle^{-1} in rice. Dwivedi and Thakur (2000) reported that organic manure application had no significant effect on thousand grain weight. Pandey *et al.* (2001) observed the beneficial effect of organic manures in influencing the panicle weight of rice. Application of FYM significantly increased filled grains panicle^{-1} and thousand grain weight of rice (Satyanarayana *et al.*, 2002). Bridgit and Potty (2002) observed significant influence of FYM in increasing the number of filled grains and filling percentage. Dutta and Bandyopadhyaya (2003) reported that yield components of rice were significantly higher in FYM treated plots as compared to unfertilized control. Under rice-rice cropping system, higher number of panicle bearing tillers, ear heads and thousand grain weight were more in organic manure applied plots as compared to inorganic fertilized plots (Satheesh and Balasubramanian, 2003). Treatment with neemsaar (Mixture of oilcakes and cowdung) resulted in highest number of panicles m^{-2} and filled grains in rice (Bhattacharya *et al.*, 2004).

Sharma (1994) stated 26 per cent increase in yield of rice with the application of 10 t ha^{-1} of FYM. Sharma and Sharma (1994) also obtained significantly higher grain yields of rice through FYM incorporation. Rathore *et al.* (1995) reported significantly higher grain yield of rice with FYM addition. Deepa (1998) found that straw yield of rice variety Kanchana was better in plots which received organic manure, when compared to treatments which received 100 per cent recommended NPK through chemical fertilizers. There was a linear increase in the yield of rice with the increasing levels of FYM, the maximum being with FYM at 10 t ha^{-1} (Tiwari *et al.*, 2001).

Application of farmyard manure at 10 t ha^{-1} increased grain yield of rice by 25 per cent compared to no farmyard manure control. Application of FYM significantly increased straw yield of rice (Satyanarayana *et al.*, 2002). Dutta and Bandyopadhyaya (2003) reported that yield of rice was significantly high in FYM treated plots as compared to unfertilized control. Grain yield of rice increased significantly with the application of organic manures over the recommended NPK (through chemical fertilizer) during two years (1996 and 1997) of experimentation (Satheesh and Balasubramanian, 2003). Application of neemsaar (mixture of oilcakes and cow dung) increased the grain yield of rice over chemical fertilizers (Bhattacharya *et al.*, 2004). Significantly higher grain and straw yield was obtained in FYM treated plots (Tamal and Sinha, 2006). Roul and Mahapatra (2006) observed that application of N as granulated compost gave the highest grain yield of rice, and produced maximum number of panicle m^{-2}, filled spikelets $panicle^{-1}$ and test weight.

Sharma and Sharma (1994) reported significant increase in the straw yield of rice with FYM incorporation. Babu (1996) could observe significant increase in the straw yield of rice variety Pavizham with FYM addition @ 10 t ha^{-1}. However, he could not observe any significant impact on harvest index. Sudha (1999) and Sindhu (2002) reported that different levels and sources of organic manures could not significantly influence straw yield and harvest index.

Difference in quality characters of aromatic rice cultivars consequent to organic manure application have been reported by Tripathi *et al.* (1995) and Singh *et al.* (1997). Sudha (1999) showed significant influence on chlorophyll content of rice with higher levels of FYM addition (10 t ha^{-1}). Hemalatha *et al.* (2000) observed higher crude protein content in rice grains from plots treated with organic manures *viz.*, FYM, dhaincha and sunhemp, than control plots. They also reported that incorporation of organics increased the optimum cooking time of rice over control.

2.2. Effect of organic manures on nutrient uptake

Rathore *et al.* (1995) reported that application of organic manures including FYM could increase NPK uptake in rice. On the contrary, Babu (1996) reported that the uptake of N, P and K by rice was not influenced by the application of organic manures, even @ 10 t ha^{-1}. Dhillon (1998) observed higher NPK uptake in rice-wheat cropping system, with the application of FYM as compared to absolute control and graded levels of nitrogen. Tiwari *et al.* (2001) reported that concentration of N, P and K in grain and straw increased significantly with the application of FYM @ 5 t ha^{-1}.

Dutta and Bandyopadhyaya (2003) observed increased uptake of nutrients (N, P and K) when FYM was applied to the rice compared to control. Total nutrient uptake by rice differed significantly due to organic manure application which exhibited 22.7 per cent and 21.5 per cent higher total P and K respectively in both the seasons of study (rabi and kharif) when compared to chemical nitrogen fertilizer applied treatments (Satheesh and Balasubramanian, 2003). Khan *et al.* (2006) observed the application of FYM increased the total nitrogen uptake and attributed it to the favourable effects of organic manures on the physico-chemical properties of the soil.

2.3. Effect of organic manures on the available nutrient status of the soil

Neem, mahua, and castor cakes have great value as means of immobilizers, thus conserving the applied and soil nitrogen and mineralizing steadily over a longer period (Sathianathan, 1982). Swarup (1984) reported that application of FYM increased the availability of both native and applied micronutrient cations. These cations form stable complexes with organic ligands which decrease their susceptibility to adsorption and fixation. Srivastava (1985) observed that increased use of nitrogenous fertilizers decreased organic carbon content, total N and available P and K status of soil whereas FYM addition increased all these parameters in the soil.

Sharma and Sharma (1994) reported that incorporation of FYM in rice could increase the soil organic carbon and available N, P and K status. Waghmer (1998) reported higher available NPK content in soil with the application of FYM @ 10 t ha^{-1}. Considerable improvement in available N status of soil due to the application of FYM has been reported by Gupta *et al.* (1998). Chellamuthu *et al.* (1998) found that K availability in soil was increased significantly by FYM application. Sudha (1999) reported that organic manure addition at all levels could maintain the available N, P, K and S status of soil well above the original status before the experiment. Addition of FYM improved the N, P and K status of soil (Bandgopadhyay and Puste, 2002). Charjan and Gaikwad (2005) stated that application of nutrients through organic manures reduced the losses of nutrients and ultimately increased the NPK balance of the soil. Application of FYM significantly increased the ammonical nitrogen content of soil and the increase reported was from 30.1 to 110.1 mg kg^{-1} soil (Duha *et al.*, 2005). Singh *et al.* (2005) suggested that lowest amount of K was leached from FYM treatment (1.8 %) as compared to poultry manure (17.3 %), fertilizer K (15.8 %) and rice straw (14.4 %).

Roul and Mahapatra (2006) reported a continuous supply of nitrogen by organic manure addition, preventing loss of N through denitrification, volatilization or leaching. Further, nitrogen enriched manures maintained a higher level of available N and P in soil for a longer period than fertilizer alone. They also found that cattle manure improved the organic carbon, P and K contents of soil. Khan *et al.* (2006) also reported an enhanced soil nitrogen supply due to FYM application.

2.4. Effect of organic manures on the soil properties

The favourable effect of FYM application on the structural properties of the soil was observed by several workers. Aravind (1987) observed that when FYM was applied as an organic source of nitrogen, bulk density of soil lowered form 1.30 to 1.06 g cc^{-1} compared to the poultry manure application, which lowered the same from 1.30 to 1.10 g cc^{-1}. Maheswarappa *et al.* (1999) reported a decrease in soil bulk density value from 1.55 g cc^{-1} to 1.38 g cc^{-1} with the application of FYM @ 32 t ha^{-1}. According to Singh *et al.* (2000) application of FYM significantly brought down the bulk density of both surface and subsurface soil in comparison with the control. However, application of different levels of fertilizer did not affect the bulk density.

Increase in soil moisture retention due to addition of FYM was observed by Salter and Williams (1963). Biswas *et al.* (1969) observed that application of FYM in a rice fallow rotation for ten years improved the water retention characteristics of an alluvial sandy loam soil.

Lal and Mather (1988) reported that application of N, P and K fertilizers reduced the pH from 5.5 to 3.8 but FYM application maintained or increased the pH of the soil, while the combination of fertilizers and manures decreased the pH. FYM application resulted in lowest acidity due to the decrease in exchangeable and soluble aluminum in soil (Nambiar, 1994).

Srivastava (1985) observed that increased use of nitrogenous fertilizer decreased organic C content and total N, while FYM increased the above parameters. Application of neem cake added organic carbon and potash to the soil (Sadanandan and Iyer, 1986). Udayasoorian *et al.* (1988) reported that carbon content of soil increased form 0.91 to 1.58 per cent by the continuous application of organic manures and among the organic manures FYM had a significant influence.

Increase in cation exchange capacity by the application FYM alone or in combination with fertilizers or lime and a reduction in CEC by the application of fertilizers alone was noticed in the permanent manurial experiment conducted by Sharma *et al.* (1988) at Chotanagpur.

Organic manure contains large population of bacteria, actinomycetes and fungi. Addition of organic manure profoundly influences the different groups of microorganisms in the rice rhizosphere (Bhattacharya *et al.*, 1996). Maheswarappa *et al.* (1999) opined that organic amendments produce more microbial biomass than inorganic fertilizers because they increase the proportion of labile carbon and nitrogen directly stimulating the activity of microorganisms.

Gopalaswamy and Kannaiyan (2000) reported that increased microbial population was highest in FYM and vermicompost applied treatments.

2.5. Effect of organic manures on soil enzyme activity

Soil enzymes catalyze reactions in soils that are important in the transformation of nutrients such as C, N, P and S. Thus the level of enzyme activity can be used as an indicator of soil fertility (Skujins, 1976). Soil enzymes play an important role in the mineralization process and also many other soil biological reactions (Tate, 1987). Urease catalyzes the hydrolysis of urea to CO_2 and NH_3 and its activity in soil decides directly the hydrolysis of urea and indirectly its loss due to volatilization and denitrification (Srinivas *et al.*, 2004).

Phosphatase perform an important function in soil by transforming organic P to inorganic phosphate. Although organic P in soil accounts for up to 80 per cent of total soil P, it is considered to be unavailable to plants unless first mineralized by the action of phosphatase. In addition to the hydrolysis of soil organic P compounds, phosphatase take part in the hydrolysis and subsequent reuptake of P esters leaked from plant roots (Hayes *et al.*, 1999).

Dehydrogenase is considered to exist in soil as integral parts of intact cells and is thought to reflect the total range of oxidative activities of soil micro flora. Bergstrom *et al.* (1998) suggested that dehydrogenase activity is a respiratory measurement and hence is more strongly representative of the size and activity of viable microbial community than the activity of other soil enzymes, which exist in viable cells and as enzymes stabilized in soil matrix.

Soil enzymes are produced by living organisms and hence it is obvious that any action altering the life functions of soil organisms could indirectly affect soil enzyme activities. Incorporation of organic amendments in soil promotes microbial and enzyme activity (Balasubramanian *et al.*, 1972).

Studies relating to the effect of soil properties on the level of urease activity have indicated that the activity tends to increase with organic matter content (Silva and Perera, 1971). Harrison (1983) suggested a positive relationship between phosphatase and organic matter content since the enzyme was seen bound to humic–protein complex. Briton (1989) reported that addition of farmyard manure annually for 18 years to a Swedish soil under a wheat-clover-grass-potato rotation increased both the dehydrogenase activity and soil respiration thus increasing the microbial population. Haider *et al.* (1991) observed an increased C: N ratio due to the application of cow dung along with oil cake, resulting in an increased microbial biomass carbon, activity of urease and dehydrogenase. Gupta *et al.* (1992) suggested FYM as a good source of P and attributed increased levels of enzyme activities and microbial biomass due to the decomposition products of the manure. According to Goyal *et al.* (1993), the application FYM increases the microbial biomass and also the enzyme activities.

Joseph and Prasad (1993) found that neem cake inhibited the activity of urease by reducing the hydrolysis of urea derived NH_4. Aparna (2000) reported that application of organic amendments in combination with lime and fertilizers recorded higher activities of urease, phosphatase and dehydrogenase than that of FYM or green leaf manure alone. A pot culture experiment and laboratory incubation studies were carried out to evaluate the addition of different organic manures on soil urease activity using rice as test crop. Urease activity increased during the active growth period of rice (20-60 DAT) and the activity decreased to initial low levels at harvest. Among the organic manures, FYM @10 t ha^{-1} recorded significantly higher urease activity as compared to poultry manure, paddy straw and green manures. Urease activity also increased up to 60 days and there after decreased in the soils incubated with different organic manures (Srinivas *et al.*, 2004).

2.6. Effect of organic manures on incidence of pest and disease

Lyashenko *et al.* (1982) reported that higher levels of leucoanthocyanins, catachins and flavanolglycosides and phenol carboxylic acid in plants that received FYM and cause lower pest attack. Chino *et al.* (1987) opined that asparagines content of plant phloem sap was significantly lower under organic cultivation there by adversely affecting the feeding activity of BPH. Surekha and Arjuna Rao (2001) reported that higher levels of polyphenol contents in organic manure (FYM and Vermi compost) treated plots cause low pest build up. Atteri and Nicholls (2003) reported that the crops grown on soils with high organic matter and active soil organisms tend to be less infested with insect pests.

2.7. Effect of integrated nutrient management on the growth, yield attributes, yield and quality of rice

Application of organic manures along with inorganic fertilizers led to increased productivity of the system and also sustained the soil health for longer period (Hegde and Dwivedi, 1992). Integrated nutrient management involves the judicious use of organic, chemical and / or microbial sources so as to sustain optimum yields and to improve or sustain the soil health to provide crop nutrition packages which are technically sound, economically attractive, practically feasible and environmentally safe (Ahlawat, 1997).

Nutrient supply is the key factor in crop production. But imbalanced nutrition is a matter of concern for sustained production. In spite of heavy inputs the crop yields are declining because of limitation of one or more micro nutrients (Swarup *et al.*, 1998). Use of organic manures has been prescribed as the remedy to this declining trend in yield. However, organic sources alone cannot meet the total nutrient requirement of modern agriculture and hence integrated use of nutrients is regarded as appropriate (Gawai and Pawar, 2006).

In an experiment conducted on INM at Regional Agricultural Research Station, Pattambi, Mathew *et al.* (1994) observed higher plant height and tiller count in rice with the combined use of FYM @ 10 t ha^{-1} along with chemical fertilizers. Peeran and Sreeramulu (1995) found that application of FYM along with urea gave significantly taller plants than urea alone. Babu (1996) observed that the integration of FYM @ 10 t ha^{-1}along with chemical fertilizers could increase the plant height, tiller count, LAI and DMP of medium duration rice variety pavizham. Jadhav *et al.* (1997) in a pot culture experiment conducted on rice with INM, observed that the DMP was highest with 25 per cent substitution of urea with organic manure. Dubey and Verma (1999) found out an improvement in growth characters of rice with conjunctive fertilizer N and organic sources.

Singh *et al.* (2000) opined that the combined application of FYM @ 6.5 t ha^{-1} and NPK @ 120:60:40 kg ha^{-1} produced almost double the root mass than NPK alone. The growth parameters *viz.*, plant height, number of tillers and dry matter content were significantly improved by the application of 100 per cent RDF through urea + 25 per cent RDF through FYM. This was attributed to the adequate quantity of nitrogen made available to the crop, which in turn favoured vigourous and luxuriant growth. Application of organic manure promoted growth of rice by increasing plant height (Bayan, 2000). Growth characters were improved by integrated use of organic and inorganic fertilizers in rice (Patra *et al.*, 2000). Jha *et al.* (2004) reported that the application of inorganic fertilizers at 30:20:15 kg NPK ha^{-1} in combination with cow dung urine mix significantly increased the plant height. The inorganic fertilizer application of 60:40:30 kg NPK ha^{-1} along with FYM 5 t ha^{-1} produced highest plant height, LAI, number of tillers $hill^{-1}$ and DMP in scented rice (Santhosh *et al.*, 2004). Vasantharao *et al.* (2004) observed that growth characters like plant height, tiller number, leaf area index and dry matter production increased in those treatments which received combination of 50 per cent N each through fertilizer and different organic sources like FYM and neem cake. Integrated use of organic and inorganic manures accelerated the growth components compared to inorganic fertilizer application.

The growth was more with combined application of chemical fertilizer and FYM as compared to 100 per cent NPK. Organic manures in combination with inorganic fertilizers were superior to application of inorganic fertilizers alone, in promoting growth of rice (Ganapathy *et al.*, 2006).

Singh *et al.* (1998) noted an increase in the grain number panicle^{-1} and thousand grain weight of rice with higher NPK rates along with 7.5 t ha^{-1} FYM. Sudha (1999) found that combination of 10 t ha^{-1} of FYM along with the highest NPK dose recorded higher panicle number m^{-2} and grain number panicle^{-1} of rice. Yield characters were improved by the integrated use of organic and inorganic fertilizers in rice (Patra *et al.*, 2000). Panicle length, number of filled grains panicle^{-1} and 1000 grain weight increased significantly due to combined application of 100 per cent RDF through urea + 25 per cent RDF through FYM (Dwivedi and Thakur, 2000). Bastia (2002) reported that the number of panicles m^{-2}, weight panicle^{-1}, total grain panicle^{-1}, filled grains panicle^{-1}, test weight and grain yield were maximum for the treatment, FYM (5 t ha^{-1}) + half the RDF (30:15:15 kg NPK ha^{-1}). Application of inorganic fertilizer (60:40:30 kg NPK ha^{-1}) along with farmyard manure 5 t ha^{-1} recorded highest effective tillers m^{-2} in scented rice (Santhosh *et al.*, 2004).Yield attributes such as panicles m^{-2}, total number of grains panicle^{-1}, number of filled grains panicle^{-1} and thousand grain weight were improved by application of 50 per cent N each through fertilizer and different organic sources like farmyard manure and neem cake (Vasantharao *et al.*, 2004).

Higher yield with integrated use of organic and inorganic fertilizers has been reported by many workers (Kundu and Pillai, 1992; Pandey *et al.*, 1995; Chettri *et al.*, 1998, Baggie and Bah, 2001; Pandey *et al.*, 2001).

Combined use of organic and inorganic sources of N yielded better than inorganic sources alone (Saxena *et al.*, 1983). Khan *et al.* (1988) observed comparable yield in rice through the application of 30 kg N ha^{-1} in the form of FYM at puddling and 30 kg N ha^{-1} as urea to that of 60 kg N ha^{-1} as urea. Singh and Verma (1990) obtained significant improvement in grain and straw yields of rice through application of FYM as the same level of inorganic fertilizers than without FYM. Half to one third dose of chemical nitrogen could be substituted by organic N without any yield loss (Malik and Jaiswal, 1993). Mathew *et al.* (1993) showed that when FYM was regularly applied in all seasons @ 5 t ha^{-1}, saving of fertilizers from a recommended fertilizer dose of 70:35:35 kg NPK ha^{-1} could be achieved to the extent of 1/3 dose of N and K_2O and 2/3 dose of P_2O_5. Jayakrishnakumar *et al.* (1994) reported that permanent pot experiments on integrated nutrient supply system in rice sequence in different locations revealed that 50 to 25 per cent of fertilizer nitrogen could be substituted by locally available organic sources of N like FYM, and paddy straw. Rajamannar *et al.* (1995) concluded that combined application of organic manures with the recommended levels of N increased the grain yields of rice over sole application of organic manures or inorganic nitrogen. Sheeba and Chellamuthu (1996) reported increased grain yields up to 5.6 t ha^{-1} and straw yield upto 7.3 t ha^{-1} with the combined application of organic manures and chemical fertilizers. Increase in yield of rice through substitution of 25 per cent of inorganic nitrogen by FYM was reported by Singh *et al.* (1996). Roy *et al.* (1997) observed higher grain yield of rice with the combined application of NPK @ 90:60:90 kg ha^{-1} along with 10 t ha^{-1} of FYM. Dhillon (1998) obtained the highest production under 100 kg N ha^{-1} as urea combined with 5 t of FYM. In a study on integrated nutrient management in a rice-rice cropping system, Deepa (1998) obtained higher straw yield with integration of nutrients, which supplied 50 per cent of the recommended N through FYM and the rest through chemical fertilizers for rice variety Kanchana.

All organic sources including FYM can be used to substitute 25 to 50 per cent nitrogen needs of rice crop with significant yield advantage in some cases (Hegde, 1998). Through integrated nutrient management in rice-rice system, saving of 25 per cent of applied nitrogen and reduction of 50 per cent in application of inorganic nitrogen can be achieved (Thakur *et al.*, 1999).

Saxena *et al.* (1999) reported that NPK @ 100:80:60 kg ha^{-1} along with 10 t ha^{-1} of FYM produced significantly higher yield of rice. Singh and Verma (1999) also reported that FYM + 50 per cent recommended NPK application gave the highest rice yields. Grain yield and straw yield was highest when different types of organic amendments were applied in combination with nitrogen fertilizer in 50:50 ratio in comparison to the treatment where nitrogen was applied as urea alone (Salik and Samjoy, 1999).

The increased tiller number, panicle m^{-2}, panicle length and grains per panicle observed under integrated nutrition resulted in increased grain and straw yields (Dixit and Gupta, 2000; Pandey *et al.*, 2001). The results of long term trial in a rice-rice cropping system in Kerala, Orissa and Andhra Pradesh revealed that the application of 25-50 per cent nitrogen in organic form gave the best yield stability (Katyal *et al.*, 2000). Singh *et al.* (2000) found out that FYM with recommended dose of NPK gave the highest grain yield (5.16 t ha^{-1}) and application of FYM contributed to yield up to 50 per cent of the recommended NPK. Fifty per cent and 75 per cent substitution of recommended dose of nutrients with organic sources did not result in significant yield reduction (Sujathamma *et al.*, 2001).

Sindhu (2002) observed that a nutrient dose of 90:45:67.5 kg NPK ha^{-1} with 50 per cent N applied as FYM and 50 per cent as chemical fertilizer could be recommended for maximizing yield in basmati rice. Prakash *et al.* (2003) in their study on integrated nutrient management in basmati rice, var. Pusa Basmati, observed that application of organic manure including oil cakes, on balancing with chemical fertilizers to supply recommended dose of NPK favoured high dry matter production and grain yield as compared to application of chemical fertilizers alone. Chakraborty *et al.* (2003) reported that combined application of inorganic (urea) and organic (farmyard manure) sources increased the grain yield by 72 per cent over no input (control). In rice-maize sequence, results indicated that there is possibility of saving of N fertilizer to extend of 50 per cent by using rice straw or FYM without reduction in grain yield (Mallikarjuna *et al.*, 2004). Parihar (2004) opined that grain yields with 80 kg N ha^{-1} (50 % through green manure and 50 % through urea) were comparable to 80 kg N ha^{-1} (50 % through FYM and 50 % through urea), but both were significantly higher than 80 kg N ha^{-1} through urea.

Santhosh *et al.* (2004) found out significant increase in grain and straw yield of rice when 5 t ha^{-1} of FYM was applied in combination with inorganic fertilizer dose of 60:40:30 kg NPK ha^{-1}. Integrated use of organic and inorganic fertilizers led to increased grain yield in rice (Khanda *et al.*, 2005). Chettri and Mondal (2005), in a field experiment conducted at Kalyani, observed that the maximum grain yields of both rainy season (4.66 t ha^{-1}) and winter (5.47 t ha^{-1}) rice were observed with 75 per cent of recommended dose of nitrogen, phosphorus and potassium through fertilizers along with FYM @ 10 t ha^{-1}. Higher yield in rice crop could be achieved by the combined application of 100 per cent RDF through urea + 25 per cent RDF through FYM (Mrudhula *et al.*, 2005). The conjunctive use of 75 per cent N through fertilizer and 25 per cent N through bulky organic manures like FYM significantly increased the mean rice yield as compared to the application of recommended nitrogen as fertilizer (Aruna and Mohammad, 2005).

Application of organic manures was reported to maintain soil fertility and to sustain higher crop yield levels in rice-rice crop sequence (Reddy *et al.*, 2006). Integrated use of organic and inorganic fertilizers was found to be effective in enhancing the productivity of the cropping systems (Roul and Mahapatra, 2006). Substituting 50 per cent of the inorganic nitrogen with neem cake was found to increase the grain yield in rice (Singh *et al.*, 2006). Panda *et al.* (2007) reported that higher yield was obtained in the NPK + FYM treatment and also concluded that balanced use of N, P and K fertilizers in conjunction with FYM was the best nutrient management option for obtaining higher and sustainable rice yield and for promoting soil health.

Babu (1996) observed significant increase in the straw yield of medium duration rice variety Pavizham up to 7.3 t ha^{-1} by the combined use of organic manures and inorganic fertilizers. Maximum straw yield for rice variety Kanchana was obtained during Kharif season through an integrated management, which provided 50 per cent recommended N through FYM and the rest through NPK fertilizers (Deepa, 1998; Pandey *et al.*, 2001). Sudha (1999) reported that different levels and sources of organic manures could not significantly influence the straw yield.

Unnever *et al.* (1992) reported that rice grain quality was a multi dimensional character, composed of many components such as eating quality, cooking quality and nutritional quality. Nitrogen application at higher dosage increased the amylose content in long slender varieties (Rao *et al.*, 1993). Quality was defined as the degree of excellence possessed by the grain (Srivastava, 1997). Hemalatha *et al.* (1999) reported that incorporation of organic fertilizers along with the application of inorganic N significantly increased the crude protein content of rice grains. Veenapal and Pandey (2000) could not observe any definite trend in the rice quality with the application of different sources of nutrients. According to the farmers' perception, organic manures produce grains of better quality compared to inorganics (Singh and Singh, 2003). Integrated nitrogen management resulted in higher values of quality parameters as compared to control (Adhikari *et al.*, 2005).

Sikka *et al.* (1993) found that with increasing doses of nitrogen fertilizer, there was an increase in protein content. Singh (1993) stated that starch is a mixture of amylose and amylopectin. Aberg (1994) found that starch is the nutritional reservoir in plants. Devi *et al.* (1997) stated that proteins present in food were a mixture of several fractions and each fraction varied in its solubility. Pillai (1998) observed higher crude protein in rice, with 75 per cent of the recommended dose of nitrogen as inorganics and 25 per cent as FYM. Juliano (1998) reported starch as the major constituent of rice and as such, starch and protein accounted for 98.5 per cent of the constituents of milled rice. Amylose content ranged from 9-37 per cent in the starch, corresponding to 63-91 per cent amyopectin. Amylose content was therefore regarded as an index of amylose/ amylopectin ratio (Dela and Khush, 2000). Sources of nitrogen did not produce any significant difference in the protein content of rice (Sindhu, 2002). The protein and amylose content varied significantly with the application of FYM in conjunction with chemical fertilizers (Reddy and Reddy, 2003).

2.8. Effect of integrated nutrient management on nutrient uptake and available nutrient status of the soil

Sheeba and Chellamuthu (1996) opined that application of FYM conjointly with 100 per cent NPK registered higher N and P uptake. Deepa (1998) reported the highest N and K uptake, when 50 per cent N was supplied through FYM + 50 per cent N through inorganic fertilizers and the highest P uptake, when 25 per cent of N was supplied through inorganic fertilizers, in the Kharif season. Mondal and Chettri (1998) studied the effect of INM on productivity and fertility building under rice based cropping systems and reported significantly higher NPK and sulphur uptake in rice which combined application of 50 per cent of the recommended nitrogen along with 10 t ha^{-1} FYM than that with inorganic alone. FYM proved superior to biofertilizer with respect to nutrient uptake (Kumari *et al.*, 2000). Sengar *et al.* (2000) reported increased uptake of NPK when FYM used in combination with chemical fertilizers. Combined use of organic manures and inorganic fertilizers was found to be significantly better than inorganic fertilizers alone for N uptake (Pandey *et al.*, 2001).

Singh *et al.* (2001) reported that the available soil N in case of 100 per cent N treated plots was higher than urea + FYM plots after rice harvest. But the organic carbon trend was reverse. The authors also found that substituting 50 per cent of the recommended N through various sources like FYM and green manure did not show any significant variation in the total uptake of N, P and K by rice. Sujathamma *et al.* (2001) recorded the highest P uptake with 25 per cent substitution with organic source. Sindhu (2002) could not observe significant difference in the NPK uptake with different sources and levels of nitrogen. Better uptake of applied N through substitution of 50 per cent of N fertilizer with organic manures (Mallikarjuna *et al.*, 2004). Parihar (2004) opined that total NPK uptake with 80 kg N ha^{-1} (50 % through green manure and 50 % through urea) were comparable to 80 kg N ha^{-1} (50 % through FYM and 50 % through urea), but both were significantly higher than 80 kg N ha^{-1} through urea. Chettri and Mondal (2005) reported that N, P and K uptake was highest when the rice crop was fertilized with 75 per cent of the recommended dose of N, P and K through chemical fertilizers along with 10 t ha^{-1} FYM applied at Kharif seasons. Integrated use of organic and inorganic fertilizers led to increased NPK uptake in rice (Khanda *et al.*, 2005).

Tiwari and Tripathi (1998) suggested that organic manures could be substituted upto 50 per cent of nutrients along with improvement of physico-chemical properties in paddy soils without hindering the production of succeeding crop. The NPK fertility of the soil was enhanced and more organic carbon was present following the FYM + N treatment than with NPK fertilizers applied at the currently recommended rate (Roy *et al.*, 2001). Singh *et al.* (2001a) observed a slight increase in the available N status of soil, by incorporating either total or part of N through organic sources as compared to N applied solely through prilled urea. Katyal *et al.* (2001) showed that application of FYM at 5 t ha^{-1} in addition to recommended dose of nitrogen @ 120 kg ha^{-1} tended to increase the available soil P and K. While Sindhu (2002), in her study with different sources and levels of nitrogen in basmati rice, observed significant variation in the available K status of the soil, whereas, the available N and P remained unaffected. Selvi *et al.* (2003) reported that the total nitrogen content, exchangeable Ca and Mg, available P and available K increased in plots receiving combined application of 100 per cent NPK (90:45:17.5 kg ha^{-1}) + FYM (10 t ha^{-1}).

Jha *et al.* (2004) observed the highest potassium solubilisation was observed in the treatments where inorganic fertilizers (60:40:30 NPK kg ha^{-1}) were applied in conjunction with FYM @ 5 t ha^{-1}. Application of NPK + FYM showed the highest increase in organic C, available N, available P and available K content in soil. Integrated nutrient management is one of the best methods for improving soil fertility under rice-wheat cropping system (Sharma and Sharma, 2004). FYM used alone or in combination with chemical fertilizers improved the available N and P status of soil than the initial status (Chettri and Mondal, 2005). Increase in organic carbon and available phosphorus was pronounced in the treatments receiving organic manures in combination with chemical fertilizers (Reddy *et al.*, 2006). Application of 100 per cent NPK + FYM @ 15 t ha^{-1} recorded highest organic carbon content (Laxminarayana, 2006).

2.9. Effect of integrated nutrient management on soil properties

Combination with organic and inorganic has added advantage of improvements in the microbial activity, stabilization of soil structure, enhanced moisture retention capacities and availability of all major nutrients (Santhy *et al.*, 2000).

Selvi *et al.* (2003) reported that the application of 10 t ha^{-1} of FYM along with 100 per cent NPK recorded significantly low bulk density. They also got the result that FYM + 100 per cent inorganics increased the hydraulic conductivity, water stable aggregates, porosity and WHC. Dutta and Sharma (2004) opined that the addition of 5 t ha^{-1} of organic fertilizers such as FYM , press mud , biogas slurry or green manures in combination with NPK fertilizers increased the percentage of micro aggregation and there by the mean diameter of the soil.

Dutta and Sharma (2004) found that the highest organic carbon and CEC was found in the plots receiving 50 per cent NPK + 10 t ha^{-1} FYM in rice-linseed cropping system. Selvi *et al.* (2005) observed that the highest organic carbon was recorded in plots where fertilizers were incorporated with FYM, continuously. They also got the result that combined application organics and inorganics resulted in significant increase in CEC over control (No fertilizers).

Selvi *et al.* (2004) reported that application of FYM @ 10 t ha^{-1} to finger millet annually along with 100 per cent NPK recorded the highest bacterial counts at the end of rotation followed by 150 per cent NPK. Addition of rice straw and rock phosphate and pyrite at the level equal to poultry droppings brought about a significant increase in the population of non symbiotic nitrogen fixing and ammonifying bacteria (Debnath *et al.*, 2005).

2.10. Effect of integrated nutrient management on incidence of pest and disease

Ito and Sakamoto (1942) opined that the vulnerability of plants to disease with heavy N application is due to the accumulation of soluble N in plants, for unfavourable N and carbohydrate balance in plants. Parcer and Chahal (1963) reported that heavy application of nitrogenous fertilizers increased the incidence of fungal diseases of rice. Phenolic and other compounds produced during decomposition of organic matter absorbed by the plants, conferred protection against pathogenic organisms (Flaig, 1984). Bhadoria *et al.* (2003) reported that the tolerance of rice plants to pathogens, measured in terms of grain yield was highest in the treatments with FYM. Integrated use of organics and inorganics, in general, reduced the incidence of most of the diseases in rice (Khan *et al.*, 2004).

2.11. Effect of integrated nutrient management on economics of cultivation

Mathew *et al.* (1994) noted the highest gross income, net income and BCR with the use of 66 per cent of recommended N, K_2O and 33 per cent P_2O_5 + 5 t FYM ha^{-1} as compared to 100 per cent recommended N, P_2O_5 and K_2O and all the other inorganic - organic combinations. Tripathi and Chaubey (1996) opined that incorporation of FYM in combination with inorganic fertilizers economized the fertilizer need.

Sudha (1999) reported that different levels and sources of organic manures had no significant influence on the benefit cost ratio and the highest BCR of 1.59 was recorded with the application of FYM @ 5t ha^{-1}. Sindhu (2002) reported that use of FYM for substituting 50 per cent N resulted in higher net returns and BCR. Balasubramaniyan (2004) stated that INM resulted in highest net returns and BCR. Higher gross and net returns and net return per rupee invested were observed under 50:50 ratio of poultry manure or FYM combined with chemical N in comparison to N applied as urea alone (Roul and Mahapatra, 2006). Singh *et al.* (2006a) observed that even though the cost of cultivation was marginally higher, integrated use of organic and inorganic fertilizers resulted in higher net income and BCR due to higher grain and straw yields. In general, the perusal of the research done on integrated nutrient management showed that the integrated use of organics and inorganics helped in improving the productivity of rice and increased the returns realized by the farmers, without impairing, but maintaining or improving the soil fertility status. So it is imperative to study the response of levels and sources under integrated nitrogen nutrition in lowland rice.

2.12. Influence of nitrogen on growth, yield attributes, yield and quality of rice

Babu (1996) noticed significant increase in plant height of rice with higher N level of 120 kg ha^{-1} over 90 kg ha^{-1} at maximum tillering and harvest stages. Pandian (1999) reported that application of 120 kg N ha^{-1} produced taller rice plants. Taller rice plants were observed with incremental doses of N upto 120 kg ha^{-1} (Kumari *et al.*, 2000). Significant increase in the height of rice plants was recorded with increased levels of N upto 60 kg ha^{-1} (Thomas, 2000). Plant height in rice increased significantly with incremental doses of N upto 80 kg ha^{-1}

(Anu, 2001). Ranjini (2002) found a significant increase in the plant height of upland rice with incremental levels of N upto 90 kg ha^{-1}.

Thomas (2000) reported an increase in tiller number of upland rice with higher levels of N upto 60 kg ha^{-1}. Tiller production in upland rice was significantly influenced by incremental doses of N upto 80 kg ha^{-1} (Anu, 2001). Ranjini (2002) reported that tiller production in upland rice was increased with incremental doses of N upto 90 kg ha^{-1}.

Increase in N rate upto 60 kg ha^{-1} could produce significant increase in LAI of upland rice (Thomas, 2000). Anu (2001) observed that in upland rice, higher levels of N upto 80 kg ha^{-1} produced significantly higher LAI. In upland rice, incremental doses of N upto 90 kg ha^{-1} gave significantly higher values of LAI (Ranjini, 2002).

Kumari *et al.* (2000) reported that dry matter production (DMP) was maximum in rice at 120 kg N ha^{-1}. Increase in DMP due to incremental levels of N was noticed upto 60 kg ha^{-1} by Thomas (2000). Anu (2001) opined that DMP in upland rice increased with incremental levels of N upto 80 kg N ha^{-1}. Ranjini (2002) obtained the maximum DMP of 10140 kg ha^{-1} at 90 kg N ha^{-1} in upland rice.

Patel *et al.* (1997) obtained significantly higher number of productive tillers per hill upon application of 80 and 120 kg N ha^{-1} compared to 40 kg N ha^{-1}. Kumari *et al.* (2000) found that number of productive tillers increased significantly with incremental levels of N upto 120 kg ha^{-1}. Thomas (2000) reported maximum number of productive tillers per hill at 60 kg N ha^{-1} while Anu (2001) obtained the same at 80 kg N ha^{-1} in the case of upland rice. Ranjini (2002) found that number of productive tillers increased significantly with incremental levels of N upto 90 kg ha^{-1}.

Sharma and Gupta (1992) reported that panicle length increased from 18 to 21.3 cm by the application of 120 kg N ha^{-1}. Panicle length was significantly higher in rice at 80 and 120 kg N ha^{-1} (Patel *et al.*, 1997). The longest panicle in upland rice was obtained by Thomas (2000) at 60 kg N ha^{-1} and by Anu (2001) at

80 kg N ha^{-1}. Ranjini (2002) found that maximum panicle length was produced at 90 kg N ha^{-1}.

Thomas (2000) opined significant increase in spikelet number with increasing rates of N upto 60 kg ha^{-1}. Anu (2001) also found that upto 80 kg N ha^{-1}, the number of spikelets $panicle^{-1}$ as well as weight of panicle increased significantly. Increase in the number of filled grains with increase in N level was also noticed by Kumari *et al.* (2000). In upland rice, maximum number of filled grains was obtained at a level of 60 kg N ha^{-1} by Thomas (2000) and 80 kg ha^{-1} by Anu (2001). Ranjini (2002) reported that maximum number of filled grains was obtained by the application of 90 kg N ha^{-1}.

Kumari *et al.* (2000) observed an increase in thousand grain weight due to N application. Thousand grain weight in upland rice was significantly greater at higher levels of N and the maximum value was recorded at 60 kg N ha^{-1} (Thomas, 2000). Anu (2001) reported that the maximum thousand grain weight was obtained at 80 kg N ha^{-1}. Ranjini (2002) also obtained similar findings and the maximum value was recorded at 90 kg N ha^{-1}.

Jadhav and Sahane (1997) obtained remarkable increase in grain yield with 120 kg N ha^{-1} whereas Singh and Sreedevi (1997) got similar results upto 90 kg N ha^{-1}. Maximum grain yield was obtained by Jaesaing (1998) with 150 kg N ha^{-1}. Mishra (1999) reported that 40 to 60 kg N ha^{-1} was the optimum dose for most of the upland rice growing parts of India. According to Rajarathinam and Balasubramaniyan (1999) increased yield was obtained at higher levels of N upto 200 kg ha^{-1}. In upland rice, maximum grain production of 3.3 t ha^{-1} was recorded at a N level of 60 kg ha^{-1} (Thomas, 2000) whereas under shaded condition the maximum grain yield was only 2.3 t ha^{-1} at a N level of 80 kg N ha^{-1} (Anu, 2001). Under open condition Ranjini (2002) obtained grain yield of 2.4 t ha^{-1} at a N level of 90 kg ha^{-1} in upland rice.

Rajarathinam and Balasubramaniyan (1999) reported that straw yield increased with higher levels of N upto 200 kg ha^{-1}. At 60 kg N ha^{-1} maximum straw yield of 7 t ha^{-1} was recorded by Thomas (2000). Anu (2001) obtained the highest straw yield of 6.6 t ha^{-1} under shaded condition at N level of 80 kg N ha^{-1}. Ranjini (2002) obtained the maximum straw yield of 7.7 t ha^{-1} at 90 kg N ha^{-1} in upland rice.

Thomas (2000) found that HI increased significantly with incremental doses of N and the maximum harvest index of 0.195 was recorded at 60 kg N ha^{-1} in upland rice. Similar results in case of HI of upland rice were observed by Anu (2001) under shaded condition where maximum HI of 0.26 was registered at 80 kg N ha^{-1}. Ranjini (2002) found that HI increased significantly with incremental doses of N and the maximum value of 0.24 was recorded at 90 kg N ha^{-1} in upland rice.

Singh *et al.* (1992) observed significant influence in the chlorophyll content of rice with N application up to 150 kg ha^{-1}. Higher N level of 120 kg ha^{-1} could significantly increase the chlorophyll content in rice leaves (Babu, 1996).

Singh and Modgal (1978) opined that protein content of rice grains was increased due to the increase in N level. In Basmati rice, the highest protein content of 9.34 per cent was recorded at 90 kg N ha^{-1} (Akram *et al.*, 1985). Maximum grain protein content of 7.13 per cent was obtained at 120 kg N ha^{-1} (Reddy *et al.*, 1986). Thomas (2000) reported maximum grain protein content of 4.97 per cent at 60 kg N ha^{-1} in upland rice. Under shaded condition, upland rice recorded the maximum grain protein content of 5.57 per cent at 80 kg N ha^{-1} (Anu, 2001). Under open condition, upland rice recorded the maximum grain protein percentage of 4.91 at 90 kg N ha^{-1} (Ranjini, 2002).

2.13. Influence of nitrogen on nutrient uptake

Reddy *et al.* (1986) reported that in rice incremental doses of N upto 120 kg ha^{-1} increased the N uptake and the maximum uptake of 65.2 kg ha^{-1} was recorded at harvest. Grain and straw yields as well as the total N uptake were higher when N was applied at the rate of 180 kg ha^{-1} (Sudhakar *et al.*, 1987). Uptake of N, P and K by rice was significantly increased with 90 kg N ha^{-1} over 60 and 30 kg N ha^{-1} (Pandey *et al.*, 1991). Uptake of N by rice was significantly higher when higher dose of 120 kg N ha^{-1} was applied over 40 kg N ha^{-1} and the highest total N uptake of 95 kg ha^{-1} was recorded at 120 kg N ha^{-1} (Patel *et al.*, 1997). N uptake was increased significantly at the maximum level of 90 kg N ha^{-1}

(Sarmah and Baruah, 1997). When N level was increased upto 150 kg ha^{-1}, N uptake was found to increase (Jaesaing, 1998). Wilson and Norman (1998) found that increased rates of N favourably influenced N uptake in rice.

In upland rice, the increasing level of N and maximum uptake values were registered when N was applied at the rate of 60 kg ha^{-1} (Thomas, 2000). Anu (2001) reported that the uptake of N, P and K were significantly increased with increasing N rates and the highest uptake values were recorded at 80 kg ha^{-1} in upland rice under shaded situation. Ranjini (2002) found that the uptake of N, P and K were significantly increased with increasing N rates and the highest uptake values were recorded at 90 kg ha^{-1} in upland rice. Increase in nitrogen level significantly influenced the status of N, P and K in soil (Anu, 2001; Ranjini, 2002).

2.14. Influence of nitrogen on soil properties

Dutta and Sharma (2004) opined that in a continuous cropping system of Rice-Linseed for three years there was decrease WHC of soil from the original level of 44.7 per cent to 42.1 per cent in control (No fertilizer NPK) and 42 per cent in 100 per cent NPK treatments. They also found that lowest micro aggregation and mean weight diameter was seen in 100 per cent NPK treatments.

Selvi *et al.* (2003a) reported that increase in fertilizer levels from 50-100 per cent of RDF of NPK ha^{-1} gradually increased the CEC of soil. They also pointed out that in plots receiving 100 per cent phosphorus in addition to 100 per cent nitrogen, when compared to plots receiving 100 per cent nitrogen only, showed an increase in CEC. Dutta and Sharma (2004) opined that in a continuous cropping system of Rice-Linseed, continued application of chemical fertilizer alone, decreased the CEC of the soil from that of the original level of 7.1 Cmol (P+) kg^{-1}.

Population of fungi reduced by more than one half by NPK + lime treatment in an All India coordinated long term fertilizer trial conducted on a red loam soil at Ranchi (Nambiar, 1994), while the same treatment presented a favourable impact on nodular bacteria in Soybean increasing the number of nodules and also their weight per plant. Elevated CO_2 concentration significantly increased the microbial biomass when nitrogen 90 kg ha^{-1} was in sufficient supply (Li Zong *et al.*, 2004). The application of 100 per cent nitrogen alone and control recorded lower values of microbial population than 100 per cent NPK (Selvi *et al.*, 2004).

2.15. Influence of nitrogen on pest and disease incidence

Golden Apple Snail (GAS) population was reduced by 54 per cent by the basal application of complete fertilizers 60:40:40 kg NPK ha^{-1} with urea at recommended rate, thus preventing the GAS damage in rice crop during the first two days (De la Cruz *et al.*, 2001). Girijarani and Sreerama Reddy (2002) reported that accumulation of cell wall bound phenols in rice plant may show resistance of rice to blast, and phenol content in rice cell wall is correlated with silicon accumulation in cell wall and such direct relationship may not occur when there is change in environmental conditions like high soil nitrogen.

2.16. Influence of nutrient ratio on growth, yield, quality and nutrient uptake

Studies at Vellayani revealed that fertilizer dose of 60:30:45 kg ha^{-1} NPK improved the growth characters and was superior to lower levels (Thomas, 2000). Studies conducted at Vellayani revealed that NPK at 67.5: 33.75: 33.75 kg ha^{-1} produced the maximum value for panicle length, panicle weight and thousand grain weight and produced the maximum grain yield of 3.3 t ha^{-1} (Sheela and Alexander, 1995). According to Turkhade *et al.* (1996) higher NPK rates of 100:50:50 kg ha^{-1} produced significantly higher number of grains $panicle^{-1}$. Similar results were reported by Dhiman *et al.* (1997). According to Singh *et al.* (1998), an increase of 25 per cent over the recommended fertilizer dose of 100:50:50 kg NPK ha^{-1} could bring about a significant increase in number of both total and filled grains $panicle^{-1}$. Thomas (2000) observed that maximum value for yield attributing characters and yield were obtained at highest NPK level of 60:30:45 kg ha^{-1} compared to the lowest level.

Rai *et al.* (1990) observed that increased doses of chemical fertilizers resulted in enhanced production of chlorophyll for performing more photosynthesis. Combined application of NPK at 67.5: 33.75: 33.75 kg ha^{-1} recorded the maximum value for protein content (Sheela and Alexander, 1995). High NPK levels of 120:60: 60 kg ha^{-1} could significantly increase the chlorophyll content in rice leaves (Babu, 1996). Thomas (2000) reported from Vellayani that maximum values for protein content, praline content and chlorophyll content were obtained at highest NPK level of 60:30: 45 kg ha^{-1}.

Talukdar and Chakravarthy (1988) reported that N uptake was increased with applied N, P and K. The optimum economic fertilizer rates were 70 kg N ha^{-1} and 30 kg P_2O_5 ha^{-1}. Sheela (1993) observed that maximum uptake of nutrients were recorded at NPK levels of 67.35: 33.75: 33.75 kg ha^{-1}. Mishra and Sharma (1997) observed significant increase in the NPK uptake of rice with NPK addition of 120:50:40 kg ha^{-1} than with 60:25:20 kg ha^{-1} NPK. Thomas (2000) concluded that maximum uptake of nitrogen, phosphorus and potassium was observed at maximum NPK rates of 60:30:45 kg ha^{-1}.

2.17. Influence of moisture regime on growth, yield attributes and yield of rice

Irrigation experiments in different parts of India showed that the water requirement of rice ranged from 1500 to 2500 mm (Varade and Dhanapal, 1988). Rice required 591 and 821 mm of water during *Kharif* and summer respectively excluding water required for land preparation. Of this 410 and 510 mm was required for crop evapotranspiration and 181 and 311 mm was required for percolation (Ilangovan *et al.*, 1991). Asia's present and future food security depends largely on irrigated rice ecosystem as 75 per cent of the rice supply comes from 79 million ha of irrigated land (Bouman, 2001).

Earlier works reported that continuous submergence in rice is congenial for better and higher yield (Mandal and Chatterjee, 1984; Islam *et al.*, 1986; Tyagi *et al.*, 1991; Jayaprakash and Wahab, 1995). Similarly, Taraftar (1999) revealed that continuous submergence produced higher rice yield than alternate wetting and drying method, wherein 5 cm of irrigation was applied 5 and 10 days after disappearance of ponded water. In spite of yield advantage, continuous submergence situations resulted in enormous water loss and thereby leading to less water productivity (Sharma and De Datta, 1985). Recently, the term "water saving irrigation techniques" had been introduced (Guerra *et al.*, 1998) to denominate irrigation strategies that aim at reducing seepage and percolation losses by (i) reducing the depth of ponded water in the field; (ii) keeping the soil just saturated and (iii) alternate wetting and drying, i.e. allowing the soil to dry out to certain extend before reapplying irrigation water.

