COMPARATIVE STUDY ON GROWTH AND PRODUCTIVITY OF RICE CULTIVARS UNDER DIFFERENT FERTILITY LEVELS IN LOWLAND CONDITION OF MIZORAM

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I, C.Lalzarliana, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University / Institute.

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LIST OF ABBREVIATIONS USED

Anon.	:	Anonymous
^{o}C	:	Degree Celcius
%	:	per cent
cm	:	centimeterum : centimeter
E	:	East
Ed: (eds.)	:	Edition: editor(s) or edited
et al.	:	*et alii*: and others
etc.	:	etcetera or cetera: and the others
ex	:	published by
g/gms	:	gram(s)
ha	:	hectare
K	:	Potassium
m	:	metrum: metre
mm	:	millimetrum: millimeter
ml	:	milliliter
N	:	North / Nitrogen
no.	:	numero: number
p., pp.	:	pigina: page, pages
P	:	Phosphorus
qt	:	quintal
Repl.	:	Replication(s)
ser.	:	sercis: series
sp., spp	:	species (singular); species(plural)

Chapter- 1

INTRODUCTION

1.1 General

Rice (*Oryza sativa* L.) is the most important cereal crop after wheat in the world. It is a staple food of the people of South-east Asia and at present more than half of the world population subsists on this crop (Manzoor *et al*., 2006). Globally, it is grown extensively in tropical and sub-tropical regions of the world. More than half of the people on the globe depend on rice as their basic diet and, generally extensively consumed in the producing countries. It is expected that the world population increase by about 2 billion in the next two decades and half of this increase will be in Asia where rice is the staple food (Gregory *et al.,* 2000).

There are 20 wild species distributed mainly in Asia, Africa and America (Morishima, 1998 and Vaughan, 1989). Of the two cultivated Species *Oryza sativa* and *Oryza glaberrima,* the former is universal and the latter is endemic in West Africa (Seetraraman, 1980). Five wild species of rice share a common AA genome with two cutivated species: *Oryza rufipogon* (Asia), *Oryza longistaminata* (Africa), *Oryza barthii* (Africa), *Oryza meridionalis* (Oceania) and *Oryza glumaepatuala* (America). Of these, *Oryza rufipogon* and *Oryza barthii* are thought to be wild ancestors of Asian and African cultivated rice respectively. Two cultivated species produced fertile hybrids only with these two wild relatives (Morishima, 1998).

The nomenclature of *Oryza* species, particularly for AA genome wild species, is confusing, e.g, Asian AA genome wild taxon has been called under various names like Asian form of *Oryza perennis, Oryza rufipogon* or *Oryza sativa* f. *spontanea*. In recent years, *Oryza rufipogon* has been widely accepted by taxonomists. It tends to differentiate into perennial and annual types, but there two different views on these type: (a) Perennial and annual types are ecotypes belonging to *Oryza rufipogon* ; and (b) Perennial annual types are two distinct species. According to Morishima (1998) the first view is most acceptable because both perennial and annual types are extremely close genetically.

Domesticates and their wild progenitors have quite contrasting morphological, physiological and ecological traits, though they are genetically very close. Harlan *et al.* (1973) enumerated common traits carried by domesticated forms, assigning them “adaptive syndromes of domestication”. The essential difference between wild and domesticated plants is related to the farmer’s self- reproduction, with the latter reproducing only through human intervention, adaptive syndromes of cultivated rice involve low seed shedding, rapid germination, more seed production etc. (Oka, 1988 and Morishima *et al.*, 1992). Morishima (1986) has reported that seed productivity of annual wild rice has a 40-60 per cent harvest index (total seed weight divided by total plant weight), as high as cultivated rice. This is because annual wild rice depends on seed propagation for survival.

All characters distinguishing wild and domesticated types are quantitative traits and controlled by multiple genes. While there are few qualitative traits controlled by major genes to differentiate wild and domestic types, alleles like *ph* (negative phenol responses) *wx* (glutinous endosperm) and wx^{b} (waxy protein specifically carried for *japonica*) occur only in cultivated rice, but not in wild rice (Morishima, 1998).

Oryza sativa and *Oryza glaberrima* are distributed geographically over a wide range of climatic and edaphic conditions between 45^{o} N and 40^{o} S latitudes, embracing Central America, Southern half of the USA, West Indies, South America, Africa, Australia, India, China and Japan while 90 per cent of the rice growing areas lies in wet tropical south and South East Asia (Roy and Seetharaman, 1977).

The Asian rice (*Oryza sativa*) evolved from the ancestral wild progenitor over a broad region stretching from the Gangetic plains below the Himalayan foot hills across north – east India, Upper Burma, Northern Thailand, Laos Vietnam and South China. It is generally felt that the domestication had occurred independently and India is one of the oldest regions where domestication began. Two major sub species or race i.e *indica* and *japonica* are recognized. All the rice varieties of India belong to the former group though type resembling *japonica* or those with *japonica* type grains has also been reported from India and Nepal (Seetharaman, 1980).

1.2.1 Biology of rice

Rice is a typical grass, forming a fibrous root system bearing erect culms and developing long flat leaves. It has a semi-aquatic lifestyle, requiring water particularly during the reproductive growth phase. It forms multiple tillers, consisting of a culm and leaves, with or without a panicle. The panicle emerges on the uppermost node of a culm, from within a flag-leaf sheath and bears the flowers in spikelets. The culm consists of a number of nodes and hollow internodes that increase in length and decrease in diameter up the length of the culm. Primary tillers emerge from nodes near the base of the main culm and secondary and tertiary tillers emerge sequentially from these. Single leaves develop alternately on the culm, consisting of a sheath, which encloses the culm and a flat leaf blade. The leaf forms a collar or junctura between the sheath and blade and a ligule and two auricles develop on the inside of the junctura and base of the leaf blade respectively. Cultivars can vary widely in the length, width, colour and pubescence of the leaves.

The panicle emerges from the flag-leaf sheath and consists of a central rachis with up to four primary branches at each node. Primary and secondary branches bear the flower spikelets. Each spikelet has a single floret and two glumes. It is enclosed by a rigid, keeled lemma, which is sometimes extended to form an awn and partially envelops the smaller palea. The floret contains six stamens and a single plumose ovary with two branches. At anthesis, two lodules at the base of the floret swell and force the lemma and palea apart as the stamens elongate and emerge. The stigma is sometimes exposed as well.

The fertilised ovary is a caryopsis, meaning a small, single-seeded dry fruit with the pericarp and seed coat fused. It is commonly called a grain. The grain consists of an embryo, endosperm, pericarp and testa, surrounded by the husk or hull (the lemma and palea). Grain length varies with cultivar between 5 and 7 mm, and grains can be round, bold or slender (McDonald, 1979 and Anon., 1999).

1.2.2 Growth and Development stages

There are three main developmental stages in rice. These are germination/vegetative growth, reproductive development, and grain ripening (Anon., 2002 and 2005).

1.2.2.1 Germination and vegetative growth

After imbibition of the seed, germination begins with the emergence of the coleorhiza and coleoptile from the pericarp. The radicle gives rise to the seminal root system, which has limited branching. Germination can occur under aerobic or anaerobic conditions. Under anaerobic conditions, the coleoptile emerges first, as it is the only part of the embryo that can grow under energy derived solely from fermentation (Moldenhauer & Gibbons, 2003). The fibrous roots develop from underground nodes. The coleoptile elongates along with the epicotyl, and when the coleoptile reaches the soil or water surface, it splits open and the primary leaf emerges (McDonald, 1979). During this early phase of development, the plant can produce a leaf every four to five days as the primary culm develops. As the rice plant grows, primary tillers begin to emerge from the axial nodes of the lower leaves. These give rise to the secondary tillers, from which tertiary tillers can also develop. The internodes begin to elongate at, or near, panicle initiation (Anon., 2002; Moldenhauer and Gibbons, 2003).

1.2.2.2 Reproductive development

The reproductive stage begins with panicle initiation. The timing of this may be linked to specific photoperiods and is highly cultivar-dependent (McDonald, 1979). Panicle initiation occurs at the growing tip of the tiller. As the panicle grows inside the flag-leaf sheath, senescence of the lower leaves begins. A further three leaves develop before heading (panicle emergence) occurs. The panicle may emerge partially or fully, and greater emergence is selected for in cultivars as a means of decreasing disease occurrence (Moldenhauer & Gibbons, 2003). Flowering typically begins one day after heading and continues down the panicle for approximately seven days until all florets on the panicle have opened. Anthesis begins with the opening of the florets followed by stamen elongation and generally lasts 1.2 to 2.5 hrs between 9 am and 2 pm. However, this is temperature dependent and can take longer and occur later on cooler or cloudy days (Moldenhauer & Gibbons, 2003). As pollen shedding generally occurs within nine minutes of floret opening (Oka, 1988), pollen is usually shed onto the florets of the same panicle, resulting in self-fertilisation. Fertilisation is completed within six hours. This is the stage when rice is most sensitive to cold temperatures (McDonald, 1979).

1.2.2.3 Grain ripening

Once the florets are fertilised, the ovaries begin to develop into grains. Initially, the grain fills with a white, milky fluid as starch deposits begin to form. The panicle remains green at this stage and begins to bend downwards. Leaf senescence continues from the base of the tillers but the flag-leaf and next two lower leaves remain photosynthetically active. The grain then begins to harden into the soft dough stage. Husks begin to turn from green to yellow and senescence of the leaves and tillers is at an advanced stage. During the final stage the grain matures, becoming hard and dry. The entire plant begins to yellow and dry out, at which point the grain can be harvested (Anon., 2002).

Rice shows considerable variability in grain size, shape, colour of the hull and kernel. It may be from short bold or short slender to long bold or long slender. The length of the grain varies from 9-14mm. It may be round, oval or elongated. The colour of the hull varies from straw to purple, brown or black with various integrates. Rice is normally white, but red and purple rice are also grown. The colour is due to anthocyanin or non-anthocyanin (Anon., 2002).

1.2.3 Effect of planting density and nutrition on rice yield

The yield components of rice per unit area is directly related to planting density and fertility level, therefore, can be increased by increasing planting density and fertility levels-up to a certain limit (Murty and Murty, 1981).

The number of effective tillers (panicle) per unit area and ratio of effective tillers were more with closer spacing than with wider spacing (Rao *et al.*, 1964). Panicle length, spikelet and grain number per panicle increased as planting spacing was increased (Ahmed and Rao, 1966). The filled grains per panicle and test weight bear inverse relationship with plant density but compensated by increased panicle number to certain extent. However, plant nutrition directly influence filled grain production per panicle (Chang, 1968).

1.2.4 Climatic requirements of rice

Rice is a widely grown water loving crop and hence it is cultivated mostly during Kharif season. Temperature plays an important role in the growth and development of rice and thus, greatly influences the production and productivity. The optimum temperature requirement of rice during various growth stages are 21^0C to 31^0C for germination, 15^0C to 20^0C for transplanting 20-25^0C for growth and 25^0C to 34^0C for tillering whereas for panicles initiation, slightly lower temperature (20-22^0 C) is ideal (Seetraraman, 1980).

The critical mean temperature for flowering and fertilization ranges from 16^0-20^0C whereas during ripening, the ranges is from 18^0-32^0C. Temperatures beyond 35^0C affect not only pollen shedding but also grain filling. The earliest maturing varieties are harvested in 85 to 90 days. In contrast, there are varieties of rice that take 240 days to mature. Rice is considered a short day plant and varieties may be sensitive or insensitive to day length, temperature or both (Seetraraman, 1980).

1.2.5 Edaphic requirements

Rice is adaptable to all kind of soils varying in texture from sandy loam to clayey, with soil reactions ranging from acidic to alkaline, provided sufficient water is available either through assured rainfall or irrigation (Takahashi, 1984). The soils most suited for the cultivation of rice crops are heavy soils – clays, clay-loams and loamy soils (Thakur, 1979). The major nutrients required by rice are nitrogen, phosphorus and potassium (Seetraraman, 1980). Rice is grown from sea level to 3000m and in both temperate and tropical climates. A variety of water regimes are used, including unsubmerged upland rice, moderately submerged lowland rice (irrigated or rain-fed), and submerged rice. The semi-aquatic nature of the crop, however, necessitates of heavy soil through which rain or irrigation water does not percolate easily. The chemical properties of the soils do not appear to be as important as the physical ability of the soil to hold a flood (Scott *et al*., 2003).

1.2.6 Water and fertilizer requirement

Many research publications are available on water and fertilizer management in rice cultivation (Becker *et al*., 1994; Rautaray *et al*., 2003; Cassman *et al.,* 1996; De Datta *et al*., 1988; Dobermann *et al*., 1998; Dobermann and White, 1999; Flinn and De Datta,1984). Soil submergence suppresses weed growth and increases the availability of phosphorous and iron to rice plants, but it also enhances percolation losses of water and, thus increases the water needs of rice, and high leaching losses of mobile nutrients, particularly in coarse textured soils. Field studies have shown that shallow submergence of 5-7 cm give as much or higher yield than deep submergence, but save 10-15 per cent irrigation water. Continuous shallow submergence is also not necessary for higher yields. Instead, irrigation at saturation / soil cracking / alternate wetting and drying has given comparable yields, but reduced percolation losses resulting in reduced water need of the crop by 22-64 per cent (Singh and Singh, 2002).

Brahmanand *et al*. (2000) stated that the plot to plot or terrace to terrace of water movement in rice field should be avoided. Instead the provisions should be made to safe disposal of water, and the water should be routed through the water ways to the natural drainage way. Alternate drying and wetting system is more beneficial than the continuous submergence (Kannan and Brahmanand, 2000). In case it is not possible to keep the water level below a certain minimum level then it should be maintained at 3-5 cm (Kannan *et al*., 1999).

1.2.7 Fertilizer management

The requirements of N, P and K in rice cultivation are location specific. The research findings on the response of several high yielding transplanted rice varieties to N, P and K for a period of 10 years clearly showed that the high yielding rice varieties respond up to 180 kg N/ha, but a dose of 120kg N/ha had been found to be the most beneficial on productivity of rice. However, a balance application of 120 kg N, 60 kg $P_2 O_5$ and 60 kg K_2O per hectare is recommended for high yields of transplanted high yielding varieties of rice (Singh *et al*., 1988). For Northeastern hill states, 60-80 kg N/ha in organic form in addition to organic manure had been recommended (Singh & Singh, 2002). Split application of N fertilizes commensurate with crop growth stage is an useful approach for increasing the efficiency of applied N in rice (Sharma *et al*, 1990). Combined application of organic with inorganic nutrients would further augment the N use efficiency. It is therefore necessary to judiciously manage the inflow of inorganic source of nutrients especially the nitrogen. The integrated use of chemical fertilizers and green manuring thus assumes greater significance (Nambiar and Abrol, 1989).

Management of Phosphorus mainly dependent on soil characteristics, status of weathering, water regime, cropping intensity and cropping pattern. Intensity of phosphates activity in soil has been found to be related to soil physical and chemical properties (Hoffman and Elias-Azar, 1965). Khan (1970) has reported that addition of phosphates increases phosphates activity in soil. Early application of Phosphorus helps in root elongation. Phosphorous in rice is applied as a basal dressing. 40-60kg P_2O_5 per ha has been recommends for northeastern states (Singh & Singh, 2002).

Generally, light textured soil is potassium deficient. Response of K added to the soil is not as marked as observed in case of application of Nitrogen and Phosphorus. Potassium deficient soil is applied with 40-60kg K_2 O per ha at the time of final land preparation or at the time of transplanting. However, field trials in Orissa and at Varanasi (VP) have shown a modest (about 8-10 %) but significant effects of split K application over single basal application. For North Eastern Hill states to balance N : K ratio, modest doze of 20-30kg K_2 O per ha had been recommended (Singh & Singh, 2002).

1.2.8 Biofertilizer management

Biofertilizers are carrier based inoculants containing cells of efficient strains of specific micro-organisms used by farmers for enhancing the productivity of soil either by fixing atmospheric nitrogen or by stimulating plant growth through synthesis of growth promoting substances as secondary metabolites (Chaudhury & Rai, 2007). The use of bio-fertilizers is gaining momentum because it is safer and cheaper alternative to chemical fertilizers. Singh and Singh (2008) reported that one third of the Nitrogen fertilizer (recommended dose) can be saved without affecting rice productivity through algal inoculation.

Azospirillum along with N- fertilizer increases rice grain yield significantly (Prasad and Singh,1987). Balasubramanian *et al.* (1991) have reported that *Azospirillum* when applied with fertilizer - N, significantly increases tiller numbers, plant dry weight grain and straw yields of rice. Garcia *et al* (1993) mentions that phosphatase activity might be an indicator of organic matter in the composting process. Rice plant can utilize soil organic P by means of phosphatases (Hino, 1989). Thus, use of biofertilizers as an alternative of chemical fertilizers may be considered as an important aspect from the health point of view.

1.3 Genotypes of rice

Several genotypes of rice suit different altitudes and edaphic condition and climatic condition have been developed in India and also in other rice growing countries of the world. Many varieties have been developed for upland area. Use of improved varieties is known to contribute up to 40% of the enhanced yield and thus it plays a key role in increasing the productivity of rice (Borthakur, 1993). These varieties developed, according to the period of rainy season, resistant weed competition to some extent, suitable for temperature regimes and soil variability, and resistant to insect pests and diseases and yield potential varying between 20 q/ha to 45 q/ha have been tested at least four to five years at different locations in India. A few noted varieties are Akashi, Bala, Brown Gora, Cauvery, CR 141-191, CR-142-3-2, CRM13-321, DR-92, Govinda, Jhona, Kisan, Kranti, mahawari, Narendra-2, Nagina-22, Pusa-33, Pusa2-21, Parijat, Ramjawan, Ratna, RP-79-5, RP-79-23, Saket-4(transplanted), Sarju-49, Sarju-50 and WLK-35 etc (Singh and Singh, 2002).

Gupta *et al.*, (1995) reported rice varieties suitable for uplands, mid-altitude areas and lowlands of north eastern hill region of India, and that the varieties recommended for uplands are IRAT-144, IRAT-109, IR-36, IET-13459, Ratna, RC-Maniphou-4, RC-Maniphou-5 and TRC-87-251 etc. whereas RCPL 1-2, RCPL3-2, RCPL36, RCPL1-87-8, RCPL-1-87-4 were considered most suitable varieties for mid-altitudes of hills of northeastern India.

The most common rice varieties from advanced breeding lines suitable for lowlands of northeastern states of India are RCPL-1-87-4, RCPL 1-3, RCPL1-87-8, RCPL 3-2, RCPL 3-6, RCPL 1-30, BR-1, Prasad, Punsi, RC-Maniphou-4, RC-Maniphou-5, TRC 229-F-41, TRC-87-251, TRC-216-14, TRC-Borodhan-1, Rasi etc. Out of these RCPL-1-87-4 and RCPL 1-3 are recommended best varieties to be grown at an altitudinal range between 800 to 1300m (Gupta *et al*., 1995).

1.4 Rice cultivation and production

The rice production has increased many folds during the past few decades but the deficiency of rice is becoming more and more acute in recent years because of the rising population and fixed area of cultivable land. The increase in human population, particularly in the developing countries, has put tremendous pressure on land. The extension of crop lands, for increasing food production, has been directly responsible for the reduction in areas under forests and grass lands.

1.4.1 Rice production in the world

Rice is cultivated in 148 million hectares (ca.) worldwide which accounts for nearly 10 per cent of the world’s arable land. About 95 per cent of the world’s rice is produced in developing countries primarily in Asia which is home to 59 per cent of the world’s population. The Asian farmers harvest nearly

92 per cent of global rice produce (Chakraborty, 2001). The Asia-Pacific region produces more than 90 per cent of the world's rice. Twenty two of the thirty countries studied in the Asia-pacific region produced paddy which altogether account for 57 per cent of the total cereals produced (Singh, 1993). Rice production in some important rice growing countries in the world is presented in Table 1.1 (Anon., 2004 a).

Table 1.1 : Rice production in the world

Countries	**Rice production(tonnes)**		
	1995	**2000**	**2003**
China	187,297,968	189,814,060	166,417,00
India	115,440,000	127,464,896	132,013,00
Indonesia	49,744,140	51,898,000	52,078,832
Bangladesh	26,399,000	37,627,500	38,060,000
Vietnam	24,963,700	32,529,500	34,518,600
Thailand	22,015,500	25,844,000	27,000,000
Myanmar	17,956,900	21,323,868	24,640,000
Japan	13,435,000	11,863,000	9,740,000
Philippines	10,540,640	12,389,400	14,031,000
Brazil	11,226,064	11,089,800	10,198,900

Source: *The survey of Indian Agriculture* (ICAR, 2004)

1.4.2 Rice production in India

Rice crop occupies 42.3 m ha of cultivated land in India but produces hardly 87 million tons per year, which is extremely low in comparison to yields obtained in countries like Japan, Taiwan etc. Out of 42.3 million hectares of rice cultivable land, rain-fed upland rice occupies 6.1 million hectares of cultivable land, of which 4.3 million hectares are located in eastern India (Assam, West Bengal, Orissa, Jharkhand, Eastern U.P. and Chhattisgarh) where productivity is very low (< 1 ton ha) and unstable (Kar *et al.*, 2003).

Rice is the most important and extensively grown food crop ranking first both in terms of area and production occupying an area about 27 per cent of the total agricultural land in India. Among rice growing countries India ranks second with a production of rice about 20.40 per cent of the total world's production. It is estimated that rice demand in the country will be about 100 million tonnes by the year 2010 and by the year 2025, it would be about 140 million tones (Anon., 2004 a). Although productivity of rice in India has shown an increasing trend in the last few years, it is still among the lowest in the world. Thus, the future increase in rice production requires improvement in productivity and efficiency (Paroda, 1998). The yield of rice in India is low and unsustainable due to erratic south west monsoon, moisture stress during rice growing season and poor moisture retention capacity in light textured soils. Moisture stress condition and moderate temperature favours growth of weeds, multiplication of pests and pathogens.

In spite of low yield of rice in rain-fed upland cultivable land, farmers of eastern India grow rice due to lack of knowledge on growth and productivity of alternate rice cultivars which can improve the yield of rice in rain-fed cultivable land. Under this situation development of ecologically and economically viable rice varieties may be one of the best options for enhancing and stabilizing yield of rain-fed upland rice ecosystem. In upland, intercropping of rice with deep rooted crops gave higher economic return due to better use of land, light, rainfall and nutrient (Rao *et al*., 1982). The idea of intercropping rice with other crops in a rain-fed rice field is to emphasize that those crops would provide an assured income (Kar and Verma, 2002).

1.4.3 Rice production in North- eastern India

Rice is one of the main crops of the North-eastern region of India accounting for about 89% of the area and 92% of the total food grains production (Misra and Misra, 2006). It is also a major crop of the North Eastern hilly ecosystem with an area of around one million hectare giving an average productivity of 14.5 q/ha (Anonymous, 1995). The northeastern region of India accounts for 7.8 per cent of the total rice area in India while it's share in rice production is only 5.9 per cent. The average rice productivity of 1.4 t/ha is below the national average of 1.9 t / ha (Anon., 2000).

Rice is grown in an area of 3.49 million ha. in the north eastern region with a production of 5.46 million tones and an average productivity of 15.67 qt /

ha during the year 2000 - 2001. This accounts for 8.04 per cent of the total geographical area and 6.43 per cent of production of rice in the country (Anon., 2000). The average productivity of the northeast region is very low as compared to the national productivity of rice in the country.

Although there is a good potential for rice production in the region, the North-eastern region of India is lagging much behind the other advanced states as for as the production and productivity of rice are concerned. In post green revolution period after 1960s, there has been consolidated research efforts in the field of crop improvement and crop production, but the increase is minimal. The region has got rich diversity of local germplasm. Further, it is believed that the NEH region is the birthplace of rice in the world (Borthakur, 1993; Dhillon *et al.*, 2001). But the productivity and production of the rice are low resulting into a lower per capita consumption as well. With the rapid increase in the population, it is highly essential to increase the production of this staple diet of the people to be able to self-sufficient as the potential is already there. Due to environmental and other considerations, it is not possible to expand the horizontal area under the rice crop. The only alternative is to boost the productivity which can be achieved by:

a) genetic manipulation and development of high yielding varieties suitable to this region (Gupta *et al.* 1995; Pattanayak *et al.*, 1998; Reddy *et al.*, 1999 and Gupta, 2001); and

b) by careful manipulation, efficient and judicious utilization and management of the resources available for rice cultivation in hills (Mishra and Gupta, 1998; Mishra and Satapathy, 2003 and Mishra *et al*., 2004)

1.4.4 Rice cultivation and production in Mizoram

Rice is the staple food of people in Mizoram. It is grown mostly during Kharif season. The area under rice cultivation in the state is about 54,250 ha. with a production of 1,03,040 tonnes. And the average productivity is 1.90 t / ha. The cultivable land under lowland rice cultivation accounts for 14,150 ha. with the total production of 39,940 MT and average productivity of 2.82 t / ha. The productivity of rice under lowland is comparatively higher (2.82 t / ha) than that of productivity of rice under Jhum cultivation (1.57 t / ha). Low productivity of rice per unit area can be attributed to frequent flash flood in rain-fed low land, frequent drainage congestion during the cropping seasons resulting decrease in the plant population, lesser application of fertilizers and biofertilizers, poor irrigation facilities and use of local varieties of rice, which are less responsive to fertilizers (Anon., 2004 b).

The state of Mizoram is deficit in rice production by almost half of its total requirement. The cultivable land under rice cultivation and productivity of rice in Mizoram from 1985 to 2006 are presented in Table 1.2 (Anon., 2004 b & 2007).

Table 1.2 Rice production and area covered in Mizoram.

YEAR	JHUM		WRC	
	Area (ha)	Production (tonnes)	Area (ha)	Production (tonnes)
1985 –1986	45,920	55,209	9,092	9,571
1986 –1987	38,892	49,622	9,452	19,121
1987 – 1988	37,803	35,266	10,661	13,961
1988 – 1989	36,616	32,720	12,772	20,278
1989 – 1990	38,349	34,993	14,660	24,264
1990 – 1991	36,716	35,283	14,667	28,511
1991 –1992	39,175	38,523	16,464	32,451
1992 –1993	43,858	48,952	17,439	35,002
1993 –1994	43,234	56,699	19,218	40,028
1994 –1995	46,854	58,223	20,100	41,983
1995 – 1996	45,423	56,114	20,290	45,389
1996 – 1997	43,652	63,236	21,009	47,845
1997 –19 98	46,691	59,286	21,423	51,287
1998 – 99	46,634	58,849	21,758	51,340
1999 – 2000	36,285	53,930	13,428	34,467
2000 – 2001	35,798	59,560	16,041	45,113
2001 – 2002	40,306	63,568	15,575	42,147
2002 – 2003	41,356	67,076	15,711	42,129
2003 – 2004	43,447	72,181	15,749	42,449
2004 –2005	40,969	64,420	16,117	43,240
2005 –2006	40,100	63,100	14,150	39,940

Source : *Statistical Abstract* (2004 and 2007), Department of Agriculture, Govt. of Mizoram.

The total production of rice is not sufficient to meet the requirement of rice for the population of Mizoram (Anon., 2006) and there is an urgent need to increase the productivity of lowland in the state to achieve self sufficiency in rice which is the main staple food. Intensive and extensive lowland rice cultivation with proper management of soil fertility status, water balance, use of appropriate rice variety and adoption of effective plant protection measures may be the only possible solution to increase the productivity of rice in Mizoram. Expansion of rice cultivation area in the lowland area with introduction of suitable rice varieties / cultivars and application of appropriate soil and nutrient management systems may be helpful in increasing average production in general and overall rice production in the state on a sustainable basis.

However, research findings on suitable rice varieties / cultivars, their nutritional requirements and the influence of fertilizer/ biofertilizer application on growth and yield attributes of rice crop are very scarce. The present study, therefore, aims to investigate the growth and yield of three rice varieties with different soil nutrient management in the lowland condition of Mizoram. It is expected that the present study would help in suggesting the most suitable rice variety and appropriate soil and nutrient management to increase the productivity of rice in the cultivable lowland of Mizoram. Integrated use of chemical fertilizers and biofertilizers thus assumes greater significance (Nambiar and Abrol, 1989). Therefore the present study was initiated to find out the effect of NPK integrated with biofertilizer on productivity and economics of three rice cultivars in the lowland of Mizoram.

Thus, the specific objectives of the present study are as follows:

1. to study the growth and yield of three rice cultivars with and without application of NPK, Biofertilizer and combination of NPK & Biofertilizer

2. to test the suitability of three rice cultivars under rain-fed condition in the lowland of Mizoram.

3. to study the cost benefit ratio of cultivation of three rice varieties under different nutrient application.

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Chapter- 2

REVIEW OF LITERATURE

2.1 General

Rice cropping system is one of the oldest cropping systems in global scenario. Evidence of practicing rice crop system in India was catalogued by Kautilaya's Arthashastra (Jha and Jha, 1997; Rangarajan, 1992), and in China it was as old as the Tang dynasty between 617-907 AD (Prasad, 2005). Woodhead *et al.*, (1994) marked it obvious that rice cropping system is followed on wide variety of soil and therefore, management of soil and water resource needs utmost importance. In this chapter, an attempt has been made to review the relevant literature available in India and abroad.

Singh (1993) stated that rice is the foremost food of the developing world, it provides about two- third of calories and is also a major source of protein for the masses of Asia and that rice occupies one - third of the area planted to cereals in the developing countries, and further that more than 95 per cent of the world's rice area are in the developing countries, mostly in Asia.

Seetraraman (1980) stated that there are two main seasons for growing rice in India such as Kharif (July –December) and Rabi (December- March / April) and also Summer(April-June) season in limited areas, and that rice is essentially a short day plant and a combination of temperatures, photoperiod light intensity determines the growth period, crop performance and productivity.

Thakur (1979) stated that rice is grown mostly in tropics and sub-tropics and also indicated that India is the most important country for rice production and also mentioned that Pakistan, Indonesia ,Thailand, Burma, Japan, Phillipines, South Vietnam, Cambodia, South Korea, Taiwan etc. are the important rice producing countries.

