Flag Leaf Nutrition for Enhancing Resource Use Efficiency in Rice (*Oryza sativa* L.)

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2015

DECLARATION

I, hereby declare that this thesis entitled **"Flag leaf nutrition for enhancing resource use efficiency in rice (*Oryza sativa* L.)"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis, entitled "**Flag leaf nutrition for enhancing resource use efficiency in rice (*Oryza sativa* L.)**" is a record of research work done independently by Ms. Surya, M.S. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Surya, M.S.

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AE	Agronomic efficiency
ARE	Apparent recovery efficiency
B:C	Benefit cost ratio
BCR	Benefit cost ratio
Ca	Calcium
CD (0.05)	Critical difference at 5 per cent level
CEC	Cation exchange capacity
cm	Centimeter
cm^2	Centimeter square
DAS	Days after sowing
DAT	Days after transplanting
Day^{-1}	Per day
DMP	Dry matter production
DMSO	Di methyl sulphoxide
$dS\ m^{-1}$	Deci Siemens per metre
EC	Electrical conductivity
et al.	Co- workers/ co- authors
Fig.	Figure
FLN	Flag leaf nutrition
FYM	Farmyard manure
g	Gram
$g\ L^{-1}$	gram per litre
$g\ m^{-2}$	Gram per square metre
ha	Hectare
HI	Harvest index
$hill^{-1}$	per hill
i.e.	that is

K	Potassium
KAU	Kerala Agricultural University
kg	Kilogram
kg ha^{-1}	Kilogram per hectare
LAD	Leaf area duration
LAI	Leaf area index
log	Logarithm
L ha^{-1}	Litre per hectare
m	Metre
m^{-2}	per square metre
Mg	Magnesium
mg	milli gram
mg g^{-1}	milli gram per gram
mg $g^{-1}day^{-1}$	milli gram per gram per day
mL	millilitre
mL L^{-1}	Millilitre per litre
mm	millimetre
MOP	Muriate of potash
MSL	Mean sea level
nos.	Numbers
N	Nitrogen
NAR	Net assimilation rate
NO_3 -N	Nitrate nitrogen
NS	Not significant
NUE	Nitrogen use efficiency
P	Phosphorus
PI	Panicle initiation
plant $^{-1}$	per plant
$panicle^{-1}$	per panicle
POP	Package of practices

pH	Negative logarithm of hydrogen ion concentration
RBD	Randomized Block Design
RARS	Regional Agricultural Research Station
RGR	Relative growth rate
RH	Relative humidity
S	Significant
SEm	Standard error of mean
S	Sulphur
SLW	Specific leaf weight
t	time
t ha^{-1}	Tonnes per hectare
viz.	Namely

LIST OF SYMBOLS

%	per cent
^{0}C	Degree Celsius
@	at the rate of
₹	Rupees

Introduction

1. INTRODUCTION

Rice (*Oryza sativa* L.), a crop that has moulded diets, cultures and economies world over, is incidentally the only agricultural commodity to realize two years designated as ‘international’ in its honour. In 2012, nearly half of the world’s population – more than 3 billion people relied on rice every day. Among the food grains, the demand for rice continues to grow and is projected to increase by more than 50 per cent over the next few decades (Zeigler, 2012). Food security in India (450 million tonnes of food grains to feed 1.6 billion by 2050) is a challenge (Siddiq, 2000). A staple crop for more than three billion population worldwide, rice has been a focused research subject for agriculture scientists (Fageria, 2007; Li *et al*., 2011).

Grain yield is a complex trait, controlled by a series of biochemical and physiological processes. The grain-filling process of rice, in particular, is of great interest, as it directly relates to the productivity as well as quality of the rice. Although cultivars with large or extra-heavy panicles are available with the unrelenting efforts by the scientists, the theoretical maximum yield has not been realized due to poor grain-filling characteristics, such as non or slow-filling of the grains (Peng *et al*., 1993; Yang *et al*., 2002; Ao *et al*., 2008) clubbed together with low fertilizer use efficiency. The low grain filling rate and grain weight implicating a reduced grain yield often result from limited carbohydrate supply, especially under nutrient deficiency (Yang *et al*., 2003).

In rice, 60 to 90 per cent of the total carbohydrates in the panicles at harvest are derived from the photosynthesis after panicle initiation (Tari *et al*., 2009). Plant leaves being the organ of photosynthesis is considered to be the important determinant and characterized for higher photosynthetic capacities (Asana, 1968). Grain filling is sustained by current photosynthesis of the upper parts of the plant, *i.e*. the flag leaf and penultimate leaves and the ear (Tambussi *et al*., 2007). The top three leaves, especially the flag leaf contributes most to grain yield. Thus leaf senescence during the reproductive and maturity stages is directly related to biomass production and grain yield of rice (Misra *et al*., 1997).

Flag leaf plays a major role in the synthesis and translocation of photoassimilates to the rice seeds, affecting grain yield. Removal of the rice flag leaf at any stage after panicle emergence was reported to cause significant reduction in grain yield (Singh and Ghosh, 1981). It has been proved that the flag leaf, stem and head are the closest source to the grain. Senescence in cereals is regulated at the individual leaf level, with older leaves mobilizing nutrients to younger leaves and eventually to the flag leaf (Gregersen *et al*., 2008). Khalifa *et al*. (2008) reported that flag leaf contributed to 45 per cent of rice grain yield and served as a major source for remobilized minerals for the grains. Thus flag leaf has been assigned an important role in terms of supply of photosynthates to the grains (Asana, 1968), increasing grain yield (Raj and Tripathi, 2000) and in enhancing productivity (Padmaja, 1991).

At present, most of the research is directed towards the irrigated environments, even in areas where lowland rainfed rice predominates. The yield of rice under rainfed lowland conditions are almost always lower than that under irrigated or otherwise optimum conditions (Mackill *et al*., 1996). Many factors are responsible for increasing the yield and quality of crops - proper and balanced fertilizer application being the most important one. The recovery of nutrients, especially fertilizer nitrogen applied to the rice crop is seldom more than 30 to 40 per cent. Even with the best agronomic practices and strictly controlled conditions the recovery seldom exceeds 60 to 65 per cent (De Datta, 1981).

In the case of mobile nutrients, availability changes periodically with the mineralization of organic matter and losses due to leaching, denitrification and volatilization in soil plant systems. In rice, an increase on N during the late growth stage decreases the amount of non-productive tillers, prevents root and leaf senescence, increases photosynthesis, accelerates matter translocation, and improves grain-filling. Therefore, such practice can result in an increased seed-setting percentage, high yield and improved quality of rice (Perez *et al*., 1996). Foliar nutrition when used as a supplement to the recommended soil fertilizer application is highly beneficial, as the crop gets benefited from foliar applied nutrients when the roots are unable to meet the nutrient requirement of the crop at its critical growth stages.

Keeping the above in view, the present study was undertaken to assess the possibility of increasing the resource use efficiency of lowland rice by supplementing the recommended nutrient management practice with foliar nutrition during the reproductive stage of rice. The main objectives of the study were

- To assess the effect of flag leaf foliar nutrition on partitioning of photosynthates
- To assess the effect of flag leaf foliar nutrition on growth and productivity of rice
- To work out the economics of the practice in lowland rice cultivation system

Review of Literature

2. REVIEW OF LITERATURE

Most of the rice researches are directed towards the irrigated environments, even in areas where lowland rainfed rice predominates. The yield of rainfed lowland rice is always lower than that under irrigated conditions. To achieve high yield without an increase in maximum rate of net carbon assimilation, the rice plant will require a considerable delay in leaf senescence and maintenance of leaf nitrogen status during an extended grain filling duration. Nutrient management options which aims at delaying the senescence of leaves, closely relates to leaf metabolism and better grain filling.

In this chapter a detailed review on research done on the importance of flag leaf in rice and the effect of foliar application with different nutrient sources during the reproductive phase of rice are presented. Emphasis has been given for the effect of the practice in delaying leaf senescence and consequent yield improvement in rice.

2.1 SIGNIFICANCE OF FLAG LEAF

Leaf position on the plant is one of the major factors affecting the efficiency of leaf photosynthesis. In most of the cereals, the flag leaf is most active. The flag leaf stays longest on the plant and makes a major contribution to the grain yield in cereals.

The flag leaf plays a very important role in grain filling in small grain crops such as rice, wheat, barley, oats, etc. because of its position on the culm. It is the topmost leaf and as such it intercepts lot of radiation. Further, the translocation of assimilates from the flag leaf (source) to the panicle (reproductive sink) is enhanced by the proximity of the flag leaf to the sink. Thus flag leaf is considered as an activist leaf during the grain filling period. Thus flag leaf area could be a choosing factor for increasing rice grain yield. Flag leaves are characterised by long-term photosynthetic activity, which is particularly important during grain filling when the older leaves die off (Loss and Siddique, 1994;

Turner, 1997). Under favourable conditions, approximately 70 to 90 per cent of the total grain yield is derived from the photosynthates accumulated during grain filling period (Inoue *et al*., 2004)

In rice 60 to 90 per cent of the total carbon in panicles at harvest is derived from photosynthesis after heading, while 80 percent or more of nitrogen in the panicles at harvest is absorbed before heading and remobilised from the vegetative organs (Mae, 1997). Leaf senescence during reproductive and maturity stages is directly related to biomass production and grain yield in rice (Misra *et al*., 1997).

Flag leaf plays an important role in the assimilation and translocation of assimilates in the rice plant, and thus ultimately influence the grain yield (Singh and Ghosh, 1981). The top three leaves, especially the flag leaf contributes most to rice grain yield (Ray *et al*., 1983; Misra, 1986). Flag leaf has an important role in rice yield by increasing the grain weight by 41 to 43 per cent (Rao, 1997). Experiments conducted to study the effect of leaf cutting on the yield of rice revealed that flag leaf contributed maximum to the rice grain yield and its contribution was as high as 45 per cent (Khalifa *et al*., 2008).

2.2 EFFECT OF FOLIAR NUTRITION

Soil feeding of nutrients is a normal practice in rice, but has limitations with respect to its availability to the plants. The nutrients can be applied very effectively as foliar sprays. Foliar feeding is best used with secondary or micronutrients where plant requirements are relatively small. For major nutrients it is necessary to use several foliar applications in order to supply enough of that nutrient to significantly improve crop yield or quality. The elements such as phosphorus, potassium and most of the micronutrients are fixed in the soil complex while the more soluble nutrients such as nitrogen are easily leached down the soil. Foliar application is one such technique which reduces the losses of nutrients through immobilization, denitrification, and leaching especially with nitrogen and increases the utilization rate of nutrients.

Foliar application of nutrient solutions partially alleviates the adverse effects of salinity on photosynthesis and photosynthesis-related parameters, yield and yield components through mitigating the nutrient demands of salt-stressed plants. Foliar spray of nutrients increased the photosynthesis, dry matter accumulation, tiller number, dry weight, leaf area, number of fertile spikelet in the panicle and grain yield of rice (Hasegawa *et al*., 2000).

Strong (1982) reported that foliar application resulted in higher grain protein content levels than when nutrient was broadcasted as dry granule fertilizer at late growth stages on wheat. Sharpley *et al*. (1994) observed that foliar application not only increased the efficiency of nutrient uptake but also decreased cost of production of cereal crops. Babu (1996) could observe higher chlorophyll content in medium duration rice with enhanced NPK rates.

Foliar application provides more rapid utilization of nutrients and permits correction of observed deficiencies in less time than that of soil application (Gooding and Davis, 1992). Foliar spray of fertilizer did not only increase the crop yields but also reduced the quantities of fertilizer applied through soil. Foliar application can also reduce the lag time between application and uptake by the plant (Ahmad and Jabeen, 2005).

Amberger (1996) observed that foliar application reduces the losses of nutrients through immobilization, denitrification and leaching especially with nitrogen and increased the utilization rate of nutrients. Multiple split foliar applications of nitrogeneous fertilizers can increase nitrogen use efficiency (Cassman *et al*., 1998) and reduce N losses (Ding *et al*., 2003).

Foliar nutrition when used as a supplement to the recommended soil fertilizer application is highly beneficial as the crop gets benefited from foliar applied nutrients when the roots are unable to meet the nutrient requirement of the crop at its critical growth stage (Brar and Brar, 2004).

Ahmad and Jabeen (2005) revealed that foliar spray of nutrients increased grain yield of transplanted *aman* rice upto 9.33 per cent over conventional method. Sterility percentage and weed infestation were also lower for foliar nutrition.

Fageria and Baligar (2005) opined that the availability of mobile nutrients like N to plants changes periodically with the mineralization of organic matter and losses due to leaching, denitrification and volatilization in soil plant systems.

Girma *et al*. (2007) reported that foliar application is a visible economic way to supplement the plant nutrients for more efficient fertilization. Foliar application of phosphorus could be used as an efficient phosphorus management tool in wheat when applied at appropriate growth stage and rate.

2.3 IMPORTANCE OF FLAG LEAF NUTRITION

Crop yield is determined by the efficiency of photosynthesis, assimilates transport and distribution. Nutrients especially the major nutrients contribute to leaf area expansion and affects leaf longevity, thus influencing the efficiency of photosynthesis. Flag leaves play an important role in synthesis and translocation of photo assimilates in the rice plant, affecting grain yield, similarly they were believed to be a major source of remobilized minerals for the seeds.

Mahmood and Chowdhry (1997) reported that in wheat 34.5 per cent grain yield reduction was reported after flag leaf removal at the heading stage. Rao (1997) revealed that flag leaf is the activist leaf at grain filling period and could be chosen as a factor for increasing grain yield of rice.

Flag leaf is of utmost importance in cereals like wheat it provides maximum amount of photosynthesis assimilates to be stored in grains. Yang *et al*. (2002) observed that poor grain filling of indica-japonica rice hybrids is related to poor translocation and partitioning of assimilates to the grains, resulting in more resources for vegetative growth.

Dutta *et al*. (2002) observed that there was a positive correlation between flag leaf angle and photosynthesis material translocation, and spikelets fertility increases also for increasing grain yield in rice. A greater flag leaf area will eventually help to increase photosynthetic efficiency by increasing production of photosynthesis which is then translocated into grains increasing their weight. Therefore flag leaf has a direct relationship to grain yield (Riaz and Chowdhry, 2003).

Birsin (2005) showed that flag leaf removal resulted in reduction in grain per spike, grain weight per spike and 1000 grain weight and increase in grain protein contents. Narayan *et al*. (2007) reported that flag leaves are believed to be a major source of remobilized minerals for the seeds. Khalifa *et al*. (2008) reported that flag leaf contributed to 45per cent rice grain yield and served as a major source for remobilized minerals for grains. In rice 60-90 per cent of the total carbohydrates in the panicles at harvest are derived from the photosynthesis after panicle initiation (Tari *et al*., 2009). Yan and Shi (2013) identified flag leaf soluble protein as one of the substances produced by the source which plays an important role in increasing the grain dry matter.

Top dressing of nitrogen at full heading stage (grain fertilization) was recommended by Matsushima and Tanaka (1967) for increasing the percentage of ripened grains in rice. Fertilizer-N application up to panicle initiation stage is known to increase protein content and possibly grain yield of rice (De Datta, 1970). Cassman *et al.* (1993) reported that increased nitrogen fertilizer rates including a top dressing applied at flowering stage was found to increase the yield of IR rices. Mae (1997) observed that nitrogen absorbed during panicle initiation increases specific leaf weight and nitrogen contents in leaves which leads to enhancement of photosynthesis capacity and promotion of carbohydrate accumulation in culms and leaf sheaths.

Makino *et al*. (1985) opined that to achieve yields of 13 to 15 t ha^{-1} in the tropics without an increase in the maximum rate of net carbon assimilation of the rice plant will require a considerable delay in leaf senescence and maintenance of leaf N status during an extended grain-filling duration. The leaf senescence during the reproductive and maturity stages is directly related to biomass production and grain yield of rice (Misra *et al*., 1997). Wang *et al.* (2005) observed that top dressing N and K after panicle exertion is a good cultural practice in rice, because it enhances translocation of assimilates from the flag leaf to the panicle during ripening. According to Sarkar *et al*. (2007), late application of nutrients, especially nitrogen delayed the synthesis of abscisic acid, promoted cytokinin activity and caused higher chlorophyll retention and thereby higher photosynthetic activity in leaves for supply of photosynthates to the grains. Senescence in cereals is regulated at the individual leaf level with older leaves mobilizing nutrients to younger leaves and eventually to the flag leaf (Gregersen *et al*., 2008). The top three leaves, especially flag leaf contributes most to grain yield.