Sandhu *et al.* (1980) found that intermittent submergence after crop establishment performed as good as continuous submergence without yield reduction. Scheduling irrigation to rice crop to a depth of 5 cm to saturation saved 30-48 per cent of irrigation water compared to continuous submergence (Reddy, 1985). The highest grain yield was registered by maintaining submergence of water (5 ± 2 cm) during tillering and reproductive stages plus 7 cm irrigation a day after vanishing of ponded water during the rest of the period (Panda *et al.*, 1997). Chandrasekran *et al.* (2002) recorded higher rice grain yield when irrigation was scheduled to 5 cm depth one day after fading of ponded water.

Tabbal *et al.* (2002) reported that keeping the soil continuously around saturation reduced rice yields by 7 per cent compared to standing water for the transplanted dry season rice. However, yield reduction was relatively small and statistically non-significant. Thus rice responds well to different water management practices.

Marimuthu and Kulandaivelu (1987) stated that continuous submergence increased plant height compared to intermittent irrigation. Ganesh (2000) found non-significant difference in plant height between farmers practice (irrigating continuously subjected to availability of water) and scheduling irrigation once in three days up to 46 days after transplanting (DAT), later on once in seven days.

Tillers and leaves grow synchronously in definite pattern in rice, which is normally impaired by moisture stress during vegetative growth. Tiller number of a rice plant appears inversely related to water depth, at least over a wide range of moisture conditions. Sah and Mikkelsen (1983) concluded that there was no difference in tiller number between submergence and submergence to saturation treatment (flooding for eight days followed by saturation for eight days). Reddy (1985) found that allowing water to recede up to saturation did not affect tiller numbers.

Leaf area index basically relates to plants ability to utilize incident radiation in terms of photosynthesis. Growth and water relation studies in rice showed significant linkage between moistures regimes and leaf area index. Higher leaf area index was observed under higher moisture regimes (Turner, 1979). Mathew (1989) indicated the responsiveness of leaf area to moisture and further elaborated that even with mild stress in treatment receiving irrigation one day after disappearance of water (saturated) reduced leaf area index compared to continuous submergence. Muthukrishnan (1990) reported that leaf area index at flowering was higher (4.58-6.10) with continuous submergence, but was comparable (4.39-5.85) with that of one day after disappearance of water (saturated).

Generally, dry matter production decreases under less moisture regimes (De Datta, 1981), the accumulated dry matter until panicle initiation was a function of water used (Puckridge and O'Toole, 1981). Higher dry matter production under continuous submergence and irrigating one day after disappearance of water (saturated) was recorded at all stages of crop growth by Muthukrishnan (1990). Cabangon *et al.* (2001) observed that the differences in dry matter due to continuous flooding and alternate wetting and drying treatments were not statistically significant in all locations.

Yadav (1972) indicated that submergence of 5 ± 2 cm of water only at active vegetative and reproductive phases produced more number of panicles per hill, which was found to be on par with continuous submergence at all growth stages. Joseph and Havanagi (1987) recorded more number of panicles under continuous submergence than partial submergence (keeping saturated until panicle initiation from transplanting and 1-5 cm submergence thereafter). Irrigating 7 cm of water one day after disappearance of ponded water yielded the same number of ear bearing tillers as in the case of continuous submergence of 5 cm depth through out the crop period (Palchamy *et al.*, 1989). Manickasundaram (1992) noticed lowest number of panicles under recouping submergence once in eight days compared to that of recouping submergence once in four and six days.

The number of spikelets per panicle in rice is determined during early part of the reproductive stage, while the percentage of filled spikelets is determined before, at and after heading. Unfavorable moisture regimes may hamper the growth of spikelets during ripening stage. Experimental data on 20 rice cultivars showed little effect on filled grains, when soil moisture stress causes stomatal closure for 8 days during critical period from 20 days before flowering to 10 days after flowering. But longer periods of stomatal closure had negative effect on number of filled grains (Jones, 1981).

Ganesh (2000) reported non-significant difference between chaffy grains under farmer's practice of continuous submergence and alternate wetting and drying treatments. Li (2001) reported slightly lesser filled grain number when water is short in the booting stage, which evidently reduced if severe stress occurs during the heading and flowering stages.

The thousand grain weight is a stable variety character because the grain size is rigidly controlled by the size of the hull. Reddy (1985) reported that thousand grain weight did not differ significantly among the moisture regimes of continuous submergence, submergence to saturation and saturation to field capacity. However, significant positive effect in thousand grain weight was reported at higher moisture regimes (Prasad *et al.*, 1994). Manickasundaram (1992) also proved that continuous submergence and recouping submergence once in four days recorded higher thousand grain weight compared to recouping submergence once in six and eight days. Bouman and Tuong (2000) reported decreased thousand-grain weight with drought after flowering.

Rice yields are influenced by many inter related and often diverse environmental and biological factors, out of which, water is the most important factor affecting rice production. Past research suggested that continuous flooding is not essential for higher grain yield of rice and intermittent submergence at critical stages of crop gives yields comparable to continuous flooding. In an experiment in the Philippines, grain yields did not vary greatly with 4-8 day intervals between irrigation. Grain yield, however, dropped one t ha^{-1} when the irrigation interval was increased to 10 days (De Datta *et al.*, 1973).

Continuous submergence during critical stage of flowering and maintenance of submergence to saturation during the rest of the period resulted in comparable yield as that under continuous submergence (WTC, 1985). Uppal *et al.* (1991) revealed that irrigation after two days of fading of ponded water at vegetative stage and four days of subsidence at reproductive phase gave better grain yield than under continuous submergence in non-cracking loamy sand soils of Ludhiana. Wang and Tang (2000) demonstrated that the aerobic cultivars yielded upto 6-7.5 t ha^{-1} in farmers' field using flash irrigation in bunded fields in Northern China. Tabbal *et al.* (2002) obtained significant difference in grain yield between continuous standing water (6987 kg ha^{-1}) and application of irrigation water (upto 5-7 cm depth) one day after standing water has disappeared (6135 kg ha^{-1}).

Many workers reported that irrigation levels exerted similar effect on straw yield of rice as grain yield. Pillai and De (1980) obtained more straw yield under continuous submergence because of increased plant height under this moisture regime as result of elongation of internodes. Wahab and Daniel (1992) reported more straw under continuous submergence, followed by irrigating one day after disappearance of ponded water. In contrary to this, Muthukrishnan (1990) recorded comparable straw yield between the above regimes of irrigation. Cabangon *et al.* (2001) also recorded similar straw yields under continuous submergence and alternate wetting and drying treatments.

Dongale and Chavan (1982) also registered higher harvest index under continuous submergence. In General, harvest index vary with rice variety and environment. Reddy (1985) reported that harvest index was highest at submergence to saturation compared to other moisture regimes.

2.18. Influence of moisture regime on weed species and weed growth

Moturi (1977) reported that weed density and dry weight were higher under saturated conditions than under submergence. Bhan (1981) reported that *Echinocloa crus-galli* grows well at moisture of 80 per cent of water holding capacity. However, he reported that its emergence and growth were reduced with increased submergence up to 15 cm. Weed type and degrees of infestation in rice fields are often determined by the type of rice culture, stand establishment method, moisture regimes, land preparation and cultural practices. Ahmed and Moody (1982) reported that the composition and growth of rice weed communities are strongly influenced by water management practices. Weed species grow differently to changing water regimes (Janiya and Moody, 1982).

Studies in Asia revealed that weed growth suppression could be achieved through water control (Nartsomboon and Moody, 1988). Balasubramanian and Krishnarajan (2001) recorded lowest population of weeds with irrigation at 5 cm depth one day after disappearance of ponded water in transplanted rice.

2.19. Influence of moisture regime on root system

Higher root dry matter and root volume were produced with submergence to saturation or continuous submergence. Manickasundaram (1992) noticed maximum root dry matter at continuous submergence, while maximum root length was recorded under irrigation regime of recouping 5 cm submergence once in six days. Root length and weight were decreased in rice grown under high anaerobic conditions (-150 mV) compared to that of moderately reduced (+150 mV) conditions (Kim *et al.*, 1999). Guiting (1999) found that alternate wetting and drying promoted vitality of roots and the number of white roots per stem (37) compared to continuous submergence (21).

2.20. Influence of moisture regime on nutrient uptake and nutrient availability

Research findings revealed that climate, soil properties, quantity and type of fertilizers applied, variety and method of cultivation affect nutrient uptake. Nitrogen and phosphorus contents in the vegetative parts of rice are generally high at early growth stages and decline towards maturity. Yoshida (1981) quantified the nutrients required to produce one tone of rough rice in the tropics as 19-24 kg nitrogen, 4-6 kg phosphorus and 30-45 kg potassium.

Water regime of a soil determines the oxidation-reduction potential, pH and electrical conductivity of the soil, which in turn has profound effect on uptake of nutrients by rice. Generally, nutrient content in rice grown under submerged conditions was found to be higher than cyclic wetting and drying conditions (Biswas and Mahapatra, 1980). In particular, inorganic N transformation in the soil is greatly influenced by alternate aerobic and anaerobic conditions brought about by different water management practices, which in turn decides availability and uptake of N by crop. Khind and Ponnamperuma (1981) tested three water regimes (continuous flooding, alternate drying and flooding every two weeks, and soil drying for two weeks at six weeks after followed by flooding) on a neutral clay soil and the findings showed that none of the soil drying treatments depressed N uptake by rice. In contrast, field experiments in deep clay soils during summer season showed that continuous submergence caused higher N uptake during flowering and harvest stages of crop when compared to irrigation regime of 5 cm submergence one day and three days after vanishing of ponded water (Krishnakumar and Subramanian, 1992).

The availability of phosphorus increases after soil submergence, mainly due to the reduction of ferric phosphate to ferrous phosphate. Muthukrishnan (1990) found that continuous submergence and irrigating one day after disappearance of water registered higher and comparable phosphorus uptake at flowering and maturity phases, while continuous submergence had distinctly higher phosphorus uptake at tillering phase. Pathihar and Dikshit (1995) recorded greater phosphorus uptake under alternate submergence and saturation conditions till maximum tillering and continuous submergence resulted in considerable uptake at harvesting. Lourduraj and Rajagopal (1999) reported that phosphorus uptake was higher under irrigation regime of one day after disappearance of water compared to three days after fading of ponded water.

Uptake of potassium was higher under flooding by rice because of greater availability of potassium due to the displacement from the soil exchange complex by reduced forms of iron and manganese (Patrick *et al.*, 1985). Further Panda *et al.* (1997) confirmed that potassium uptake was higher, when the crop was kept submergence at tillering and reproductive stages compared to 7 cm irrigation a day after disappearance of ponded water.

When soils are exposed to alternate wetting and drying, aerobic conditions arise under such conditions which in turn change soil chemistry. Unlike flooded soils, more N is mineralized and phosphorus becomes unavailable in aerobic soils with sufficient moisture in the profile. Available potassium increased under flooding due to the displacement from soil the soil exchange complex (Beyrouty *et al.*, 1994). Lourduraj and Rajagopal (1999) reported that soil available N and potassium in soil were not influenced by irrigation regimes, while available phosphorus was higher under irrigation three days after disappearance of water compared to that of irrigation one day after disappearance of ponded water.

Chakraborty and Mandal (1990) found that availability of ammonium ions in the soil showed a gradual declining trend upto flowering under both continuous submergence and alternate submergence and saturation, but magnitude of ammonium ions reduction was higher under alternate submergence and saturation, whereas higher nitrate ions were recorded upto flowering stage under alternate submergence and saturation. Study on ammonia volatilization showed that water evaporation from the soil during drying might be influenced by carrying ammonium ions and bicarbonate ions upward, there by increasing ammonia at surface. The opposite might be expected to happen under flooding through leaching.

Mandal and Khan (1975) studied the transformation of various inorganic factions of phosphorous in rice soils in West Bengal under three different moisture regimes. The repeated alternate water logged - saturated moisture condition lowered Bray's and Truog's extractable phosphorus. Continuous waterlogged condition appeared beneficial for the availability of soil native phosphorus in acidic soils. Balasubramanian and Krishnarajan (2001) revealed from experiments in clay soils of Tamil Nadu that potassium availability increased under irrigation of 2.5 cm depth on three days of disappearance of ponded water.

2.21. Influence of moisture regime on microbial populations and soil enzymes

Maximum bacterial populations were found in soils of fairly high moisture content (Alexander, 1977). Zhi (1993) observed that the quantity of ammonifiers was 26 times higher under water efficient irrigation regime than under traditional flooded regime. Actinomycetes were also higher under water efficient irrigation. Bollman and Conrad (1998) studied the effect of soil moisture on NO and N_2O produced by nitrifiers and denitrifiers (bacteria) respectively and confirmed that NO release is predominant in low soil moisture status, whereas N_2O release predominant at relatively high soil moisture contents. Gayathry (2002) noticed that total bacterial populations were higher under limited irrigation (2 cm) after the formation of hairline cracks in the soil compared to that of irrigation regime of 5 cm on one day after disappearance of ponded water.

It is generally assumed that soil enzymes are largely of microbial origins, which catalyze nutrient cycling in soils. Soil enzyme activity is considered as an index of microbial activity as well as soil fertility (Burns, 1982). Glinski and Stepniewska (1985) reported that dehydrogenase enzyme plays major role in biological oxidation of the organic matter by transferring protons and electrons from substrates to acceptors. It was also found that flooding soil enhances soil dehydrogenase activity. Later Tiwari *et al.* (1989) obtained positive relationship between soil moisture and dehydrogenase activity in the soil.

Urease activity in the soil is used as an index for biological activity and for soil fertility, which involve in the hydrolysis of urea applied to the soil. Lindau *et al.* (1989) reported that urease activity is higher in aerobic soils than oxygen depleted soils. Dinesh *et al.* (1998) noticed positive relationship between soil enzyme activity (except acid phosphatase) and soil pH, which in turn is regulated by soil moisture regimes.

Salient findings of earlier investigation

The results of the earlier investigations revealed that application of FYM increased plant height, leaf area index, number of tillers, number of grains panicle^{-1}, filled grains panicle^{-1} and thousand grain weight of rice. Response was obtained upto application of FYM @10 t ha^{-1}. Combination of oilcake and cow dung was found as an ideal nutrient source for rice. About 25-26 per cent increase in grain yield was obtained by the application of FYM @ 10 t ha^{-1}. Application of FYM significantly increased straw yield also. Increase in uptake of N, P, K, chlorophyll content and crude protein by the application of FYM was reported by earlier workers.

The result of the earlier studies indicated that application of FYM reduced bulk density, enhanced CEC, organic carbon content, available N, P, K status and microbial activity. Favourable influence of FYM in promoting the activity of urease, phosphatase and dehydrogenase is evident from the results of the earlier studies.

The result of the earlier studies shows that application of FYM along with chemical fertilizer increased plant height, leaf area index, number of tillers, dry matter production, grains panicle^{-1}, filled grains panicle^{-1} thousand grain weight, grain yield and straw yield. Earlier studies also showed that FYM can substitute 25-50 per cent of the nitrogen requirement of the crop.

Results of the previous studies conducted at different locations revealed that crude protein and amylose content of rice increased with integrated nutrient management. Higher uptake of N, P and K was observed by earlier workers by the application of FYM along with chemical fertilizer. The uptake was higher at 50 per cent substitution.

Result of the earlier studies shows that organic carbon content and available N, P, K status of the soil was significantly higher in plots where integrated nutrient supply system was practiced.

An increase in growth attributes like plant height, leaf area index and dry matter partitioning with increased application of nitrogen is evident from the earlier studies. Increased application of nitrogen also promoted productive tillers, panicle length, thousand grain weight grain and straw yield. The response to nitrogen application was observed from 40 to 200 kg N ha^{-1}.

2:1:1 is the ideal nutrient ratio for rice as per the results of most of the studies. Some studies show that performance of rice was better under 2:1:1.5 nutrient ratio of NPK.

Most of the studies show that rice performed better under submerged situation. Some of the studies show that rice yield reduced by 7 per cent when grown under saturated situation compared to submerged situation. Nutrient availability was better under submerged situation.

Results revealed that the nutrients required to produce one tone of rough rice in the tropics as 19-24 kg nitrogen, 4-6 kg phosphorus and 30-45 kg potassium.

Ammonifiers, actinomycetes and total bacterial population was higher under water efficient irrigation regime. Dehydrogenase activity was higher under flooded soil whereas urease activity was higher under aerobic soils.

Results of the earlier studies stated that INM resulted in the highest net returns and BCR. Higher gross and net returns and net return per rupee invested were observed under 50:50 ratio of organic manure combined with chemical N in comparison to N applied as urea alone. In general, the perusal of the research done on integrated nutrient management showed that the integrated use of organics and inorganics helped in improving the productivity of rice and increased the returns realized by the farmers, without impairing, but maintaining or improving the soil fertility status.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The investigation entitled "Input optimization for medicinal rice (*Oryza sativa* L.) cv. Njavara" was undertaken to assess the response of Njavara in lowland situation under two levels of nitrogen, two nutrient ratios, two nutrient sources and two levels of irrigation. The materials used and methods adopted in the conduct of the experiment are presented in this chapter.

3.1. Experimental site

The experiment was conducted in lowland attached to the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala. The farm is located at 8.5° N latitude, 76. 9° E longitude and at an altitude of 29.0 m above mean sea level.

3.1.1. Climate

A humid tropical climate prevails in the experimental site. The weekly averages of temperature, relative humidity and rainfall during the cropping period were collected from the Agro meteorological observatory attached to the Department of Agronomy, College of Agriculture, Vellayani and the data are presented in Appendix I and II and illustrated graphically in Fig. 1a and 1b.

3.1.2. Cropping season

The experiments were conducted during two consecutive summer seasons of 2007 and 2008.

3.1.3. Soil

The soil of the experimental site was sandy clay loam belonging to family of Loamy Kaolinitic Isohyperthermic Typic Kandiustult. Initial soil test indicated that the soil was acidic in reaction. Nitrogen status of soil was medium whereas available phosphorus and potassium status high. Soil registered high organic carbon content. The important physiochemical and biological properties of soil are given in Table 1.

Fig. 1a. Weather parameters during the cropping period (Summer season) January 2007-April 2007

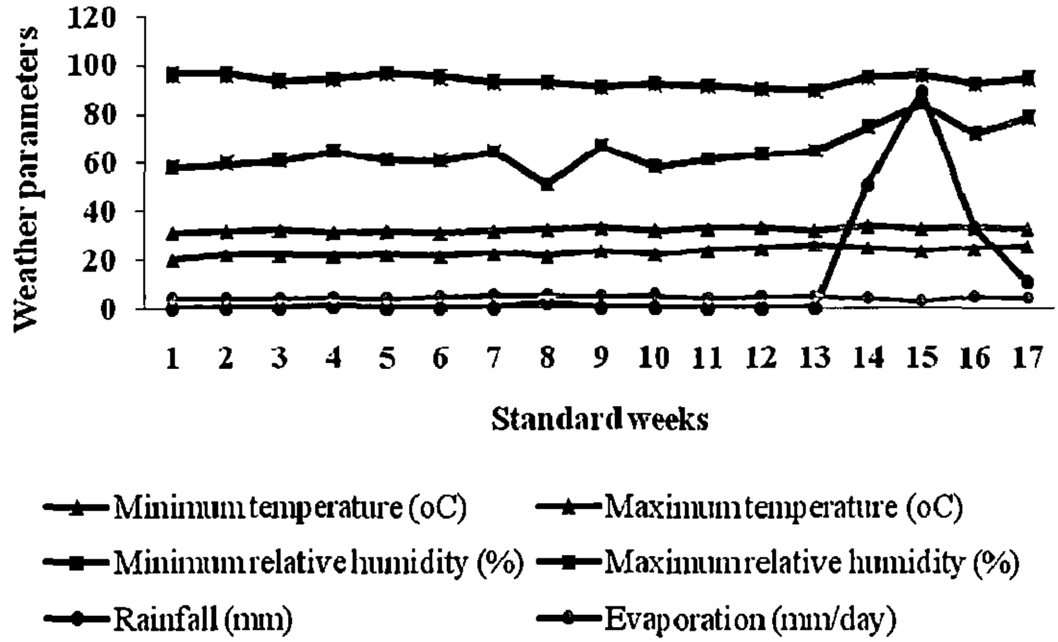


Fig. 1b. Weather parameters during the cropping period (Summer season) January 2008-April 2008

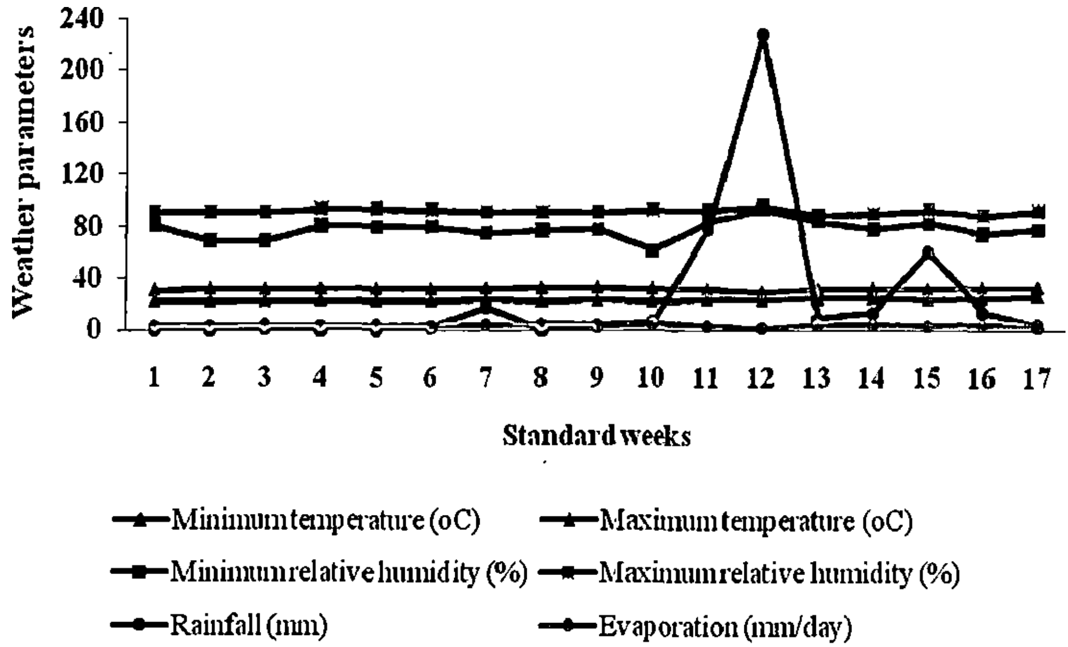


Table 1. Soil characteristics of the experimental site

A. Mechanical composition

Sl. No.	Constituent	Content (%)	Method
1	Coarse sand	47.46	Bouyoucos Hydrometer method (Bouyoucos, 1962)
2	Fine sand	10.94	
3	Silt	8.70	
4	Clay	32.90	

B. Physical property

Sl. No.	Parameter	Unit (g cc^{-1})	Method
1	Bulk density	1.79	Core method (Gupta and Dakshinamoorthi, 1980)

C. Chemical properties

Sl. No.	Constituent	Content	Methods
1	Available nitrogen (kg ha^{-1})	286.65 (medium)	Alkaline permanganate method (Subbiah and Asija, 1956)
2	Available phosphorus (kg ha^{-1})	28.03 (high)	Bray colorimetric method (Jackson, 1973)
3	Available potassium (kg ha^{-1})	333.52 (high)	Flame photometric method (Jackson, 1973)
4	Organic carbon (%)	1.29 (high)	Walkley and Black rapid titration method (Jackson, 1973)
5	Soil reaction	5.5 (acidic)	1:2.5 soil solution ratio using pH meter with glass electrode (Jackson, 1973)
6	CEC (cmol kg $^{-1}$)	6.35	Neutral normal ammonium acetate method (Jackson,1973)
7	Available sulphur (ppm)	25.20	Turbidimetric method (Chesnin and Yien, 1951)
8	DTPA extractable Zn (ppm)	3.70	Atomic absorption spectrophotometer (Lindsay and Norwell, 1969)
9	DTPA extractable Fe (ppm)	9.6	--do--
10	DTPA extractable Mn (ppm)	12.4	--do--

D. Biological properties

Sl. No.	Organisms	Population count	Method
1	Bacteria (10^4cfu g^{-1} soil)	32.37	Serial dilution plate method (Johnson and Curl, 1972)
2	Fungus (10^4 cfu g^{-1} soil)	14.42	,,
3	Actinomycetes (10^6 cfu g^{-1} soil)	2.77	,,

E. Soil enzymes

Sl. No.	Enzymes	Content	Methods
1	Urease (ppm of urea hydrolysed g^{-1} soil hr^{-1})	21.08	Broad bent *et al.* (1964)
2	Phosphatase (μg p N_{pp} g^{-1} soil hr^{-1})	63.41	Eivazi and Tabatabai (1977)
3	Dehydrogenase (μg of TPF hydrolysed g^{-1}soil 24 hrs^{-1})	2.36	Casida *et al.* (1964)

3.1.4. Cropping history of the field

Rice was the previous crop of the location.

3.2. Materials

3.2.1. Crop and variety

Black glumed Njavara was selected as the test crop for this investigation. Njavara is a tall indica rice plant with situation specific response behaviour. It has a duration ranging from 60 to 100 days. Grain yield ranged from 919 to 2684 kg ha^{-1} and straw yield from 1752 to 6818 kg ha^{-1}. The variety exhibits shattering of grain (Srinivasareddy, 2000).

3.2.2. Source of seed

Black glumed Njavara seeds were obtained from Njavara Eco Farm, Chittur College, Palakkad, Kerala.

3.2.3. Manures and fertilizers

Farmyard manure, neem cake, rock phosphate and wood ash were used as the organic nutrient sources for the experiment. Urea (46.2 % N), Mussorie rock phosphate (20 % P_2O_5) and muriate of potash (60 % K_2O) were used as the inorganic sources of nitrogen (N), phosphorus (P) and potassium (K) respectively.

Nitrogen content of organic manures was analyzed by microkjeldahl method, P content by Vanado-molybdo-phosphoric yellow colour method, K content by flame photometer method, S content by turbidimetric method and Fe, Mn and Zn content by diacid digestion method (Jackson, 1973; Chesnin and Yien, 1951). Total phenol content was estimated by the method suggested by Malick and Singh (1980) and the data are given in Table 2.

Table 2. Nutrient content of organic manures

Sl. No.	Parameter	Organic manures			
		FYM	Neem cake	Wood ash	MRP
1	N (%)	0.57	2.12	0.008	Traces
2	P (%)	0.30	0.90	0.23	14.5
3	K (%)	0.24	2.15	1.42	0.2
4	Sulphur (%)	0.26	1.88	1.70	--
5	Iron (ppm)	22.10	19.65	11.10	--
6	Manganese (ppm)	10.00	12.41	13.04	--
7	Zinc (ppm)	2.82	2.07	1.10	--
8	Phenols (mg g^{-1} of sample)	0.63	0.725	--	--

3.3. Methods

3.3.1. Design and layout

The research experiment trial consisted of two field investigations repeated for two years. One investigation was conducted under submerged moisture regime and another investigation was taken up under saturated moisture regime. Design, layout, treatments, field culture and observations were same for both field investigations. The detailed layout plan of the experiment is given in Fig. 2 and Plate 1.

Experimental design	: Randomised Block Design
Number of treatments	: 10
Number of replications	: 3
Gross plot size	: 5.0 x 4.0 m^2
Net plot size	: 4.4 x 3.6 m^2
Spacing	: 15 x 10 cm
Total number of plots	: 30

Two rows from all sides were left as border rows.

3.3.2 Treatment details

Combinations of two levels of nitrogen, two levels of nutrient ratio and two nutrient sources formed eight treatment combinations along with one absolute control and package of practices of KAU for local rice variety. So, total number of treatments is 10.

Treatments

a. Levels of nitrogen

30 kg N ha^{-1}

40 kg N ha^{-1}

b. Nutrient ratio (N:P:K)

2:1:1

1:1:1

Two nutrient levels and two nutrient ratios comprised to form four nutrients regimes, 30:15:15, 30:30:30, 40:20:20 and 40:40:40 kg NPK ha^{-1}. These nutrient regimes are denoted as N_1, N_2, N_3 and N_4.

c. Nutrient source

S_1 - Organic source (FYM + Neem cake)

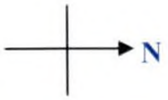
S_2 - Integrated nutrient source (50 % N as organic + 50 % N as chemical fertilizer)

d. Control

C_1 - Absolute control (No nutrient was applied)

C_2 - POP of KAU for local rice variety (FYM @ 5 t ha^{-1} + 40:20:20 kg NPK ha^{-1} as chemical fertilizer)

Fig. 2. Layout of the experimental field



R_1	$T_2(C_2)$	T_4	$T_1(C_1)$	T_5	T_3	T_6	T_{10}	T_8	T_7	T_9
	----------------------- Irrigation Channel -----------------------									
R_2	T_6	T_{10}	T_4	$T_1(C_1)$	T_8	T_3	T_9	T_5	$T_2(C_2)$	T_7
R_3	T_3	T_8	$T_2(C_2)$	T_7	$T_1(C_1)$	T_9	T_6	T_4	T_{10}	T_5
	----------------------- Irrigation Channel -----------------------									

PLATE - 1

General view of the field

Submerged situation | **Saturated situation**

Experimental field

Vegetative stage

Harvest stage

Total number of treatment combinations (8 + 2 = 10)

N_1S_1	N_1S_2	C_1
N_2S_1	N_2S_2	C_2
N_3S_1	N_3S_2	
N_4S_1	N_4S_2	

Treatment details

T_1 - C_1 - Absolute control (No nutrient was applied)

T_2 - C_2 - POP of KAU for local rice variety (FYM @ 5 t ha^{-1} + 40:20:20 kg NPK ha^{-1} as chemical fertilizer)

T_3 - N_1S_1 - FYM @ 5 t ha^{-1} + 30:15:15 kg NPK ha^{-1} as organic source

T_4 - N_1S_2 - FYM @ 5 t ha^{-1} + 30:15:15 kg NPK ha^{-1} (50 % N as organic + 50 % N as chemical fertilizer)

T_5 - N_2S_1 - FYM @ 5 t ha^{-1} + 30:30:30 kg NPK ha^{-1} as organic source

T_6 - N_2S_2 - FYM @ 5 t ha^{-1} + 30:30:30 kg NPK ha^{-1} (50 % N as organic + 50 % N as chemical fertilizer)

T_7 - N_3S_1 - FYM @ 5 t ha^{-1} + 40:20:20 kg NPK ha^{-1} as organic source

T_8 - N_3S_2 - FYM @ 5 t ha^{-1} + 40:20:20 kg NPK ha^{-1} (50 % N as organic + 50 % N as chemical fertilizer)

T_9 - N_4S_1 - FYM @ 5 t ha^{-1} + 40:40:40 kg NPK ha^{-1} as organic source

T_{10} - N_4S_2 - FYM @ 5 t ha^{-1} + 40:40:40 kg NPK ha^{-1} (50 % N as organic + 50 % N as chemical fertilizer)

3.3.3. Crop husbandry practices

3.3.3.1. Seeds and sowing

Seeds were soaked for 24 hours and the pre germinated seeds were dibbled in the next day at a spacing of 15 × 10 cm. The first and second crop were planted on 17th January 2007 and 4th February 2008 respectively and harvested on 9th April 2007 and 26th April 2008 respectively (Plate 2).

3.3.3.2. Main field preparation

The experimental area was well ploughed, puddled, levelled and brought to a weed free good condition. The plots were laid out into three blocks with 10 plots each. The plots were separated with bunds of 30 cm width

PLATE - 2

Seeds and sowing

Pre germinated Njavara seeds

Submerged situation

Saturated situation

and blocks with bunds of 50 cm width. Irrigation channels of 50 cm width were provided between the blocks. Individual plots were perfectly levelled.

3.3.3.3. Application of manures and fertilizers

FYM @ 5 t ha^{-1} was applied basally to all the plots except absolute control. FYM, neem cake, rock phosphate and ash (as per the treatments) were also incorporated at the time of first ploughing. Urea, Mussorie rock phosphate and muriate of potash were applied to each plot as per the treatments after levelling the field. The entire dose of phosphorus and half the dose of nitrogen and potassium were applied basally. The remaining nitrogen and potassic fertilizers were applied in two equal splits, at maximum tillering and panicle initiation stages respectively.

3.3.3.4. After cultivation

Almost uniform germination was obtained. Gap filling and thinning were done two weeks after sowing. Five hills were selected randomly from each plot and tagged as observational plants.

3.3.3.5. Weed management

Two hand weedings were done at 20 and 40 DAS.

3.3.3.6 Water management

3.3.3.6.1. Submerged condition

Water level was maintained to a height of 2-3 cm upto seven days from sowing and thereafter 5 cm water depth was maintained. Water was drained 13 days before harvest (KAU, 2007). Wooden pegs, painted white and suitably marked to indicate 5 cm depth, were fixed at the center of the plot.

3.3.3.6.2. Saturated condition

Field was maintained in saturated condition throughout the investigation.

3.3.3.7. Plant protection

Monocrotophos (0.03 %) and methyl parathion (0.05 %) were sprayed against stem borer, leaf roller and rice bug.

3.3.3.8. Harvest

The crop was harvested on 83rd day after sowing (straw just turned yellow). The net plot area was harvested separately, threshed, winnowed and weight of grain and straw from individual plots were recorded.

3.4. Observations

Two rows of plants were left as border on all the sides and observations were taken from the net plot area. Observations were taken on important parameters associated with growth and yield of paddy. Five hills were selected at random from the net plot area of each plot and tagged. The following observations were recorded from these sample plants and the mean values were worked out for both years for submerged and saturated situations separately.

3.4.1. Crop growth characters

3.4.1.1. Plant height

Plant height was recorded at panicle initiation and at harvest stages using the method described by Gomez (1972). The height was measured from the base of the plant to the tip of the longest leaf or tip of the longest ear head, whichever was longer and the average was recorded in centimeters.

3.4.1.2. Leaf number plant^{-1}

Leaf number was taken from the tagged observation hills at panicle initiation and harvest stages and the means worked out and expressed as number of leaves per plant.

3.4.1.3. Leaf area index

LAI was computed at panicle initiation and harvest stages using the method described by Gomez (1972). The maximum width 'w' and length 'l' of all the leaves of the five sample hills were recorded and LAI was calculated using the relationship.

Leaf area of a single leaf = l x w x k

k - Adjustment factor (0.75 at panicle initiation and 0.67 at harvest stage)

$$\text{LAI} = \frac{\text{Sum of leaf area of 5 sample hills (cm}^2\text{)}}{\text{Area of land covered by the 5 sample hills (cm}^2\text{)}}$$

3.4.1.4. Tillers m^{-2}

Tiller count was taken from the tagged observational hills at panicle initiation and harvest stages and the mean was worked out and expressed as number of tillers m^{-2}.

3.4.1.5. Culm strength

The procedure of Atkins (1938) was adapted for computing culm strength. Crop was harvested at ground level and dried for some time and was cut in equal length and made in to bundles and weighed. The culm strength was expressed in mg cm^{-1}.

3.4.1.6. Flag leaf area

Flag leaf area was recorded by leaf product method at PI stage and at harvest. The factor used was 0.75.

Leaf area (cm^2) = Length (cm) x Maximum width (cm) x 0.75

3.4.1.7. Chlorophyll content

The total chlorophyll content was estimated from the fully expanded second leaf from the top at panicle emergence stage by the method suggested by Arnon (1949) and expressed in mg g^{-1} fresh weight of leaves.

3.4.2. Crop yield attributes

3.4.2.1. Productive tillers m^{-2}

At harvest the number of productive tillers was noted from observation hills in the net plot and was expressed as number of productive tillers m^{-2}.

3.4.2.2. Panicle length

Five panicles were selected randomly from the net plot and the lengths were measured and the mean value was computed as panicle length and expressed in cm.

3.4.2.3. Grains panicle^{-1}

The number of grains in five panicles collected randomly from the net plot was counted and the mean value was expressed as number of grains per panicle.

3.4.2.4. Filled grains panicle^{-1}

The number of filled grains in five panicles collected randomly from the net plot were counted and the mean value was expressed as number of filled grains per panicle.

3.4.2.5. Thousand grain weight

Thousand grains were counted from the cleaned and dried produce from each plot and the weight was recorded in g.

3.4.2.6. Grain yield

The net plot area was harvested individually, threshed, dried, winnowed and dry weight was recorded in t ha^{-1}.

3.4.2.7. Straw yield

Straw harvested from each net plot was dried under sun to a constant weight and the weight was expressed as t ha^{-1}.

3.4.2.8. Harvest index (HI)

From grain and straw yield values, the harvest index was worked out using the following equation as suggested by Donald and Hamblin (1976).

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}}$$

3.4.2.9. Dry matter partitioning

Dry matter partitioning was done at harvest. The observational plants were uprooted, washed, plant parts (root, leaves, culms and panicle) were separated, dried under shade and later oven dried to a constant weight. Dry weight of each plant part was recorded separately using an electronic balance, and expressed as g hill^{-1}.

3.4.2.10. Sterility percentage

Sterility percentage was worked out using the following relationship.

$$\text{Sterility percentage} = \frac{\text{Number of unfilled grains per panicle}}{\text{Total number of grains per panicle}} \times 100$$

3.4.2.11. Paddy grain ratio

Weight of paddy and grain was recorded respectively and was expressed as ratio.

3.4.2.12. Grain husk ratio

Weight of grain and husk was recorded respectively and was expressed as ratio.

3.4.2.13. Crop duration

Duration from sowing to harvest of the crop from each treatment was recorded and expressed in days.

3.4.3. Plant analysis

3.4.3.1. Nutrient content

3.4.3.1.1. N, P, K, S, Fe, Mn and Zn content

Sample plants collected from each plot at harvest were first sun dried, and then oven dried to a constant weight and the samples were ground, digested and used for analysis of nutrient content. The N content (Modified microkjeldahl method), P content (Vanado-molybdo-phosphoric yellow colour method), K content (Flame photometer method), S content (Turbidimetric method) and Fe, Mn and Zn content (Diacid digestion method) were estimated for plant samples from each plot separately (Jackson, 1973; Chesnin and Yien, 1951). Plant nutrient uptake was calculated by multiplying the nutrient content of plant samples with the DMP of that treatment at harvest stage and expressed in kg ha^{-1}.

3.4.4. Biochemical components

3.4.4.1. Total amino acids

Total amino acids was determined by using Automated Ion Exchange Chromatography by the method suggested by Spackman *et al.* (1958). It was expressed as mg 100 g^{-1}. The procedure used for amino acid analysis is given in Appendix III.

3.4.4.2. Free amino acids

Free amino acids was determined by using Automated Ion Exchange Chromatography by the method suggested by Spackman *et al.* (1958). It was expressed as mg 100 g^{-1}. The procedure used for amino acid analysis is given in Appendix III.

3.4.4.3. Sulphur containing amino acids

Sulphur containing amino acids was determined by using LKB 4004 Amino Acid Analyzer by the method suggested by Spackman *et al.* (1958). It was expressed as mg 100 g^{-1}. The procedure used for amino acid analysis is given in Appendix III.

3.4.4.4. Total phenols

Total phenols content was estimated by the method of Malick and Singh (1980) by using Folin-Ciocalteau Reagent and expressed as mg g^{-1}.

3.4.4.5. Starch content

Starch was estimated by the Ferric cyanide method suggested by Aminoff *et al.* (1970).

3.4.4.6. Amylose content

Amylose content was estimated by the method of Mc Cready and Hassid (1943).

3.4.4.7. Amylopectin content

Amylopectin content of grains was determined as the difference between the total starch content and the amylose content of the grains.

3.4.4.8. Protein content

Protein content was computed by multiplying the nitrogen content of the grain with 6.25 (Simpson *et al.*, 1965).

3.4.5. Plant enzyme

3.4.5.1. Nitrate reductase activity

Nitrate reductase activity was estimated as per the method described by Nicholas *et al.* (1976) and Hageman *et al.* (1980). Nitrate reductase activity was computed from NR activity per gram of fresh leaf weight and total fresh weight of leaves per plant. It was expressed as µmole NO_2 g^{-1} fresh weight hr^{-1}. The procedure used for nitrate reductase activity is given in Appendix IV.

$$\text{NR activity} = \frac{\text{NR activity per}}{\text{gram of fresh leaf weight}} \times \frac{\text{Total fresh weight of}}{\text{leaves per plant}}$$

3.4.6. Root characters

3.4.6.1. Root weight

Five plants were picked out at panicle initiation stage, roots were separated, cleaned, dried and weighed. The mean value was calculated and expressed in g $plant^{-1}$.

3.4.6.2. Root volume

Root volume per plant was found out by displacement method and expressed in cm^3 $plant^{-1}$.

3.4.7. Weed characters

3.4.7.1. Weed flora

Major weed species that infested the experimental site during the period of experiment were identified and grouped into grasses, sedges and broad leaved weeds.

3.4.7.2. Weed biomass

Weed samples were pulled out along with roots, washed and dried under shade and later they were oven dried at 80 ± 5°C to a constant weight. The dry weight of weeds was recorded and expressed as g m^{-2}.

3.5. Soil analysis

Soil samples were collected from the experimental site plot wise for analyzing various physico-chemical properties. Composite soil samples were collected before the start of the experiment and analyzed to determine the available N, P, K, S, Fe, Zn and Mn. After the harvest of the crop, soil samples were taken from each plot separately and analyzed for available N, P, K, S, Fe, Zn and Mn.

3.5.1. Physical property

Bulk density was determined before and after the experiment by core method (Gupta and Dakshinamoorthi, 1980) and expressed as g cc^{-1}.

3.5.2. Chemical properties

3.5.2.1. Cation exchange capacity

The neutral normal ammonium acetate method suggested by Jackson (1973) was used for estimating CEC and expressed as cmol kg^{-1}.

3.5.2.2. Soil reaction (pH)

The pH was determined in a 1:2.5 soil water suspension using ELICO digital pH meter (Jackson, 1973).

3.5.2.3. Available nitrogen

Available nitrogen content of the soil was estimated by alkaline permanganate method (Subbiah and Asija, 1956) and expressed as kg ha^{-1}.

3.5.2.4. Available phosphorus

Available phosphorus in soil was determined by Bray I (0.03 N ammonium fluoride in 0.025 N hydrochloric acid) method as described by Jackson (1973) and readings were taken in spectrophotometer and expressed as kg ha^{-1}.

3.5.2.5. Available potassium

Available potassium was determined in the neutral normal ammonium acetate extract and estimated using EEL flame photometer (Jackson, 1973) and expressed as kg ha^{-1}.

3.5.2.6. Organic carbon

The wet digestion method suggested by Walkley and Black (1947) was employed for the estimation of organic carbon using ferroin as indicator. It was expressed as percentage (%).

3.5.2.7. Available sulphur

Available sulphur was determined adopting the procedure suggested by Chesnin and Yien (1951). The extraction was carried out using Morgan's extraction solution ánd expressed as ppm.

3.5.2.8. Available iron, zinc and manganese

Available iron, zinc and manganese in the digested sample (DTPA extractant) were determined by using Atomic Absorption Spectrophotometer (Lindsay and Norwell, 1969) and expressed as ppm.

3.6. Soil enzymes

3.6.1. Urease

The urease activity was determined by the method described by Broadbent *et al.* (1964). The results were expressed in terms of urea hydrolysed g^{-1} of soil hr^{-1} in ppm. The procedure used for estimating urease activity is presented in Appendix V.

3.6.2. Phosphatase

The phosphatase activity was determined by following the procedure described by Eivazi and Tabatabai (1977). The results were expressed in terms of p-nitrophenyl hydrolysed g^{-1} of soil hr^{-1} in µg. The procedure used for estimating phosphatase activity is presented in Appendix V.

3.6.3. Dehydrogenase

The dehydrogenase activity was estimated as per the procedure described by Casida *et al.* (1964). The results were expressed in terms of triphenyl formazon hydrolysed g^{-1} of soil 24 hrs^{-1}, in µg. The procedure used for estimating dehydrogenase activity is presented in Appendix V.

3.7. Soil microbial properties

3.7.1. Rhizosphere of bacteria, fungi and actinomycetes population

The total count of bacteria, fungi and actinomycetes was assessed by serial dilution plate technique (Johnson and Curl, 1972). The media and dilution used for isolation of different groups of microorganisms are given in Appendix VI. The composition of the above mentioned media are given in Appendix VII. The procedure used for soil microbial properties is given in Appendix VIII.

3.8. Scoring of pests and diseases

The pest and disease incidences did not reach the economic threshold level and hence uniform score was given to all plots. Scoring of leaf roller and earhead bug intensity was done using the score chart (given in Appendix IX) developed by International Rice Research Institute (IRRI, 1981).

The percentage of disease incidence (DI) was calculated using the formula,

$$\text{Disease incidence (DI)} = \frac{\text{Infected plants in each plot}}{\text{Total number of plants in each plot}} \times 100$$

3.9. Economics of cultivation

The economics of cultivation was worked out based on the cost of cultivation and prevailing price of the crop produce.

3.9.1. Net income

Net income was computed using the formula,

$$\text{Net income (Rs ha}^{-1}\text{)} = \text{Gross income} - \text{Total expenditure}$$

3.9.2. Benefit cost ratio (BCR)

Benefit cost ratio was computed using the formula,

$$\text{BCR} = \frac{\text{Gross income}}{\text{Total expenditure}}$$

3.10. Statistical analysis

The data generated from field trials were subjected to analysis of variance (ANOVA) as applied to Randomized Block Design with two factors (Nutrient regimes and nutrient sources) and two controls (Panse and Sukhatme, 1985). Pooled analysis was done by taking data of both years for submerged and saturated situations separately to assess the effect of moisture regimes on the growth and productivity of Njavara. Wherever significant differences among treatments were observed, CD values at 5 per cent level of significance were provided for effective comparison of means.

RESULTS

4. RESULTS

Results of the field investigation entitled "Input optimization for medicinal rice (*Oryza sativa* L.) cv. Njavara" conducted at Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala during 2007 and 2008 to assess the effect of nutrient regimes and nutrient sources on growth, productivity and quality of Njavara under submerged and saturated moisture regimes are presented in this chapter.

4.1. Effect of nutrient regimes and nutrient sources on growth and productivity of Njavara cultivated under submerged situation

4.1.1. Growth characters

Effect of nutrient regimes and nutrient sources on growth characters at panicle initiation and harvest stages under submerged situation during 2007 and 2008 are indicated in Tables 3 and 4 respectively. Nutrient regimes recorded significant influence on growth attributes at both stages in both years. Among the nutrient regimes, N_2 (30:30:30 kg NPK ha^{-1}) recorded significantly higher plant height, leaf number $plant^{-1}$, leaf area index, number of tillers m^{-2}, culm strength and flag leaf area and was significantly superior to all other regimes at both stages.

Among the nutrient sources, integrated nutrient source registered significantly higher values for all growth characters compared to organic nutrition at both stages during both years. Absolute control recorded significantly lower growth attributes whereas POP was on par with N_1 (30:15:15 kg NPK ha^{-1}) at both stages in 2007 and 2008.

Interaction between nutrient regimes and nutrient sources had significant influence on growth attributes such as plant height, leaf number $plant^{-1}$, leaf area index, number of tillers m^{-2}, culm strength and flag leaf area. All growth characters were significantly higher in N_2S_2 at both stages in both years. N_1S_1 recorded lowest growth attributes at both stages in both the years of experimentation (Tables 5 and 6).