Roy and Seetharaman (1977) reported that 90 per cent of the total area under rice is situated in wet tropical South and South-East Asia, and that rice is grown in all the states of India in which West Bengal and Andra Pradesh have the highest rice production while Punjab is highest in per hectare yield of rice, and further that rice is grown in almost all types of soils ranging from the coarse laterite soils of east and south India to black clay, clay loam and heavy clay soils of west and central India.

2.2 Rice domestication

2.1.1 Domestication and development of rice varieties

Rice (*Oryza sativa*) was domesticated approximately 10,000 years ago (Jiang and Liu, 2006). There have been many recent publications concerning rice domestication (Konishi *et al.,* 2006; Li *et al.,* 2006; Londo *et al*., 2006; Lu *et al*., 2006; Olsen *et al*., 2006; Sweeney *et al*., 2006; Tang *et al*., 2006 and Zhu *et al*. 2007). Twenty species of rice were enumerated by Roschewicz (1931) and 23 by Chatterjee (1948). Based on re-examination of specimens in major herbaria of the world, Tateoka (1963, 1964) recognized 22 species of *Oryza* to be valid.

Going through the literature regarding rice domestication, one can find agreement that rice (*Oryza sativa*) was domesticated from wild Asian species belonging to the A-genome group of the genus *Oryza* (Chang, 1976; Second, 1982; Wang, *et al*., 1992; Khush, 1997; Ge *et al*., 1999). However, controversy has persisted on two major issues. One is which wild species, *O. nivara* or *O. rufipogon*, served as the direct wild progenitor of cultivated rice and the other is whether rice was domesticated once or multiple times from divergent wild populations (Sang and Ge, 2007).

The controversy is due, at least in part, to the taxonomical inconsistency of the wild progenitors. *O. rufipogon* had been the species name widely used to accommodate the wild Asian A-genome taxa until *O. nivara* was recognized (Sharma and Shastry, 1965). *O. nivara* was established for populations that were annual, photoperiod insensitive, predominantly self-fertilized, and adapted to seasonally dry habitats. *O. rufipogon* was retained for populations that were perennial, photoperiod sensitive, largely cross-fertilized, and adapted to persistently wet habitats (Sharma *et al*., 2000). Although both species were accepted in the recent classification of *Oryza* (Lu *et al*., 2001), the argument that they should be treated as ecotypes or subspecies of *O. rufipogon* has continued (Morishima, 2001; Cheng *et al.*, 2003; Vaughan and Morishima, 2003; Zhu *et al.*, 2007).

As a diploid crop with a relatively small genome, rice holds a great potential for understanding the genetic mechanisms of crop domestication and improvement. The completion of rice genome sequencing (Goff *et al.*, 2002; Yu *et al.*,2002) has considerably accelerated the study of the history and process of rice domestication. There has been continuous gene flow between rice and its wild progenitors (Song *et al.*, 2003), which makes it challenging to trace the origin of cultivated rice. Additionally, rice has two genetically divergent cultivars, *indica* and *japonica*, and ecologically distinct wild progenitors, *Oryza nivara* and *Oryza rufipogon* (Sharma *et al.*, 2000; Chang, 2003). This diversity has spurred a long-standing debate over the origins of cultivated rice. Distinct cultivars were either independently domesticated or differentiated following a single domestication. In either case, there is no consensus on which wild species served as the direct progenitor of cultivated rice.

Wild progenitors molecular phylogenetic studies have confirmed that the closest wild relatives of cultivated rice were *O. nivara* and *O. rufipogon*, which are distributed from southeastern Asia to India. The two wild species are ecologically distinct. *O. nivara* is annual, photoperiod insensitive, self-fertilized, and adapted to seasonally dry habitats, whereas *O. rufipogonis* perennial, photoperiod sensitive, largely cross-fertilized, and adapted to persistently wet habitats (Sharma *et al.*, 2000; Chang, 2003). *Oryza nivara* evolved from an *O. rufipogon*-like ancestor as a result of habitat shift (Khush, 1993).

The hypothesis of rice domestication from *O. nivara* was based on the phenotypic similarity between *O. nivara* and *O. sativa*, including an annual life history, self-fertilization, and high reproductive allocation (Sharma *et al.* 2000; Proponents of the hypothesis that *O. rufipogon* is the ancestor of cultivated rice emphasize the benefit of higher genetic diversity of an outcrossing progenitor (Oka, 1988). Despite a growing number of phylogenetic analyses of cultivated rice with both wild species, researchers have been unable to unequivocally resolve the relationships among *O. sativa*, *O. nivara*, and *O. rufipogon*. Phylogenies based on a variety of molecular markers have been unable to place *O. nivara* and *O. rufipogon* accessions into well-supported monophyletic groups, or show a closer relationship of cultivated rice with one of the wild species (Lu *et al.*, 2002; Park *et al.*, 2003; Zhu and Ge, 2005; Kwon *et al.*, 2006; Zhu *et al.*, 2007).

2.2.2 Traits variations in domesticated and developed varieties

In rice, the cultivated type is characterized by nonshedding of seeds, rapid and uniform germination, efficient seed production, and determinate growth in comparison with the wild type. At the incipient stage of domestication, planting harvested seeds by man automatically selected this "adaptive syndrome of domestication" (Harlan, 1975). *Oryza sativa* and *O. rufipogon* are genetically very close in spite of their clear phenotypic difference, and barely distinguishable by molecular markers. Wild and cultivated plants easily interbreed if grown nearby. Gene flow is mainly from predominantly inbreeding cultivated races to partially out-breeding wild races (Oka, 1988). Gene flow might have played an important role in diversification of the domesticates as in many other crops. Even now, natural hybridization between wild and cultivated rice occurs frequently and hybrid derivatives are found abundantly as weed types. Truly wild populations without introgression of genes are rarely found from cultivated rice in tropical rice-growing areas (Oka, 1988).

In phenotypic characters, geographical variation is not so distinct in *O. rufipogon*. Polymorphism at molecular markers, however, revealed a trend of geographical differentiation. An isozyme study demonstrated that the strains collected in South Asia (particularly on the west coast of India), Southeast Asia (including the east coast of India), and China tend to differentiate (Cai *et al.*, 1996).

2.2.3 Rice varietal test

The evaluation of rice varieties for their general and specific adaptability over diverse environment is important in identifying environment specific and better adapted varieties, and presently, efficient and effective procedures specifically developed for testing varietal adaptability in rice are available (Abeysiriwardena *et al.*, 1991). Jamal *et al.* (2009) evaluated five exotic rice genotypes for yield and yield contributing traits under the climatic conditions of Swat in Pakistan.

To meet the ever growing domestic needs of food and enhance exports and to achieve sustainability and stability of rice production the research in varietal evaluation, modification of plant architecture, development of hybrid rice technology, wide-hybridization, soil and nutrient management and integrated pest management would receive priority (Jamal *et al.*, 2009).

Romyen *et al.* (1998) studied the growth and yield of different rice cultivars under lowland condition in Thailand. Channabasavanna *et al.* (1996) reported that the high yielding varieties are responding to higher levels of nitrogen, phosphorus and potassium than what is recommended. Amanullah (2008) studied the growth and productivity of four varieties of rice namely, CR 1009, CO 43, TRY 1 and Dandi with application of farmyard manure, green leaf manure, leaching and control. Poshtmasari *et al*. (2006) studied the influence of nitrogen applications and cultivar effects on some traits in relation to sink characteristics in the three contrast rice (*Oryza sativa* L.) cultivars.

2.3.1 Nutrient management in rice cultivation

Complimentary use of organic and biological source of plant nutrient along with chemical fertilizer is of great importance for the maintenance of soil health and productivity, especially under intensive cropping system (Prasad, 1999). The integrated use of FYM and NPK fertilizer significantly increased the gross and net return of the cropping system compared with the rice of NPK fertilizer alone (Khanda *et al.*, 2005).

Hussain *et al. (*1991) and Hegde (1998) opined that the integrated use of organic material and chemical fertilizers in rice cultivation is important for sustaining the crop productivity and reducing the use of chemical fertilizers. Parasuraman and Mani (2003) reported that rice responds well to fertilizer application with and without organic manure substitution. Rautanay *et al.* (2003) opined that rice straw should be applied 30 days before transplanting of rice while farmyard manure, azolla or water hyacinth 15 days before green manuring with *Sebania rostrata* in between 15 days before transplanting was equally beneficial. Janaki and Thiyagarajan (2003) reported that some of the genotype were consistent in their N use efficiency irrespective of the season and some varieties suits specific season. Shibata *et al.* (1969) observed a significant varietals differences in the effects of individual fertilizers on these characters and inter-actions between the fertilizers when N,P_2O_5 and K_2O were applied as basic dressing.

2.3.2 Varietal test alongwith application of NPK

Rice cultivars differ greatly in their ability to absorb and utilize fertilizer, and selection and breeding of NPK- efficient cultivars is one of the most promising avenues to increase short-term efficiency of fertilizer (von Uexkull, 2003). Comparatively, Potassium (K) uptake and K requirement of hybrid rice are significantly higher than that of ordinary rice (Liang, 1988).

Ravi and Shmadhan (2007) stated that adequate supply of plant nutrients is important to ensure efficient crop production, and that vegetable or animal manure are used to restore soil fertility from time immemorial; but the use of chemical fertilizers increase due to their large advantage and easy to adopt techniques tidy organic manure application slowly declined. It was stated by von Uexkull (1993) that most yield increases in rice have come from the simple combination of modern, high yielding varieties and increased use of nitrogen fertilizer.

Angus *et al. (*1990) demonstrated that soil fertility, fertilizer use, and crop response to nutrient inputs vary widely among regions, among rice fields within smaller irrigated and rain fed rice environments; and also from season to season in the same field (Cassman *et al*., 1996a; Olk *et al*., 1999; Adhikari *et al*., 1999). At present, however, many fertilizer recommendations are only given for larger areas, with little differentiation according to major agroecological zones, soil types, cropping systems, or field-specific information. Managing the location- and season-specific variability in nutrient supply is a key strategy to overcome the current mismatch of fertilizer rates and crop nutrient demand in irrigated rice environments (Dobermann and Cassman, 2002).

The NPK uptake by rice varieties increased with NPK application up to 125 percent of recommended dose (Anon., 1986). Balasubramanian *et al.* (1991) reported that higher NPK uptake of rice with high dose of inorganic fertilization. Verma (1991) found that the recommended dose of fertilizer application increased significantly the uptake of NPK by rice cultivars over that of 50 per cent recommended dose of fertilizer.

2.3.3 Varietal test alongwith biofertilizers

The use of biofertilizers is currently gaining interest as a cheap, safe alternate to conventional chemical fertilizers. Chaudhary and Mathura (2007) stated that biofertilizers are carrier based inoculants containing cells of efficient strains of specific micro-organisms used by farmers for enhancing the productivity of soil either by fixing atmospheric Nitrogen or by stimulating plant growth through synthesis of growth promoting substances as secondary metabolites.

The response of different rice varieties to biofertilizers was studied by Subhashini (2007). It is reported that a combination of N-fertilizer, N-fix bacteria and compost could increased the activities and quantity of N-fix bacteria by increasing growth, hay weight, total N in plant and rice yield which is better than applied only single factor (Anon, 2003).

Rao (1993) mentioned that Azospirillum is an associative symbiotic-N fixing bacterium which has a higher nitrogen fixing potential. Anwarulla (1998) reported that application of Azospirillum along with N gave higher grain yield of rice compared to control. Similarly, Shivappashetty *et al.* (1986) reported that the Azospirillum gave higher yield with 75 per cent recommended dose of 45kg N ha^{-1} which is at par with 100 per cent recommended N alone, thus resulting in saving of 25 per cent of recommended dose of N without reducing grain or straw yield. Prasad and Singh (1987) reported that Azospirillum along with N fertilizer increased significantly grain yield, grain N content and N uptake. N-fixation and production of growth-promoting substances by Azospirillum might have contributed to improved root mass, thereby increasing grain yields and N uptake. George *et al. (*1992) observed that N difference methods showed 24-66 per cent recoveries of green manure N by wetland rice.

Balasubramanian *et al.* (1991) reported that Azospirillum significantly increased tiller numbers and plant dry weight along with fertilizer N and also increased the grain and straw yields of rice. Similarly, Murty and Rao (1993) also reported that Azospirillum inoculation significantly increased grain and straw yield and also noticed significant increase in the root surface area.

De (1939) suggested that fertility of the tropical rice field was largely due to the activity of the nitrogen fixing blue-green algae. Singh and Singh (2008) reported that extensive field trials conducted in many part of the India on blue- green algae in rice field indicate that one third of the recommended nitrogen fertilizer could be conserved without affecting crop productivity through the algal inoculation.

Garcia *et al*. (1992) indicated that phosphatase activity might be an indicator of organic matter in the composting process. Soil microorganisms and plant can utilize soil organic P by means of phosphatases (Hino,1989**)**. Patel and Singh (1984) studied the effect of azolla as bio-fertilizer on transplanted rice along with other organic sources and chemical fertilizer (P&K) and found that the green manure either through local weed (Abrotia) or composted Azolla and 50% N through inorganic source gave higher yield than urea alone at 80 kg/ha.

2.3.4 Application of chemical fertilizers in rice cultivation

Singh *et al. (*1991) reported that the height and weight of rice seedling increased significantly within N and P nutrition. The grain yield of *Kharif* rice increased significantly up to 125 per cent of recommended fertilizers (150:75:

75 kg NPK ha^{-1}.) (Anon., 1986). According to Setty *et al.* (1987) grain yield increased significantly up to 80-40-40 kg NPK ha^{-1}. Basubramanian *et al.* (1991) indicated that organic fertilizer increased grain yield significantly upto 200: 100: kg N and K ha^{-1} in Kharif. The maximum uptake of 121.5 kg N ha^{-1} was observed with the application of 120 kg N ha^{-1} and it was significantly higher when compared to application of 60 and 90 kg N ha^{-1} (Reddeppa, 1988).

The greater precision of N management reduced nitrogen losses from the applied fertilizer from volatilization and denitrification (Fillery *et al.*,1986; Buresh and De Datta, 1990). Some workers reported that reducing the proportion of total N fertilizer applied at planting and increasing the number of N top dressings can result in significant improvements in yield, and protein content of rice (Cassman *et al.*, 1996 b; Peng *et al.*, 1996; Perez. *et al.*, 1996). Singh and Singh (1994) reported that increasing the dose of Nitrogen from 80 to 160 kg per ha applied to drilled rice cultivar IR- 8, enhanced paddy yields from 3.16 to 4.3 t/ha and increased N and P_2O_5 contents in the grain, however, the yields were not further increased with 200 kg N/ha.

Singh *et al.* (2002) suggested that application of N influences the growth and yield parameters of rice significantly and that N applied in two split at 20 and 40 days after germination was useful to improve the upland rice productivity under variable rainfall. Nitrogen, Phosphorus and Potash, along with Sulphur and Zinc, have a marked effect on increasing rice yields by promoting growth and better movement of photosynthesis from the leaf to the grain (Dong *et al*., 1981). Raja (1966) observed that as compared to application of 60 1b N/ ac alone, 60 1b N plus 25 1b P_2O_5/ac gave the higher grain yields and that the application of fertilizer in 2 doses is more effective than applying it in one dose.

Bahmaniar and Ranjbar (2007) reported that grain yield, number of grain per panicle, number of tiller, plant height, length of flag leaf, total and shoot dry matter, 1000 grain weight and harvest index have been increased by N application in field conditions, and further that simultaneous application of N and K have increasingly affected on grain yield, plant height, shoot dry matter and harvest index in field conditions and on plant height, length of flag leaf and shoot dry matter in pot conditions ($p \leq 0.05$).

Hoffman and Elias-Azar (1965) reported that the intensity of phosphates activity in soils has been found to be related to soil physical and chemical properties, such as soil pH, contents of nitrogen, organic matter and plant available phosphorus. Khan (1970) reported that the addition of fertilizer P increases phosphates activity in soil. The phosphates activity in soils mediates the release of inorganic phosphorus from organically bound phosphorus returned to soil in leaf-litter, dead root systems and other organic debris.

In soil ecosystems, phosphates and arylsulphates are believed to play pivotal roles in phosphorous and sulphur cycle, respectively (Speir and Ross, 1978). Phosphatase has also been shown to vary with soil depth (Harison,1979), Seasonal (Harison and Pearce, 1979), soil type parent material (Burangulova and Khaziev,1965). Plants may take up some forms of organic P from soils, however, most organic phosphate must first undergo an enzymatic hydrolysis to inorganic P to become available for plants (Islam *et al*., 1979).

Kang and Freeman (1999) revealed that phosphatase enzyme mediates the release of inorganic phosphorus from organically bound phosphorus returned to soil as litter and other organic debris. Raju and Devi (2005) reported that the mean nutrient response of hybrid rice to N and P was maximum at 120kg N + 60kg P_2O_5 ha^{-1} and closely followed by 90 kg N + 60 kg P_2O_5 ha^{-1} and 150 kg N + 60 kg $P_2O_5^{-1}$ respectively.

Subbaiah *et al.* (2001) showed that higher cost benefit cost ratio for different NP levels under different hybrids is highest at 90 kg + 40kg P_2O_5 ha^{-1} followed by 90kg N+60 kg P_2O_5 ha^{-1} and minimum at 120kg N+60 kg P_2O_5 ha^{-1}. Waksman (1922) studied the effect of chemical fertilizers on the soil micro flora. Waksman and Starkey (1924) reported that various chemicals fertilizers like potassium chloride, calcium phosphate, potassium nitrate, ammonium sulphate and wood ash extract exert a beneficial effect on the fungal population.

Summer and Somers (1953) opined that a large number of microorganisms including bacteria, actinomycetes and fungi might hydrolyze urea intracellular. Macura (1958) reported marked increase in the number of bacteria and fungi in the rhizosphere following the spraying of urea.

Mishra (1971) studied the rhizosphere fungal flora of *Oryza sativa* L.grown in pots containing different doses of ammonium nitrate, urea, super phosphate and potassium sulphate, and found that rhizosphere and non-rhizosphere fungal population was always higher in fertilized soils than those of corresponding controls. Trolldenier (1973) reported that number of bacteria in the rhizosphere depends on the chemical state of nitrogen and potassium fertilizers.

Mishra and Das (1975) studied the effect of six different combinations of inorganic fertilizers and farmyard manure on the bacterial flora in the rhizosphere of the transplanted paddy, at tillering, pre-flowering and grain formation stages, and observed that the bacterial population of rhizosphere in both treated and untreated soils was significantly higher than that found in corresponding non-rhizosphere soils. Ventura and Yoshida (1977) reported that the most of the ammonia volatilization losses occurred during the first 9 days application of nitrogen fertilizers to rice soils. Trolldenier (1981) reported that rhizosphere microorganisms are influenced directly and indirectly by fertilization.

Sahrawat (1982) suggested that for efficient and judicious use of fertilizer nitrogen, it is imperative to assess the nitrogen supplying power of soils, and that soil organic carbon and total nitrogen contents seem to be good indices of available nitrogen in tropical wetland rice soils. Domsch (1986) indicated that in agricultural soils, ploughing, tillage, application of fertilizers and biocides and type of cultivation affect the microorganisms. Kang (1993) reported that repeated application of inorganic fertilizers nutrient also cause a decline in soil productivity through excessive soil erosion, nutrient runoff and deteriorated soil chemical properties. Elliot and Lynch (1994) and Pankhurst *et al*. (1996) indicated that broad functional diversity might be additionally important in influencing the resilience of soils.

Agbenin and Goladi (1997) stated that continuous cultivation caused significant losses of C, N and P, and that the combination of farmyard manure with N+P and N+P+K fertilization enabled C, N and P to be maintained equal to, or greater than, the native site soil. Katayama *et al.* (1998) reported that the applications of fertilizers are known to directly affect often the composition of the soil microbial community under plant monoculture and fallow soils (Ruppel and Makswitat, 1998). Plant species are also known to influence microbial (Grayston *et al.*,1998) and micro-faunal (Yeates *et al.,* 1997) diversity of the rhizosphere, and microbial activity.

Bardgett and Shine (1999) reported that the microbial community in soil is indirectly affected by the changes in the plant community composition, which result from the application of fertilizers. The urease and alkaline phosphatase activities of soils increased significantly with a combination of inorganic fertilizers and organic amendments (Goyal *et al.*, 1999). Saviozzi *et al.* (1999) reported that only farm yard manure is inadequate for the restoration of soil organic matter lost as a consequence of cultivation. Sarathchandra *et al.* (2001) determined the effect of fertilizer inputs on biological characteristic that may be used as indicator of soil quality. Animal manure-P is relatively more mobile but less available for plants than inorganic fertilizer-P. Long-term application of cattle manure did not result in excessive accumulation of P in the surface 0-30 cm soils, but promoted microbiological activities and P cycling in soil (Parham *et al*., 2002).

2.3.5 Management and role of Nitrogen (N) in rice cultivation

Nitrogen is the nutrient most limiting rice production worldwide (Khan *et al*., 2004). In Asia, where more than 90% of the world's rice is produced, about 60% of the N fertilizer consumed is used on rice (Stangel and De Dutta, 1985). Ladha and People (1995) stated that subsistence rice farming of the pre-chemical era sustained the Nitrogen status of soils by maintaining equilibrium between N loss from crop harvest and N gain from biological Nitrogen fixation. Nitrogen deficiency is the most common nutritional disorder of rice, and high yields are not possible without nitrogen added in the form of fertilizers or organic manures (Singh, 1993).

Dobermann *et al.* (2000) reported that increased solar radiation, increased N rate, and improved timing of N applications accounted for the restoration of yields in the dry season. Van Gestel *et al*. (1993) stated that soil aeration or soil drying has increased N mineralization. Ladha *et al. (*2000) concluded that in a lowland continuous double-rice cropping system, both total and plant-available soil N pools are maintained on a long-term basis whether urea or green manure is the source of Nitrogen. It is reported that in rice–rice systems biological N_2 fixation plays a vital role in replenishing the soil N pool by helping to maintain a good balance between N losses and N gains (Ladha, 1998).

Ladha *et al.* (1993) reported that the efficiency with which the nitrogen absorbed in the rice crop is utilized towards grain production and other production parameters are important component of overall utilization efficiency. Craswell *et al*. (1984) and Cassman *et al*. (1994 & 1996) opined that the N absorption efficiency is defined in terms of producing unit of grain yield per unit of N absorbed from the soil flood water system.

The increase in N content (%) and N uptake (kg/ha) with increase in the application of fertilizer nitrogen up to 120 kg/ha have been reported by several researchers (Dubey and Bisen,1989; Pradeep *et al.*, 1994; Wani *et al.*, 1999; Dar *et al.*, 2002; Velu and Ramanathan, 2000; Paikaray *et al.*, 2002; Sudhakar *et al*., 2003; Budhar and Tamilselvan, 2003).

The successive increase in the rates of nitrogen application increased the N concentration and N uptake by biomass at all the growth stages of rice (Hatwar *et al*., 1992; Mahajan and Tripathi, 1992; Bhardwaj and Singh, 1993; Somasundaram *et al*., 2002). However, Adhikari (2003) found that increase N did not have any significant influence on N concentration in plant, but significantly increased the N uptake by plants. Similarly, it was revealed that N at 100 and 150 kg/ha resulted in accumulation of higher N in both grain and straw (Naw Lar, 2004). Both apparent N recovery (%) and agronomic N use efficiency (kg grain/ kg N are correlated with N uptake, grain yield as well as N added to the crop. In general, there is a decreasing trend of these parameters values reflected in higher N utilization by rice (Shivay and Singh, 2003).

Singh and Verma (1999) observed that the effect of integrated nitrogen management on yield attributes viz., number of tillers/ hill, panicle length, grains / panicle and grain yield of rice were significant. Kwon and Kang (1969) stated that when N was top- dressed to aid panicle development, percentage of degenerated primary panicle branches increases with N level from 3.1 per cent with 60 kg N/ha to 4.75 with 120 kg/ha.

Bhandari *et al*. (1992) reported that grain yields of rice increased significantly with increasing levels of NPK fertilizers up to 100 per cent recommended dose in both the crops. Tiwana *et al*. (1999) found that significantly higher grain yields of rice and wheat were obtained with maximum economic yield fertilizer level (MEYFL) of 180, 30 and 30kg/ha and 180,60 and 30kg/ha of N, P_2O_5 and K_2O_5/ha over the recommended fertilizer level (RFL) of 120, 30 and 30kg/ha and 120, 60 and 30 kg/ha N, P_2O_5 and K_2O, respectively for rice.

Patra *et al*. (2000) observed that the application of 100% recommended NPK through fertilizer to each of rice recorded the maximum effective tiller / m^2 and grains/ panicle, followed by application of 100 per cent NPK to rice. Sharma and Bali (2001) reported that grain yields of rice increased significantly with the increasing levels of NPK up to an additional 25 per cent over the recommended doses.

Singh *et al*. (1998) reported that rice is grown in an environment, prone to N loses due to which application methods of N have been developed to meet the demand of N to the rice and further stated that higher N- fertilizer recovery rate recorded with single pre-plant application of the controlled release urea over split application of urea at varying level of nitrogen in shallow lowland in Eastern India.

2.3.6 Role of bio-fertilizers in rice cultivation.

The role of biofertilizers rice cultivation and production was studied by various workers (Ventura and Ladha, 1997; Vaishampayan *et al*., 2002; Sangam *et al*., 2006; Satapathy and Chand, 2008). Biofertilizers like *Rhizobium, Azotobacter, Azosprillum,* blue green algae (BGA), azolla, phosphate solubilizing organisms, vescicular arbuscular mycorrhyza (VAM) can become an important component of integrated plant nutrient supply system (Swarnalakshmi *et al*., 2006; Tewatia *et al*., 2007) specially under low-land rice cultivation and dryland agriculture, where only low levels of fertilizers are applied.

Roger (1995) summarized the current status of utilization of N_2 fixing organisms as biofertilizer in rice cultivation, and stated that biological N_2 fixation has been the most effective system for sustaining production in low-input traditional rice cultivation. Castro *et al.* (2002) observed that rice supplemented with Azolla showed an increase in the number of grains per panicle/m^2 and crop yield. Singh and Datta (2007) reported that application of diazotrophic cyanobacteria *Anabaena variabilis,* as biofertilizer for rice cultivation has beneficial effect on crop productivity and maintenance of soil fertility. Gupta *et al.* (1989) stated that *Azospirillum,* BGA and *Azolla* play a vital role in promoting rice productivity. It was also reported that repeated usage of Phosphobacteria along with inorganic fertilizers resulted in higher crop value (Santhi and Selvakumari, 1999).

2.3.7 Integrated Nutrient Management in rice cultivation

Several studies were carried out by various workers on the integrated nutrient management in rice cultivation (Gaur *et al.,* 1972; Tan, 1992; Padalia, 1975; Mishra and Sharma, 1997). Integrated farming system approach is not only a reliable way of obtaining fairly high productivity with substantial fertilizer economy but also a concept of ecological soundness leading to sustainable agriculture (Swaminathan, 1987).

Sudha and Chandini (2002) stated that higher inorganic nutrient levels alone deteriorate soil health, an integration of organic manures and inorganic nutrients is the best solution for yield improvement, and further that improvement in the uptake of nutrients was also mainly associated with the increase in dry matter production with increased levels of organic matter addition. Jayanathi *et al.* (2003) reported that recycled organic residues of crops and allied activities could supplement the chemical fertilizers and would certainly pave way for increasing the productivity, profitability and also help in sustaining the nutrient potential of the soil under lowland farms. Increased uptake of P and K with higher doses of organic manure has been reported by Sharma and Mittra (1991) and that of N by Mishra and Sharma (1997).

Organic manure has been recorded to enhance the efficiency and reduce the requirement of chemical fertilizers (Khan *et al.,* 2004). Partial nitrogen substitution through organic manure recorded significant superiority in yield over farmer’s practice (Singh and Gangwar, 2000). For sustainability in crop production, it is neither chemical fertilizer nor organic manures alone but their integrated use has been observed to be highly beneficial (Khan *et al.*, 2000).