Mingzhu (1996) concluded that delaying flag leaf senescence is an important part of high yield wheat in the late stage of process of the plants growth and development. Yield of wheat crop is affected by flag leaf physiology and the changes in enzymatic activity affect the speed of senescence of its flag leaf (Dingyi and Dang, 2007). Changes in enzyme activity of wheat flag leaf after anthesis will help to elucidate the mechanism of leaf senescence and be of great significance on delaying leaf senescence process (Xusheng *et al*., 2008).

Nitrogen absorbed by plant from tillering to panicle initiation tend to increase the number of tillers and panicles, and the absorbed during panicle development increases number of filled spikelets per panicle (De Datta, 1981). Jiang *et al*. (2004) observed that the most critical times to apply nutrients are when crop is under stress likely when plant is changing from a vegetative to reproductive stage Heavy nitrogen during panicle development so called panicle nitrogen fertilizer has been popular in China to improve population dynamics, make fertilizer use more efficient and enhance grain yield in recent years. Application of nitrogen sources after panicle initiation resulted in higher leaf area, leaf greenness and leaf nitrogen concentration during the grain filling stage in rice. Regression analysis revealed that flag leaf greenness and flag leaf area accounted for about 75 per cent and 78 per cent changes in yield respectively (Abbasi *et al*., 2007).

Ottis *et al*. (2008) opined that nitrogen availability influences the efficiency of assimilated mobilization to sink during leaf senescence and thus effect leaf viability and activity. Higher nitrogen fertilization contributed to an increase in net photosynthesis rates of the flag leaf (Olszewski *et al*., 2014). Under low nitrogen supply, plants use photosynthesis to maintain life functions not related to the yield forming process.

Flag leaf contributed to 45 per cent of rice grain yield and when removed was the major component for yield loss (Khalifa *et al*., 2008).

2.4 EFFECT OF DIFFERENT NUTRIENT SOURCES IN RICE

Scientists have tried different nutrient sources for their efficacy in delaying senescence of leaves, increasing photosynthetic efficiency and promoting a favourable source – sink dynamics.

The amount of dry matter stored in the grains, the rate of dry matter production during the grain filling period and the length of grain filling period or growth rate duration are the three major yield deciding criteria. Nutrient supply is one of the major factors that decide these three (Peng *et al*., 1993). Channabasavanna *et al*. (1996) reported increase in panicle number of rice with increase in major nutrients upto 150:75:75 kg ha^{-1}. Luo *et al*. (2000) concluded that foliar as well as soil application of nitrogen on wheat at optimum timings has increased grain protein contents and improved bread making quality. The low grain filling rate and grain weight implicating a reduced grain yield often result from limited carbohydrate supply, especially under nutrient deficiency (Yang *et al*., 2003). Many factors are responsible for increasing the yield and quality of crops – proper and balanced fertilizer application being most important one (Ali *et al*., 2007).

Nitrogen is one of the major plant nutrients required for plant growth. It is essential for the synthesis of protein, which is the constituent of protoplasm and chloroplasts. It is a constituent of numerous important compounds found in living cells, including amino acid, protein (enzymes), nucleic acid and chlorophyll (Traore and Maranville, 1999). In many cases aerial spray of nutrients is preferred and gives quicker and better results than the soil application (Jamal *et al*., 2006). Increase in nitrogen concentration at anthesis resulted in increase in leaf area index and in intercepting the incoming photosynthetically active radiations (Salvagiotti and Miralles, 2008). Alam *et al*. (2010) reported that foliar application could be considered only as a supplement to soil application of nitrogen. An appropriate increase in nitrogen application at late growth stage strengthened the adversity defence ability of leaf during grain filling by delaying degradation of chlorophyll and solute protein and prolonging photosynthesis (Zhang *et al*., 2011).

Phosphorus is a major component in ATP, the molecule that provides energy to that plant for such processes as photosynthesis, protein synthesis, nutrient translocation, nutrient uptake and respiration. Phosphorus is also a component of other compounds necessary for protein synthesis and transfer of genetic material DNA, RNA (Wilson *et al*., 2006). Phosphorus deficiency is the most important restrictive factor in plant growth and recognition of mechanisms that increase plant phosphorus use efficiency is important (Sisie and Mirshekari, 2011). Pandey *et al*. (2013) observed that the concentration of phosphorus in soil solution is usually 1000 times less than that of the root cell due to fixation of phosphorus. However, when applied as foliar spray, phosphorus does not get bound with other elements on the leaf surface, resulting in almost 100 per cent absorption of phosphorus into the leaf.

Rice crop removes considerable amounts of potassium from the soil and yields are highly dependent on potassium fertilization. Application of K increased the availability of nitrogen and phosphorus (Sahai, 2004). Potassium helps in photosynthesis, carbohydrate distribution and starch synthesis in the storage organs (Imas and Magen, 2007). Son *et al*. (2012) reported that foliar application of potassium nitrate (3 per cent) at panicle initiation and flowering stages improved the grain filling and consequently the grain yield of rice. Habibi *et al*. (2014) studied the effect of foliar applied potassium on the dry matter remobilization in rice and observed that foliar application of 0.5 per cent potassium improved the drymatter production and remobilization in rice.

Calcium (Ca^{2+}) may substantially increase N and P uptake and this may prove to be helpful in promoting root growth (Friessen *et al*., 1980). As per Kondratev et al. (1984), presence of Ca^{2+} may result in more rational utilization of soil N and result in more active assimilation of NO_3^- N in roots and leaves. Calcium increases ammonium, potassium and phosphorus absorption, stimulates photosynthesis (Hallmark *et al*., 1997). Calcium, being a constituent of cell wall, plays a key role in cellular functions and enzyme activity (Bush, 1995).

Magnesium is the only mineral constituent of the chlorophyll molecule. Although not a constituent sulphur is required for the synthesis of chlorophyll (Tisdale *et al*., 1995). Magnesium has major physiological and molecular roles in plants, such as being a component of the chlorophyll molecule, a cofactor for many enzymatic processes associated with phosphorylation, dephosphorylation, and the hydrolysis of various compounds, and as a structural stabilizer for various nucleotides. Studies indicate that 15 to 30% of the total magnesium in plants is associated with the chlorophyll molecule (Marschner, 1995). El-Zanaty *et al*. (2012) found that application of magnesium sulphate as soil and foliar treatments increased the growth and yield of wheat. Bohri *et al*. (2012) reported a positive effect for foliar application of magnesium sulphate on dry biomass accumulation, nutrient uptake and assimilate translocation in rice. Studies conducted by Biswas *et al*. (2013) revealed that application of magnesium sulphate improved the growth and yield of paddy.

Muraleedharan and Jose (1993) found significant increase in tiller production of rice with sulphur levels up to 30 kg per hectare and a reduction in the same with higher sulphur rates of 60 kg per hectare. Significantly higher tiller number in rice has been reported with 10 kg sulphur per hectare. The yield of rice was significantly influenced by sulphur application irrespective of source and dose (Singh *et al*., 1993). Increased straw yield of rice with S application has been reported in rice with 40 kg sulphur per hectare as optimum level. Higher sulphur levels enhanced uptake of N, K, and S in rice (Nair, 1995).

A field experiment was conducted during rainy season of 2005 and 2006 at Baruipur to evaluate the effect of foliar nutrition of potassium nitrate (KNO_3) and calcium nitrate ($Ca(NO_3)_2$) on growth and yield of rice. The results revealed that foliar application of 0.406per cent $Ca(NO_3)_2$ followed by 0.50per cent KNO_3 during 50per cent flowering stage increased the growth parameters and yield attributes which ultimately resulted in higher grain yield than foliar spray of 0.25 and 1.00per cent KNO_3 and 0.203 and 0.812per cent $Ca(NO_3)_2$ and water spray. Foliar spray of 0.406 per cent Ca $(NO_3)_2$ resulted in maximum grain yield (5.47 t ha^{-1}), net returns (₹ 14,733 ha^{-1}) and benefit cost ratio 1.38 (Kundu and Sarkar, 2009). Tari *et al*. (2009) observed an increase in the flag leaf area with increase in the application of nitrogen and potassium.

The field experiment conducted by Rani *et al*. (2014) to study the effect of foliar fertilization on growth and yield of rice revealed significantly higher grain yield when the recommended dose of fertilizers was supplemented with foliar application of 19:19:19 complex @ 2.5 kg ha^{-1}, at tillering and panicle initiation stages.

2.4.1 Effect on growth, yield attributes and yield

The amount of dry matter stored in the grains, the rate of dry matter production during the grain filling period and the length of grain filling period or growth rate duration. Nutrient supply is one of the major factors that decide these three (Peng *et al*., 1993). Nair (1995) observed that the straw yield was found to increase with sulphur levels upto 30 kg per hectare. Higher straw yield was also observed with 25 per cent increase in NPK level of 100:50:50 kg per hectare. He also observed enhanced N uptake with higher sulphur levels.

Channabasavanna *et al*. (1996) reported that increased availability of NPK in soil followed by increased plant uptake leads to improvement in yield attributing characters which is reflected in grain yield. Misra *et al*. (1997) reported that leaf senescence during the reproductive and maturity stages is directly related to biomass production and grain yield of rice crop. Shen *et al*. (1997) observed a progressive increase in uptake of P, K with increase in nitrogen. Lina *et al*. (1999) reported greater carbohydrate translocation from vegetative plant parts to the spikelets and larger leaf area index (LAI) during the grain filling period.

Studies have shown that foliar as well as soil application of nitrogen on wheat at optimum timings has increased grain protein contents and improved bread making quality (Luo *et al*., 2000). The low grain filling rate and grain weight implicating a reduced grain yield often result from limited carbohydrate supply, especially under nutrient deficiency (Yang *et al*., 2003). Birsin (2005) showed that flag leaf removal resulted in approximately 13, 34, 24 per cent reduction in grain per spike, grain weight per spike and 1000-grain weight, respectively, and 2.8per cent increase in grain protein contents.

Rahman *et al*. (2007) reported that increased nitrogen application increased grain yield in rice but further increase in nitrogen level produced higher straw yield that ultimately gave the lower harvest index. Increase in nitrogen concentration at anthesis results in increase in leaf area index and incoming photosynthetically active radiations (Salvagrotti and Miralles, 2008). Tari *et al*. (2009) observed that increasing the applications of nitrogen fertilization the flag leaf area was significantly increased and flag leaf angle was decreased ($P<0.01$). Kundu and Sarkar (2009) observed that foliar application of calcium nitrate 0.406 per cent followed by potassium nitrate 0.5 per cent during 50 per cent flowering stage increased growth parameters and yield attributes of lowland rice.

As appropriate increase of nitrogen application at late growth stage, the adversity- defence ability of leaf was strengthened during grain filling by delaying degradation of chlorophyll and soluble protein, prolonging photosynthesis (Zhang *et al*., 2011). Studies conducted by Bhuyan *et al*. (2012) revealed that foliar application of nitrogen during late growth stages reduced sterility per cent and increased thousand grain weight and yield. Bohri *et al*. (2012) reported a positive effect for foliar application of magnesium sulphate on dry biomass accumulation, nutrient uptake and assimilate translocation in rice.

2.4.2 Effect on Physiological Parameters

Higher leaf nitrogen content results in greater leaf rubisco and increased NAR during the grain filling period particularly in the later stages of grain filling (Makino *et al*., 1985). The duration of canopy photosynthetic activity can be prolonged by fertilizer-N application later in the growing season (Spiertz and Vos, 1985).

Mingzhu (1996) found that delaying flag leaf senescence is an important part of high yield wheat in the late stage of process of the plants growth and development. Nitrogen absorbed during panicle initiation increases specific leaf weight and nitrogen contents in leaves which leads to enhancement of photosynthesis capacity and promotion of carbohydrate accumulation in culms and leaf sheaths (Mae, 1997). Minjun *et al*. (2002) showed that during growth and development of wheat, the level of soluble protein content not only reflected the level of plant nitrogen metabolism, but also was regarded as an important indicator of the degree of leaf senescence, especially in wheat grain filling stage, increasing soluble protein content of flag leaf was conducive to the maintenance of the flag leaf growth and extending the photosynthetic function, so as to lay the substances basis for the accumulation of grain carbohydrates.

Flag leaf is of utmost importance in cereals like wheat it provides maximum amount of photosynthesis assimilates to be stored in grains. A greater flag leaf area will eventually help to increase photosynthetic efficiency by increasing production of photosynthesis which is then translocated into grains increasing their weight. Therefore flag leaf has a direct relationship to grain yield (Riaz and Chowdhry, 2003). Guo *et al*. (2004) opined that high nitrogen fertilization level enhances the chlorophyll and carotenoid content of leaves.

The duration of canopy photosynthesis activity can be prolonged by fertilizer nitrogen application later in growing season (Duan *et al*., 2007). Yield of wheat crop is affected by flag leaf physiological activities and the changes in enzymatic activity affect the speed of senescence of its flag leaf (Dingyi and Dang, 2007). Aminopeptidase activity gradually increased with the flag leaf senescence (Gao *et al*., 2007). Zhang and Shangguan (2007) reported that nitrogen application significantly increased the actual photochemical efficiency of wheat at the jointing stage and the maximum photochemical efficiency at the flowering and grain filling stages.

Xusheng *et al.* (2008) observed that studying the changes in enzyme activity of wheat flag leaf after anthesis will help to elucidate the mechanism of leaf senescence and be of great significance on delaying leaf senescence process. Yan and Shi (2013) revealed that when the nitrogen application was within the range of 0 to 300 kg m^{-2}, with the increased amount of nitrogen, soluble protein content, the activity of nitrate reductase and the glutamine synthetase increased.

From the above review it was observed that among all the leaves of paddy, flag leaf plays a key role in deciding the productivity of the crop. Any practice which could help in delaying the leaf senescence during the reproductive stage, could improve the photosynthetic efficiency of the crop. Several studies reviewed, showed that supplementing the recommended dose of nutrients with foliar nutrition, towards the later stages of crop growth, (especially booting and heading stages) could appreciably improve yield through better partitioning of assimilates and superior grain filling.

Materials and Methods

3. MATERIALS AND METHODS

The field experiment entitled "Flag leaf nutrition for enhancing resource use efficiency in rice (*Oryza sativa* L.)" was conducted during the first crop season (June to October) of 2014. The primary objectives of the study were to assess the effect of flag leaf foliar nutrition on partitioning of photosynthates, growth and productivity of rice and to work out the economics of the practice in lowland rice cultivation system. The materials used and the methods adopted in the conduct of the experiment are presented in this chapter.

3.1 EXPERIMENTAL SITE

The experiment was conducted in the wetlands of the Instructional Farm College of Agriculture, Vellayani, Kerala. The experimental field is located at 8^{o} 25' 49" N latitude and 76^{o} 39' 04" E longitude at an altitude of 29 m above the mean sea level.

3.1.1 Soil

A composite soil sample was collected prior to the experiment from 0-15 cm depth and analyzed for its physico-chemical properties. The data on the physico-chemical properties of the soil of the experimental site are presented in Tables 1 and 2 respectively. The chemical properties of soil were rated as per the package of practices recommendations of the Kerala Agricultural University (KAU, 2011).

The soil of the experimental site was sandy clay loam, acidic in reaction, high in organic carbon, medium in available nitrogen, high in available phosphorus and medium in available potassium.

Table 1. Mechanical composition of the soil of the experimental site

Sl. No.	Fractions	Content (%)	Method used
1	Coarse sand	47.78	Bouyoucos hydrometer method (Bouyoucos, 1962)
2	Fine sand	10.66	
3	Silt	8.56	
4	Clay	33.00	

Table 2. Chemical properties of the soil of the experimental site

Sl. No.	Parameter	Content	Rating	Method used
1	Available N (kg ha^{-1})	300.64	medium	Alkaline permanganate method (Subbiah and Asija, 1956)
2	Available P_20_5 (kg ha^{-1})	27.52	high	Bray colorimetric method (Jackson, 1973)
3	Available K_20 (kg ha^{-1})	186.35	medium	Ammonium acetate method (Jackson, 1973)
4	Available Ca (mg kg^{-1})	113.72	very low	Ammonium acetate method (Jackson, 1973)
5	Available Mg (mg kg^{-1})	57.85	very low	Ammonium acetate method (Jackson, 1973)
6	Available S (mg kg^{-1})	10.00	medium	Turbidimetric method (Chesnin and Yien, 1950)
7	Organic carbon (%)	1.78	high	Walkley and Black rapid titration method (Jackson, 1973)
8	Soil reaction (pH)	5.50	acidic	1:2.5 soil solution ratio using pH meter with glass electrode (Jackson, 1973)

3.1.2 Climate and Season

The experimental site enjoys a warm humid tropical climate. The experiment was conducted during the first crop season (*Virippu*), from July to October, 2014. The data on weekly mean temperature, relative humidity, rainfall and bright sunshine hours recorded during the cropping period were collected from the Class B Agromet Observatory of the Department of Agricultural

Meteorology, College of Agriculture, Vellayani. The data are presented in appendix-1 and illustrated graphicaly in Fig.1. The mean maximum temperature ranged between 29.2^0C -30.7^0C and minimum mean temperature ranged between 23.5^0C - 25.7^0C.