Table 3. Effect of nutrient regimes and nutrient sources on growth attributes of Njavara under submerged situation (2007)

Treatments	Plant height (cm)		Leaf number plant^{-1}		Leaf area index		Tillers m^{-2}		Culm strength (mg cm^{-1})		Flag leaf area (cm^2)	
	PI stage	Harvest	PI stage	Harvest	PI stage	Harvest	PI stage	Harvest	PI stage	Harvest	PI stage	Harvest
Nutrient regimes												
N_1 (30:15:15)	89.51	105.31	4.82	5.48	1.47	1.31	412.96	434.94	21.37	24.86	10.65	11.08
N_2 (30:30:30)	96.28	114.16	5.43	6.64	2.51	2.07	498.64	526.57	34.03	36.02	16.55	19.55
N_3 (40:20:20)	93.83	110.86	5.22	6.22	2.08	1.82	468.95	491.95	29.38	32.24	14.21	16.53
N_4 (40:40:40)	95.90	113.48	5.39	6.56	2.38	2.04	495.83	518.13	33.14	35.38	15.92	19.12
SE	0.07	0.153	0.01	0.006	0.02	0.004	0.87	0.89	0.123	0.14	0.04	0.03
CD (0.05)	0.16	0.31	0.02	0.01	0.02	0.01	1.76	1.76	0.25	0.22	0.06	0.08
Nutrient sources												
S_1 (OS)	91.84	108.26	5.05	5.88	1.79	1.59	442.75	465.24	25.80	29.02	12.51	14.04
S_2 (INM)	95.93	113.64	5.38	6.56	2.44	2.02	495.44	520.56	33.16	35.23	16.15	19.10
SE	0.057	0.103	0.004	0.006	0.005	0.004	0.622	0.65	0.087	0.074	0.02	0.04
CD (0.05)	0.11	0.21	0.01	0.01	0.01	0.01	1.25	1.24	0.17	0.15	0.04	0.06
Controls												
C_1 (Absolute control)	86.13	99.30	4.46	4.93	0.89	0.85	368.81	386.08	15.53	19.80	6.86	7.14
C_2 (POP)	89.49	105.36	4.81	5.47	1.46	1.32	412.29	434.37	21.36	24.90	10.60	11.00
SE	0.12	0.214	0.014	0.01	0.017	0.02	1.247	1.243	0.172	0.154	0.043	0.07
C_2 vs Treatments	S	S	S	S	S	S	S	S	S	S	S	S
C_1 vs Treatments	S	S	S	S	S	S	S	S	S	S	S	S
Between controls	S	S	S	S	S	S	S	S	S	S	S	S

Table 4. Effect of nutrient regimes and nutrient sources on growth attributes of Njavara under submerged situation (2008)

Treatments	Plant height(cm)		Leaf number $plant^{-1}$		Leaf area index		Tillers m^{-2}		Culm strength ($mg\ cm^{-1}$)		Flag leaf area (cm^2)	
	PI stage	Harvest	PI stage	Harvest	PI stage	Harvest	PI stage	Harvest	PI stage	Harvest	PI stage	Harvest
Nutrient regimes												
N_1 (30:15:15)	87.92	99.42	4.74	5.21	1.41	1.26	411.03	407.76	19.88	23.46	8.94	10.37
N_2 (30:30:30)	94.49	110.93	5.31	6.45	2.42	2.00	492.63	511.83	32.67	34.55	15.30	17.44
N_3 (40:20:20)	92.35	107.04	5.12	6.03	2.01	1.74	463.86	475.48	27.98	30.92	13.11	15.10
N_4 (40:40:40)	94.13	110.34	5.28	6.38	2.29	1.96	487.85	505.98	32.10	33.98	14.95	17.22
SE	0.104	0.236	0.004	0.03	0.013	0.01	1.90	2.702	0.13	0.13	0.14	0.114
CD (0.05)	0.21	0.47	0.01	0.04	0.03	0.02	3.40	5.41	0.24	0.22	0.20	0.20
Nutrient sources												
S_1 (OS)	90.19	103.65	4.93	5.64	1.72	1.53	439.84	444.84	24.45	27.54	11.12	13.12
S_2 (INM)	94.25	110.22	5.29	6.39	2.35	1.95	487.84	505.69	31.87	33.92	15.03	16.94
SE	0.073	0.162	0.006	0.013	0.02	0.01	1.202	1.913	0.082	0.076	0.08	0.06
CD (0.05)	0.15	0.33	0.01	0.03	0.02	0.02	2.41	3.83	0.17	0.15	0.14	0.16
Controls												
C_1 (Absolute control)	84.94	94.24	4.39	4.63	0.83	0.80	370.46	359.04	14.90	18.67	6.13	6.89
C_2 (POP)	88.05	99.43	4.74	5.18	1.41	1.28	411.04	407.77	20.07	23.31	9.18	10.26
SE	0.144	0.334	0.01	0.04	0.022	0.03	2.402	3.832	0.172	0.13	0.147	0.18
C_2 vs Treatments	S	S	S	S	S	S	S	S	S	S	S	S
C_1 vs Treatments	S	S	S	S	S	S	S	S	S	S	S	S
Between controls	S	S	S	S	S	S	S	S	S	S	S	S

Table 5. Interaction effect of nutrient regimes and nutrient sources on growth attributes of Njavara under submerged situation (2007)

Treatment combinations	Plant height (cm)				Leaf number plant^{-1}				Leaf area index			
Nutrient sources / Nutrient regimes	PI stage		Harvest		PI stage		Harvest		PI stage		Harvest	
	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	87.89	91.14	103.02	107.60	4.67	4.97	5.20	5.75	1.19	1.75	1.13	1.49
N_2 (30:30:30)	93.40	99.16	110.46	117.85	5.22	5.63	6.16	7.11	2.07	2.95	1.77	2.37
N_3 (40:20:20)	91.78	95.89	108.27	113.45	5.04	5.41	5.88	6.55	1.78	2.38	1.60	2.03
N_4 (40:40:40)	94.29	97.52	111.30	115.66	5.29	5.51	6.28	6.84	2.10	2.66	1.87	2.20
SE	0.12		0.214		0.014		0.01		0.017		0.02	
CD (0.05)	0.22		0.43		0.03		0.02		0.03		0.02	

Treatment combinations	Tillers m^{-2}				Culm strength (mg cm^{-1})				Flag leaf area (cm^2)			
Nutrient sources / Nutrient regimes	PI stage		Harvest		PI stage		Harvest		PI stage		Harvest	
	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	393.32	432.60	411.39	458.49	18.41	24.32	22.25	27.46	8.81	12.48	9.12	13.04
N_2 (30:30:30)	460.79	536.48	488.81	564.33	28.96	39.10	31.74	40.30	14.19	18.90	16.04	23.05
N_3 (40:20:20)	441.56	496.33	465.72	518.17	25.65	33.11	29.11	35.36	12.63	15.79	13.93	19.13
N_4 (40:40:40)	475.31	516.34	495.02	541.23	30.16	36.12	32.97	37.79	14.40	17.44	17.07	21.16
SE	1.247		1.243		0.172		0.154		0.043		0.07	
CD (0.05)	2.49		2.49		0.35		0.31		0.09		0.12	

Table 6. Interaction effect of nutrient regimes and nutrient sources on growth attributes of Njavara under submerged situation (2008)

Treatment combinations	Plant height (cm)				Leaf number $plant^{-1}$				Leaf area index			
Nutrient sources / Nutrient regimes	PI stage		Harvest		PI stage		Harvest		PI stage		Harvest	
	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	85.72	90.12	96.81	102.03	4.58	4.89	4.89	5.52	1.14	1.68	1.09	1.42
N_2 (30:30:30)	92.07	96.91	106.32	115.54	5.07	5.54	5.94	6.95	1.98	2.85	1.70	2.30
N_3 (40:20:20)	90.54	94.15	103.73	110.35	4.95	5.29	5.67	6.39	1.73	2.28	1.53	1.95
N_4 (40:40:40)	92.44	95.81	107.72	112.96	5.12	5.43	6.05	6.70	2.01	2.57	1.79	2.12
SE	0.144		0.334		0.01		0.04		0.022		0.03	
CD (0.05)	0.29		0.67		0.02		0.06		0.05		0.04	

Treatment combinations	Tillers m^{-2}				Culm strength (mg cm^{-1})				Flag leaf area (cm^2)			
Nutrient sources / Nutrient regimes	PI stage		Harvest		PI stage		Harvest		PI stage		Harvest	
	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	391.76	430.29	383.42	432.10	17.11	22.64	20.94	25.98	7.60	10.28	8.54	12.20
N_2 (30:30:30)	459.08	526.18	469.24	554.41	27.56	37.78	30.11	38.98	12.57	18.03	14.91	19.97
N_3 (40:20:20)	439.85	487.86	444.95	506.01	23.89	32.07	27.64	34.20	11.14	15.07	13.18	17.01
N_4 (40:40:40)	468.66	507.03	481.74	530.22	29.23	34.97	31.45	36.51	13.16	16.74	15.86	18.57
SE	2.402		3.832		0.172		0.13		0.147		0.18	
CD (0.05)	4.81		7.67		0.35		0.30		0.29		0.32	

Table 7. Effect of nutrient regimes and nutrient sources on leaf chlorophyll content of Njavara at panicle initiation stage under submerged situation (2007 and 2008)

Treatments	Leaf chlorophyll content (mg g^{-1})	
	2007	2008
Nutrient regimes		
N_1 (30:15:15)	1.00	0.89
N_2 (30:30:30)	2.00	1.87
N_3 (40:20:20)	1.54	1.41
N_4 (40:40:40)	1.89	1.77
SE	0.09	0.085
CD (0.05)	0.16	0.18
Nutrient sources		
S_1 (OS)	1.28	1.17
S_2 (INM)	1.94	1.79
SE	0.006	0.030
CD (0.05)	NS	NS
Controls		
C_1 (Absolute control)	0.57	0.51
C_2 (POP)	1.00	0.89
SE	0.013	0.040
C_2 vs Treatments	NS	NS
C_1 vs Treatments	S	S
Between controls	S	S

(Interaction effect not significant)

Table 7 revealed that nutrient regimes significantly influenced leaf chlorophyll content at panicle initiation in both the years of experimentation. Nutrient sources and interaction effects were not significant.

N_2 recorded the highest leaf chlorophyll content of 2.00 mg g^{-1} in 2007 and 1.87 mg g^{-1} in 2008 which was significantly higher than N_3 and N_1 and was on par with N_4 (1.89 mg g^{-1} in 2007 and 1.77 mg g^{-1} in 2008).

4.1.2. Yield attributes

Effect of nutrient regimes and nutrient sources on yield attributes of Njavara grown under submerged situation during 2007 and 2008 are presented in Tables 8 and 9 respectively.

Number of productive tillers increased significantly with increased application of nutrients. Maximum number of productive tillers m^{-2} was observed at N_2 regime (347 and 339 in 2007 and 2008 respectively). Same nutrient regime recorded maximum number of grains panicle^{-1} (72 and 70 in 2007 and 2008 respectively) and filled grains panicle^{-1} (60 and 58 in 2007 and 2008 respectively). This regime was significantly superior to the other three nutrient regimes.

Effect of nutrient sources on productive tillers, panicle length, grains panicle^{-1} and filled grains panicle^{-1} was significant. Integrated nutrient source recorded significantly higher values compared to organic nutrition. In 2007 integrated nutrient source recorded 341 productive tillers m^{-2} which was significantly higher than organic source, which recorded 289 productive tillers m^{-2}. The corresponding values during 2008 were 334 and 281 respectively. Panicle length, grains panicle^{-1} and filled grains panicle^{-1} were also significantly higher under integrated nutrient supply system during both years.

POP recorded significantly lower number of productive tillers compared to all nutrient regimes except N_1 during 2007. POP and N_1 regime of nutrients (30:15:15 kg NPK ha^{-1}) had similar effects on all other yield attributes and were inferior to other nutrient regimes. Same trend was observed during 2008. Absolute control recorded the lowest values for all yield attributes during both years.

Table 8. Effect of nutrient regimes and nutrient sources on yield attributes of Njavara under submerged situation (2007)

Treatments	Productive tillers m^{-2}	Panicle length (cm)	Grains $panicle^{-1}$	Filled grains $panicle^{-1}$	Thousand grain weight (g)	Sterility percentage
Nutrient regimes						
N_1 (30:15:15)	258.56	15.04	55.68	43.82	17.42	21.40
N_2 (30:30:30)	347.21	19.80	71.65	59.51	17.82	17.12
N_3 (40:20:20)	315.19	17.87	65.48	53.18	17.71	18.89
N_4 (40:40:40)	339.88	19.26	70.10	57.78	17.82	17.64
SE	0.454	0.062	0.080	0.070	0.09	0.060
CD (0.05)	0.91	0.13	0.16	0.16	NS	0.12
Nutrient sources						
S_1 (OS)	289.08	16.49	60.82	48.66	17.56	20.13
S_2 (INM)	341.33	19.49	70.64	58.48	17.82	17.40
SE	0.330	0.043	0.054	0.052	0.07	0.050
CD (0.05)	0.64	0.09	0.11	0.11	NS	0.08
Controls						
C_1 (Absolute control)	206.00	12.34	46.38	35.30	17.04	23.89
C_2 (POP)	259.46	15.04	55.70	43.78	17.30	21.40
SE	0.620	0.093	0.130	0.120	0.13	0.082
C_2 vs Treatments	S	S	S	S	NS	S
C_1 vs Treatments	S	S	S	S	NS	S
Between controls	S	S	S	S	NS	S

Table 9. Effect of nutrient regimes and nutrient sources on yield attributes of Njavara under submerged situation (2008)

Treatments	Productive tillers m^{-2}	Panicle length (cm)	Grains $panicle^{-1}$	Filled grains $panicle^{-1}$	Thousand grain weight (g)	Sterility percentage
Nutrient regimes						
N_1 (30:15:15)	248.38	14.43	50.32	39.58	17.49	21.45
N_2 (30:30:30)	339.35	19.56	70.19	58.42	17.86	17.01
N_3 (40:20:20)	307.36	17.68	63.24	51.31	17.78	18.99
N_4 (40:40:40)	334.10	19.09	69.06	56.90	17.85	17.69
SE	1.53	0.104	0.44	0.184	0.08	0.074
CD (0.05)	3.08	0.21	0.82	0.37	NS	0.15
Nutrient sources						
S_1 (OS)	280.58	16.04	57.37	45.91	17.67	20.18
S_2 (INM)	334.01	19.34	69.03	57.19	17.82	17.39
SE	1.09	0.072	0.30	0.14	0.06	0.054
CD (0.05)	2.18	0.15	0.58	0.26	NS	0.11
Controls						
C_1 (Absolute control)	205.52	11.87	40.81	31.11	17.16	23.77
C_2 (POP)	248.39	14.64	50.33	39.48	17.51	21.56
SE	2.17	0.14	0.58	0.26	0.11	0.14
C_2 vs Treatments	S	S	S	S	NS	S
C_1 vs Treatments	S	S	S	S	NS	S
Between controls	S	S	S	S	NS	S

Table 10. Interaction effect of nutrient regimes and nutrient sources on yield attributes of Njavara under submerged situation (2007)

Treatment combinations	Productive tillers m^{-2}		Panicle length (cm)		Grains $panicle^{-1}$		Filled grains $panicle^{-1}$		Thousand grain weight (g)		Sterility percentage	
Nutrient sources / Nutrient regimes	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	235.00	282.11	13.74	16.33	51.50	59.86	39.85	47.78	17.25	17.58	22.62	20.18
N_2 (30:30:30)	312.00	382.41	17.77	21.83	64.95	78.34	52.65	66.36	17.66	17.97	18.94	15.30
N_3 (40:20:20)	290.46	339.91	16.47	19.27	60.84	70.12	48.60	57.75	17.60	17.81	20.12	17.65
N_4 (40:40:40)	318.87	360.88	17.98	20.54	65.97	74.22	53.55	62.01	17.73	17.91	18.83	16.45
SE	0.620		0.093		0.130		0.120		0.13		0.082	
CD (0.05)	1.28		0.19		0.22		0.22		NS		0.17	

Table 11. Interaction effect of nutrient regimes and nutrient sources on yield attributes of Njavara under submerged situation (2008)

Treatment combinations	Productive tillers m^{-2}		Panicle length (cm)		Grains $panicle^{-1}$		Filled grains $panicle^{-1}$		Thousand grain weight (g)		Sterility percentage	
Nutrient sources / Nutrient regimes	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	226.97	269.79	12.88	15.98	45.58	55.05	35.28	43.87	17.36	17.62	22.60	20.30
N_2 (30:30:30)	301.98	376.72	17.30	21.81	62.09	78.29	50.32	66.51	17.80	17.91	18.97	15.05
N_3 (40:20:20)	280.61	334.11	16.26	19.10	57.41	69.07	45.77	56.84	17.70	17.85	20.28	17.70
N_4 (40:40:40)	312.76	355.43	17.71	20.47	64.41	73.70	52.25	61.54	17.81	17.88	18.88	16.50
SE	2.17		0.14		0.58		0.26		0.11		0.14	
CD (0.05)	4.36		0.30		1.16		0.52		NS		0.22	

Interaction between nutrient regimes and sources had significant influence on all yield attributes such as productive tillers m^{-2}, panicle length, grains $panicle^{-1}$ and filled grains $panicle^{-1}$ except 1000 grain weight. N_2S_2 recorded significantly higher yield attributes than all other treatment combinations in both years. N_1S_1 recorded lowest yield attributes in both years. Highest sterility percentage was recorded in N_1S_1 (22.62 % in 2007 and 22.60 % in 2008) and lowest sterility percentage was recorded in N_2S_2 (15.30 % in 2007 and 15.05 % in 2008) (Tables 10 and 11).

Analysis of the data on thousand grain weight showed that nutrient regimes, nutrient sources and their interactions had no significant influence on thousand grain weight during both the years of experimentation. Results are presented in Tables 8, 9, 10 and 11.

4.1.3. Grain yield

Data on grain yield as influenced by nutrient regimes, nutrient sources and their interactions in 2007 and 2008 are given in Tables 12, 13, 14 and 15 respectively.

Effect of nutrient regimes, nutrient sources and interactions on grain yield were significant in both the years. Maximum grain yield was recorded in N_2 (30:30:30 kg NPK ha^{-1}) (2.87 t ha^{-1} in 2007 and 2.70 t ha^{-1} in 2008) which was on par with N_4 (40:40:40 kg NPK ha^{-1}) (2.76 t ha^{-1} in 2007 and 2.58 t ha^{-1} in 2008) and was significantly superior to N_1 and N_3. During both the years, N_1 recorded the lowest yield (1.70 t ha^{-1} in 2007 and 1.56 t ha^{-1} in 2008). POP recorded an yield of 1.58 t ha^{-1} during 2007 and 1.41 t ha^{-1} during 2008 and was on par with N_1 regimė (30:15:15 kg NPK ha^{-1}). Absolute control recorded the lowest grain yield (0.96 t ha^{-1} in 2007and 0.87 t ha^{-1} in 2008).

During 2007 and 2008, integrated nutrient source recorded highest grain yield which was significantly superior to organic source. Grain yield obtained by adopting integrated nutrient supply system was 2.82 t ha^{-1} in 2007 and 2.60 t ha^{-1} in 2008. Grain yield obtained under organic nutrition was 2.04 t ha^{-1} in 2007 and 1.92 t ha^{-1} in 2008.

Under organic nutrition, N_4 regime recorded the highest yield which was significantly superior to other two regimes and was on par with N_2 regime. Under integrated nutrition, N_2 regime recorded significantly higher yield than other two nutrient regimes and was on par with N_4 regime. Both under organic and integrated nutrition yield obtained with N_4 and N_2 were on par.

Among all interactions, N_2S_2 recorded maximum grain yield of 3.41 t ha^{-1} in 2007 and 3.23 t ha^{-1} in 2008 which were on par with N_4S_2 during 2007 and 2008. Lowest grain yield was obtained under N_1S_1 (1.40 t ha^{-1} in 2007 and 1.39 t ha^{-1} in 2008).

4.1.4. Straw yield

The results are presented in Tables 12, 13, 14 and 15. Significant variation in straw yield was observed among nutrient regimes, nutrient sources and their interactions during both the years of study.

Maximum straw yield was recorded in N_2 (30:30:30 kg NPK ha^{-1}) (3.99 t ha^{-1} in 2007 and 3.78 t ha^{-1} in 2008) which was on par with N_4 (40:40:40 kg NPK ha^{-1}) (3.84 t ha^{-1} in 2007 and 3.64 t ha^{-1} in 2008) and was significantly superior to N_1 and N_3 during 2007 and 2008. POP was on par with N_1 regime (30:15:15 kg NPK ha^{-1}).

Application of integrated nutrient sources recorded highest straw yield which was significantly superior to organic source in both the years. In 2007, straw yields was 3.92 t ha^{-1} under integrated nutrient supply system and 2.87 t ha^{-1} under organic nutrition. During 2008 straw yield was 3.65t ha^{-1} under integrated nutrient system and 2.69 t ha^{-1} under organic nutrition.

Under organic nutrition N_4 regime recorded the highest straw yield (3.40 t ha^{-1} in 2007 and 3.22 t ha^{-1} in 2008) which was significantly superior to other two regimes and was on par with N_2 regime (3.25 t ha^{-1} in 2007 and 3.09 t ha^{-1} in 2008). Under Integrated nutrient source, N_2 regime recorded significantly higher straw yield than other two nutrient regimes and was on par with N_4 regime.

Among all interactions, N_2S_2 recorded significantly higher straw yield of 4.72 t ha^{-1} in 2007 and 4.47 t ha^{-1} in 2008 and was on par with N_4S_2 in 2007 and 2008. N_1S_1 recorded the lowest straw yield during both the years.

4.1.5. Harvest index

Nutrient regimes, nutrient sources and their interactions exerted significant influence on harvest index during both the years of experimentation. The results are presented in Tables 12, 13, 14 and 15.

During 2007 and 2008, N_2 recorded maximum harvest index (41.80 % in 2007 and 41.54 % in 2008). It was significantly higher than all other nutrient regimes except N_4. N_2 and N_4 were on par.

Adoption of integrated nutrition resulted in maximum harvest index (41.78 % in 2007 and 41.48 % in 2008) and was significantly higher than organic nutrition (41.18 % in 2007 and 40.66 % in 2008).

In both the years N_2S_2 registered the maximum harvest index (41.94 % in 2007 and 2008). N_4S_2 was on par with N_2S_2 in 2007. Minimum harvest index was recorded under N_1S_1 (39.75 % in 2007 and 39.37 % in 2008).

4.1.6. Dry matter partitioning

Data on dry matter partitioning at harvest is presented in Tables 12, 13, 14 and 15. Significant variation in dry matter partitioning was observed among nutrient regimes, nutrient sources and their interactions during both the years of study.

N_2 recorded the highest dry matter accumulation in shoot, panicle and root and was significantly higher than all other nutrient regimes. This was followed by the nutrient regimes N_4, N_3 and N_1 respectively. POP was on par with N_1 regime (30:15:15 kg NPK ha^{-1}).

Combined application of organic and inorganic nutrient sources produced highest dry matter in shoot, panicle and root, which was significantly superior to that realized from the application of organic sources.

Table 12. Effect of nutrient regimes and nutrient sources on yield and yield attributes of Njavara (Harvest stage) under submerged situation (2007)

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)	Dry matter partitioning (g $hill^{-1}$)	Shoot weight (g $hill^{-1}$)	Panicle weight (g $hill^{-1}$)	Root weight (g $hill^{-1}$)
Nutrient regimes							
N_1 (30:15:15)	1.70	2.39	40.67	40.90	29.48	4.86	6.57
N_2 (30:30:30)	2.87	3.99	41.80	57.76	40.61	7.32	9.83
N_3 (40:20:20)	2.41	3.37	41.69	51.63	36.59	6.43	8.61
N_4 (40:40:40)	2.76	3.84	41.76	56.60	39.86	7.13	9.62
SE	0.11	0.12	0.035	0.163	0.13	0.024	0.04
CD (0.05)	0.21	0.27	0.06	0.33	0.22	0.05	0.06
Nutrient sources							
S_1 (OS)	2.04	2.87	41.18	46.87	33.53	5.64	7.70
S_2 (INM)	2.82	3.92	41.78	56.58	39.74	7.22	9.61
SE	0.08	0.11	0.037	0.113	0.072	0.04	0.03
CD (0.05)	0.18	0.23	0.07	0.23	0.15	0.04	0.04
Controls							
C_1 (Absolute control)	0.96	1.52	38.70	32.77	23.85	2.96	5.96
C_2 (POP)	1.58	2.30	40.72	41.04	29.58	4.86	6.60
SE	0.19	0.24	0.07	0.235	0.155	0.04	0.04
C_2 vs Treatments	S	S	S	S	S	S	S
C_1 vs Treatments	S	S	S	S	S	S	S
Between controls	S	S	S	S	S	S	S

Table 13. Effect of nutrient regimes and nutrient sources on yield and yield attributes of Njavara (Harvest stage) under submerged situation (2008)

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)	Dry matter partitioning (g $hill^{-1}$)	Shoot weight (g $hill^{-1}$)	Panicle weight (g $hill^{-1}$)	Root weight (g $hill^{-1}$)
Nutrient regimes							
N_1 (30:15:15)	1.56	2.13	40.02	38.40	28.05	4.49	5.86
N_2 (30:30:30)	2.70	3.78	41.54	54.26	38.40	6.84	9.02
N_3 (40:20:20)	2.20	3.13	41.22	48.74	34.89	5.98	7.88
N_4 (40:40:40)	2.58	3.64	41.49	53.20	37.75	6.70	8.76
SE	0.12	0.13	0.044	0.33	0.24	0.057	0.054
CD (0.05)	0.25	0.25	0.09	0.64	0.42	0.11	0.11
Nutrient sources							
S_1 (OS)	1.92	2.69	40.66	44.11	31.89	5.22	7.00
S_2 (INM)	2.60	3.65	41.48	53.19	37.66	6.78	8.76
SE	0.08	0.11	0.05	0.222	0.14	0.05	0.04
CD (0.05)	0.16	0.20	0.06	0.45	0.30	0.08	0.08
Controls							
C_1 (Absolute control)	0.87	1.37	38.83	31.65	23.18	2.78	5.69
C_2 (POP)	1.41	2.10	40.12	38.53	28.07	4.51	5.95
SE	0.20	0.19	0.04	0.458	0.50	0.072	0.06
C_2 vs Treatments	S	S	S	S	S	S	S
C_1 vs Treatments	S	S	S	S	S	S	S
Between controls	S	S	S	S	S	S	S

Table 14. Interaction effect of nutrient regimes and nutrient sources on yield and yield attributes of Njavara (Harvest stage) under submerged situation (2007)

Treatment combinations (Nutrient regimes \ Nutrient sources)	Grain yield ($t\ ha^{-1}$)		Straw yield ($t\ ha^{-1}$)		Harvest index (%)		Dry matter partitioning ($g\ hill^{-1}$)		Shoot weight ($g\ hill^{-1}$)		Panicle weight ($g\ hill^{-1}$)		Root weight ($g\ hill^{-1}$)	
	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	1.40	2.00	1.97	2.81	39.75	41.58	36.90	44.90	26.79	32.17	4.28	5.43	5.83	7.30
N_2 (30:30:30)	2.32	3.41	3.25	4.72	41.65	41.94	51.08	64.44	36.43	44.79	6.20	8.44	8.45	11.21
N_3 (40:20:20)	2.04	2.78	2.86	3.88	41.63	41.74	46.73	56.52	33.45	39.73	5.67	7.18	7.61	9.61
N_4 (40:40:40)	2.43	3.08	3.40	4.28	41.68	41.84	52.76	60.44	37.44	42.27	6.41	7.84	8.91	10.33
SE	0.19		0.24		0.07		0.235		0.155		0.04		0.04	
CD (0.05)	0.37		0.47		0.14		0.47		0.31		0.08		0.08	

Table 15. Interaction effect of nutrient regimes and nutrient sources on yield and yield attributes of Njavara (Harvest stage) under submerged situation (2008)

Treatment combinations / Nutrient sources / Nutrient regimes	Grain yield (t ha^{-1})		Straw yield (t ha^{-1})		Harvest index (%)		Dry matter partitioning (g $hill^{-1}$)		Shoot weight (g $hill^{-1}$)		Panicle weight (g $hill^{-1}$)		Root weight (g $hill^{-1}$)	
	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	1.39	1.72	1.74	2.51	39.37	40.66	34.87	41.92	25.78	30.32	3.95	5.03	5.14	6.57
N_2 (30:30:30)	2.16	3.23	3.09	4.47	41.14	41.94	47.73	60.78	34.17	42.63	5.75	7.92	7.81	10.23
N_3 (40:20:20)	1.86	2.54	2.69	3.57	40.87	41.57	44.21	53.26	32.01	37.76	5.21	6.74	6.99	8.76
N_4 (40:40:40)	2.26	2.90	3.22	4.05	41.24	41.73	49.61	56.78	35.58	39.91	5.98	7.41	8.05	9.46
SE	0.20		0.19		0.04		0.458		0.50		0.072		0.06	
CD (0.05)	0.39		0.45		0.12		0.91		0.60		0.15		0.16	

Among the interactions, N_2S_2 recorded highest dry matter accumulation in shoot, panicle and root, which was significantly superior to all other interactions. Lowest dry matter production was obtained under N_1S_1.

4.1.7. Paddy grain ratio

Analysis of the data revealed no significant influence of nutrient regimes and nutrient sources on paddy grain ratio during both the years of study and the results are presented in Table 16.

4.1.8. Grain husk ratio

The results presented in Table 16 showed that nutrient regimes and nutrient sources did not influence grain husk ratio during both the years of study.

4.1.9. Crop duration

Crop duration was not influenced by nutrient regimes and nutrient sources during both the years of experimentation. The results are presented in Table 16.

4.1.10. Nutrient uptake (Uptake of N, P, K, S, Fe, Mn and Zn)

Data on uptake of N, P, K, S, Fe, Mn and Zn as influenced by nutrient regimes, sources of nutrients and their interactions during both the years of study are presented in Tables 17, 18, 19 and 20.

Effect of nutrient regimes, nutrient sources and interaction effects on uptake of N, P and K were significant in both the years.

During both the years, uptake of N, P and K was highest in N_2 (81.80 kg N ha^{-1}, 29.21 kg P ha^{-1} and 99.29 kg K ha^{-1} in 2007 and 79.36 kg N ha^{-1}, 31.82 kg P ha^{-1} and 96.52 kg K ha^{-1} in 2008). This was followed by N_4, N_3 and N_1 respectively. POP was on par with N_1 regime (30:15:15 kg NPK ha^{-1}).

During 2007 and 2008, N, P and K uptake obtained under different nutrient sources differed significantly. In both the years, nutrient uptake was higher under integrated nutrition compared to organic nutrition.

In both the years of study N_2S_2 recorded significantly higher uptake of N, P and K (98.27 kg N ha^{-1}, 33.22 kg P ha^{-1} and 108.26 kg K ha^{-1} in 2007 and 95.74 kg N ha^{-1}, 36.18 kg P ha^{-1} and 105.24 kg K ha^{-1} in 2008). The least uptake

Table 16. Effect of nutrient regimes and nutrient sources on yield attributes of Njavara under submerged situation (2007 and 2008)

Treatments	2007			2008		
	Paddy grain ratio	Grain husk ratio	Crop duration (Days)	Paddy grain ratio	Grain husk ratio	Crop duration (Days)
Nutrient regimes						
N_1 (30:15:15)	1.83	1.21	83.00	1.83	1.21	83.00
N_2 (30:30:30)	1.59	1.73	82.00	1.60	1.72	83.00
N_3 (40:20:20)	1.65	1.56	83.00	1.66	1.54	83.00
N_4 (40:40:40)	1.60	1.68	83.00	1.60	1.68	83.00
SE	0.001	0.006	0.001	0.0014	0.0046	0.002
CD (0.05)	NS	NS	NS	NS	NS	NS
Nutrient sources						
S_1 (OS)	1.73	1.37	83.00	1.74	1.37	83.00
S_2 (INM)	1.60	1.72	82.00	1.61	1.70	82.00
SE	0.0004	0.0034	0.001	0.002	0.0033	0.001
CD (0.05)	NS	NS	NS	NS	NS	NS
Controls						
C_1 (Absolute control)	1.90	1.11	83.00	1.87	1.15	83.00
C_2 (POP)	1.80	1.25	83.00	1.82	1.22	83.00
SE	0.0014	0.006	0.010	0.003	0.0067	0.007
C_2 vs Treatments	NS	NS	NS	NS	NS	NS
C_1 vs Treatments	NS	NS	NS	NS	NS	NS
Between controls	NS	NS	NS	NS	NS	NS

(Interaction effect not significant)

Table 17. Effect of nutrient regimes and nutrient sources on nutrient uptake of Njavara under submerged situation (2007)

Treatments	N	P	K	S	Fe	Mn	Zn
	(kg ha^{-1})						
Nutrient regimes							
N_1 (30:15:15)	41.98	19.62	75.84	4.55	0.41	0.42	0.24
N_2 (30:30:30)	81.80	29.21	99.29	5.98	0.76	0.68	0.42
N_3 (40:20:20)	66.55	25.78	91.15	5.34	0.59	0.56	0.33
N_4 (40:40:40)	78.18	28.44	97.98	5.88	0.71	0.66	0.40
SE	0.30	0.044	0.13	0.01	0.003	0.0013	0.001
CD (0.05)	0.40	0.09	0.24	NS	NS	NS	NS
Nutrient sources							
S_1 (OS)	55.02	22.94	84.41	4.98	0.51	0.50	0.29
S_2 (INM)	79.23	28.58	97.72	5.89	0.73	0.66	0.41
SE	0.15	0.034	0.087	0.004	0.0016	0.002	0.001
CD (0.05)	0.28	0.07	0.17	NS	NS	NS	NS
Controls							
C_1 (Absolute control)	20.32	14.18	61.34	3.21	0.07	0.18	0.08
C_2 (POP)	41.62	19.71	75.67	3.76	0.23	0.29	0.14
SE	0.29	0.063	0.16	0.014	0.004	0.0022	0.0014
C_2 vs Treatments	S	S	S	NS	NS	NS	NS
C_1 vs Treatments	S	S	S	S	S	S	S
Between controls	S	S	S	S	S	S	S

Table 18. Effect of nutrient regimes and nutrient sources on nutrient uptake of Njavara under submerged situation (2008)

Treatments	N	P	K	S	Fe	Mn	Zn
	(kg ha^{-1})						
Nutrient regimes							
N_1 (30:15:15)	39.52	20.71	73.50	4.39	0.40	0.41	0.23
N_2 (30:30:30)	79.36	31.82	96.52	5.89	0.70	0.67	0.40
N_3 (40:20:20)	64.53	27.80	88.58	5.25	0.55	0.54	0.32
N_4 (40:40:40)	76.06	31.24	95.27	5.77	0.65	0.64	0.37
SE	1.04	0.30	0.64	0.037	0.02	0.004	0.005
CD (0.05)	2.06	0.55	1.20	NS	NS	NS	NS
Nutrient sources							
S_1 (OS)	53.29	24.69	81.90	4.86	0.47	0.49	0.27
S_2 (INM)	76.44	31.09	95.03	5.79	0.68	0.64	0.39
SE	0.72	0.206	0.443	0.026	0.006	0.005	0.004
CD (0.05)	1.46	0.41	0.89	NS	NS	NS	NS
Controls							
C_1 (Absolute control)	19.53	14.97	58.11	3.17	0.06	0.16	0.07
C_2 (POP)	39.17	20.68	72.94	3.70	0.22	0.27	0.13
SE	1.457	0.43	0.90	0.06	0.01	0.02	0.0063
C_2 vs Treatments	S	S	S	NS	NS	NS	NS
C_1 vs Treatments	S	S	S	S	S	S	S
Between controls	S	S	S	S	S	S	S

Table 19. Interaction effect of nutrient regimes and nutrient sources on nutrient uptake of Njavara under submerged situation (2007)

Treatment combinations	N		P		K	
Nutrient sources / Nutrient regimes	(kg ha^{-1})					
	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	31.64	52.31	17.14	22.10	70.02	81.65
N_2 (30:30:30)	65.32	98.27	25.20	33.22	90.32	108.26
N_3 (40:20:20)	55.03	78.06	23.20	28.35	84.63	97.67
N_4 (40:40:40)	68.07	88.29	26.22	30.66	92.68	103.28
SE	0.29		0.063		0.16	
CD (0.05)	0.56		0.13		0.34	

Table 20. Interaction effect of nutrient regimes and nutrient sources on nutrient uptake of Njavara under submerged situation (2008)

Treatment combinations	N		P		K	
Nutrient sources / Nutrient regimes	(kg ha^{-1})					
	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	30.14	48.89	17.92	23.49	67.32	79.68
N_2 (30:30:30)	62.97	95.74	27.45	36.18	87.79	105.24
N_3 (40:20:20)	53.79	75.27	24.67	30.92	82.53	94.62
N_4 (40:40:40)	66.25	85.86	28.71	33.76	89.95	100.58
SE	1.457		0.43		0.90	
CD (0.05)	2.91		0.82		1.78	

was recorded in N_1S_1 (31.64 kg N ha^{-1}, 17.14 kg P ha^{-1} and 70.02 kg K ha^{-1} in 2007 and 30.14 kg N ha^{-1}, 17.92 kg P ha^{-1} and 67.32 kg K ha^{-1} in 2008).

The results presented in Tables 17, 18, 19 and 20 showed no significant influence of nutrient regimes and nutrient sources on uptake of S, Fe, Mn and Zn during both the years of study.

4.1.11. Biochemical components of grain

Biochemical components that govern the nutritional quality of grain were assessed in terms of total, free and sulphur containing amino acids, phenols, starch, amylose, amylopectin and protein content.

4.1.11.1. Total, free and sulphur containing amino acids

Perusal of the data presented in Tables 21 and 22 revealed that nutrient regimes significantly influenced total amino acid content of grain in both the years. Effect of nutrient sources and interaction effects were not significant.

During 2007 and 2008, N_2 recorded highest total amino acid content (0.78 mg 100 g^{-1} in 2007 and 0.76 mg 100 g^{-1} in 2008) and was on par with N_4 and both were significantly higher than N_3 and N_1 regimes.

The results presented in Tables 21 and 22 showed no significant influence of nutrient regimes and nutrient sources on free and sulphur containing amino acids content of grain during both the years of study.

4.1.11.2. Phenols, starch, amylose and amylopectin content

Data presented in Tables 21 and 22 showed that nutrient regimes and nutrient sources had no significant influence on grain content of phenols, starch, amylose and amylopectin during both the years.

4.1.11.3. Protein content

Data presented in Tables 21 and 22 showed that nutrient regimes significantly influenced the protein content of grain during both the years of experimentation. Nutrient sources and interaction effects were not significant.

Highest content of protein was recorded in N_2 (7.56 % in 2007 and 7.46 % in 2008) and it was on par with N_4 (7.44 % in 2007 and 7.31 % in 2008).

Table 21. Effect of nutrient regimes and nutrient sources on biochemical components of Njavara grain under submerged situation (2007)

Treatments	Harvest stage							
	Total amino acids (mg 100 g^{-1})	Free amino acids (mg 100 g^{-1})	Sulphur containing amino acids (mg 100 g^{-1})	Phenols (mg g^{-1})	Starch content (%)	Amylose content (%)	Amylopectin content (%)	Protein content (%)
Nutrient regimes								
N_1 (30:15:15)	0.47	0.12	0.02	2.82	58.86	22.32	36.55	5.89
N_2 (30:30:30)	0.78	0.19	0.05	6.32	67.53	23.67	43.86	7.56
N_3 (40:20:20)	0.67	0.16	0.04	4.86	64.69	23.26	41.43	6.93
N_4 (40:40:40)	0.77	0.18	0.04	5.83	67.21	23.65	43.56	7.44
SE	0.05	0.00033	0.00016	0.015	0.08	0.017	0.077	0.07
CD (0.05)	0.09	NS	NS	NS	NS	NS	NS	0.14
Nutrient sources								
S_1 (OS)	0.58	0.14	0.03	3.84	62.08	22.84	39.23	6.43
S_2 (INM)	0.77	0.19	0.04	6.07	67.06	23.60	43.47	7.48
SE	0.002	0.00022	0.0002	0.01	0.063	0.02	0.056	0.006
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Controls								
C_1 (Absolute control)	0.32	0.08	0.01	0.92	53.75	21.45	32.29	4.85
C_2 (POP)	0.47	0.11	0.02	2.86	59.03	22.35	36.68	5.87
SE	0.003	0.0006	0.0003	0.027	0.15	0.03	0.102	0.01
C_2 vs Treatments	NS	NS	NS	NS	NS	NS	NS	NS
C_1 vs Treatments	S	NS	NS	NS	NS	NS	NS	S
Between controls	S	NS	NS	NS	NS	NS	NS	S

(Interaction effect not significant)

Table 22. Effect of nutrient regimes and nutrient sources on biochemical components of Njavara grain under submerged situation (2008)

Treatments	Harvest stage							
	Total amino acids (mg 100 g^{-1})	Free amino acids (mg 100 g^{-1})	Sulphur containing amino acids (mg 100 g^{-1})	Phenols (mg g^{-1})	Starch content (%)	Amylose content (%)	Amylopectin content (%)	Protein content (%)
Nutrient regimes								
N_1 (30:15:15)	0.46	0.11	0.02	2.76	56.95	21.56	35.40	5.78
N_2 (30:30:30)	0.76	0.19	0.04	6.19	65.53	23.06	42.47	7.46
N_3 (40:20:20)	0.65	0.16	0.03	4.76	62.55	22.44	40.12	6.79
N_4 (40:40:40)	0.75	0.18	0.04	5.71	65.10	22.91	42.19	7.31
SE	0.04	0.003	0.0007	0.08	0.13	0.024	0.123	0.10
CD (0.05)	0.08	NS	NS	NS	NS	NS	NS	0.19
Nutrient sources								
S_1 (OS)	0.56	0.13	0.03	3.76	60.08	22.09	37.99	6.32
S_2 (INM)	0.75	0.18	0.04	5.95	64.98	22.89	42.10	7.35
SE	0.004	0.0017	0.0008	0.063	0.103	0.015	0.09	0.040
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Controls								
C_1 (Absolute control)	0.30	0.08	0.01	0.87	52.11	20.87	31.24	4.74
C_2 (POP)	0.45	0.11	0.02	2.77	57.10	21.59	35.51	5.77
SE	0.02	0.004	0.001	0.122	0.24	0.037	0.178	0.063
C_2 vs Treatments	NS	NS	NS	NS	NS	NS	NS	NS
C_1 vs Treatments	S	NS	NS	NS	NS	NS	NS	S
Between controls	S	NS	NS	NS	NS	NS	NS	S

(Interaction effect not significant)

4.1.12. Nitrate reductase activity (Plant enzyme)

Data presented in Table 23 indicated that nutrient regimes and sources of nutrients significantly influenced nitrate reductase activity at panicle initiation stage in both the years. Interaction effects were not significant.

Both in 2007 and 2008, nitrate reductase activity was in the order $N_4 \geq N_2 > N_3 > N_1$. N_4 recorded maximum nitrate reductase activity of 735.29 μmole NO_2 g^{-1} fresh weight hr^{-1} in 2007 and 721.24 μmole NO_2 g^{-1} fresh weight hr^{-1} in 2008 which was on par with N_2 (731.92 μmole NO_2 g^{-1} fresh weight hr^{-1} in 2007 and 720.92 μmole NO_2 g^{-1} fresh weight hr^{-1} in 2008). Nitrate reductase activity was lowest in N_1.

In both the years, integrated nutrient source recorded maximum nitrate reductase activity (734.81 μmole NO_2 g^{-1} fresh weight hr^{-1} in 2007 and 721.49 μmole NO_2 g^{-1} fresh weight hr^{-1} in 2008) which was significantly higher than that under organic nutrition (508.65 μmole NO_2 g^{-1} fresh weight hr^{-1} in 2007 and 496.74 μmole NO_2 g^{-1} fresh weight hr^{-1} in 2008).

4.1.13. Root weight and root volume

Data on root weight $plant^{-1}$ and root volume $plant^{-1}$ of Njavara at panicle initiation stage are presented in Table 24. Nutrient sources significantly influenced the root weight of Njavara whereas nutrient regimes and interaction effects were not significant during both the years of study.

Integrated nutrition registered the highest root weight of Njavara (4.48 g $plant^{-1}$ in 2007 and 4.38 g $plant^{-1}$ in 2008) which was significantly higher than organic nutrition that produced 3.63 g $plant^{-1}$ in 2007 and 3.54 g $plant^{-1}$ in 2008. Nutrient regimes and nutrient sources did not influence root volume of Njavara during both the years of study.

4.1.14. Major weed flora and weed biomass

The weeds collected from the experimental fields were classified into grasses, sedges and broad leaved weeds and are presented in Table 25. The important species of weeds found under submerged situation were *Echinochloa colona* (L.) Link and *Isachne miliacea* Roth ex Roem. et Schult among grasses, *Cyperus iria* L., *Cyperus difformis* L. and *Fimbristylis miliacea* (L.) Vahl. among

Table 23. Effect of nutrient regimes and nutrient sources on nitrate reductase activity of Njavara at panicle initiation stage under submerged situation (2007 and 2008)

Treatments	Nitrate reductase activity (μmole NO_2 g^{-1} fresh weight hr^{-1})	
	2007	2008
Nutrient regimes		
N_1 (30:15:15)	397.18	381.68
N_2 (30:30:30)	731.92	720.92
N_3 (40:20:20)	622.54	612.62
N_4 (40:40:40)	735.29	721.24
SE	1.83	7.59
CD (0.05)	3.64	15.16
Nutrient sources		
S_1 (OS)	508.65	496.74
S_2 (INM)	734.81	721.49
SE	1.284	5.33
CD (0.05)	2.57	10.72
Controls		
C_1 (Absolute control)	181.38	173.14
C_2 (POP)	393.83	381.51
SE	2.58	10.582
C_2 vs Treatments	NS	NS
C_1 vs Treatments	S	S
Between controls	S	S

(Interaction effect not significant)

Table 24. Effect of nutrient regimes and nutrient sources on root weight and root volume of Njavara at panicle initiation stage under submerged situation (2007 and 2008)

Treatments	2007		2008	
	Root weight (g plant^{-1})	Root volume (cm^3 plant^{-1})	Root weight (g plant^{-1})	Root volume (cm^3 plant^{-1})
Nutrient regimes				
N_1 (30:15:15)	3.11	6.66	2.95	6.46
N_2 (30:30:30)	4.54	8.54	4.46	8.26
N_3 (40:20:20)	4.12	7.78	4.05	7.47
N_4 (40:40:40)	4.46	8.32	4.39	8.05
SE	0.006	0.016	0.034	0.05
CD (0.05)	NS	NS	NS	NS
Nutrient sources				
S_1 (OS)	3.63	7.21	3.54	6.99
S_2 (INM)	4.48	8.44	4.38	8.12
SE	0.03	0.01	0.027	0.04
CD (0.05)	0.08	NS	0.05	NS
Controls				
C_1 (Absolute control)	3.02	6.59	3.00	6.41
C_2 (POP)	3.16	6.64	3.11	6.46
SE	0.02	0.026	0.06	0.07
C_2 vs Treatments	NS	NS	NS	NS
C_1 vs Treatments	S	NS	S	NS
Between controls	S	NS	S	NS

(Interaction effect not significant)

Table 25. Major weed flora observed in experimental field (Submerged situation)

Scientific name	Common name	Family
Grasses		
Echinochloa colona (L.) Link	Jungle rice	Poaceae
Isachne miliacea Roth ex Roem. et Schult	Blood grass	Poaceae
SEges		
Cyperus iria L.	Yellow SEge	Cyperaceae
Cyperus difformis L.	Umbrella SEge	Cyperaceae
Fimbristylis miliacea (L.) Vahl.	Globe fingerush	Cyperaceae
Broadleaved weeds		
Ludwigia perennis L.	Water primrose	Onagraceae
Monochoria vaginalis (Burm. f.) Presl.ex Kunth.	Pickerel weed	Pontenderiaceae
Marsilea quadrifoliata Linn.	Airy pepper wort	Marsileaceae
Eclipta alba (L.) Hassk	False daisy	Asteraceae
Ammania baccifera (L.)	Blistering ammania	Lytharaceae

sedges and *Ludwigia perennis* L., *Monochoria vaginalis* (Burm. f.) Presl.ex Kunth., *Marsilea quadrifoliata* Linn., *Eclipta alba* (L.) Hassk and *Ammania baccifera* (L.) among broad leaved weeds.

The data on weed biomass was recorded at 20 and 40 DAS in both the years of experimentation and are presented in Table 26.

The data revealed significant effect of nutrient sources on weed biomass during both stages in both the years of experimentation. Nutrient regimes and interaction effects were not significant on weed biomass during both the stages in both the years.

Weed biomass at 20 DAS (36.82 g m^{-2} in 2007 and 33.27 g m^{-2} in 2008) was significantly higher in crops raised with organic nutrition compared to that in the crop raised with integrated nutrition (27.32 g m^{-2} in 2007 and 23.90 g m^{-2} in 2008). Highest weed biomass was recorded in absolute control (48.02 g m^{-2} in 2007 and 44.75 g m^{-2} in 2008).

At 40 DAS weed biomass in plots applied with organic sources was 48.97 g m^{-2} in 2007 and 46.34 g m^{-2} in 2008, which were significantly higher than that in plots applied with integrated nutrient sources (38.42 g m^{-2} in 2007 and 35.17 g m^{-2} in 2008). Highest weed biomass was recorded in absolute control (60.12 g m^{-2} in 2007 and 58.72 g m^{-2} in 2008).