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Chapter- 3

STUDY AREA

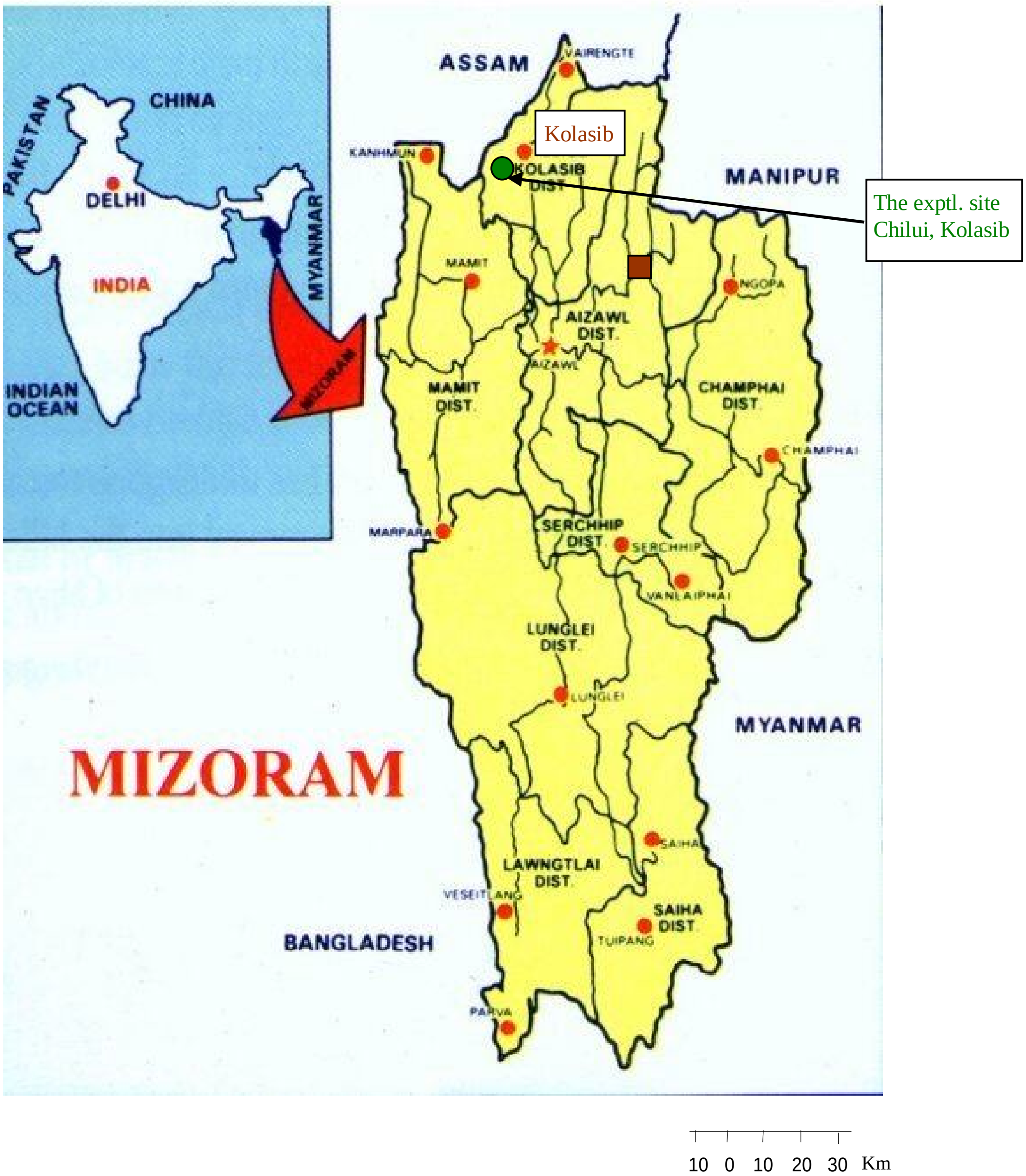
3.1 Geographical location

3.1.1 Mizoram

With a geographical area of over 21,087 Sq km and perched on the high hills of the North Eastern part of the country, Mizoram possibly has the most difficult terrain, over 80% of the total geographical area being hilly and with steep hills separated by rivers flowing North to South, thus, creating innumerable hurdles in intra-state as well as inter-state communication. This landlocked area is bounded by foreign countries on all sides except for a small stretch that rubs shoulder with Assam, Manipur and Tripura. Its International border, which is about 722 km, is almost 3 times longer than its border with the mainland. Mizoram lies between 21^{o} 30' N -23^{o}15'N Latitudes and 92^{o}16'E – 93^{o}26'E longitudes (Rintluanga, 1994). Mizoram is bounded on the North side by Cachar district of Assam and Manipur state; on the East and South by Chin Hills of Myanmar; on the West by Chittagong hill tracts of Bangladesh and Tripura.

The topography of Mizoram is, by and large, mountainous with precipitous slopes forming deep gorges culminating into several streams and rivers. Almost all the hill ranges traverse in the North-South direction. The eastern part of Mizoram is at a higher elevation compared to the western part. The average height of hill ranges is around 920m, although the highest peak, the Blue Mountain (Phawngpui), goes upto 2165 m.

Map 1: Map of Mizoram showing location of the experimental site (Chilui, Kolasib)



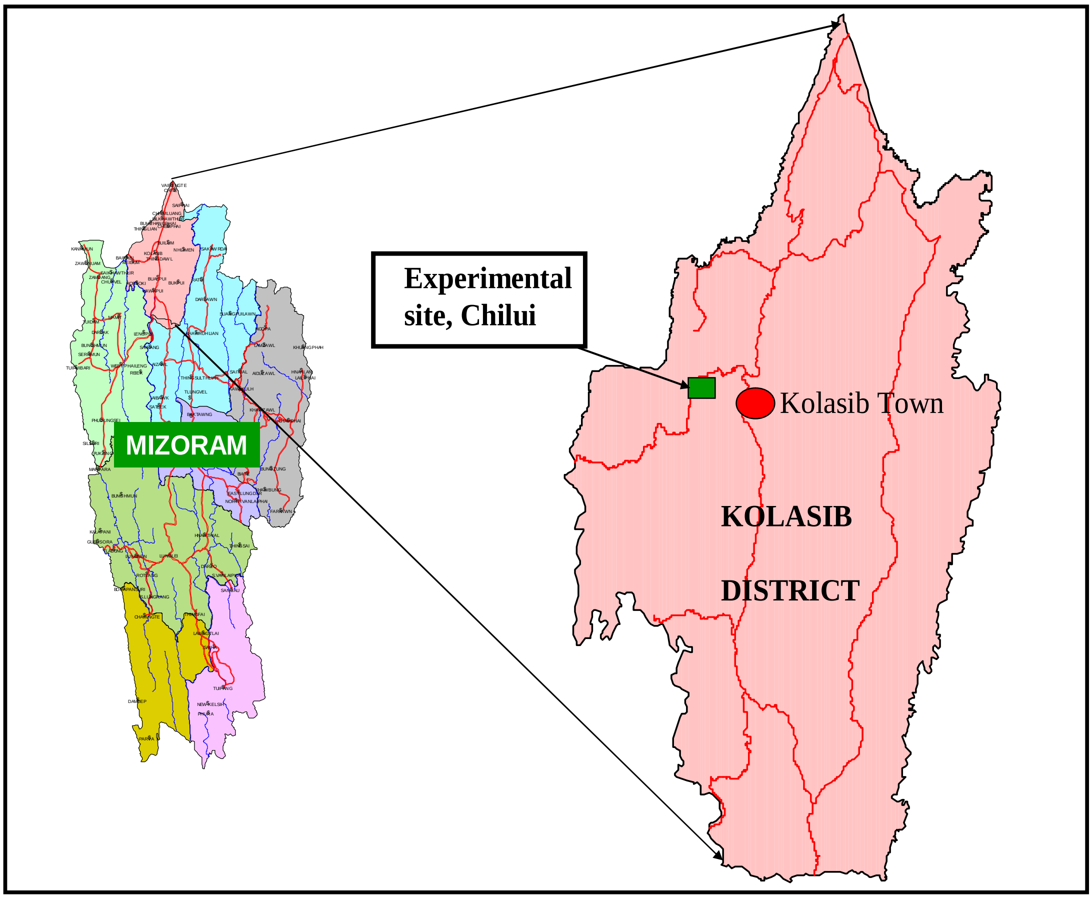
3.1.2 Kolasib district

Kolasib district is situated in the northern part of Mizoram between a latitude of 23^o 70^o S and 24^o 50^o N and 92^o 50^o W – 93^oE longitude. It is bounded by Cachar and Hailakandi districts of Assam in the north and north-west respectively; in the south and east by Aizawl district and in the south-west by Mamit district.

3.1.3 Location of the experimental field

The experimental field is located at 5 kms away from Kolasib town along the side of Bairabi main road at 24^O 15.19.94^O N Latitude and 92^O 39 .23.05^O E longitude. The elevation of the study site is 218 ft above mean sea level (Map 2).

Map 2: Map of Mizoram and Kolasib district showing location of the experimental site (Chilui)



3.2 Climate and weather

3.2.1 Mizoram

Mizoram has a pleasant climate. The upper part of the hills are predictably cold, cool during the summer, while the lower reaches are relatively warm and humid. Storms break out during March-April, just before or around the summer. During winter, the mean air temperature varies from 11°C to 21°C and in the summer it varies between 20°C to 32°C. The entire state is under the direct influence of the South west monsoon. The rainy season normally starts from June and continues upto September and the rainfall is more or less evenly distributed throughout the state excepting the South-western parts that generally receive slightly higher rainfall.

3.2.2 Kolasib

Owing to its location, physiographic characteristics and the influence of the southwest maritime air mass, Kolasib district enjoys a typical monsoon type of climate. It is humid and warm in summer and dry and cool in winter. The climate of the study site is also influenced by the periodic cyclonic disturbances, local mountain and valley breezes. The study area falls under sub-tropical with hot and wet summer and moderately cold and dry winter. May and June are the hottest months in a year with maximum air temperature of 36 ± 2^{o} C. The air temperature is lowest in the months of January with minimum temperature of $7 \pm 2^{O}C$. The mean Relative Humidity (RH %) increases from May to August reaches maximum humidity with on-set of North East monsoon and the RH is lowest during dry period of January to March.

3. 3 Soils

3.3.1 Mizoram

The soils of Mizoram are dominated by sedimentary formation. These are generally young, immature, mostly developed from parent materials such as fereginous sandstones and shale. Three soil of Mizoram are classified into three orders such as ultisols, inceptisols and entisols (Sarkar and Nandy, 1976; Singh and Dutta, 1989). The soils in the foot hills are collocium deposit and in plain areas alluvial deposits are predominant. The soils as a whole are well drained except in few valley flat lands. The soils in general have low inherent fertility viz. bases and mineral reserves. The soils in the hills are strongly acidic in reaction, whereas the soils in alluvial deposits are less acidic in nature (Anon., 1991a).

The surface soils of the hilly terrains of Mizoram are dark, highly leached and poor in bases, rich in iron and mostly acidic with pH values ranging from 4.5 to 6.0. The soils are well drained, deep to very deep, rich in organic carbon, low in available phosphorus content and high in available potash. The surface soil textures are loam to clay loam with clay content increasing with depth. The percentages of clay, silt and sand within 50cm of the surface in most cases are 20-30 per cent and 25-45 per cent respectively. The pH and organic carbon contents decrease and clay increases with depth. The base saturation above a lithic or paralithic contact is mostly low which is below 35 per cent (Anon., 1991a). They are capable of providing substantial oxygen supply for plant growth and have capability to retain moisture and maintain supply through the growing seasons of most crops.

3.3.2 Kolasib district

The soils in the valley flat lands of Kolasib District are dominated mainly by loose sedimentary formations. The soils are brown to dark brown, poor in bases, moderately acidic to neutral with pH ranging from 6.5 to 7.5, medium to high in organic carbon content, low available phosphate and medium to high available potash. These are deep to very deep but moderately to poorly drained. The texture of the soil is mostly sandy loam to sandy clay loam. The percentage of clay, silt and sand in the upper 50cm ranges 15-35 per cent, 5-34 per cent and 40-75 per cent respectively (Anon., 2010).

3.4 Forest and vegetation

3.4.1 Mizoram

The state of Mizoram falls under the tropical semi-evergreen belt. However, due to reduced jhum cycles it is replaced by bamboo interspersed with secondary forests. Various authors have classified the vegetation of the state. Based on Champion and Seth's Classification (1968) the following types of forest are found to be present in the state : (a) Tropical wet-evergreen forests (up to 900 m), (b) Tropical semi-evergreen forests (900–1500m), and (c) Montane sub-tropical pine forests (1500–2158 m).

Of the three types, the most important one is Tropical Wet Evergreen Forests and are found in the Southern and Western parts of Mizoram. The common timber species found in these areas are *Dipterocarpus turbinatus, Artocarpus chaplasa, Terminalia myriocarpa, Duabanga sonneratoides, Michelia champaca* growing in association with undergrowth (Anon., 2003).

Tropical semi-evergreen forest covers the central bio-geographic zone and the coverage is approximately 50 per cent of the total geographical area. The common tree species are *Michelia champaca, Schima wallichi, Gmelina arborea, Castanopsis tribuloidies* etc, Bamboo species like *Melocanna baccifera* and *Dendrocalamus* spp and canes are abundant, especially in shady and low lying areas (Anon. 2003). The montane sub-tropical pine forest occurs in the eastern fringes bordering Myanmar and approximately extending from 1500 – 2158 msl and constitutes about 24 per cent of the total geographical area. The common tree species are *Pinus kesiya, Rhododendron arboreum, Quercus serrata, Quercus griffithii,* etc. (Anon., 2003).

3.4.2 Kolasib district

Kolasib district falls under the Tropical Wet Evergreen Forests. The common tree species found here are *Acrocarpus fraxinifolius, Adina cordifolia, Albizzia lebbek, Areca catechu, Artocarpus chaplasa, Bauhnia variegata, Bombax ceiba, Butea parviflora, Callicarpa arborea, Duabanga grandiflora, Erythrina stricta, Emblica officinalis, Ficus hirsuta, Garuga pinnata, Gmelina arborea, Lagerstroemia parviflora, Parkia rouxburghii, Sapium baccatum, Schima wallichi, Sterculia villosa* and *Tectona grandis.* The dominant herb species growing around the experimental plot are *Mikania micrantha, Euphatorium odoratum, Saccharum spontaneum* and *Imperata cylindrica*. *Thysanolaena maxima* is also found in abundance.

3.5 Landuse pattern and cropping system

3.5.1 Mizoram

Land within Mizoram, like some other states of Northeast, is in the customary ownership of the communities. Village lands falling within the jurisdiction of villages are controlled by the Village Council(s) and land distribution is done as per the customary practice to the villagers for jhuming and other farming activities. The land use pattern of the State has been affected primarily by land capability as determined by characteristics of micro and mini watersheds. Besides, several social and legal factors such as land tenure system etc. also affect the land use pattern.

Agriculture is the mainstay for about 60 per cent of the population of Mizoram. Of the total area only 21 percent is put on the paddy / seasonal crops. As high as 63 per cent of the total crop area is under shifting cultivation. The crops grown in the jhum are mixed. The principal crop is paddy and others are maize, cucumber, beans arum ginger mustard sesame, cotton etc. There is vast scope for cultivation of tapioca, sugarcane, cotton, pulses and oilseeds in the State. Oilseeds crops like sesame, mustard and soybean are growing well in the state. Paddy occupies almost 50 per cent of the total cropped area and more than 88 per cent of the total area under food grains. Mainly two types of paddy seeds are sown in the same field – early paddy and principal paddy. Yield of early paddy is rather poor but it ripens early and provides sustenance till the principal paddy is harvested. In spite of the fact that the rice being the most important crop occupying the largest share in area and production, Mizoram is still not self sufficient in rice production (Anon., 2010).

3.5.2 Kolasib district

Majority of the population in Kolasib district are mostly shifting cultivators. Rice cultivation in lowland and traditional shifting cultivation in hill slopes is the main livelihood of the villagers. In general, the economic condition of the rural people is low. The crop productivity per unit area is low due to poor technical-know-how and biophysical causes associated with the land. Tenancy arrangements are becoming more common in Kolasib district, usually in respect of terrace and valley land, although at present they probably represent less than 10 per cent of the land area. All tenancies are governed by customary practices and are usually on a crop share basis with rents fixed at 33-50 per cent of the production. Most of such tenants are coming from the neighbouring of state of Assam and earn their livelihood at the cost of the local population.

3.9 Cropping history of the experimental site:

The cropping history of the experimental field was collected from the statistical abstract (Anon., 2007) which is given in the table below:

Table 1.3 : Cropping history of the experimental site.

Year	**Kharif season**	**Rabi season**	**Remark**
2001	Rice	Fallow	No fertilizer apllied
2002	Rice	-do-	-do-
2003	Rice	-do-	-do-
2004	Rice	-do-	-do-
2005*	Rice	-do-	Present Experiment
2006*	Rice	-do-	-do-

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Chapter- 4

EXPERIMENTAL DESIGN AND METHODOLOGY

The investigations reported in this thesis were carried out during wet seasons in the months of May to October in the year 2005 and 2006. The experiment was performed using Randomized Block Design (RBD) with three replications. There were 12 sub plots in each replication (3 Rice cultivars x 4 nutrients) and the total sub – plots were 36 for 3 replications. The size of each sub - plot is 4m x 4m (16 sq m) and 0.5 gap between the sub-plots.

4. 2 Experimental design

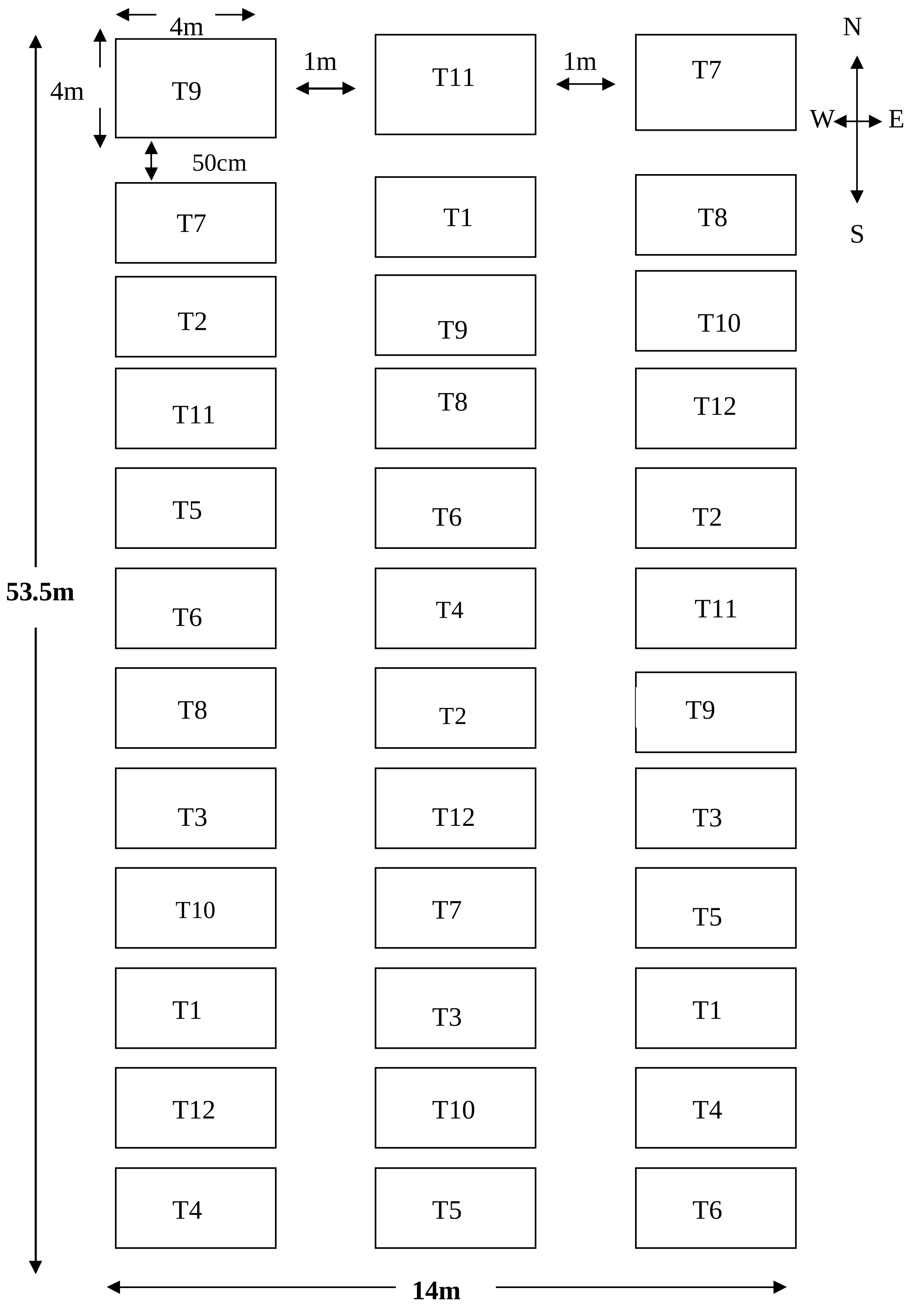
Experimental Design	:	Randomized Block Design (RBD)
Replications	:	3 (Three)
Sub-plot size	:	4m x 4m (16 Sq.m)
Treatments	:	(12 Twelve)
Nutrient Application	:	4 (Four)

i)	Control	=	N_o
ii)	NPK	=	N_1
iii)	NPK+ Biofertilizers	=	N_1
iv)	Biofertilizers	=	N_3

Rice cultivars : 3 (Three)

i)	IR- 64	=	CV_1
ii)	RCP L – I - 87-4 (Lumpanas)	=	CV_2
iii)	Shahsarang	=	CV_3

4.3 Experimental Layout



4.4 Treatments Details

T_1	=	CV_1	+	N_0
T_2	=	CV_1	+	N_1
T_3	=	CV_1	+	N_2
T_4	=	CV_1	+	N_3
T_5	=	CV_2	+	N_0
T_6	=	CV_2	+	N_1
T_7	=	CV_2	+	N_2
T_8	=	CV_2	+	N_3
T_9	=	CV_3	+	N_0
T_{10}	=	CV_3	+	N_1
T_{11}	=	CV_3	+	N_2
T_{12}	=	CV_3	+	N_3

4.5.1 Application of NPK fertilizer:

A mixture of Urea(N), Super phosphate (P) and Muriate of Potash (K) is applied in the field at 80, 60 and 40 kg / ha respectively at two split doses in the main field before and after transplanting of rice. The full dose of Phosphorus & Potassium with half dose of Nitrogen was applied in two splits dose at tillering and panicle initiation stages.

4.5.2 Application of Biofertilizer:

Azospirillum and Phosphobacter are used as a biofertilizer in the present study. These are symbiotic bacteria and are important biofertilizers used in rice cultivation. Azospirillum and Phosphobacter treatment is given in the seed and seedlings of rice before transplanting. 200 gm powder of Azospirillum and

Phosphobacter in equal quantity is dissolved in 450 ml of water where the seeds are soaked one night before sowing in the nursery bed and dried. The root portions of transplanted rice seedlings are dipped in bacterial suspension for 15-30 minutes and then they are transplanted.

4.6 Characteristics of Rice cultivars used in the experiment

4.6.1 RCPL 1 – 87- 4 (Lumpanah 1)

The rice cultivar RCPL 1 – 87- 4 (Lumpanah 1) is a selection from the cross IR 29 x Ngoba, bred at ICAR Complex for NEH Region, Meghalaya. It is a high yielding (5.5 t/ha or 55 qntl / ha) maturing in 125-165 days. It is a semi-dwarf variety (80-85 cm.) plant parts green panicle medium and well exorted. It is recommended for lowland ecology of mid altitude areas and the recommended time of sowing for Kharif is June-July. Grains long bold, Kernal colour white, grain chalk opaque centre. It is a non-scented variety. RCPL 1 – 87- 4 (Lumpanah 1) is moderately resistant to stem borer and gall midge, and also moderately resistant to leaf and neck blast but tolerant to temporary flooding and mild iron toxicity.

4.6.2 Shahsarang

Shahsarang is a selection from the cross Mirikrak x Rasi and released by State variety release committee of Meghalaya in 2002. It is a high yielding variety with yield potential 5-5.5 t/ha, and is a medium duration variety which takes around 140-165 days to mature. It is a semi-dwarf variety (90-95 cm) plant parts green, medium size panicle and well exerted tillers. It is recommended for lowland ecology of mid altitude areas. The recommended time of sowing for Kharif is June-July. Grains short bold, kernel colour is red but becomes white after milling, grain chalk opaque centre. Shahsarang is a non-scented rice and the head rice recovery is 61.6%. It is moderately resistant to stem borer and gall midge and also moderately resistant to leaf and neck blast. It is tolerant to temporary flooding and high iron toxicity.

4.6.3 IR – 64

It is Indicia type rice variety developed at IRRI, by using parentage, IR 5657-35-2-1/IR 2061465-1-5-5 and its pedigree is IR 18348-36-3-3. IR-64 has a high yield capacity of 5-6 t/ha (50-60 qntl/ha). It is a medium early duration variety and takes about 110-125 days to mature. It is a semi dwarf grows about 115-120 cm tall. It's distinguishing character is erect with dark green leaves, profuse and compact tillering, long slender grain straw colour husk. The grains are fine with a white colour, 10.1 mm in length and 2.9 mm in breath. It is recommended for irrigated condition.

4.7.1 Details of cultural operations

The detail of cultural operations practiced during the course of the present investigation is given in the table below:

Table 1.4 : Details of cultural operations

Name of operations	**Dates of operations**	
	2005	**2006**
Preparation of nursery		
Ploughing	24. 5. 2005	26. 5. 2006
Sowing	30. 5. 2005	01. 6. 2006
Weeding	15. 5. 2005	17. 6. 2006
Main field operation		
Ploughing	15. 5. 2005	17. 5. 2006
Puddling	16. 5. 2005	18. 5. 2006
Puddling	17. 5. 2005	19. 5. 2006
Layout and bunding	22. 5. 2005	23. 5. 2006
Fertilizer application as basal	29. 5. 2005	30. 5. 2006
Transplanting	23.6. 2005	24. 6. 2006
Hand weeding 1st	20. 7. 2005	22. 7. 2006
1st Dose of nutrient application	22. 7. 2005	25. 7. 2006
Biometrict observations	23. 7. 2005	27. 7. 2006
2nd nutrient application	20. 8. 2005	24. 8. 2006
Biometrict observations	23. 8. 2005	29. 8. 2006
Biometrict observations	21. 9. 2005	26. 9. 2006
Harvesting of border rows	18. 10. 2005	16. 10. 2006
Harvesting of net plot	21. 10. 2005	19. 10. 2006
Threshing and drying	23. 10. 2005	22. 10. 2006

4.7.2 Preparation of nursery

In summer, two ploughings were done in the nursery area. For final preparation, the nursery area was puddle in standing water and a bed of 10mx 1m was prepared for each variety. No fertilizer and Biofertilizer were applied in the nursery. Sprouted seeds of rice variety of IR-64, Shahsarang and Lumpanas were broadcasted uniformly on the wet nursery field and covered with thin layer of compost. Then, the seedlings were allowed to grow for a period of 24 days.

4.7.3 Major field operations

The experimental field was filled with water and puddles twice using a power tiller and was leveled with the help of blanks. The bunds and channels were made as per requirement of the experimental layout.

i) Transplanting of rice seedlings in the experimental field

Two to three healthy rice seedlings of 25 day were planted at a spacing of 20 cm row to row and 10 cm plant to plant.

ii) Gap filling

A week after transplanting of rice, the experimental plots were carefully inspected and found that no gap filling and thinning were necessary as plant population was found uniform.

iii) Intercultural Operations

Two hand – weedings were done at 30 and 60 days after transplanting (DAT) of rice seedlings.

iv) Irrigation

As the experimental site is rain-fed lowland area no artificial irrigation was available. As such, there is enough standing water during the monsoon season for rice cultivation. As such the standing water was adjusted according to the requirement. At the time of transplanting in the field the standing water was adjusted to depth of 5 ± 2 cm and as per the requirement of the treatment the standing water was adjusted and stopped 10 days before harvesting.

v) Harvesting and threshing

Rice were harvested at dried ripen stages from each net plot, after 3-4 days in the field. Grains were cleaned and weighed from each net plot for expressing yield in kg ha^{-1}. The weight of straw rice were also recorded separately and expressed as threshed as kg ha^{-1}. Rice was harvested manually and threshed plot wise by mechanically operated thresher.

4.8 Details of collection of Data.

4.8.1 Soil Sample Collection

Soil samples were collected from 12 locations in each replication using spade from a depth of 0-30cm on one day before the start of experiment and after the harvesting of crop. Soil samples were collected, at a regular interval from each plot and packed in polythene bag. The soil samples were serially registered giving all the necessary information in the information sheets as given in table below:

Table 1.5 : Information sheet to accompany soil sample

Sl. No.	Place of collection	Sample No	Depth of collection of samples	Site description
1	2	3	4	5

4.8.2 Processing of soil samples

The samples were air dried and crushed and passed through sieves of finer mesh size (Ghosh *et al.*, 1983).

4.8.3 Determination of pH

The pH of the soil samples was measured by the methods of soil to water ratio of 1:2. Soil sample of 20 g was taken in a 100ml beaker to which 40 ml of water was added. The suspension was stirred at regular intervals for 30 minutes and the pH was recorded with the help of pH meter.

4.8.4 Estimation of Organic Carbon

The method given by Walkley and Black (1934) was adopted to estimate Organic Carbon. Soil samples were grounded and completely passed through 0.2mm sieve, and 1.00 g of it was kept at the bottom of a dry 500 ml. conical flask; then 10 ml of 1N $K_2Cr_2O_7$ was pipetted in and swirled a little.

The flask was kept on asbestos sheet. Then 20 ml of H_2SO_4 (containing 1.25 % Ag_2SO_4) was run in and swirled again two or three times. The flask was allowed to stand for 30 minutes; thereafter, 200 ml of distilled water was added. Thereafter, 10 ml of phosphoric acid or 0.5 g Sodium Fluoride and 1ml. of diphenylamine indicator was added and titrated with Ferrous Ammonium

Sulphate solution till the colour flashes from the blue violet to green. Simultaneously, a blank was run without soil. The result was calculated by the following method:

$$\text{Organic Carbon (\%)} = \frac{10(B-T) \times 0.003}{B} \times \frac{100}{\text{Wt. of soil}}$$

(Where B= volume (in ml) of ferrous ammonium sulphate solution required for blank titration; & T = volume of ferrous ammonium sulphate needed for soil sample).

4.8.5 Estimation of Nitrogen (N) content

The procedure for the analysis of Nitrogen content in the soil samples was divided into three steps, viz. digestion, distillation and titration.

Digestion : 1gm of soil sample was taken in each of Kjeldahl flask for digestion tube and 10ml Conc. Sulphuric Acid was added in each flask. Also, 3gms of catalyst mixture (Kjeldahl catalyst) was added in each of digestion tube and the balance without a soil sample was maintained. Temperature was set at 420^{o}C and it was digested for approximately 1hr till the sample became green colour. Then, the digester was switched off and the flask was allowed to cool.

Distillation : Firstly, the conical flask was loaded (with 20ml of 40 % Boric acid) in the receiver side which will be pink colour as it contain 3 drops of Bromo cresol green and Methyl red solution of 5 drops. Then, the digested sample was loaded for distillation. Again, 40% of NaOH was added slowly in automode in the order of 10ml each time till the color changes from bluish green to brown precipitation and the process time was set for 6 minutes for soil sample. After 6 minutes, the sample colour in a conical flask changed from pink to green colour which was the end point. The flask was then prepared for titration.

Titration : The distillated was then titrated against 0.1 N HCl. The titration was stopped when the colour changed from green to pale pink.

$$\% \text{ of Nitrogen} = \frac{14 \times \text{Titrant value} \times \text{Normality of acid} \times 100}{1000 \times \text{Sample wt.}}$$

4.8.6 Estimation of phosphorus

The methods developed by Olsen *et al.* (1954) and Dickman & Brays (1940) has been followed for estimation of Phosphorus in the soil samples. 2.5 g of the soil sample is taken in 100 ml conical flask, and a little of Dargo G 60 or equivalent grade of activated carbon (free of phosphorus) is added followed by 50ml of Olsen's reagent. A blank is run without soil. Then the flasks are shaken for 30 minutes on a platform type shaker and the contents are filtered immediately through dry filter paper (Whatman No.1) into clean and dry beakers or vials.