While the mean maximum relative humidity ranged from 85.0 per cent to 95.4 per cent, the minimum relative humidity ranged from 73.6 per cent to 85.9 per cent. A total rainfall of 1172.8 mm was recorded during the cropping period.

3.1.3 Cropping History of the Field

The experiment site was lying fallow for few months before the experiment and prior to that it was under a bulk crop of rice.

3.2 MATERIALS

3.2.1 Crop and Variety

The rice variety selected for experiment was Aiswarya (PTB 52) released from the Regional Agricultural Research Station (RARS), Pattambi. The important varietal characters are given in Table 2. The seeds of Aiswarya were obtained from RARS, Pattambi, Kerala.

Table 3. Important characters of rice variety Aiswarya (PTB 52)

Parameter	Character
Stature	Semi tall
Duration (days)	120-125
Tillering	High
Flag leaf	Broad and erect
Grain type	Long, bold
Kernel colour	Red
Stress tolerance	Resistant to blast and bacterial blight diseases and BPH

(Nair, 2011)

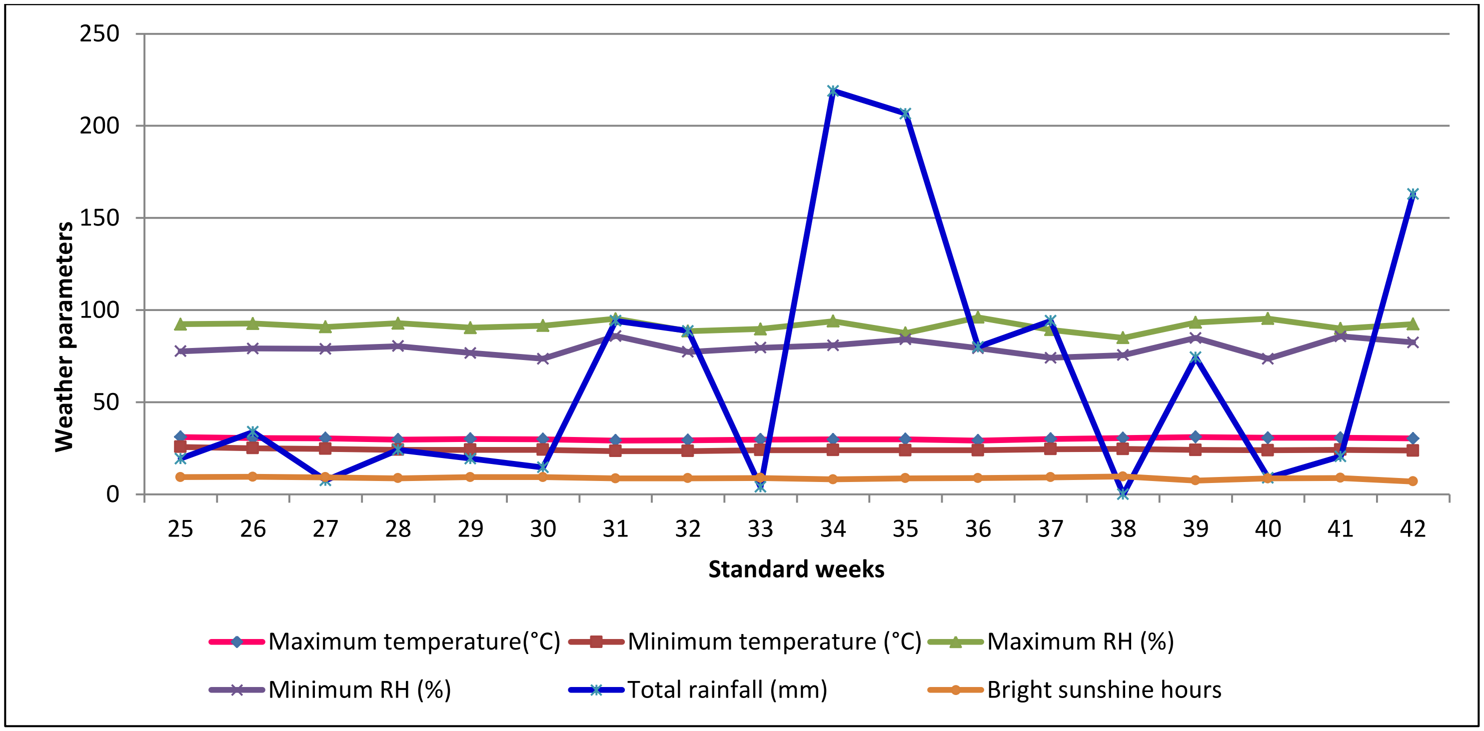


Fig. 1. Weather data during the cropping period (June to October 2014)

3.2.2 Manures and Fertilizers

Well decomposed farmyard manure (0.48 per cent N, 0.21 per cent P_2O_5 and 0.42 per cent K_2O) was used as the organic manure source, calcium carbonate as the liming material and urea (46 per cent N), rock phosphate (20 per cent P_2O_5), muriate of potash (60 per cent K_2O) were used as chemical fertilizers.

3.2.3 Nutrient Sources for Flag Leaf Nutrition

Potassium nitrate, calcium nitrate, magnesium sulphate and 19:19:19 complex were used as the nutrient sources for flag leaf nutrition. The composition of nutrient sources used for flag leaf nutrition are presented in Table 4.

Table 4. Nutrient sources used for flag leaf nutrition

Sl. No.	Nutrient source	Chemical formula	Chemical composition	Price (₹ kg^{-1})
1	Potassium nitrate	KNO_3	13 per cent $N\text{-}NO_3$ 46 per cent K_2O	150
2	Calcium nitrate	$Ca(NO_3)_2$	15.5 per cent $N\text{-}NO_3$ 18.8 per cent Ca	150
3	Magnesium sulphate	$MgSO_4$	9.1 per cent Mg 14.0 per cent S	110
4	19:19:19 complex	-	10.5 per cent N-amide 4.5 per cent $N\text{-}NH_4$ 4.0 per cent $N\text{-}NO_3$ 19.0 per cent P_2O_5 19.0 per cent K_2O	180

3.3 METHODS

3.3.1 Design and Layout

The effect of four nutrient sources (S_1 to S_4) and a combination treatment ($S_2 + S_3 + S_4$) applied at three growth stages was evaluated for their flag leaf nutrition potential. The treatments were compared against a control, maintained as per the Kerala Agricultural University Package of Practices Recommendations

(KAU POP) for medium duration rice. The field experiment was laid out as detailed below. The layout plan of the experiment is given in Fig.2.

Design	:	Randomised Block Design (RBD)
Treatments	:	(5 x 3) +1
Replications	:	3
Plot size	:	5 m x 4 m
Variety	:	PTB 52 (Aiswarya)
Spacing	:	20 cm x 15 cm
Season	:	First crop, 2014-15

3.3.1.1 Treatments

Nutrient sources (S) - 5

S_1	-	Potassium nitrate	(0.5 per cent)
S_2	-	Calcium nitrate	(0.5 per cent)
S_3	-	Magnesium sulphate	(0.5 per cent)
S_4	-	19 : 19 : 19 complex	(0.5 per cent)
S_5	-	$S_2 + S_3 + S_4$	

Crop growth stages (G) - 3

G_1	-	Booting stage
G_2	-	Booting + Flowering stages
G_3	-	Booting + Flowering + Milk stages

Control (C)

KAU package of practices recommendation for medium duration rice

Treatment combinations

s_1g_1	-	Potassium nitrate (0.5 %) at booting stage
s_1g_2	-	Potassium nitrate (0.5 %) at booting and flowering stages
s_1g_3	-	Potassium nitrate (0.5 %) at booting, flowering and milk stages

s_2g_1 - Calcium nitrate (0.5 %) at booting stage

s_2g_2 - Calcium nitrate (0.5 %) at booting and flowering stages

s_2g_3 - Calcium nitrate (0.5 %) at booting, flowering and milk stages

s_3g_1 - Magnesium sulphate (0.5 %) at booting stage

s_3g_2 - Magnesium sulphate (0.5 %) at booting and flowering stages

s_3g_3 - Magnesium sulphate (0.5 %) at booting, flowering and milk stages

s_4g_1 - 19 : 19 : 19 complex (0.5 %) at booting stage

s_4g_2 - 19 : 19 : 19 complex (0.5 %) at booting and flowering stages

s_4g_3 - 19 : 19 : 19 complex (0.5 %) at booting, flowering and milk stages

s_5g_1 - $S_2 + S_3 + S_4$ at booting stage

s_5g_2 - $S_2 + S_3 + S_4$ at booting and flowering stages

s_5g_3 - $S_2 + S_3 + S_4$ at booting, flowering and milk stages

Control- KAU POP for medium duration rice

3.3.2 Crop Management

The crop was raised as per the KAU POP recommendations till the panicle initiation stage (KAU, 2011). Foliar nutrition was carried out from the booting stage onwards as per the treatment combinations detailed above.

3.3.2.1 Nursery

The nursery area was ploughed, leveled, and made weed free. FYM @ 1 kg m^{-2} was applied and incorporated. Pre-germinated seeds of paddy (variety Aiswarya) were sown @ 70 kg ha^{-1}. The nursery was managed as per the KAU POP.

3.3.2.2 Main Field

The experimental area was ploughed twice, puddled and leveled. Weeds and stubbles were removed. The experimental area was divided into 3 blocks of 16 plots each. The blocks and plots were separated with bunds of 30 cm width. Irrigation and drainage channels were provided for all the plots.

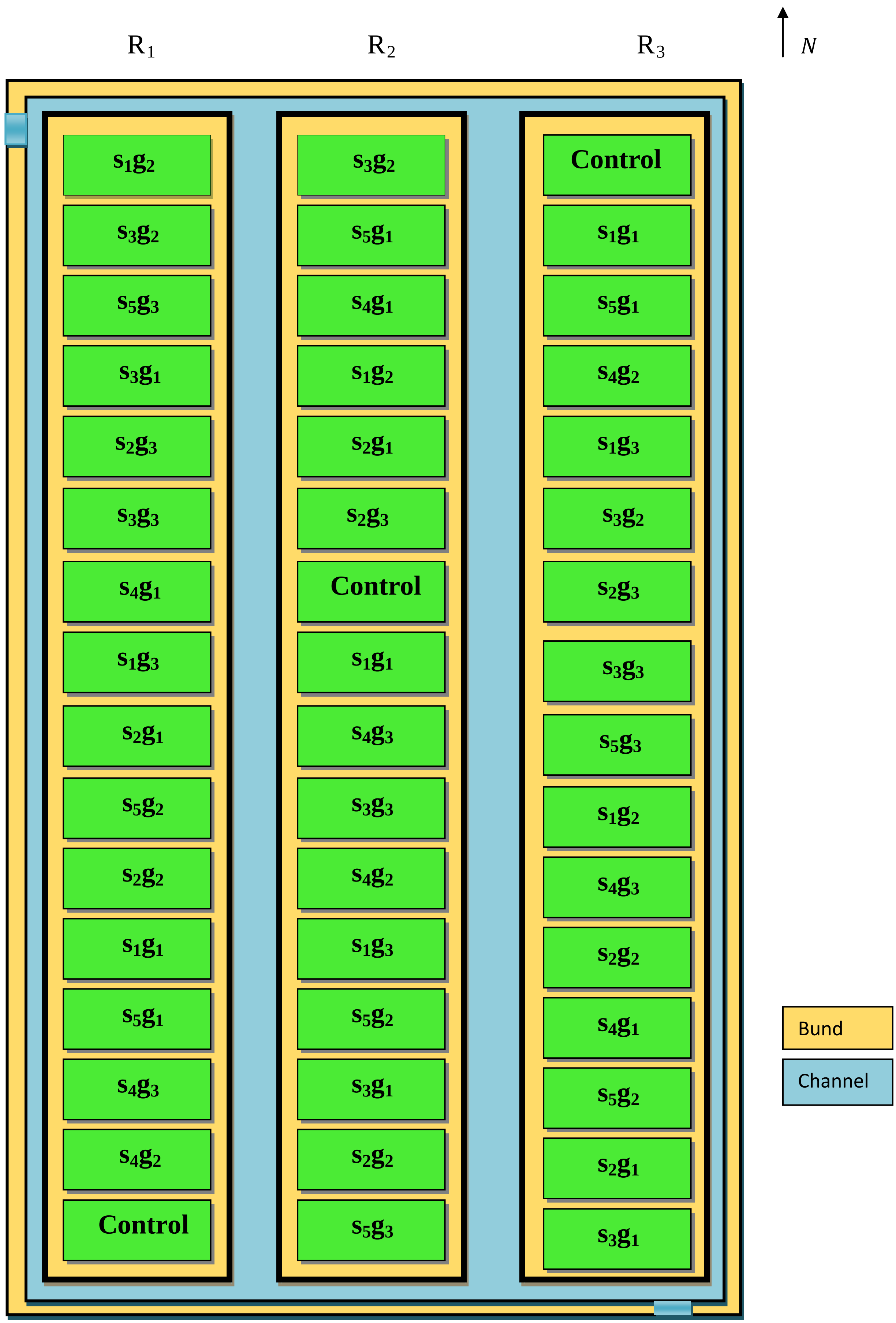


Fig. 2. Lay out of the experimental field

Plate 1. General view of the experimental field

3.3.2.3 Application of Lime

Lime @ 600 kg ha^{-1} was applied in two split doses *i.e.* 350 kg ha^{-1} just after the second tillage and the remaining at tillering stage (25 DAT).

3.3.2.4 Manures and Fertilizers

Well decomposed farmyard manure @ 5 t ha^{-1} was applied uniformly to all the plots at the time of land preparation. Urea, rock phosphate and MOP were applied so as to supply the major nutrients @ 90:45:45 kg NPK per hectare. Half the dose of nitrogen, entire dose of phosphorus and half potassium was applied basally. The remaining nitrogen and potassic fertilizers were applied at panicle initiation stage. Foliar application of the various nutrient sources was done at booting, flowering, and milk stages as per the treatments along with an adjuvant (Stanowet).

3.3.3.5 Transplanting

Twenty one days old seedlings were uprooted from the nursery and transplanted @ 2-3 seedlings per hill at a spacing of 20 cm x 15 cm, at a depth of 3-4 cm. Gap filling was done one week after transplanting so as to maintain uniform plant population, maintaining two seedlings per hill.

3.3.3.6 Water Management

The water level was maintained at about 1.5 cm during transplanting. Thereafter the water level was increased gradually to about 5 cm throughout the growth period, with occasional drainage. Water was drained 10 days before harvest.

3.3.3.7 Weed Management

The field was maintained weed free upto 45 DAT with two hand weedings, at 20 DAT and 40 DAT.

Plate 2. Flag leaf nutrition in field

3.3.3.8 Flag Leaf Nutrition

Flag leaf nutrition was done at 5 days prior to booting (45 DAT), 5 days prior to 50 per cent flowering (60 DAT) and at milk stages (75 DAT) as per treatments, following the procedure of Fageria *et al*. (2009). Booting, flowering and milk stages were characterized as described by De Datta (1981). Potassium nitrate, calcium nitrate, magnesium sulphate and 19:19:19 complex were used as the nutrient sources for flag leaf nutrition. The nutrient sources (0.5 per cent) were sprayed along with an adjuvant (Stanowet @ 1 mL per 10 litres of spray fluid) at a spray volume of 500 L ha^{-1}. Spraying was done after 3.00 pm under calm atmospheric conditions. The individual plots were separated using screens to avoid the effect of any possible spray drift.

3.3.3.9 Plant Protection

Rice case worm and rodent damage were observed. Acephate (2g L^{-1}), chlorpyriphos (2mL L^{-1}) was used to manage rice case worm. Rats were the common menace in the area, where the experiment was laid out. Poison baits containing zinc phosphide (2 per cent) was used to manage the rats. None of the diseases were observed in the field.

3.3.3.10 Harvest

The crop in the individual plots was harvested leaving two rows on all sides as border rows. The net plot area was harvested separately, threshed, winnowed and weight of grain and straw were recorded separately from the individual plots.