4.1.15. Soil properties

4.1.15.1. Bulk density

Analysis of the data on bulk density showed no significant influence due to nutrient regimes and nutrient sources during both the years of experimentation and the results are presented in Table 27.

4.1.15.2. CEC and pH

Nutrient regimes and nutrient sources had no significant effect on CEC and pH of the soil in both the years and the results are presented in Tables 28 and 29.

Table 26. Effect of nutrient regimes and nutrient sources on weed biomass of Njavara under submerged situation (2007 and 2008)

Treatments	Weed biomass (g m^{-2})			
	2007		2008	
	20 DAS	40 DAS	20 DAS	40 DAS
Nutrient regimes				
N_1 (30:15:15)	41.52	54.03	38.07	51.89
N_2 (30:30:30)	26.48	37.48	23.65	34.31
N_3 (40:20:20)	32.31	44.25	28.31	41.27
N_4 (40:40:40)	27.98	39.02	24.31	35.55
SE	0.074	0.07	0.24	0.40
CD (0.05)	NS	NS	NS	NS
Nutrient sources				
S_1 (OS)	36.82	48.97	33.27	46.34
S_2 (INM)	27.32	38.42	23.90	35.17
SE	0.06	0.052	0.177	0.22
CD (0.05)	0.10	0.11	0.35	0.42
Controls				
C_1 (Absolute control)	48.02	60.12	44.75	58.72
C_2 (POP)	41.80	53.93	38.09	52.87
SE	0.20	0.13	0.355	0.53
C_2 vs Treatments	NS	NS	NS	NS
C_1 vs Treatments	S	S	S	S
Between controls	S	S	S	S

(Interaction effect not significant)

Table 27. Effect of nutrient regimes and nutrient sources on bulk density of soil under submerged situation (2007 and 2008)

Treatments	Bulk density (g cc^{-1})	
	2007	2008
Nutrient regimes		
N_1 (30:15:15)	1.68	1.63
N_2 (30:30:30)	1.40	1.34
N_3 (40:20:20)	1.53	1.46
N_4 (40:40:40)	1.45	1.33
SE	0.004	0.006
CD (0.05)	NS	NS
Nutrient sources		
S_1 (OS)	1.61	1.54
S_2 (INM)	1.41	1.34
SE	0.002	0.0037
CD (0.05)	NS	NS
Controls		
C_1 (Absolute control)	1.80	1.76
C_2 (POP)	1.73	1.70
SE	0.005	0.0074
C_2 vs Treatments	NS	NS
C_1 vs Treatments	NS	NS
Between controls	NS	NS

(Interaction effect not significant)

4.1.16. Soil fertility status (available N, P, K, S, Fe, Zn and Mn)

The fertility status of soil was studied after the experiment in terms of available nitrogen, available phosphorus, available potassium, available sulphur, available iron, available zinc, available manganese and organic carbon and the data is presented in Tables 28 and 29.

During 2007 and 2008, available N, P and K were highest in N_2 (259.19 kg N ha^{-1}, 45.80 kg P ha^{-1} and 258.03 kg K ha^{-1} in 2007 and 252.36 kg N ha^{-1}, 46.50 kg P ha^{-1} and 252.27 kg K ha^{-1} in 2008) which was significantly higher than all other nutrient regimes in both the years. Available N, P and K in N_1 was significantly higher than POP during both the years of experimentation.

In both the years, effect of nutrient sources on available N, P and K status of soil differed significantly from one another. During 2007 and 2008, available N, P and K were highest in integrated nutrient source (259.31 kg N ha^{-1}, 45.41 kg P ha^{-1} and 256.17 kg K ha^{-1} in 2007 and 252.73 kg N ha^{-1}, 45.87 kg P ha^{-1} and 250.61 kg K ha^{-1} in 2008) and it was significantly superior to organic source (215.82 kg N ha^{-1}, 33.28 kg P ha^{-1} and 207.06 kg K ha^{-1} in 2007 and 210.69 kg N ha^{-1}, 33.53 kg P ha^{-1} and 203.40 kg K ha^{-1} in 2008).

Among the interactions, N_2S_2 recorded the highest available N, P and K (294.11 kg N ha^{-1}, 55.42 kg P ha^{-1} and 297.34 kg K ha^{-1} in 2007 and 286.77 kg N ha^{-1}, 56.23 kg P ha^{-1} and 289.85 kg K ha^{-1} in 2008) which was significantly superior to all other interaction effects (Table 30). The least values of available N, P and K was recorded in N_1S_1.

The results on the available sulphur, iron, zinc and manganese status of the soil after the experiment (Tables 28 and 29) revealed non-significant effect for nutrient regimes and sources of nutrients in both the years of study.

4.1.16.1. Organic carbon

Nutrient sources and nutrient regimes had no significant effect on organic carbon content of the soil in both the years (Tables 28 and 29).

Table 28. Effect of nutrient regimes and nutrient sources on chemical properties of soil under submerged situation (2007)

Treatments	CEC (cmol kg^{-1})	pH	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Organic carbon (%)	Available S (ppm)	Available Fe (ppm)	Available Zn (ppm)	Available Mn (ppm)
Nutrient regimes										
N_1 (30:15:15)	7.32	5.51	203.07	28.11	189.17	1.50	53.51	18.14	8.24	9.39
N_2 (30:30:30)	7.63	5.78	259.19	45.80	258.03	1.62	75.99	27.26	11.27	14.05
N_3 (40:20:20)	7.53	5.68	236.05	38.73	231.72	1.57	67.33	23.71	10.15	12.32
N_4 (40:40:40)	7.62	5.75	251.95	44.75	247.55	1.60	74.93	26.37	10.97	13.47
SE	0.0064	0.004	0.65	0.15	0.54	0.002	0.193	0.073	0.026	0.05
CD (0.05)	NS	NS	1.26	0.28	1.12	NS	NS	NS	NS	NS
Nutrient sources										
S_1 (OS)	7.43	5.58	215.82	33.28	207.06	1.53	59.99	20.88	9.20	10.86
S_2 (INM)	7.62	5.77	259.31	45.41	256.17	1.61	75.88	26.86	11.11	13.75
SE	0.0042	0.003	0.448	0.10	0.393	0.06	0.133	0.052	0.03	0.04
CD (0.05)	NS	NS	0.89	0.20	0.79	NS	NS	NS	NS	NS
Controls										
C_1 (Absolute control)	5.91	5.20	161.11	18.26	143.85	1.38	38.92	11.73	5.45	5.76
C_2 (POP)	6.98	5.34	192.35	26.59	179.28	1.45	45.55	14.94	7.15	7.75
SE	0.008	0.005	0.892	0.30	0.792	0.0017	0.274	0.12	0.05	0.056
C_2 vs Treatments	NS	NS	S	S	S	NS	NS	NS	NS	NS
C_1 vs Treatments	NS	NS	S	S	S	NS	S	S	S	S
Between controls	NS	NS	S	S	S	NS	S	S	S	S

Table 29. Effect of nutrient regimes and nutrient sources on chemical properties of soil under submerged situation (2008)

Treatments	CEC (cmol kg^{-1})	pH	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Organic carbon (%)	Available S (ppm)	Available Fe (ppm)	Available Zn (ppm)	Available Mn (ppm)
Nutrient regimes										
N_1 (30:15:15)	7.22	5.70	197.52	28.29	185.23	1.46	52.22	15.95	7.50	8.49
N_2 (30:30:30)	7.50	5.92	252.36	46.50	252.27	1.58	73.76	24.25	10.21	12.78
N_3 (40:20:20)	7.39	5.81	230.99	38.94	226.36	1.53	65.43	20.85	9.00	11.06
N_4 (40:40:40)	7.47	5.87	245.99	45.08	244.17	1.57	73.13	23.55	10.00	12.54
SE	0.014	0.004	1.27	0.50	1.55	0.0024	0.45	0.17	0.040	0.084
CD (0.05)	NS	NS	2.56	0.80	3.08	NS	NS	NS	NS	NS
Nutrient sources										
S_1 (OS)	7.31	5.75	210.69	33.53	203.40	1.50	58.28	18.56	8.18	9.70
S_2 (INM)	7.48	5.89	252.73	45.87	250.61	1.57	73.99	23.74	10.17	12.73
SE	0.02	0.003	0.902	0.27	1.09	0.06	0.33	0.114	0.034	0.070
CD (0.05)	NS	NS	1.81	0.56	2.18	NS	NS	NS	NS	NS
Controls										
C_1 (Absolute control)	5.79	5.26	163.21	18.37	139.96	1.33	37.23	10.28	5.59	4.89
C_2 (POP)	6.89	5.42	189.83	27.05	175.83	1.39	43.71	12.46	6.71	6.13
SE	0.03	0.02	1.80	0.564	2.177	0.0034	0.63	0.25	0.077	0.126
C_2 vs Treatments	NS	NS	S	S	S	NS	NS	NS	NS	NS
C_1 vs Treatments	NS	NS	S	S	S	NS	S	S	S	S
Between controls	NS	NS	S	S	S	NS	S	S	S	S

Table 30. Interaction effect of nutrient regimes and nutrient sources on soil fertility status under submerged situation (2007 and 2008)

Treatment combinations	2007						2008					
Nutrient sources / Nutrient regimes	Available N (kg ha^{-1})		Available P (kg ha^{-1})		Available K (kg ha^{-1})		Available N (kg ha^{-1})		Available P (kg ha^{-1})		Available K (kg ha^{-1})	
	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	189.47	216.66	24.49	31.72	172.41	205.93	187.42	207.61	24.68	31.89	169.12	201.34
N_2 (30:30:30)	224.27	294.11	36.17	55.42	218.71	297.34	217.95	286.77	36.76	56.23	214.68	289.85
N_3 (40:20:20)	219.64	252.46	33.28	44.18	215.73	247.71	213.26	248.71	33.36	44.51	210.23	242.49
N_4 (40:40:40)	229.90	273.99	39.19	50.30	221.40	273.69	224.14	267.84	39.30	50.86	219.57	268.77
SE	0.892		0.30		0.792		1.80		0.564		2.177	
CD (0.05)	1.79		0.40		1.59		3.62		1.13		4.35	

4.1.17. Soil enzymes activity

4.1.17.1. Urease activity

Activity of urease enzyme differed significantly under nutrient regimes and nutrient sources during both the years of experimentation and the results are presented in Table 31. Interaction effects were not significant.

N_4 recorded highest activity of urease (305.10 ppm g^{-1} hr^{-1} in 2007 and 307.21 ppm g^{-1} hr^{-1} in 2008) which was significantly higher than N_3, N_2 and N_1.

Effect of nutrient sources on urease activity differed significantly from each other. Highest activity of urease was recorded in organic source (323.59 ppm g^{-1} hr^{-1} in 2007 and 325.70 ppm g^{-1} hr^{-1} in 2008) compared to integrated nutrient source (242.30 ppm g^{-1} hr^{-1} in 2007 and 244.41 ppm g^{-1} hr^{-1} in 2008).

4.1.17.2. Phosphatase and dehydrogenase activity

The results on the phosphatase and dehydrogenase activity of the soil after the experiment (Table 31) revealed no significant effect under nutrient regimes and nutrient sources in both the years of study.

4.1.18. Soil microbial population (Bacteria, fungi and actinomycetes)

The results pertaining to soil microbial population after the experiments are presented in Table 32. The data revealed significant influence of nutrient regimes and nutrient sources on bacterial population in both the years. Interaction effects were not significant. N_4 recorded significantly higher bacterial population (37.44 10^4 cfu g^{-1} soil in 2007 and 38.29 10^4 cfu g^{-1} soil in 2008) than all other regimes in both the years.

Significantly higher bacterial population was recorded in organic sources applied plots (38.75 10^4 cfu g^{-1} soil in 2007 and 39.63 10^4 cfu g^{-1} soil in 2008) which was significantly superior to that in integrated nutrient sources applied plots.

Effect of nutrient regimes and sources of nutrients on soil fungal and actinomycete population in 2007 and 2008 were not significant and the results are presented in Table 32.

Table 31. Effect of nutrient regimes and nutrient sources on soil enzymes under submerged situation (2007 and 2008)

Treatments	2007			2008		
	Urease (ppm g^{-1} hr^{-1})	Phosphatase (µg g^{-1} hr^{-1})	Dehydrogenase (µg g^{-1} 24 hrs^{-1})	Urease (ppm g^{-1} hr^{-1})	Phosphatase (µg g^{-1} hr^{-1})	Dehydrogenase (µg g^{-1} 24 hrs^{-1})
Nutrient regimes						
N_1 (30:15:15)	249.17	35.67	306.22	251.28	35.97	308.97
N_2 (30:30:30)	276.85	37.82	333.25	278.96	38.24	336.14
N_3 (40:20:20)	300.65	40.72	356.30	302.76	41.24	359.31
N_4 (40:40:40)	305.10	40.78	362.68	307.21	41.53	365.72
SE	0.53	0.06	0.537	1.778	0.18	1.84
CD (0.05)	1.02	NS	NS	3.55	NS	NS
Nutrient sources						
S_1 (OS)	323.59	42.87	381.84	325.70	43.55	384.97
S_2 (INM)	242.30	34.62	297.38	244.41	34.94	300.10
SE	0.38	0.034	0.39	1.254	0.127	1.33
CD (0.05)	0.72	NS	NS	2.51	NS	NS
Controls						
C_1 (Absolute control)	159.78	27.35	212.08	161.89	27.47	214.37
C_2 (POP)	189.67	29.57	241.61	191.78	29.64	244.04
SE	0.727	0.08	0.77	2.52	0.257	2.613
C_2 vs Treatments	NS	NS	NS	NS	NS	NS
C_1 vs Treatments	S	NS	NS	S	NS	NS
Between controls	S	NS	NS	S	NS	NS

(Interaction effect not significant)

Table 32. Effect of nutrient regimes and nutrient sources on soil microbial population under submerged situation (2007 and 2008)

Treatments	2007			2008		
	Rhizosphere bacterial population (10^4 cfu g^{-1} soil)	Rhizosphere fungal population (10^4 cfu g^{-1} soil)	Rhizosphere actinomycetes population (10^6 cfu g^{-1} soil)	Rhizosphere bacterial population (10^4 cfu g^{-1} soil)	Rhizosphere fungal population (10^4 cfu g^{-1} soil)	Rhizosphere actinomycetes population (10^6 cfu g^{-1} soil)
Nutrient regimes						
N_1 (30:15:15)	33.94	28.98	4.60	34.72	29.42	4.80
N_2 (30:30:30)	35.01	30.43	4.93	35.81	30.89	5.10
N_3 (40:20:20)	37.00	33.18	5.50	37.84	33.67	5.68
N_4 (40:40:40)	37.44	34.50	5.56	38.29	35.00	5.74
SE	0.08	0.20	0.03	0.23	0.28	0.045
CD (0.05)	0.18	NS	NS	0.41	NS	NS
Nutrient sources						
S_1 (OS)	38.75	35.83	5.87	39.63	36.34	6.06
S_2 (INM)	32.94	27.72	4.42	33.70	28.15	4.60
SE	0.067	0.08	0.014	0.18	0.20	0.036
CD (0.05)	0.13	NS	NS	0.34	NS	NS
Controls						
C_1 (Absolute control)	22.90	19.94	3.10	23.46	20.19	3.26
C_2 (POP)	27.87	22.96	3.51	28.53	23.34	3.67
SE	0.124	0.147	0.026	0.337	0.39	0.066
C_2 vs Treatments	NS	NS	NS	NS	NS	NS
C_1 vs Treatments	S	NS	NS	S	NS	NS
Between controls	S	NS	NS	S	NS	NS

(Interaction effect not significant)

4.1.19. Economics of cultivation

Effect of nutrient regimes, nutrient sources and their interactions on gross income, net income and BCR were significant in both the years (Tables 33, 34 and 35).

Highest gross income (Rs 84200.50 ha^{-1} in 2007 and Rs 79235.50 ha^{-1} in 2008), net income (Rs 43501.00 ha^{-1} in 2007 and Rs 38536.00 ha^{-1} in 2008) and BCR (2.08 in 2007 and 1.95 in 2008) were obtained by the application of 30:30:30 kg NPK ha^{-1} (N_2 regime).

POP recorded significantly lower gross income, net income and BCR compared to all other nutrient regimes. POP and N_1 had similar effects and were inferior to other nutrient regimes. Absolute control was found least economic during both years.

Among the nutrient sources, highest gross income (Rs 82807.84 ha^{-1} in 2007 and Rs 76377.84 ha^{-1} in 2008), net income (Rs 42666.33 ha^{-1} in 2007 and Rs 36236.33 ha^{-1} in 2008) and BCR (2.06 in 2007 and 1.90 in 2008) were obtained by integrated nutrition. Application of organic sources resulted in gross income (Rs 60173.25 ha^{-1} in 2007 and Rs 56386.50 ha^{-1} in 2008), net income (Rs 18441.75 ha^{-1} in 2007 and Rs 14655 ha^{-1} in 2008) and BCR (1.45 in 2007 and 1.35 in 2008). Net income obtained under integrated nutrition was 57 to 60 per cent higher than that obtained by organic nutrition.

Under organic nutrition N_4 recorded the highest gross income, net income and BCR compared to other two regimes and was on par with N_2. Under Integrated nutrient source N_2 recorded the highest gross income, net income and BCR.

N_2S_2 recorded highest gross income (Rs 100190.70 ha^{-1} in 2007 and Rs 94910.34 ha^{-1} in 2008), net income (Rs 60225.67 ha^{-1} in 2007 and Rs 54945.33 ha^{-1} in 2008) and BCR (2.51 in 2007 and 2.37 in 2008). Lowest gross income, net income and BCR were obtained at N_1S_1 (Tables 34 and 35).

Table 33. Effect of nutrient regimes and nutrient sources on economics of Njavara cultivation under submerged situation (2007 and 2008)

Treatments	2007			2008		
	Gross income (Rs ha^{-1})	Net income (Rs ha^{-1})	BCR	Gross income (Rs ha^{-1})	Net income (Rs ha^{-1})	BCR
Nutrient regimes						
N_1 (30:15:15)	49941.00	9904.00	1.25	45688.34	5651.33	1.14
N_2 (30:30:30)	84200.50	43501.00	2.08	79235.50	38536.00	1.95
N_3 (40:20:20)	70845.34	29809.33	1.73	64730.00	23694.00	1.58
N_4 (40:40:40)	80975.33	39001.84	1.94	75874.83	33901.34	1.81
SE	1371.64	1371.64	0.03	1196.53	1196.53	0.02
CD (0.05)	2941.69	2941.69	0.08	2402.36	2402.36	0.06
Nutrient sources						
S_1 (OS)	60173.25	18441.75	1.45	56386.50	14655.00	1.35
S_2 (INM)	82807.84	42666.33	2.06	76377.84	36236.33	1.90
SE	969.89	969.89	0.02	792.054	792.054	0.02
CD (0.05)	2080.09	2080.09	0.05	1698.73	1698.73	0.04
Controls						
C_1 (Absolute control)	28410.33	-6863.67	0.81	25739.67	-9534.33	0.73
C_2 (POP)	46530.67	8097.67	1.21	41589.33	3156.33	1.08
SE	2040.29	2040.29	0.04	2069.196	2069.196	0.03
C_2 vs Treatments	S	S	S	S	S	S
C_1 vs Treatments	S	S	S	S	S	S
Between controls	S	S	S	S	S	S

Table 34. Interaction effect of nutrient regimes and nutrient sources on economics of Njavara cultivation under submerged situation (2007)

Treatment combinations	Gross income (Rs ha^{-1})		Net income (Rs ha^{-1})		BCR	
Nutrient sources / Nutrient regimes	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	41072.00	58810.00	388.00	19420.00	1.01	1.49
N_2 (30:30:30)	68210.34	100190.70	26776.33	60225.67	1.65	2.51
N_3 (40:20:20)	59970.67	81720.00	18066.67	41552.00	1.43	2.03
N_4 (40:40:40)	71440.00	90510.66	28536.00	49467.67	1.67	2.21
SE	2040.29		2040.29		0.04	
CD (0.05)	4160.183		4160.183		0.10	

Table 35. Interaction effect of nutrient regimes and nutrient sources on economics of Njavara cultivation under submerged situation (2008)

Treatment combinations	Gross income (Rs ha^{-1})		Net income (Rs ha^{-1})		BCR	
Nutrient sources / Nutrient regimes	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	40715.67	50661.00	31.67	11271.00	1.00	1.29
N_2 (30:30:30)	63560.67	94910.34	22126.67	54945.33	1.53	2.37
N_3 (40:20:20)	54769.67	74690.34	12865.67	34522.33	1.31	1.86
N_4 (40:40:40)	66500.00	85249.66	23596.00	44206.67	1.55	2.08
SE	2069.196		2069.196		0.03	
CD (0.05)	4134.37		4134.37		0.08	

4.2. Effect of nutrient regimes and nutrient sources on growth and productivity of Njavara cultivated under saturated situation

4.2.1. Growth characters

Effect of nutrient regimes and nutrient sources on growth characters at panicle initiation and harvest stages under saturated situation during 2007 and 2008 are indicated in Tables 36 and 37 respectively. Nutrient regimes recorded significant influence on growth attributes at both stages in both years. Among the nutrient regimes, N_2 (30:30:30 kg NPK ha^{-1}) recorded significantly higher plant height, leaf number $plant^{-1}$, leaf area index, number of tillers m^{-2}, culm strength and flag leaf area and was significantly superior to all other regimes at both stages.

Among the nutrient sources, integrated nutrient source registered significantly higher values for all growth characters compared to organic nutrition at both stages during both years. Absolute control recorded significantly lower growth attributes whereas POP was on par with N_1 (30:15:15 kg NPK ha^{-1}) at both stages in 2007 and 2008.

Interaction between nutrient regimes and nutrient sources had significant influence on growth attributes such as plant height, leaf number $plant^{-1}$, leaf area index, number of tillers m^{-2}, culm strength and flag leaf area. All growth characters were significantly higher in N_2S_2 at both stages in both years. N_1S_1 recorded lowest growth attributes at both stages in both the years of experimentation (Tables 38 and 39).

Table 40 revealed that nutrient regimes significantly influenced leaf chlorophyll content at panicle initiation in both the years of experimentation. Nutrient sources and interaction effects were not significant.

N_2 recorded the highest leaf chlorophyll content of 1.96 mg g^{-1} in 2007 and 1.82 mg g^{-1} in 2008 which was significantly higher than N_3 and N_1 and was on par with N_4 (1.85 mg g^{-1} in 2007 and 1.69 mg g^{-1} in 2008).

Table 36. Effect of nutrient regimes and nutrient sources on growth attributes of Njavara under saturated situation (2007)

Treatments	Plant height (cm)		Leaf number plant^{-1}		Leaf area index		Tillers m^{-2}		Culm strength (mg cm^{-1})		Flag leaf area (cm^{2})	
	PI stage	Harvest	PI stage	Harvest	PI stage	Harvest	PI stage	Harvest	PI stage	Harvest	PI stage	Harvest
Nutrient regimes												
N_1 (30:15:15)	86.14	98.17	4.66	5.30	1.27	1.17	445.88	437.07	20.94	24.68	9.50	11.03
N_2 (30:30:30)	91.45	108.55	5.31	6.55	2.38	2.01	502.27	518.31	32.30	34.94	15.10	19.05
N_3 (40:20:20)	89.67	103.68	5.07	6.08	1.94	1.76	482.93	489.83	28.21	31.26	12.94	16.26
N_4 (40:40:40)	91.13	106.22	5.26	6.45	2.26	1.97	498.75	511.16	31.56	34.26	14.61	18.59
SE	0.082	0.104	0.006	0.038	0.027	0.013	0.612	0.832	0.14	0.10	0.112	0.163
CD (0.05)	0.17	0.21	0.01	0.07	0.05	0.03	1.23	1.67	0.22	0.20	0.23	0.33
Nutrient sources												
S_1 (OS)	88.12	101.07	4.87	5.71	1.62	1.49	465.52	466.35	24.85	28.26	11.29	13.88
S_2 (INM)	91.07	107.24	5.28	6.48	2.30	1.96	498.89	511.83	31.66	34.31	14.79	18.58
SE	0.07	0.077	0.004	0.028	0.016	0.02	0.433	0.60	0.07	0.08	0.086	0.112
CD (0.05)	0.12	0.15	0.01	0.05	0.03	0.02	0.87	1.18	0.16	0.14	0.17	0.23
Controls												
C_1 (Absolute control)	83.66	93.35	4.31	4.62	0.75	0.72	390.81	388.12	15.25	19.71	6.54	7.12
C_2 (POP)	86.15	98.14	4.65	5.29	1.27	1.17	447.58	437.35	21.01	24.60	9.53	11.02
SE	0.13	0.142	0.01	0.044	0.04	0.027	0.88	1.19	0.15	0.143	0.167	0.232
C_2 vs Treatments	S	S	S	S	S	S	S	S	S	S	S	S
C_1 vs Treatments	S	S	S	S	S	S	S	S	S	S	S	S
Between controls	S	S	S	S	S	S	S	S	S	S	S	S

Table 37. Effect of nutrient regimes and nutrient sources on growth attributes of Njavara under saturated situation (2008)

Treatments	Plant height(cm)		Leaf number plant^{-1}		Leaf area index		Tillers m^{-2}		Culm strength (mg cm^{-1})		Flag leaf area (cm^2)	
	PI stage	Harvest	PI stage	Harvest	PI stage	Harvest	PI stage	Harvest	PI stage	Harvest	PI stage	Harvest
Nutrient regimes												
N_1 (30:15:15)	80.91	94.04	4.56	4.76	1.12	1.03	427.06	423.91	18.31	20.60	8.48	9.72
N_2 (30:30:30)	87.69	105.38	5.20	5.86	2.23	1.85	491.56	502.05	29.93	32.12	13.86	16.98
N_3 (40:20:20)	85.49	101.08	4.96	5.44	1.81	1.59	468.41	472.95	25.76	28.02	11.79	14.85
N_4 (40:40:40)	87.22	104.44	5.14	5.78	2.15	1.80	486.83	494.00	29.12	31.41	13.43	16.74
SE	0.18	0.296	0.004	0.01	0.04	0.03	1.50	1.40	0.25	0.232	0.15	0.10
CD (0.05)	0.34	0.59	0.01	0.02	0.06	0.04	2.80	3.20	0.48	0.47	0.28	0.20
Nutrient sources												
S_1 (OS)	83.45	97.77	4.77	5.12	1.47	1.33	449.33	451.04	22.34	24.67	10.27	12.51
S_2 (INM)	87.20	104.70	5.16	5.81	2.17	1.81	487.60	495.42	29.22	31.41	13.51	16.64
SE	0.13	0.22	0.004	0.02	0.03	0.014	0.97	1.12	0.19	0.164	0.10	0.138
CD (0.05)	0.24	0.42	0.01	0.02	0.04	0.03	1.98	2.26	0.34	0.33	0.20	0.27
Controls												
C_1 (Absolute control)	77.69	88.33	4.21	4.17	0.54	0.50	384.81	381.70	12.77	15.21	5.79	6.14
C_2 (POP)	80.91	94.02	4.55	4.76	1.12	1.03	428.15	424.12	18.32	20.58	8.51	9.78
SE	0.25	0.44	0.02	0.013	0.03	0.04	1.986	2.27	0.35	0.334	0.194	0.28
C_2 vs Treatments	S	S	S	S	S	S	S	S	S	S	S	S
C_1 vs Treatments	S	S	S	S	S	S	S	S	S	S	S	S
Between controls	S	S	S	S	S	S	S	S	S	S	S	S

Table 38. Interaction effect of nutrient regimes and nutrient sources on growth attributes of Njavara under saturated situation (2007)

Treatment combinations	Plant height (cm)				Leaf number plant $^{-1}$				Leaf area index			
Nutrient sources / Nutrient regimes	PI stage		Harvest		PI stage		Harvest		PI stage		Harvest	
	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	84.94	87.34	95.78	100.55	4.50	4.82	4.98	5.61	0.98	1.56	0.91	1.43
N_2 (30:30:30)	89.41	93.48	103.53	113.57	5.04	5.58	6.03	7.06	1.91	2.84	1.72	2.29
N_3 (40:20:20)	88.18	91.15	101.13	106.23	4.87	5.27	5.69	6.47	1.62	2.26	1.54	1.97
N_4 (40:40:40)	89.95	92.30	103.85	108.60	5.08	5.43	6.12	6.78	1.97	2.55	1.80	2.13
SE	0.13		0.142		0.01		0.044		0.04		0.027	
CD (0.05)	0.24		0.29		0.02		0.07		0.05		0.05	

Treatment combinations	Tillers m $^{-2}$				Culm strength (mg cm $^{-1}$)				Flag leaf area (cm ^{2})			
Nutrient sources / Nutrient regimes	PI stage		Harvest		PI stage		Harvest		PI stage		Harvest	
	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	430.64	461.12	417.25	456.89	18.23	23.65	22.21	27.14	8.05	10.95	9.10	12.96
N_2 (30:30:30)	480.22	524.31	487.49	549.12	27.57	37.03	30.78	39.10	12.69	17.51	15.78	22.31
N_3 (40:20:20)	467.33	498.52	468.47	511.18	24.81	31.61	28.23	34.29	11.24	14.64	13.91	18.60
N_4 (40:40:40)	485.88	511.62	492.17	530.14	28.77	34.35	31.81	36.71	13.15	16.06	16.72	20.46
SE	0.88		1.19		0.15		0.143		0.167		0.232	
CD (0.05)	1.74		2.36		0.32		0.29		0.33		0.47	

Table 39. Interaction effect of nutrient regimes and nutrient sources on growth attributes of Njavara under saturated situation (2008)

Treatment combinations	Plant height (cm)				Leaf number plant $^{-1}$				Leaf area index			
Nutrient sources / Nutrient regimes	PI stage		Harvest		PI stage		Harvest		PI stage		Harvest	
	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	79.22	82.59	91.18	96.89	4.40	4.71	4.48	5.04	0.82	1.41	0.74	1.32
N_2 (30:30:30)	85.12	90.25	100.59	110.16	4.93	5.46	5.39	6.33	1.77	2.68	1.56	2.14
N_3 (40:20:20)	83.56	87.42	97.73	104.43	4.77	5.15	5.10	5.78	1.45	2.16	1.37	1.80
N_4 (40:40:40)	85.90	88.54	101.57	107.30	4.97	5.31	5.49	6.07	1.85	2.44	1.63	1.96
SE	0.25		0.44		0.02		0.013		0.03		0.04	
CD (0.05)	0.48		0.84		0.02		0.03		0.06		0.06	

Treatments combination	Tillers m $^{-2}$				Culm strength (mg cm $^{-1}$)				Flag leaf area (cm ^{2})			
Nutrient sources / Nutrient regimes	PI stage		Harvest		PI stage		Harvest		PI stage		Harvest	
	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	410.33	443.78	404.26	443.56	15.50	21.11	17.93	23.27	7.14	9.82	7.91	11.53
N_2 (30:30:30)	465.54	517.58	471.87	532.22	25.16	34.69	27.42	36.82	11.63	16.08	14.29	19.67
N_3 (40:20:20)	450.15	486.67	452.36	493.53	22.38	29.13	24.64	31.40	10.21	13.37	12.65	17.04
N_4 (40:40:40)	471.30	502.35	475.65	512.35	26.30	31.94	28.67	34.14	12.10	14.75	15.18	18.30
SE	1.986		2.27		0.35		0.334		0.194		0.28	
CD (0.05)	3.97		3.70		0.68		0.67		0.39		0.54	

Table 40. Effect of nutrient regimes and nutrient sources on leaf chlorophyll content of Njavara at panicle initiation stage under saturated situation (2007 and 2008)

Treatments	Leaf chlorophyll content (mg g^{-1})	
	2007	2008
Nutrient regimes		
N_1 (30:15:15)	0.89	0.81
N_2 (30:30:30)	1.96	1.82
N_3 (40:20:20)	1.52	1.33
N_4 (40:40:40)	1.85	1.69
SE	0.07	0.10
CD (0.05)	0.14	0.21
Nutrient sources		
S_1 (OS)	1.21	1.09
S_2 (INM)	1.91	1.73
SE	0.01	0.013
CD (0.05)	NS	NS
Controls		
C_1 (Absolute control)	0.37	0.30
C_2 (POP)	0.89	0.77
SE	0.02	0.03
C_2 vs Treatments	NS	NS
C_1 vs Treatments	S	S
Between controls	S	S

(Interaction effect not significant)

4.2.2. Yield attributes

Effect of nutrient regimes and nutrient sources on yield attributes of Njavara grown under saturated situation during 2007 and 2008 are presented in Tables 41 and 42 respectively.

Number of productive tillers increased significantly with increased application of nutrients. Maximum number of productive tillers m^{-2} was observed at N_2 regime (319 and 315 in 2007 and 2008 respectively). Same nutrient regime recorded maximum number of grains $panicle^{-1}$ (75 and 74 in 2007 and 2008 respectively) and filled grains $panicle^{-1}$ (62 and 61 in 2007 and 2008 respectively). This regime was significantly superior to the other three nutrient regimes.

Effect of nutrient sources on productive tillers, panicle length, grains $panicle^{-1}$ and filled grains $panicle^{-1}$ was significant. Integrated nutrient source recorded significantly higher values compared to organic nutrition. In 2007, integrated nutrient source recorded 314 productive tillers m^{-2} which was significantly higher than organic source, which recorded 267 productive tillers m^{-2}. The corresponding values during 2008 were 310 and 262 respectively. Panicle length, grains $panicle^{-1}$ and filled grains $panicle^{-1}$ were also significantly higher under integrated nutrient supply system during both years.

POP recorded significantly lower number of productive tillers compared to all nutrient regimes except N_1 during 2007. POP and N_1 regime of nutrients (30:15:15 kg NPK ha^{-1}) had similar effects on all other yield attributes and were inferior to other nutrient regimes. Same trend was observed during 2008. Absolute control recorded the lowest values for all yield attributes during both years.

Interaction between nutrient regimes and sources had significant influence on all yield attributes such as productive tillers m^{-2}, panicle length, grains $panicle^{-1}$ and filled grains $panicle^{-1}$ except 1000 grain weight. N_2S_2 recorded significantly higher yield attributes than all other treatment combinations in both years. N_1S_1 recorded lowest yield attributes in both years. Highest sterility percentage was recorded in N_1S_1 (22.41 % in 2007 and 23.61 % in 2008) and lowest sterility

Table 41. Effect of nutrient regimes and nutrient sources on yield attributes of Njavara under saturated situation (2007)

Treatments	Productive tillers m^{-2}	Panicle length (cm)	Grains $panicle^{-1}$	Filled grains $panicle^{-1}$	Thousand grain weight (g)	Sterility percentage
Nutrient regimes						
N_1 (30:15:15)	240.61	16.29	55.61	43.81	17.75	21.33
N_2 (30:30:30)	319.03	21.67	74.93	61.87	17.85	17.61
N_3 (40:20:20)	288.97	19.43	67.09	54.30	17.82	19.16
N_4 (40:40:40)	311.80	20.97	72.65	59.56	17.85	18.09
SE	0.385	0.075	0.095	0.09	0.09	0.055
CD (0.05)	0.77	0.15	0.19	0.18	NS	0.11
Nutrient sources						
S_1 (OS)	266.66	17.88	61.53	49.17	17.78	20.23
S_2 (INM)	313.55	21.30	73.61	60.59	17.85	17.87
SE	0.27	0.05	0.065	0.06	0.07	0.04
CD (0.05)	0.54	0.10	0.13	0.12	NS	0.08
Controls						
C_1 (Absolute control)	200.93	13.20	44.99	33.88	17.69	24.69
C_2 (POP)	240.03	16.29	55.59	43.76	17.74	21.28
SE	0.545	0.105	0.135	0.125	0.12	0.08
C_2 vs Treatments	S	S	S	S	NS	S
C_1 vs Treatments	S	S	S	S	NS	S
Between controls	S	S	S	S	NS	S

Table 42. Effect of nutrient regimes and nutrient sources on yield attributes of Njavara under saturated situation (2008)

Treatments	Productive tillers m^{-2}	Panicle length (cm)	Grains $panicle^{-1}$	Filled grains $panicle^{-1}$	Thousand grain weight (g)	Sterility percentage
Nutrient regimes						
N_1 (30:15:15)	233.56	15.60	53.22	41.35	17.53	22.45
N_2 (30:30:30)	314.56	20.80	73.65	60.77	17.81	17.68
N_3 (40:20:20)	286.09	18.65	65.90	53.09	17.74	19.56
N_4 (40:40:40)	309.88	20.12	71.38	58.50	17.81	18.12
SE	2.2	0.09	0.55	0.334	0.07	0.2
CD (0.05)	4.20	0.18	1.08	0.67	NS	0.20
Nutrient sources						
S_1 (OS)	262.26	17.15	59.75	47.46	17.66	20.81
S_2 (INM)	309.79	20.43	72.32	59.39	17.80	18.10
SE	1.482	0.063	0.387	0.233	0.05	0.06
CD (0.05)	2.97	0.13	0.77	0.47	NS	0.14
Controls						
C_1 (Absolute control)	195.39	12.42	42.08	31.48	17.25	25.19
C_2 (POP)	233.57	15.60	51.93	40.51	17.56	22.48
SE	2.99	0.15	0.764	0.45	0.10	0.15
C_2 vs Treatments	S	S	S	S	NS	S
C_1 vs Treatments	S	S	S	S	NS	S
Between controls	S	S	S	S	NS	S

Table 43. Interaction effect of nutrient regimes and nutrient sources on yield attributes of Njavara under saturated situation (2007)

Treatment combinations	Productive tillers m^{-2}		Panicle length (cm)		Grains $panicle^{-1}$		Filled grains $panicle^{-1}$		Thousand grain weight (g)		Sterility percentage	
Nutrient regimes \ Nutrient sources	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	221.06	260.16	14.78	17.79	50.37	60.85	39.08	48.53	17.72	17.78	22.41	20.25
N_2 (30:30:30)	286.75	351.31	19.38	23.96	66.77	83.08	53.95	69.78	17.80	17.89	19.20	16.01
N_3 (40:20:20)	266.65	311.29	17.89	20.97	61.53	72.65	49.11	59.48	17.78	17.85	20.19	18.13
N_4 (40:40:40)	292.17	331.44	19.47	22.46	67.44	77.86	54.55	64.57	17.83	17.87	19.11	17.07
SE	0.545		0.105		0.135		0.125		0.12		0.08	
CD (0.05)	1.09		0.21		0.27		0.25		NS		0.16	

Table 44. Interaction effect of nutrient regimes and nutrient sources on yield attributes of Njavara under saturated situation (2008)

Treatment combinations	Productive tillers m^{-2}		Panicle length (cm)		Grains $panicle^{-1}$		Filled grains $panicle^{-1}$		Thousand grain weight (g)		Sterility percentage	
Nutrient sources / Nutrient regimes	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	214.50	252.61	14.10	17.09	46.59	59.84	35.59	47.10	17.45	17.60	23.61	21.29
N_2 (30:30:30)	281.32	347.80	18.61	22.98	65.72	81.57	52.92	68.61	17.74	17.89	19.48	15.88
N_3 (40:20:20)	262.30	309.87	17.18	20.11	60.43	71.37	47.76	58.41	17.65	17.83	20.97	18.15
N_4 (40:40:40)	290.90	328.86	18.69	21.55	66.27	76.49	53.56	63.44	17.78	17.85	19.17	17.06
SE	2.99		0.15		0.764		0.45		0.10		0.15	
CD (0.05)	5.94		0.26		1.53		0.94		NS		0.28	

percentage was recorded in N_2S_2 (16.01 % in 2007 and 15.88 % in 2008) (Tables 43 and 44).

Analysis of the data on thousand grain weight showed that nutrient regimes, nutrient sources and their interactions had no significant influence on thousand grain weight during both the years of experimentation. Results are presented in Tables 41, 42, 43 and 44.

4.2.3. Grain yield

Data on grain yield as influenced by nutrient regimes, nutrient sources and their interactions in 2007 and 2008 are given in Tables 45, 46, 47 and 48 respectively.

Effect of nutrient regimes, nutrient sources and interactions on grain yield were significant in both the years. Maximum grain yield was recorded in N_2 (30:30:30 kg NPK ha^{-1}) (2.72 t ha^{-1} in 2007 and 2.60 t ha^{-1} in 2008) which was on par with N_4 (40:40:40 kg NPK ha^{-1}) (2.64 t ha^{-1} in 2007 and 2.51 t ha^{-1} in 2008) and was significantly superior to N_1 and N_3. During both the years, N_1 recorded the lowest yield (1.60 t ha^{-1} in 2007 and 1.52 t ha^{-1} in 2008). POP recorded an yield of 1.45 t ha^{-1} during 2007 and 1.41 t ha^{-1} during 2008 and was on par with N_1 regime (30:15:15 kg NPK ha^{-1}). Absolute control recorded the lowest grain yield (0.89 t ha^{-1} in 2007 and 0.75 t ha^{-1} in 2008).

During 2007 and 2008, integrated nutrient source recorded highest grain yield which was significantly superior to organic source. Grain yield obtained by adopting integrated nutrient supply system was 2.67 t ha^{-1} in 2007 and 2.52 t ha^{-1} in 2008. Grain yield obtained under organic nutrition was 1.95 t ha^{-1} in 2007 and 1.85 t ha^{-1} in 2008.

Under organic nutrition, N_4 regime recorded the highest yield which was significantly superior to other two regimes and was on par with N_2 regime. Under integrated nutrition, N_2 regime recorded significantly higher yield than other two nutrient regimes and was on par with N_4 regime. Both under organic and integrated nutrition yields obtained with N_4 and N_2 were on par.

Among all interactions, N_2S_2 recorded maximum grain yield of 3.24 t ha^{-1} in 2007 and 3.12 t ha^{-1} in 2008 which were on par with N_4S_2 during 2007 and 2008. Lowest grain yield was obtained under N_1S_1 (1.41 t ha^{-1} in 2007 and 1.40 t ha^{-1} in 2008).

4.2.4. Straw yield

The results are presented in Tables 45, 46, 47 and 48. Significant variation in straw yield was observed among nutrient regimes, nutrient sources and their interactions during both the years of study.

Maximum straw yield was recorded in N_2 (30:30:30 kg NPK ha^{-1}) (3.86 t ha^{-1} in 2007 and 3.70 t ha^{-1} in 2008) which was on par with N_4 (40:40:40 kg NPK ha^{-1}) (3.74 t ha^{-1} in 2007 and 3.58 t ha^{-1} in 2008) and was significantly superior to N_1 and N_3 during 2007 and 2008. POP was on par with N_1 regime (30:15:15 kg NPK ha^{-1}).

Application of integrated nutrient sources recorded highest straw yield which was significantly superior to organic source in both the years. In 2007 straw yields was 3.79 t ha^{-1} under integrated nutrient supply system and 2.74 t ha^{-1} under organic nutrition. During 2008 straw yield was 3.59 t ha^{-1} under integrated nutrient system and 2.56 t ha^{-1} under organic nutrition.

Under organic nutrition N_4 regime recorded the highest straw yield (3.28 t ha^{-1} in 2007 and 3.15 t ha^{-1} in 2008) which was significantly superior to other two regimes and was on par with N_2 regime (3.16 t ha^{-1} in 2007 and 3.00 t ha^{-1} in 2008). Under Integrated nutrient source, N_2 regime recorded significantly higher straw yield than other two nutrient regimes and was on par with N_4 regime.

Among all interactions, N_2S_2 recorded significantly higher straw yield of 4.55 t ha^{-1} in 2007 and 4.40 t ha^{-1} in 2008 and was on par with N_4S_2 in 2007 and 2008. N_1S_1 recorded the lowest straw yield during both the years.

4.2.5. Harvest index

Nutrient regimes, nutrient sources and their interactions exerted significant influence on harvest index during both the years of experimentation. The results are presented in Tables 45, 46, 47 and 48.

During 2007, highest harvest index was recorded in N_4 (41.39 %) which was followed by N_2 (41.32 %) which in turn were on par.

During 2008, N_2 recorded maximum harvest index (41.22 %). It was significantly higher than all other nutrient regimes except N_4 (41.19 %). N_2 and N_4 were on par.

Adoption of integrated nutrition resulted in maximum harvest index (41.30 % in 2007 and 41.16 % in 2008) and was significantly higher than organic nutrition (40.69 % in 2007 and 40.45 % in 2008).

In both the years, N_2S_2 registered the maximum harvest index (41.59 % in 2007 and 41.49 % in 2008). N_2S_2 was statistically on par with N_4S_2 and N_3S_2 in 2007 and was on par with N_4S_2 in 2008. Minimum harvest index was recorded under N_1S_1 (39.52 % in 2007 and 39.15 % in 2008).

4.2.6. Dry matter partitioning

Data on dry matter partitioning at harvest is presented in Tables 45, 46, 47 and 48. Significant variation in dry matter partitioning was observed among nutrient regimes, nutrient sources and their interactions during both the years of study.

N_2 recorded the highest dry matter accumulation in shoot, panicle and root and was significantly higher than all other nutrient regimes. This was followed by the nutrient regimes N_4, N_3 and N_1 respectively. POP was on par with N_1 regime (30:15:15 kg NPK ha^{-1}).

Combined application of organic and inorganic nutrient sources produced highest dry matter in shoot, panicle and root, which was significantly superior to that realized from the application of organic sources.

Among the interactions, N_2S_2 recorded highest dry matter accumulation in shoot, panicle and root, which was significantly superior to all other interactions. Lowest dry matter production was obtained under N_1S_1.