In the filtrate phosphorus is estimated colorimetrically by Dickman and Bray's procedure (Dickman & Brays, 1940). 5 ml of soil extract is pipette into a 25 ml volumetric flask to which 5 ml of the Dickman and Bray's reagent is poured in. The rock of the flask is washed down and the content is diluted to about 22 ml. Thereafter, 1 ml of the diluted stannous chloride solution is added and volume makes up to the mark level. The intensity of the blue colour is measured (using 600 mμ filter) just after 10 minutes and the concentration of Phosphorus is determined from the standard curve. With each sample a blank is maintained.

4.8.7 Estimation of Potassium

Available Potassium (K) incorporates both exchangeable and water soluble forms of the nutrient present in the soil. The estimation of K of water soluble forms has been carried out with the help of Flame Photometer as suggested by Ghosh *et al.* (1983). 5gm of soil sample is shaken with 25ml of normal of Ammonium acetate (pH 7) for 5 minutes and filtered immediately through a dry filter paper (Whatman No.1). First few ml of the filtrate is rejected. Potassium concentration in the extract is determined in the flame photometer.

4.9 Biometrical observations.

For sampling and recording plant growth observations two rows (second from either side) were selected. The plants samples were placed in polythene bags after carefully washing of roofs. A wetted cotton/ tissue paper is placed in polythene bag to maintain turgour pressure of leaf and brought to laboratory for analysis. First sample was taken at 30 days after transplanting (DAT) and subsequent samples were taken at 30days interval and the last sample was taken at maturity.

4.9.1 Growth parameters of rice

i) **Plant height:** Five hills plants of rice were selected randomly from each plot and heights was measured from the ground level, up to the last leaf at 30-60 DAT and from ground level to the tip of the longest panicle at harvest. The mean values were computed and expressed in cm.

ii) **Number of tillers:** Number of tillers of five hills of rice was counted at 30 and 60 DAT and at harvest and average was expressed as number of tillers per hills.

iii) **Leaf area Index:** The leaf area of rice was measured with the help of (Leaf area meter) Leaf area was directly obtained in cm2 per plant and used to compute the leaf area index (LAI) which was determined by the following formula,

LAI= Leaf area / Ground area covered.

iv) **Dry matter accumulation**: In rice plants of five hills and one in row length, respectively were selected randomly from each plot were separated cut at ground level. Leaves from the stems of the samples were separated to the samples were oven dried at 60-65^{o}C till a constant weight was obtained and the weight was reported as the dry matter production (a) per hill or per m row length.

4.9.2 Yield parameters of rice

i) **Number of panicles per hill :** Five hills were selected randomly in the net plot and the total numbers of fertile panicles were counted and the numbers of fertile panicles per hill were recorded.

ii) **Length of panicles:** Ten panicles per plot were randomly selected at the time of harvesting length was measured from the neck to the tip of panicle and mean panicle length was computed.

iii) **Number of grains per panicle:** The grains of ten panicles selected for calculating length were counted. Mean value of number of grains was then calculated.

iv) **Test weight (1000 grain weight):** One thousand filled grains were counted from grain sample and their weight was recorded in grams.

v) **Grain and straw yield:** The next plots leaving 2 border rows on both the side of the plots were harvested and kept for sun drying for 3-4 days in the field and then the total biomass yield was recorded. After threshing, cleaning and drying the grain yields were recorded straw yield was obtained by subtracting the grain yield from the yield of total biomass.

vi) **Harvest index:** The harvest index of rice for each treatment was calculated by using the formula,

$$\text{Harvest index \%} = \frac{\text{Economic yield (grains)}}{\text{Biological yield (straw + grains)}} \times 100$$

4.9.3 Cost benefit analysis

The cost of cultivation of rice right from the preparation of land, and all the requirements of the cultivation up to the harvesting and packaging till it reaches the market was recorded and calculated. The cost-benefit ratio of the different treatments in the present experiment was calculated by dividing the net return by the gross operational costs. The net returns of rice cultivation under the different treatments were calculated by deducting the gross operational costs per hectare from the gross returns per hectare.

4.9.4 Statistical Analysis.

The experimental data pertaining to each parameters was analyzed statistically with the help of Statistica software package by using analyses of variance technique (ANOVA) for Randomized Block Design. The significance of the treatment different was tested by "F" test (Variance ratio) at 1 and 5 per cent level and critical difference (CD / LSD) at 5 per cent level of probability case in which "F" test was significant.

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Chapter- 5

RESULT, DISCUSSION AND CONCLUSION

5.1 Climate and weather of the study site

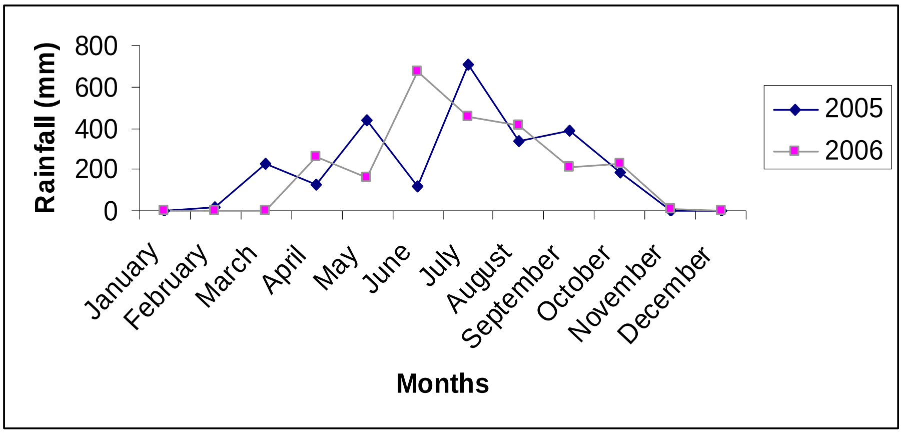
5.1.1 Rainfall

The total rainfall in the study site during the first year of the study (2005) was 2537.8 mm whereas in the second year (2006) it was 2721.1 mm (table 1.6). In the first year of experiment pre-monsoon rain started in the month of March and the monsoon season occurred during July to October. The pre-monsoon rain in the second year of experiment started in the month of April while the rainy season started from June and continued upto October. Out of the total annual rainfall in the experimental site more than 70 per cent of rain was received during the rice cropping season i.e. May to October in each year (table 1.6).

Table 1.6: Annual rainfall at the experimental site during the study period

Month	Rainfall (mm)	
	2005	**2006**
January	0	0
February	14	0
March	228.4	1.2
April	129.3	264.7
May	435.2	162.1
June	121	673.1
July	705	457.1
August	332.7	415.4
September	383.8	214.4
October	189.4	224.8
November	0	8.3
December	0	0
Total	**2537.8**	**2721.1**

Graph 1.1 : Annual rainfall at the experimental site during the study period.



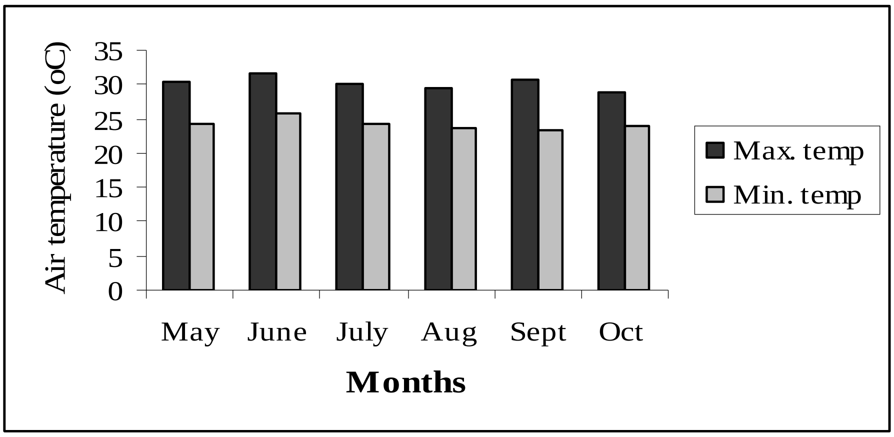
5.1.2 Air temperature

The maximum air temperature at noon during the study period in the first year of the study (2005) was recorded in June (31.6^{o}C) while the same for the second year (2006) was 30.3 in the months of May and July. The minimum air temperature in the first year was recorded in September (23.4^{o}C) while in the second year it was 23.3 ^{o}C in the month of July (Table 1.7).

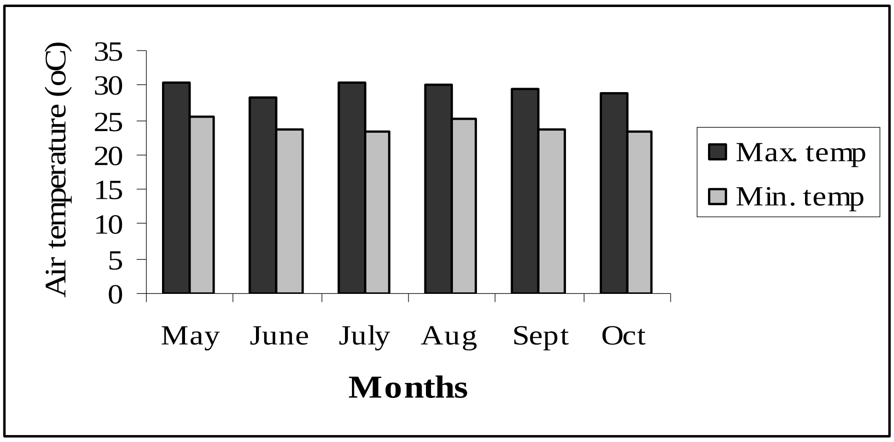
Table 1.7 : Air temperature of the experimental site during the study period.

Months	1st year (2005)		2nd Year (2006)	
	Min	Max	Min	Max
May	24.2	30.3	25.4	30.3
June	25.8	31.6	23.6	28.3
July	24.2	30.1	23.3	30.3
August	23.5	29.6	25.1	30.2
September	23.4	30.6	23.6	29.4
October	23.8	28.8	23.4	29.0

Graph 1.2: Air temperature of the experimental site in the first year (2005)



Graph 1.3 : Air temperature of the experimental site in the second year (2006)



5.1.3 Relative humidity (RH %)

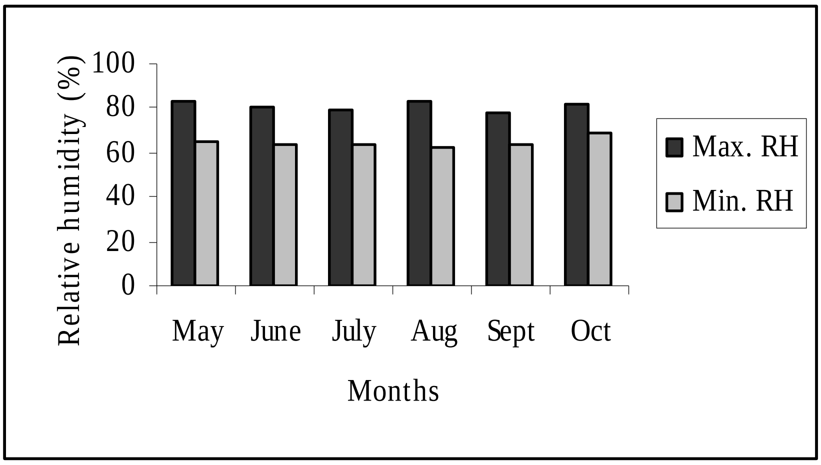
The mean Relative Humidity (RH %) of the experimental site ranged from 62.1 % to 83.5% during the study period in the first year. The RH was recorded to be highest in May and August with RH of 83.5 % and 82.9 %

respectively (table 1.8). The maximum RH (%) in the second year was recorded in June (89.5%) while the minimum RH was recorded to be 63.9% in the month of August (2006).

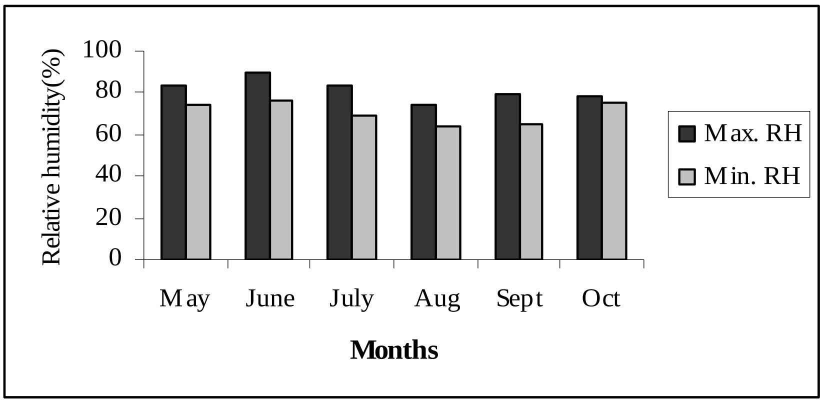
Table 1.8 : Relative Humidity (RH %) of the study area during the study period.

Months	**1st Year(2005)**		**Second Year (2006)**	
	Max. RH	Min. RH	Max. RH	Min. RH
May	83.5	64.8	83.6	74.5
June	80.76	64.06	89.5	76.36
July	79.46	63.43	83.8	68.8
Aug	82.9	62.1	74.6	63.9
Sept	78.53	63.0	78.9	65.1
Oct	82.2	68.8	78.7	75.7

Graph 1.4 : Relative humidity (RH %) of the experimental site in the first year (2005)



Graph 1.5 : Relative humidity (RH %) of the experimental site in the second year (2006)



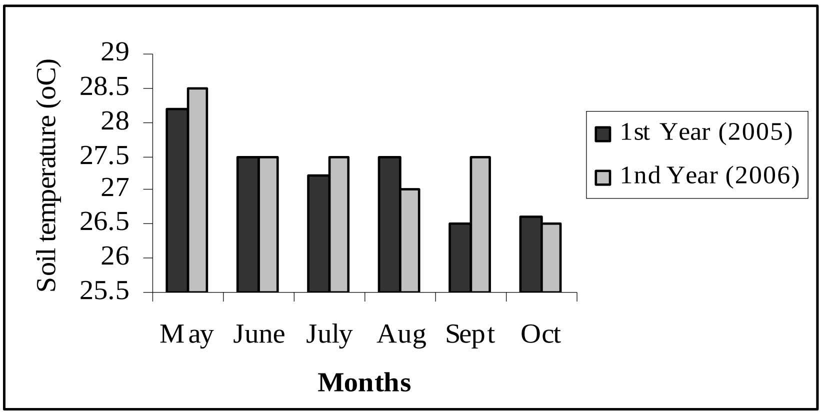
5.1.4 Soil temperature of the experimental site

The soil temperature (°C) at noon collected from the experimental site was presented in table 1.9 and graph 1.6. In general, the soil temperature was highest in the month of May for the two years of the experiment (28.2 °C and 28.5 °C for first year and second year respectively. The soil temperature declined with the onset of rains, but has slightly increased in the months of August (2005) and September (2006)

Table 1.9 Soil temperature of the experimental plot during the study period

Months	Soil temperature (°C)	
	1st Year (2005)	2nd Year (2006)
May	28.2	28.5
June	27.5	27.5
July	27.2	27.5
August	27.5	27.0
September	26.5	27.5
October	26.6	26.5

Table 1.6: Soil temperature of the experimental plot.



5.2 Observation on growth parameters of three rice cultivars

Observations on growth parameters of rice grown under different fertility levels were recorded at monthly interval. Average of 5 observations from each sub-plots were recorded. The observations are tabulated in Appendix-1 for the three rice varieties viz. IR – 64 (CV_1), RCPL – 187-4 (CV_2) and Shahsarang (CV_3) grown under different fertilizer treatments viz. Control (N_0), NPK(N_1), NPK + Biofertilizers (N_2), and Biofertilizers (N_3).

The recorded growth parameters of rice i.e. plant height, number of tillers, leave area index and biomass accumulation of 5 samples plants for the two years of the study are presented in tables 2.1.1 to 2.1.8. The growth performances were recorded at 30, 60 and 90 days after transplanting (DAT) from each sub-plot without fertilizer (N_0), with NPK (N_1), with NPK + Biofertilizer (N_2), and Biofertilizer (N_3).

The yield components of rice for the two years of the study are given in tables 3.1.1 to 3.2.5. The rice samples for measurement of yield parameters were collected in the month of September 2005 and 2006. The growth and yield parameters were estimated based upon 5 samples collected from each sub-plot and total 60 samples from one replication and 180 samples from three replications.

The study aims to incorporate 4 x 3 x 3 (4 fertility levels x 3 species x 3 replications with five observations under each) random block design (RBD) for the studies on growth parameters of three rice varieties/ cultivars. Here, it deserves mention that random block design (RBD) under each of the 12 – groups (4 levels x 3 species) with 3 replications and five observations under each was employed to achieve the objectives. Therefore, it becomes obligatory to check the differential growth patterns under the different plots for the same treatment condition. For this purpose, Man – Whitney **U** test was applied to check the growth and yield patterns of rice under the 12-groups in all probable combinations at each level of replication.

The results manifested non-significant patterns of mean differences (leaving aside a very few and far between instances of significant differences that too in different treatment conditions). This does not warrant for rejection of the null hypothesis. This was expected as different sub-plots from within the main plot were assigned at random for planting rice under the different treatment conditions. Therefore, the average of the growth parameters (of the five observations under each of the treatment conditions and their replication) was taken into consideration for further analysis. At this juncture, a foreword is felt desirable to be appended for precision and clarity of the findings.

The Mean ± SD values for the 12 – groups (4 fertility levels x 3 species) with 3 replications and five observations under each (for the first and years of observations) on growth parameters of rice were analyzed. 4 x 3 x 3 ANOVA (4 fertility levels x 3 species x 3 replications with five observations under each) were separately analyzed. Furthermore, the significant independent and interaction effects of fertilizer & rice cultivars/ varieties, and replications were analyzed (on the assumptions of post-hoc mean comparisons) to mark out the patterns of mean difference existing therein. The Scheffe's test was applied to achieve the objectives. Still further, the significant mean trends was attempted to be portrayed through graphs. Following the broad format of analysis, the results relating to the growth patterns of rice are presented in order.

5.2.1 Growth patterns of rice

The Mean ±SD values for the 36-groups 4 x 3 x 3 (4 fertility levels x 3 species x 3 replications with five samples under each) on each growth parameters of the three rice cultivars are given together in tables 2.1.1 to 2.1.8. The ANOVA results for the 36 groups viz. 4 x 3 x 3 (4 fertility levels x 3 species x 3 replications with five observations under each and repeated measures on the last component) on the different growth parameters of the three selected rice cultivars under varying fertility levels for the two years of the study are presented in tables 2.1.9 to 2.2.3.

5.2.1.1 Plant height

The 4 x 3 x 3 ANOVA (4 fertility levels x 3 cultivars x 3 replications under each and repeated measures on the last component) results for the first and the second years (Tables 2.1.9, 2.2.1, 2.2.2 and 2.2.3) revealed significant effects ($p \leq 0.01$) of NPK, Biofertilizer and NPK + Biofertilizer on (i) plant height at 60 and 90 days after transplanting (DAT). The pattern of mean differences is given together in tables 2.1.1 and 2.1.2 and portrayed in graphs 2.1.1 and 2.1.2. The results revealed significantly greater growth in plant height under NPK (N1) and NPK+ Biofertilizer (N2) treatments as compared to Biofertilizer (N3), and all greater than Control (N0).

The first year result manifested significant difference in the plant height at 60 and 90 DAT while there is no significant variation in the plant height at 30 DAT. Nevertheless, the variation in the plant height of rice cultivars in the second year is found to be significant at 90 DAT while the same at 30 and 60 DAT shows no significant difference. The maximum plant height was observed in IR-64 at 60 DAT followed by that of RCPL – 187-4 and Shahsarang. However, plant height of RCPL – 187-4 (CV_2) at 90 DAT is greatest among the three varieties, followed by that of Shahsarang CV_3 and least in case of IR-64 (CV_1).

5.2.1.2 Number of tillers

The present experiment revealed significant variation in the number of tillers under NPK, Biofertilizer and NPK + Biofertilizer at 30, 60 and 90 DAT ($p \leq 0.01$). The pattern of mean differences is given together in Tables 2.1.3 & 2.1.4, and portrayed in Graphs 2.1.3 & 2.1.4. The results revealed a maximum number of rice tillers in the plots treated with NPK+ Biofertilizer (N_2), which was followed by that under NPK (N1) and Biofertilizer (N3), and all greater than Control (N_0) revealing the same pattern at 30, 60 and 90 DAT. Statistical analysis shows that there is no significant cultivar-wise variation in the number of tillers produced by the three rice cultivars (Table 2.2.1 and 2.2.3).

5.2.1.3 Leaf area index (LAI)

The statistical analysis for Leaf Area Index (LAI) (Tables 2.1.9, 2.2.2 and 2.2.3) revealed significant effects of NPK, Biofertilizer and NPK + Biofertilizer on the Leaf Area Index at 30, 60 and 90 DAT ($p \leq 0.01$). The pattern of mean differences is given together in tables 2.1.5 and 2.1.6, and the same is portrayed in Graphs 2.1.5 & 2.1.6.

The results revealed that Leaf Area Index was highest under NPK+ Biofertilizer (N_2) treatments followed by NPK (N_1) and Biofertilizer (N_3), and all greater than Control (N_0) showing the same pattern at 60 and 90 DAT. There is no significant variation in cultivar-wise Leaf Area Index (LAI) of the three rice cultivars in the first year. However, cultivar-wise significant variation in the leaf area index of rice at 60 and 90 DAT was observed in the second year (table 2.2.3).

5.2.1.4 Biomass accumulation

It has been observed that NPK, Biofertilizer and NPK + Biofertilizer have significant effect on the Biomass Accumulation at 30, 60 and 90 DAT ($P < 0.01$). The pattern of mean differences is given together in the tables 2.1.7 & 2.1.8, and portrayed in Graphs 2.1.7 & 2.1.8. The statistical analysis revealed maximum biomass accumulation under NPK+ Biofertilizer (N_2) treatments followed by NPK (N_1) and Biofertilizer (N_3), and all greater than Control (N0) revealing the same pattern at 30, 60 and 90 DAT in the two years of the study except for the biomass accumulation of Shahsarang in the first year. However, no significant cultivar-wise variation in the biomass accumulation among the three rice cultivars was observed (tables 2.2.1 & 2.2.3).

The present study revealed that the application of NPK, NPK + Biofertilizer, and Biofertilizer shows significant effect ($p \leq 0.01$) on the growth parameters (plant height, leaf area index, number of tillers and biomass accumulation) of the three rice cultivars (Tables 2.1.1 to 2.3.2). It was further observed from the post-hoc mean comparison that combined application of NPK with Biofertilizer has maximum positive effect on the growth performance followed by NPK and Biofertilizer, and all greater than that of control condition(without application of fertilizer).

Table 2.1.1 : Plant height of rice (1st Year)

Days after transplanting (DAT)	Plant height (cm)	Rice Cultivars	Fertilizer treatments			
			N_0	N_1	N_2	N_3
30 DAT	Mean	IR – 64	14.88	17.85	19.66	16.38
		RCPL – 187-4	14.84	17.48	18.65	15.96
		Shahsarang	14.34	16.50	18.75	15.35
	SE	IR – 64	0.18	0.43	0.22	0.14
		RCPL – 187-4	0.09	0.12	0.15	0.29
		Shahsarang	0.15	0.18	0.15	0.05
	SD	IR – 64	0.32	0.75	0.39	0.24
		RCPL – 187-4	0.16	0.22	0.26	0.50
		Shahsarang	0.26	0.32	0.27	0.10
60 DAT	Mean	IR – 64	46.54	56.42	60.61	51.47
		RCPL – 187-4	42.33	53.34	59.15	50.9
		Shahsarang	42.35	53.58	59.63	50.64
	SE	IR – 64	0.08	0.62	0.937	0.5
		RCPL – 187-4	0.69	1.27	1.0	1.2
		Shahsarang	0.66	1.13	1.6	0.4
	SD	IR – 64	2.3	2.8	3.3	25.75
		RCPL – 187-4	1.20	2.20	1.7	2.22
		Shahsarang	1.14	1.96	2.8	0.82
90 DAT	Mean	IR – 64	55.47	75.11	85.25	69.04
		RCPL – 187-4	67.00	83.4	88.74	78.40
		Shahsarang	69.88	81.91	84.45	79.92
	SE	IR – 64	0.32	0.12	2.6	0.66
		RCPL – 187-4	0.93	0.31	0.64	2.02
		Shahsarang	0.82	0.33	0.52	0.50
	SD	IR – 64	0.56	0.22	4.5	1.1
		RCPL – 187-4	1.62	0.53	1.1	3.5
		Shahsarang	1.43	0.57	0.9	0.8

Table 2.1.2 Plant height of rice (2^{nd} Year)

Days after transplanting (DAT)	Plant height (cm)	Rice Cultivars	Fertilizer treatments			
			N_0	N_1	N_2	N_3
30 DAT	Mean	IR – 64	16.01	17.61	18.87	16.65
		RCPL – 187-4	15.43	18.66	19.66	15.90
		Shahsarang	14.56	18.00	18.80	16.92
	SE	IR – 64	0.55	0.78	0.68	0.69
		RCPL – 187-4	0.52	1.13	1.55	0.49
		Shahsarang	0.22	0.696	0.75	0.47
	SD	IR – 64	0.96	1.35	1.18	1.21
		RCPL – 187-4	0.90	1.97	2.68	0.86
		Shahsarang	0.39	1.20	1.30	0.82
60 DAT	Mean	IR – 64	50.23	59.80	60.90	54.08
		RCPL – 187-4	44.33	58.78	57.8	43.38
		Shahsarang	45.25	60.42	58.02	48.41
	SE	IR – 64	2.164	1.24	0.96	4.02
		RCPL – 187-4	4.39	3.64	2.51	3.90
		Shahsarang	2.58	2.34	4.63	3.63
	SD	IR – 64	3.75	2.16	1.67	6.97
		RCPL – 187-4	7.61	6.31	4.35	6.77
		Shahsarang	4.47	4.07	8.02	6.28
90 DAT	Mean	IR – 64	60.58	65.76	69.65	64.66
		RCPL – 187-4	76.78	84.09	84.31	80.48
		Shahsarang	77.99	82.26	85.45	78.87
	SE	IR – 64	2.11	1.56	2.04	0.96
		RCPL – 187-4	2.43	2.57	0.57	0.47
		Shahsarang	1.00	0.91	1.79	1.83
	SD	IR – 64	3.67	2.70	3.54	1.67
		RCPL – 187-4	4.22	4.45	0.99	0.82
		Shahsarang	1.74	1.57	3.10	3.18

Table 2.1.3 Number of tillers (per hill) (1st Year)

Days after transplanting (DAT)	No. of tillers	Rice Cultivars	Fertilizer treatments			
			N_0	N_1	N_2	N_3
30 DAT	Mean		8.66	11.46	12.2	10.0
		RCPL – 187-4	9.06	11.2	13.6	10.4
		Shahsarang	9.66	12.4	13.26	11.33
	SE	IR – 64	0.40	0.24	0.11	0.23
		RCPL – 187-4	0.06	0.01	0.2	0.30
		Shahsarang	0.29	0.23	0.06	0.06
	SD	IR – 64	0.70	0.41	0.2	0.4
		RCPL – 187-4	0.11	0.01	0.34	0.52
		Shahsarang	0.50	0.4	0.11	0.11
60 DAT	Mean	IR – 64	9.2	11.73	12.6	10.73
		RCPL – 187-4	10.06	12.53	13.6	11.66
		Shahsarang	9.93	11.53	13	10.93
	SE	IR – 64	0.30	0.484	0.11	0.37
		RCPL – 187-4	0.06	0.24	0.4	0.48
		Shahsarang	0.37	0.17	0	0.06
	SD	IR – 64	0.52	0.83	0.2	0.64
		RCPL – 187-4	0.11	0.41	0.698	0.83
		Shahsarang	0.64	0.30	0	0.11
90 DAT	Mean	IR – 64	8.73	10.46	12.0	9.8
		RCPL – 187-4	8.46	10.16	12.13	10.2
		Shahsarang	9.46	10.66	11.33	9.66
	SE	IR – 64	0.06	0.06	0.23	0.11
		RCPL – 187-4	0.06	0.2	0.24	0.2
		Shahsarang	0.17	0.24	0.26	0.24
	SD	IR – 64	0.11	0.11	0.4	0.2
		RCPL – 187-4	0.11	0.35	0.41	0.34
		Shahsarang	0.30	0.41	0.46	0.41

Table 2.1.4 Number of tillers (per hill) (2^{nd} Year)

Days after transplanting (DAT)	No. of tillers	Rice Cultivars	Fertilizer treatments			
			N_0	N_1	N_2	N_3
30 DAT	Mean	IR – 64	8.4	13.86	14.4	11.06
		RCPL – 187-4	10.26	13.33	14.2	11
		Shahsarang	9.53	13.0	13.6	11.93
	SE	IR – 64	0.11	0.06	0.23	0.52
		RCPL – 187-4	0.17	0.33	0.41	0.4
		Shahsarang	0.98	0	0.30	0.29
	SD	IR – 64	0.2	0.11	0.4	0.90
		RCPL – 187-4	0.30	0.57	0.72	0.93
		Shahsarang	1.70	0	0.52	0.96
60 DAT	Mean	IR – 64	8.73	11.2	10.6	9.26
		RCPL – 187-4	8.86	9.86	10.46	9.53
		Shahsarang	8.6	10.33	11.2	9.46
	SE	IR – 64	0.17	0.91	0.11	0.33
		RCPL – 187-4	0.13	0.06	0.06	0.17
		Shahsarang	0.30	0.24	0.239	0.17
	SD	IR – 64	0.30	1.58	0.2	0.57
		RCPL – 187-4	0.23	0.11	0.11	0.30
		Shahsarang	0.52	0.41	0.4	0.30
90 DAT	Mean	IR – 64	7.8	9.93	10.4	8.33
		RCPL – 187-4	7.73	8.73	9.73	8.46
		Shahsarang	7.53	9.46	9.86	8.6
	SE	IR – 64	0.11	0.17	0.2	0.24
		RCPL – 187-4	0.06	0.40	0.06	0.40
		Shahsarang	0.26	0.17	0.06	0.2
	SD	IR – 64	0.2	0.30	0.34	0.41
		RCPL – 187-4	0.11	0.70	0.11	0.70
		Shahsarang	0.46	0.30	0.11	0.34