3.4 OBSERVATIONS

3.4.1 Growth and Growth Attributes

Six hills were selected randomly from the net plot area of each plot and tagged as sample plants. Two rows from all sides of the plot were left as border rows. The following observations were recorded from the sample plants and the mean values were worked out.

3.4.1.1 Plant Height

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

3.4.1.2 Tillers per Hill

Tiller count was taken from six tagged observation hills at panicle initiation, booting, flowering and harvest stages and the mean value was recorded as number of tillers per hill.

3.4.1.3 Leaf Area Index

The leaf area index (LAI) was calculated at panicle initiation, booting, flowering and harvest stages using the method suggested by Yoshida *et al.* (1976). The maximum length 'l' and width 'w' of all the leaves of the middle tiller of the six sample hills were recorded from all the plots and leaf area index was calculated.

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

k- Adjustment factor (0.75 at panicle initiation, booting and flowering stages and 0.67 at harvest stage).

$$\text{LAI} = \frac{\text{Sum of leaf area / hill of 6 sample hills (cm}^2\text{)}}{\text{Area of land covered by the 6 sample hills (cm}^2\text{)}}$$

3.4.1.4 Flag Leaf Area

Flag leaf area at booting, flowering, harvest stages was calculated by leaf product method. The factor (k) used were 0.75 (booting and flowering stages) and 0.67 (harvest stage).

Leaf area (cm^2) = Length (cm) x maximum width (cm) x k

3.4.1.5 Days to Panicle Exsertion

Panicle exsertion refers to the extension of the panicle and a portion of uppermost internode beyond the flag leaf sheath. The number of days taken for panicle exsertion was recorded as the duration taken from transplanting to panicle exsertion, in days.

3.4.1.6 Days to 50 per cent Flowering

Number of days taken by 50 per cent of the hills to flower was recorded.

3.4.1.7 Latent Tillers per Hill

The tillers which emerged after flowering were counted as latent tillers and recorded as the number of latent tillers per hill.

3.4.2 Physiological Studies

3.4.2.1 Leaf Area Duration

Leaf area duration (LAD) at booting, flowering and harvest stages was calculated using the formula suggested by Watson (1947) and expressed in days.

$$LAD = \frac{L_i + (L_i + 1) \times (t_2 - t_1)}{2}$$

L_i = LAI at first stage

$L_i + 1$ = LAI at second stage

$(t_2 - t_1)$ = time interval between stages in days

3.4.2.2 Specific Leaf Weight

Specific leaf weight (SLW) was calculated by using the formula suggested by Pearce *et al*. (1968) and expressed in g m^{-2}.

$$SLW = \frac{\text{Leaf dry weight per plant (g)}}{\text{Leaf area per plant } (m^2)}$$

3.4.2.3 Relative Growth Rate

Relative growth rate (RGR) at booting, flowering, and harvest stages was determined using the formulae of Williams (1946) and expressed in mg $g^{-1} day^{-1}$.

$$RGR = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

W_1 and W_2 = plant dry weight (g) at time t_1 and t_2 respectively

$t_2 - t_1$ = time interval in days

3.4.2.4 Net Assimilation Rate

The method proposed by Williams (1946) was used for calculating the net assimilation rate (NAR) on leaf dry weight basis and the values were expressed as mg cm^{-2} day^{-1}. Net assimilation rate was recorded at booting, flowering and harvest stages.

$$NAR = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{\log_e L_2 - \log_e L_1}{L_2 - L_1}$$

W_1 and W_2 = leaf dry weight (mg) at t_1 and t_2 respectively

L_1 and L_2 = leaf area (cm^2) at t_1 and t_2 respectively

$t_2 - t_1$ = time interval in days

3.4.2.5 Plant Pigments

The chlorophyll and carotenoid pigments of flag leaf and sheath were analyzed at booting, flowering and harvest stages, using the DMSO (Di methyl sulphoxide) method suggested by (Yoshida *et al*., 1976) and expressed in mg g^{-1}.

3.4.2.6 Total Soluble Protein

Total soluble protein of flag leaf at booting, flowering and harvest stages was estimated using simple protein-dry binding method of Bradford (1976) using bovine serum albumin as the standard and expressed as mg g^{-1} fresh weight.

3.4.2.7 Nutrient Use Efficiency

3.4.2.7.1 Nitrogen Use Efficiency

Nitrogen use efficiency (NUE) at booting, flowering and harvest stages was determined in terms of partial factor productivity (Cassman *et al.*, 1996) and was expressed in kg grain per kg nutrient applied.

$$\text{Partial factor productivity} = \frac{Y_f}{N_a}$$

Y_f = Yield from nutrient fertilized plot

N_a = kg nutrient ha^{-1} applied

3.4.2.7.2 Agronomic Efficiency

Agronomic efficiency (AE) was calculated by using the formula given below (Fageria and Baligar, 2005), and expressed as kg yield per kg nutrient applied.

$$AE = (Y-Y_0)/F$$

Y=crop yield with applied nutrients

Y_0 = crop yield in control F = fertilizer rate

3.4.2.7.3 Apparent Recovery Efficiency

Apparent recovery efficiency (ARE) was computed using the formula (Fageria and Baligar, 2005), and expressed as kg increase in uptake per kg applied.

$ARE = (U-U_0)/ F$

U = plant nutrient uptake of above ground biomass at physiological maturity in treated plot

U_0= plant uptake in control

F = fertilizer rate

3.4.3 Yield Attributes and Yield

3.4.3.1 Productive Tillers per Square Meter

At harvest, the number of productive tillers was recorded from the net plot area and expressed as number of productive tillers m^{-2}.

3.4.3.2 Panicle Length

Ten panicles were selected at random and panicle length was measured as the length from the neck of the panicle to the tip. The mean panicle length was expressed in cm.

3.4.3.3 Grain Weight per Panicle

The grains from the ten randomly selected panicles were removed, dried, weighed and the weight was recorded as grain weight per panicle in grams.

3.4.3.4 Spikelets per Panicle

The number of spikelets per panicle was recorded by counting the spikelets separated from the ten randomly selected panicles.

3.4.3.5 Filled Grains per Panicle

The filled grains were counted from the 10 randomly selected panicles from each plot and expressed as the mean number of filled grains per panicle.

3.4.3.6 Sterility Percentage

The sterility percentage was worked out using the following relationship

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

3.4.3.7 Thousand Grain Weight

One thousand grains were counted from the cleaned and dried produce from the net plot area of each plot and the weight of the grains was recorded in grams.

3.4.3.8 Grain Yield

The net plot area was harvested individually, threshed, cleaned, dried and weighed to express the grain yield in kg ha^{-1} at 14 per cent moisture.

3.4.3.9 Straw Yield

The straw harvested from net plot area was dried to constant weight under sun and then weighed to express the straw yield in kg ha^{-1}.

3.4.3.10 Harvest Index

The harvest index (HI) was worked out using the formula suggested by Donald and Hamblin (1976).

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

3.4.3.11 Grain to Straw Ratio

Grain to straw ratio was calculated as the ratio between the dry weights of grain and straw respectively.

3.5 CHEMICAL ANALYSIS

3.5.1 Plant Analysis

The plant samples and leaf samples collected at harvest were dried under shade and then in an electric hot air oven to constant weight, ground and passed through a 0.5 mm sieve. The required quantity of sample was weighed out, subjected to acid extraction and analyzed for total N, P, K, Ca, Mg and S. The grain and straw were analyzed separately.

3.5.1.1 Index Leaf Analysis

Flag leaf is the index leaf for rice (Singh and Ghosh, 1981). The index leaf collected at harvest were analyzed for total nitrogen, phosphorus, potassium, calcium, magnesium and sulphur and expressed as per cent.

The total nitrogen content was estimated by modified microkjeldal method (Jackson, 1973). Total phosphorus content was found out using Vanado-molybdo phosphate yellow colour method (Jackson, 1973). Total potassium content was determined using EEL Flame photometer (Jackson, 1973). Total calcium and magnesium contents were assessed using spectrophotometer after wet digestion with di acid mixture as suggested by Perkin-Elmer Corporation (1982). Total sulphur content was determined turbidimetrically (Chesnin and Yien, 1950).

5.1.2 Uptake of Nutrients

The total uptake of nitrogen, phosphorus, potassium, calcium, magnesium, sulphur by the plant at harvest was calculated as the product of the respective nutrient content and plant dry weight and expressed as kg ha^{-1}.

3.5.1.3 Crude Protein Content of Grain

The crude protein content of grains was calculated by multiplying the N content of grains by a factor, 6.25 (Simpson *et al*., 1965).

3.5.2 Soil Analysis

After the experiment, soil samples were taken from each plot separately and analyzed for the available nutrient status.

3.5.2.1 Organic Carbon

Organic carbon content was determined using the Walkley and Black rapid titration method (Jackson, 1973) and expressed in percentage.

3.5.2.2 Available Nitrogen

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

3.5.2.3 Available Phosphorus

Available phosphorus content of the soil was determined by Dickman and Bray's molybdenum blue method using a spectrophotometer and expressed as kg P_2O_5 ha^{-1}.

3.5.2.4 Available Potassium

Available potassium content was determined in neutral normal ammonium acetate extract, estimated in a Flame photometer (Jackson, 1973) and expressed in kg K_2O ha^{-1}.

3.5.2.5 Available Calcium and Magnesium

Available calcium and magnesium contents of the soil was determined by ammonium acetate method, (Jackson, 1973) and expressed in mg kg^{-1} soil.

3.5.2.6 Available Sulphur

Available sulphur content was determined by turbidimetric method, (Chesnin and Yien, 1950) and expressed in mg kg^{-1} soil.

3.6 ECONOMIC ANALYSIS

The economics of cultivation was expressed in terms of net income and benefit cost ratio based on cost of cultivation and prevailing price of the produce.

3.6.1 Net income

Net income (₹ ha^{-1}) = Gross income – Cost of cultivation

3.6.2 Benefit cost ratio (BCR)

$$\text{Benefit cost ratio (BCR)} = \frac{\text{Gross income}}{\text{Cost of cultivation}}$$

3.6.3 Return per Rupee Invested on Nutrient Sources Including Manures

$$\text{Return per rupee} = \frac{\text{Gross returns – Cost of cultivation excluding expenses for nutrient sources including manures}}{\text{Cost of manures and fertilizers}}$$

3.7 STATISTICAL ANALYSIS

The data generated from the experiment were statistically analyzed using Analysis of Variance technique (ANOVA) as applied to Randomized Block Design (Panse and Sukhatme, 1985) and the significance was tested using F test (Snedecor and Cochran, 1967). Wherever the F values were found significant, critical difference was worked out at five per cent and one per cent probability levels. The significance of the control as compared against the treatments was also tested. The treatment *vs*. control comparison was denoted as 'S' when significant and 'NS' when not significant.

Results

4. RESULTS

The experiment entitled "Flag leaf nutrition for enhancing resource use efficiency in rice (*Oryza sativa* L.)" was undertaken in the wet lands of the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, during June to October, 2014. The main objectives of the study were to assess the effect of flag leaf foliar nutrition on partitioning of photosynthates, growth and productivity of rice and to work out the economics of the practice in lowland rice cultivation system. The results of the experiment are presented in this chapter.

4.1 GROWTH AND GROWTH ATTRIBUTES

4.1.1 Plant Height

The results on the effect of flag leaf nutrition at different crop growth stages on the height of rice are presented in the Table 5.

The effect of various nutrient sources on plant height was observed to be significant during the booting and harvest stages. The plant height was significantly higher under flag leaf nutrition (FLN) with 19:19:19 complex @ 0.5 per cent (S_4) at booting (85.47 cm) and with potassium nitrate @ 0.5 per cent (S_1) at harvest (113.73 cm). Flag leaf nutrition at 0.5 per cent with magnesium sulphate (S_3), calcium nitrate (S_2) and combination treatment of calcium nitrate, magnesium sulphate and 19:19:19 complex (S_5) remained at par with respect to plant height at the booting stage. At harvest the effect of all the other nutrient sources were at par.

Plant height varied significantly with crop growth stages. Flag leaf nutrition at booting + flowering + milk stages (G_3) recorded maximum plant height at harvest stage (106.15 cm). The interaction effect of nutrient sources and crop growth stages also exerted significance with treatment s_1g_2 recording tallest plants (115.84 cm). The treatments and control did not exhibit any significant variation in plant height.

Table 5. Effect of nutrient sources, growth stages and their interaction on plant height, cm

Treatments	Booting	Flowering	Harvest
Nutrient sources			
S_1	73.38	94.33	113.73
S_2	79.18	91.50	102.19
S_3	79.51	92.16	102.20
S_4	85.47	93.87	102.66
S_5	77.47	91.44	101.38
Growth stages			
G_1	78.28	89.74	103.20
G_2	80.18	93.30	103.96
G_3	78.54	91.64	106.15
Interaction effects			
s_1g_1	70.87	94.27	109.65
s_1g_2	71.94	94.61	115.84
s_1g_3	77.34	94.09	115.70
s_2g_1	79.82	93.03	100.84
s_2g_2	80.85	92.34	102.41
s_2g_3	76.87	89.13	103.33
s_3g_1	78.99	94.13	100.68
s_3g_2	79.46	92.27	104.04
s_3g_3	80.09	90.08	101.89
s_4g_1	84.20	93.32	101.74
s_4g_2	87.19	90.60	99.23
s_4g_3	85.02	97.71	107.01
s_5g_1	77.52	87.32	103.09
s_5g_2	81.49	96.66	98.25
s_5g_3	73.39	90.35	102.79
Treatment mean	79.00	91.56	103.77
Control	79.37	88.62	103.16
SEm (±) : S	2.212	2.521	2.037
G	1.713	1.952	1.578
SG	4.210	3.837	3.529
CD (0.05) : S	4.531	-	4.172
G	-	-	3.235
SG	-	-	7.223
Treatment *Vs* Control	NS	NS	NS

4.1.2 Tillers per Hill

The number of tillers per hill as influenced by nutrient sources, crop growth stages and their interaction recorded at different crop growth stages are presented in Table 6.

Neither the nutrient sources, crop growth stages, nor their interactions had significant effect on the tiller count at booting, flowering and harvest stages. No significant difference could be observed between the treatments and the control.

The treatments and the control did not exhibit any significant variation.

4.1.3 Leaf Area Index

The results on the effect of nutrient sources, crop growth stages and their interaction on the leaf area index of rice are presented in Table 7.

The effect of nutrient sources, crop growth stages, and their interactions on leaf area index was observed to be non significant at all the stages.

No significant difference was observed between the treatments and the control with respect to leaf area index.

4.1.4 Flag Leaf Area

The results on the effect of nutrient sources, crop growth stages and their interaction on flag leaf area are presented in Table 8.

The flag leaf area varied significantly with the different nutrient sources at booting and flowering stages. Flag leaf area was significantly higher under foliar feeding with potassium nitrate (S_1) at booting (4.98 cm^2) and flowering (8.11 cm^2) stages. While the effect of potassium nitrate was on par with that of S_4 (19:19:19 complex) at booting stage, it remained at par with 19:19:19 complex (S_4) and calcium nitrate (S_2) at the flowering stage. Flag leaf area at harvest stage remained unaffected by the different nutrient sources.

Flag leaf area did not show any significant variation among the different crop growth stages.

The interaction effect between nutrient sources and crop growth stages was observed to be significant at flowering and harvest stages. Foliar spraying of potassium nitrate @ 0.5 per cent at booting and flowering stages (s_1g_2) recorded the highest flag leaf area (9.08 cm^2) at flowering stage and was at par with calcium nitrate at the same concentration at booting stage (s_2g_1).

Foliar spray of calcium nitrate at booting, flowering and milk stages (s_2g_3) resulted in the highest flag leaf area (11.65 cm^2) at harvest stage. It was on par with s_1g_1, s_1g_2, s_1g_3, s_2g_2, s_3g_1, s_4g_2, and s_5g_1.

Significant difference was observed in the flag leaf area between the treatments and the control at flowering stage. The treatment effect was significantly superior (7.52 cm^2) to control (6.38 cm^2) at this stage. The treatments and control failed to vary significantly at booting and harvest stages.

4.1.5 Days to Panicle Exsertion

The effect of nutrient sources, crop growth stages and their interactions on the number of days to panicle exsertion are presented in Table 9.

The number of days taken for panicle exsertion was not observed to vary significantly under the influence of nutrient sources, crop growth stages and their interaction. However flag leaf nutrition with potassium nitrate resulted in earlier panicle exsertion (60.22 days). The treatments and the control did not show any significant variation.

Table 6. Effect of nutrient sources, growth stages and their interaction on number of tillers per hill, nos.