Table 45. Effect of nutrient regimes and nutrient sources on yield and yield attributes of Njavara (Harvest stage) under saturated situation (2007)

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)	Dry matter partitioning (g hill^{-1})	Shoot weight (g hill^{-1})	Panicle weight (g hill^{-1})	Root weight (g hill^{-1})
Nutrient regimes							
N_1 (30:15:15)	1.60	2.20	40.03	39.18	27.04	4.24	7.90
N_2 (30:30:30)	2.72	3.86	41.32	57.15	37.98	6.82	12.35
N_3 (40:20:20)	2.29	3.26	41.25	50.23	33.88	5.80	10.56
N_4 (40:40:40)	2.64	3.74	41.39	55.41	36.98	6.54	11.90
SE	0.08	0.13	0.05	0.172	0.05	0.022	0.03
CD (0.05)	0.15	0.26	0.08	0.35	0.10	0.05	0.04
Nutrient sources							
S_1 (OS)	1.95	2.74	40.69	45.20	30.82	5.07	9.31
S_2 (INM)	2.67	3.79	41.30	55.79	37.13	6.62	12.04
SE	0.10	0.12	0.05	0.14	0.034	0.03	0.016
CD (0.05)	0.18	0.21	0.06	0.24	0.07	0.04	0.03
Controls							
C_1 (Absolute control)	0.89	1.40	38.86	31.20	21.70	2.48	7.02
C_2 (POP)	1.45	2.15	40.27	39.01	26.90	4.24	7.87
SE	0.15	0.23	0.07	0.244	0.077	0.032	0.04
C_2 vs Treatments	S	S	S	S	S	S	S
C_1 vs Treatments	S	S	S	S	S	S	S
Between controls	S	S	S	S	S	S	S

Table 46. Effect of nutrient regimes and nutrient sources on yield and yield attributes of Njavara (Harvest stage) under saturated situation (2008)

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)	Dry matter partitioning (g hill^{-1})	Shoot weight (g hill^{-1})	Panicle weight (g hill^{-1})	Root weight (g hill^{-1})
Nutrient regimes							
N_1 (30:15:15)	1.52	2.00	39.80	36.41	25.40	3.89	7.13
N_2 (30:30:30)	2.60	3.70	41.22	53.37	35.44	6.30	11.63
N_3 (40:20:20)	2.11	3.02	41.02	46.71	31.24	5.35	10.12
N_4 (40:40:40)	2.51	3.58	41.19	51.84	34.42	6.07	11.36
SE	0.09	0.11	0.04	0.37	0.212	0.06	0.084
CD (0.05)	0.20	0.23	0.10	0.70	0.43	0.10	0.17
Nutrient sources							
S_1 (OS)	1.85	2.56	40.45	41.88	28.38	4.70	8.80
S_2 (INM)	2.52	3.59	41.16	52.29	34.87	6.10	11.32
SE	0.10	0.10	0.036	0.244	0.16	0.034	0.07
CD (0.05)	0.18	0.22	0.07	0.49	0.30	0.07	0.12
Controls							
C_1 (Absolute control)	0.75	1.22	38.07	28.42	19.89	2.27	6.26
C_2 (POP)	1.41	1.94	40.12	36.43	25.14	3.98	7.31
SE	0.18	0.22	0.06	0.50	0.20	0.07	0.13
C_2 vs Treatments	S	S	S	S	S	S	S
C_1vs Treatments	S	S	S	S	S	S	S
Between controls	S	S	S	S	S	S	S

Table 47. Interaction effect of nutrient regimes and nutrient sources on yield and yield attributes of Njavara (Harvest stage) under saturated situation (2007)

Treatment combinations (Nutrient sources / Nutrient regimes)	Grain yield (t ha^{-1})		Straw yield (t ha^{-1})		Harvest index (%)		Dry matter partitioning (g hill^{-1})		Shoot weight (g hill^{-1})		Panicle weight (g hill^{-1})		Root weight (g hill^{-1})	
	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	1.41	1.80	1.76	2.64	39.52	40.54	34.75	43.60	24.39	29.69	3.52	4.95	6.84	8.96
N_2 (30:30:30)	2.20	3.24	3.16	4.55	41.04	41.59	49.95	64.34	33.69	42.27	5.79	7.84	10.47	14.23
N_3 (40:20:20)	1.91	2.67	2.75	3.76	40.98	41.52	45.12	55.34	30.81	36.95	5.07	6.52	9.24	11.87
N_4 (40:40:40)	2.30	2.98	3.28	4.19	41.22	41.56	50.96	59.86	34.37	39.59	5.91	7.16	10.68	13.11
SE	0.15		0.23		0.07		0.244		0.077		0.032		0.04	
CD (0.05)	0.31		0.43		0.12		0.49		0.15		0.07		0.06	

Table 48. Interaction effect of nutrient regimes and nutrient sources on yield and yield attributes of Njavara (Harvest stage) under saturated situation (2008)

Treatment combinations (Nutrient regimes \ Nutrient sources)	Grain yield (t ha^{-1})		Straw yield (t ha^{-1})		Harvest index (%)		Dry matter partitioning (g hill^{-1})		Shoot weight (g hill^{-1})		Panicle weight (g hill^{-1})		Root weight (g hill^{-1})	
	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	1.40	1.65	1.57	2.43	39.15	40.44	32.41	40.41	23.01	27.78	3.32	4.46	6.08	8.17
N_2 (30:30:30)	2.08	3.12	3.00	4.40	40.94	41.49	46.10	60.64	30.73	40.15	5.32	7.28	10.05	13.21
N_3 (40:20:20)	1.73	2.48	2.52	3.52	40.71	41.33	41.62	51.79	28.12	34.36	4.67	6.03	8.83	11.40
N_4 (40:40:40)	2.19	2.83	3.15	4.01	41.01	41.37	47.37	56.30	31.65	37.18	5.49	6.64	10.23	12.48
SE	0.18		0.22		0.06		0.50		0.20		0.07		0.13	
CD (0.05)	0.34		0.41		0.14		0.98		0.60		0.15		0.24	

4.2.7. Paddy grain ratio

Analysis of the data revealed no significant influence of nutrient regimes and nutrient sources on paddy grain ratio during both the years of study and the results are presented in Table 49

4.2.8. Grain husk ratio

The results presented in Table 49 showed that nutrient regimes and nutrient sources did not influence grain husk ratio during both the years of study.

4.2.9. Crop duration

Crop duration was not influenced by nutrient regimes and nutrient sources during both the years of experimentation. The results are presented in Table 49.

4.2.10. Nutrient uptake (Uptake of N, P, K, S, Fe, Mn and Zn)

Data on uptake of N, P, K, S, Fe, Mn and Zn as influenced by nutrient regimes, sources of nutrients and their interactions during both the years of study are presented in Tables 50, 51, 52 and 53.

Effect of nutrient regimes, nutrient sources and interaction effects on uptake of N, P and K were significant in both the years.

During both the years uptake of N, P and K was highest in N_2 (79.79 kg N ha^{-1}, 27.60 kg P ha^{-1} and 96.02 kg K ha^{-1} in 2007 and 76.05 kg N ha^{-1}, 28.21 kg P ha^{-1} and 91.37 kg K ha^{-1} in 2008). This was followed by N_4, N_3 and N_1 respectively. POP was on par with N_1 regime (30:15:15 kg NPK ha^{-1}).

During 2007 and 2008 N, P and K uptake obtained under different nutrient sources differed significantly. In both the years, nutrient uptake was higher under integrated nutrition compared to organic nutrition.

In both the years of study N_2S_2 recorded significantly higher uptake of N, P and K (97.23 kg N ha^{-1}, 32.64 kg P ha^{-1} and 107.41 kg K ha^{-1} in 2007 and 92.86 kg N ha^{-1}, 33.57 kg P ha^{-1} and 102.39 kg K ha^{-1} in 2008). The least uptake was recorded in N_1S_1 (28.88 kg N ha^{-1}, 13.12 kg P ha^{-1} and 60.16 kg K ha^{-1} in 2007 and 27.34 kg N ha^{-1}, 13.40 kg P ha^{-1} and 57.51 kg K ha^{-1} in 2008).

Table 49. Effect of nutrient regimes and nutrient sources on yield attributes of Njavara under saturated situation (2007 and 2008)

Treatments	2007			2008		
	Paddy grain ratio	Grain husk ratio	Crop duration (Days)	Paddy grain ratio	Grain husk ratio	Crop duration (Days)
Nutrient regimes						
N_1 (30:15:15)	1.83	1.21	83.00	1.83	1.21	83.00
N_2 (30:30:30)	1.60	1.71	82.00	1.60	1.71	83.00
N_3 (40:20:20)	1.66	1.55	83.00	1.66	1.55	83.00
N_4 (40:40:40)	1.61	1.66	83.00	1.60	1.66	83.00
SE	0.001	0.0044	0.002	0.0014	0.0044	0.003
CD (0.05)	NS	NS	NS	NS	NS	NS
Nutrient sources						
S_1 (OS)	1.74	1.37	83.00	1.74	1.36	83.00
S_2 (INM)	1.61	1.70	82.00	1.60	1.70	82.00
SE	0.0004	0.0037	0.001	0.002	0.0036	0.002
CD (0.05)	NS	NS	NS	NS	NS	NS
Controls						
C_1 (Absolute control)	1.89	1.13	83.00	1.89	1.13	83.00
C_2 (POP)	1.81	1.23	83.00	1.80	1.25	83.00
SE	0.0017	0.0064	0.004	0.003	0.0067	0.004
C_2 vs Treatments	NS	NS	NS	NS	NS	NS
C_1 vs Treatments	NS	NS	NS	NS	NS	NS
Between controls	NS	NS	NS	NS	NS	NS

(Interaction effect not significant)

Table 50. Effect of nutrient regimes and nutrient sources on nutrient uptake of Njavara under saturated situation (2007)

Treatments	N	P	K	S	Fe	Mn	Zn
	(kg ha^{-1})						
Nutrient regimes							
N_1 (30:15:15)	38.87	15.84	66.89	4.32	0.38	0.43	0.21
N_2 (30:30:30)	79.79	27.60	96.02	5.86	0.71	0.65	0.40
N_3 (40:20:20)	64.59	23.05	86.41	5.12	0.54	0.54	0.30
N_4 (40:40:40)	77.39	26.69	94.84	5.68	0.67	0.63	0.38
SE	0.854	0.304	0.70	0.01	0.02	0.02	0.0033
CD (0.05)	1.71	0.61	1.10	NS	NS	NS	NS
Nutrient sources							
S_1 (OS)	52.68	19.72	77.68	4.75	0.46	0.48	0.26
S_2 (INM)	77.64	26.87	94.40	5.74	0.68	0.64	0.38
SE	0.602	0.214	0.427	0.006	0.005	0.004	0.0022
CD (0.05)	1.21	0.43	0.85	NS	NS	NS	NS
Controls							
C_1 (Absolute control)	18.20	10.07	53.13	3.16	0.08	0.17	0.07
C_2 (POP)	38.96	15.78	66.67	3.71	0.21	0.29	0.13
SE	1.20	0.434	0.86	0.013	0.01	0.02	0.007
C_2 vs Treatments	S	S	S	NS	NS	NS	NS
C_1 vs Treatments	S	S	S	S	S	S	S
Between controls	S	S	S	S	S	S	S

Table 51. Effect of nutrient regimes and nutrient sources on nutrient uptake of Njavara under saturated situation (2008)

Treatments	N	P	K	S	Fe	Mn	Zn
	(kg ha^{-1})						
Nutrient regimes							
N_1 (30:15:15)	36.71	16.19	63.95	4.25	0.36	0.40	0.20
N_2 (30:30:30)	76.05	28.21	91.37	5.77	0.68	0.62	0.38
N_3 (40:20:20)	61.58	23.84	81.86	5.04	0.51	0.51	0.28
N_4 (40:40:40)	73.39	27.79	89.94	5.60	0.63	0.59	0.36
SE	0.68	0.20	0.47	0.044	0.01	0.004	0.0047
CD (0.05)	1.34	0.39	0.94	NS	NS	NS	NS
Nutrient sources							
S_1 (OS)	50.15	20.23	73.80	4.67	0.44	0.45	0.25
S_2 (INM)	73.71	27.79	89.76	5.65	0.65	0.61	0.36
SE	0.474	0.16	0.34	0.04	0.006	0.004	0.004
CD (0.05)	0.95	0.30	0.66	NS	NS	NS	NS
Controls							
C_1 (Absolute control)	17.38	10.37	50.37	3.11	0.08	0.16	0.07
C_2 (POP)	37.12	15.93	63.65	3.65	0.20	0.28	0.12
SE	0.97	0.296	0.667	0.066	0.02	0.01	0.007
C_2 vs Treatments	S	S	S	NS	NS	NS	NS
C_1 vs Treatments	S	S	S	S	S	S	S
Between controls	S	S	S	S	S	S	S

Table 52. Interaction effect of nutrient regimes and nutrient sources on nutrient uptake of Njavara under saturated situation (2007)

Treatment combinations	N		P		K	
Nutrient sources / Nutrient regimes	(kg ha^{-1})					
	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	28.88	48.85	13.12	18.56	60.16	73.62
N_2 (30:30:30)	62.34	97.23	22.56	32.64	84.63	107.41
N_3 (40:20:20)	52.06	77.12	19.48	26.62	77.65	95.16
N_4 (40:40:40)	67.43	87.35	23.71	29.67	88.28	101.39
SE	1.20		0.434		0.86	
CD (0.05)	2.42		0.87		1.70	

Table 53. Interaction effect of nutrient regimes and nutrient sources on nutrient uptake of Njavara under saturated situation (2008)

Treatment combinations	N		P		K	
Nutrient sources / Nutrient regimes	(kg ha^{-1})					
	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	27.34	46.07	13.40	18.98	57.51	70.39
N_2 (30:30:30)	59.23	92.86	22.84	33.57	80.35	102.39
N_3 (40:20:20)	49.54	73.62	19.86	27.82	73.67	90.04
N_4 (40:40:40)	64.50	82.28	24.80	30.78	83.68	96.20
SE	0.97		0.296		0.667	
CD (0.05)	1.90		0.59		1.33	

The results presented in Tables 50, 51, 52 and 53 showed no significant influence of nutrient regimes and nutrient sources on uptake of S, Fe, Mn and Zn during both the years of study.

4.2.11. Biochemical components of grain

Biochemical components that govern the nutritional quality of grain were assessed in terms of total, free and sulphur containing amino acids, phenols, starch, amylose, amylopectin and protein content.

4.2.11.1. Total, free and sulphur containing amino acids

Perusal of the data presented in Tables 54 and 55 revealed that nutrient regimes significantly influenced total amino acid content of grain in both the years. Effect of nutrient sources and interaction effects were not significant.

During 2007 and 2008, N_2 recorded highest total amino acid content (0.77 mg 100 g^{-1} in 2007 and 0.70 mg 100 g^{-1} in 2008) and was on par with N_4 and both were significantly higher than N_3 and N_1 regimes.

The results presented in Tables 54 and 55 showed no significant influence of nutrient regimes and nutrient sources on free and sulphur containing amino acids content of grain during both the years of study.

4.2.11.2. Phenols, starch, amylose and amylopectin content

Data presented in Tables 54 and 55 showed that nutrient regimes and nutrient sources had no significant influence on grain content of phenols, starch, amylose and amylopectin during both the years.

4.2.11.3. Protein content

Data presented in Tables 54 and 55 showed that nutrient regimes significantly influenced the protein content of grain during both the years of experimentation. Nutrient sources and interaction effects were not significant.

Highest content of protein was recorded in N_2 (7.52 % in 2007 and 7.15 % in 2008) and it was on par with N_4 (7.40 % in 2007 and 7.03 % in 2008).

Table 54. Effect of nutrient regimes and nutrient sources on biochemical components of Njavara grain under saturated situation (2007)

Treatments	Harvest stage							
	Total amino acids (mg 100 g^{-1})	Free amino acids (mg 100 g^{-1})	Sulphur containing amino acids (mg 100 g^{-1})	Phenols (mg g^{-1})	Starch content (%)	Amylose content (%)	Amylopectin content (%)	Protein content (%)
Nutrient regimes								
N_1 (30:15:15)	0.47	0.11	0.01	2.52	58.37	22.30	36.07	5.64
N_2 (30:30:30)	0.77	0.19	0.04	6.08	66.65	23.66	42.99	7.52
N_3 (40:20:20)	0.67	0.16	0.03	4.61	63.97	23.30	40.68	6.84
N_4 (40:40:40)	0.76	0.18	0.04	5.69	66.35	23.62	42.73	7.40
SE	0.05	0.00036	0.00014	0.03	0.087	0.016	0.08	0.09
CD (0.05)	0.08	NS	NS	NS	NS	NS	NS	0.17
Nutrient sources								
S_1 (OS)	0.58	0.14	0.02	3.58	61.43	22.85	38.58	6.29
S_2 (INM)	0.76	0.18	0.04	3.87	66.24	23.59	42.65	7.40
SE	0.003	0.00027	0.0002	0.017	0.08	0.02	0.06	0.040
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Controls								
C_1 (Absolute control)	0.31	0.08	0.003	0.47	53.52	20.87	32.64	4.70
C_2 (POP)	0.47	0.11	0.014	2.49	58.71	22.60	36.11	5.63
SE	0.007	0.0006	0.0003	0.022	0.13	0.02	0.13	0.057
C_2 vs Treatments	NS	NS	NS	NS	NS	NS	NS	NS
C_1 vs Treatments	S	NS	NS	NS	NS	NS	NS	S
Between controls	S	NS	NS	NS	NS	NS	NS	S

(Interaction effect not significant)

Table 55. Effect of nutrient regimes and nutrient sources on biochemical components of Njavara grain under saturated situation (2008)

Treatments	Harvest stage							
	Total amino acids (mg 100 g^{-1})	Free amino acids (mg 100 g^{-1})	Sulphur containing amino acids (mg 100 g^{-1})	Phenols (mg g^{-1})	Starch content (%)	Amylose content (%)	Amylopectin content (%)	Protein content (%)
Nutrient regimes								
N_1 (30:15:15)	0.39	0.11	0.01	2.28	56.33	21.63	34.70	5.35
N_2 (30:30:30)	0.70	0.18	0.04	5.79	64.65	22.95	41.70	7.15
N_3 (40:20:20)	0.59	0.15	0.03	4.30	61.85	22.57	39.28	6.50
N_4 (40:40:40)	0.67	0.18	0.04	5.45	64.36	22.89	41.48	7.03
SE	0.04	0.003	0.0004	0.077	0.174	0.04	0.143	0.08
CD (0.05)	0.07	NS	NS	NS	NS	NS	NS	0.15
Nutrient sources								
S_1 (OS)	0.50	0.13	0.02	3.33	59.48	22.15	37.34	5.98
S_2 (INM)	0.67	0.18	0.04	5.57	64.11	22.87	41.24	7.03
SE	0.006	0.0014	0.0007	0.060	0.15	0.03	0.105	0.024
CD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Controls								
C_1 (Absolute control)	0.24	0.07	0.002	0.45	51.92	20.73	31.19	4.47
C_2 (POP)	0.38	0.11	0.013	2.32	56.48	21.92	34.56	5.34
SE	0.010	0.003	0.002	0.104	0.242	0.05	0.205	0.06
C_2 vs Treatments	NS	NS	NS	NS	NS	NS	NS	NS
C_1 vs Treatments	S	NS	NS	NS	NS	NS	NS	S
Between controls	S	NS	NS	NS	NS	NS	NS	S

(Interaction effect not significant)

4.2.12. Nitrate reductase activity (Plant enzyme)

Data presented in Table 56 indicated that nutrient regimes and sources of nutrients significantly influenced nitrate reductase activity at panicle initiation stage in both the years. Interaction effects were not significant.

Both in 2007 and 2008, nitrate reductase activity was in the order $N_4 \geq N_2 > N_3 > N_1$. N_4 recorded maximum nitrate reductase activity of 727.41 µmole NO_2 g^{-1} fresh weight hr^{-1} in 2007 and 715.29 µmole NO_2 g^{-1} fresh weight hr^{-1} in 2008 which was on par with N_2 (725.15 µmole NO_2 g^{-1} fresh weight hr^{-1} in 2007 and 708.07 µmole NO_2 g^{-1} fresh weight hr^{-1} in 2008). Nitrate reductase activity was lowest in N_1.

In both the years, integrated nutrient source recorded maximum nitrate reductase activity (747.01 µmole NO_2 g^{-1} fresh weight hr^{-1} in 2007 and 726.09 µmole NO_2 g^{-1} fresh weight hr^{-1} in 2008) which was significantly higher than that under organic nutrition (499.81 µmole NO_2 g^{-1} fresh weight hr^{-1} in 2007 and 487.40 µmole NO_2 g^{-1} fresh weight hr^{-1} in 2008).

4.2.13. Root weight and root volume

Data on root weight $plant^{-1}$ and root volume $plant^{-1}$ of Njavara at panicle initiation stage are presented in Table 57. Nutrient sources significantly influenced the root weight of Njavara whereas nutrient regimes and interaction effects were not significant during both the years of study.

Integrated nutrition registered the highest root weight of Njavara (4.87 g $plant^{-1}$ in 2007 and 4.69 g $plant^{-1}$ in 2008) which was significantly higher than organic nutrition that produced 3.86 g $plant^{-1}$ in 2007 and 3.73 g $plant^{-1}$ in 2008. Nutrient regimes and nutrient sources did not influence root volume of Njavara during both the years of study.

4.2.14. Major weed flora and weed biomass

The weeds collected from the experimental fields were classified into grasses, sedges and broad leaved weeds and are presented in Table 58. The important species of weeds found under saturated situation were *Echinochloa colona* (L.) Link and *Isachne miliacea* Roth ex Roem. et Schult among grasses, [illegible] L., *Cyperus difformis* L. and *Fimbristylis miliacea* (L.) Vahl among

Table 56. Effect of nutrient regimes and nutrient sources on nitrate reductase activity of Njavara at panicle initiation stage under saturated situation (2007 and 2008)

Treatments	Nitrate reductase activity (µmole NO_2 g^{-1} fresh weight hr^{-1})	
	2007	2008
Nutrient regimes		
N_1 (30:15:15)	381.87	372.74
N_2 (30:30:30)	725.15	708.07
N_3 (40:20:20)	609.22	594.88
N_4 (40:40:40)	727.41	715.29
SE	1.945	7.944
CD (0.05)	3.89	15.89
Nutrient sources		
S_1 (OS)	499.81	487.40
S_2 (INM)	747.01	726.09
SE	1.373	5.65
CD (0.05)	2.75	11.24
Controls		
C_1 (Absolute control)	163.85	159.83
C_2 (POP)	381.70	372.19
SE	2.757	11.25
C_2 vs Treatments	NS	NS
C_1 vs Treatments	S	S
Between controls	S	S

(Interaction effect not significant)

Table 57. Effect of nutrient regimes and nutrient sources on root weight and root volume of Njavara at panicle initiation stage under saturated situation (2007 and 2008)

Treatments	2007		2008	
	Root weight (g plant^{-1})	Root volume (cm^3 plant^{-1})	Root weight (g plant^{-1})	Root volume (cm^3 plant^{-1})
Nutrient regimes				
N_1 (30:15:15)	3.15	6.88	3.03	6.64
N_2 (30:30:30)	5.00	9.38	4.84	9.13
N_3 (40:20:20)	4.40	8.39	4.24	8.07
N_4 (40:40:40)	4.91	9.07	4.73	8.85
SE	0.01	0.02	0.05	0.07
CD (0.05)	NS	NS	NS	NS
Nutrient sources				
S_1 (OS)	3.86	7.62	3.73	7.39
S_2 (INM)	4.87	9.24	4.69	8.95
SE	0.02	0.02	0.04	0.05
CD (0.05)	0.04	NS	0.06	NS
Controls				
C_1 (Absolute control)	3.13	6.90	3.08	6.47
C_2 (POP)	3.14	6.94	3.13	6.58
SE	0.02	0.014	0.057	0.09
C_2 vs Treatments	NS	NS	NS	NS
C_1 vs Treatments	S	NS	S	NS
Between controls	S	NS	S	NS

(Interaction effect not significant)

Table 58. Major weed flora observed in experimental field (Saturated situation)

Scientific name	Common name	Family
Grasses		
Echinochloa colona (L.) Link	Jungle rice	Poaceae
Isachne miliacea Roth ex Roem. et Schult	Blood grass	Poaceae
SEges		
Cyperus iria L.	Yellow SEge	Cyperaceae
Cyperus difformis L.	Umbrella SEge	Cyperaceae
Fimbristylis miliacea (L.) Vahl.	Globe fingerush	Cyperaceae
Broadleaved weeds		
Ludwigia perennis L.	Water primrose	Onagraceae
Monochoria vaginalis (Burm. f.) Presl.ex Kunth.	Pickerel weed	Pontenderiaceae
Marsilea quadrifoliata Linn.	Airy pepper wort	Marsileaceae
Eclipta alba (L.) Hassk	False daisy	Asteraceae
Ammania baccifera (L.)	Blistering ammania	Lytharaceae

sedges and *Ludwigia perennis* L., *Monochoria vaginalis* (Burm. f.) Presl.ex Kunth., *Marsilea quadrifoliata* Linn., *Eclipta alba* (L.) Hassk and *Ammania baccifera* (L.) among broad leaved weeds.

The data on weed biomass was recorded at 20 and 40 DAS in both the years of experimentation and are presented in Table 59.

The data revealed significant effect of nutrient sources on weed biomass during both stages in both the years of experimentation. Nutrient regimes and interaction effects were not significant on weed biomass during both the stages in both the years.

Weed biomass at 20 DAS (47.09 g m^{-2} in 2007 and 48.03 g m^{-2} in 2008) was significantly higher in crops raised with organic nutrition compared to that in the crop raised with integrated nutrition (38.75 g m^{-2} in 2007 and 39.53 g m^{-2} in 2008). Highest weed biomass was recorded in absolute control (56.89 g m^{-2} in 2007 and 58.12 g m^{-2} in 2008).

At 40 DAS weed biomass in plots applied with organic sources was 59.72 g m^{-2} in 2007 and 60.93 g m^{-2} in 2008, which were significantly higher than that in plots applied with integrated nutrient sources (48.89 g m^{-2} in 2007 and 49.86 g m^{-2} in 2008). Highest weed biomass was recorded in absolute control (72.98 g m^{-2} in 2007 and 74.53 g m^{-2} in 2008).

4.2.15. Soil properties

4.2.15.1. Bulk density

Analysis of the data on bulk density showed no significant influence due to nutrient regimes and nutrient sources during both the years of experimentation and the results are presented in Table 60.

4.2.15.2. CEC and pH

Nutrient regimes and nutrient sources had no significant effect on CEC and pH of the soil in both the years and the results are presented in Tables 61 and 62.

Table 59. Effect of nutrient regimes and nutrient sources on weed biomass of Njavara under saturated situation (2007 and 2008)

Treatments	Weed biomass (g m^{-2})			
	2007		2008	
	20 DAS	40 DAS	20 DAS	40 DAS
Nutrient regimes				
N_1 (30:15:15)	50.77	65.96	51.79	67.29
N_2 (30:30:30)	37.72	47.52	38.47	48.47
N_3 (40:20:20)	43.46	54.37	44.33	55.45
N_4 (40:40:40)	39.75	49.38	40.53	50.36
SE	0.123	0.174	0.25	0.374
CD (0.05)	NS	NS	NS	NS
Nutrient sources				
S_1 (OS)	47.09	59.72	48.03	60.93
S_2 (INM)	38.75	48.89	39.53	49.86
SE	0.09	0.15	0.20	0.264
CD (0.05)	0.18	0.24	0.38	0.53
Controls				
C_1 (Absolute control)	56.89	72.98	58.12	74.53
C_2 (POP)	50.75	66.12	51.77	67.41
SE	0.176	0.244	0.382	0.55
C_2 vs Treatments	NS	NS	NS	NS
C_1 vs Treatments	S	S	S	S
Between controls	S	S	S	S

(Interaction effect not significant)

Table 60. Effect of nutrient regimes and nutrient sources on bulk density of soil under saturated situation (2007 and 2008)

Treatments	Bulk density (g cc^{-1})	
	2007	2008
Nutrient regimes		
N_1 (30:15:15)	1.71	1.62
N_2 (30:30:30)	1.42	1.35
N_3 (40:20:20)	1.55	1.47
N_4 (40:40:40)	1.47	1.40
SE	0.006	0.0064
CD (0.05)	NS	NS
Nutrient sources		
S_1 (OS)	1.63	1.55
S_2 (INM)	1.43	1.34
SE	0.007	0.0045
CD (0.05)	NS	NS
Controls		
C_1 (Absolute control)	1.91	1.81
C_2 (POP)	1.80	1.71
SE	0.0094	0.008
C_2 vs Treatments	NS	NS
C_1 vs Treatments	NS	NS
Between controls	NS	NS

(Interaction effect not significant)

4.2.16. Soil fertility status (available N, P, K, S, Fe, Zn and Mn)

The fertility status of soil was studied after the experiment in terms of available nitrogen, available phosphorus, available potassium, available sulphur, available iron, available zinc, available manganese and organic carbon and the data is presented in Tables 61 and 62.

During 2007 and 2008, available N, P and K were highest in N_2 (256.89 kg N ha^{-1}, 43.88 kg P ha^{-1} and 255.26 kg K ha^{-1} in 2007 and 248.26 kg N ha^{-1}, 45.33 kg P ha^{-1} and 240.13 kg K ha^{-1} in 2008) which was significantly higher than all other nutrient regimes in both the years. Available N, P and K in N_1 was significantly higher than POP during both the years of experimentation.

In both the years, effect of nutrient sources on available N, P and K status of soil differed significantly from one another. During 2007 and 2008 available N, P and K were highest in integrated nutrient source (255.56 kg N ha^{-1}, 43.23 kg P ha^{-1} and 254.02 kg K ha^{-1} in 2007 and 247.29 kg N ha^{-1}, 44.75 kg P ha^{-1} and 238.20 kg K ha^{-1} in 2008) and it was significantly superior to organic source (211.16 kg N ha^{-1}, 29.86 kg P ha^{-1} and 202.87 kg K ha^{-1} in 2007 and 204.50 kg N ha^{-1}, 32.06 kg P ha^{-1} and 190.76 kg K ha^{-1} in 2008).

Among the interactions, N_2S_2 recorded the highest available N, P and K (292.81 kg N ha^{-1}, 54.47 kg P ha^{-1} and 297.18 kg K ha^{-1} in 2007 and 282.61 kg N ha^{-1}, 55.49 kg P ha^{-1} and 280.16 kg K ha^{-1} in 2008) which was significantly superior to all other interaction effects (Table 63). The least values of available N, P and K was recorded in N_1S_1.

The results on the available sulphur, iron, zinc and manganese status of the soil after the experiment (Tables 61 and 62) revealed non - significant effect for nutrient regimes and sources of nutrients in both the years of study.

4.2.16.1. Organic carbon

Nutrient sources and nutrient regimes had no significant effect on organic carbon content of the soil in both the years (Tables 61 and 62).

Table 61. Effect of nutrient regimes and nutrient sources on chemical properties of soil under saturated situation (2007)

Treatments	CEC (cmol kg^{-1})	pH	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Organic carbon (%)	Available S (ppm)	Available Fe (ppm)	Available Zn (ppm)	Available Mn (ppm)
Nutrient regimes										
N_1 (30:15:15)	7.25	5.46	195.78	23.16	184.02	1.45	52.09	16.51	7.40	8.78
N_2 (30:30:30)	7.59	5.75	256.89	43.88	255.26	1.59	76.09	25.13	10.45	13.65
N_3 (40:20:20)	7.47	5.63	231.77	36.50	227.21	1.54	66.95	21.60	9.29	11.72
N_4 (40:40:40)	7.58	5.72	249.00	42.65	247.29	1.58	74.48	24.50	10.25	13.04
SE	0.03	0.01	1.393	0.568	1.444	0.0014	0.25	0.25	0.062	0.05
CD (0.05)	NS	NS	2.79	1.13	2.89	NS	NS	NS	NS	NS
Nutrient sources										
S_1 (OS)	7.37	5.55	211.16	29.86	202.87	1.49	59.94	18.41	8.32	10.20
S_2 (INM)	7.57	5.73	255.56	43.23	254.02	1.58	74.86	25.46	10.37	13.39
SE	0.014	0.006	0.982	0.50	1.024	0.05	0.182	0.153	0.047	0.04
CD (0.05)	NS	NS	1.97	0.80	2.05	NS	NS	NS	NS	NS
Controls										
C_1 (Absolute control)	5.84	5.16	156.82	13.01	143.40	1.35	37.59	10.24	5.42	5.60
C_2 (POP)	7.00	5.30	187.78	21.26	173.42	1.41	44.54	13.88	6.71	7.58
SE	0.026	0.014	1.974	0.797	2.04	0.003	0.38	0.32	0.09	0.055
C_2 vs Treatments	NS	NS	S	S	S	NS	NS	NS	NS	NS
C_1 vs Treatments	NS	NS	S	S	S	NS	S	S	S	S
Between controls	NS	NS	S	S	S	NS	S	S	S	S

Table 62. Effect of nutrient regimes and nutrient sources on chemical properties of soil under saturated situation (2008)

Treatments	CEC (cmol kg^{-1})	pH	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})	Organic carbon (%)	Available S (ppm)	Available Fe (ppm)	Available Zn (ppm)	Available Mn (ppm)
Nutrient regimes										
N_1 (30:15:15)	6.89	5.59	190.60	25.75	171.29	1.41	48.39	14.51	7.02	8.07
N_2 (30:30:30)	7.22	5.87	248.26	45.33	240.13	1.54	71.23	21.77	9.92	11.58
N_3 (40:20:20)	7.09	5.73	224.18	38.34	214.33	1.49	62.56	18.42	8.83	10.33
N_4 (40:40:40)	7.20	5.81	240.54	44.21	232.18	1.53	70.80	21.02	9.74	11.47
SE	0.014	0.005	1.654	0.533	1.94	0.005	0.534	0.190	0.064	0.093
CD (0.05)	NS	NS	3.31	1.07	3.86	NS	NS	NS	NS	NS
Nutrient sources										
S_1 (OS)	7.00	5.66	204.50	32.06	190.76	1.45	55.72	16.11	7.89	9.01
S_2 (INM)	7.19	5.84	247.29	44.75	238.20	1.54	70.77	21.75	9.86	11.71
SE	0.02	0.004	1.18	0.375	1.365	0.07	0.390	0.140	0.047	0.080
CD (0.05)	NS	NS	2.34	0.75	2.73	NS	NS	NS	NS	NS
Controls										
C_1 (Absolute control)	5.56	5.22	154.79	16.12	133.47	1.30	34.92	9.04	5.40	4.85
C_2 (POP)	6.65	5.35	183.39	23.94	161.85	1.37	41.07	12.97	6.37	6.04
SE	0.024	0.01	2.344	0.757	2.724	0.007	0.754	0.254	0.096	0.136
C_2 vs Treatments	NS	NS	S	S	S	NS	NS	NS	NS	NS
C_1 vs Treatments	NS	NS	S	S	S	NS	S	S	S	S
Between controls	NS	NS	S	S	S	NS	S	S	S	S

Table 63. Interaction effect of nutrient regimes and nutrient sources on soil fertility status under saturated situation (2007 and 2008)

Treatment combinations	2007						2008					
Nutrient sources / Nutrient regimes	Available N (kg ha^{-1})		Available P (kg ha^{-1})		Available K (kg ha^{-1})		Available N (kg ha^{-1})		Available P (kg ha^{-1})		Available K (kg ha^{-1})	
	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	181.47	210.09	19.16	27.15	169.21	198.83	177.65	203.55	21.95	29.54	158.38	184.20
N_2 (30:30:30)	220.96	292.81	33.29	54.47	213.33	297.18	213.91	282.61	35.17	55.49	200.09	280.16
N_3 (40:20:20)	215.02	248.52	30.18	42.81	206.94	247.48	207.26	241.09	32.42	44.25	195.92	232.73
N_4 (40:40:40)	227.17	270.83	36.80	48.49	221.98	272.60	219.18	261.89	38.68	49.73	208.64	255.71
SE	1.974		0.797		2.04		2.344		0.757		2.724	
CD (0.05)	3.95		1.59		4.10		4.69		1.51		5.45	

4.2.17. Soil enzymes activity

4.2.17.1. Urease activity

Activity of urease enzyme differed significantly under nutrient regimes and nutrient sources during both the years of experimentation and the results are presented in Table 64. Interaction effects were not significant.

N_4 recorded highest activity of urease (300.11 ppm g^{-1} hr^{-1} in 2007 and 303.55 ppm g^{-1} hr^{-1} in 2008) which was significantly higher than N_3, N_2 and N_1.

Effect of nutrient sources on urease activity differed significantly from each other. Highest activity of urease was recorded in organic source (319.42 ppm g^{-1} hr^{-1} in 2007 and 322.57 ppm g^{-1} hr^{-1} in 2008) compared to integrated nutrient source (237.35 ppm g^{-1} hr^{-1} in 2007 and 240.62 ppm g^{-1} hr^{-1} in 2008).

4.2.17.2. Phosphatase and dehydrogenase activity

The results on the phosphatase and dehydrogenase activity of the soil after the experiment (Table 64) revealed no significant effect under nutrient regimes and nutrient sources in both the years of study.

4.2.18. Soil microbial population (Bacteria, fungi and actinomycetes)

The results pertaining to soil microbial population after the experiments are presented in Table 65. The data revealed significant influence of nutrient regimes and nutrient sources on bacterial population in both the years. Interaction effects were not significant. N_4 recorded significantly higher bacterial population (37.13 10^4 cfu g^{-1} soil in 2007 and 37.97 10^4 cfu g^{-1} soil in 2008) than all other regimes in both the years.

Significantly higher bacterial population was recorded in organic sources applied plots (38.03 10^4 cfu g^{-1} soil in 2007 and 39.18 10^4 cfu g^{-1} soil in 2008) which was significantly superior to that in integrated nutrient sources applied plots.

Effect of nutrient regimes and sources of nutrients on soil fungal and actinomycete population in 2007 and 2008 were not significant and the results are presented in Table 65.

Table 64. Effect of nutrient regimes and nutrient sources on soil enzymes under saturated situation (2007 and 2008)

Treatments	2007			2008		
	Urease (ppm g^{-1} hr^{-1})	Phosphatase (µg g^{-1} hr^{-1})	Dehydrogenase (µg g^{-1} 24 hrs^{-1})	Urease (ppm g^{-1} hr^{-1})	Phosphatase (µg g^{-1} hr^{-1})	Dehydrogenase (µg g^{-1} 24 hrs^{-1})
Nutrient regimes						
N_1 (30:15:15)	247.53	34.45	304.27	249.98	35.18	309.32
N_2 (30:30:30)	272.37	36.86	327.06	275.18	37.79	333.41
N_3 (40:20:20)	293.54	39.45	352.90	297.67	40.40	359.81
N_4 (40:40:40)	300.11	39.98	355.32	303.55	40.84	363.49
SE	1.036	0.117	0.98	2.187	0.246	2.184
CD (0.05)	2.07	NS	NS	4.37	NS	NS
Nutrient sources						
S_1 (OS)	319.42	42.21	374.95	322.57	43.13	383.13
S_2 (INM)	237.35	33.17	294.82	240.62	33.98	299.88
SE	0.74	0.09	0.60	1.541	0.176	1.547
CD (0.05)	1.46	NS	NS	3.09	NS	NS
Controls						
C_1 (Absolute control)	154.71	24.12	215.92	156.29	24.39	218.27
C_2 (POP)	181.20	27.01	245.57	184.14	27.41	246.42
SE	1.47	0.18	1.50	3.08	0.344	3.087
C_2 vs Treatments	NS	NS	NS	NS	NS	NS
C_1 vs Treatments	S	NS	NS	S	NS	NS
Between controls	S	NS	NS	S	NS	NS

(Interaction effect not significant)

Table 65. Effect of nutrient regimes and nutrient sources on soil microbial population under saturated situation (2007 and 2008)

Treatments	2007			2008		
	Rhizosphere bacterial population (10^4 cfu g^{-1} soil)	Rhizosphere fungal population (10^4 cfu g^{-1} soil)	Rhizosphere actinomycetes population (10^6 cfu g^{-1} soil)	Rhizosphere bacterial population (10^4 cfu g^{-1} soil)	Rhizosphere fungal population (10^4 cfu g^{-1} soil)	Rhizosphere actinomycetes population (10^6 cfu g^{-1} soil)
Nutrient regimes						
N_1 (30:15:15)	33.62	28.03	4.25	34.39	28.23	4.39
N_2 (30:30:30)	34.93	29.77	4.53	35.51	30.02	4.72
N_3 (40:20:20)	36.28	33.03	5.10	37.54	33.37	5.24
N_4 (40:40:40)	37.13	33.54	5.20	37.97	34.04	5.35
SE	0.07	0.06	0.01	0.23	0.27	0.06
CD (0.05)	0.12	NS	NS	0.40	NS	NS
Nutrient sources						
S_1 (OS)	38.03	35.54	5.53	39.18	35.93	5.68
S_2 (INM)	32.95	26.64	4.01	33.53	26.90	4.17
SE	0.046	0.037	0.006	0.157	0.21	0.036
CD (0.05)	0.09	NS	NS	0.31	NS	NS
Controls						
C_1 (Absolute control)	24.56	19.98	2.74	25.05	20.19	2.84
C_2 (POP)	27.71	21.47	3.25	28.21	21.67	3.37
SE	0.09	0.077	0.014	0.32	0.394	0.08
C_2 vs Treatments	NS	NS	NS	NS	NS	NS
C_1 vs Treatments	S	NS	NS	S	NS	NS
Between controls	S	NS	NS	S	NS	NS

(Interaction effect not significant)

4.2.19. Economics of cultivation

Effect of nutrient regimes, nutrient sources and their interactions on gross income, net income and BCR were significant in both the years (Tables 66, 67 and 68).

Highest gross income (Rs 80010.83 ha^{-1} in 2007 and Rs 76500.00 ha^{-1} in 2008), net income (Rs 39311.34 ha^{-1} in 2007 and Rs 35800.50 ha^{-1} in 2008) and BCR (1.97 in 2007 and 1.89 in 2008) were obtained by the application of 30:30:30 kg NPK ha^{-1} (N_2 regime).

POP recorded significantly lower gross income, net income and BCR compared to all other nutrient regimes. POP and N_1 had similar effects and were inferior to other nutrient regimes. Absolute control was found least economic during both years.

Among the nutrient sources, highest gross income (Rs 78612.91 ha^{-1} in 2007 and Rs 74152.25 ha^{-1} in 2008), net income (Rs 38471.42 ha^{-1} in 2007 and Rs 34010.75 ha^{-1} in 2008) and BCR (1.96 in 2007 and 1.84 in 2008) were obtained by integrated nutrition. Application of organic sources resulted in gross income (Rs 57433.25 ha^{-1} in 2007 and Rs 54364.83 ha^{-1} in 2008), net income (Rs 15701.75 ha^{-1} in 2007 and Rs 12633.33 ha^{-1} in 2008) and BCR (1.37 in 2007 and 1.30 in 2008). Net income obtained under integrated nutrition was 59 to 62 per cent higher than that obtained by organic nutrition.

Under organic nutrition N_4 recorded the highest gross income, net income and BCR compared to other two regimes and was on par with N_2. Under Integrated nutrient source N_2 recorded the highest gross income, net income and BCR.

N_2S_2 recorded highest gross income (Rs 95261.66 ha^{-1} in 2007 and Rs 91760.00 ha^{-1} in 2008), net income (Rs 55296.67 ha^{-1} in 2007 and Rs 51795.00 ha^{-1} in 2008) and BCR (2.38 in 2007 and 2.30 in 2008). Lowest gross income, net income and BCR were obtained at N_1S_1 (Tables 67 and 68).

Table 66. Effect of nutrient regimes and nutrient sources on economics of Njavara cultivation under saturated situation (2007 and 2008)

Treatments	2007			2008		
	Gross income (Rs ha^{-1})	Net income (Rs ha^{-1})	BCR	Gross income (Rs ha^{-1})	Net income (Rs ha^{-1})	BCR
Nutrient regimes						
N_1 (30:15:15)	47051.34	7014.33	1.18	44714.16	4677.17	1.12
N_2 (30:30:30)	80010.83	39311.34	1.97	76500.00	35800.50	1.89
N_3 (40:20:20)	67370.50	26334.50	1.65	61960.00	20924.00	1.52
N_4 (40:40:40)	77659.67	35686.17	1.86	73860.00	31886.50	1.77
SE	1179.395	1179.395	0.03	1040.045	1040.045	0.02
CD (0.05)	2344.09	2344.09	0.07	2498.87	2498.87	0.06
Nutrient sources						
S_1 (OS)	57433.25	15701.75	1.37	54364.83	12633.33	1.30
S_2 (INM)	78612.91	38471.42	1.96	74152.25	34010.75	1.84
SE	1003.24	1003.24	0.02	881.49	881.49	0.01
CD (0.05)	2037.81	2037.81	0.05	1766.97	1766.97	0.04
Controls						
C_1 (Absolute control)	26320.00	-8954.00	0.75	22229.33	-13044.67	0.63
C_2 (POP)	42750.00	4317.00	1.11	41326.67	2893.67	1.08
SE	2161.81	2161.81	0.04	1760.21	1760.21	0.04
C_2 vs Treatments	S	S	S	S	S	S
C_1 vs Treatments	S	S	S	S	S	S
Between controls	S	S	S	S	S	S

Table 67. Interaction effect of nutrient regimes and nutrient sources on economics of Njavara cultivation under saturated situation (2007)

Treatment combinations	Gross income (Rs ha^{-1})		Net income (Rs ha^{-1})		BCR	
Nutrient sources / Nutrient regimes	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	41062.67	53040.00	378.67	13650.00	1.01	1.35
N_2 (30:30:30)	64760.00	95261.66	23326.00	55296.67	1.56	2.38
N_3 (40:20:20)	56221.00	78520.00	14317.00	38352.00	1.34	1.95
N_4 (40:40:40)	67689.34	87630.00	24785.33	46587.00	1.58	2.14
SE	2161.81		2161.81		0.04	
CD (0.05)	4323.62		4323.62		0.09	

Table 68. Interaction effect of nutrient regimes and nutrient sources on economics of Njavara cultivation under saturated situation (2008)

Treatment combinations	Gross income (Rs ha^{-1})		Net income (Rs ha^{-1})		BCR	
Nutrient sources / Nutrient regimes	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	40789.00	48639.33	105.00	9249.33	1.00	1.23
N_2 (30:30:30)	61240.00	91760.00	19806.00	51795.00	1.48	2.30
N_3 (40:20:20)	50960.00	72960.00	9056.00	32792.00	1.22	1.82
N_4 (40:40:40)	64470.33	83249.66	21566.33	42206.67	1.50	2.03
SE	1760.21		1760.21		0.04	
CD (0.05)	3533.94		3533.94		0.09	

4.3. Effect of nutrient regimes and nutrient sources on growth and productivity of Njavara cultivated under submerged situation (Pooled analysis)

4.3.1. Growth characters

Pooled analysis of the data on growth attributes showed that nutrient regimes, nutrient sources and their interactions had significant influence on growth characters of Njavara at harvest stage under submerged situation. Effect of years was not significant (Tables 69 and 70).

Maximum leaf number plant^{-1}, leaf area index, number of tillers m^{-2}, culm strength and flag leaf area were recorded in N_2 which was on par with N_4 and was significantly superior to other two nutrient regimes.

Among the nutrient sources, integrated nutrient sources registered significantly higher values for all growth characters compared to organic nutrition.

Interaction between nutrient regimes and nutrient sources had significant influence on growth attributes such as leaf number plant^{-1}, leaf area index, number of tillers m^{-2}, culm strength and flag leaf area. All growth characters were highest in N_2S_2 which was on par with N_4S_2. N_1S_1 recorded lowest growth attributes.

4.3.2. Yield attributes

Pooled effect of nutrient regimes, nutrient sources and their interactions on yield attributes of Njavara grown under submerged situation are presented in Tables 71 and 72 respectively. Effect of years was not significant.

Productive tillers increased significantly with increased application of nutrients. Maximum productive tillers m^{-2}, number of grains panicle^{-1} and filled grains panicle^{-1} were observed in N_2 which was on par with N_4 and were significantly superior to the other two nutrient regimes.

Effect of nutrient sources on productive tillers m^{-2}, grains panicle^{-1} and filled grains panicle^{-1} was significant. Integrated nutrient system recorded significantly higher values compared to organic nutrition.

Interaction between nutrient regimes and sources had significant influence on yield attributes such as productive tillers m^{-2}, grains panicle^{-1} and filled grains

Table 69. Effect of nutrient regimes and nutrient sources on growth attributes of Njavara at harvest stage under submerged situation (Pooled data)

Treatments	Plant height (cm)	Leaf number $plant^{-1}$	Leaf area index	Tillers m^{-2}	Culm strength ($mg\ cm^{-1}$)	Flag leaf area (cm^2)
Nutrient regimes						
N_1 (30:15:15)	102.37	5.34	1.28	421.34	24.16	10.73
N_2 (30:30:30)	112.56	6.54	2.04	519.21	35.28	18.49
N_3 (40:20:20)	108.95	6.12	1.78	483.70	31.58	15.81
N_4 (40:40:40)	111.89	6.47	2.00	512.06	34.68	18.17
SE	3.10	0.05	0.02	11.37	0.21	0.13
CD (0.05)	9.30	0.15	0.06	34.11	0.63	0.39
Nutrient sources						
S_1 (OS)	105.95	5.76	1.56	455.03	28.28	13.58
S_2 (INM)	111.94	6.48	1.99	513.12	34.57	18.02
SE	1.93	0.04	0.03	9.51	0.34	0.09
CD (0.05)	5.79	0.12	0.09	28.53	1.02	0.27
Years						
2007	110.95	6.22	1.81	492.89	32.12	16.57
2008	106.93	6.04	1.74	475.26	30.73	15.03
SE	1.55	0.07	0.03	6.72	0.48	0.56
CD (0.05)	NS	NS	NS	NS	NS	NS

Table 70. Interaction effect of nutrient regimes and nutrient sources on growth attributes of Njavara at harvest stage under submerged situation (Pooled data)

Treatment combinations	Plant height (cm)		Leaf number $plant^{-1}$		Leaf area index		Tillers m^{-2}		Culm strength (mg cm^{-1})		Flag leaf area (cm^2)	
Nutrient sources / Nutrient regimes	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	99.91	104.82	5.05	5.64	1.11	1.46	397.38	445.30	21.60	26.72	8.83	12.62
N_2 (30:30:30)	108.40	116.72	6.05	7.03	1.74	2.33	479.03	559.38	30.93	39.64	15.48	21.51
N_3 (40:20:20)	106.01	111.90	5.78	6.47	1.57	1.99	455.32	512.08	28.38	34.78	13.56	18.07
N_4 (40:40:40)	109.48	114.30	6.17	6.77	1.83	2.16	488.40	535.72	32.21	37.15	16.47	19.87
SE	4.38		0.11		0.07		15.10		1.44		0.68	
CD (0.05)	13.14		0.32		0.21		45.30		4.32		2.04	

panicle^{-1}. N_2S_2 recorded highest yield attributes and it was on par with N_4S_2. N_1S_1 recorded lowest yield attributes under submerged situation.

Nutrient regimes and nutrient sources had no significant influence on thousand grain weight under submerged situation.

4.3.3. Grain yield

Pooled data on grain yield as influenced by nutrient regimes, nutrient sources and their interactions under submerged situation is given in Tables 71 and 72. Year effect was not significant.