Table 2.1.5 Leaf Area Index (1st Year)

Days after transplanting (DAT)	Leaf Area Index	Rice Cultivars	Fertilizer treatments			
			N_0	N_1	N_2	N_3
30 DAT	Mean	IR – 64	1.53	2.7	3.3	1.74
		RCPL – 187-4	1.39	2.80	3.39	1.71
		Shahsarang	1.83	2.55	3.41	2.18
	SE	IR – 64	0.22	0.15	0.12	0.06
		RCPL – 187-4	0.006	0.08	0.20	0.04
		Shahsarang	0.03	0.04	0.16	0.06
	SD	IR – 64	0.39	0.26	0.22	0.11
		RCPL – 187-4	0.01	0.15	0.35	0.08
		Shahsarang	0.06	0.08	0.27	0.10
60 DAT	Mean	IR – 64	3.29	5.74	6.57	3.8
		RCPL – 187-4	3.43	5.9	7.2	4.12
		Shahsarang	3.30	5.71	6.84	3.94
	SE	IR – 64	0.12	0.15	0.1244	0.16
		RCPL – 187-4	0.11	0.20	0.17	0.17
		Shahsarang	0.11	0.18	0.173	0.10
	SD	IR – 64	0.21	0.26	0.21	0.27
		RCPL – 187-4	0.20	0.35	0.29	0.29
		Shahsarang	0.20	0.31	0.29	0.18
90 DAT	Mean	IR – 64	1.87	2.88	3.52	2.64
		RCPL – 187-4	2.07	3.07	3.82	2.75
		Shahsarang	2.08	3.26	3.74	2.65
	SE	IR – 64	0.13	0.15	0.17	0.20
		RCPL – 187-4	0.15	0.03	0.08	0.04
		Shahsarang	0.05	0.10	0.11	0.08
	SD	IR – 64	0.22	0.27	0.30	0.35
		RCPL – 187-4	0.27	0.06	0.14	0.08
		Shahsarang	0.10	0.18	0.19	0.14

Table 2.1.6 Leaf Area Index (2nd Year)

Days after transplanting (DAT)	Leaf Area Index	Rice Cultivars	Fertilizer treatments			
			N_0	N_1	N_2	N_3
30 DAT	**Mean**	IR – 64	1.56	3.16	3.54	1.94
		RCPL – 187-4	1.67	3.49	3.72	2.32
		Shahsarang	1.57	3.47	3.95	2.14
	SE	IR – 64	0.09	0.36	0.19	0.12
		RCPL – 187-4	0.12	0.18	0.19	0.04
		Shahsarang	0.12	0.02	0.27	0.17
	SD	IR – 64	0.16	0.62	0.33	0.22
		RCPL – 187-4	0.21	0.32	0.34	0.07
		Shahsarang	0.21	0.04	0.47	0.30
60 DAT	**Mean**	IR – 64	2.41	3.19	3.67	2.88
		RCPL – 187-4	3.51	4.67	4.91	3.87
		Shahsarang	3.33	4.76	4.95	3.75
	SE	IR – 64	0.07	0.13	0.17	0.02
		RCPL – 187-4	0.23	0.07	0.04	0.11
		Shahsarang	0.16	0.10	0.13	0.23
	SD	IR – 64	0.12	0.24	0.29	0.05
		RCPL – 187-4	0.40	0.13	0.07	0.19
		Shahsarang	0.29	0.18	0.22	0.4
90 DAT	**Mean**	IR – 64	1.12	1.94	2.15	1.27
		RCPL – 187-4	1.91	2.56	2.74	2.18
		Shahsarang	1.91	2.85	3.49	2.14
	SE	IR – 64	0.06	0.04	0.07	0.07
		RCPL – 187-4	0.16	0.06	0.09	0.06
		Shahsarang	0.04	0.08	0.25	0.13
	SD	IR – 64	0.11	0.07	0.12	0.13
		RCPL – 187-4	0.28	0.11	0.17	0.11
		Shahsarang	0.08	0.14	0.43	0.23

Table 2.1.7 Biomass accumulation (qt/ha) (1st Year)

Days after transplanting (DAT)	Biomass accumulation	Rice Cultivars	Fertilizer treatments N_0	N_1	N_2	N_3
30 DAT	Mean	IR – 64	23.44	33.28	38.97	28.33
		RCPL – 187-4	21.72	35.09	40.66	25.77
		Shahsarang	25.46	38.21	39.63	30.94
	SE	IR – 64	zz0.89	2.24	2.71	0.85
		RCPL – 187-4	1.25	1.34	1.80	0.87
		Shahsarang	0.76	0.64	2.92	1.01
	SD	IR – 64	1.55	3.88	4.69	1.48
		RCPL – 187-4	2.175	2.332	3.12	1.51
		Shahsarang	1.32	1.11	5.06	1.75
60 DAT	Mean	IR – 64	55.91	75.90	82.27	71.07
		RCPL – 187-4	58.05	72.74	81.76	63.45
		Shahsarang	54.60	68.87	80.11	60.92
	SE	IR – 64	1.83	1.06	1.04	2.44
		RCPL – 187-4	2.64	0.85	0.85	1.08
		Shahsarang	1.86	1.911	1.22	1.28
	SD	IR – 64	3.18	1.84	1.81	4.23
		RCPL – 187-4	4.57	1.47	1.48	1.88
		Shahsarang	3.23	3.32	2.11	2.23
90 DAT	Mean	IR – 64	69.76	95.40	105.04	80.68
		RCPL – 187-4	59.78	86.59	92.14	71.44
		Shahsarang	63.57	91.53	102.1	74.62
	SE	IR – 64	3.90	2.06	1.56	3.42
		RCPL – 187-4	2.89	0.43	2.20	4.53
		Shahsarang	2.65	6.76	6.65	3.18
	SD	IR – 64	6.75	3.57	2.70	5.93
		RCPL – 187-4	5.01	0.75	3.81	7.85
		Shahsarang	4.59	11.71	11.52	5.51

Table 2.1.8 Biomass accumulation (qt/ha) (2nd Year)

Days after transplanting (DAT)	Biomass accumula-tion	Rice Cultivars	Fertilizer treatments			
			N_0	N_1	N_2	N_3
30 DAT	**Mean**	IR – 64	23.66	36.46	40.1	27.9
		RCPL – 187-4	25.73	35.33	38.1	28.96
		Shahsarang	25.4	37.33	39.93	29.4
	SE	IR – 64	1.09	0.93	0.05	1.11
		RCPL – 187-4	0.78	0.49	0.76	0.90
		Shahsarang	0.43	0.50	0.66	0.35
	SD	IR – 64	1.89	1.61	0.1	1.93
		RCPL – 187-4	1.36	0.85	1.32	1.56
		Shahsarang	0.75	0.87	1.15	0.60
60 DAT	**Mean**	IR – 64	54.23	75.23	82.7	68.26
		RCPL – 187-4	57.2	74.76	83.7	64.93
		Shahsarang	55.1	73.1	83.6	64.4
	SE	IR – 64	2.165	1.61	0.8	3.8
		RCPL – 187-4	2.08	1.28	1.17	1.41
		Shahsarang	1.58	0.94	1.35	2.05
	SD	IR – 64	3.75	2.8	1.4	6.6
		RCPL – 187-4	3.6	2.2	2.02	2.4
		Shahsarang	2.7	1.6	2.3	3.5
90 DAT	**Mean**	IR – 64	67.36	94.5	101.6	83.56
		RCPL – 187-4	67.8	90.2	99.567	74.1
		Shahsarang	66.43	92.133	98.7	71.56
	SE	IR – 64	0.42	1.88	1.91	2.21
		RCPL – 187-4	0.64	2.64	3.39	2.23
		Shahsarang	1.15	0.76	0.26	0.85
	SD	IR – 64	0.73	3.2	3.3	3.84
		RCPL – 187-4	1.11	4.58	5.87	3.87
		Shahsarang	2.0	1.32	0.45	1.48

Table 2.1.9 : ANOVA table for growth parameters of rice as affected by nutrients application(1st Year)

Source of variation	Parameter	Rice cultivar	30 DAT		60 DAT		90 DAT	
			F-Ratio	*p-Level*	*F-Ratio*	*p-Level*	*F-Ratio*	*p-Level*
N_0 x N_1 x N_2 x N_3	Plant height	IR – 64	56.6567	.00001*	91.4272	.000002*	81.7783	.000002*
		RCPL – 187-4	84.3880	.000002*	40.9577	.000034*	62.4615	.000007*
		Shahsarang	165.4006	.000000*	44.9418	.000024*	122.3506	.000001*
	No. of tillers (per Hill)	IR – 64	34.1897	.000065*	17.9190	.000065*	99.0392	.000001*
		RCPL – 187-4	105.2903	.000001*	19.6732	.000475*	62.6641	.000007*
		Shahsarang	65.5354	.000006*	37.9744	.000044*	14.0612	.001484*
	Leaf Area Index (LAI)	IR – 64	28.8387	.000122*	123.7778	.000000*	16.4103	.000885*
		RCPL – 187-4	65.9527	.000006*	102.5792	.000001*	59.1540	.000008*
		Shahsarang	55.4016	.000011*	121.5285	.000001*	61.5126	.000007*
	Biomass accumulation (qntl / ha)	IR – 64	12.7964	.002021*	43.0521	.000028*	28.8969	.000121*
		RCPL – 187-4	40.3503	.000035*	41.8310	.000031*	14.5182	.001335*
		Shahsarang	16.5124	.000867*	33.0890	.000074*	11.0069	.003270*

* significant at P>0.01, ** significant at P>0.05

Table 2.2.1 : ANOVA table for cultivar-wise growth parameters of rice (1st Year)

Source of variation	Parameter	Fertilizer Level	30 DAT		60 DAT		90 DAT	
			F-Ratio	*p-Level*	*F-Ratio*	*p-Level*	*F-Ratio*	*p-Level*
$CV_1xCV_2xCV_3$	Plant height	N_0	4.156	0.073675	18.906	0.002568*	104.424	0.000022*
		N_1	6.079	0.036075**	2.659	0.148944	260.702	0.000001*
		N_2	9.2189	0.014800*	.367	0.706864	2.0275	0.212469
		N_3	7.379	0.024148**	.245	0.789976	21.653	0.001802*
	No. of tillers (per Hill)	N_0	3.000	0.125000	2.773	0.140290	20.111	0.002187*
		N_1	10.720	0.010454*	2.625	0.151704	1.838	0.238328
		N_2	27.769	0.000927*	4.384	0.067047	3.024	0.123488
		N_3	9.294	0.014530*	1.940	0.223902	2.080	0.205955
	Leaf Area Index (LAI)	N_0	2.880	0.132792	.433	0.666954	.965	0.433039
		N_1	1.460	0.304162	.338	0.725869	2.929	0.129501
		N_2	.127	0.882893	4.381	0.067136	1.393	0.318343
		N_3	18.927	0.002561*	1.161	0.374721	.191	0.830588
	Biomass accumulation (qntl / ha)	N_0	3.588	0.094426	.656	0.552085	2.490	0.163158
		N_1	2.567	0.156454	1.186	0.368055	1.165	0.374326
		N_2	.111	0.896251	1.165	0.373616	.158	0.856550
		N_3	8.037	0.020080**	9.492	0.13849	1.559	0.284802

* significant at P>0.01, ** significant at P>0.05

Table 2.2.2: ANOVA table for growth parameters of rice as affected by nutrients application (2nd Year)

Source of variation	Parameter	Rice cultivar	30 DAT		60 DAT		90 DAT	
			F-Ratio	*p-Level*	*F-Ratio*	*p-Level*	*F-Ratio*	*p-Level*
N_0 x N_1 x N_2 x N_3	Plant height	IR – 64	3.1551	.086085	4.2882	.044243**	4.6147	.037192**
		RCPL – 187-4	4.0546	.050324**	5.1459	.028461**	3.8524	.056449
		Shahsarang	10.2340	.004104*	4.5947	.037583**	5.5209	.23798
	No. of tillers (per Hill)	IR – 64	89.8355	.000002*	5.2664	.026848**	43.6979	.000026*
		RCPL – 187-4	29.3333	.000115*	30.8462	.000095*	8.1053	.008274*
		Shahsarang	11.2620	.003042*	21.2579	.000362*	29.1717	.000117*
	Leaf Area Index (LAI)	IR – 64	18.5425	.000583*	20.2448	.000430*	57.2215	.000010*
		RCPL – 187-4	41.9929	.000031*	22.8926	.000279*	12.1558	.002385*
		Shahsarang	40.2584	.000036*	22.1854	.000312*	22.4760	.000298*
	Biomass accumulation (qntl / ha)	IR – 64	69.1625	.003270*	25.8841	.000005*	72.0337	.000180*
		RCPL – 187-4	56.9346	.000004*	50.8929	.000010*	35.4737	.000057*
		Shahsarang	180.6142	.000000*	55.2273	.000011*	55.2273	.000000*

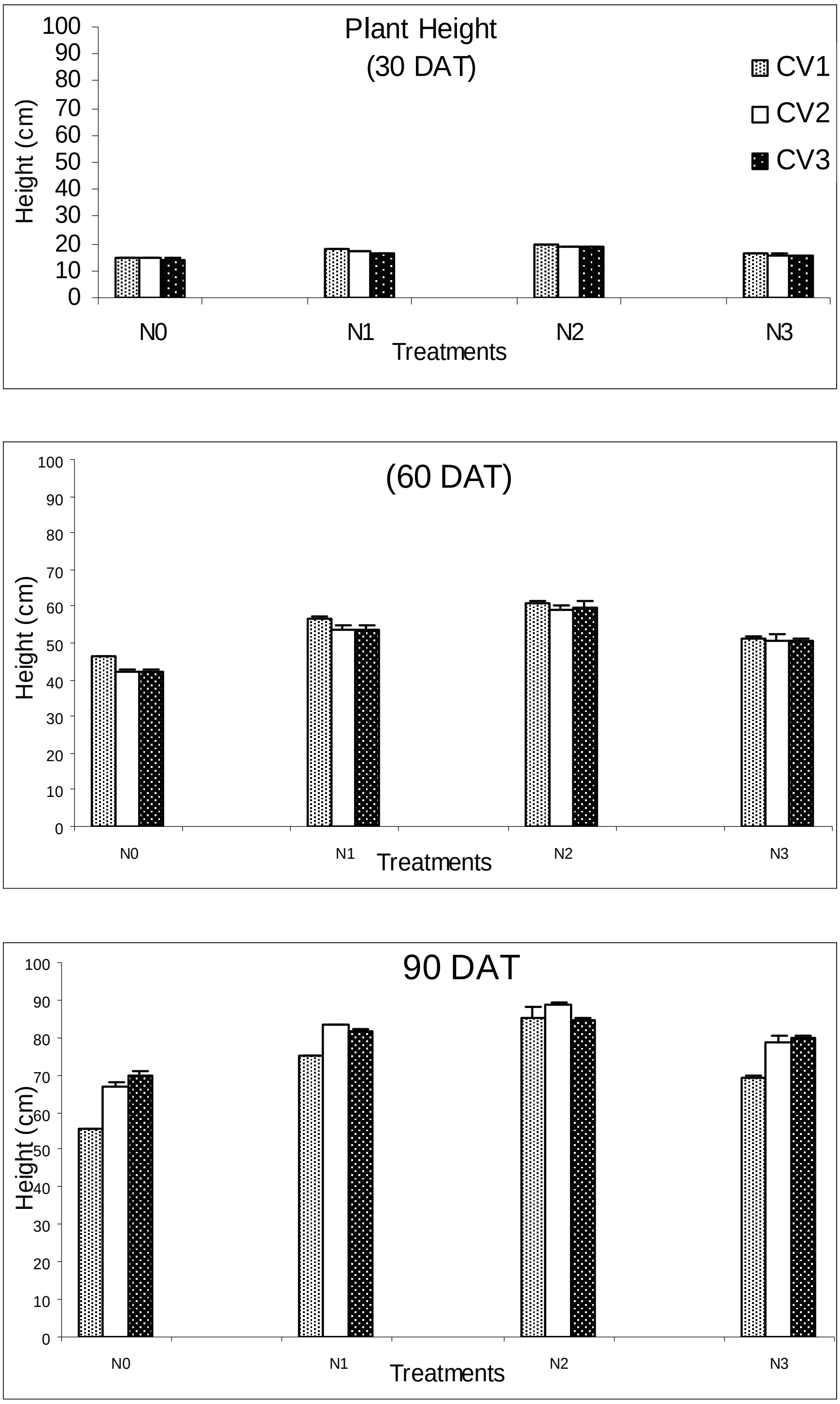
* significant at P>0.01, ** significant at P>0.05

Table 2.2.3: ANOVA table for cultivar-wise growth parameters of rice (2[nd] Year)

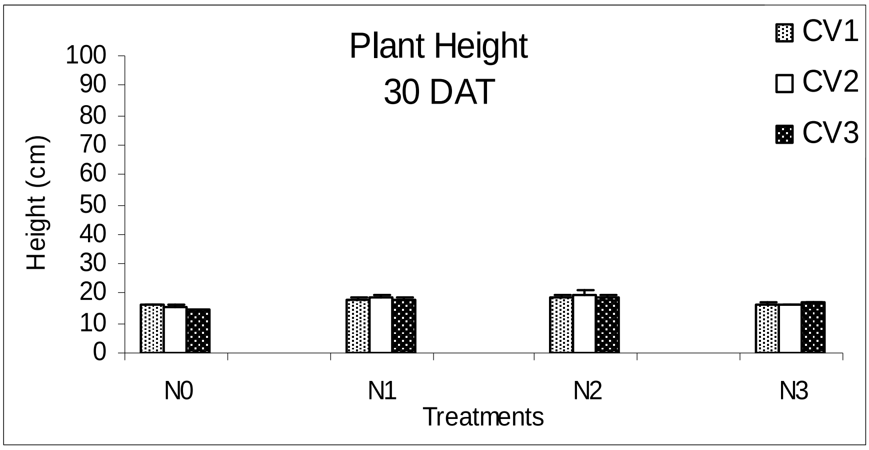
Source of variation	Parameter	Fertilizer Level	30 DAT		60 DAT		90 DAT	
			F-Ratio	*p-Level*	*F-Ratio*	*p-Level*	*F-Ratio*	*p-Level*
$CV_1xCV_2xCV_3$	Plant height	N_0	2.509	0.161424	.985	0.426577	24.752	0.001263*
		N_1	.356	0.714263	.100	0.905857	30.920	0.000744*
		N_2	.215	0.811758	.313	0.742466	30.106	0.000744*
		N_3	.870	0.465765	1.924	0.226077	50.100	0.000180*
	No. of tillers (per Hill)	N_0	2.629	0.151303	.375	0.702332	.650	0.555246
		N_1	4.961	0.053502	1.522	0.291960	4.843	0.055962
		N_2	1.625	0.272916	6.437	0.032121	7.636	0.022438**
		N_3	1.577	0.281484	.333	0.729000	.203	0.821362
	Leaf Area Index (LAI)	N_0	.273	0.770057	11.690	0.008517	17.845	0.002981*
		N_1	.602	0.577633	63.569	0.000092	48.321	0.000200*
		N_2	.859	0.469796	32.737	0.000592	17.158	0.003296*
		N_3	2.123	0.200812	13.044	0.006537	27.541	0.000948*
	Biomass accumulation (qntl / ha)	N_0	1.841	0.237909	.605	0.575932	.693	0.191125
		N_1	2.208	0.191125	1.775	0.247955	1.248	0.352079
		N_2	3.571	0.095145	.139	0.872858	.435	0.665596
		N_3	.817	0.485446	.597	0.579784	11.259	0.009311*

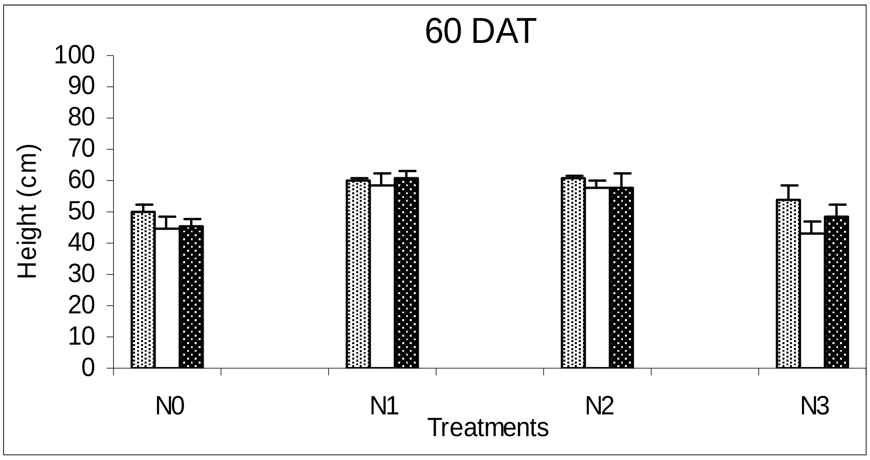
* significant at P>0.01, ** significant at P>0.05

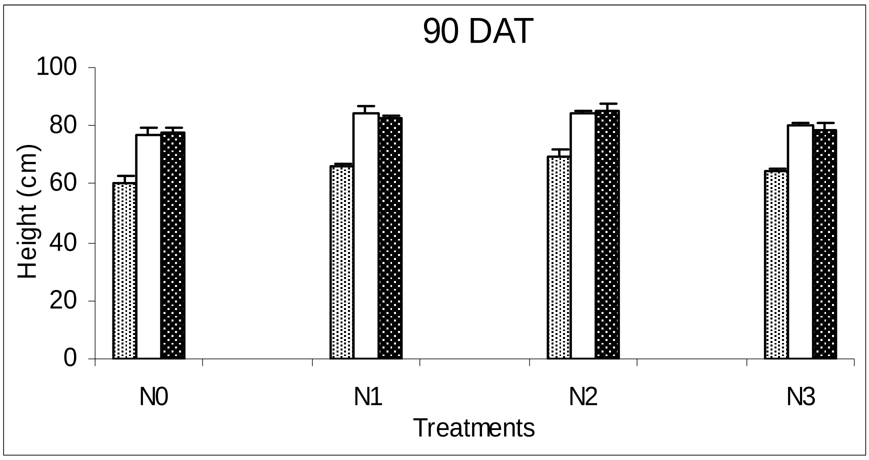
Graph 2.1.1 : Plant height of rice under different fertilizer treatments (1^{st} Year)



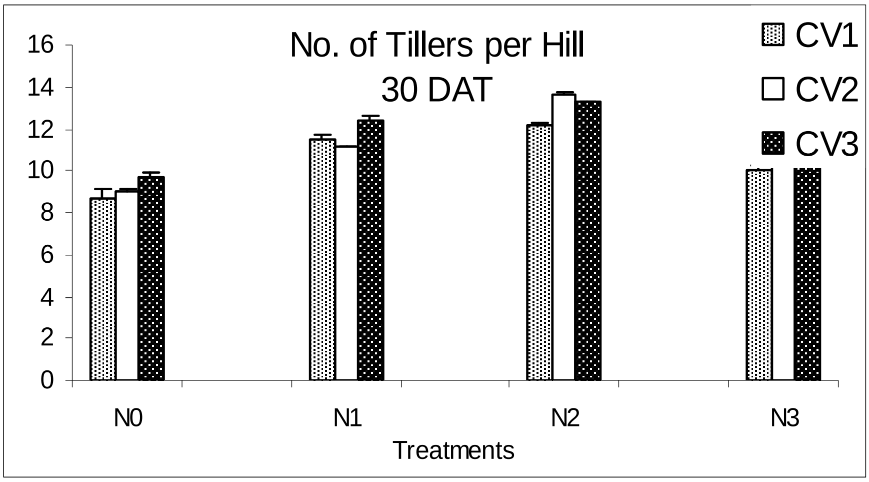
Graph 2.1.2 : Plant height of rice under different fertilizer treatments (2nd Year)

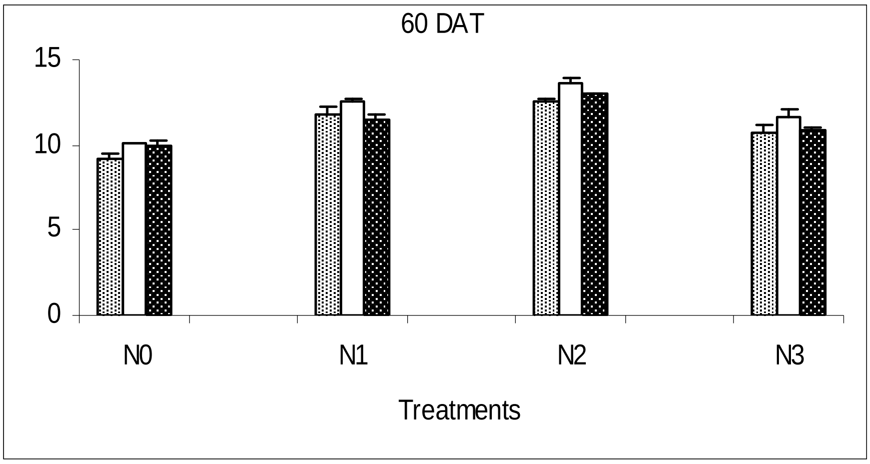


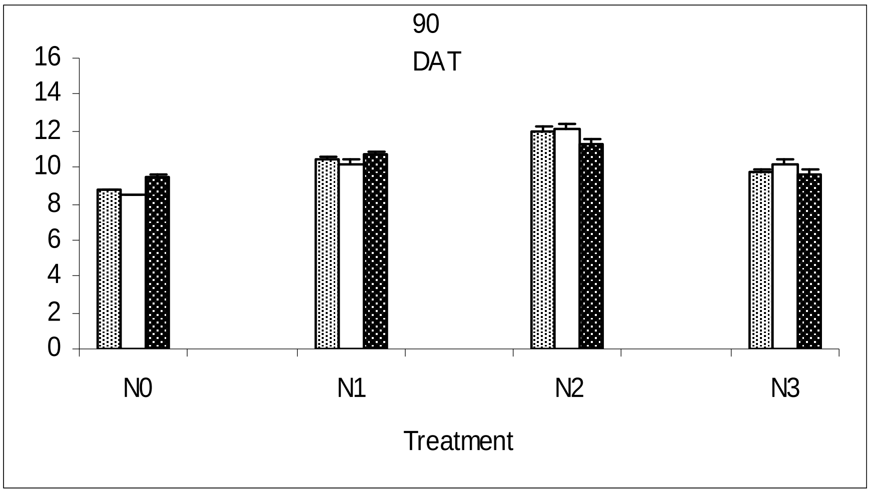




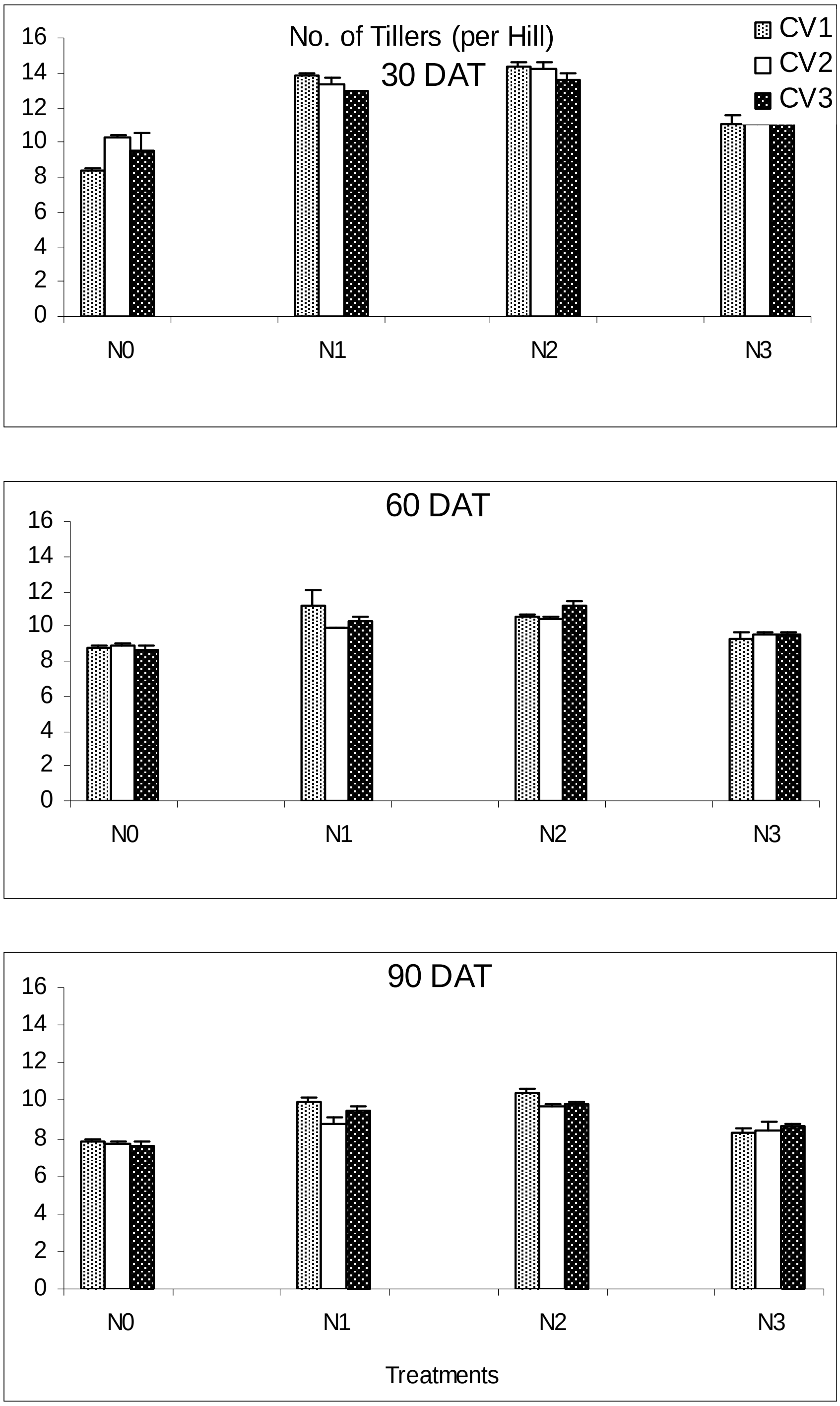
Graph 2.1.3: Number of tillers of rice under different fertilizer treatments (1st Year)