Treatments	Booting	Flowering	Harvest
Nutrient sources			
S_1	14.59	14.53	12.93
S_2	13.70	13.57	12.14
S_3	13.10	13.78	11.60
S_4	13.22	13.69	12.53
S_5	12.94	15.70	12.31
Growth stages			
G_1	13.25	13.97	12.43
G_2	13.54	14.36	12.35
G_3	13.74	14.44	12.12
Interaction effects			
s_1g_1	14.02	13.61	13.31
s_1g_2	14.13	15.56	12.84
s_1g_3	15.63	14.41	12.66
s_2g_1	14.13	14.49	12.00
s_2g_2	13.70	12.76	12.63
s_2g_3	13.28	13.48	11.78
s_3g_1	12.82	13.12	11.17
s_3g_2	12.72	13.62	11.23
s_3g_3	13.76	14.62	12.40
s_4g_1	13.30	13.30	13.32
s_4g_2	13.79	14.43	12.31
s_4g_3	12.58	13.35	11.97
s_5g_1	11.97	15.36	12.37
s_5g_2	13.37	15.42	12.78
s_5g_3	13.48	16.33	11.79
Treatment mean	13.51	14.25	12.30
Control	13.06	13.73	12.21
SEm (±) : S	0.576	0.595	0.466
G	0.446	0.461	0.361
SG	0.990	1.071	0.845
CD (0.05) : S	-	-	-
G	-	-	-
SG	-	-	-
Treatment *Vs* Control	NS	NS	NS

Table 7. Effect of nutrient sources, growth stages and their interaction on leaf area index

Treatments	Booting	Flowering	Harvest
Nutrient sources			
S_1	4.06	4.78	3.54
S_2	4.23	4.83	3.17
S_3	3.87	4.45	3.14
S_4	4.21	4.87	3.35
S_5	4.34	5.11	3.07
Growth stages			
G_1	4.06	4.89	3.26
G_2	4.15	4.65	3.21
G_3	4.22	4.88	3.30
Interaction effects			
s_1g_1	3.93	4.59	3.60
s_1g_2	4.05	4.47	3.56
s_1g_3	4.22	5.28	3.47
s_2g_1	4.46	5.15	3.10
s_2g_2	4.19	4.52	2.73
s_2g_3	4.03	4.81	3.67
s_3g_1	3.54	4.49	3.20
s_3g_2	3.92	4.51	3.42
s_3g_3	4.16	4.36	2.81
s_4g_1	3.98	5.22	3.36
s_4g_2	4.15	4.45	3.33
s_4g_3	4.48	4.94	3.36
s_5g_1	4.41	5.00	3.03
s_5g_2	4.43	5.31	3.03
s_5g_3	4.19	5.03	3.17
Treatment mean	4.41	4.77	3.25
Control	4.07	4.52	3.40
SEm (±) : S	0.193	0.170	0.231
G	0.150	0.131	0.179
SG	0.375	0.541	0.397
CD (0.05) : S	-	-	-
G	-	-	-
SG	-	-	-
Treatment *Vs* Control	NS	NS	NS

Table 8. Effect of nutrient sources, growth stages and their interaction on flag leaf area, cm^2

Treatments	Booting	Flowering	Harvest
Nutrient sources			
S_1	4.98	8.11	10.20
S_2	4.13	7.78	10.69
S_3	3.99	6.82	8.81
S_4	4.68	7.80	10.03
S_5	4.23	7.08	9.69
Growth stages			
G_1	4.45	7.48	10.04
G_2	4.39	7.58	10.06
G_3	4.37	7.50	9.55
Interaction effects			
s_1g_1	5.02	7.52	10.05
s_1g_2	4.96	9.08	10.59
s_1g_3	4.97	7.73	9.95
s_2g_1	4.17	8.53	9.60
s_2g_2	3.98	7.34	10.82
s_2g_3	4.25	7.47	11.65
s_3g_1	3.86	6.70	10.20
s_3g_2	3.93	6.68	8.16
s_3g_3	4.17	7.10	8.07
s_4g_1	4.94	7.67	9.48
s_4g_2	4.89	7.87	10.91
s_4g_3	4.20	7.85	9.69
s_5g_1	4.25	6.98	10.85
s_5g_2	4.19	6.95	9.81
s_5g_3	4.24	7.33	8.42
Treatment mean	4.40	7.52	9.88
Control	3.85	6.38	10.34
SEm (±) : S	0.152	0.181	0.343
G	0.118	0.140	0.265
SG	0.290	0.306	0.627
CD (0.05) : S	0.442	0.526	-
G	-	-	-
SG	-	0.883	1.804
Treatment *Vs* Control	NS	S	NS

Table 9. Effect of nutrient sources, growth stages and their interaction on days to panicle exsertion, days to 50 per cent flowering, number of latent tillers hill^{-1} and leaf area duration

Treatments	Days to panicle exsertion	Days to 50% flowering	Latent tillers hill^{-1}	leaf area duration (days)
Nutrient sources				
S_1	60.22	78.22	2.78	38.85
S_2	65.11	77.55	0.67	41.88
S_3	64.44	81.22	0.67	40.40
S_4	61.77	77.11	0.78	40.86
S_5	60.77	77.11	0.89	40.96
Growth stages				
G_1	61.60	78.00	1.13	39.92
G_2	63.00	78.60	1.20	40.20
G_3	62.80	78.13	1.13	41.65
Interaction effects				
s_1g_1	60.66	78.00	2.67	37.09
s_1g_2	60.33	78.00	2.67	39.49
s_1g_3	59.66	78.66	3.00	39.99
s_2g_1	61.00	77.33	0.67	41.60
s_2g_2	68.00	77.33	0.67	41.76
s_2g_3	66.33	78.00	0.67	42.30
s_3g_1	64.00	80.33	0.67	40.25
s_3g_2	64.66	83.33	0.67	39.22
s_3g_3	64.66	80.00	0.67	41.74
s_4g_1	61.66	77.00	0.67	40.77
s_4g_2	62.00	77.33	1.00	41.20
s_4g_3	61.66	77.00	0.67	40.63
s_5g_1	60.66	77.33	1.00	39.91
s_5g_2	60.00	77.00	1.00	39.36
s_5g_3	61.66	77.00	0.67	43.62
Treatment mean	58.15	78.2	1.16	40.59
Control	61.66	77.00	0.20	42.56
SEm (±) : S	1.383	0.542	0.273	0.947
G	1.072	0.420	0.211	0.734
SG	2.505	0.882	0.224	1.709
CD (0.05) : S	-	1.570	0.550	2.744
G	-	-	-	-
SG	-	-	-	-
Treatment *Vs* Control	NS	NS	NS	NS

4.1.6 Days to 50 per cent Flowering

The results on the effect of nutrient sources, crop growth stages and their interactions on the number of days taken by the crop to reach 50 per cent flowering are presented in Table 9.

The nutrient sources alone had significant effect on the days to 50 per cent flowering. FLN with S_3 (magnesium sulphate @ 0.5 per cent) resulted in significantly longer duration to 50 per cent flowering (81.22 days). The effect of all the other nutrient sources tested were at par.

No significant difference was observed between the treatments and the control with respect to the number of days to 50 per cent flowering.

4.1.7 Latent Tillers per Hill

The effect of nutrient sources, crop growth stages and their interactions on latent tillers per hill are presented in Table 9.

The nutrient sources alone showed significant effect on the latent tiller count. The latent tiller count was significantly higher (2.78) under foliar feeding with potassium nitrate @ 0.5 per cent (S_1).

The crop growth stages and the interaction effect failed to exert significance. No significant difference could be observed between the treatments and control.

4.2 PHYSIOLOGICAL STUDIES

4.2.1 Leaf Area Duration

The results on the leaf area duration recorded at harvest stage as effected by nutrient sources, crop growth stages and their interactions are presented in Table 9.

The leaf area duration varied significantly with different nutrient sources. Leaf area duration was longest with (S_2) calcium nitrate (41.88 days) and it remained at par with all the other treatments except S_1 (potassium nitrate). Leaf area duration remained unaffected by crop growth stages and their interaction.

The treatment and the control did not show any significant variation.

4.2.2 Specific Leaf Weight

The data on specific leaf weight as effected by nutrient sources, crop growth stages and their interactions at booting, flowering and harvest stages are presented in Table 10.

The nutrient sources used for flag leaf nutrition had significant effect on the specific leaf weight at flowering and harvest stages. Spraying a combination of calcium nitrate, magnesium sulphate and 19:19:19 complex (S_5) recorded the highest specific leaf weight at flowering (2.11 g m^{-2}) and foliar spraying of 19:19:19 complex @ 0.5 per cent (2.58 g m^{-2}) recorded the highest value at harvest stage. However the effect of other nutrient sources tested *viz*., S_3 (magnesium sulphate), S_1 (potassium nitrate) and S_4 (19:19:19 complex) remained at par with S_5 at flowering stage. At harvest stage S_4 (19:19:19 complex) remained at par with S_1 (potassium nitrate), S_3 (magnesium sulphate) and S_2 (calcium nitrate) indicating that they were also equally effective in increasing the specific leaf weight of the crop.

The specific leaf weight was not observed to vary significantly among the crop growth stages chosen for flag leaf nutrition.

The interaction effect was significant only at the flowering stage. Flag leaf nutrition with potassium nitrate at booting stage (s_1g_1) was significantly superior in terms of specific leaf weight (2.57 g m^{-2}). The treatments s_3g_2, s_3g_3, s_4g_2, s_5g_2, s_5g_3 are on par with s_1g_1. Treatments and the control did not show any significant variation.

Table 10. Effect of nutrient sources, growth stages and their interaction on specific leaf weight, g m^{-2}

Treatments	Booting	Flowering	Harvest
Nutrient sources			
S_1	1.31	2.09	2.54
S_2	1.37	1.64	2.30
S_3	1.10	2.09	2.49
S_4	1.22	2.07	2.58
S_5	1.12	2.11	2.18
Growth stages			
G_1	1.29	2.03	2.50
G_2	1.21	2.04	2.37
G_3	1.16	1.93	2.39
Interaction effects			
s_1g_1	1.60	2.57	2.75
s_1g_2	0.99	2.03	2.16
s_1g_3	1.34	1.66	2.71
s_2g_1	1.49	1.59	2.29
s_2g_2	1.33	1.64	2.27
s_2g_3	1.29	1.70	2.36
s_3g_1	1.00	1.90	2.33
s_3g_2	1.27	2.18	2.59
s_3g_3	1.02	2.19	2.55
s_4g_1	1.14	2.06	2.81
s_4g_2	1.27	2.16	2.66
s_4g_3	1.25	1.99	2.29
s_5g_1	1.22	2.03	2.32
s_5g_2	1.21	2.17	2.17
s_5g_3	0.92	2.14	2.03
Treatment mean	1.22	2.00	2.41
Control	1.29	2.11	2.14
SEm (±) : S	0.134	0.08	0.103
G	0.104	0.060	0.080
SG	0.231	0.150	0.178
CD (0.05) : S	-	0.207	0.300
G	-	-	-
SG	-	0.435	-
Treatment *Vs* Control	NS	NS	NS

Table 11. Effect of nutrient sources, growth stages and their interaction on relative growth rate, mg g^{-1} day^{-1}

Treatments	Booting	Flowering	Harvest
Nutrient sources			
S_1	0.174	0.057	0.028
S_2	0.078	0.047	0.019
S_3	0.074	0.047	0.013
S_4	0.087	0.052	0.027
S_5	0.076	0.046	0.021
Growth stages			
G_1	0.135	0.060	0.024
G_2	0.080	0.051	0.019
G_3	0.079	0.059	0.021
Interaction effects			
s_1g_1	0.358	0.049	0.027
s_1g_2	0.083	0.048	0.029
s_1g_3	0.080	0.043	0.027
s_2g_1	0.078	0.049	0.020
s_2g_2	0.080	0.048	0.019
s_2g_3	0.077	0.043	0.019
s_3g_1	0.072	0.049	0.013
s_3g_2	0.074	0.050	0.012
s_3g_3	0.078	0.042	0.014
s_4g_1	0.089	0.047	0.027
s_4g_2	0.086	0.053	0.026
s_4g_3	0.085	0.058	0.027
s_5g_1	0.078	0.047	0.034
s_5g_2	0.077	0.048	0.010
s_5g_3	0.074	0.043	0.018
Treatment mean	0.090	0.050	0.020
Control	0.076	0.040	0.012
SEm (±) : S	0.040	0.001	0.003
G	0.031	0.001	0.002
SG	0.067	0.004	0.005
CD (0.05) : S	-	0.005	0.010
G	-	-	-
SG	-	-	-
Treatment *Vs* Control	NS	NS	NS

Table 12. Effect of nutrient sources, growth stages and their interaction on net assimilation rate, mg cm^{-2} day^{-1}

Treatments	Booting	Flowering	Harvest
Nutrient sources			
S_1	3.76	2.23	0.71
S_2	1.95	2.23	0.26
S_3	2.32	2.44	0.56
S_4	2.57	2.58	0.44
S_5	2.10	2.38	0.48
Growth stages			
G_1	2.66	2.37	0.46
G_2	2.70	2.39	0.41
G_3	2.26	2.36	0.59
Interaction effects			
s_1g_1	4.19	2.13	0.85
s_1g_2	3.80	2.33	0.73
s_1g_3	3.30	2.25	0.55
s_2g_1	1.96	2.16	0.22
s_2g_2	2.13	2.28	0.42
s_2g_3	1.75	2.26	0.14
s_3g_1	2.26	2.54	0.46
s_3g_2	2.29	2.26	0.35
s_3g_3	2.42	2.51	0.87
s_4g_1	2.48	2.65	0.45
s_4g_2	3.38	2.55	0.21
s_4g_3	1.87	2.56	0.65
s_5g_1	2.40	2.37	0.35
s_5g_2	1.94	2.52	0.34
s_5g_3	1.96	2.26	0.75
Treatment mean	2.5	2.37	0.48
Control	2.04	2.15	0.35
SEm (±) : S	0.227	0.082	0.117
G	0.176	0.064	0.090
SG	0.376	0.158	0.204
CD (0.05) : S	0.658	0.240	-
G	-	-	-
SG	-	-	-
Treatment *Vs* Control	NS	NS	NS

4.2.3 Relative Growth Rate

The results on the effect of nutrient sources, crop growth stages, and their interactions on the relative growth rate are presented in Table 11.

The nutrient sources alone had significant effect on relative growth rate at flowering and harvest stages. S_1 (potassium nitrate @ 0.5 per cent) recorded the maximum relative growth rate (0.057 mg g^{-1} day^{-1}) at flowering and harvest stages (0.028 mg g^{-1} day^{-1}). At harvest it was at par with S_4 (19:19:19 complex) and S_5 (a combination of calcium nitrate, magnesium sulphate and 19:19:19 complex).

The crop growth stages and interaction effect between nutrient sources and crop growth stages failed to prove significance. The treatment and control also did not exhibit any significant variation in relative growth rate.

4.2.4 Net Assimilation Rate

The results on the net assimilation rate recorded at booting, flowering and harvest stages as effected by the nutrient sources, crop growth stages and their interactions are presented in Table 12.

The different nutrient sources had significant effect on the net assimilation rate at booting and flowering stage. Potassium nitrate @ 0.5 per cent concentration (S_1) recorded the maximum net assimilation rate of 3.76 mg cm^{-2} day^{-1} at booting and S_4 (19:19:19 complex) recorded maximum net assimilation rate (2.58 mg cm^{-2} day^{-1}) at flowering stage. At flowering stage the effect of magnesium sulphate (S_3) and combination treatment of calcium nitrate, magnesium sulphate and 19:19:19complex (S_5), were observed to remain at par with S_4 .

The crop growth stages chosen for foliar nutrition and the interaction between nutrient sources and crop growth stages failed to exert any significant effect on net assimilation rate. No significant difference was observed between the treatments and the control.

4.2.5 Plant Pigments- Sheath and Leaf

4.2.5.1 Chlorophyll Content of Flag Leaf Sheath

The results on the effect of nutrient sources, crop growth stages and their interactions on the chlorophyll content of flag leaf of rice are presented in Table 13.

The effect of nutrient sources on chlorophyll content of leaf sheath was observed to be significant only during the flowering stage. The treatment (S_5) a combination of calcium nitrate, magnesium sulphate and 19:19:19 complex @ 0.5 per cent recorded the maximum chlorophyll content (0.63 mg g^{-1}).

It was at par with potassium nitrate (S_1) and 19:19:19 complex (S_4). The treatment and the control did not show any significant variation.