Effect of nutrient regimes, nutrient sources and interaction effect on grain yield were significant. Maximum grain yield was recorded in N_2 (30:30:30 kg NPK ha^{-1}) (2.78 t ha^{-1}) which was on par with N_4 (40:40:40 kg NPK ha^{-1}) (2.67 t ha^{-1}) and was significantly superior to N_1 and N_3. N_1 recorded the lowest yield (1.63 t ha^{-1}).

Integrated nutrient sources recorded the highest grain yield of 2.71 t ha^{-1} which was significantly superior to organic sources which recorded a grain yield of 1.98 t ha^{-1}.

Among interactions, N_2S_2 recorded highest grain yield of 3.32 t ha^{-1} and was on par with N_4S_2. Lowest grain yield was obtained at N_1S_1 (1.39 t ha^{-1}).

4.3.4. Straw yield

The results are presented in Tables 71 and 72. Significant variation in straw yield was observed among nutrient regimes, nutrient sources and their interactions under submerged situation. Effect of years was not significant.

Maximum straw yield of 3.88 t ha^{-1} was recorded in N_2 (30:30:30 kg NPK ha^{-1}) which was on par with N_4 (40:40:40 kg NPK ha^{-1}) (3.74 t ha^{-1}) and was significantly superior to N_1 and N_3.

Application of integrated nutrient sources recorded significantly higher straw yield (3.79 t ha^{-1}) than organic source (2.78 t ha^{-1}).

Table 71. Effect of nutrient regimes and nutrient sources on yield and yield attributes of Njavara under submerged situation (Pooled data)

Treatments	Productive tillers m^{-2}	Filled grains $panicle^{-1}$	Grains $panicle^{-1}$	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Thousand grain weight (g)
Nutrient regimes						
N_1 (30:15:15)	253.48	41.70	53.00	1.63	2.26	17.45
N_2 (30:30:30)	343.29	58.96	70.92	2.78	3.88	17.83
N_3 (40:20:20)	311.27	52.24	64.36	2.31	3.25	17.74
N_4 (40:40:40)	336.99	57.34	69.58	2.67	3.74	17.84
SE	5.31	1.74	1.28	0.06	0.06	0.06
CD (0.05)	15.93	5.22	3.84	0.18	0.18	NS
Nutrient sources						
S_1 (OS)	284.84	47.29	59.09	1.98	2.78	17.62
S_2 (INM)	337.68	57.83	69.83	2.71	3.79	17.81
SE	3.76	1.23	0.90	0.04	0.05	0.13
CD (0.05)	11.28	3.69	2.70	0.12	0.15	NS
Years						
2007	315.21	53.57	65.73	2.43	3.40	17.69
2008	307.30	51.55	63.20	2.26	3.17	17.74
SE	2.66	0.71	0.86	0.08	0.09	0.06
CD (0.05)	NS	NS	NS	NS	NS	NS

Table 72. Interaction effect of nutrient regimes and nutrient sources on yield and yield attributes of Njavara under submerged situation (Pooled data)

Treatment combinations	Productive tillers m^{-2}		Filled grains $panicle^{-1}$		Grains $panicle^{-1}$		Grain yield ($t\ ha^{-1}$)		Straw yield ($t\ ha^{-1}$)		Thousand grain weight (g)	
Nutrient sources / Nutrient regimes	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	231.00	275.95	37.57	45.83	48.54	57.46	1.39	1.86	1.86	2.66	17.31	17.60
N_2 (30:30:30)	307.00	379.58	51.49	66.43	63.52	78.32	2.24	3.32	3.17	4.60	17.73	17.93
N_3 (40:20:20)	285.53	337.00	47.19	57.30	59.13	69.60	1.95	2.66	2.78	3.73	17.65	17.83
N_4 (40:40:40)	315.82	358.17	52.90	61.78	65.19	73.96	2.35	2.99	3.31	4.17	17.78	17.90
SE	7.52		1.61		1.81		0.12		0.17		0.18	
CD (0.05)	22.56		4.83		5.43		0.36		0.51		NS	

Among interactions, N_2S_2 recorded maximum straw yield of 4.60 t ha^{-1} and was on par with N_4S_2. N_1S_1 recorded the lowest straw yield under submerged situation.

4.3.5. Nutrient uptake (N, P and K)

Pooled analysis showed that effect of nutrient regimes, nutrient sources and interaction effects on uptake of N, P and K was significant under submerged situation Tables 73 and 74. Year effect was not significant.

Uptake of N, P and K were highest in N_2 (80.58 kg N ha^{-1}, 30.51 kg P ha^{-1} and 97.90 kg K ha^{-1}). This was followed by N_4, N_3 and N_1. N_2 was on par with N_4.

Uptake of N, P and K were significantly higher under integrated nutrient source compared to organic source. N_2S_2 recorded highest uptake of N, P and K and was on par with N_4S_2. The least uptake of N, P and K were recorded in N_1S_1.

4.3.6. Soil fertility status (Available N, P and K)

The fertility status of soil was studied after the experiment in terms of available nitrogen, phosphorus and potassium and results are presented in Tables 75 and 76. The data revealed significant influence of nutrient regimes, nutrient sources and their interaction effects on available nitrogen, phosphorus and potassium under submerged situation. Effect of years was not significant.

Available N, P and K were highest in N_2 (255.78 kg N ha^{-1}, 46.15 kg P ha^{-1} and 255.14 kg K ha^{-1}) which was on par with N_4 and were significantly higher than all other nutrient regimes.

Available N, P and K were highest in integrated nutrient source (256.02 kg N ha^{-1}, 45.64 kg P ha^{-1} and 253.39 kg K ha^{-1}) which was significantly superior to organic source (213.26 kg N ha^{-1}, 33.40 kg P ha^{-1} and 205.23 kg K ha^{-1}).

Among the interactions, N_2S_2 recorded the highest available N, P and K status (290.45 kg N ha^{-1}, 55.83 kg P ha^{-1} and 293.60 kg K ha^{-1}) which was significantly superior to all other interaction effects except N_4S_2. Available N, P and K status was least in N_1S_1.

Table 73. Effect of nutrient regimes and nutrient sources on uptake of N, P and K of Njavara under submerged situation (Pooled data)

Treatments	Uptake of N (kg ha^{-1})	Uptake of P (kg ha^{-1})	Uptake of K (kg ha^{-1})
Nutrient regimes			
N_1 (30:15:15)	40.75	20.16	74.67
N_2 (30:30:30)	80.58	30.51	97.90
N_3 (40:20:20)	65.54	26.78	89.86
N_4 (40:40:40)	77.12	29.84	96.62
SE	1.18	0.50	1.56
CD (0.05)	3.54	1.50	4.68
Nutrient sources			
S_1 (OS)	54.15	23.81	83.16
S_2 (INM)	77.84	29.83	96.37
SE	0.84	0.36	1.10
CD (0.05)	2.52	1.08	3.30
Years			
2007	67.12	25.76	91.06
2008	64.86	27.89	88.47
SE	0.84	0.76	0.89
CD (0.05)	NS	NS	NS

Table 74. Interaction effect of nutrient regimes and nutrient sources on uptake of N, P and K of Njavara under submerged situation (Pooled data)

Treatment combinations	Uptake of N (kg ha^{-1})		Uptake of P (kg ha^{-1})		Uptake of K (kg ha^{-1})	
Nutrient sources / Nutrient regimes	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	30.89	50.60	17.53	22.80	68.67	80.67
N_2 (30:30:30)	64.15	97.01	26.33	34.70	89.06	106.75
N_3 (40:20:20)	54.41	76.67	23.94	29.63	83.58	96.15
N_4 (40:40:40)	67.16	87.08	27.47	32.21	91.32	101.92
SE	3.46		0.91		2.19	
CD (0.05)	10.38		2.73		6.57	

Table 75. Effect of nutrient regimes and nutrient sources on available N, P and K status of soil under submerged situation (Pooled data)

Treatments	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
Nutrient regimes			
N_1 (30:15:15)	200.29	28.20	187.20
N_2 (30:30:30)	255.78	46.15	255.14
N_3 (40:20:20)	233.52	38.83	229.03
N_4 (40:40:40)	248.97	44.91	245.86
SE	2.31	0.43	3.36
CD (0.05)	6.93	1.29	10.08
Nutrient sources			
S_1 (OS)	213.26	33.40	205.23
S_2 (INM)	256.02	45.64	253.39
SE	1.63	0.30	1.67
CD (0.05)	4.89	0.90	5.01
Years			
2007	237.57	39.34	231.61
2008	231.71	39.70	227.00
SE	1.98	0.21	1.58
CD (0.05)	NS	NS	NS

Table 76. Interaction effect of nutrient regimes and nutrient sources on available N, P and K status of soil under submerged situation (Pooled data)

Treatment combinations	Available N (kg ha^{-1})		Available P (kg ha^{-1})		Available K (kg ha^{-1})	
Nutrient sources / Nutrient regimes	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	188.45	212.13	24.59	31.81	170.78	203.62
N_2 (30:30:30)	221.12	290.45	36.47	55.83	216.68	293.60
N_3 (40:20:20)	216.45	250.58	33.32	44.34	212.95	245.12
N_4 (40:40:40)	227.02	270.92	39.25	50.58	220.48	271.23
SE	6.72		1.86		7.68	
CD (0.05)	20.16		5.58		23.04	

4.3.7. Economics of cultivation

Effect of nutrient regimes, nutrient sources and their interactions on BCR was significant under submerged situation (Tables 77 and 78). Effect of years was not significant. Highest BCR (2.02) was recorded by N_2 which was on par with N_4 and was significantly higher than N_3 and N_1. Higher BCR (1.98) was recorded in integrated nutrient sources compared to organic sources (1.39).

Among the interactions, N_2S_2 recorded highest BCR (2.44) and was on par with N_4S_2 (2.14). Lowest BCR was obtained at N_1S_1 (1.01).

Table 77. Effect of nutrient regimes and nutrient sources on BCR of Njavara cultivation under submerged situation (Pooled data)

Treatments	BCR
Nutrient regimes	
N_1 (30:15:15)	1.20
N_2 (30:30:30)	2.02
N_3 (40:20:20)	1.66
N_4 (40:40:40)	1.87
SE	0.06
CD (0.05)	0.18
Nutrient sources	
S_1 (OS)	1.39
S_2 (INM)	1.98
SE	0.03
CD (0.05)	0.09
Years	
2007	1.75
2008	1.62
SE	0.05
CD (0.05)	NS

Table 78. Interaction effect of nutrient regimes and nutrient sources on BCR of Njavara cultivation under submerged situation (Pooled data)

Treatment combinations	BCR	
Nutrient sources / Nutrient regimes	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	1.01	1.39
N_2 (30:30:30)	1.59	2.44
N_3 (40:20:20)	1.37	1.95
N_4 (40:40:40)	1.61	2.14
SE	0.11	
CD (0.05)	0.32	

4.4. Effect of nutrient regimes and nutrient sources on growth and productivity of Njavara cultivated under saturated situation (Pooled analysis)

4.4.1. Growth characters

Pooled analysis of the data on growth attributes showed that nutrient regimes, nutrient sources and their interactions had significant influence on growth characters of Njavara at harvest stage under saturated situation. Effect of years was not significant (Tables 79 and 80).

Maximum leaf number plant^{-1}, leaf area index, number of tillers m^{-2}, culm strength and flag leaf area were recorded in N_2 which was on par with N_4 and was significantly superior to other two nutrient regimes.

Among the nutrient sources, integrated nutrient sources registered significantly higher values for all growth characters compared to organic nutrition.

Interaction between nutrient regimes and nutrient sources had significant influence on growth attributes such as leaf number plant^{-1}, leaf area index, number of tillers m^{-2}, culm strength and flag leaf area. All growth characters were highest in N_2S_2 which was on par with N_4S_2. N_1S_1 recorded lowest growth attributes.

4.4.2. Yield attributes

Pooled effect of nutrient regimes, nutrient sources and their interactions on yield attributes of Njavara grown under saturated situation are presented in Tables 81 and 82 respectively. Effect of years was not significant.

Productive tillers increased significantly with increased application of nutrients. Maximum productive tillers m^{-2}, number of grains panicle^{-1} and filled grains panicle^{-1} were observed in N_2 which was on par with N_4 and were significantly superior to the other two nutrient regimes.

Effect of nutrient sources on productive tillers m^{-2}, grains panicle^{-1} and filled grains panicle^{-1} was significant. Integrated nutrient system recorded significantly higher values compared to organic nutrition.

Interaction between nutrient regimes and sources had significant influence on yield attributes such as productive tillers m^{-2}, grains panicle^{-1} and filled grains

Table 79. Effect of nutrient regimes and nutrient sources on growth attributes of Njavara at harvest stage under saturated situation (Pooled data)

Treatments	Plant height (cm)	Leaf number plant^{-1}	Leaf area index	Tillers m^{-2}	Culm strength (mg cm^{-1})	Flag leaf area (cm^2)
Nutrient regimes						
N_1 (30:15:15)	96.10	5.03	1.10	430.48	22.64	10.37
N_2 (30:30:30)	106.97	6.20	1.93	510.18	33.53	18.01
N_3 (40:20:20)	102.38	5.76	1.67	481.38	29.64	15.55
N_4 (40:40:40)	105.33	6.12	1.88	502.57	32.83	17.66
SE	2.82	0.10	0.03	8.34	0.27	0.17
CD (0.05)	8.46	0.30	0.09	25.02	0.81	0.51
Nutrient sources						
S_1 (OS)	99.42	5.41	1.41	458.69	26.46	13.19
S_2 (INM)	105.97	6.14	1.88	503.62	32.86	17.61
SE	1.99	0.07	0.06	8.02	0.19	0.05
CD (0.05)	5.97	0.21	0.18	24.06	0.57	0.15
Years						
2007	104.16	6.09	1.72	489.08	31.28	16.23
2008	101.23	5.46	1.57	473.23	28.04	14.57
SE	1.41	0.24	0.07	5.67	1.14	0.57
CD (0.05)	NS	NS	NS	NS	NS	NS

Table 80. Interaction effect of nutrient regimes and nutrient sources on growth attributes of Njavara at harvest stage under saturated situation (Pooled data)

Treatment combinations	Plant height (cm)		Leaf number $plant^{-1}$		Leaf area index		Tillers m^{-2}		Culm strength ($mg\ cm^{-1}$)		Flag leaf area (cm^2)	
Nutrient sources / Nutrient regimes	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	93.48	98.73	4.73	5.33	0.83	1.38	410.73	450.23	20.07	25.21	8.51	12.24
N_2 (30:30:30)	102.06	111.88	5.71	6.70	1.64	2.22	479.70	540.67	29.10	37.96	15.04	20.99
N_3 (40:20:20)	99.42	105.34	5.40	6.13	1.46	1.89	460.40	502.35	26.43	32.85	13.28	17.82
N_4 (40:40:40)	102.70	107.95	5.81	6.43	1.72	2.05	483.92	521.22	30.24	35.43	15.95	19.38
SE	3.98		0.14		0.07		12.04		0.89		0.61	
CD (0.05)	11.94		0.42		0.21		36.12		2.67		1.82	

panicle^{-1}. N_2S_2 recorded highest yield attributes and it was on par with N_4S_2. N_1S_1 recorded lowest yield attributes under saturated situation.

Nutrient regimes and nutrient sources had no significant influence on thousand grain weight under saturated situation.

4.4.3. Grain yield

Pooled data on grain yield as influenced by nutrient regimes, nutrient sources and their interactions under saturated situation is given in Tables 81 and 82. Year effect was not significant.

Effect of nutrient regimes, nutrient sources and interaction effect on grain yield were significant. Maximum grain yield was recorded in N_2 (30:30:30 kg NPK ha^{-1}) (2.66 t ha^{-1}) which was on par with N_4 (40:40:40 kg NPK ha^{-1}) (2.58 t ha^{-1}) and was significantly superior to N_1 and N_3. N_1 recorded the lowest yield (1.56 t ha^{-1}).

Integrated nutrient sources recorded the highest grain yield of 2.60 t ha^{-1} which was significantly superior to organic sources which recorded a grain yield of 1.90 t ha^{-1}.

Among interactions, N_2S_2 recorded highest grain yield of 3.18 t ha^{-1} and was on par with N_4S_2. Lowest grain yield was obtained at N_1S_1 (1.40 t ha^{-1}).

4.4.4. Straw yield

The results are presented in Tables 81 and 82. Significant variation in straw yield was observed among nutrient regimes, nutrient sources and their interactions under saturated situation. Effect of years was not significant.

Maximum straw yield of 3.78 t ha^{-1} was recorded in N_2 (30:30:30 kg NPK ha^{-1}) which was on par with N_4 (40:40:40 kg NPK ha^{-1}) (3.66 t ha^{-1}) and was significantly superior to N_1 and N_3.

Application of integrated nutrient sources recorded significantly higher straw yield (3.69 t ha^{-1}) than organic source (2.65 t ha^{-1}).

Table 81. Effect of nutrient regimes and nutrient sources on yield and yield attributes of Njavara under saturated situation (Pooled data)

Treatments	Productive tillers m^{-2}	Filled grains $panicle^{-1}$	Grains $panicle^{-1}$	Grain yield ($t\ ha^{-1}$)	Straw yield ($t\ ha^{-1}$)	Thousand grain weight (g)
Nutrient regimes						
N_1 (30:15:15)	237.10	42.58	54.41	1.56	2.10	17.64
N_2 (30:30:30)	316.79	61.32	74.29	2.66	3.78	17.83
N_3 (40:20:20)	287.53	53.69	66.50	2.20	3.14	17.78
N_4 (40:40:40)	310.86	59.03	72.02	2.58	3.66	17.83
SE	6.95	0.93	1.61	0.05	0.05	0.19
CD (0.05)	20.85	2.79	4.83	0.15	0.15	NS
Nutrient sources						
S_1 (OS)	264.47	48.32	60.64	1.90	2.65	17.72
S_2 (INM)	311.68	59.99	72.96	2.60	3.69	17.82
SE	4.92	0.66	1.14	0.04	0.03	0.14
CD (0.05)	14.76	1.98	3.42	0.12	0.09	NS
Years						
2007	290.11	54.88	67.57	2.31	3.26	17.82
2008	286.03	53.42	66.04	2.19	3.08	17.72
SE	3.48	0.52	0.81	0.05	0.07	0.10
CD (0.05)	NS	NS	NS	NS	NS	NS

Table 82. Interaction effect of nutrient regimes and nutrient sources on yield and yield attributes of Njavara under saturated situation (Pooled data)

Treatment combinations	Productive tillers m^{-2}		Filled grains $panicle^{-1}$		Grains $panicle^{-1}$		Grain yield ($t\ ha^{-1}$)		Straw yield ($t\ ha^{-1}$)		Thousand grain weight (g)	
Nutrient sources / Nutrient regimes	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	217.80	256.40	37.34	47.82	48.48	60.35	1.40	1.73	1.67	2.54	17.59	17.69
N_2 (30:30:30)	284.03	349.55	53.44	69.20	66.25	82.33	2.14	3.18	3.08	4.48	17.77	17.88
N_3 (40:20:20)	264.48	310.58	48.44	58.95	60.98	72.01	1.82	2.58	2.64	3.64	17.72	17.84
N_4 (40:40:40)	291.55	330.17	54.06	64.01	66.86	77.18	2.25	2.91	3.22	4.10	17.81	17.86
SE	9.84		1.78		2.28		0.10		0.15		0.27	
CD (0.05)	29.53		5.34		6.84		0.30		0.45		NS	

Among interactions, N_2S_2 recorded maximum straw yield of 4.48 t ha^{-1} and was on par with N_4S_2. N_1S_1 recorded the lowest straw yield under saturated situation.

4.4.5. Nutrient uptake (N, P and K)

Pooled analysis showed that effect of nutrient regimes, nutrient sources and interaction effects on uptake of N, P and K was significant under saturated situation Tables 83 and 84. Year effect was not significant.

Uptake of N, P and K were highest in N_2 (77.92 kg N ha^{-1}, 27.90 kg P ha^{-1} and 93.70 kg K ha^{-1}). This was followed by N_4, N_3 and N_1. N_2 was on par with N_4.

Uptake of N, P and K were significantly higher under integrated nutrient source compared to organic source. N_2S_2 recorded highest uptake of N, P and K and was on par with N_4S_2. The least uptake of N, P and K were recorded in N_1S_1.

4.4.6. Soil fertility status (Available N, P and K)

The fertility status of soil was studied after the experiment in terms of available nitrogen, phosphorus and potassium and results are presented in Tables 85 and 86. The data revealed significant influence of nutrient regimes, nutrient sources and their interaction effects on available nitrogen, phosphorus and potassium under saturated situation. Effect of years was not significant.

Available N, P and K were highest in N_2 (252.58 kg N ha^{-1}, 44.61 kg P ha^{-1} and 247.70 kg K ha^{-1}) which was on par with N_4 and were significantly higher than all other nutrient regimes.

Available N, P and K were highest in integrated nutrient source (251.42 kg N ha^{-1}, 43.99 kg P ha^{-1} and 246.11 kg K ha^{-1}) which was significantly superior to organic source (207.83 kg N ha^{-1}, 30.96 kg P ha^{-1} and 196.81 kg K ha^{-1}).

Among the interactions, N_2S_2 recorded the highest available N, P and K status (287.72 kg N ha^{-1}, 54.98 kg P ha^{-1} and 288.68 kg K ha^{-1}) which was significantly superior to all other interaction effects except N_4S_2. Available N, P and K status was least in N_1S_1.

Table 83. Effect of nutrient regimes and nutrient sources on uptake of N, P and K of Njavara under saturated situation (Pooled data)

Treatments	Uptake of N (kg ha^{-1})	Uptake of P (kg ha^{-1})	Uptake of K (kg ha^{-1})
Nutrient regimes			
N_1 (30:15:15)	37.79	16.01	65.42
N_2 (30:30:30)	77.92	27.90	93.70
N_3 (40:20:20)	63.09	23.45	84.13
N_4 (40:40:40)	75.39	27.24	92.39
SE	0.92	0.27	0.46
CD (0.05)	2.76	0.81	1.38
Nutrient sources			
S_1 (OS)	51.42	19.97	75.74
S_2 (INM)	75.67	27.33	92.08
SE	0.17	0.12	0.22
CD (0.05)	0.51	0.36	0.66
Years			
2007	65.16	23.30	86.04
2008	61.93	24.01	81.78
SE	1.12	0.29	1.47
CD (0.05)	NS	NS	NS

Table 84. Interaction effect of nutrient regimes and nutrient sources on uptake of N, P and K of Njavara under saturated situation (Pooled data)

Treatment combinations	Uptake of N (kg ha^{-1})		Uptake of P (kg ha^{-1})		Uptake of K (kg ha^{-1})	
Nutrient sources / Nutrient regimes	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	28.11	47.46	13.26	18.77	58.84	72.01
N_2 (30:30:30)	60.79	95.05	22.70	33.11	82.49	104.90
N_3 (40:20:20)	50.80	75.37	19.67	27.22	75.66	92.61
N_4 (40:40:40)	65.97	84.82	24.26	30.23	85.98	98.80
SE	3.44		0.98		2.11	
CD (0.05)	10.32		2.94		6.34	

Table 85. Effect of nutrient regimes and nutrient sources on available N, P and K status of soil under saturated situation (Pooled data)

Treatments	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
Nutrient regimes			
N_1 (30:15:15)	193.20	24.45	177.66
N_2 (30:30:30)	252.58	44.61	247.70
N_3 (40:20:20)	227.97	37.41	220.76
N_4 (40:40:40)	244.76	43.43	239.73
SE	2.67	0.46	2.79
CD (0.05)	8.01	1.38	8.37
Nutrient sources			
S_1 (OS)	207.83	30.96	196.81
S_2 (INM)	251.42	43.99	246.11
SE	0.88	0.03	1.27
CD (0.05)	2.64	0.09	3.81
Years			
2007	233.37	36.54	228.45
2008	225.88	38.40	214.48
SE	2.64	0.72	4.90
CD (0.05)	NS	NS	NS

Table 86. Interaction effect of nutrient regimes and nutrient sources on available N, P and K status of soil under saturated situation (Pooled data)

Treatment combinations	Available N (kg ha^{-1})		Available P (kg ha^{-1})		Available K (kg ha^{-1})	
Nutrient sources / Nutrient regimes	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	179.58	206.82	20.56	28.34	163.80	191.52
N_2 (30:30:30)	217.43	287.72	34.23	54.98	206.72	288.68
N_3 (40:20:20)	211.13	244.80	31.30	43.53	201.42	240.10
N_4 (40:40:40)	223.17	266.35	37.74	49.11	215.32	264.15
SE	7.24		2.04		8.32	
CD (0.05)	21.72		6.12		24.96	

4.4.7. Economics of cultivation

Effect of nutrient regimes, nutrient sources and their interactions on BCR was significant under saturated situation (Tables 87 and 88). Effect of years was not significant. Highest BCR (1.93) was recorded by N_2 which was on par with N_4 and was significantly higher than N_3 and N_1. Higher BCR (1.90) was recorded in integrated nutrient sources compared to organic sources (1.34).

Among the interactions, N_2S_2 recorded highest BCR (2.34) and was on par with N_4S_2 (2.08). Lowest BCR was obtained at N_1S_1 (1.01).

Table 87. Effect of nutrient regimes and nutrient sources on BCR of Njavara cultivation under saturated situation (Pooled data)

Treatments	BCR
Nutrient regimes	
N_1 (30:15:15)	1.15
N_2 (30:30:30)	1.93
N_3 (40:20:20)	1.58
N_4 (40:40:40)	1.81
SE	0.05
CD (0.05)	0.15
Nutrient sources	
S_1 (OS)	1.34
S_2 (INM)	1.90
SE	0.03
CD (0.05)	0.09
Years	
2007	1.66
2008	1.57
SE	0.04
CD (0.05)	NS

Table 88. Interaction effect of nutrient regimes and nutrient sources on BCR of Njavara cultivation under saturated situation (Pooled data)

Treatment combinations	BCR	
Nutrient sources / Nutrient regimes	S_1 (OS)	S_2 (INM)
N_1 (30:15:15)	1.01	1.29
N_2 (30:30:30)	1.52	2.34
N_3 (40:20:20)	1.28	1.89
N_4 (40:40:40)	1.54	2.08
SE	0.09	
CD (0.05)	0.27	

4.5. Relative performance of Njavara under two moisture regimes

Effect of nutrient regimes and nutrient sources on growth and productivity of Njavara was studied under two moisture regimes. Relative performance of the crop under submerged and saturated situations was analysed and the results are presented in Table 89.

Njavara crop cultivated under submerged situation was significantly taller than that cultivated under saturated situation. No significant difference was observed in all other parameters between the two moisture regimes. Grain and straw yield under submerged situation were 2.35 t ha^{-1} and 3.28 t ha^{-1} and they were only 4 and 3 per cent higher than the productivity obtained under saturated situation (2.25 t ha^{-1} and 3.17 t ha^{-1}).

Table 89. Relative performance of Njavara under two moisture regimes

Parameters	Submerged situation	Saturated situation	SE	CD (0.05)
Plant height (cm)	108.94	102.69	1.19	S
Leaf number $plant^{-1}$	6.12	5.78	0.15	NS
Leaf area index	1.77	1.64	0.05	NS
Tillers m^{-2}	484.08	481.15	5.60	NS
Culm strength (mg cm^{-1})	31.42	29.66	0.80	NS
Flag leaf area (cm^2)	15.80	15.40	0.56	NS
Productive tillers m^{-2}	311.26	288.07	7.82	NS
Filled grains $panicle^{-1}$	52.56	54.15	0.61	NS
Grains $panicle^{-1}$	64.46	66.80	0.81	NS
Grain yield (t ha^{-1})	2.35	2.25	0.06	NS
Straw yield (t ha^{-1})	3.28	3.17	0.08	NS
Thousand grain weight (g)	17.71	17.77	0.04	NS
Uptake of N (kg ha^{-1})	65.99	63.55	1.05	NS
Uptake of P (kg ha^{-1})	26.82	23.65	1.09	NS
Uptake of K (kg ha^{-1})	89.76	83.91	2.04	NS
Available N (kg ha^{-1})	234.64	229.63	2.34	NS
Available P (kg ha^{-1})	39.52	37.47	0.74	NS
Available K (kg ha^{-1})	229.31	221.46	3.46	NS
BCR	1.69	1.62	0.04	NS

DISCUSSION

5. DISCUSSION

A field investigation entitled "Input optimization for medicinal rice (*Oryza sativa* L.) cv. Njavara" was conducted during summer seasons of 2007 and 2008 in the wetlands attached to Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, to formulate nutrient schedule for Njavara variety of rice cultivated under submerged and saturated situations. The investigation comprised of two field experiments repeated for two consecutive summer seasons. The results obtained are discussed under the following titles

- Growth and productivity of Njavara as influenced by nutrient regimes under two moisture regimes
- Grain quality and nutrient uptake of Njavara as influenced by nutrient regimes under two moisture regimes
- Soil physical, chemical and biological properties as influenced by nutrient regimes under two moisture regimes
- Growth and productivity of Njavara as influenced by nutrient sources under two moisture regimes
- Grain quality and nutrient uptake of Njavara as influenced by nutrient sources under two moisture regimes
- Soil physical, chemical and biological properties as influenced by nutrient sources under two moisture regimes
- Relative performance of Njavara under two moisture regimes
- Interaction between nutrient regimes and nutrient sources on growth and productivity of Njavara under two moisture regimes
- Comparative performance of Njavara under POP of KAU recommendation and best economic treatment (N_2S_2)
- Economics of Njavara cultivation under two moisture regimes

5.1. Growth and productivity of Njavara as influenced by nutrient regimes under two moisture regimes

Field investigations were conducted to assess the effect of four nutrient regimes, constituted by two levels of nitrogen and two nutrient ratios, 30:15:15, 30:30:30, 40:20:20, 40:40:40 kg NPK ha^{-1} on growth and productivity of Njavara rice cultivated under submerged and saturated moisture regimes. Maximum grain and straw yield was obtained at 30:30:30 kg NPK ha^{-1} under both moisture regimes.

Application of 30:30:30kg NPK ha^{-1} recorded maximum grain yield of 2.87 t ha^{-1} and 2.70 t ha^{-1} under submerged situation during 2007 and 2008 respectively, which was significantly superior to 30:15:15, 40:20:20 kg NPK ha^{-1} and was on par with 40:40:40 kg NPK ha^{-1} (Fig. 3).Maximum straw yield was also obtained at this nutrient regime (Fig. 4). Perusal of the data indicated that almost all growth and yield attributes were higher at 30:30:30 kg NPK ha^{-1}. The superiority of the 30:30:30 kg NPK ha^{-1} in producing maximum yield is a direct reflection of the favourable influence on growth and yield attributes.

Application of 30:30:30 kg NPK ha^{-1} resulted in higher chlorophyll content and LAI. Better LAI coupled with high chlorophyll content must have increased the photosynthetic activity and thereby resulted in better growth and yield attributes. Nitrogen being a constituent of chlorophyll, increased application of nitrogen helped in increasing the chlorophyll content. Singh *et al.* (1992) and Babu (1996) observed significant influence in the chlorophyll content of rice with increased application of nitrogen. LAI also increased with increased level of nitrogen .Similar result was reported by Thomas (2000). Role of nitrogen in promoting vegetative growth is well documented.

The number of productive tillers m^{-2} produced by the application of 30:30:30 kg NPK ha^{-1} was 34 and 10 percentage higher than that realised

Fig. 3. Effect of nutrient regimes on grain yield of Njavara under submerged situation during 2007 and 2008

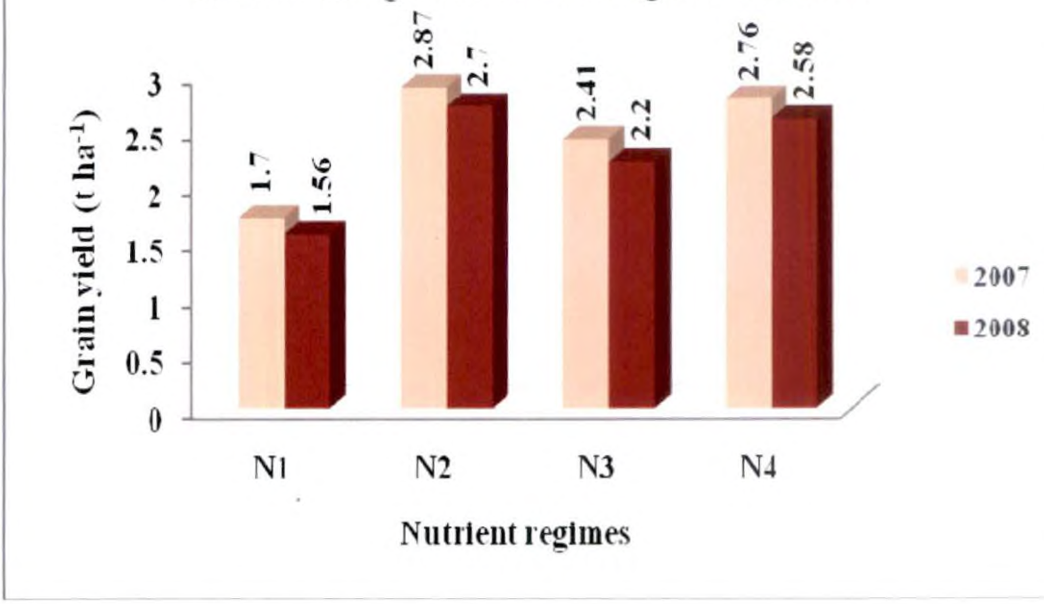
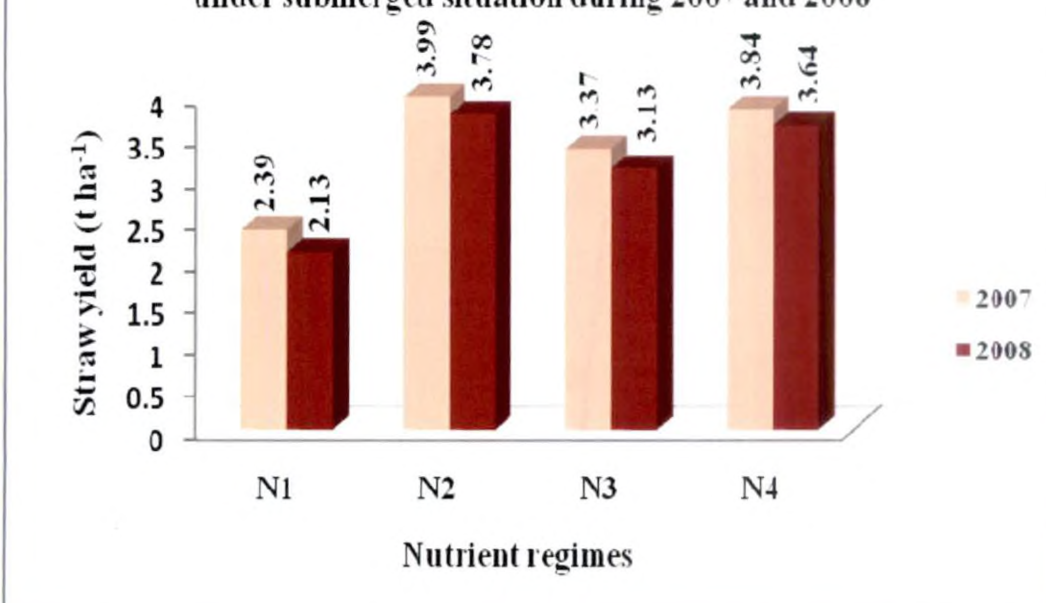


Fig. 4. Effect of nutrient regimes on straw yield of Njavara under submerged situation during 2007 and 2008



from 30:15:15 and 40:20:20 kg NPK ha^{-1} respectively in 2007. The corresponding increase in grains $panicle^{-1}$ was 28 and 9 percentage and filled grains $panicle^{-1}$ also increased by 35 and 11 percentage under submerged situation (Fig. 5, 6 and 7). Same trend was observed during 2008 also. The favourable effect of nitrogen in increasing the number of spikelets $panicle^{-1}$ was previously reported by Khanda and Dixit (1996). Patel *et al.* (1997) and Thomas (2000) obtained significantly higher number of productive tillers $hill^{-1}$ with increased application of nitrogen. Increase in filled grains with increase in N level was also noticed by Kumari *et al.* (2000). Anu (2001) also found that the number of spikelets $panicle^{-1}$ and weight of panicle increased significantly with increased application of nitrogen. Better chlorophyll content coupled with higher LAI might have increased the synthesis of photosynthates and thus resulted in better growth and yield attributes. Phosphorus being a nutrient highly essential for all energy transfer reaction, increased level of application must have promoted the growth and productivity of the crop. Potassium plays a very important role in the synthesis and translocation of carbohydrate (Tisdale *et al.*, 1995). Better synthesis of carbohydrate with increased application of potassium might have resulted in the production of more number of leaves, better tiller production which ultimately must have resulted in better growth and yield attributes. Yield is a function of productive tillers m^{-2}, grains $panicle^{-1}$, filled grains $panicle^{-1}$ and thousand grain weight. Singh *et al.* (1998) noted an increase in the no of productive tillers m^{-2} and grains $panicle^{-1}$ with the application of higher levels of NPK. Application of 60:40:30 kg NPK ha^{-1} recorded highest plant height, LAI, number of tillers $hill^{-1}$ and DMP in scented rice (Santhosh *et al.*, 2004).

All these resulted in maximum grain yield at 30:30:30 kg NPK ha^{-1} under submerged situation. No response was obtained by application of nutrients above this level.

Fig. 5. Effect of nutrient regimes on productive tillers m^{-2} of Njavara under submerged situation during 2007 and 2008

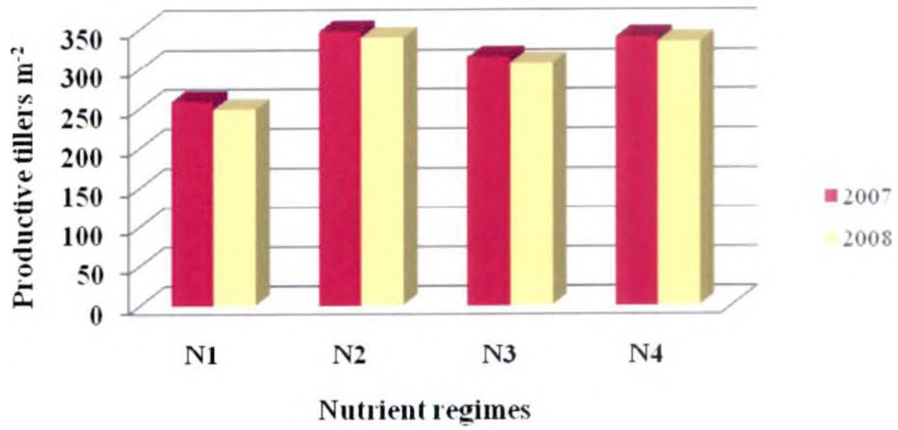


Fig. 6. Effect of nutrient regimes on grains panicle^{-1} of Njavara under submerged situation during 2007 and 2008

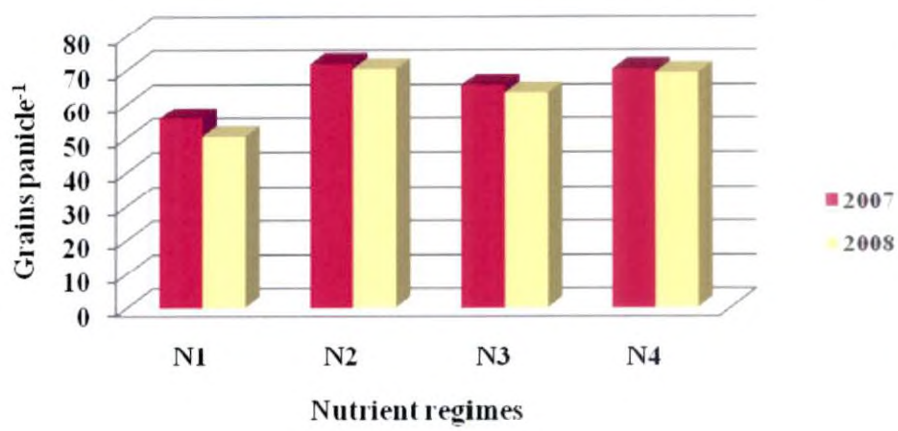
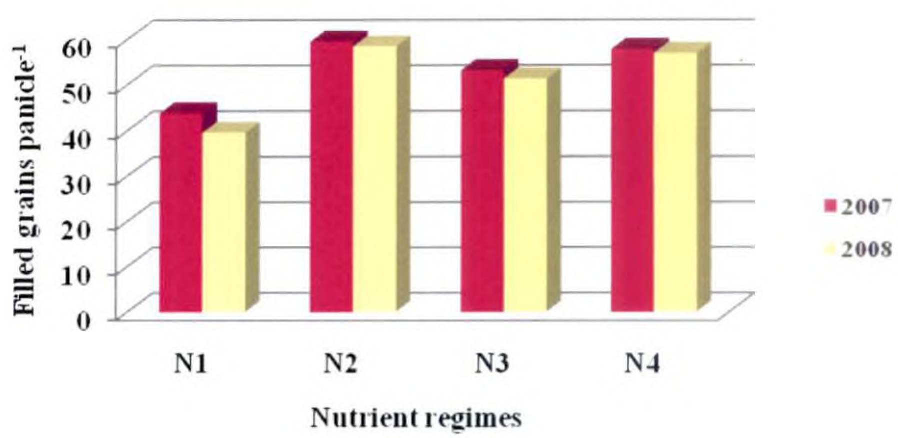


Fig. 7. Effect of nutrient regimes on filled grains panicle^{-1} of Njavara under submerged situation during 2007 and 2008



Njavara did not respond to application of nitrogen above 30 kg N ha^{-1}. Njavara is a land race with all the characteristics of traditional indica rice which are non responsive to fertilizers (Tanaka *et al.*, 1964). No response in grain yield was obtained by the application of 40:40:40 kg NPK ha^{-1}. Though some growth and yield attributes were higher at this nutrient regime, no significant difference was observed in thousand grain weight. Thousand grain weight is an index of post flowering photosynthetic efficiency as well as translocation. The failure of higher regime of nutrients to increase grain yield may be due to its failure in effective translocation to the grain in the post panicle initiation stage. Meera Menon (1996) also obtained higher grain yield at 30 kg N ha^{-1} and increasing the regimes of nitrogen above 30 kg did not increase grain yield significantly. Maximum straw yield was obtained at 30:30:30 kg NPK ha^{-1}. Application of 30:30:30 kg NPK ha^{-1} resulted in better plant height, number of tillers m^{-2}, leaf number $plant^{-1}$ and culm strength. All these resulted in higher straw yield under this nutrient regime.

During saturated situation also the same trend was observed. Application of 30:30:30 kg NPK ha^{-1} recorded maximum grain yield of 2.72 t ha^{-1} and 2.60 t ha^{-1} under saturated situation during 2007 and 2008 respectively, which was significantly superior to 30:15:15, 40:20:20 kg NPK ha^{-1} and was on par with 40:40:40 kg NPK ha^{-1} (Fig. 8). Same trend was observed for straw yield also (Fig. 9). The number of productive tillers m^{-2} obtained at 30:30:30 kg NPK ha^{-1} was 32 and 10 percentage more than that of 30:15:15 and 40:20:20 kg NPK ha^{-1}. The corresponding increase in grains $panicle^{-1}$ was 34 and 11 percentage and that of filled grains $panicle^{-1}$ was 41 and 13 percentage under saturated situation (Fig. 10, 11 and 12). Same trend was observed during 2008 also. So, this indicated that nutrient interaction and pattern of uptake were similar in both moisture regimes.

Dry matter accumulation was also the highest at N_2 regime. Increase in DMP due to incremental levels of N was noticed upto 60 kg N ha^{-1} by

Fig. 8. Effect of nutrient regimes on grain yield of Njavara under saturated situation during 2007 and 2008

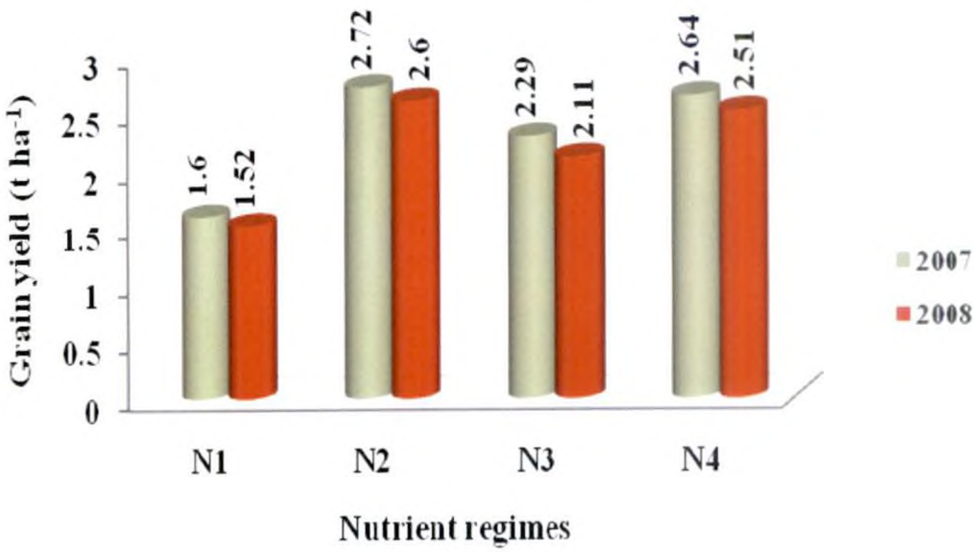


Fig. 9. Effect of nutrient regimes on straw yield of Njavara under saturated situation during 2007 and 2008

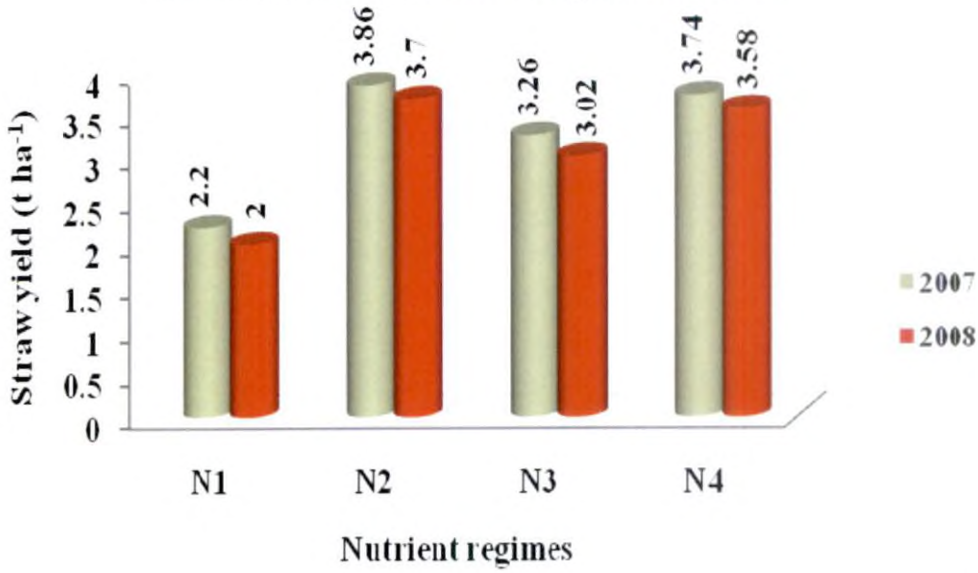


Fig. 10. Effect of nutrient regimes on productive tillers m^{-2} of Njavara under saturated situation during 2007 and 2008

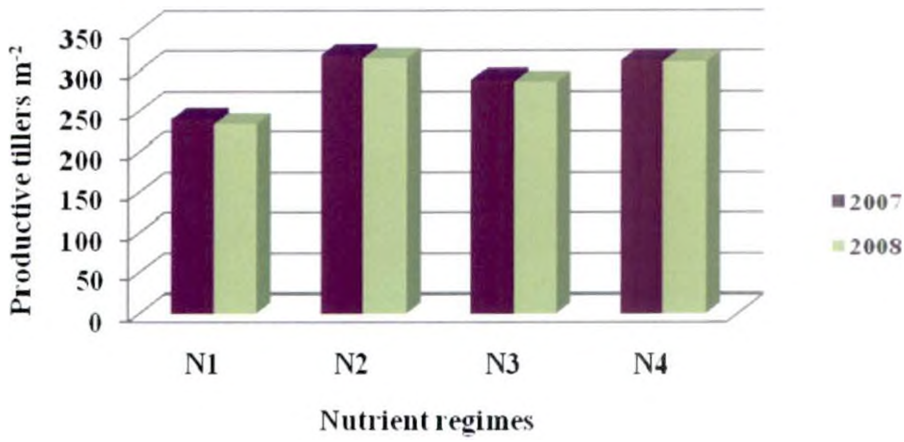


Fig. 11. Effect of nutrient regimes on grains $panicle^{-1}$ of Njavara under saturated situation during 2007 and 2008

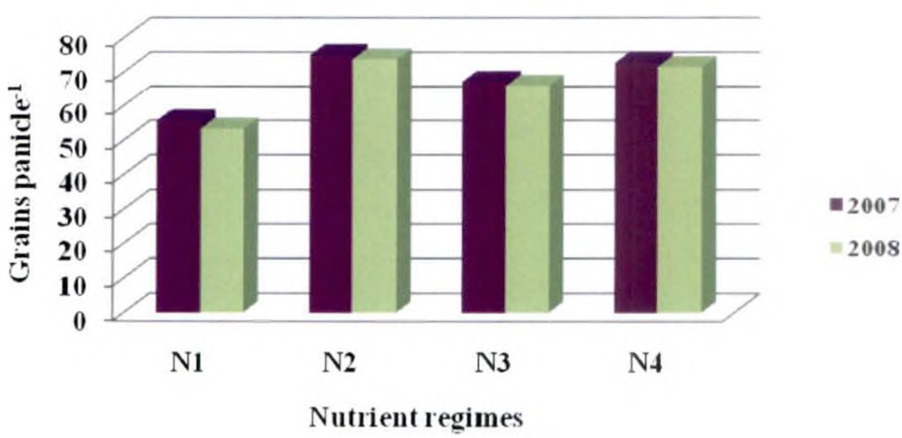
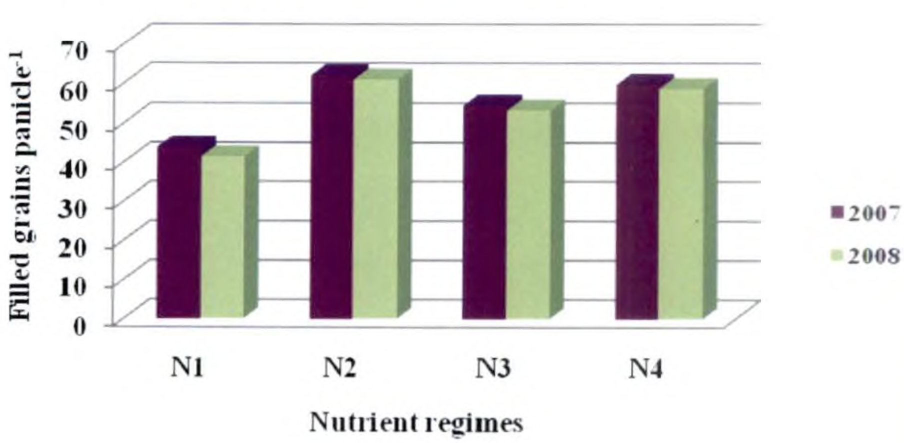


Fig. 12. Effect of nutrient regimes on filled grains $panicle^{-1}$ of Njavara under saturated situation during 2007 and 2008



Thomas (2000). Lack of response to higher regimes of nutrients may be due to better nutrient status of soil. The soil was medium in nitrogen whereas phosphorus and potassium was high. In general, nutrient uptake was related to the crop yield regimes. As the dry matter accumulation increased, nutrient uptake was also observed to increase. This is in accordance with the findings of Fageria and Baligar (2005) who have stated that nutrient accumulation pattern in plants followed dry matter accumulation.