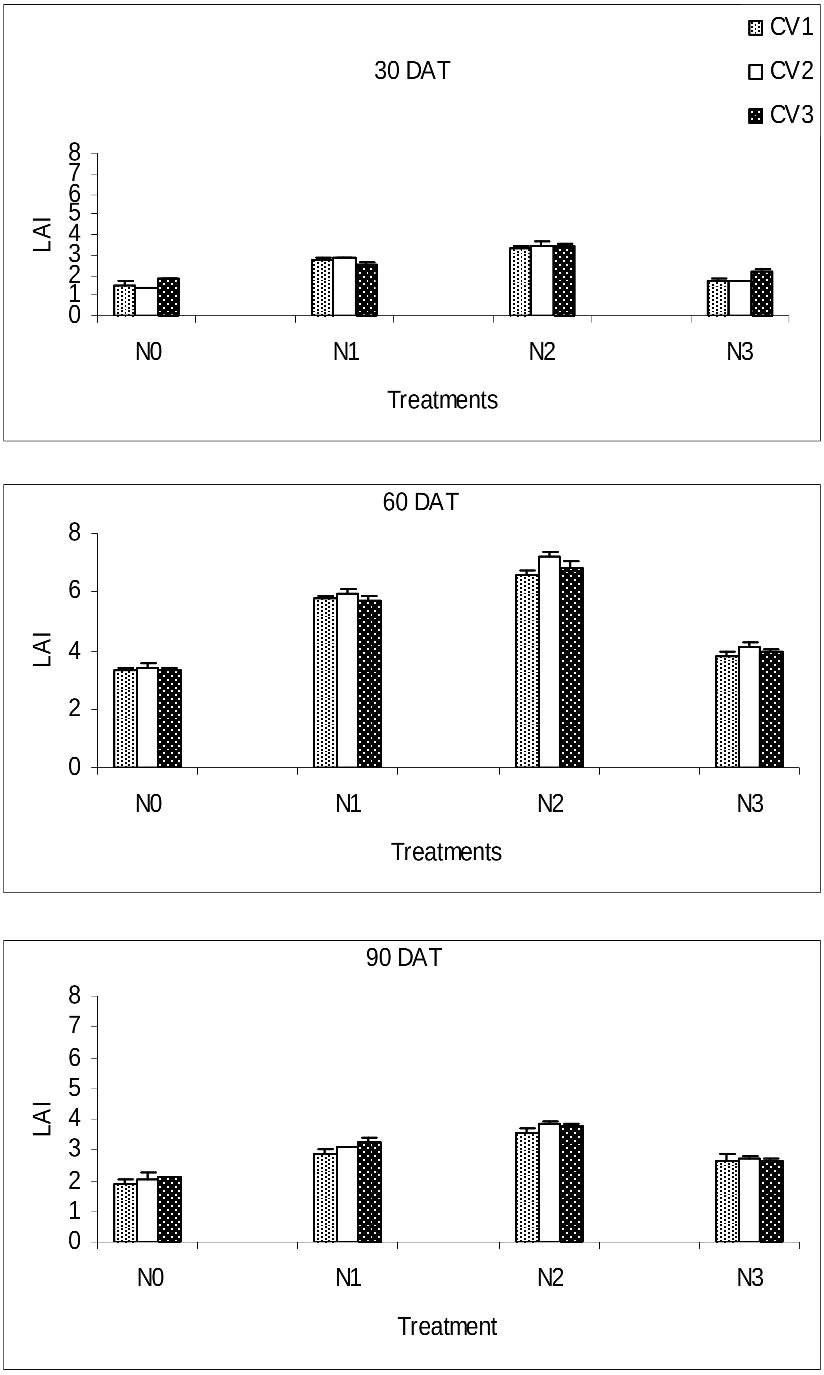




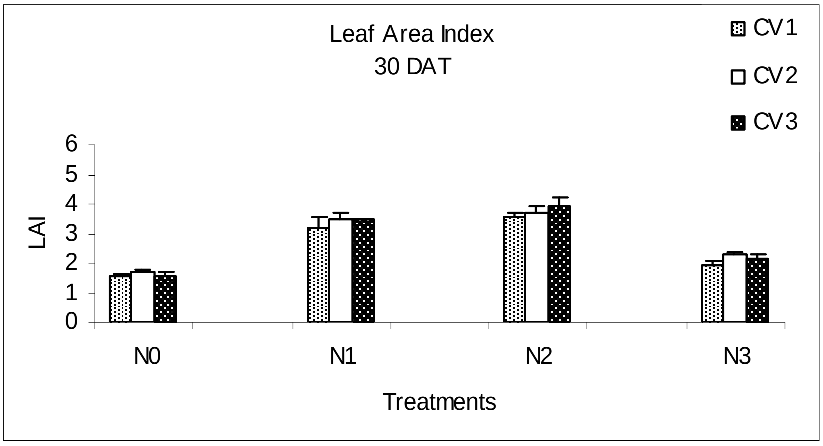
Graph 2.1.4: Number of tillers of rice under different fertilizer treatments (2^{nd} Year)

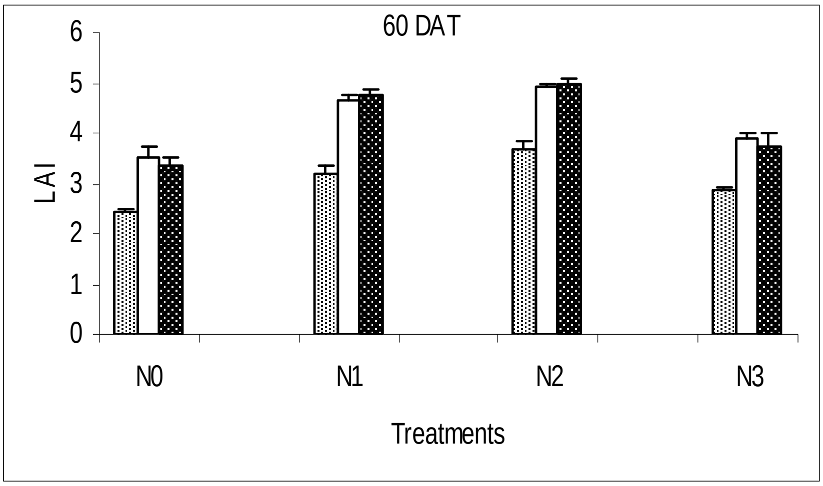


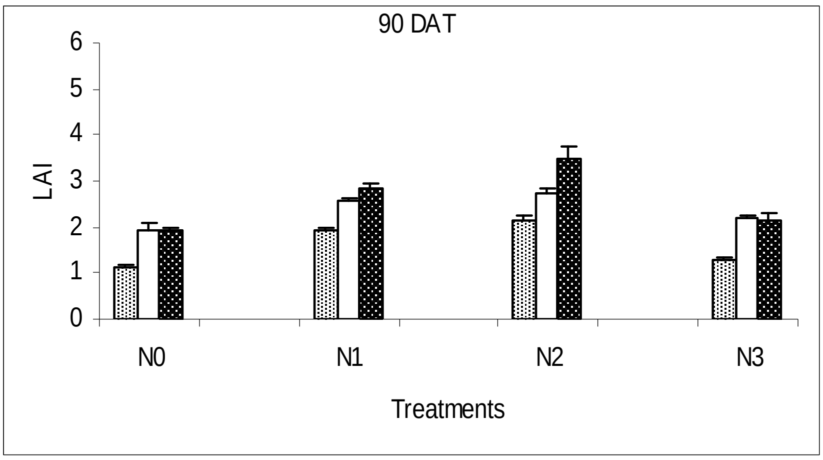
Graph 2.1.5 Leaf Area Index of rice under different fertilizer treatments (1^{st} Year)



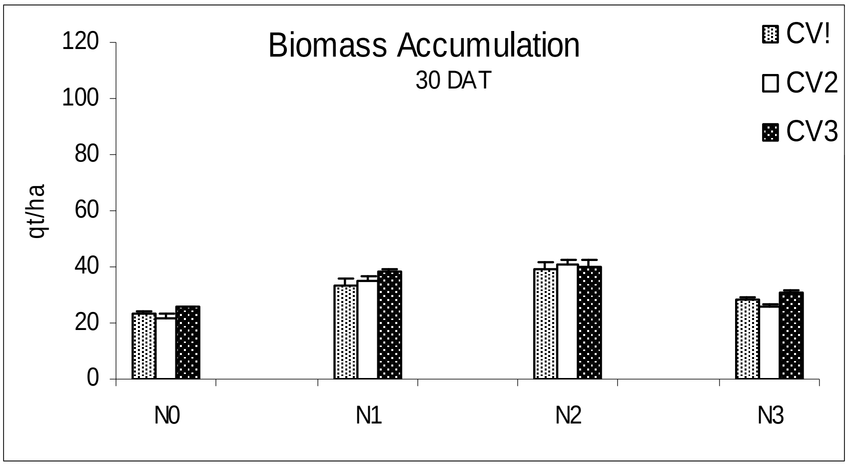
Graph 2.1.6: Leaf Area Index of rice under different fertilizer treatments (2^{nd} Year)

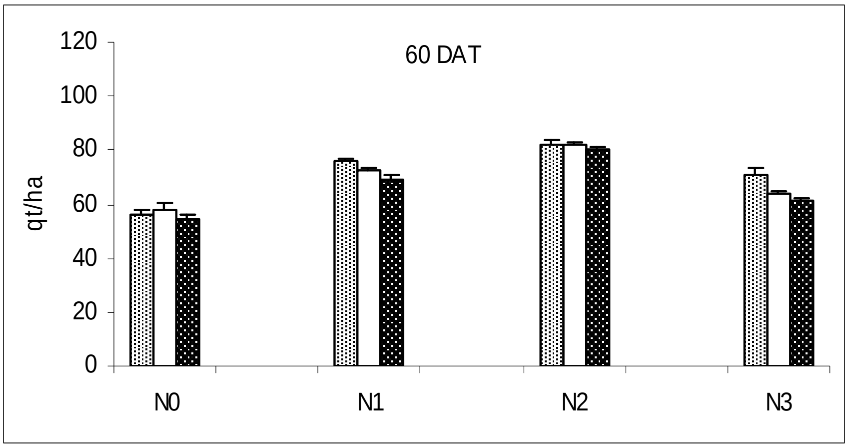


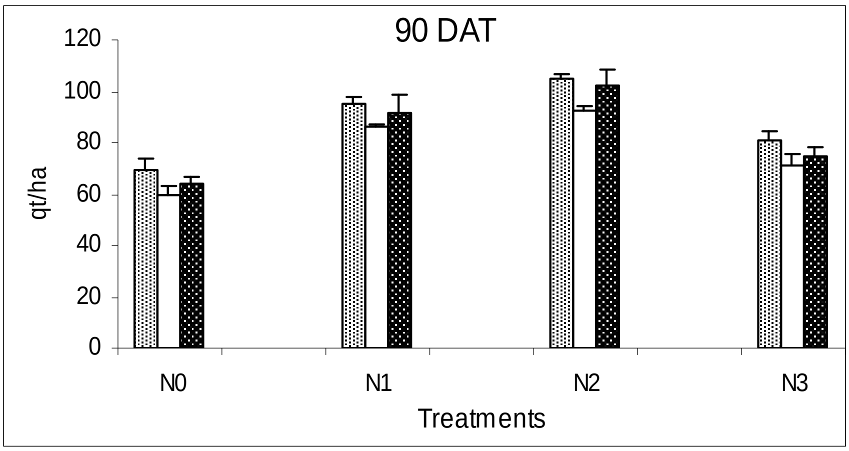




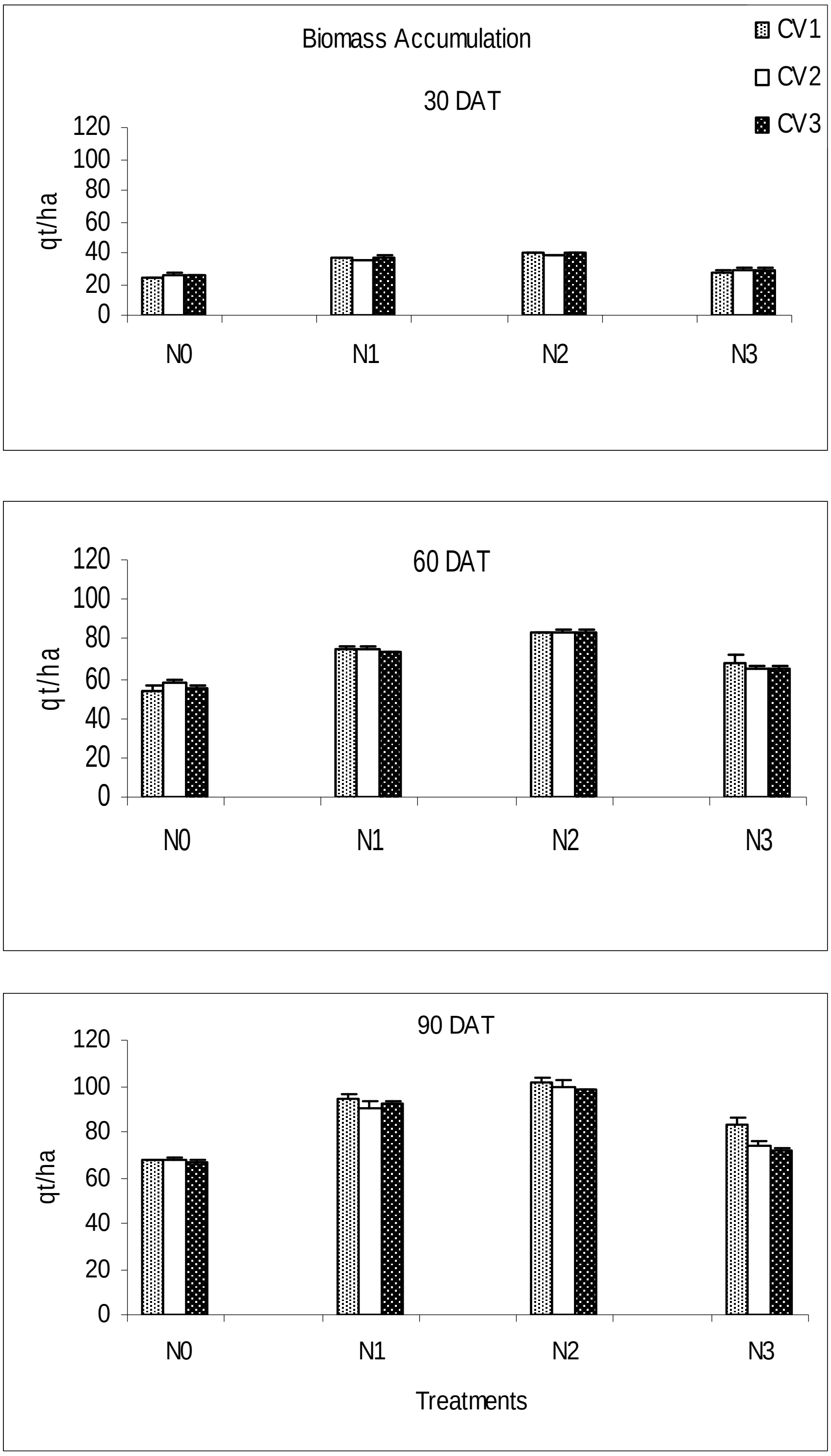
Graph 2.1.7: Biomass accumulation (qt / ha) of rice under different fertilizer treatments (1st Year)







Graph 2.1.8: Biomass accumulation (qt / ha) of rice under different fertilizer treatments (2nd Year)



5.2.2 Yield pattern of rice cultivars under different treatments

The results of 4 x 3 x 3 (4 fertility levels x 3 cultivars x 3 replications with five observations under each and repeated measures on the last component) on the different yield parameters of three rice cultivars grown under different fertilizer treatments for two years are given in tables 3.1.1 to 3.2.9 and portrayed in graphs 3.1.1 to 3.1.7

5.2.2.1 Crop biomass at harvest

The statistical analysis for the crop biomass at harvest of three rice cultivars for the two years of the study revealed significant effects of NPK, Biofertilizer and NPK + Biofertilizer ($p \leq 0.01$) on the crop biomass at harvest in both the two years of the study (table 3.2.6 and table 3.2.7). The pattern of mean differences is given together in Tables 3.1.1 & 3.1.2 and portrayed in graph 3.1.1. The results revealed maximum crop biomass at harvest under NPK+ Biofertilizer (N_2) treatments as compared to NPK (N_1) and Biofertilizer (N_3), and all greater than Control (N_0). However, no significant variety-wise variation was observed in the crop biomass at harvest.

5.2.2.2 Grain yield

The ANOVA table for the grain yield (per hectare) of three rice cultivars for the two years of the study is presented in tables 3.2.6 and table 3.2.7 which revealed significant effects of NPK, Biofertilizer and NPK + Biofertilizer on the grain yield of rice ($p \leq 0.01$). The pattern of mean differences is presented together in Tables 3.1.3 and 3.1.4, and portrayed in graph 2.2.3. The maximum grain yield of rice was recorded under NPK+ Biofertilizer (N_2) treatments followed by that under NPK (N_1) and Biofertilizer (N_3), and all greater than Control (N_0). However, the two years study shows no significant cultivar- wise variation in grain yield of rice.

5.2.2.3 Straw yield

The ANOVA table for the straw yield of three rice cultivars for the first year shows no significant effects of different fertilizers treatments on the straw yield of rice while the second year's result showed that the effect of fertilizers treatments on the straw yield was significant at $P<0.01$ for CV_1, $P<0.05$ for CV_2 but no significant effect of fertilizer is observed for CV_3 (Table 3.2.8). The mean value of straw yield (tables 3.1.5 & 3.1.6 and graphs 2.2.4) shows greatest straw yield of rice per hectare under NPK+ Biofertilizer (N_2) treatments as compared to NPK (N_1) and Biofertilizer (N_3), and all greater than Control (N_0). The statistical analysis shows no significant cultivar-wise variation in the straw yield of rice (Tables 3.2.7 and 3.2.9).

5.2.2.4 Panicle length

The statistical analysis for the panicle length of three rice cultivars shows that the effects of NPK, Biofertilizer and NPK + Biofertilizer on the panicle length of rice is significant ($P<0.01$) at for CV_2 and CV_3 in the first year of the study but the same is not significant in the second year of the study. The pattern of mean differences is given together in tables 3.1.7 and 3.1.8 and portrayed in graph 2.2.5. The first year's data on the panicle length in case of RCPL-187- 4 (CV_2) and Shahsarang (CV_3) revealed significantly greater panicle length under NPK+ Biofertilizer (N_2) treatments which is followed by that under NPK (N_1) and Biofertilizer (N_3), and all greater than Control (N_0).

The ANOVA (table 3.2.7 & table 3.2.9) for the two years shows that the three rice cultivars exhibit significantly varying response to biofertilizer (N_3) application in terms of the panicle length with IR-64 (CV_1) having the greatest panicle length followed by that of Shahsarang (CV_3) and least in RCPL – 187-4 (CV_2) (tables 3.1.7 & 3.1.8 and Graph 2.2.5). However, the three rice cultivars do not exhibit significant variation in the panicle length under Control, N_1 and N_2 treatments.

5.2.2.5 Number of grains per panicle

The statistical analysis for the number of grains per panicle of the three rice cultivars for the first year shows that the effect of fertilizer treatments on the number of grains per panicle is significant ($P<0.01$ for IR-64 and Shahsarang , $P<0.05$ for RCPL – 187-4). The pattern of mean differences is given together in tables 3.1.9 & 3.2.1 and portrayed in Graph 2.2.6. The results revealed highest number of grains per panicle under NPK+ Biofertilizer (N_2) treatments followed by NPK (N_1) and Biofertilizer (N_3), and all greater than Control (N_0). The ANOVA table shows no significant effect of fertilizer treatments on the number of grains per panicle in the second year of the study. Further, analysis of the two years data shows that there is no significant cultivar-wise variation in the number of grains per panicle (Table 3.2.7 & 3.2.9).

5.2.2.6 Harvest index (%)

The ANOVA tables for the harvest index (%) of three rice cultivars for the two years of the study (Tables 3.2.6 & 3.2.8) revealed significant effects of fertilizer treatments on the harvest index (%) for IR-64 ($P < 0.05$) and RCPL – 187-4 ($P< 0.01$). The mean values of harvest index (%) are presented in tables 3.2.2 & 3.2.3 which showed the maximum value of harvest index (%) under NPK + Biofertilizer (N_2) treatments, followed by that under NPK (N_1) and Biofertilizer (N_3) with Control (N_0) showing the minimum harvest index (%). However, it was observed that there is no significant effect of fertilizer treatments on the harvest index in case of Shahsarang (CV_3). Further, the analysis of the data shows that there is no significant cultivar-wise variation on the harvest index (%) among the rice cultivars (Tables 3.2.7 & 3.2.9).

5.2.2.7 Test weight (1000 grain weight).

The statistical analysis for the test weight (1000 grain weight) of rice for the two years of the study (Tables 3.2.6 & 3.2.8) revealed significant variation in the test weight (1000 grain weight) of IR-64 (CV_1) and Shahsarang (CV_3) as affected by the fertilizer treatments. The mean values of the test weight are presented together in tables 3.2.4 & 3.2.5 and portrayed in graph 2.2.8. The results revealed maximum test weight (1000 grain weight) under NPK+ Biofertilizer (N_2) treatments followed by that of NPK (N_1) and Biofertilizer (N_3), and the minimum value of test weight was recorded in case of Control (N_0). However, no significant cultivar-wise variation in the test weight among the three rice cultivars was observed.

From the present study, it has been observed that the different fertilizers applied in the rice field have significant effect on the growth performance and yield of the three rice cultivars which were tested under rain-fed lowland condition. It was further observed that a combined application of NPK + Biofertilizer treatment (N_2) has a maximum influence on the growth and yield of rice cultivars which was followed by that of NPK treatment (N_1) and Biofertilizer (N_3) with Control (N_0) having the minimum effect.

Table 3.1.1 Crop biomass (qt /ha) at harvest (1st Year)

	Rice Cultivars	Fertilizer treatments			
		N0	**N1**	**N2**	**N3**
Mean	IR – 64	72.80	100.55	115.5	84.74
	RCPL – 187-4	61.69	91.37	99.45	74.0
	Shahsarang	66.65	96.50	108.72	79.01
SE	IR – 64	3.84	2.90	1.32	3.37
	RCPL – 187-4	2.92	0.91	4.74	5.49
	Shahsarang	2.24	6.908	7.92	3.05
SD	IR – 64	6.65	5.03	2.3	5.85
	RCPL – 187-4	5.06	1.59	8.22	9.52
	Shahsarang	3.88	11.96	13.72	5.29

Table 3.1.2 Crop biomass (qt /ha) at harvest (2nd Year)

	Rice Cultivars	Fertilizer treatments			
		N0	N1	N2	N3
Mean	IR – 64	69.3	97.56	105	86.56
	RCPL – 187-4	68.53	93.6	98.11	77.5
	Shahsarang	68.63	96.2	101.37	77.36
SE	IR – 64	0.43	1.73	2.6	1.9
	RCPL – 187-4	0.63	2.71	4.5	1.49
	Shahsarang	1.01	1.46	0.61	2.5
SD	IR – 64	0.75	3.00	4.5	3.4
	RCPL – 187-4	1.1	4.7	7.8	2.5
	Shahsarang	1.7	2.5	1.05	4.38

Table 3.1.3 Grain Yield of rice (Dry Weight) qt / ha (1st Year)

	Rice Cultivars	Fertilizer treatments			
		N_0	N_1	N_2	N_3
Mean	IR – 64	16.87	26.08	36.97	24.54
	RCPL – 187-4	15.42	29.97	38.05	23.13
	Shahsarang	16.07	29.27	36.78	22.45
SE	IR – 64	0.94	0.64	0.51	1.69
	RCPL – 187-4	1.75	0.37	0.29	0.93
	Shahsarang	1.1	0.9	0.19	1.3
SD	IR – 64	1.63	1.116	0.88	2.94
	RCPL – 187-4	3.04	0.65	0.51	1.61
	Shahsarang	1.94	1.57	0.34	2.39

Table 3.1.4 Grain Yield of rice (Dry Weight) qt / ha (2nd Year)

	Rice Cultivars	Fertilizer treatments			
		N_0	N_1	N_2	N_3
Mean	IR – 64	19.06	34.33	36.93	24.96
	RCPL – 187-4	20.36	34.16	36.86	25.26
	Shahsarang	19.86	34.63	37.53	25.66
SE	IR – 64	0.29	0.37	0.38	0.32
	RCPL – 187-4	0.32	0.13	0.37	0.46
	Shahsarang	0.69	0.13	0.29	0.68
SD	IR – 64	0.51	0.65	0.66	0.56
	RCPL – 187-4	0.56	0.23	0.65	0.80
	Shahsarang	1.2	0.23	0.5	1.1

Table 3.1.5 Straw yield of rice (Dry Weight) qt/ha (1st Year)

	Rice Cultivars	Fertilizer treatments			
		N_0	N_1	N_2	N_3
Mean	IR – 64	55.93	74.47	78.53	60.2
	RCPL – 187-4	46.26	61.39	60.73	50.86
	Shahsarang	50.57	66.56	71.93	56.56
SE	IR – 64	4.57	3.4	1.8	2.15
	RCPL – 187-4	2.8	1.15	4.8	4.71
	Shahsarang	2.85	7.72	7.9	2.14
SD	IR – 64	7.9	5.8	3.14	3.72
	RCPL – 187-4	4.98	1.9	8.4	8.16
	Shahsarang	4.94	13.38	13.7	3.7

Table 3.1.6 Straw yield of rice (Dry Weight) qt/ha (2nd Year)

	Rice Cultivars	Fertilizer treatments			
		N_0	N_1	N_2	N_3
Mean	IR – 64	50.23	63.23	68.06	61.6
	RCPL – 187-4	48.1	59.43	67.9	52.23
	Shahsarang	48.76	61.56	61.56	51.7
SE	IR – 64	0.14	1.87	2.8	1.67
	RCPL – 187-4	0.77	2.58	2.71	1.21
	Shahsarang	1.53	1.41	1.41	3.2
SD	IR – 64	0.25	3.2	5.0	2.8
	RCPL – 187-4	1.34	4.4	4.7	2.1
	Shahsarang	2.66	2.45	2.45	5.55

Table 3.1.7 Panicle length (cm) (1st Year)

	Rice Cultivars	Fertilizer treatments			
		N_0	N_1	N_2	N_3
Mean	IR – 64	22.27	23.21	23.43	23.87
	RCPL – 187-4	22.15	23.67	24.47	21.79
	Shahsarang	22.47	22.48	23.96	22.09
SE	IR – 64	0.81	0.41	0.49	0.18
	RCPL – 187-4	0.06	0.22	0.05	0.33
	Shahsarang	0.28	0.18	0.17	0.15
SD	IR – 64	1.4	0.7	0.85	0.32
	RCPL – 187-4	0.11	0.39	0.08	0.58
	Shahsarang	0.5	0.3	0.3	0.26

Table 3.1.8 Panicle length (cm) (2nd Year)

	Rice Cultivars	Fertilizer treatments			
		N_0	N_1	N_2	N_3
Mean	IR – 64	22.68	23.73	23.737	24.48
	RCPL – 187-4	22.28	23.17	22.63	22.27
	Shahsarang	22.81	23.76	22.88	22.48
SE	IR – 64	0.19	0.42	0.75	0.25
	RCPL – 187-4	0.26	0.31	0.39	0.24
	Shahsarang	0.34	0.83	0.26	0.17
SD	IR – 64	0.33	0.72	1.3	0.45
	RCPL – 187-4	0.46	0.54	0.68	0.42
	Shahsarang	0.59	1.44	0.35	0.3

Table 3.1.9 Number of grains per panicle (1st Year)

	Rice Cultivars	Fertilizer treatments			
		N_0	N_1	N_2	N_3
Mean	IR – 64	84.53	99.76	103.98	93.78
	RCPL – 187-4	86.78	97.31	101.2	92.49
	Shahsarang	80.42	97.44	101.2	87.26
SE	IR – 64	3.19	2.17	1.67	2.88
	RCPL – 187-4	3.71	2.82	2.98	2.82
	Shahsarang	3.1	1.2	3.9	1.5
SD	IR – 64	5.53	3.75	2.9	5.0
	RCPL – 187-4	6.4	4.8	5.167	4.8
	Shahsarang	5.3	2.09	6.8	2.7

Table 3.2.1 Number of grains per panicle (2nd Year)

	Rice Cultivars	Fertilizer treatments			
		N_0	N_1	N_2	N_3
Mean	IR – 64	85.60	89.98	91.04	103.76
	RCPL – 187-4	85.87	85.18	89.87	85.85
	Shahsarang	93.93	98.2	91.15	91.33
SE	IR – 64	4.67	7.12	6.7	3.9
	RCPL – 187-4	8.8	1.03	6.05	7.53
	Shahsarang	11.36	6.1	5.56	1.87
SD	IR – 64	8.1	12.34	11.61	6.9
	RCPL – 187-4	15.33	1.8	10.4	13.04
	Shahsarang	19.6	10.56	9.6	3.2

Table 3.2.2 Harvest Index (%) (1st Year)

	Rice Cultivars	Fertilizer treatments			
		N_0	N_1	N_2	N_3
Mean	IR – 64	23.39	26.00	32.02	28.92
	RCPL – 187-4	25.01	32.81	38.41	31.46
	Shahsarang	24.20	30.72	34.17	28.38
SE	IR – 64	2.29	1.33	0.79	1.17
	RCPL – 187-4	2.73	0.64	1.53	1.48
	Shahsarang	2.07	2.87	2.36	1.15
SD	IR – 64	3.96	2.30	1.37	2.03
	RCPL – 187-4	4.7	1.12	2.6	2.57
	Shahsarang	3.6	4.9	4.09	2.0