The effect of crop growth stages for foliar nutrition on chlorophyll content of flag leaf sheath was found to be non significant. The treatment and the control also did not show any significant difference.

4.2.5.2 Chlorophyll Content of Flag Leaf Blade

The results on the effect of nutrient sources, crop growth stages and their interaction on the chlorophyll content of flag leaf of rice are presented in Table 13.

The nutrient sources used for flag leaf nutrition had significant effect on chlorophyll content of flag leaf blade at flowering stage. The treatment S_4 (19:19:19 complex) recorded maximum chlorophyll content of 2.58 mg g^{-1}. This remained at par with nutrient sources magnesium sulphate (S_3) and a combination treatment of calcium nitrate, magnesium sulphate and19:19:19 complex (S_5).

Table 13. Effect of nutrient sources, growth stages and their interaction on chlorophyll content in flag leaf, mg g^{-1}

Treatments	Booting		Flowering		Harvest	
	Leaf sheath	Leaf blade	Leaf sheath	Leaf blade	Leaf sheath	Leaf blade
(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
Nutrient sources						
S_1	0.41	0.68	0.58	2.23	0.40	0.62
S_2	0.48	0.79	0.51	2.23	0.38	0.74
S_3	0.54	0.75	0.49	2.44	0.40	0.61
S_4	0.41	0.89	0.55	2.58	0.39	0.53
S_5	0.42	0.83	0.63	2.38	0.41	0.66
Growth stages						
G_1	0.49	0.67	0.55	2.37	0.40	0.58
G_2	0.49	0.79	0.55	2.39	0.42	0.66
G_3	0.39	0.91	0.56	2.36	0.37	0.65
Interaction effects						
s_1g_1	0.33	0.62	0.52	2.13	0.35	0.62
s_1g_2	0.45	0.71	0.46	2.33	0.42	0.62
s_1g_3	0.46	0.71	0.68	2.25	0.41	0.61
s_2g_1	0.61	0.73	0.54	2.16	0.38	0.61
s_2g_2	0.58	0.63	0.61	2.28	0.41	0.73
s_2g_3	0.45	1.02	0.58	2.26	0.45	0.89
s_3g_1	0.57	0.65	0.54	2.54	0.38	0.69
s_3g_2	0.54	0.72	0.60	2.26	0.38	0.57
s_3g_3	0.34	0.87	0.39	2.51	0.39	0.57
s_4g_1	0.43	0.62	0.64	2.65	0.34	0.51
s_4g_2	0.48	1.00	0.35	2.55	0.45	0.45
s_4g_3	0.37	1.05	0.50	2.56	0.41	0.63
s_5g_1	0.53	0.75	0.55	2.37	0.40	0.47
s_5g_2	0.39	0.87	0.73	2.52	0.45	0.96

Table 13. continued

(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
s_5g_3	0.33	0.89	0.62	2.26	0.36	0.56
Treatment mean	0.45	0.78	0.55	2.37	0.39	0.67
Control	0.53	0.55	0.60	2.15	0.51	0.65
SE : S	0.034	0.075	0.033	0.082	0.029	0.050
G	0.026	0.058	0.025	0.064	0.022	0.039
SG	0.057	0.134	0.064	0.158	0.065	0.101
CD: S	-	-	0.096	0.240	-	-
G	-	-	-	-	-	-
SG	-	-	-	-	-	0.291
Treatment *Vs* Control	NS	NS	NS	NS	NS	NS

Table 14. Effect of nutrient sources, growth stages and their interaction on carotenoid content in flag leaf, mg g^{-1}

Treatments	Booting		Flowering		Harvest	
	Leaf sheath	Leaf blade	Leaf sheath	Leaf blade	Leaf sheath	Leaf blade
(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
Nutrient sources						
S_1	0.41	0.40	0.55	1.83	0.39	0.46
S_2	0.54	0.47	0.58	1.17	0.41	0.46
S_3	0.48	0.52	0.51	1.34	0.38	0.43
S_4	0.42	0.60	0.49	1.44	0.40	0.60
S_5	0.41	0.59	0.63	1.52	0.40	0.42
Growth stages						
G_1	0.49	0.53	0.56	1.43	0.37	0.47
G_2	0.49	0.52	0.55	1.33	0.42	0.50
G_3	0.39	0.51	0.55	1.43	0.40	0.46
Interaction effects						
s_1g_1	0.33	0.40	0.52	1.93	0.35	0.46
s_1g_2	0.45	0.44	0.46	1.74	0.42	0.46
s_1g_3	0.46	0.37	0.68	1.81	0.41	0.47
s_2g_1	0.61	0.34	0.54	1.49	0.38	0.48
s_2g_2	0.58	0.46	0.61	1.01	0.41	0.45
s_2g_3	0.45	0.60	0.58	1.01	0.45	0.45
s_3g_1	0.57	0.65	0.54	1.23	0.38	0.39
s_3g_2	0.54	0.46	0.60	1.28	0.38	0.52
s_3g_3	0.34	0.46	0.39	1.52	0.39	0.39
s_4g_1	0.43	0.67	0.64	1.27	0.34	0.63
s_4g_2	0.48	0.64	0.35	1.04	0.45	0.58
s_4g_3	0.37	0.49	0.50	1.58	0.41	0.59
s_5g_1	0.53	0.60	0.55	1.71	0.40	0.41
s_5g_2	0.39	0.59	0.73	1.61	0.45	0.49

Table 14. continued

(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)
s_5g_3	0.33	0.61	0.62	1.24	0.39	0.38
Treatment mean	0.45	0.53	0.55	1.45	0.43	0.47
Control	0.48	0.92	0.54	1.69	0.65	0.4
SE : S	0.041	0.026	0.029	0.092	0.024	0.030
G	0.050	0.054	0.022	0.071	0.019	0.020
SG	0.083	0.057	0.051	0.156	0.024	0.009
CD: S	-	0.076	0.086	0.267	-	0.096
G	-	-	-	-	-	-
SG	-	0.166	0.016	0.111	0.291	-
Treatment *Vs* Control	NS	S	NS	NS	NS	NS

The effect of crop growth stages for foliar nutrition on chlorophyll content of flag leaf blade was found to be non significant. The interaction effect was significant only at the harvest stage. Foliar spray of combination of calcium nitrate, magnesium sulphate and 19:19:19 complex at booting and flowering stages (s_5g_2) recorded the highest value (0.96).

However the other treatment combinations *viz*., s_2g_2 (calcium nitrate at booting and flowering stage), s_2g_3 (calcium nitrate at booting, flowering and milk stages) and s_3g_1 (magnesium sulphate at booting stage) remained at par. The treatments and the control did not show any significant variation.

4.2.5.3 Carotenoid Content of Flag Leaf Sheath

The results on the effect of nutrient sources, crop growth stages and their interaction on the carotenoid content are presented in Table 14.

The nutrient sources used for flag leaf nutrition had significant effect on the carotenoid content of flag leaf sheath at flowering stage. The nutrient source S_5 (combination of calcium nitrate, magnesium sulphate and 19:19:19 complex) recorded maximum carotenoid content (0.63 mg g^{-1}). It was at par with S_2 (calcium nitrate) and S_1 (potassium nitrate).

The effect of crop growth stages on carotenoid content of flag leaf sheath was also found to be non significant at all stages. The interaction between nutrient sources and crop growth stages had significant effect on carotenoid content of flag leaf sheath at flowering stage. The treatment s_5g_2 (combination of calcium nitrate, magnesium sulphate and 19:19:19 complex at booting and flowering stages) recorded highest carotenoid content (0.73 mg g^{-1}). No significant difference was observed between the treatments and the control.

4.2.5.4 Carotenoid Content of Flag Leaf Blade

The effect of nutrient sources, crop growth stages and their interactions on the carotenoid content of flag leaf blade are presented in Table 14.

The leaf nutrition varied significantly with the different nutrient sources at booting, flowering, and harvest stages. The carotenoid content of leaf blade was significantly higher under foliar feeding with (S_4) at booting (0.60 mg g^{-1}), foliar feeding of (S_1) at flowering (1.83 mg g^{-1}) and foliar feeding of (S_4) at harvest (0.60 mg g^{-1}) stage. The treatment (S_5) was on a par with that of 19:19:19 complex (S_4) at booting. Carotenoid content of leaf blade did not show any significant variation with crop growth stages chosen for flag leaf nutrition.

The interaction between nutrient sources and crop growth stages had significant effect on carotenoid content of leaf blade at booting stage recording maximum carotenoid content(0.67 mg g^{-1}) at s_4g_1 and flowering stage with highest value at s_1g_1 (1.93 mg g^{-1}). At booting stage this treatment remained at par with s_2g_3, s_3g_1, s_4g_2, s_5g_1, s_5g_2 and s_5g_3. At flowering stage the best treatment combination s_1g_1 (flag leaf nutrition of potassium nitrate at booting stage). Treatment and the control did not show any significant variation except carotenoid content of leaf blade at booting stage.

4.2.6 Total Soluble Protein

The results on the total soluble protein recorded at booting, flowering and harvest stages as effected on the nutrient sources, crop growth stages and their interactions are presented in Table 15.

The different nutrient sources had significant effect on the total soluble protein at booting and flowering stages. Magnesium sulphate @ 0.5 per cent concentration (S_3) recorded the maximum total soluble protein (1.04 mg g^{-1}) at

Table 15. Effect of nutrient sources, growth stages and their interaction on total soluble protein, mg g^{-1}

Treatments	Booting	Flowering	Harvest
Nutrient sources			
S_1	0.66	1.31	1.69
S_2	0.88	1.97	0.92
S_3	1.04	1.84	0.98
S_4	1.02	1.71	0.94
S_5	0.70	1.89	1.03
Growth stages			
G_1	0.75	1.53	0.91
G_2	0.92	1.76	1.91
G_3	0.90	1.95	1.51
Interaction effects			
s_1g_1	0.36	0.82	0.69
s_1g_2	0.92	1.59	0.74
s_1g_3	0.70	1.54	3.64
s_2g_1	0.82	1.58	0.62
s_2g_2	0.94	1.99	1.03
s_2g_3	0.89	2.33	1.11
s_3g_1	0.86	1.85	0.89
s_3g_2	0.98	1.88	0.97
s_3g_3	1.27	1.78	1.09
s_4g_1	0.95	1.43	0.95
s_4g_2	1.07	1.80	1.08
s_4g_3	1.04	1.92	0.80
s_5g_1	1.77	1.98	1.39
s_5g_2	1.71	1.52	0.76
s_5g_3	0.61	2.18	0.94
Treatment mean	0.85	1.74	1.11
Control	0.703	1.78	0.74
SEm (±) : S	0.094	0.136	0.472
G	0.072	0.205	0.366
SG	0.161	0.232	0.770
CD (0.05) : S	0.272	0.394	-
G	-	-	-
SG	-	-	-
Treatment *Vs* Control	NS	NS	NS

booting stage and was at par with S_2 (calcium nitrate) and S_4 (19:19:19 complex). At flowering stage the foliar spraying of calcium nitrate recorded the highest total soluble protein (1.97 mg g^{-1}) and was at par with S_5 (combination of calcium nitrate, magnesium sulphate and 19:19:19 complex), S_3 (magnesium sulphate) and S_4 (19:19:19 complex).

The effect of crop growth stages for foliar nutrition on total soluble protein was found to be non significant at all stages. The interaction between nutrient sources and crop growth stages failed to exert any significant effect on total soluble protein. No significant difference was observed between the treatments and the control.

4.2.7 Nutrient Use Efficiency

4.2.7.1 Nitrogen Use Efficiency

The results on the nitrogen use efficiency recorded at harvest stage as effected on the nutrient sources, crop growth stages and their interactions are presented in Table 16.

The efficiency of various nutrient sources on nitrogen use efficiency was observed to be significant. Flag leaf nutrition with potassium nitrate @ 0.5 per cent (S_1) recorded the maximum nitrogen use efficiency (66.20 kg kg^{-1}) followed by S_4 (19:19:19 complex).

The effect of crop growth stages for foliar nutrition on nitrogen use efficiency was found to be significantly superior for the treatment to which foliar spraying was done at booting + flowering + milk stages (G_3). It was at par with G_2 (foliar nutrition at booting and flowering stages).

The interaction effect was significant. The treatment combination s_1g_1 (potassium nitrate at booting stage) recorded the maximum value (69.84), which was

Table 16. Effect of nutrient sources, growth stages and their interaction on nitrogen use efficiency, agronomic efficiency and apparent recovery efficiency

Treatments	Nitrogen use efficiency (kg grain per kg fertilizer)	Agronomic efficiency (kg yield increase per kg nutrient applied)			Apparent recovery efficiency (kg increase in uptake per kg applied)		
		N	P	K	N	P	K
(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
Nutrient sources							
S_1	66.20	31.69	63.85	60.74	0.63	0.19	1.00
S_2	41.15	6.81	13.75	13.75	0.15	0.04	0.22
S_3	43.57	9.29	18.60	18.60	0.18	0.05	0.27
S_4	55.74	21.22	41.98	41.98	0.36	0.10	0.65
S_5	43.59	9.46	18.88	18.88	0.18	0.05	0.29
Growth stages							
G_1	47.13	13.54	27.14	27.14	0.27	0.08	0.41
G_2	49.78	15.98	31.97	31.97	0.31	0.09	0.51
G_3	52.07	17.56	35.13	35.13	0.32	0.09	0.54
Interaction effects							
s_1g_1	69.84	29.22	71.14	67.68	0.65	0.19	1.11
s_1g_2	63.61	35.31	58.67	57.20	0.62	0.19	0.95
s_1g_3	65.15	30.54	61.74	57.35	0.62	0.19	0.93
s_2g_1	39.05	6.20	9.55	9.55	0.14	0.04	0.16
s_2g_2	40.50	4.73	12.44	12.44	0.16	0.05	0.23
s_2g_3	43.90	9.50	19.26	19.26	0.16	0.04	0.28
s_3g_1	40.60	10.95	12.66	12.65	0.12	0.03	0.17
s_3g_2	45.22	6.32	21.90	21.90	0.22	0.06	0.34
s_3g_3	44.90	10.62	21.25	21.25	0.20	0.06	0.31

Table 16. continued

(i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)
s_4g_1	50.45	18.78	31.66	31.66	0.30	0.08	0.45
s_4g_2	50.45	16.00	37.37	37.37	0.33	0.09	0.59
s_4g_3	63.63	28.89	56.90	56.90	0.46	0.12	0.92
s_5g_1	39.74	14.74	10.69	10.69	0.16	0.05	0.15
s_5g_2	49.16	5.36	29.46	29.45	0.23	0.06	0.45
s_5g_3	42.78	8.27	16.49	16.49	0.16	0.05	0.29
Treatment mean	50.11	15.69	31.41	30.78	0.30	0.08	0.48
Control	49.00	0.00	0.00	0.00	0.00	0.00	0.00
SEm (±) : S	1.410	1.397	2.783	2.780	0.023	0.007	0.046
G	1.093	1.082	2.157	2.150	0.018	0.005	0.035
SG	4.159	3.297	6.580	6.540	0.053	0.015	0.105
CD (0.05) : S	4.085	4.047	8.064	8.060	0.068	0.021	0.134
G	3.165	3.134	6.240	6.240	-	-	0.104
SG	11.940	9.465	18.880	18.800	-	-	0.300
Treatment *Vs* Control	S	S	S	S	S	S	S

at par with s_1g_1, s_4g_3 and s_1g_3. The treatments were significantly superior (50.11 kg kg^{-1}) than control (49.00 kg kg^{-1}).

4.2.7.2 Agronomic Efficiency

The effect of nutrient sources, crop growth stages, and their interactions on agronomic efficiency is presented in Table 16.

The effect of various nutrient sources on the agronomic efficiency expressed in terms of kg yield increase per kg N, P and K applied was observed to be significant. S_1 (potassium nitrate @ 0.5 per cent) recorded the maximum agronomic efficiency for all the three nutrients followed by S_4 (19:19:19 complex).

The effect of crop growth stages for foliar nutrition on agronomic efficiency was found to be significant. Foliar application at G_3 (booting + flowering + milk stage) recorded the maximum agronomic efficiency which was at par with G_2 (booting + flowering stage).

The interaction effect also had significant effect on agronomic efficiency.

4.2.7.3 Apparent Recovery Efficiency

The data on the effect of nutrient sources, crop growth stages and their interaction on apparent recovery efficiency are presented in Table 16.

The effect of various nutrient sources on apparent recovery efficiency was observed to be significant. FLN with S_1 (potassium nitrate @ 0.5 per cent) recorded the maximum apparent recovery efficiency followed by S_4 (19:19:19 complex) .