Observation on yield attributes show that all yield attributes were significantly lower at NPK ratio of 2:1:1 compared to 1:1:1. Njavara being a tall variety, lodging is a major problem. So, adequate quantity of P and K is essential for imparting culm strength. The data presented in the Tables 3, 4, 36 and 37 shows favourable influence of 1:1:1 ratio on culm strength. Adequate quantity of P and K increased culm strength (Tisdale *et al.*, 1995). All growth and yield parameters were higher under 1:1:1 ratio. Result of this study shows that 1:1:1 is the ideal nutrient ratio for Njavara rice variety.

5.2. Grain quality and nutrient uptake of Njavara as influenced by nutrient regimes under two moisture regimes

Significant difference was observed only in total amino acid and protein content of grain with increased application of nutrients. Increase in the content of total amino acid with increased regime of nutrients may be due to better availability of nitrogen. Total amino acid content increased from 0.47 mg 100 g^{-1} to 0.78 mg 100 g^{-1} under submerged situation during 2007 and from 0.46 mg 100 g^{-1} to 0.76 mg 100 g^{-1} during 2008. The corresponding values were 0.47 mg 100 g^{-1} to 0.77 mg 100 g^{-1} in 2007 and 0.39 mg 100 g^{-1} to 0.70 mg 100 g^{-1} in 2008 under saturated situation. An increase in protein content was observed with increase in nutrient regime. Singh and Modgal (1978) opined that protein content of rice grain increased due to the increase in N level. Protein being the polymer of amino acid, increased level of amino acid might have increased the protein content. Sikka *et al.* (1993) found that with increasing doses of nitrogen fertilizer, there was an increase in protein content. Thomas (2000) reported maximum protein content at 60:30: 45 kg NPK ha^{-1}.

In general, increased application of N, P and K increased the uptake of respective nutrients. This is due to better availability of nutrients at higher regimes. The same trend was observed in both years. Lowest uptake of 40.75 kg N ha^{-1}, 20.16 kg P ha^{-1} and 74.67 kg K ha^{-1} was observed at 30:15:15 kg NPK ha^{-1} under submerged situation. Maximum uptake of 80.58 kg N ha^{-1}, 30.51 kg P ha^{-1} and 97.90 kg K ha^{-1} was observed at 30:30:30 kg NPK ha^{-1} under submerged situation. Uptake of N, P and K by rice increased significantly with increased application of nitrogen (Pandey *et al.*, 1991). Increasing the regime from 30:30:30 to 40:20:20 and 40:40:40 kg NPK ha^{-1} did not increase the uptake. This again shows the lack of response to higher regime of nutrients. Under saturated situation lowest uptake of nitrogen, phosphorus and potassium (37.79 kg N ha^{-1}, 16.01 kg P ha^{-1} and 65.42 kg K ha^{-1}) was observed at lowest nutrient regime of 30:15:15 kg NPK ha^{-1}. Maximum uptake of nitrogen, phosphorus and potassium (77.92 kg N ha^{-1}, 27.90 kg P ha^{-1} and 93.70 kg K ha^{-1}) was observed at N_2 regime. No significant difference was observed in the uptake of secondary and micronutrients under submerged and saturated situations.

5.3. Soil physical, chemical and biological properties as influenced by nutrient regimes under two moisture regimes

Nutrient regimes fail to influence bulk density, pH and CEC. In general an increase in available nitrogen, available phosphorus and available potassium was observed with increase in application of respective nutrients. When the regime was increased from 30:15:15 to 30:30:30 kg NPK ha^{-1} available nitrogen increased by 27 per cent, available phosphorus increased by 62 per cent and available potassium increased by 36 per cent, under submerged situation during 2007. Same trend was observed in 2008. Under saturated situation also available nutrient status was higher under N_2 regime.

Reduction in available nitrogen at 40:20:20 kg NPK ha^{-1} may be due to increased nutrient loss due to increased bacterial population observed under increased regime of nutrient application (Tables 32 and 65). In general, an increase in urease activity was observed. This shows increased transformation of nitrogen. Same trend was observed in saturated situation also.

Significant difference was observed only in bacterial population while no significant difference was observed in fungal and actinomycetes population. In general an increase in bacterial population was observed with increased application of nutrients. More or less same trend was observed under submerged and saturated moisture regimes. Elevated CO_2 concentration significantly increased the microbial biomass when nitrogen was in sufficient supply (Li Zong *et al.*, 2004).

5.4. Growth and productivity of Njavara as influenced by nutrient sources under two moisture regimes

The investigation was conducted to assess the effect of two systems of nutrient management *viz.*, organic and integrated on the growth and productivity of direct sown Njavara during summer seasons of 2007 and 2008. Organic nutrient schedule comprised of combination of farmyard manure, neem cake, rock phosphate and wood ash to supply four nutrient regimes 30:15:15, 30:30:30, 40:20:20, 40:40:40 kg NPK ha^{-1}. Entire quantity of manures was applied as basal. In integrated nutrient management system, 5 t FYM ha^{-1} was applied as basal, 50 per cent NPK was applied as organic and 50 per cent NPK was applied as chemical fertilisers (urea, rock phosphate and muriate of potash) to supply four nutrient regimes 30:15:15, 30:30:30, 40:20:20, 40:40:40 kg NPK ha^{-1} .

The results of the trial indicated that integrated nutrient management recorded significant increase in plant height, LAI, leaf number $plant^{-1}$, tiller number, culm strength and flag leaf area under submerged condition. This favourable influence on growth attributes have significantly increased yield contributing characters like productive tillers m^{-2}, grains $panicle^{-1}$ and filled grains $panicle^{-1}$ (Fig. 13, 14, 15). Same trend was observed under saturated situation during both years (Fig. 16, 17, 18) Bastia (2002) also reported that number of grains $panicle^{-1}$ and number of filled grains $panicle^{-1}$ were maximum in integrated nutrient system.. All these cumulatively resulted in better dry matter production and thereby better grain and straw yields under integrated nutrient management system under both submerged and saturated situations. (Fig. 19 to 22)

Dwivedi and Thakur (2000) and Bastia (2002) reported higher grain yield in rice by integrated nutrient management. Panda *et al.* (2007) reported that higher grain yield was obtained in the NPK + FYM treatment and also concluded that balanced use of N, P and K fertilizers in conjunction with FYM was the best nutrient management option for obtaining higher and sustainable rice yield and for promoting soil health. This result is supported by the finding of Rani (2010) who reported that grain and straw yield in integrated nutrient source was significantly higher than that obtained under organic nutrition.

5.5. Grain quality and nutrient uptake of Njavara as influenced by nutrient source under two moisture regimes

Perusal of the data indicated a significant increase in nutrient uptake in integrated nutrient treatment compared to organic treatment. Under integrated nutrition uptake of nitrogen increased by 31 per cent, P uptake by 20 per cent and K uptake by 14 per cent on an average over two years under submerged situation and corresponding increase in N, P and K uptake under saturated situation were 33, 26 and 17 per cent respectively. Maximum nutrient uptake was in integrated nutrient sources under submerged and saturated situations. Better uptake of applied N was obtained through substitution of 50 per cent of N fertilizer with organic manures (Mallikarjuna *et al.*, 2004). Integrated use of organic and inorganic fertilizers led to increased NPK uptake in rice (Khanda *et al.*, 2005).

Fig. 13. Effect of nutrient sources on productive tillers m^{-2} of Njavara under submerged situation during 2007 and 2008

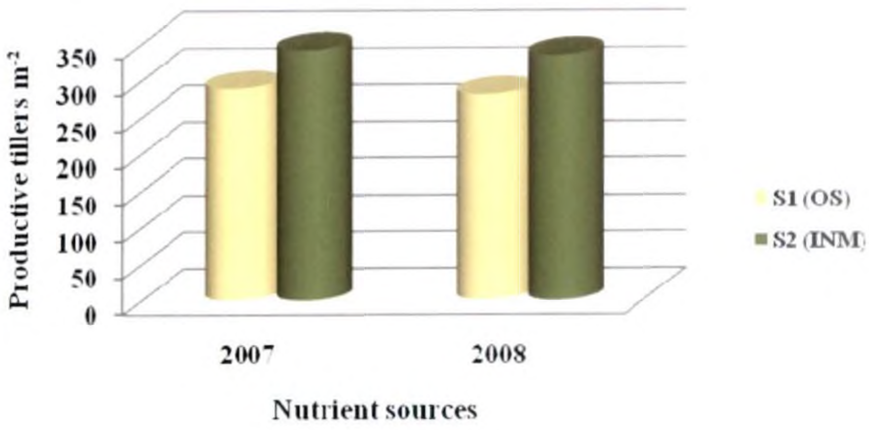


Fig. 14. Effect of nutrient sources on grains $panicle^{-1}$ of Njavara under submerged situation during 2007 and 2008

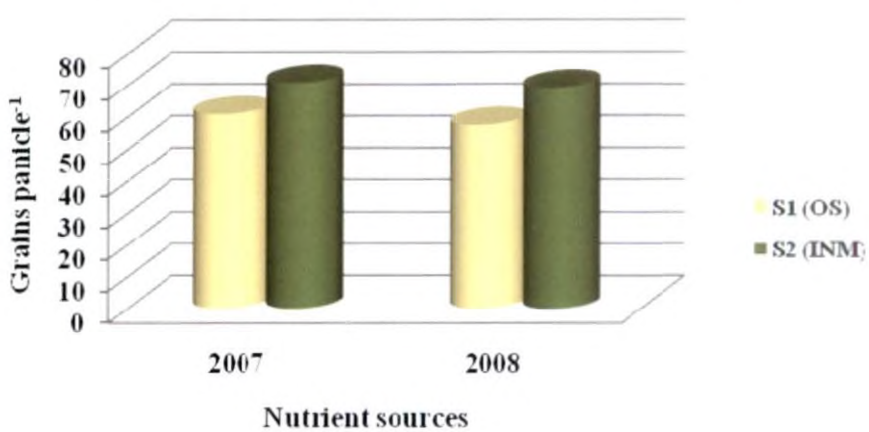


Fig. 15. Effect of nutrient sources on filled grains $panicle^{-1}$ of Njavara under submerged situation during 2007 and 2008

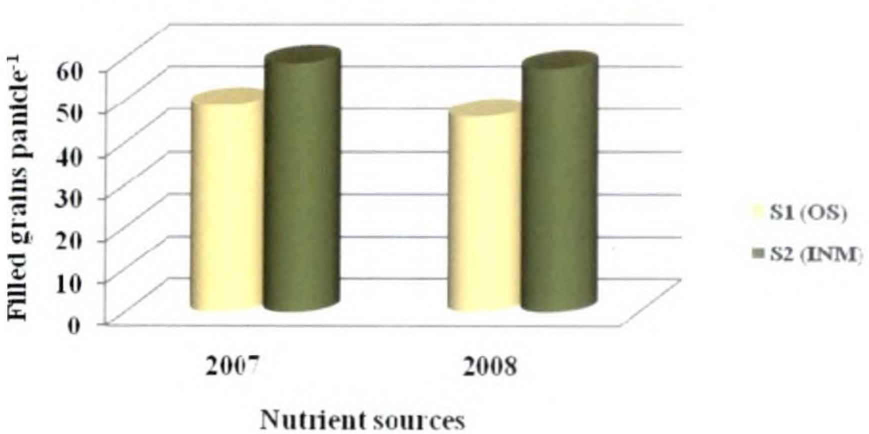


Fig. 16. Effect of nutrient sources on productive tillers m^{-2} of Njavara under saturated situation during 2007 and 2008

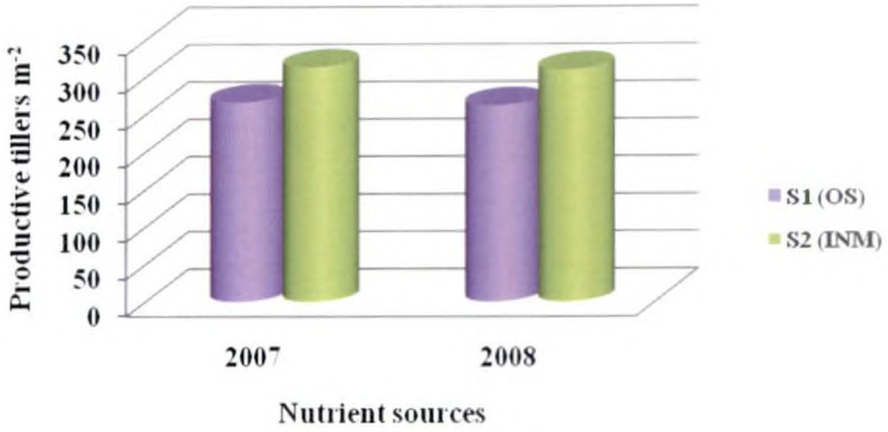


Fig. 17. Effect of nutrient sources on grains panicle^{-1} of Njavara under saturated situation during 2007 and 2008

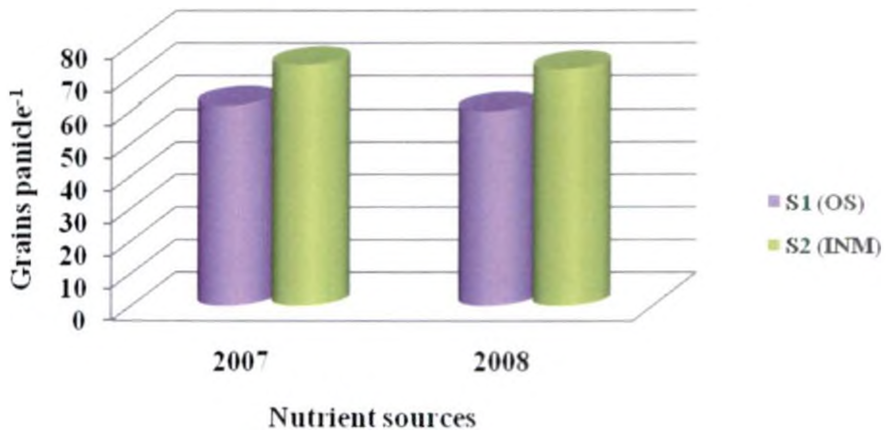


Fig. 18. Effect of nutrient sources on filled grains panicle^{-1} of Njavara under saturated situation during 2007 and 2008

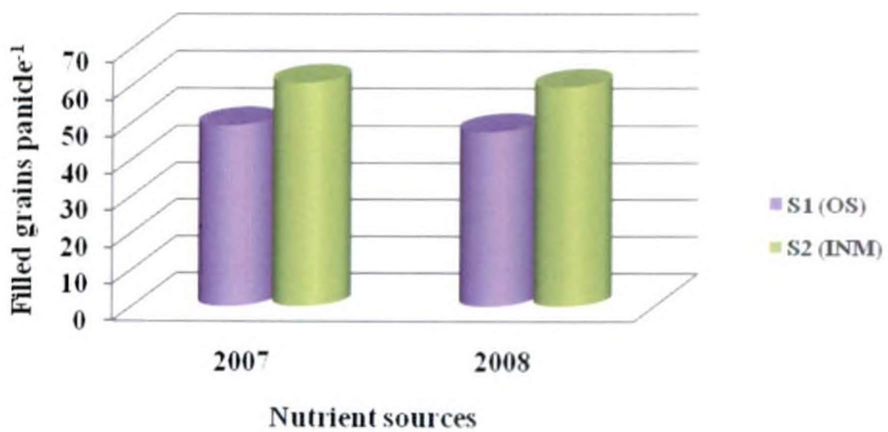


Fig. 19. Effect of nutrient sources on grain yield of Njavara under submerged situation during 2007 and 2008

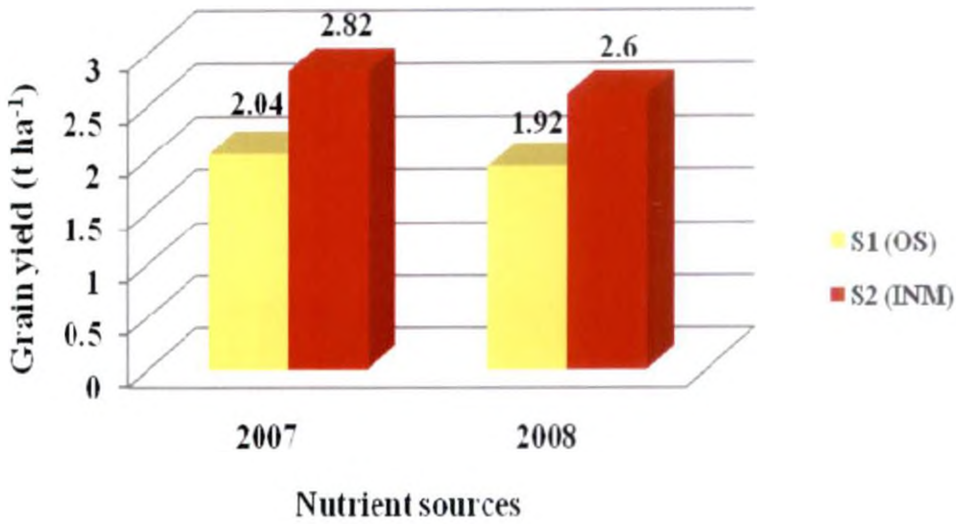


Fig. 20. Effect of nutrient sources on straw yield of Njavara under submerged situation during 2007 and 2008

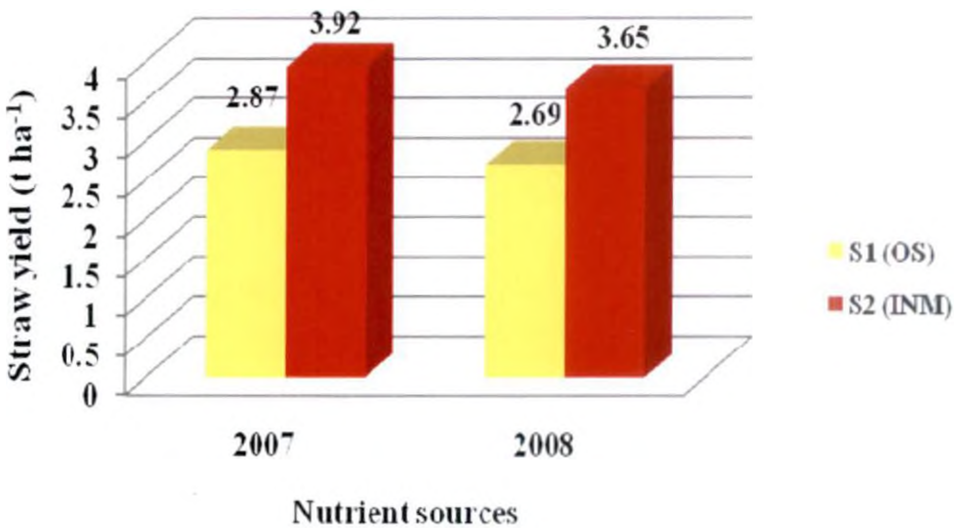


Fig. 21. Effect of nutrient sources on grain yield of Njavara under saturated situation during 2007 and 2008

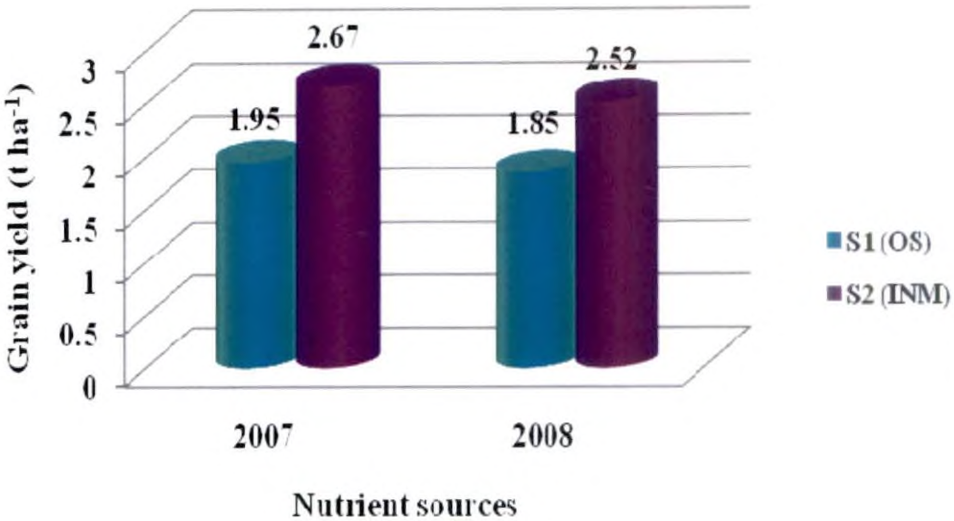
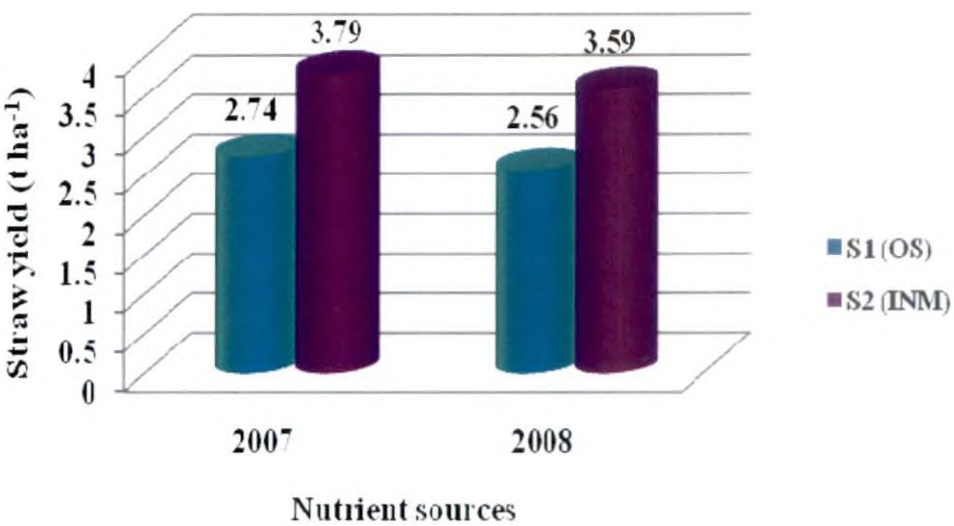


Fig. 22. Effect of nutrient sources on straw yield of Njavara under saturated situation during 2007 and 2008



Uptake being a function of nutrient content and dry matter production, higher level of dry matter production in integrated treatments must have resulted in higher nutrient uptake. Dry matter production increased by 18 per cent in first year and 17 per cent in second year in integrated nutrient management system under submerged situation. Same trend was observed under saturated moisture regime. Grain quality was not influenced by nutrient sources. Veenapal and Pandey (2000) could not observe any definite trend in the rice quality with the application of different sources of nutrients.

5.6. Soil physical, chemical and biological properties as influenced by nutrient sources under two moisture regimes

Nutrient sources did not influence bulk density, pH and CEC of the soil whereas available N, P, and K status was higher under integrated nutrient management system. Significant reduction in available nutrient status was observed in organic treated plots. This may be due to the slow mineralization that occurred under organic nutrition. One of the nutrient sources used is FYM and it is reported that only one-third of nitrogen, two-third of phosphorus and most of the potash is available for the first crop (Yawalkar *et al.*, 1977).

Jha *et al.* (2004) reported that application of NPK + FYM registered higher content of available N, available P and available K in soil. Integrated nutrient management is one of the best methods for improving soil fertility under rice-wheat cropping system (Sharma and Sharma, 2004). FYM used alone or in combination with chemical fertilizers improved the available N and P status of soil (Chettri and Mondal, 2005). No significant difference was observed in organic carbon, secondary and micro nutrient status between the organic and integrated nutrient management treatments.

Regarding the microbial properties, fungal and actinomycetes populations were not influenced by the nature of nutrient source whereas an increase in bacterial population was observed in organic treatments (Fig. 23 and 24). This may be because of the higher availability of substrate favourable for bacterial activity in organic treatments. Urease activity was also higher in organic treatments (Fig. 25 and 26). Similar result was reported by Reddy (2002). Higher organic matter in soil stimulates ureolytic microorganisms by serving as source of carbon, energy and other nutrients essential for microbial growth.

5.7. Relative performance of Njavara under two moisture regimes

Grain yield of Njavara under submerged situation was 2.35 t ha^{-1} which was 4 per cent higher than that obtained under saturated situation (2.25 t ha^{-1}). Straw yield of Njavara under submerged situation was 3.28 t ha^{-1} which was 3 per cent higher than that obtained under saturated situation (3.17 t ha^{-1}) (Fig. 27 and 28). This result is supported by the finding of Tabbal *et al.* (2002). They reported that keeping the soil continuously around saturation reduced rice yields by 7 per cent compared to standing water for the transplanted dry season rice. However, yield reduction was relatively small. Thus rice responds well to different water management practices. This better performance under submerged situation is mainly due to more number of productive tillers. On an average under submerged situation productive tillers m^{-2} was 8 per cent higher than that produced under saturated situation. N, P and K uptake also was higher under submerged situation compared to saturated situation. Nutrient content in rice grown under submerged condition was found to be higher than cyclic wetting and drying conditions (Biswas and Mahapatra, 1980). Panda *et al.* (1997) confirmed that potassium uptake was higher, when the crop was kept under submergence at tillering and reproductive stages compared to irrigation one day after disappearance of water.

Compared to saturated situation weed growth was less under submerged situation (Fig. 29 and 30). That must have resulted in less crop-weed competition which must have resulted in better nutrient uptake by the

Fig. 23. Effect of nutrient sources on bacterial population of soil under submerged situation during 2007 and 2008

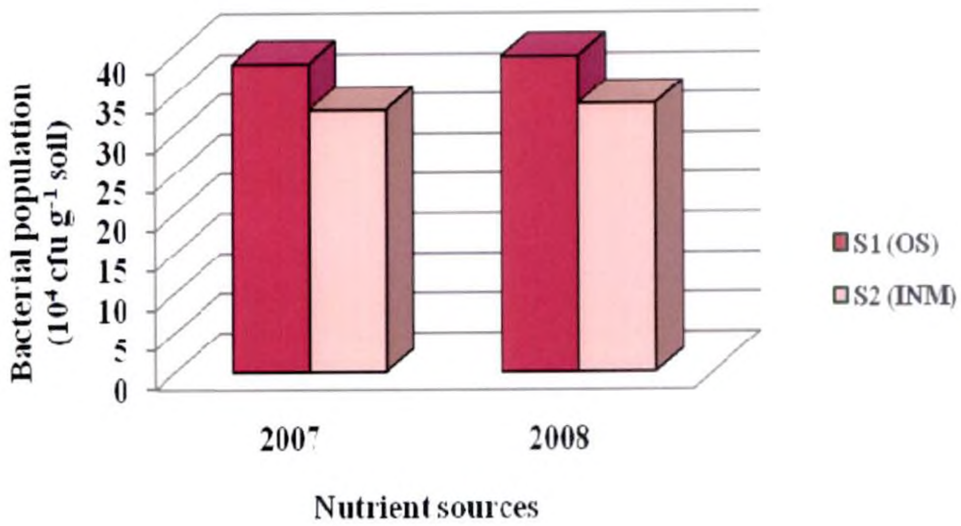


Fig. 24. Effect of nutrient sources on bacterial population of soil under saturated situation during 2007 and 2008

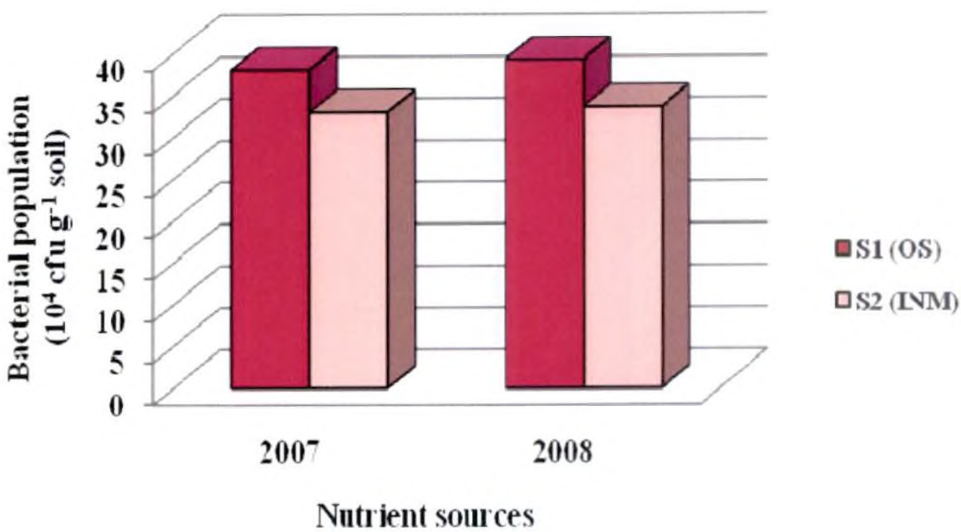


Fig. 25. Effect of nutrient sources on urease activity of soil under submerged situation during 2007 and 2008

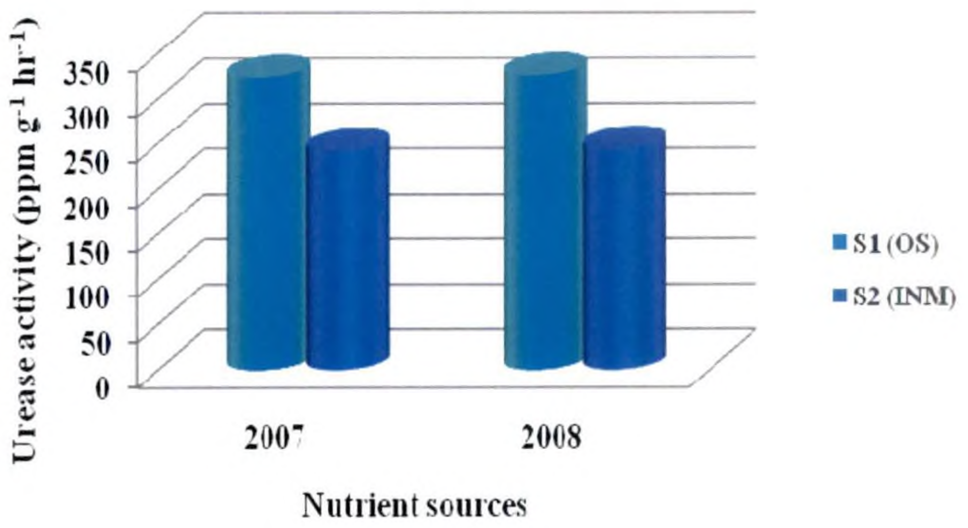


Fig. 26. Effect of nutrient sources on urease activity of soil under saturated situation during 2007 and 2008

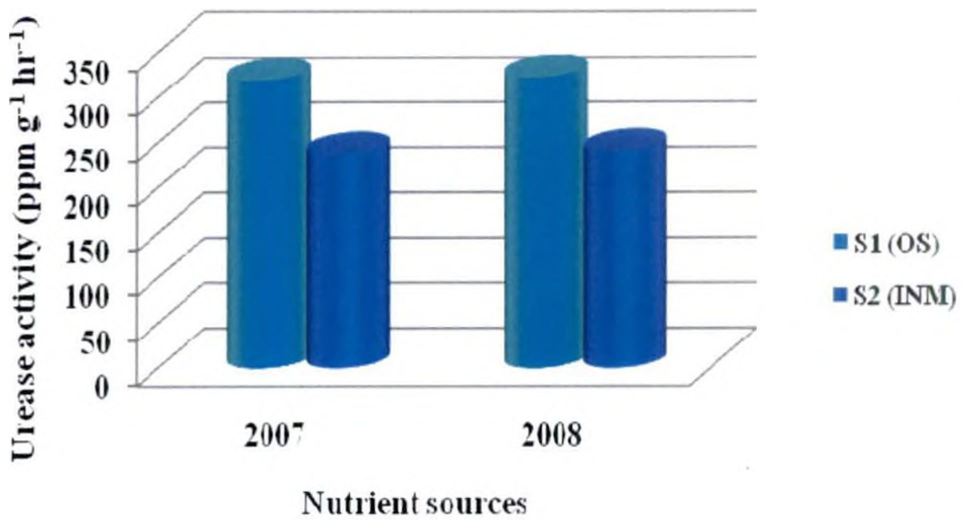


Fig. 27. Grain yield of Njavara under two moisture regimes (Pooled data)

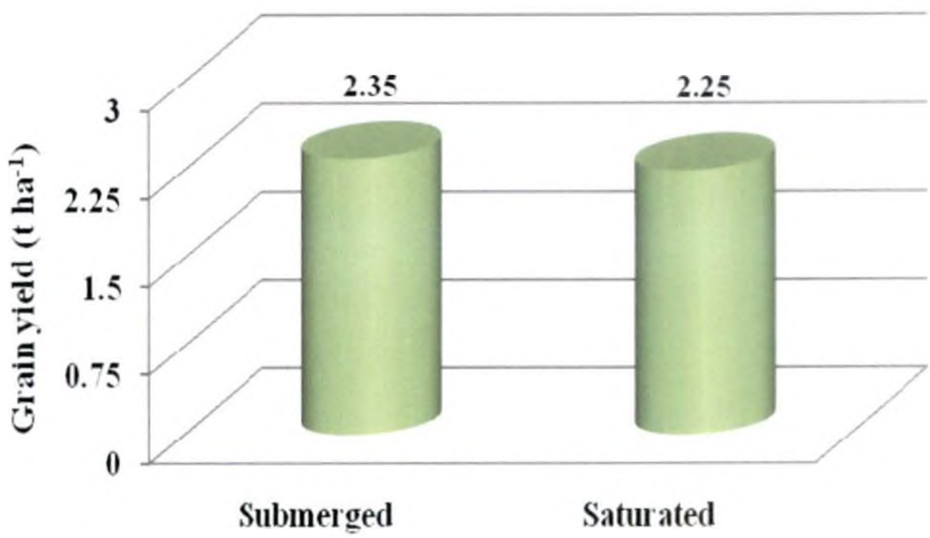


Fig. 28. Straw yield of Njavara under two moisture regimes (Pooled data)

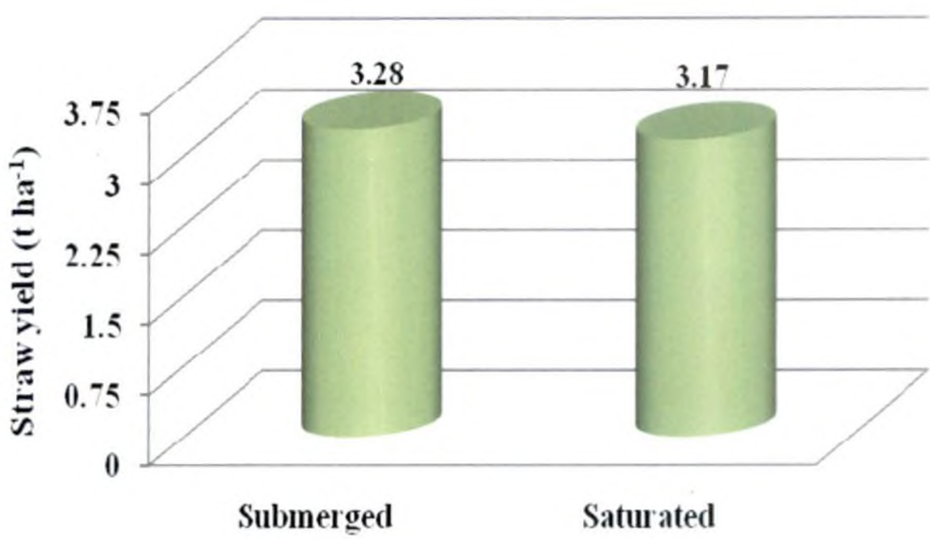


Fig. 29. Weed biomass as influenced by two moisture regimes during 2007

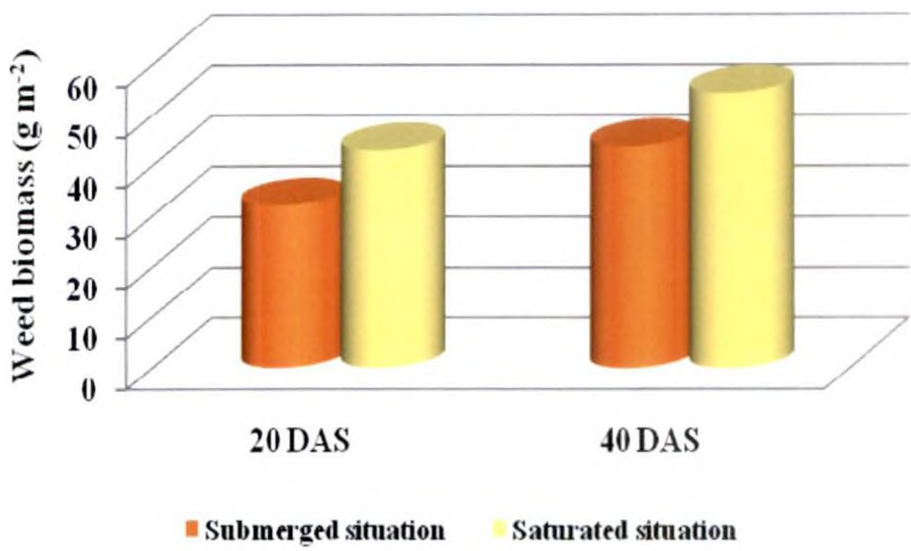
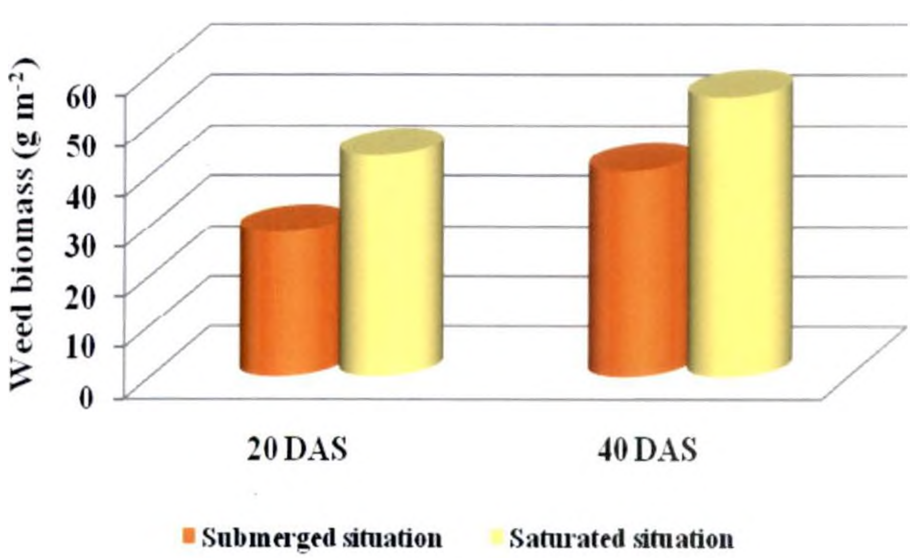


Fig. 30. Weed biomass as influenced by two moisture regimes during 2008



crop. Absence of standing water created a favourable condition for weed growth. Higher weed growth and lower nutrient uptake under saturated situation resulted in lower productivity compared to submerged situation. Similar results were reported by Moturi (1977) who found that weed density and dry weight were higher under saturated conditions than under submergence. Ahmed and Moody (1982) reported that the composition and growth of rice weed communities were strongly influenced by water management practices.

5.8. Interaction between nutrient regimes and nutrient sources on growth and productivity of Njavara under two moisture regimes

Under both nutrient sources, N_2 was on par with N_4 and was superior to other regimes. Under submerged situation, N_2S_2 recorded a mean grain yield of 3.32 t $ha^{-1}$and N_4S_1 recorded a mean grain yield of 2.35 t ha^{-1} (Fig. 31). Under saturated situation N_2S_2 recorded a mean grain yield of 3.18 t ha^{-1} and N_4S_1 recorded a mean grain yield of 2.25 t ha^{-1} (Fig. 33). N_2S_2 recorded a mean straw yield of 4.60 t ha^{-1} and 4.48 t ha^{-1} under submerged and saturated situations respectively (Fig. 32 and 34). All growth and yield attributes were higher at N_2 and N_4 compared to N_3 and N_1 under both nutrient sources. All these might have resulted in better performance of Njavara under N_2S_2, N_4S_2, N_4S_1 and N_2S_1 under both moisture regimes (Plate 3).