Table 3.2.3 Harvest Index (%) (2nd Year)

	Rice Cultivars	Fertilizer treatments			
		N_0	N_1	N_2	N_3
Mean	IR – 64	27.50	28.85	37.72	36.01
	RCPL – 187-4	35.21	29.72	36.94	37.03
	Shahsarang	35.23	36.55	28.97	33.29
SE	IR – 64	0.25	0.28	1.72	0.51
	RCPL – 187-4	0.81	0.59	3.9	0.5
	Shahsarang	1.13	0.94	1.33	1.9
SD	IR – 64	0.44	0.49	2.9	0.89
	RCPL – 187-4	1.41	1.02	6.8	0.88
	Shahsarang	1.97	1.63	2.31	3.2

Table 3.2.4 Test Weight (1000 grains dry weight) (1st Year)

	Rice Cultivars	Fertilizer treatments			
		N_0	N_1	N_2	N_3
Mean	IR – 64	22.27	23.43	24.62	22.68
	RCPL – 187-4	24.57	26.59	27.48	26.15
	Shahsarang	24.12	26.36	27.69	25.91
SE	IR – 64	0.22	0.51	0.28	0.36
	RCPL – 187-4	0.64	1.24	1.33	1.07
	Shahsarang	0.53	0.34	0.60	0.42
SD	IR – 64	0.38	0.90	0.48	0.63
	RCPL – 187-4	1.11	2.15	2.30	1.86
	Shahsarang	0.93	0.60	1.05	0.72

Table 3.2.5 Test Weight (1000 grains dry weight) (2nd Year)

	Rice Cultivars	Fertilizer treatments			
		N_0	N_1	N_2	N_3
Mean	IR – 64	23.33	24.66	26.66	24.0
	RCPL – 187-4	24.33	27.33	27.33	26.0
	Shahsarang	20.66	27.66	30.0	25.0
SE	IR – 64	0.33	0.33	0.33	1.0
	RCPL – 187-4	1.2	1.8	0.33	1.15
	Shahsarang	2.18	0.33	1.0	2.0
SD	IR – 64	0.57	0.57	0.57	1.73
	RCPL – 187-4	2.08	3.21	0.57	2.0
	Shahsarang	3.78	0.57	1.73	3.46

Table 3.2.6 : ANOVA table for yield parameters of rice as affected by nutrient application(1st Year)

Source of Variation	Parameter	Rice Cultivar	F-Ratio	P-Level
Control (N_0) x NPK(N_1) x NPK + Biofer-tilizer (N_2) x Biofertilizer (N_3)	Crop Biomass at Harvest (Dry wt.)	CV_1	38.04733	.000044*
		CV_2	18.75396	.000561*
		CV_3	11.07625	.003206*
	Grain Yield per Hectare (dry wt.)	CV_1	16.44.96	.000878*
		CV_2	88.7414	.000002*
		CV_3	78.4165	.000003*
	Straw Yield Per Hectare (Dry wt.)	CV_1	1.34223	.327502
		CV_2	1.87378	.212381
		CV_3	2.73906	.113150
	Panicle Length (Cm)	CV_1	1.64517	.254714
		CV_2	36.72159	.000050*
		CV_3	15.90619	.000984*
	No. of Grains per Panicle	CV_1	10.89487	.003377*
		CV_2	4.01494	.051459
		CV_3	12.28225	.002307*
	Harvest Index (%)	CV_1	6.122671	.018137**
		CV_2	9.725017	.004801*
		CV_3	3.589824	.065845
	Test Weight (1000 Grains Dry Weight)	CV_1	7.971534	.008685*
		CV_2	1.219379	.363868
		CV_3	9.097174	.005878*

* significant at $P>0.01$, ** significant at $P>0.05$

Table 3.2.7: ANOVA table for cultivar-wise yield parameters of rice (1st Year)

Source of Variation	Parameter	Fertilizer level	F-Ratio	P-Level
IR-64 (CV_1) x RCPL – 187-4 (CV_2) x Shahsarang (CV_3)	Crop Biomass at Harvest (Dry wt.)	N_0	3.280256	.109001
		N_1	1.084704	.396170
		N_2	2.234242	.188279
		N_3	1.701666	.259782
	Grain Yield Per Hectare (dry wt.)	N_0	.293063	.756073
		N_1	9.344448	.014353**
		N_2	3.655688	.091577
		N_3	.602811	.577350
	Straw Yield Per Hectare (Dry wt.)	N_0	.530581	.613515
		N_1	1.790761	.245556
		N_2	2.695639	.146129
		N_3	1.700211	.260023
	Panicle Length (Cm)	N_0	.10540	.901593
		N_1	4.15742	.073637
		N_2	2.90228	.131312
		N_3	21.85680	.001758
	No. of Grains per Panicle	N_0	.923755	.446949
		N_1	.401779	.685876
		N_2	.281832	.763861
		N_3	1.889652	.230956
	Harvest Index (%)	N_0	.115038	.893251
		N_1	3.488129	.098857
		N_2	3.694274	.090002
		N_3	1.644634	.269469
	Test Weight (1000 Grains Dry Weight)	N_0	5.883733	.38510
		N_1	4.800853	.056877
		N_2	3.979218	.079422
		N_3	7.700738	.022035

* significant at P>0.01, ** significant at P>0.05

Table 3.2.8 : ANOVA table for yield parameters of rice as affected by nutrient application (2nd Year)

Source of Variation	Parameter	Rice Cultivar	F-Ratio	P-Level
Control (N_0) x NPK(N_1) x NPK + Biofertilizer (N_2) x Biofertilizer (N_3)	Crop Biomass at Harvest (Dry wt.)	CV_1	68.06272	.000005
		CV_2	24.88540	.000207
		CV_3	96.01381	.000001
	Grain Yield per Hectare (dry wt.)	CV_1	567.5191	.000000
		CV_2	490.3649	.000000
		CV_3	250.1025	.000000
	Straw Yield per Hectare (Dry wt.)	CV_1	15.54717	.001062
		CV_2	6.77980	.013744
		CV_3	.99989	.441141
	Panicle Length (Cm)	CV_1	2.54560	.129279
		CV_2	1.85742	.215114
		CV_3	1.33511	.329489
	No. of Grains per Panicle	CV_1	1.82465	.220715
		CV_2	.10620	.954109
		CV_3	.21481	.883416
	Harvest Index (%)	CV_1	6.122671	.018137**
		CV_2	9.725017	.004801*
		CV_3	3.589824	.065845
	Test Weight (1000 Grains Dry Weight)	CV_1	6.222222	.017369**
		CV_2	1.280702	.345156
		CV_3	6.486891	.015516**

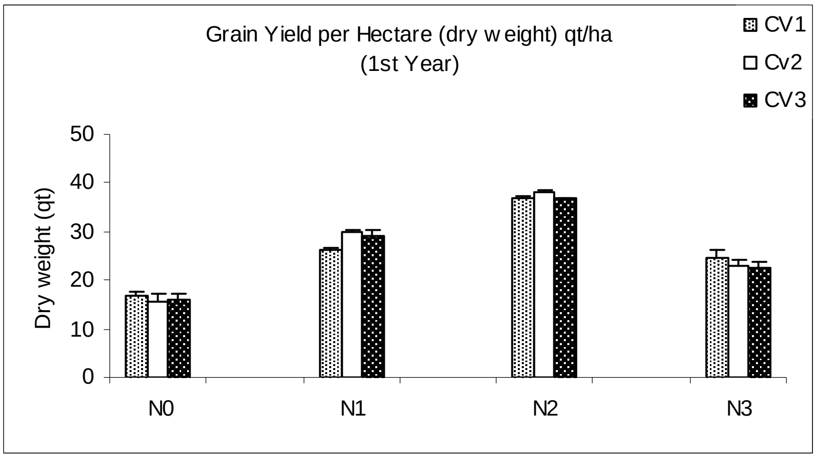
* significant at P>0.01, ** significant at P>0.05

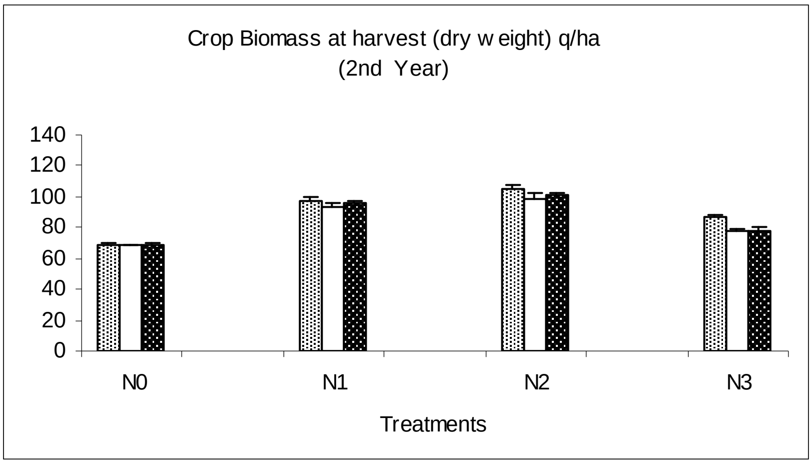
Table 3.2.9: ANOVA table for cultivar-wise yield parameters of rice (2nd Year)

Source of Variation	Parameter	Fertilizer level	F-Ratio	P-Level
IR-64 (CV_1) x RCPL – 187-4 (CV_2) x Shahsarang (CV_3)	Crop Biomass at Harvest (Dry wt.)	N_0	.321	0.736997
		N_1	.973	0.430501
		N_2	1.271	0.346336
		N_3	6.611	0.30407
	Gram Yield (dry wt)	N_0	1.906	0.228599
		N_1	.949	0.438204
		N_2	1.083	0.396569
		N_3	.464	0.649331
	Straw Yield (Dry wt.)	N_0	.937	0.442400
		N_1	.891	0.458092
		N_2	.996	0.422939
		N_3	6.393	0.032572
	Panicle Length (Cm)	N_0	1.030	0.412335
		N_1	.333	0.729082
		N_2	1.288	0.342238
		N_3	28.268	0.000883*
	No. of Grains per panicle	N_0	.293	0.755864
		N_1	1.458	0.304567
		N_2	.013	0.986568
		N_3	3.318	0.107046
	Harvest Index (%)	N_0	.115	0.893251
		N_1	3.488	0.098857
		N_2	3.694	0.090002
		N_3	1.644	0.269469
	Test Weight (1000 Grains Dry Weight)	N_0	1.701	0.259767
		N_1	2.212	0.190687
		N_2	7.636	0.22438
		N_3	.473	0.644159

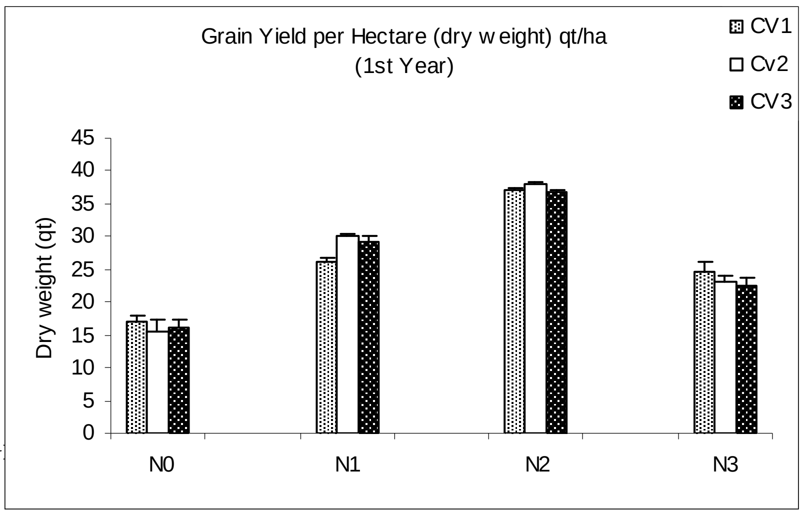
* * significant at P>0.01, ^{NS} not significant

Graph 3.1.1: Crop biomass at harvest (qt / ha)





Graph 3.1.2: Grain yield of rice (qt / ha) (1st Year)



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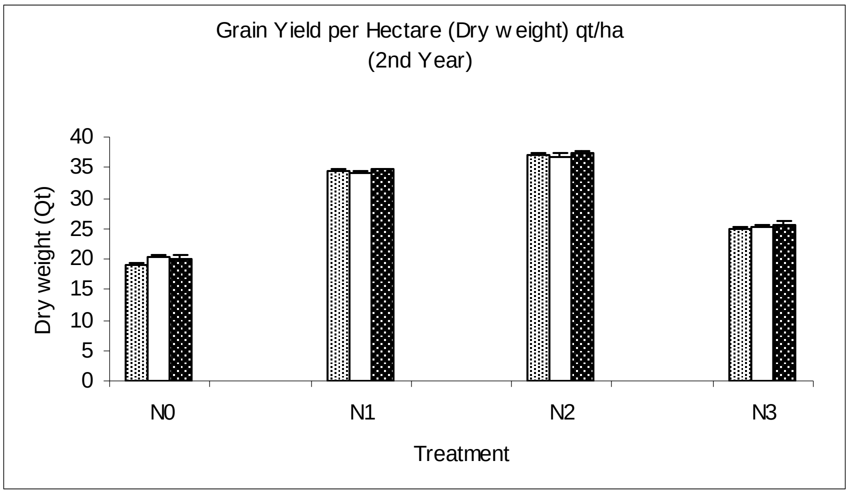
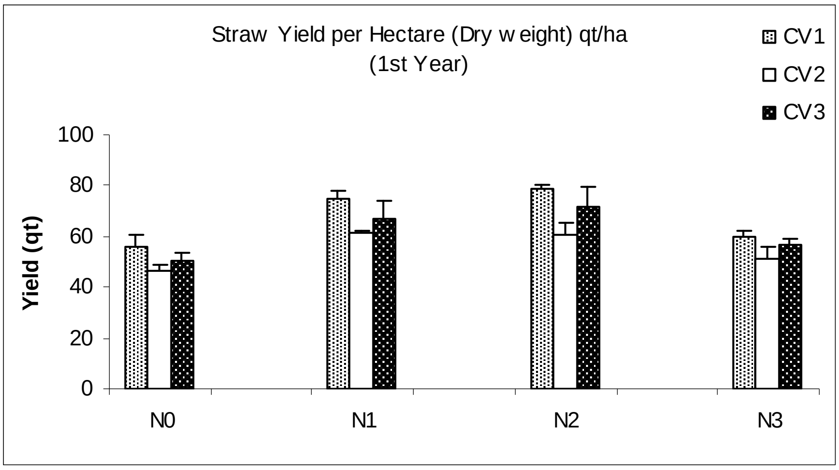
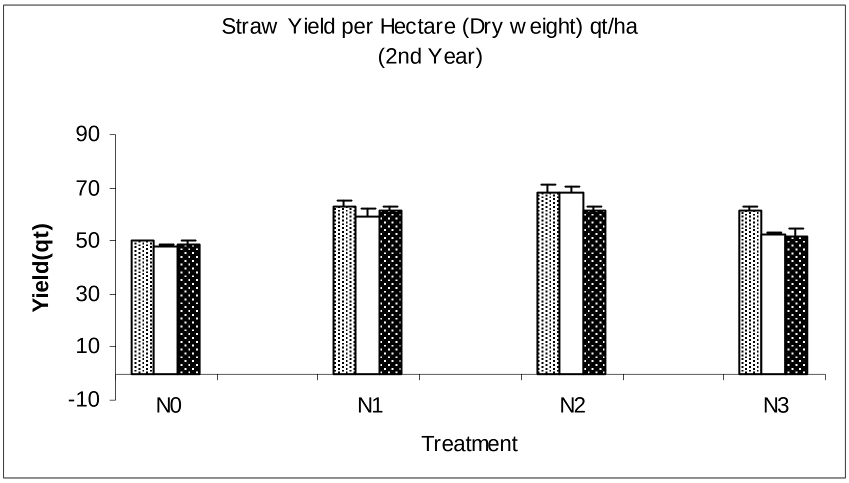
Graph 3.1.3: Grain yield of rice (qt / ha) (2nd Year)

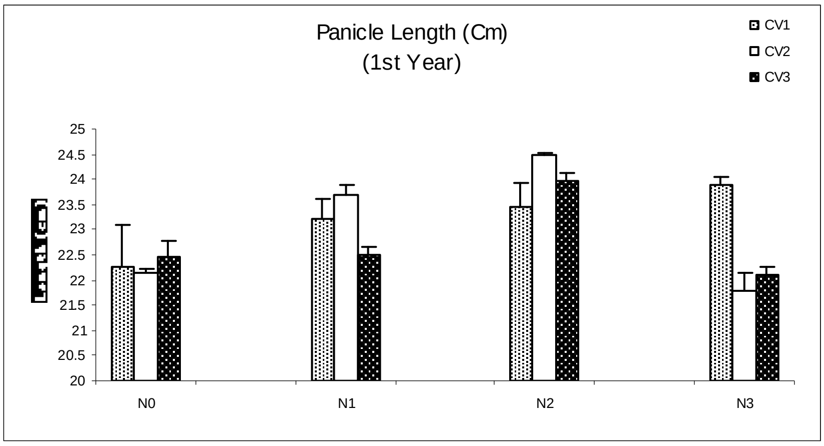


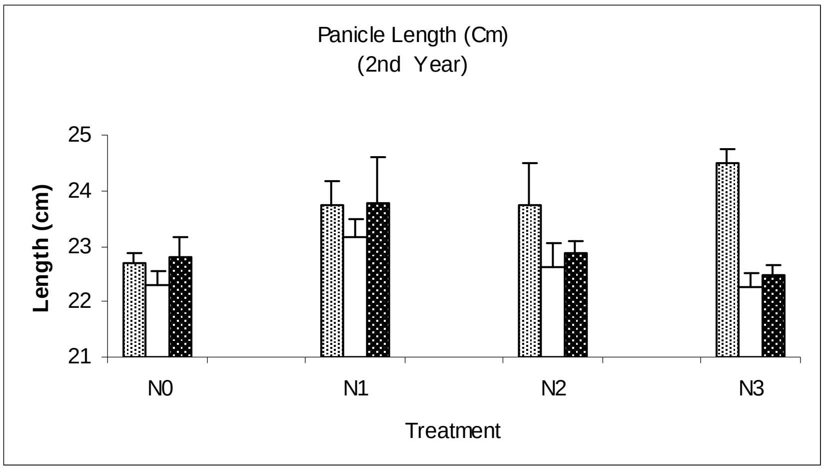
Graph 3.1.4: Straw yield of rice (qt / ha)



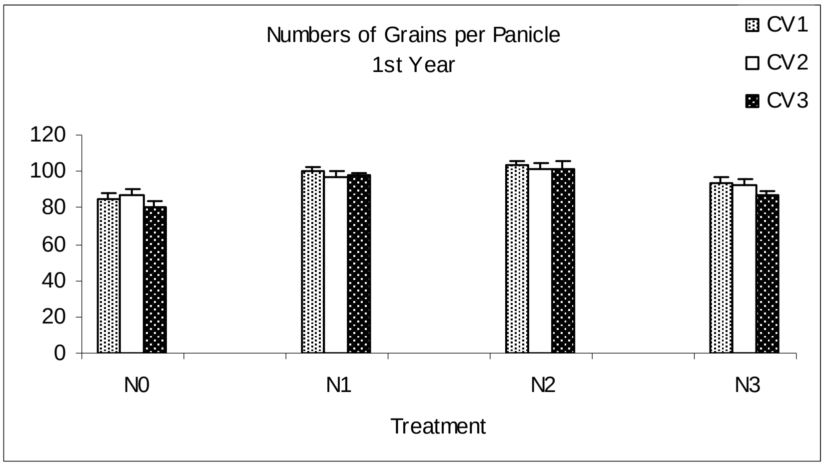


Graph 3.1.5: Panicle length of rice

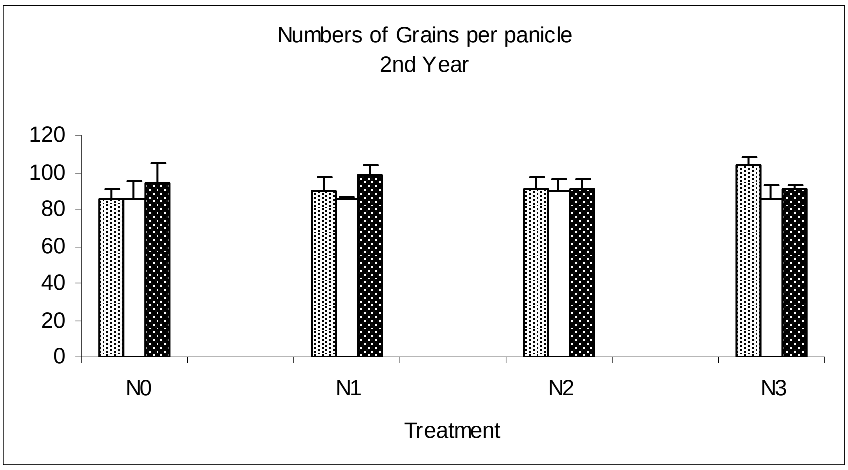




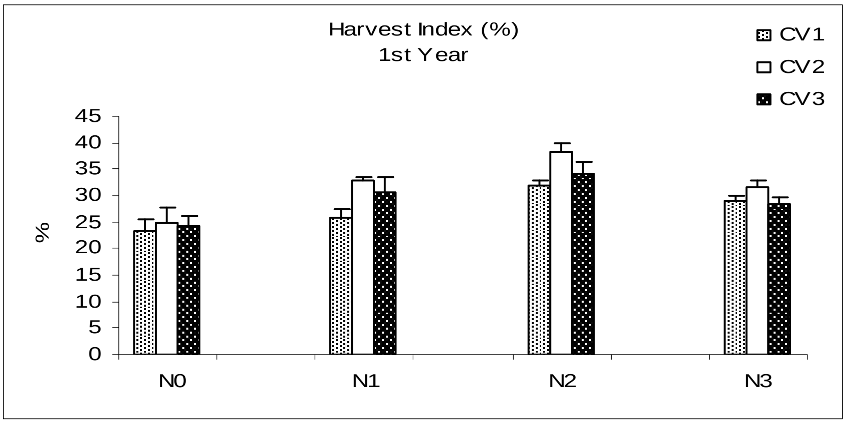
Graph 3.1.6: Number of grains per Panicle (1st Year)

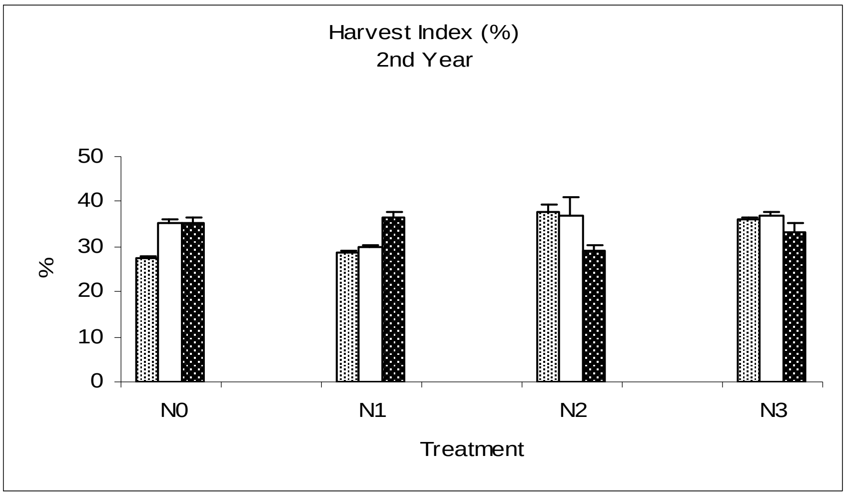


Graph 3.1.7: Number of grains per Panicle (2^{nd} Year)

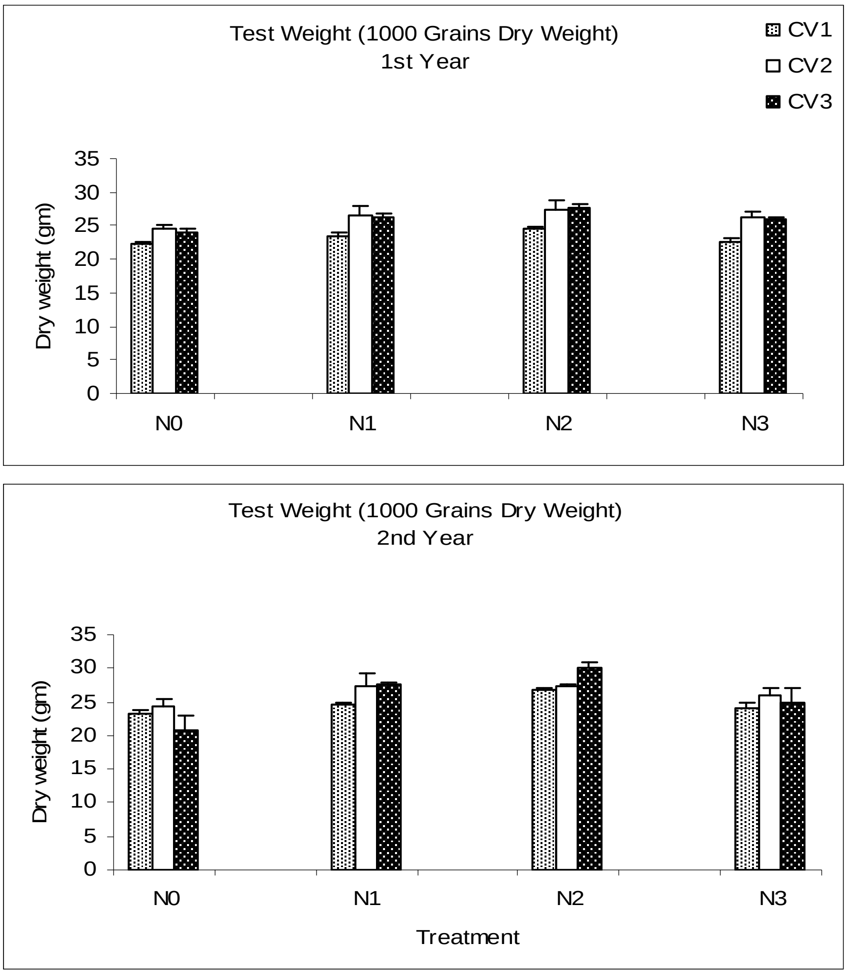


Graph 3.1.6: Harvest Index (%) of rice





Graph 3.1.7: Test weight of rice grains



5.2.3 Cultivar-wise growth performance and yield of rice

The statistical analysis shows that the three rice cultivars do not exhibit significant variations in the growth performance and in the yields of rice in the two years of the study. It was, however, observed that the performance of IR-64 was better than the other two cultivars in parameters like crop biomass, number of grains per panicle, straw yield and panicle length in the two years of the study, although the differences are not significant.

However, it was observed that RCPL- 187- 4 exhibited maximum values in the harvest index and test weight (1000 grains dry weight) in the two years of the study but there is no significant variation in these parameters. The average grain yield of Shahsarang is higher than the other two cultivars in the first year, whereas RCPL- 187-4 show the highest average yield closely followed by that of Shahsarang in the second year but the differences are not significant.

5.3 Analysis of soil nutrient status of the experimental site

The soil nutrient status of the study site (pH, OC, N, P and K) was recorded before the start of the experiment, after application of fertilizer (NPK) and biofertilizers and after harvest of rice for the two years of the study. The results are presented in tables 4.1.1 and 4.1.2, and the soil nutrient status during the two years is portrayed in graphs 4.1.1 to 4.1.5.

The soil texture varies from clayey loam to clay and the soil pH before start of the experiment is more or less neutral ranging from 6.5 to 7.5. It was observed that the soil pH tended to increase after application of fertilizers while in the control plots the pH was observed to decrease during the study period (table 4.1.1 & 4.1.2 and graph 4.1.1) However, details of the mechanisms behind the decreases in soil pH and exchangeable cations were not apparent from this study but addition of mineral fertilizers appeared to have slightly increased the pH level of the soil.

Result of the chemical analysis of the soil samples taken from 0 – 15cm of the surface soil, before the start of the experiment of the present study, showed that all the soil samples are low in available Nitrogen content, thus, application of Nitrogen @ 80 Kg/ha was recommended. The result further showed that the Organic Carbon, Phosphorus and Potassium content of the study site was low to medium before the start of the experiment.

After the application of NPK and Biofertilizer, the nutrient level of the soil had increased remarkably. The maximum increase in the Nitrogen, Phosphorus and Potassium level of soil was recorded in plots treated with NPK + Biofertilizer, followed by that of the plots treated with NPK and the minimum increase was recorded in plots treated with Biofertilizer.

The soil analysis after harvest of rice has shown a remarkable decline in its nutrient content. This may be attributed to high uptake of nutrients by the rice plants and may also be due to leaching of the nutrients, especially during the heavy rain. It was observed that the nutrient content of plots treated with biofertilizer was not much decline after harvest of rice; this may be attributed to continuous microbial activity in the soils which appears to have improved the soil fertility of the treatment plots.

In the present study, remarkable decrease in the Nitrogen levels of the soil were observed after harvest of rice in all the plots; this may be attributed to the fact that a large quantity of Nitrogen is absorbed by the rice plants while the unused portion is lost from the soil through leaching, runoff, denitrification and ammonia volatilization, with denitrification and ammonia volatilization being the main pathways of N loss (von Uexkull, 2003).

The soil analysis has shown a remarkable decline of P and K after the harvest of rice in the two years of the study. The Potassium and Phosphorus content of the soil tended to continually decline in all the control plots and has a minimum P and K content while minimum fluctuations in the P and K levels were observed in the plots treated with biofertilizer. In general, the plots treated with NPK+ biofertilizers tended to be highest in P and K content after fertilizer application as well as after harvest of rice. Long term experiments clearly indicated that a balanced use of NPK fertilizer, especially in combination with organic manure not only maintained, but even improved soil productivity (Nambiar and Ghosh, 1984; De Datta *et al.*, 1988).