The effect of crop growth stages for foliar nutrition on apparent recovery was non significant with respect to apparent recovery efficiency of N and P. Flag leaf nutrition at booting+ flowering + milk stages (G_3) recorded significantly higher apparent recovery efficiency for K (0.54 kg kg^{-1}) and it was on par with G_2 (booting + flowering stage). The interaction effect between nutrient sources and crop growth stages also had significant effect on the apparent recovery efficiency of potassium. The treatment combination s_1g_1 (flag leaf nutrition with potassium nitrate at booting stage) recorded significantly higher apparent recovery efficiency for potassium (1.11 kg kg^{-1}). It was on a par with s_1g_2, s_1g_3 and s_4g_3.

4.3 YIELD ATTRIBUTES AND YIELD

4.3.1 Productive Tillers per m^2

The data on the effect of nutrient sources, crop growth stages and their interactions on the productive tillers per m^2 are presented in Table 17.

The nutrient sources had significant effect on productive tillers. S_1 (potassium nitrate @ 0.5 per cent) resulted in maximum productive tiller count (490.19 per m^{-2}).

The effect of crop growth stages for foliar nutrition on productive tillers per m^2 was found to be significant. Foliar nutrition at booting and flowering stage recorded the highest value of 432.95 per m^2. It was at par with foliar nutrition at booting stage (G_1).

The interaction between nutrient sources and crop growth stages also had significant effect on productive tillers per m^2 with s_1g_1 (potassium nitrate @ 0.5 per cent at booting stage) recording the maximum productive tillers per m^2. It was on par with s_1g_2, s_1g_3, and s_2g_3. The treatment and the control did not show any significant variation.

4.3.2 Panicle Length

The data on panicle length as effected by nutrient sources, crop growth stages, and their interactions are presented in Table 17.

The panicle length varied significantly among the different nutrient sources. Panicles were significantly longer (21.38 cm) with flag leaf nutrition with potassium nitrate (S_1) @ 0.5 per cent. The effect of all the other four nutrient sources was at par.

The panicle length did not show any significant variation among different crop growth stages chosen for flag leaf nutrition. The interaction effect between nutrient sources and crop growth stages also failed to prove significance. The treatments and control did not exhibit any significant variation in panicle length.

4.3.3 Grain Weight per Panicle

The results on the effect of nutrient sources, crop growth stages, and their interactions on grain weight per panicle are presented in Table 17.

Nutrient sources had significant effect on the grain weight per panicle. Foliar spray of potassium nitrate @ 0.5 per cent (S_1) resulted in maximum grain weight per panicle (2.18 g), followed by 19:19:19 complex (S_4) which recorded a grain weight of 1.84 g per panicle. The treatments S_5 (combination of calcium nitrate, magnesium sulphate and 19:19:19 complex) and S_2 (calcium nitrate) remained at par.

The crop growth stages chosen for foliar nutrition and the interaction between nutrient sources and crop growth stages failed to exert any significant effect on grain weight per panicle. However the treatment (1.74 g per panicle) and the control (1.43 g per panicle) showed significant variation.

4.3.4 Spikelets per Panicle

The results on the effect of flag leaf foliar nutrition at different crop growth stages on spikelets per panicle are presented in Table 18.

The nutrient sources used for flag leaf nutrition had significant effect on the number of spikelets per panicle. Potassium nitrate @ 0.5 per cent (S_1) recorded the highest number of spikelets per panicle (89.11). The effect of all the other four nutrient sources was at par.

The crop growth stages chosen for foliar nutrition failed to exert any significant effect on spikelets per panicle.

The interaction between nutrient sources and crop growth stages had significant effect on spikelets per panicle. The treatment s_1g_1 (potassium nitrate at booting stage) recorded the maximum value (90.87) and remained on a par with s_1g_2 (potassium nitrate at booting and flowering stages). No significant difference was observed between treatments and the control.

4.3.5 Filled Grains per Panicle

The results on the effect of nutrient sources, crop growth stages and their interactions on filled grains per panicle are presented in Table 18.

The effect of nutrient sources on filled grains per panicle was observed to be significant. The nutrient source (S_1) potassium nitrate (86.33) recorded the maximum filled grains per panicle. It was at par with S_2 (calcium nitrate @ 0.5 per cent).

The filled grains per panicle did not show any significant variation among different crop growth stages. The interaction effect between nutrient source and crop growth stages also failed to prove significance. The treatment and the control did not show any significant variation.

4.3.6 Sterility Percentage

The data on sterility percentage as effected by nutrient source, crop growth stages and their interactions are presented in Table 18.

The effect of various nutrient sources on sterility percentage was observed to be significant. Flag leaf nutrition with potassium nitrate recorded the minimum

Table 17. Effect of nutrient sources, growth stages and their interaction on productive tillers per m^2, panicle length and grain weight per panicle

Treatments	Productive tillers per m^2	Panicle length (cm)	Grain weight per panicle (g)
Nutrient sources			
S_1	490.19	21.38	2.18
S_2	447.09	19.55	1.62
S_3	379.42	18.96	1.44
S_4	405.58	19.76	1.84
S_5	386.47	19.82	1.63
Growth stages			
G_1	429.28	19.71	1.73
G_2	432.95	20.45	1.75
G_3	403.02	19.52	1.75
Interaction effects			
s_1g_1	494.84	21.50	2.16
s_1g_2	481.70	21.70	2.13
s_1g_3	494.03	20.93	2.26
s_2g_1	412.44	19.35	1.73
s_2g_2	435.13	19.96	1.70
s_2g_3	493.70	19.33	1.43
s_3g_1	447.25	19.61	1.36
s_3g_2	377.45	19.63	1.46
s_3g_3	313.57	17.65	1.50
s_4g_1	464.63	18.69	1.76
s_4g_2	438.17	20.42	1.86
s_4g_3	313.94	20.16	1.90
s_5g_1	327.24	19.42	1.63
s_5g_2	432.32	20.53	1.60
s_5g_3	399.85	19.51	1.66
Treatment mean	421.75	19.89	1.74
Control	417.24	19.40	1.43
SEm (±) : S	4.117	0.348	0.052
G	3.191	0.270	0.040
SG	8.646	0.584	0.095
CD (0.05) : S	11.927	1.010	0.153
G	9.238	-	-
SG	24.824	-	-
Treatment *Vs* Control	NS	NS	S

Table 18. Effect of nutrient sources, growth stages and their interaction on spikelets per panicle, filled grains per panicle, sterility percentage and thousand grain weight

Treatments	Spikelets per panicle	Filled grains per panicle	Sterility percentage	1000 grain weight (g)
Nutrient sources				
S_1	89.11	86.33	11.94	28.55
S_2	83.47	84.82	14.67	24.28
S_3	81.83	79.50	14.22	24.50
S_4	82.58	80.88	12.66	26.73
S_5	81.85	82.15	13.97	23.09
Growth stages				
G_1	84.21	82.55	13.39	25.18
G_2	83.44	82.91	13.68	25.48
G_3	83.64	82.75	13.40	25.63
Interaction effects				
s_1g_1	90.87	87.18	11.54	27.32
s_1g_2	88.92	86.53	12.82	27.16
s_1g_3	87.53	85.28	11.48	31.17
s_2g_1	86.60	81.02	14.91	25.42
s_2g_2	81.20	88.93	14.65	24.31
s_2g_3	82.62	84.52	14.45	23.12
s_3g_1	82.28	80.93	14.42	24.68
s_3g_2	81.80	77.11	14.03	25.03
s_3g_3	81.40	80.46	14.20	23.79
s_4g_1	80.76	79.78	12.91	24.90
s_4g_2	84.01	81.24	12.15	28.09
s_4g_3	82.96	81.63	12.93	27.21
s_5g_1	80.57	83.83	13.17	23.60
s_5g_2	81.27	80.77	14.77	22.82
s_5g_3	83.70	81.87	13.97	22.85
Treatment mean	83.76	82.73	13.49	25.43
Control	82.57	81.02	16.05	21.51
SEm (±) : S	0.578	1.284	0.173	0.733
G	0.448	0.995	0.289	0.568
SG	1.084	2.216	0.624	1.219
CD (0.05) : S	1.676	3.722	1.081	2.125
G	-	-	-	-
SG	3.114	-	-	-
Treatment *Vs* Control	NS	NS	S	S

sterility percentage (11.94 per cent) and it remained on a par with S_4 (19:19:19 complex). Sterility percentage was significantly higher at S_2 (calcium nitrate) which remained on a par with S_3 (magnesium sulphate) and S_5 (combination of calcium nitrate, magnesium sulphate and 19:19:19 complex).

The crop growth stages and the interaction between nutrient sources and crop growth stages failed to exert any significant effect on sterility percentage. However the treatment and the control showed significant variation. Treatment effect recorded significantly lower sterility percentage (13.49 per cent) than control (16.05 per cent).

4.3.7 Thousand Grain Weight

The data on sterility percentage as effected by nutrient source, crop growth stages and their interactions are presented in Table 18.

The effect of various nutrient sources on thousand grain weight was observed to be significant recording the highest value for the nutrient source (S_1) potassium nitrate (28.55 g). It was at par with S_4 (19:19:19 complex).

The crop growth stages and the interaction between nutrient sources and crop growth stages failed to exert any significant effect on thousand grain weight. However the treatment and the control showed significant variation. The thousand grain weight was observed to be significantly higher in treatments (25.43 g) as compared to control (21.51 g).

4.3.8 Grain Yield

The data on the effect of nutrient sources, crop growth stages and their interactions on the grain yield are presented in Table 19.

The effect of nutrient sources used for foliar nutrition had significant effect on grain yield. Potassium nitrate @ 0.5 per cent (S_1) recorded the highest value (5.95 t ha^{-1}) followed by 19:19:19 complex (S_4). Foliar spraying of S_5 (combination of calcium nitrate, magnesium sulphate and 19:19:19 complex), S_3 (magnesium sulphate) and S_2 (calcium nitrate) remained at par.

The growth stage chosen for foliar nutrition exerted significant effect on grain yield. The treatment G_3 (flag leaf nutrition at booting + flowering +milk stage) recorded the maximum grain yield (4.68 t ha^{-1}). It was at par with G_2 (flag leaf nutrition at booting and flowering stages).

The interaction between nutrient source and crop growth stages also had significant effect on grain yield. The treatment s_1g_1 (potassium nitrate at booting stage) recorded the highest yield of 6.28 t ha^{-1}. It was at par with s_1g_1 and s_1g_3. The treatment (4.50 t ha^{-1}) and the control (4.41 t ha^{-1}) also showed significant variation.

4.3.8 Straw Yield

The straw yield as influenced by nutrient sources, crop growth stages and their interactions recorded are presented in Table 19.

The effect of various nutrient sources on straw yield was observed to be significant. Potassium nitrate @ 0.5 per cent (S_1) recorded the highest straw yield (9.29 t ha^{-1}) followed by 19:19:19 complex. Flag leaf nutrition of S_5 (combination of calcium nitrate, magnesium sulphate and 19:19:19 complex), S_3 (magnesium sulphate) and S_2 (calcium nitrate) remained at par.

The crop growth stages used for foliar nutrition and their interaction between nutrient sources and crop growth stages failed to exert any significant effect on straw yield. However the treatment and the control showed significant variation with respect to straw yield.

4.3.9 Harvest Index

The results on the effect of nutrient sources, crop growth stages and their interactions on harvest index are presented in Table 19.

Table 19. Effect of nutrient sources, growth stages and their interaction on grain yield, straw yield, harvest index and grain to straw ratio

Treatments	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index	Grain:Straw
Nutrient sources				
S_1	5.95	9.29	0.39	0.64
S_2	3.70	5.15	0.42	0.72
S_3	3.92	5.17	0.43	0.77
S_4	5.01	6.40	0.44	0.80
S_5	3.95	5.24	0.43	0.79
Growth stages				
G_1	4.31	6.13	0.41	0.72
G_2	4.52	6.38	0.42	0.73
G_3	4.68	6.24	0.43	0.77
Interaction effects				
s_1g_1	6.28	9.01	0.37	0.70
s_1g_2	5.72	9.59	0.41	0.60
s_1g_3	5.86	9.28	0.39	0.63
s_2g_1	3.51	5.31	0.41	0.66
s_2g_2	3.64	5.34	0.40	0.69
s_2g_3	3.95	4.81	0.45	0.82
s_3g_1	3.65	4.53	0.42	0.81
s_3g_2	4.06	5.67	0.45	0.72
s_3g_3	4.04	5.31	0.43	0.76
s_4g_1	4.54	6.14	0.44	0.76
s_4g_2	4.78	6.26	0.43	0.77
s_4g_3	5.72	6.80	0.46	0.86
s_5g_1	3.57	5.68	0.46	0.69
s_5g_2	4.42	5.04	0.38	0.87
s_5g_3	3.85	5.01	0.44	0.80
Treatment mean	4.50	6.25	0.42	0.74
Control	4.41	4.58	0.49	0.96
SEm (±) : S	0.127	0.275	0.027	0.150
G	0.098	0.213	0.030	0.131
SG	0.374	0.589	0.109	0.112
CD (0.05) : S	0.368	0.798	0.030	0.115
G	0.285	-	-	-
SG	1.074	-	-	-
Treatment *Vs* Control	S	S	NS	NS

The nutrient sources alone showed significant effect on harvest index. Foliar feeding with 19:19:19 complex @ 0.5 per cent (S_4) recorded the maximum harvest index (0.44). The other nutrient sources S_3 (magnesium sulphate) and S_5 (combination of calcium nitrate, magnesium sulphate and 19:19:19 complex) were on par with S_4. The treatment and the control did not show any significant difference with respect to harvest index.

4.3.10 Grain to Straw Ratio

The results on the effect of nutrient sources, crop growth stages and their interactions on grain to straw ratio are presented in Table 19.

The nutrient sources had significant effect on grain to straw ratio with 19:19:19 complex @ 0.5 per cent (S_4) recording the maximum grain to straw ratio (0.80). The nutrient sources S_2 (calcium nitrate), S_3 (magnesium sulphate) and S_5 (combination of calcium nitrate, magnesium sulphate and 19:19:19 complex) were on par with S_4. The treatment and the control did not show any significant variation.

4.4 PLANT ANALYSIS

4.4.1 Index Leaf Analysis

The results on the index leaf (flag leaf) analysis with respect to its nitrogen, phosphorus, potassium, calcium, magnesium and sulphur contents are presented in Tables 20 and 21.

Nitrogen content of the index varied significantly with the nutrient sources. Flag leaf nutrition with a combination treatment of calcium nitrate, magnesium sulphate and 19:19:19 complex (S_5) recorded the highest N content (1.85 per cent). It was on a par with (S_1) potassium nitrate @ 0.5 per cent. Neither the crop growth stages nor the interaction effects was found to be significant. The treatment and the control did not show any significant variation.

Table 20. Effect of nutrient sources, growth stages and their interaction on index leaf analysis, per cent

Treatments	N	P	K
Nutrient sources			
S_1	1.80	0.62	1.56
S_2	1.74	0.54	1.54
S_3	1.55	0.67	1.49
S_4	1.66	0.68	1.42
S_5	1.85	0.73	1.54
Growth stages			
G_1	1.70	0.63	1.48
G_2	1.73	0.65	1.54
G_3	1.73	0.66	1.50
Interaction effects			
s_1g_1	1.75	0.65	1.47
s_1g_2	1.91	0.60	1.31
s_1g_3	1.74	0.60	1.29
s_2g_1	1.73	0.60	1.37
s_2g_2	1.81	0.46	1.30
s_2g_3	1.68	0.57	1.35
s_3g_1	1.45	0.67	1.34
s_3g_2	1.61	0.72	1.26
s_3g_3	1.58	0.62	1.26
s_4g_1	1.71	0.61	1.15
s_4g_2	1.63	0.70	1.23
s_4g_3	1.65	0.74	1.27
s_5g_1	1.85	0.74	1.36
s_5g_2	1.71	0.67	1.31
s_5g_3	2.01	0.77	1.34
Treatment mean	1.72	0.59	1.30
Control	1.59	0.59	1.25
SEm (±) : S	0.077	0.035	0.032
G	0.034	0.027	0.025
SG	0.105	0.060	0.008
CD (0.05) : S	0.092	0.102	0.095
G	-	-	-
SG	-	-	-
Treatment *Vs* Control	NS	NS	NS

Table 21. Effect of nutrient sources, growth stages and their interaction on index leaf analysis, per cent

Treatments	Ca	Mg	S
Nutrient sources			
S_1	0.278	0.177	0.070
S_2	0.340	0.257	0.068
S_3	0.336	0.273	0.084
S_4	0.291	0.266	0.079
S_5	0.321	0.263	0.070
Growth stages			
G_1	0.318	0.233	0.069
G_2	0.320	0.283	0.077
G_3	0.301	0.226	0.077
Interaction effects			
s_1g_1	0.170	0.160	0.059
s_1g_2	0.393	0.216	0.075
s_1g_3	0.273	0.156	0.076
s_2g_1	0.360	0.210	0.070
s_2g_2	0.350	0.270	0.065
s_2g_3	0.310	0.293	0.068
s_3g_1	0.356	0.253	0.067
s_3g_2	0.353	0.243	0.091
s_3g_3	0.300	0.296	0.094
s_4g_1	0.363	0.250	0.081
s_4g_2	0.173	0.243	0.075
s_4g_3	0.336	0.320	0.082
s_5g_1	0.343	0.253	0.068
s_5g_2	0.333	0.300	0.078
s_5g_3	0.286	0.176	0.065
Treatment mean	0.260	0.240	0.080
Control	0.380	0.210	0.060
SEm (±) : S	0.025	0.019	0.002
G	0.019	0.015	0.001
SG	0.050	0.034	0.003
CD (0.05) : S	-	0.057	0.006
G	-	0.044	0.005
SG	-	-	0.113
Treatment *Vs* Control	NS	NS	NS

Nutrient sources alone had significant effect on phosphorus content of index leaf. Flag leaf nutrition with a combination treatment of calcium nitrate, magnesium sulphate and 19:19:19 complex (S_5) recorded the highest P content (0.73 per cent) .It was on a par with S_4 (19:19:19 complex) and S_3 (magnesium sulphate). The treatment mean and control did not show any significant variation.