5.9. Comparative performance of Njavara under POP of KAU recommendation and best economic treatment (N_2S_2)

Under submerged situation, N_2S_2 registered a grain yield of 3.41 t ha^{-1} and 3.23 t ha^{-1} (2007 and 2008) which was 54 and 56 per cent higher than the yield obtained from POP of KAU for local variety which registered a grain yield of 1.58 t ha^{-1} in 2007 and 1.41 t ha^{-1} in 2008. Same trend was seen in straw yield also (Fig. 35 and 36). Better performance of N_2S_2 over POP of KAU is due to more favourable effect on almost all growth and yield attributes. N_2S_2 registered 44 per cent increase in LAI, 32 per cent increase

Fig. 31. Grain yield of Njavara as influenced by nutrient sources under different nutrient regimes in submerged situation (Pooled data)

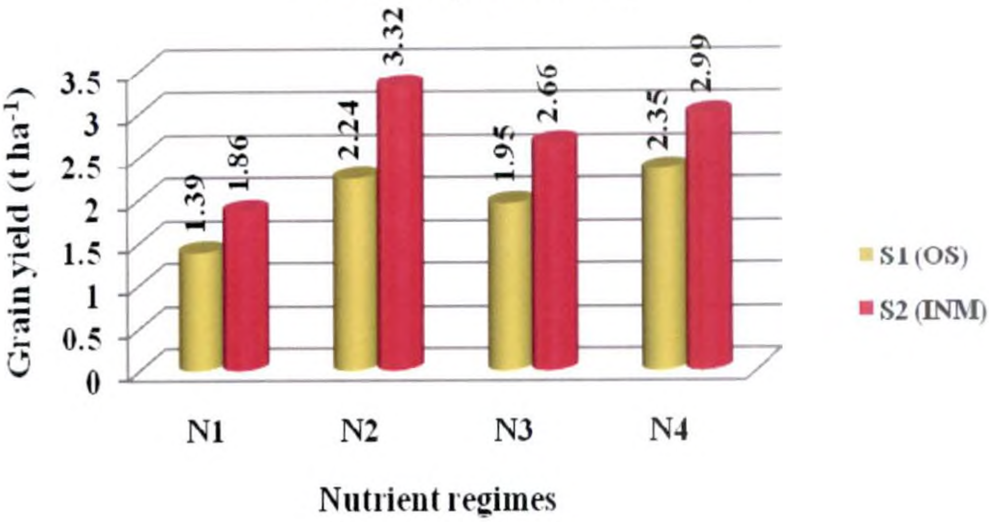


Fig. 32. Straw yield of Njavara as influenced by nutrient sources under different nutrient regimes in submerged situation (Pooled data)

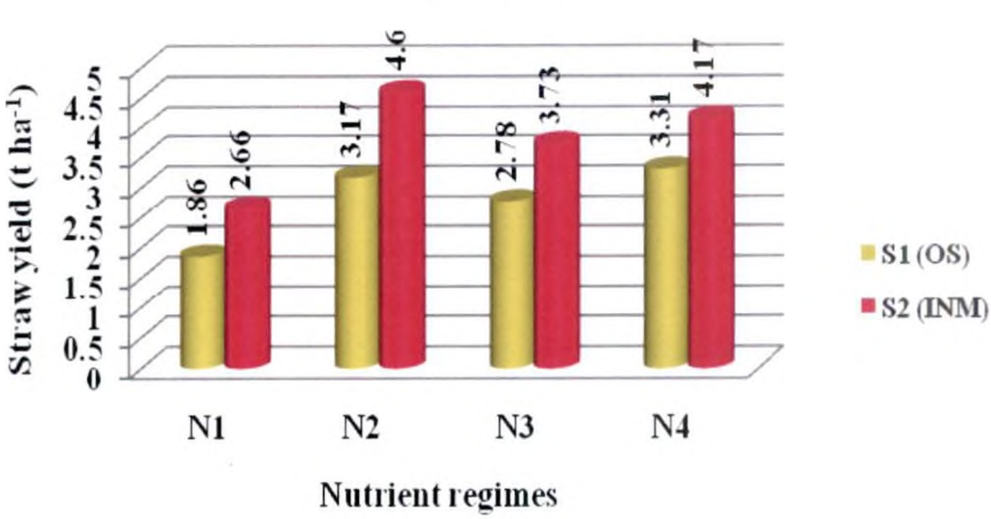


Fig. 33. Grain yield of Njavara as influenced by nutrient sources under different nutrient regimes in saturated situation (Pooled data)

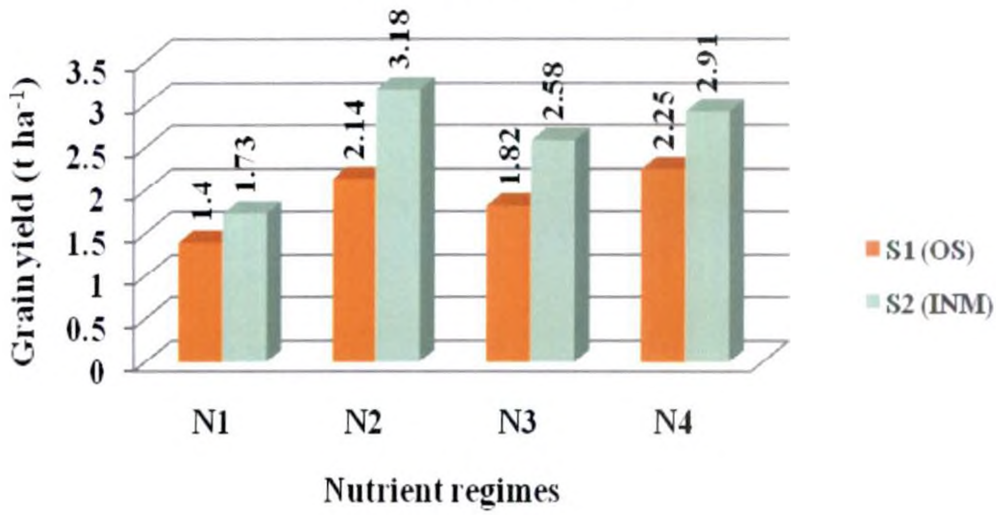


Fig. 34. Straw yield of Njavara as influenced by nutrient sources under different nutrient regimes in saturated situation (Pooled data)

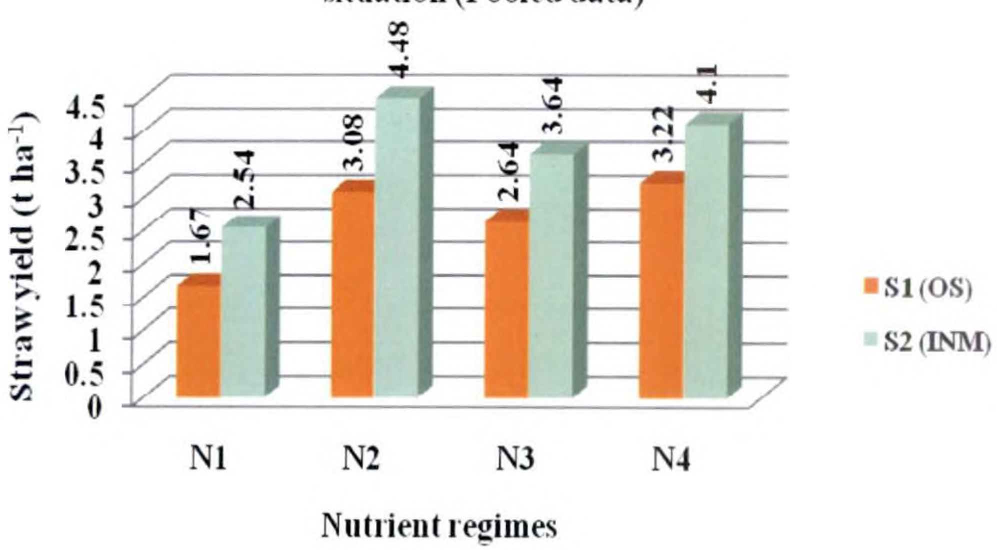


PLATE - 3

Performance of Njavara as influenced by nutrient sources under different nutrient regimes in submerged and saturated situations

Submerged situation

N_2S_2 - FYM @ 5 t ha^{-1} + 30:30:30 kg NPK ha^{-1}
(50 % N as organic + 50 % N as chemical fertilizer)

N_4S_2 - FYM @ 5 t ha^{-1} + 40:40:40 kg NPK ha^{-1}
(50 % N as organic + 50 % N as chemical fertilizer)

N_1S_1 - FYM @ 5 t ha^{-1} + 30:15:15 kg NPK ha^{-1}
as organic source

Saturated situation

N_2S_2 - FYM @ 5 t ha^{-1} + 30:30:30 kg NPK ha^{-1}
(50 % N as organic + 50 % N as chemical fertilizer)

N_4S_2 - FYM @ 5 t ha^{-1} + 40:40:40 kg NPK ha^{-1}
(50 % N as organic + 50 % N as chemical fertilizer)

N_1S_1 - FYM @ 5 t ha^{-1} + 30:15:15 kg NPK ha^{-1}
as organic source

Fig. 35. Grain yield of Njavara under POP of KAU and N_2S_2 under submerged situation during 2007 and 2008

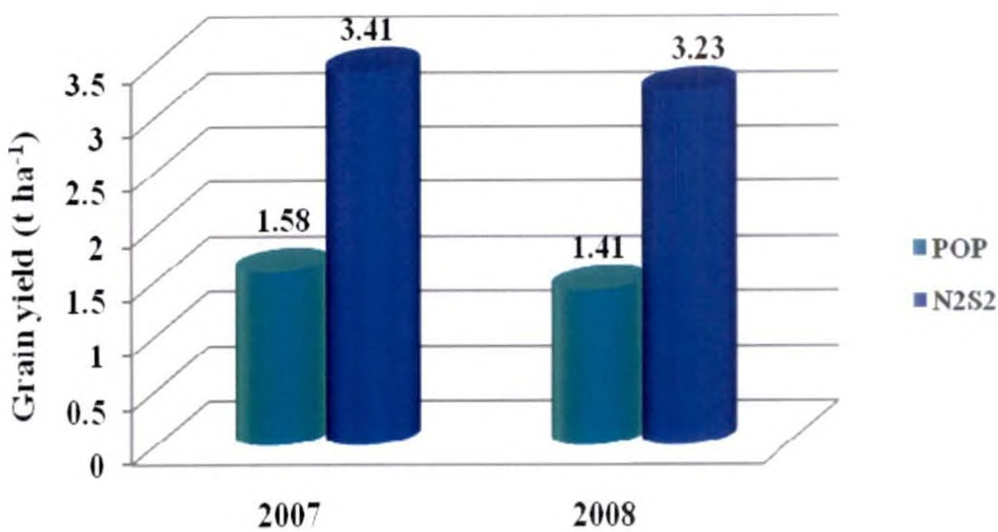


Fig. 36. Straw yield of Njavara under POP of KAU and N_2S_2 under submerged situation during 2007 and 2008

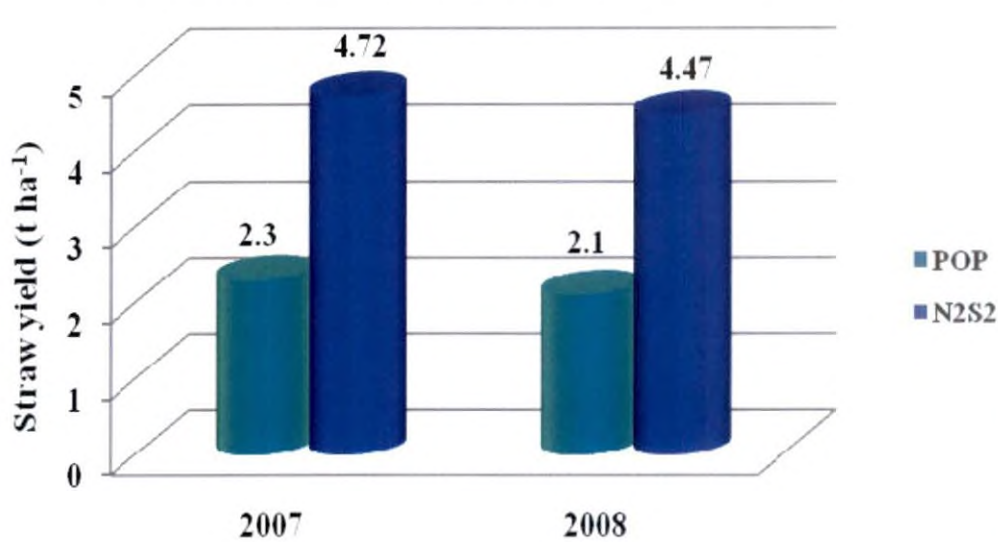


Fig. 37. Grain yield of Njavara under POP of KAU and N_2S_2 under saturated situation during 2007 and 2008

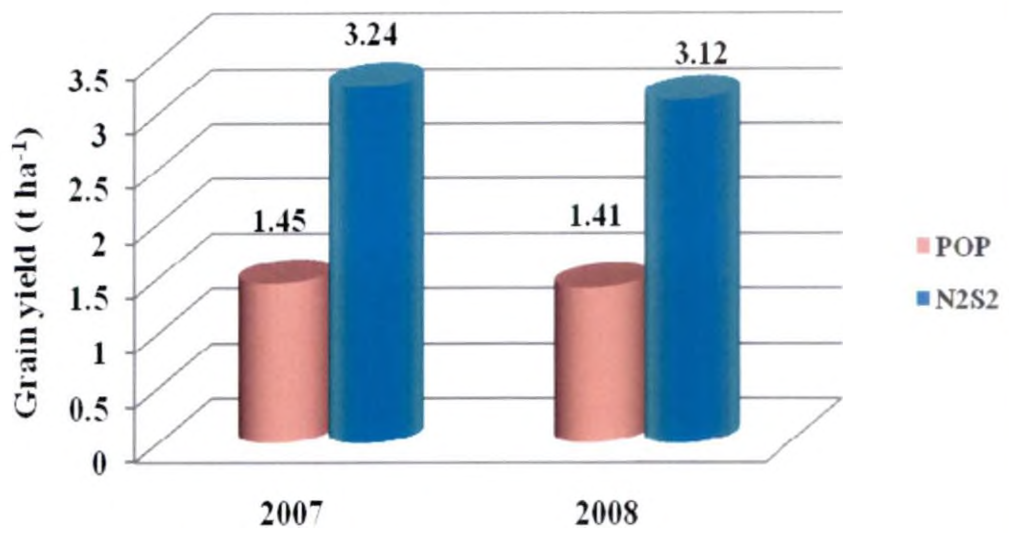
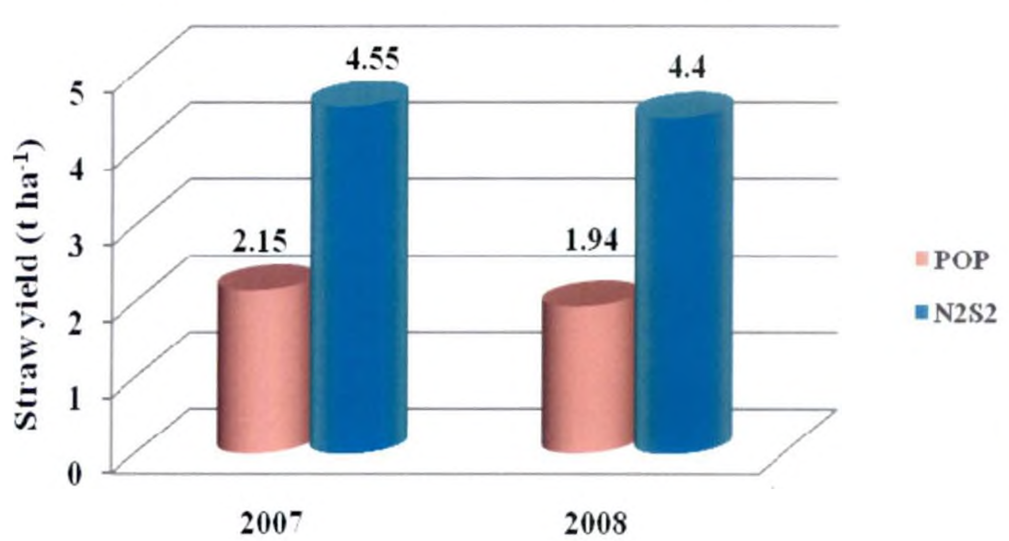


Fig. 38. Straw yield of Njavara under POP of KAU and N_2S_2 under saturated situation during 2007 and 2008



in productive tillers m^{-2} and 28 per cent increase in grains $panicle^{-1}$ in 2007. This better expression of growth and yield attributes resulted in better performance of N_2S_2 compared to POP of KAU. Greater availability of P and K from N_2S_2 also must have resulted in better growth and productivity of Njavara. During both the years same trend was observed in saturated situation (Fig. 37 and 38).

5.10. Economics of Njavara cultivation under two moisture regimes

The details of economics of Njavara cultivation under two moisture regimes is furnished in Appendix X. Application of 30:30:30 kg NPK ha^{-1} (N_2) recorded maximum gross income, net income and BCR. This nutrient regime registered a net income of Rs 41019 ha^{-1} and Rs 37556 ha^{-1} with a BCR of 2.02 and 1.93 under submerged and saturated situations respectively (Fig. 39 and 42). Two nutrient regimes N_2 and N_4 were on par with respect to productivity. But economically N_2 was superior to N_4 mainly due to low cost of cultivation resulted from application of lower level of nutrients. N_2 registered 3 per cent reduction in cost of cultivation that resulted in 11 and 10 percentage increase in net income under submerged and saturated situations respectively.

Maximum net returns was obtained under integrated nutrition. Net income obtained under integrated nutrition was Rs 39451 ha^{-1} and Rs 36241 ha^{-1} and it was 58 and 60 percentage higher than organic nutrition under submerged and saturated situations respectively (Fig. 40 and 43). Better economic viability of integrated nutrition is attributed to better productivity, lesser cost of inputs and less cost of cultivation compared to organic nutrition. This result is supported by the findings of (Roul and Mahapatra, 2006). Barik *et al.* (2006) observed higher net income and BCR when 50 per cent of the recommended dose of fertilizers was substituted with FYM.

Among treatment combinations, maximum net profit of Rs 57586 ha^{-1} and Rs 53546 ha^{-1} and BCR of 2.44 and 2.34 were obtained at N_2S_2 (FYM @

5 t ha^{-1} + 30:30:30 kg NPK ha^{-1}); N_4S_2 resulted in a net profit of Rs 46837 ha^{-1} and Rs 44397 ha^{-1} and BCR of 2.15 and 2.09 under submerged and saturated situations respectively (Fig. 41 and 44). Low cost of cultivation and high productivity resulted in maximum returns for N_2S_2. Under organic nutrition maximum net profit and BCR was obtained at N_4S_1. This is due to greater grain and straw yield obtained under N_4S_1. N_2S_1 was the second best treatment.

Fig. 39. Effect of nutrient regimes on net income of Njavara cultivation under submerged situation (Pooled data)

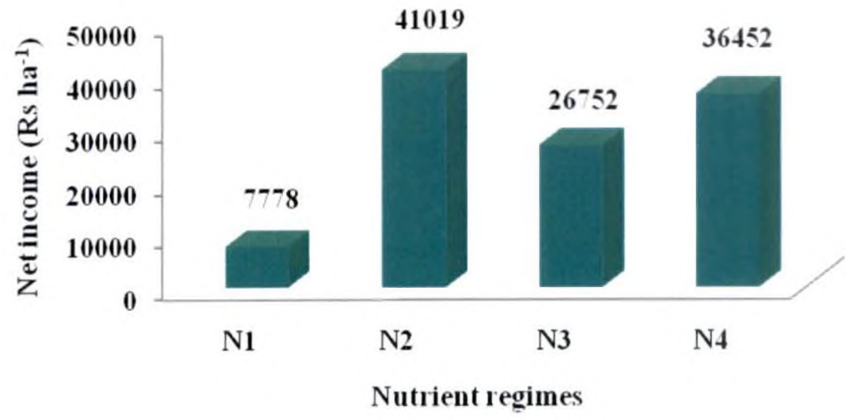


Fig. 40. Effect of nutrient sources on net income of Njavara cultivation under submerged situation (Pooled data)

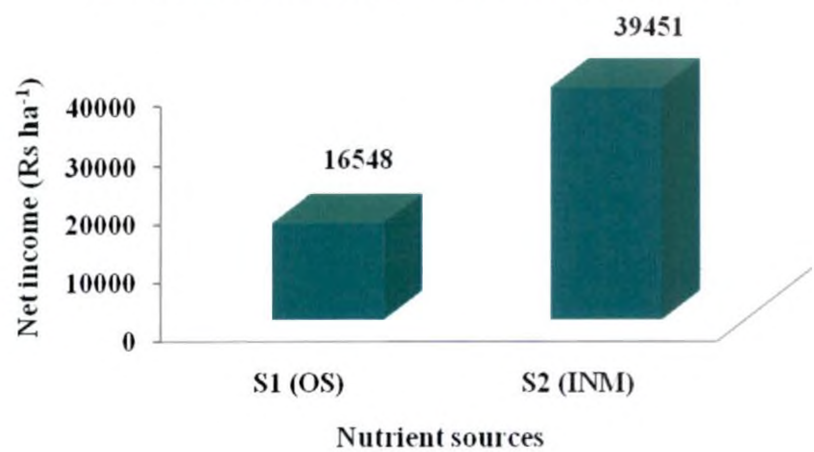


Fig. 41. Interaction effect of nutrient regimes and nutrient sources on net income of Njavara cultivation under submerged situation (Pooled data)

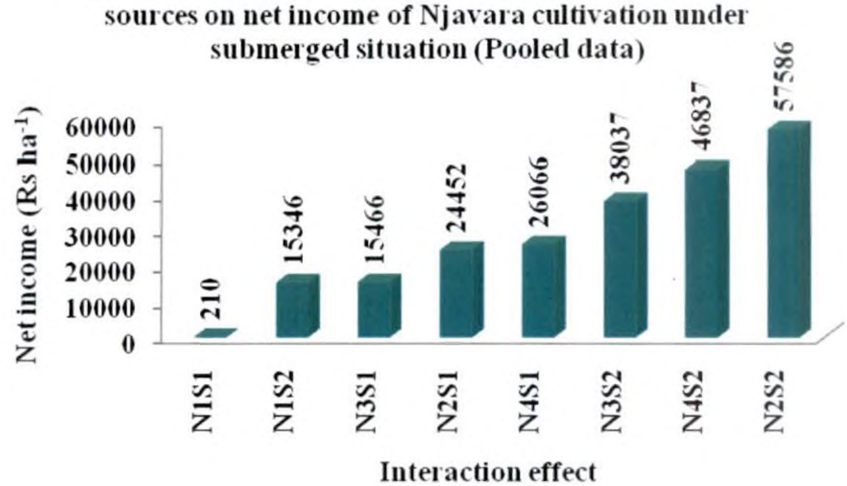


Fig. 42. Effect of nutrient regimes on net income of Njavara cultivation under saturated situation (Pooled data)

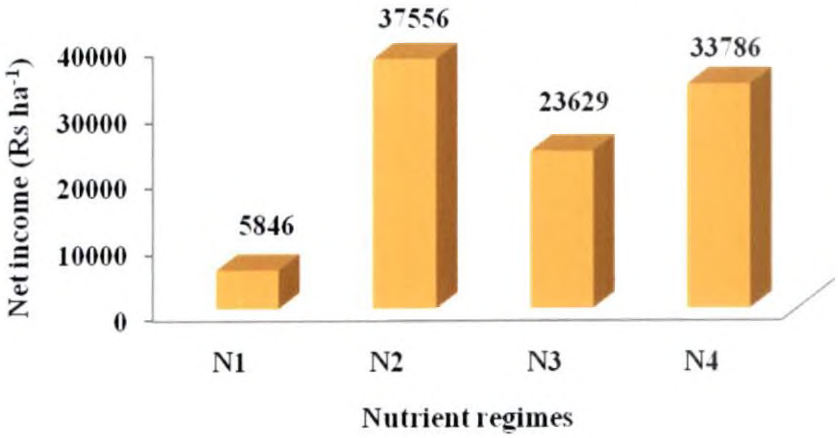


Fig. 43. Effect of nutrient sources on net income of Njavara cultivation under saturated situation (Pooled data)

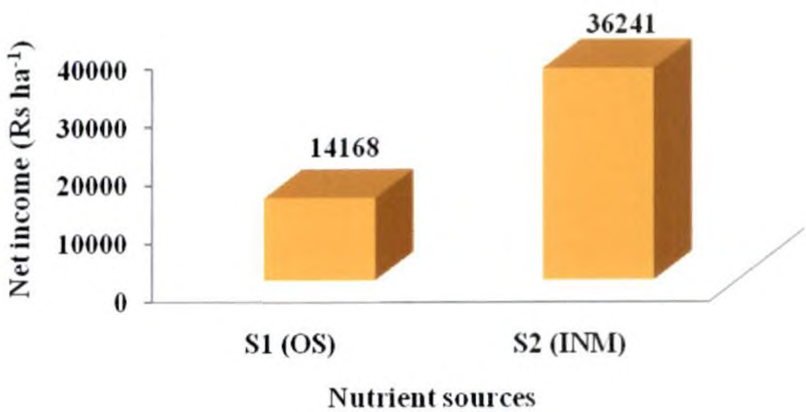
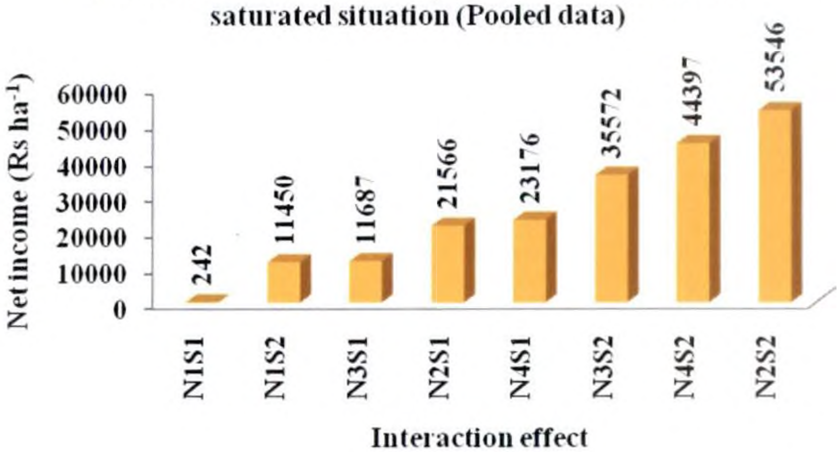


Fig. 44. Interaction effect of nutrient regimes and nutrient sources on net income of Njavara cultivation under saturated situation (Pooled data)



SUMMARY

SUMMARY

The investigation entitled "Input optimization for medicinal rice (*Oryza sativa L.*) cv. Njavara" was conducted at Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, during the summer seasons of 2007 and 2008 (January to April) to standardize an ideal nutrient schedule under two moisture regimes for sustaining Njavara production in lowlands, to investigate the soil physical, chemical and biological properties as influenced by regimes and sources of nutrients and to work out the economics of Njavara cultivation. Both the experiments (submerged and saturated situations) were laid out in randomised block design with ten treatments each and three replications. The treatments comprised four nutrient regimes *viz.*, N_1 - 30:15:15, N_2 - 30:30:30, N_3 - 40:20:20 and N_4 - 40:40:40 kg NPK ha^{-1}, two nutrient sources *viz.*, organic nutrient source (S_1)and integrated nutrient source (S_2) and two controls *viz.*, absolute control (no nutrient was applied) (C_1) and POP for local rice variety (C_2).

Growth components like plant height, leaf number $plant^{-1}$, leaf area index (LAI), number of tillers m^{-2}, culm strength and flag leaf area, yield and yield attributes like number of productive tillers m^{-2}, panicle length, number of grains $panicle^{-1}$, number of filled grains $panicle^{-1}$, 1000 grain weight, harvest index, sterility percentage, dry matter partitioning, paddy grain ratio and grain husk ratio were recorded. Leaf chlorophyll content was also estimated. Uptake of nutrients (N, P, K, S, Fe, Mn and Zn) and economics of cultivation were computed. Biochemical components of grains such as total, free and sulphur containing amino acids, phenols, starch, amylose, amylopectin and protein content were estimated. Data on weed biomass, weed flora and crop duration were also recorded. Soil enzymes (urease, phosphatase and dehydrogenase), soil microbial population (bacteria, fungi and actinomycetes population) and soil fertility status (available nitrogen, phosphorus, potassium, sulphur, iron, zinc and manganese) were assessed before and after the crop.

Effect of nutrient regimes

- Effect of nutrient regimes on all growth parameters was significant. Growth parameters like plant height, leaf number $plant^{-1}$, leaf area index (LAI),

number of tillers m^{-2}, culm strength and flag leaf area were significantly higher in N_2.

- N_2 recorded leaf chlorophyll content which was significantly higher than N_3 and N_1 and was on par with N_4.
- All yield attributes except 1000 grain weight were significantly influenced by nutrient regimes resulting in significant variation in the crop yield (grain and straw).
- Maximum grain yield was recorded in N_2 (30:30:30 kg NPK ha^{-1}) (2.78 and 2.66 t ha^{-1}) which was on par with N_4 (40:40:40 kg NPK ha^{-1}) (2.67 and 2.58 t ha^{-1}) and was significantly superior to N_1 and N_3 under submerged and saturated situations respectively. Duration of the crop did not show significant variation due to nutrient regimes.
- Total amino acid and protein content of grain were significantly influenced by nutrient regimes and were maximum in N_2.
- Nutrient regimes significantly influenced N, P and K uptake. Uptake of N, P and K in N_2 was significantly higher than that in the other three nutrient regimes. Nutrient regimes did not significantly influence uptake of S, Fe, Mn and Zn.
- Results of the study also revealed that *Echinochloa colona* (L.) Link, *Isachne miliacea* Roth ex Roem. et Schult; *Cyperus iria* L., *Cyperus difformis* L. *Fimbristylis miliacea* (L.) Vahl.; *Marsilea quadrifoliata* Linn., *Monochoria vaginalis* (Burm. f.) Presl. ex Kunth and *Ludwigia perennis* L were the most predominant weed species in the experimental field under both situations. Weed biomass at 20 and 40 DAS did not differ significantly under different nutrient regimes during both the years of experimentation.
- Nutrient regimes showed significant influence on available nitrogen, phosphorus and potassium status of the soil after the investigation.
- Available sulphur, iron, zinc and manganese status of the soil after the experiment revealed non-significant effect of nutrient regimes in both the years of study.
- Among the soil enzymes, urease activity was influenced significantly by the nutrient regimes and it was in the order $N_4 > N_3 > N_2 > N_1$.
- Bacterial population was influenced significantly by the nutrient regimes and it was in the order $N_4 > N_3 > N_2 > N_1$.

Effect of nutrient sources

- Nutrient sources had significant influence on all the growth characters of Njavara. Integrated nutrient source registered significantly higher growth characters compared to organic nutrition.
- Yield attributing characters like number of grains panicle^{-1}, number of filled grains panicle^{-1}, harvest index as well as crop yield (grain and straw) were significantly influenced by nutrient sources. Highest number of grains panicle^{-1}, filled grains panicle^{-1} and crop yield (grain and straw) were realized in integrated nutrient source and they were significantly higher than that realized from organic source. Integrated nutrient source recorded the highest grain yield of 2.71 and 2.60 t ha^{-1} which was significantly superior to organic source which recorded a grain yield of 1.98 and 1.90 t ha^{-1} under submerged and saturated situations respectively.
- Duration of crop did not differ significantly between the nutrient sources.
- Integrated nutrient source registered significantly higher nitrate reductase activity and root weight compared to organic source.
- Biochemical components such as total, free and sulphur containing amino acids, phenols, starch, amylose, amylopectin and protein content of grain did not differ significantly between nutrient sources.
- Highest uptake of N, P and K was in integrated nutrient source. Sources of nutrients did not influence uptake of S, Fe, Mn and Zn during both the years of experimentation.
- Weed biomass under different nutrient sources at both 20 DAS and 40 DAS differed significantly from one another. Weed biomass during both stages and both the years of experimentation was more in organic source compared to integrated nutrient source. Highest weed biomass was recorded in absolute control at both stages during both the years.
- Available nitrogen, available phosphorus and available potassium status of the soil after the experiment in the plots receiving integrated nutrient source and organic nutrient source differed significantly from each other. Available N, P and K status of the soil were higher in integrated nutrient source.

- Organic carbon, available sulphur, iron, zinc and manganese status of the soil after the experiment were not significantly influenced by nutrient sources.
- Urease activity and bacterial population in the soil were influenced significantly by nutrient sources. Highest activity of urease and bacterial population in the soil were recorded in organic source compared to integrated nutrient source.
- Phosphatase and dehydrogenase activity as well as fungal and actinomycetes population in the soil were not influenced by nutrient sources.

Economics of crop production

- Gross income, net income and BCR were highest in N_2S_2. Application of FYM @ 5 t ha^{-1} along with 30:30:30 kg NPK ha^{-1} (50 % N as organic + 50 % N as chemical fertilizer) (N_2S_2) recorded a net profit of Rs. 57,586 ha^{-1} and Rs 53,546 ha^{-1} under submerged and saturated situations respectively.
- The lowest gross income, net income and BCR were recorded in N_1S_1 (FYM @ 5 t ha^{-1} along with 30:15:15 kg NPK ha^{-1} as organic source).

Conclusion

- N_2S_2 – FYM @ 5 t ha^{-1} + 30:30:30 kg NPK ha^{-1} (50 % N as organic + 50 % N as chemical fertilizer) is the ideal nutrient schedule for sustaining the productivity of Njavara cultivated under both submerged and saturated moisture regimes.
- Integrated nutrition resulted in 27 and 26 per cent increase in grain yield and 58 and 60 per cent increase in net income than organic nutrition under submerged and saturated situations respectively.
- Organic nutrition realized a grain yield of 1.98 and 1.90 t ha^{-1} under submerged and saturated situations respectively.
- Productivity realized under submerged and saturated situations were on par and only 3 to 4 per cent yield reduction was observed under saturated situation.
- No significant difference was observed in uptake of nutrients and available nutrient status of soil between the two moisture regimes. Uptake of N, P and K under submerged and saturated situations were about 66 and 64 kg N ha^{-1}, 27 and 24 kg P ha^{-1}, 90 and 84 kg K ha^{-1} respectively.

- Build up of P and depletion of N and K was observed both under organic and integrated nutrition. The tune of reduction of N ranged from 31-79 kg N ha^{-1}, for K the range was 81-137 kg K ha^{-1}. The tune of increase in P status was 3 - 18 kg P ha^{-1}.
- N_2S_2 is the most economically viable nutrient schedule for Njavara cultivation under both submerged and saturated moisture regimes. This nutrient management realized a net income of Rs 57,586 ha^{-1} and Rs 53,546 ha^{-1} under submerged and saturated situations respectively.

Future line of work

- Detailed studies are needed to assess the effect of various growth factors on therapeutic value of Njavara.
- Suitability of cultivating Njavara under upland situations also needs investigation.
- Attempts can be made to evolve site specific nutrient management strategies for Njavara rice.
- Permanent manurial experiment is to be conducted to assess the long term effect of organic nutrition on the growth and productivity of Njavara.

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* Original not seen

APPENDICES

APPENDIX – I

Weather data for the cropping period (Summer season) (January 2007 to April 2007)

Standard week	Temperature (°C)		Rainfall (mm)	Relative humidity (%)		Evaporation (mm day^{-1})
	Minimum	Maximum		Minimum	Maximum	
1	19.9	31.3	0	58.1	96.3	4.2
2	22.1	31.9	0	59.6	96.3	4.4
3	21.7	32.2	0	60.7	93.7	4.2
4	21.2	31.2	0.6	64.6	94.0	4.3
5	22.0	31.9	0	61.3	96.6	4.4
6	21.2	31.0	0	60.4	95.1	5.0
7	22.4	31.8	0	64.4	93.1	5.4
8	21.0	32.2	2.2	50.9	92.9	5.6
9	23.5	32.9	0	66.6	90.7	5.2
10	22.2	32.0	0	58.1	92.0	5.4
11	23.6	32.7	0	61.3	91.6	4.3
12	24.4	33.2	0	63.4	90.4	4.7
13	25.9	32.0	0	64.4	89.7	4.7
14	24.8	33.7	50.3	74.3	94.6	4.1
15	23.3	32.6	88.7	83.4	95.3	2.8
16	24.4	32.9	32.8	71.7	92.1	4.8
17	25.2	32.6	11.0	78.0	94.4	4.2

APPENDIX – II

Weather data for the cropping period (Summer season) (January 2008 to April 2008)

Standard week	Temperature (°C)		Rainfall (mm)	Relative humidity (%)		Evaporation (mm day^{-1})
	Minimum	Maximum		Minimum	Maximum	
1	22.9	31.0	0	80.3	90.9	3.5
2	22.9	31.9	0	68.4	91.0	3.5
3	22.5	31.3	1.2	68.3	91.0	3.6
4	22.8	31.5	0	79.9	92.7	3.5
5	22.8	32.0	0	79.6	93.1	3.9
6	23.0	31.3	2.1	79.4	92.6	3.4
7	23.1	32.1	17.6	74.6	90.4	3.9
8	22.6	32.4	0	76.3	90.3	4.0
9	23.1	32.8	3.1	77.3	90.8	4.0
10	22.9	32.0	6.2	61.3	92.4	5.4
11	24.1	31.2	77.6	83.0	91.9	3.4
12	23.4	29.3	226.1	92.9	95.7	1.6
13	24.3	32.0	9.2	83.7	88.4	4.0
14	24.6	32.1	13.8	77.7	89.4	4.1
15	24.1	31.3	59.8	81.9	92.6	3.3
16	24.9	32.7	14.4	74.4	89.0	4.4
17	26.0	32.7	3.0	77.4	91.7	4.1

APPENDIX – III

PROCEDURE FOR AMINO ACID ANALYSIS

Weighed amounts of protein samples were hydrolysed with 6 N HCL (1 mg protein/ml of 6 N HCL) at 110° C for 22 hours in tubes sealed under vacuum. Acid in the hydrolysates were removed under vacuum at room temperature. The residue was dissolved in a known volume of 0.2 M citrate buffer pH 2.2 and stored frozen until use. Amino acid analysis was carried out by automated ion-exchange chromatography on an LKB 4004 amino acid analyzer using the procedure of Spackman *et al.* (1958) and expressed as mg 100 g^{-1}.

APPENDIX – IV
PROCEDURE FOR NITRATE REDUCTASE ACTIVITY

Nitrate reductase activity in leaf was done according to the procedure of Hageman *et al.* (1980). Fresh leaf was cut into 2 mm slices and placed in ice-cold incubation medium containing 3.0 ml of 0.05 M potassium phosphate buffer (pH – 7.8) and 3.0 ml of 0.4 M KNO_3 solution. The tubes were evacuated with a vacuum pump and then incubated in water bath at 35°C for 75 minutes under dark conditions. At the end of incubation period, tubes were kept in boiling water bath for 5 minutes to stop the enzyme activity and complete leaching of the nitrite in the medium. Nitrite was estimated by the method of Nicholas *et al.* (1976). 0.2 ml of the aliquot from reaction mixture was taken and 1.0 ml each of 1.0 per cent sulphanilamide in 1N-HCL and 0.025 per cent N-(1-Napthyl)-ethylene diammonium dichloride (NEDD) in double distilled water were added. The pink colour due to diazotisation was allowed to develop for 30 minutes after which the volume was made upto 6.0 ml with double distilled water. The absorbance was read at 540 nm, using uv-vis-spectrophotometer (Model DU 640B). The calibration curve was prepared using sodium nitrite solution. The enzyme activity was expressed as μmole NO_2 g^{-1} fresh weight hr^{-1}.

APPENDIX – V

PROCEDURE FOR SOIL ENZYMES

Urease

25 g of soil was weighed into an Erlen Meyer flask, to which 4 ml of urea substrate solution was added. Enough water was added to each flask to maintain a tension of 1/3 bar and incubated for 24 hours at 30°C. Then the flasks were removed, $CaSO_4$ solution was added to make up the volume to 100 ml. About 15 ml of the supernatant was taken and colour was developed by adding 10 ml of P-dimethyl amino benzaldehyde, which was read in a spectrophotometer at a wavelength of 420 mm. Standards were also prepared by using urea solutions of known concentrations. The results were expressed in terms of urea hydrolysed g^{-1} of soil hr^{-1} in ppm.

Phosphatase

To 1 g soil in a 50 ml Erlen Meyer Flask, 0.2 ml toluene, 4 ml modified universal buffer (pH - 6.5) and 1 ml P- nitrophenyl phosphate solution were added and incubated at 23°C for one hour. After incubation, 0.5 M $CaCl_2$ (1 ml) and 0.05 M NaOH (1 ml) were added. The contents were swirled and filtered and the intensity of the yellow colour developed was read in a spectrophotometer at 420 nm wavelength. One per cent solution of P-nitrophenyl phosphate was used for the preparation of standards. The results were expressed in terms of p-nitrophenyl hydrolysed g^{-1} of soil hr^{-1} in μg.

Dehydrogenase

About 6 g of the air dried soil was weighed to a 250 ml Erlen Meyer flask. One ml of 3 per cent triphenyl tetrazolium chloride was added and incubated for 24 hours at 27°C. After incubation, the soil was transferred to a glass funnel and was given ethanol washings consecutively till the volume reached 100 ml. The colour intensity was then read in a spectrophotometer at 485 nm. A series of standards were prepared and the results were expressed in terms of triphenyl formazon hydrolysed g^{-1} of soil 24 hrs^{-1} in μg.

APPENDIX – VI

The dilution and media used for the estimation of microflora

Organism	Dilution	Medium
Bacteria	10^4	Soil extract Agar
Fungi	10^4	Martin's Rose Bengal Agar
Actinomycetes	10^6	Kenknight's Agar

APPENDIX – VII

The composition of media used for the study

1. Rose Bengal Agar

Dextrose	-	10 g
Peptone	-	1 g
KH_2PO_4	-	1 g
$MgSO_4.7H_2O$	-	0.5 g
Rose Bengal	-	33 g
Agar	-	15 g
Distilled water	-	1000 ml
Streptomycin	-	30 g

2. Soil Extract Agar

Soil extract	-	100 ml
Glucose	-	1 g
$KHPO_4$	-	0.5 g
Agar	-	15 g
Tap water	-	900 ml
pH	-	6.8

3. Kenknight's Agar

Dextrose	-	1 g
KH_2PO_4	-	0.1 g
$MgSO_4.7H_2O$	-	0.1 g
$NaNO_3$	-	0.1 g
KCl	-	0.1 g
Agar	-	15 g
Distilled water	-	1000 ml

4. Potato Dextrose Agar

Potato	-	200 g
Dextrose	-	20 g
Agar	-	20 g
Distilled water	-	1000 ml

APPENDIX – VIII

PROCEDURE FOR MICROBIAL POPULATION

Serial dilution

One g soil was added to 100 ml of sterilized distilled water in a 250 ml conical flask under aseptic condition and shaken for 30 minutes in orbital shaker for uniform mixing for obtaining 10^{-2} dilution. With a sterile pipette, 1 ml of 10^{-2} dilution was transferred to 99 ml sterile water blank and mixed well to obtain a 10^{-4} dilution. Further 1 ml of 10^{-4} dilution was transferred to 99 ml sterile water blank and mixed well to obtain a 10^{-6} dilution. One ml aliquots of 10^{-4} dilution were transferred to sterile petridishes for enumeration of fungi and bacteria. Similarly 1 ml aliquot of 10^{-6} dilution was used for the estimation of actinomycetes. Melted and cooled Rose Bengal Agar, Soil Extract Agar and Kenknight's Agar media were poured into these petridishes @ 20 ml/dish for the estimation of fungi, bacteria and actinomycetes respectively. Plates were incubated at 28° C. Observations were taken for the colonies after 24 hours in the case of bacteria, 72 hours for fungi and 154 hours for actinomycetes.

APPENDIX – IX

SCORE CHART

Leaf roller

Scale	Percentage damage
0	No damage
1	< 1 % damage
3	1-15 % damage
5	16-30 % damage
7	31-50 % damage
9	> 51 % damage

Earhead bug

Scale	Percentage damage
0	No damage
1	1-10 % damage
3	11-20 % damage
5	21-30 % damage
7	31-50 % damage
9	> 50 % damage

APPENDIX – X

ECONOMICS OF NJAVARA CULTIVATION UNDER TWO MOISTURE REGIMES

Economics of nutrient regimes under submerged and saturated situations

Parameters / Nutrient regimes	Submerged situation		Saturated situation	
	N_2	N_4	N_2	N_4
Gross income (Rs ha^{-1})	81718	78425	78255	75760
Net income (Rs ha^{-1})	41019	36452	37556	33786
BCR	2.02	1.88	1.93	1.82
Cost of cultivation (Rs ha^{-1})	40700	41974	40700	41974

Economics of nutrient sources under submerged and saturated situations

Parameters / Nutrient sources	Submerged situation		Saturated situation	
	S_1 (OS)	S_2 (INM)	S_1 (OS)	S_2 (INM)
Gross income (Rs ha^{-1})	58280	79593	55899	76383
Net income (Rs ha^{-1})	16548	39451	14168	36241
BCR	1.40	1.98	1.34	1.90
Cost of cultivation (Rs ha^{-1})	41732	40142	41732	40142

Economics of nutrient regimes and nutrient sources (Integrated nutrition) under submerged and saturated situations

Treatment combinations	Submerged situation		Saturated situation	
Parameters / Nutrient regimes and sources	N_2S_2	N_4S_2	N_2S_2	N_4S_2
Gross income (Rs ha^{-1})	97551	87880	93511	85440
Net income (Rs ha^{-1})	57586	46837	53546	44397
BCR	2.44	2.15	2.34	2.09
Cost of cultivation (Rs ha^{-1})	39965	41043	39965	41043

Economics of nutrient regimes and nutrient sources (Organic nutrition) under submerged and saturated situations

Treatment combinations	Submerged situation		Saturated situation	
Parameters / Nutrient regimes and sources	N_4S_1	N_2S_1	N_4S_1	N_2S_1
Gross income (Rs ha^{-1})	68970	65886	66080	63000
Net income (Rs ha^{-1})	26066	24452	23176	21566
BCR	1.61	1.59	1.54	1.52
Cost of cultivation (Rs ha^{-1})	42904	41434	42904	41434

INPUT OPTIMIZATION FOR MEDICINAL RICE

(*Oryza sativa* L.) cv. NJAVARA.

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Abstract of the
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for the degree of

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ABSTRACT

The investigation entitled "Input optimization for medicinal rice (*Oryza sativa L.*) cv. Njavara" was conducted at Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, during the summer seasons of 2007 and 2008 (January to April) to standardize an ideal nutrient schedule under two moisture regimes for sustaining Njavara production in lowlands, to investigate the soil physical, chemical and biological properties as influenced by regimes and sources of nutrients and to work out the economics of Njavara cultivation. Both the experiments (submerged and saturated situations) were laid out in randomised block design with ten treatments each and three replications. The treatments comprised four nutrient regimes *viz.*, N_1 - 30:15:15, N_2 - 30:30:30, N_3 - 40:20:20 and N_4 - 40:40:40 kg NPK ha^{-1}, two nutrient sources *viz.*, organic nutrient source (S_1) and integrated nutrient source (S_2) and two controls *viz.*, absolute control (no nutrient was applied) (C_1) and POP for local rice variety (C_2).

Growth components like plant height, leaf number $plant^{-1}$, leaf area index (LAI), number of tillers m^{-2}, culm strength and flag leaf area, yield and yield attributes like number of productive tillers m^{-2}, panicle length, number of grains $panicle^{-1}$, number of filled grains $panicle^{-1}$, 1000 grain weight, harvest index, sterility percentage, dry matter partitioning, paddy grain ratio and grain husk ratio were recorded. Leaf chlorophyll content was also estimated. Uptake of nutrients (N, P, K, S, Fe, Mn and Zn) and economics of cultivation were computed. Biochemical components of grains such as total, free and sulphur containing amino acids, phenols, starch, amylose, amylopectin and protein content were estimated. Data on weed biomass, weed flora and crop duration were also recorded. Soil enzymes (urease, phosphatase and dehydrogenase), soil microbial population (bacteria, fungi and actinomycetes population) and soil fertility status (available nitrogen, phosphorus, potassium, sulphur, iron, zinc and manganese) were assessed before and after the crop.

Effect of nutrient regimes

Effect of nutrient regimes on all growth parameters was significant. Growth parameters like plant height, leaf number $plant^{-1}$, leaf area index (LAI),

number of tillers m^{-2}, culm strength and flag leaf area were significantly higher in N_2. N_2 recorded leaf chlorophyll content which was significantly higher than N_3 and N_1 and was on par with N_4.

All yield attributes except 1000 grain weight were significantly influenced by nutrient regimes resulting in significant variation in the crop yield (grain and straw). Maximum grain yield was recorded in N_2 (30:30:30 kg NPK ha^{-1}) (2.78 and 2.66 t ha^{-1}) which was on par with N_4 (40:40:40 kg NPK ha^{-1}) (2.67 and 2.58 t ha^{-1}) and was significantly superior to N_1 and N_3 under submerged and saturated situations respectively. Duration of the crop did not show significant variation due to nutrient regimes.

Total amino acid and protein content of grain were significantly influenced by nutrient regimes and were maximum in N_2.

Nutrient regimes significantly influenced N, P and K uptake. Uptake of N, P and K in N_2 was significantly higher than that in the other three nutrient regimes. Nutrient regimes did not significantly influence uptake of S, Fe, Mn and Zn.

Results of the study also revealed that *Echinochloa colona* (L.) Link, *Isachne miliacea* Roth ex Roem. et Schult; *Cyperus iria* L., *Cyperus difformis* L. *Fimbristylis miliacea* (L.) Vahl.; *Marsilea quadrifoliata* Linn., *Monochoria vaginalis* (Burm. f.) Presl. ex Kunth and *Ludwigia perennis* L were the most predominant weed species in the experimental field under both situations. Weed biomass at 20 and 40 DAS were not significantly influenced by nutrient regimes during both the years of experimentation.

Nutrient regimes showed significant influence on available nitrogen, phosphorus and potassium status of the soil after the investigation. Available sulphur, iron, zinc and manganese status of the soil after the experiment revealed non-significant effect of nutrient regimes in both the years of study.

Among the soil enzymes, urease activity was influenced significantly by the nutrient regimes and it was in the order $N_4 > N_3 > N_2 > N_1$. Bacterial population was influenced significantly by the nutrient regimes and it was in the order $N_4 > N_3 > N_2 > N_1$.

Effect of nutrient sources

Nutrient sources had significant influence on all the growth characters, yield attributing characters like number of grains panicle^{-1}, number of filled grains panicle^{-1}, harvest index as well as crop yield (grain and straw). Highest number of grains panicle^{-1}, filled grains panicle^{-1} and crop yield (grain and straw) were realized in integrated nutrient source and they were significantly higher than that realized from organic source. Duration of crop did not differ significantly between the nutrient sources.

Integrated nutrient source registered significantly higher nitrate reductase activity and root weight compared to organic source. Biochemical components such as total, free and sulphur containing amino acids, phenols, starch, amylose, amylopectin and protein content of grain did not differ significantly between nutrient sources.

Highest uptake of N, P and K was in integrated nutrient source. Sources of nutrients did not influence uptake of S, Fe, Mn and Zn during both the years of experimentation.

Weed biomass under different nutrient sources at both 20 DAS and 40 DAS differed significantly from one another. Weed biomass during both stages and both the years of experimentation was more in organic source compared to integrated nutrient source. Highest weed biomass was recorded in absolute control at both stages during both the years.

Available nitrogen, available phosphorus and available potassium status of the soil after the experiment in the plots receiving integrated nutrient source and organic nutrient source differed significantly from each other. Available N, P and K status of the soil were higher in integrated nutrient source. Organic carbon, available sulphur, iron, zinc and manganese status of the soil after the experiment were not significantly influenced by nutrient sources.

Urease activity and bacterial population in the soil were influenced significantly by nutrient sources. Highest activity of urease and bacterial population in the soil were recorded in organic source compared to integrated nutrient source. Phosphatase and dehydrogenase activity as well as fungal and actinomycetes population in the soil were not influenced by nutrient sources.

Economics of crop production

Gross income, net income and BCR were highest in N_2S_2. Application of FYM @ 5 t ha^{-1} along with 30:30:30 kg NPK ha^{-1} (50 % N as organic + 50 % N as chemical fertilizer) (N_2S_2) recorded a net profit of Rs 57,586 ha^{-1} and Rs 53,546 ha^{-1} under submerged and saturated situations respectively. The lowest gross income, net income and BCR were recorded in N_1S_1 (FYM @ 5 t ha^{-1} along with 30:15:15 kg NPK ha^{-1} as organic source).

The ideal nutrient schedule for sustaining Njavara production in lowlands under both submerged and saturated situations is N_2S_2 - FYM @ 5 t ha^{-1} + 30:30:30 kg NPK ha^{-1} (50 % N as organic + 50 % N as chemical fertilizer). This nutrient system realised highest grain yield, straw yield and net income.