The soil nutrient status at the end of the experiment is lowest in control plot (without fertilizer treatment). This shows that crop yield can not be sustained in the long term without the application of mineral fertilizers and biofertilizers, and strategies that increase the efficiency of their use. The optimization of nutrient management, their extrapolation to suitable target environments and the further development, site and season-specific production systems and technical options requires more and also long term research in a range of environments. Further, in order to make an in-depth evaluation of the nutritional aspects of soil a separate investigation involving interdisciplinary approach would be needed.

Table 4.1.1 : Soil Nutrient status of experimental plot in the first year

Treatment Plots	pH			Org C (%)			Nitrogen (Kg/ha)			Phosphorus (Kg/ha)			Potassium (Kg/ha)		
	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3
Control Plot	6.9	7.0	6.5	0.65	0.65	0.54	185.5	185.3	162.0	21.5	20.4	17.53	196.7	198.34	142.7
NPK Plot	6.8	7.2	6.9	0.72	0.91	0.85	180.7	245.6	188.6	21.8	26.6	23.24	201.4	243.33	158.6
NPK + Biofertilizer Plot	6.7	7.1	6.8	0.69	0.89	0.88	171.4	264.3	180.3	20.7	29.5	19.26	198.4	273.67	168.3
Biofertilizer Plot	6.8	6.9	6.8	0.66	0.75	0.78	177.5	205.8	172.0	19.6	24.3	19.23	189.3	222.34	174.2

S_1- Before the start of the experiment

S_2- After nutrient application

S_3- After harvest of rice

Table 4.1.2: Soil Nutrient status of experimental plot in the second year

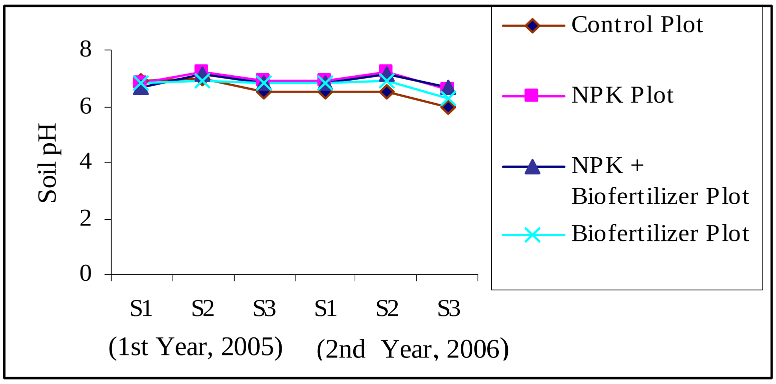
Treatment Plots	pH			Org C (%)			Nitrogen (Kg/ha)			Phosphorus (Kg/ha)			Potassium (Kg/ha)		
	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3	S_1	S_2	S_3
Control Plot	6.5	6.5	6.0	0.52	0.52	0.45	162.0	163.3	138.0	17.53	17.9	14.4	142.7	141.5	125.3
NPK Plot	6.9	7.2	6.6	0.85	0.88	0.71	188.6	235.2	158.4	23.24	26.6	20.5	158.6	233.6	153.8
NPK + Biofertilizer Plot	6.8	7.1	6.7	0.88	0.92	0.82	180.3	244.3	160.3	19.26	29.5	21.2	168.3	243.67	158.3
Biofertilizer Plot	6.8	6.9	6.3	0.78	0.81	0.76	172.0	182.3	132.0	19.23	24.3	20.23	174.2	212.34	154.2

S_1- Before the start of the experiment

S_2- After nutrient application

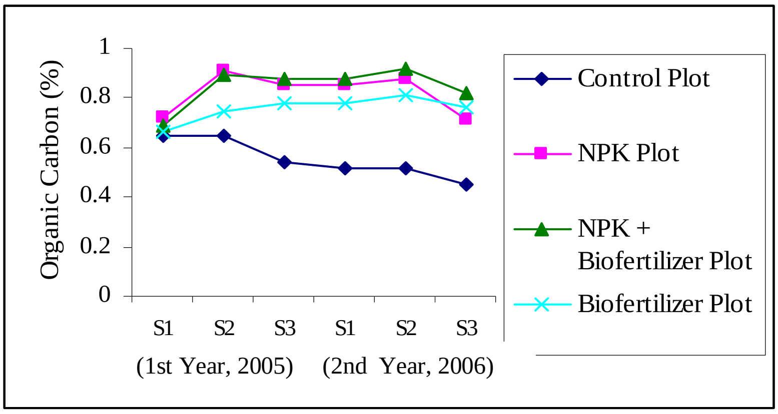
S_3- After harvest of rice

Graph 4.1.1: Soil pH of the experimental site during the study period

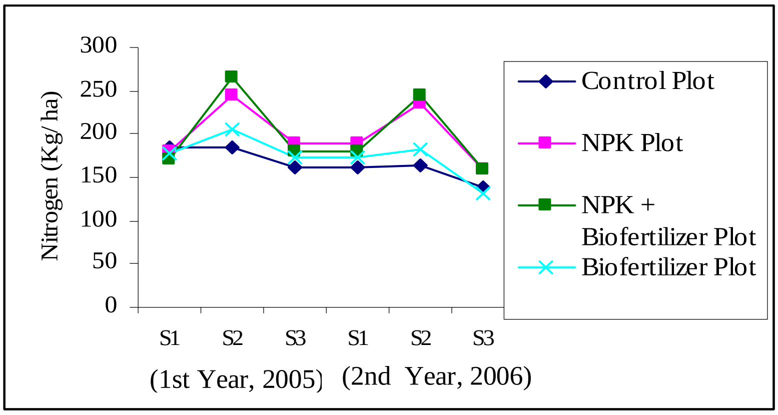


S1- Before the start of the experiment
S2- After nutrient application
S3- After harvest of rice

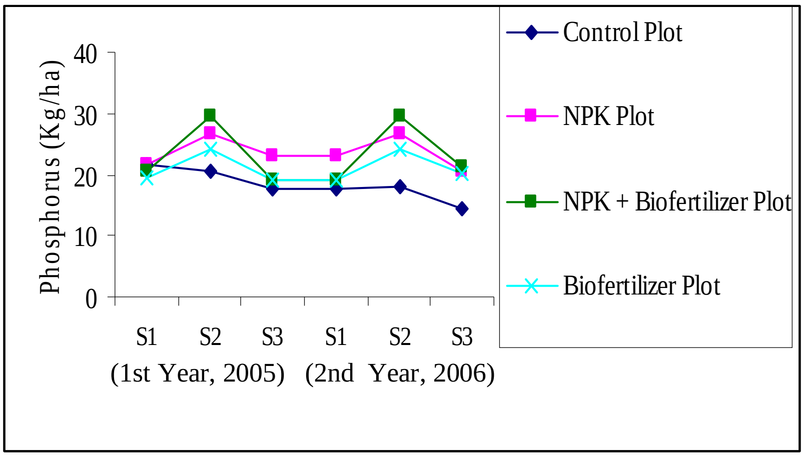
Graph 4.1.2 : Soil Organic Carbon of the experimental site.



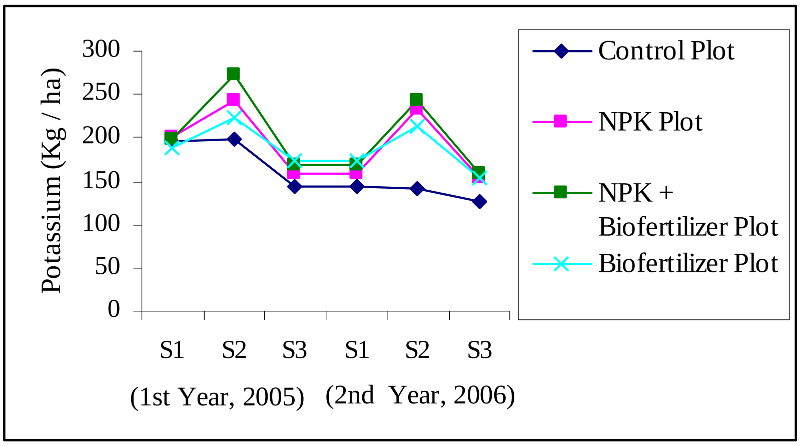
Graph 4.1.3: Soil Organic Carbon of the experimental site.



Graph 4.1.4 : Soil Phosphorus content of the experimental site during the study period



Graph 4.1.5: Soil Potassium content of the experimental site during the study period



S1- Before the start of the experiment

S2- After nutrient application

S3- After harvest of rice

5.4 Cost-benefit analysis

The cost-benefit ratio in cultivation of rice under NPK, NPK & Biofertilizer, Biofertilizer and Control is worked out to be 1:2.69, 1:2.98, 1:2.78 and 1:1.93 respectively (Table 4.2.1). The cost-benefit ratio (C/B ratio) suggests that farmers can get higher profit by applying a combination of NPK & Biofertilizer for grain yield of rice as its C/B ratio was maximum (1: 2.98) followed by that of Biofertilizer (1: 2.78) and NPK (1: 2.69), and the value is minimum in case of Control (1: 1.93). This indicates that the productivity of rice cultivation in the lowland of Mizoram can be increased by applying the appropriate nutrients in optimum dose. The Cost-benefit ratio of rice cultivation for NPK + Biofertilizer is almost double to that of Control condition. This indicated that the benefit from rice cultivation in the lowland of Mizoram can be almost doubled by application of appropriate combination of NPK and Biofertilizers.

The Cost-benefit analysis further suggests that application of Biofertilizers like *Azotobacter* and *Rhizobium* is more beneficial than that of NPK. Further, it is seen from the present study that a combination of biofertilizer and NPK is more efficient than biofertilizer and NPK alone; thus, it may be recommended to emphasize use of NPK and Biofertilizers to make the wet rice cultivation more efficient. However, the optimum dose of fertilizer would need further study for a few more years in Mizoram condition. It is apparent that the three rice cultivars can be successfully cultivated in the lowland areas of Mizoram with appropriate nutrients management.

Table 4.2.1: Cost-returns profile of rice production under different treatments.

Input/ Output	**Soil treatments**			
	Control (N_0)	**NPK (N_1)**	**NPK + Biofertilizer (N_2)**	**Biofertilizer (N_3)**
Cost of land preparation (Rs./ha)	5,600.00	5,600.00	5,600.00	5,600.00
Cost of fertilizer / manure(Rs./ha)	0.00	4,280.00	4,300.00	20.00
Cost of weeding (Rs. / ha)	2,875.00	2,978.00	2,978.00	2,772.00
Cost of harvesting (Rs./ ha)	3,296.00	3,399.00	3,399.00	3,296.00
Gross operational costs(Rs./ha)	11,771.00	16,257.00	16,277.00	11,688.00
Gross returns(Rs./ha)	34,575.00	60,125.00	64,925.00	44,275.00
Net returns(Rs./ha)	22,804.00	43,868.00	48,648.00	32,587.00
Cost Benefit ratio (Rs./ha)	**1:1.93**	**1:2.69**	**1:2.98**	**1:2.78**

Graph 4.2.1: Cost benefit ratio of rice cultivation under different soil treatments

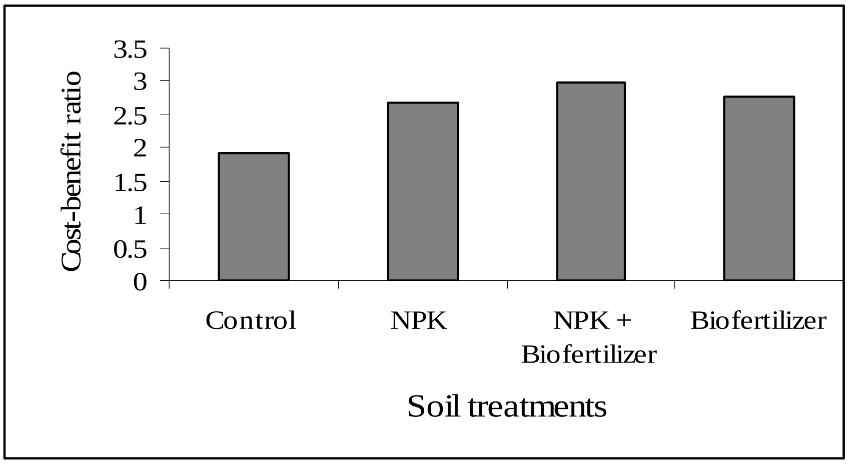


Table 4.2.2 : Cost-returns profile for cultivar-wise production of rice.

Parameters	**Rice cultivars**		
	IR – 64 (CV_1)	**RCPL – 187-4 (CV_2)**	**Shahsarang (CV_3)**
Gross operational costs (Rs./ha)	14,740.00	14,740.00	14,740.00
Gross returns((Rs./ha)	50,425.00	51,025.00	51,475.00
Net returns(Rs./ha)	35,685.00	36,285.00	36,735.00
Cost Benefit ratio	**1: 2.42**	**1: 2.46**	**1: 2.49**

5.4 Discussion

The present investigation aimed at a comparison of the growth performance of three rice cultivars viz. IR – 64, RCPL – 187-4 (Lumpanas) and Shahsarang planted at a spacing of 20 cm row to row and 10 cm plant to plant under different fertilizer treatments viz. NPK, NPK + Biofertilizer, Biofertilizer and Control (without fertilizer). The experiment also attempts to determine the most suitable rice cultivars for optimum growth and yield in the lowlands of Mizoram. Further, the soil nutrient status of the experimental field was determined before sowing of rice and after harvest of rice (pH, Org. C, N, P and K).

Keeping in view the experimental design 4 x 3 x 3 ANOVA (4 fertility levels x 3 cultivars x 3 replications with five observations under each) and repeated measures on the last component for the two years of the study, and the separate analysis for each year, one would reason that 4 x 3 x 3 ANOVA (4 fertility levels x 3 cultivars x 3 replications x 2 years of observation) with five observations under each and repeated measures on the last two components should have been analyzed. The same is not incorporated for (i) want of simplicity of presentation of the growth and yield patterns of rice cultivars for each year; and (ii) the interest was not in the higher order interactions.

In general, it was observed that the application of NPK and Biofertilizer have significant effect on the growth and yield parameters of rice as compared to Control (without fertilizer) in the two years of the study. It was observed that the combined application of NPK + Biofertilizer has maximum positive effect on the growth and yield of the three rice cultivars, followed by that of NPK alone which is followed by the application of Biofertilizer and lowest in Control(without nutrient application).

The result is supported by the finding of Khanda *et al.* (2005) who reported that integrated use of farmyard manure (FYM) or biofertilizer and NPK fertilizer significantly increased the gross and net return of the rice cropping system compared with the rice of NPK fertilizer alone. This is also in agreement with the observation of Hussain *et al. (*1991) who opined that the integrated use of organic material and chemical fertilizers in rice cultivation is important for sustaining the crop productivity and reducing the use of chemical fertilizers. Prasad *et al.* (1987) reported that Azospirillum along with N fertilizer increased significantly grain yield, grain N content and N uptake.

The above results are also in accordance with the finding of Prasad (1999) who stated that complimentary use of organic and biological source of plant nutrient along with chemical fertilizer is of great importance for the maintenance of soil health and productivity, especially under intensive cropping system. Further, the present observation is supported by the research finding of Patel and Munda (1991) who stated that application of fresh azolla @ 10 t/ha or composted azolla @ 2 t/ha in combination with Nitrogen through inorganic sources gave maximum yield of rice.

The growth and yield of the three rice cultivars under study is significantly higher under inorganic NPK fertilizer and biofertilizer treatments as compared to control in the first and second years of the present experiment; this indicates the positive effect of NPK fertilizer and biofertilizer on the productivity of rice which is in agreement with the findings of Singh *et al*. (1979) and Velu (1990). The marked increase in grain yield was due to the enrichment of soil fertility through application of NPK and biofertilizer in the soil (Gopalsamy and Vidhyasekaran, 1987) and improved growth parameters and yield attributes (Thiagarajan, 1991). Azospirillum inoculation increased the grain and straw yields over inorganic NPK alone due to atmospheric N fixation (Gopalsamy and Vidhyasekaran, 1987) and reduction in the N loss (Murali and Purshothaman, 1987). The findings of the previous studies stated above supported the present observation.

However, it was observed that the growth performance and yield of the three rice cultivars do not exhibit significant differences in the two years of the study. The maximum recorded grain yield per hectare (36.97 quintals/ ha) of rice in the present experiment is still lower than the potential yield (50-60 quintals/ ha). This suggests that there might be mismatch of fertilizer rates and crop nutrient demand of the rice cultivars in the present experiment or else the prevailing rain-fed lowland condition of the study site may be the limiting factor for the yield of rice. According to Dobermann and Cassman (2002), managing the location - and season - specific variability in nutrient supply is a key strategy to overcome the current mismatch of fertilizer rates and crop nutrient demand in irrigated rice environments.

The ecological impact of nutrient management on the productivity of rice in lowland of Mizoram in the long run and the optimum doses of fertilizer would need continuation of the present experiment for a few more years. According to Singh *et al.* (2002), application of Nitrogen fertilizer influences the growth and yield parameters of rice significantly, and that Nitrogen applied in two split at 20 and 40 days after germination was useful to improve the rice productivity under variable rainfall. It was also reported by Dong *et al.* (1981) that Nitrogen, Phosphorus and Potash, along with Sulphur and Zinc, have a marked effect on increasing rice yields by promoting growth and better movement of photosynthesis from the leaf to the grain in rice.

In general application of chemical fertilizer (NPK) and biofertilizer resulted higher rice yield due to improvement in soil properties. Such favourable response to the yield might be attributed to the better availability of sufficient amount of plant nutrients throughout the growth period and especially in critical growth period of crops that has resulted into better plant vigour and superior yield attributes (Khan *et al.,* 2004).

The soil fertility level of the experimental site has been found to decrease after harvesting of rice; hence, it can be assumed that the rice production have declined without application of fertilizers. Neither organic sources nor inorganic fertilizers alone can achieve sustainability in crop production. Continuous use of farmyard manure (FYM) is effective in stabilizing rice productivity under low to medium cropping intensity where the nutrient demand is relatively small.

The nub of the declining nutrient in the lowland rice cultivation is how to maintain nutrient availability in these areas over multiple annual cropping cycles. Organic additions (e.g. cattle manure, pig dung, composted litter, crop residues) with or without commercial fertilizer are much more ecologically efficient than commercial fertilizer alone (Eastmond & Faust, 2006; Kato *et al*., 1999). However, their availability is often limited because the cost of collecting and transporting these bulky materials from adjacent areas is prohibitive (Bruun *et al*., 2009). Careful use of commercial fertilizers in combination with biofertilizer is a key to maintaining sustainability of lowland rice cultivation in Mizoram. However, it is needed to screen more cultivars to identify the most suitable rice cultivar(s), the appropriate dose and combination of NPK and biofertilizers to increase yield of rice.

The potential strategies to increase rice production include cultivation of rice varieties tolerant to nutrient deficiencies and toxicities. Exploitation of the production potential of high yielding rice varieties through agronomic management is the only alternative to fulfill the growing food needs of the large expanding population. (Sudha and Chandini, 2002). Rice productivity in the lowland of Mizoram can be improved faster through an integrated approach including soil management and development of tolerant varieties. With most of the physical, chemical and biochemical and microbial processes governing growth and productivity of rice reasonably well understood, there are now many avenues open to increase fertilizer use efficiency. But as yields go up, future gains will have to come increasingly from more complex interaction effects.

Although the research results presented here are highly encouraging, the grain yield of rice is still low compared to the potential yield of the rice cultivars tested at the ICAR Research Complex, Barapani (Meghalaya). The comparatively lower grain yield obtained in the present study and the production potential of the three rice cultivars underline the large gap remaining between actual and potential yields and thus, indicates the potential to further improve the productivity of lowland rice cultivation under rain-fed condition in Mizoram. Bridging the yield gap requires integrated and holistic approaches and adequate institutional support to farmers. It is not static but dynamic with technological developments in rice production, as the gap tends to enlarge with the improvement of the yield potential of rice varieties. Mechanization, nutrient management, timely availability of rain water and proper management of pests and diseases will help in bridging the yield gaps of rice.

Bridging the yield gaps is the local solution to the national problem. It results in increased production with the additional incentives of cost reduction, poverty alleviation, social justice and equity. Closing the yield gap alone could supply 60 percent of the increased annual rice demand by the year 2025 (Nirmala *et al.,* 2009). Hence, it is essential to expedite the bridging of yield gaps for improving the productivity and efficiency of rice production and thereby food security. For this purpose institutional and policy support to farmers is crucial for ensuring agricultural input supplies, farm credit, and minimum support price in a holistic approach for sustainable increase in rice production. Even with the existing technologies it is possible to increase the production by closing the yield gaps in rice.

Until now, most yield increases in rice have come from the simple combination of modern, high yielding varieties and increased use of fertilizer. While this approach was highly efficient, there are strong indications that yield is plateauing and that nitrogen use efficiency is on the decline. Thus, enhancement of nutrient use efficiency must focus primarily on minimizing Nitrogen losses and maximizing physiological Nitrogen utilization by the rice plant.

The problem of feeding an increasing population from a finite land resource was addressed in the 1960s / 70s by the 'Green Revolution' which relied on greatly expanded use of commercial fertilizer and pesticides as well as novel crop strains developed using genetics and biotechnology (Mooney *et al*., 2005). Commercial fertilizer applications to tropical soils under intensive agriculture often reduce overall soil fertility because of the eventual depletion of other plant nutrients as well as effects of depleted soil organic matter content, and lead to eutrophication of rivers and lakes because of incomplete nutrient uptake and retention by plants and the soil. In fact, India will spend nearly as much in the next 5 years on initiatives to restore soil health in the ‘breadbasket of India’ (Punjab and Haryana states) as it will to develop Mizoram’s New Land-use Policy (Misra, 2010).

In recognition of these issues, the Mizoram government banned commercial fertilizer and pesticides in 2005 to achieve ‘organic’ agricultural production status within India. Although this is undoubtedly a laudable ecological goal, it appears that the decision was based primarily on human health rather than on environmental concerns, and that politicians and the public have not made the critical distinction between the very high health risks associated with pesticides (Alavanja *et al.*, 2004 and Kesavachandran, 2009) and the nominal health risks associated with commercial fertilizer (Rao and Puutanna, 2000).

With the introduction of New Land-use Programme (NLUP) in Mizoram, the state government has made a plan to extend crop cultivation in the low land while keeping a larger area of the hill slopes for afforestation and forestry sector. In this regard, proposal has been made to reclaim land having potential for wet rice cultivation and also to provide irrigation facilities to encourage settled cultivation in valleys and terraced rice cultivation on slopes (Anon., 2010).

The potential area for lowland rice cultivation in Mizoram is estimated to be 74,644 hectares, which is 3.54 per cent of the state's total geographical area. The net area cultivated is about 11,198 hectares i.e. about 15 per cent of the total WRC potential area. Forests cover account for about 9610.95 Sq Km or 9,61,095 hectares, i.e. 45.58 per cent of the total land area. An area of 3965.91 Sq. Km is under 'jhum' which is 18.80 per cent of the geographical area. These jhum lands are devoid of tree growth due to repeated process of burning but are covered with bamboo and scrub growth. The area annually affected by shifting cultivation is estimated as 1049.64 Sq. Km (Anon., 2008). Thus, development of lowlands having potential for rice cultivation and providing minor irrigation may be recommended to encourage settled cultivation in valleys and terraced slopes. This would hopefully reduce the pressure to the declining forests in the hill slopes for shifting cultivation.

5.6 Conclusion

In the present study, three rice cultivars namely, IR – 64, RCPL – 187-4 (Lumpanas) and Shahsarang have been tested in the rain-fed lowland condition of Mizoram. From the experimental finding it may be inferred that all the three cultivars of rice can be grown successfully under permanent farming system, in the rain-fed lowland of Mizoram, with the appropriate nutrient management.

The integrated use of organic and inorganic fertilizers has been found to be more effective in maintaining higher productivity and stability of rice cultivation through correction of deficiencies of secondary and micronutrients in the course of mineralization on one hand and favourable physical and soil ecological conditions on the other. Organic manuring also improves the physical and microbial conditions of soil and enhances fertilizer use efficiency when applied in conjunction with mineral fertilizers. Thus, all the major sources of plant nutrients such as soil, mineral, organic and biological may be utilized in an efficient and judicious manner for sustainable rice production in the lowland of Mizoram.

If all the potential lowlands are developed for rice cultivation with appropriate nutrient management, the rice production will significantly increase which would probably help Mizoram to become self sufficient in rice production. Other cropping activities like cultivation of maize, soyabean and pulses may also be taken up in the lowland in rotation with rice cultivation. However, this would require a separate investigation before introduction in a larger scale.

Thus, extension of rice cultivation in lowland of Mizoram on permanent basis may be suggested as one of the most effective and viable alternative to increase the rice production, and would also be an ecologically and economically sound option to replace rice cultivation in hill slopes of Mizoram. If the potential area of 74,644 hectares is used for lowland rice cultivation with appropriate soil and nutrient management, the annual rice production could be doubled or even tripled. Farmers may be encouraged to grow other cash crops depending upon the slopes, edaphic and climatic factors, or they may be advised to take up other trades related to forestry, horticulture and agroforestry sectors.

The present findings are based on the two years' experiment, and it may further be predicted that a better growth and yield of rice could have been obtained by applying optimum doses and a combination of inorganic fertilizers and biofertilizers. Thus, there is a need to conduct further experiments on lowland rice cultivation in Mizoram in order to establish the most appropriate doses and combination of nutrients. Finally, to ensure the adoption of nutrient management in lowland rice cultivation in Mizoram, farmers' participation in further activities will be imperative.

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Photo plate No. I

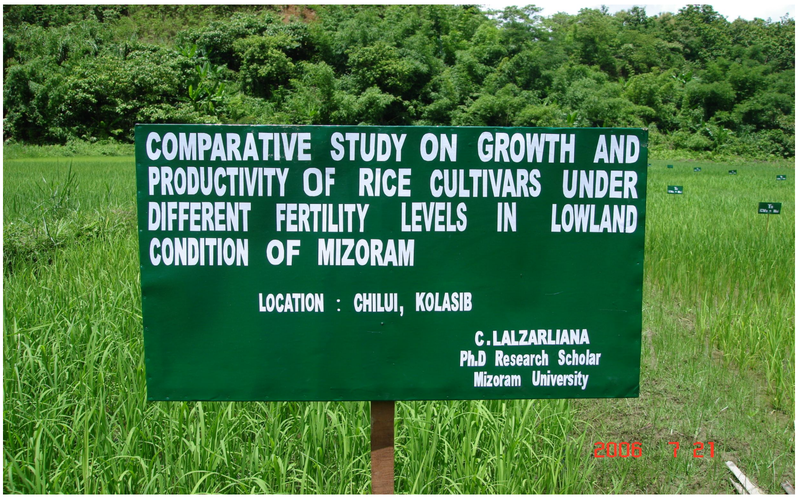

Photo 1: Experimental plot at Chilui, Kolasib

Photo 2: The experimental plot at the time of transplanting of rice (1st year)

Photo 3: The research scholar in the experimental plot during transplanting of rice (2nd year)

Photo plate No. II

Photo 4 : The experimental plot at 30 days after transplanting of rice (1^{st} year)

Photo 5 : The experimental plot at 30 days after transplanting of rice (2^{nd} year)

Photo 6: Research scholar counting the number of tillers at 30 days after transplanting (DAT)

Photo plate No. III

Photo 7: Experimental field with rice at 60 DAT (1^{st} year)

Photo 8: RCPL- 187-4 (Lumpanas) in Biofertilizer plot at 60 days after transplanting (DAT)

Photo 9: IR-64 grown in a Biofertilizer plot at 60 days after transplanting (DAT)

Photo plate No. IV

Photo 10: Shahsarang in NPK+Biofertilizer plot at 60 DAT

Photo 11: RCPL- 187-4 (Lumpanas) in a control plot at 60 DAT

Photo 12: Research scholar and Jt. Supervisor in the experimental field

Photo plate No. V

Photo 13: Research scholar measuring leaf area of rice

Photo 14: Research scholar and Supervisor (August, 2006)

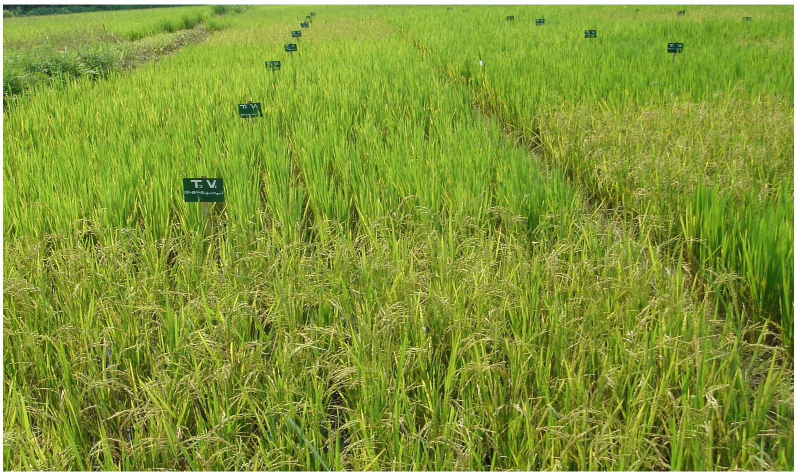

Photo 15: IR-64 started maturing and ripened to be harvested (1st year)

Photo plate No. VI

Photo 16: Harvesting of rice (October, 2006)


Photo 17: Bundles of rice harvested rice from different treatment plots (1st year)

Photo 18: Bundles of rice harvested rice from different treatment plots (2nd year)

Photo plate No. VII

Photo 19 : Weight of rice straw from different treatment plots were measured and recorded.

Photo 20: Rice grains from different treatment plots (2nd year)

Photo 21: Weight of rice grains from different treatment plots measured and recorded.

Photo plate No. VIII

Photo 22 : Rice grains were counted to record the weight of 1000 grains

Photo 23: Weight of 1000 rice grains measured using weighing machine

Photo 24: Rice grains (bags) and 1000 grains (in envelops) from different treatment plots.