The potassium content of index leaf also exhibited significant variation among the different nutrient sources. Flag leaf nutrition with (S_1) potassium nitrate @ 0.5 per cent recorded significantly higher K content (1.56 per cent). It was at par with S_2 (calcium nitrate), (S_5) combination treatment of calcium nitrate, magnesium sulphate and 19:19:19 complex and S_3 (magnesium sulphate). The effect of crop growth stages and interaction between nutrient sources and crop growth stages proved to be non significant. The K content of index leaf did not vary significantly between treatments and the control.

Calcium content of the index leaf did not vary significantly with the treatments or their interactions. The treatment and the control did not show any significant variation.

The magnesium content of index leaf was observed to vary significantly with nutrient sources and crop growth stages. The treatment magnesium sulphate (S_3) recorded the highest magnesium content (0.27 per cent). It was at a par with S_4 (19:19:19 complex), S_2 (calcium nitrate), and S_5 (combination treatment of calcium nitrate, magnesium sulphate and 19:19:19 complex). Flag leaf nutrition at booting + flowering stage recorded highest magnesium content (0.283 per cent).

The effect of nutrient sources used for foliar nutrition had significant effect on sulphur content of index leaf. The treatment (S_3) magnesium sulphate @ 0.5 per cent recorded the highest sulphur content (0.084 per cent). It was at par with S_4 (19:19:19 complex). The growth stage chosen for foliar nutrition exerted significant effect on sulphur content of index leaf. The treatment G_3 (foliar spray at booting, flowering and milk stage) recorded the maximum sulphur content (0.077 per cent). It was at par with G_2 (booting + flowering stages). The interaction between nutrient source and crop growth stages also had significant effect on sulphur content. The treatment s_3g_3 (magnesium sulphate at booting + flowering + milk stages) recorded the highest sulphur content of 0.094 per cent. The treatment and the control did not show any significant variation.

4.4.2 Nutrient Uptake

4.4.2.1 Uptake of Major Nutrients

The data on the effect of nutrient sources, crop growth stages and their interactions on uptake of the major nutrients *viz*., nitrogen, phosphorus and potassium are presented in Table 22.

The nutrient sources had significant effect on nitrogen uptake. Flag leaf nutrition with potassium nitrate @ 0.5 per cent (S_1) recorded significantly higher nitrogen uptake (106.05 kg ha^{-1}) followed by 19:19:19 complex (S_4). The crop growth stages chosen for foliar nutrition and the interaction between nutrient sources and crop growth stages failed to exert any significant effect in nitrogen uptake. No significant difference was found between the treatments and the control.

As in the case of nitrogen uptake, nutrient sources alone had significant effect on P uptake. Significantly superior P uptake (15.25 kg ha^{-1}) was recorded with flag leaf nutrition of potassium nitrate @ 0.5 per cent (S_1). The next best treatment was S_4 (19:19:19 complex). The effect of all the other three sources were at par. However significant difference was observed between the treatments and the control with the treatments exhibiting superiority (10.76 kg ha^{-1}) over control (6.66 kg ha^{-1}).

Potassium uptake varied significantly with nutrient sources, growth stage sand their interaction. The treatment S_1 (potassium nitrate @ 0.5 per cent) recorded significantly higher K uptake (107.59 kg ha^{-1}), followed by S_4 (19:19:19 complex at

0.5 per cent). The treatments S_5 (combination treatment of calcium nitrate, magnesium sulphate and 19:19:19 complex), S_3 (magnesium sulphate) and S_2 (calcium nitrate) remained at par. The crop growth stages chosen for foliar nutrition exerted significant effect on potassium uptake. Flag leaf nutrition at booting + flowering + milk stages (G_3) recorded the maximum K uptake (85.95 kg ha^{-1}). It was at par with G_2 (booting + flowering stage). The interaction effect was also significant effect. The treatment combination, s_1g_1 (potassium nitrate 0.5 per cent at booting stage recorded significantly higher K uptake (113.10 kg ha^{-1}). The treatments s_1g_2, s_1g_3 and s_4g_3 remained at par. The treatment and the control did not show any significant variation.

4.4.2.2 Uptake of Secondary Nutrients

The data on the effect of nutrient sources, crop growth stages and their interactions on uptake of the secondary nutrients *viz*., calcium, magnesium and sulphur are presented in Table 23.

Nutrient sources alone had significant effect on calcium uptake. Flag leaf nutrition with calcium nitrate @ 0.5 per cent (S_2) recorded significantly higher uptake (12.21 kg ha^{-1}). It was at par with S_5 (combination treatment of calcium nitrate, magnesium sulphate and 19:19:19 complex). Further, the treatments S_4 (19:19:19 complex) and S_1 (potassium nitrate) remained at par. The crop growth stages chosen for foliar nutrition and the interaction between nutrient sources and crop growth stages failed to exert any significant effect on calcium uptake. No significant difference could be observed in calcium uptake between the treatments and the control.

Magnesium uptake was not observed to vary significantly under the influence of nutrient sources, crop growth stages and their interactions. The treatments and control also failed to vary significantly in magnesium uptake.

Sulphur uptake showed significant difference with nutrient sources, crop growth stages chosen for flag leaf nutrition and their interaction. Flag leaf nutrition with magnesium sulphate @ 0.5 per cent (S_3) recorded significantly higher sulphur uptake (10.59 kg ha^{-1}), followed by S_4 (19:19:19 complex) and S_2 (calcium nitrate), which recorded sulphur uptake values of 9.75 kg ha^{-1} and 8.02 kg ha^{-1} respectively. The effect of S_1 and S_5 remained at par. Among the three crop growth stages chosen for flag leaf nutrition, G_3 (booting + flowering + milk stages) was observed to record significantly higher sulphur uptake (9.37kg ha^{-1}). The treatment combination, s_3g_2 (magnesium sulphate at booting + flowering stages) recorded significantly higher sulphur uptake (11.20 kg ha^{-1}). Significant variation was also observed between the treatments (8.71 kg ha^{-1}) and the control (7.24 kg ha^{-1}).

4.4.3 Crude Protein Content of Grain

The results on crude protein content of grain as affected by nutrient sources, crop growth stages and their interactions are presented in Table 23.

The crude protein content varied significantly with different nutrient sources. Flag leaf nutrition of (S_1) potassium nitrate @ 0.5 per cent recorded the maximum crude protein content (8.26 per cent), which remained at par (7.73 per cent) with 19:19:19 complex (S_4). While the effect of crop growth stages chosen for flag leaf nutrition had no significant effect, the interaction effect between nutrient sources and crop growth stages was significant with respect to the crude protein content of the grain. The crude protein content of the grain was significantly higher (8.34 per cent) with flag leaf nutrition of 0.5 per cent potassium nitrate at booting + flowering stages (s_1g_2). The treatments s_1g_2, s_1g_3, s_2g_1, s_4g_1, s_4g_2 and s_4g_3 were at par. The treatment and the control also did not show any significant variation.

Table 22. Effect of nutrient sources, growth stages and their interaction on uptake of N, P and K, kg ha^{-1}

Treatments	N	P	K
Nutrient sources			
S_1	106.05	15.25	107.59
S_2	62.71	8.86	70.47
S_3	64.30	9.09	71.69
S_4	82.39	11.41	90.34
S_5	63.73	9.19	73.96
Growth stages			
G_1	74.81	10.45	78.78
G_2	75.31	10.91	83.70
G_3	77.38	10.92	85.95
Interaction effects			
s_1g_1	107.92	15.30	113.10
s_1g_2	105.19	15.31	104.05
s_1g_3	105.03	15.14	105.63
s_2g_1	59.62	8.83	67.67
s_2g_2	62.28	8.99	70.77
s_2g_3	66.23	8.76	72.97
s_3g_1	63.04	8.18	64.90
s_3g_2	61.92	9.75	75.89
s_3g_3	67.94	9.35	74.30
s_4g_1	81.13	10.68	80.94
s_4g_2	79.61	11.04	87.08
s_4g_3	86.15	12.53	103.01
s_5g_1	62.05	9.25	67.31
s_5g_2	67.58	9.47	80.73
s_5g_3	61.57	8.86	73.85
Treatment mean	75.81	10.76	82.81
Control	84.15	6.66	99.90
SEm (±) : S	2.635	0.340	2.271
G	2.043	0.263	1.760
SG	11.399	0.891	6.314
CD (0.05) : S	7.635	0.985	6.579
G	-	-	5.096
SG	-	-	16.134
Treatment *Vs* Control	NS	S	NS

Table 23. Effect of nutrient sources, growth stages and their interaction on uptake of Ca, Mg, S and crude protein content of grain

Treatments	Ca (kg ha^{-1})	Mg (kg ha^{-1})	S (kg ha^{-1})	Crude protein (per cent)
Nutrient sources				
S_1	11.45	7.71	7.64	8.26
S_2	12.21	11.41	8.02	6.61
S_3	10.12	12.02	10.59	5.71
S_4	11.52	6.52	9.75	7.73
S_5	12.13	7.54	7.56	6.40
Growth stages				
G_1	11.37	7.78	7.90	6.93
G_2	11.64	8.44	8.87	7.02
G_3	11.49	10.90	9.37	6.80
Interaction effects				
s_1g_1	11.23	7.38	7.44	8.25
s_1g_2	11.34	8.29	8.33	8.34
s_1g_3	11.78	7.46	7.14	8.19
s_2g_1	11.76	6.82	7.28	6.80
s_2g_2	12.40	6.80	6.86	7.46
s_2g_3	12.49	20.62	9.91	5.57
s_3g_1	10.21	11.48	10.16	5.68
s_3g_2	10.30	12.33	11.20	5.78
s_3g_3	9.85	12.26	10.41	5.67
s_4g_1	11.88	5.36	8.09	7.63
s_4g_2	11.61	7.46	11.01	7.23
s_4g_3	11.07	6.74	10.17	8.33
s_5g_1	11.55	7.89	6.52	6.73
s_5g_2	12.59	7.31	6.96	5.84
s_5g_3	12.26	7.43	9.21	6.64
Treatment mean	11.48	9.04	8.71	6.94
Control	11.82	6.88	7.24	7.03
SEm (±) : S	0.22	1.996	0.092	0.206
G	0.17	1.547	0.071	0.159
SG	0.41	3.357	0.164	0.497
CD (0.05) : S	0.66	-	0.267	0.598
G	-	-	0.207	-
SG	-	-	0.047	1.337
Treatment *Vs* Control	NS	NS	S	NS

4.5 SOIL ANALYSIS AFTER THE EXPERIMENT

4.5.1 Organic Carbon

The data on soil organic carbon content after the experiment are presented in Table 24.

The soil organic carbon was not observed to vary significantly under the influence of nutrient sources, crop growth stages, and their interactions. The treatment and the control also did not show any significant variation.

4.5.2 Available Nitrogen

The data on available soil nitrogen as effected by nutrient sources, crop growth stages and their interactions are presented in Table 24.

The effect of nutrient sources used for foliar nutrition had significant effect on available soil nitrogen status. The treatment (S_1) potassium nitrate @ 0.5 per cent recorded the highest available nitrogen (290.76 kg ha^{-1}).

The growth stage chosen for flag leaf nutrition exerted significant effect on the available nitrogen status of soil. The treatment G_2 (foliar spray at booting and flowering stage) recorded the maximum soil available nitrogen (223.71 kg ha^{-1}). It was at par with G3 (booting + flowering + milk stage).

The interaction between nutrient source and crop growth stages also had significant effect on available soil nitrogen. The treatment s_1g_3 (potassium nitrate at booting stage, flowering and milk stage) recorded the highest available nitrogen (319.07 kg ha^{-1}). It was at at par with s_1g_2 (potassium nitrate at booting and flowering stage) and s_4g_1 (19:19:19 complex at booting stage). The treatment and the control showed significant variation.

4.5.3 Available Phosphorus

The results on the effect of nutrient sources, crop growth stages and their interaction on soil available phosphorus are presented in Table 24.

The nutrient sources alone had significant effect on phosphorus content. Potassium nitrate @ 0.5 per cent (S_1) recorded the maximum available phosphorus (33.86 kg ha^{-1}). It was at a par with S_5 (combination of calcium nitrate, magnesium sulphate and 19:19:19 complex) and S_2 (calcium nitrate).

The crop growth stages chosen for foliar nutrition and the interaction between nutrient sources and crop growth stages failed to exert any significant effect on the available phosphorus status of soil. No significant difference was found between the treatments and the control.

4.5.4 Available Potassium

The results on the effect of nutrient sources, crop growth stages and their interaction on available soil potassium status are presented in Table 24.

The nutrient sources used for flag leaf nutrition had significant effect on the available potassium status of soil. Potassium nitrate @ 0.5 per cent (S_1) recorded the highest available potassium content (185.66 kg ha^{-1}). It was at par with (S_3) magnesium sulphate.

The crop growth stages chosen for foliar nutrition failed to exert any significant effect on soil available potassium.

The interaction between nutrient sources and crop growth stages had significant effect on soil available potassium. The treatment s_1g_3 (potassium nitrate at booting, flowering and milk stage) recorded the maximum available potassium status of soil (203.25 kg ha^{-1}). It was at a par with s_3g_2 (magnesium sulphate at booting and flowering stages). The available potassium status of soil was significantly higher with the treatments (171.94 kg ha^{-1}) than control (157.29 kg ha^{-1}).

4.5.5 Available Calcium

The data on soil calcium as effected by nutrient sources, crop growth stages, and their interactions are presented in Table 25.

Nutrient sources, crop growth stages and their interaction exhibited significant effect on the available calcium status of the soil after the experiment. While flag leaf nutrition with calcium nitrate @ 0.5 per cent (S_2) recorded significantly higher available Ca (283.24 mg kg^{-1}), the treatments S_1 (potassium nitrate) and S_4 (19:19:19 complex) remained at par. The treatment G_2 (foliar spray at booting and flowering stage) recorded the maximum available calcium (272.75 mg kg^{-1}). The treatment combination s_4g_1 (19:19:19 complex at booting stage) recorded the highest available calcium status (309.94 mg kg^{-1}). It was on par with s_3g_3 (magnesium sulphate at booting + flowering + milk stage).

The control (291.15 mg kg^{-1}) proved significantly superior than treatment (267.48 mg kg^{-1}) in maintaining the available calcium status of soil.

4.5.6 Available Magnesium

The results on the effect of nutrient sources, crop growth stages and their interaction on available soil magnesium are presented in Table 25.

The nutrient sources used for flag leaf nutrition had significant effect on the available magnesium status of soil. S_3 (magnesium sulphate @ 0.5 per cent) recorded the highest available magnesium status (66.20 mg kg^{-1}) and was at par with (S_4) 19:19:19 complex.

The crop growth stages chosen for foliar nutrition failed to exert any significant effect on available soil magnesium status.

Table 24. Effect of nutrient sources, growth stages and their interaction on organic carbon and available NPK status of soil after the experiment

Treatments	Organic carbon (per cent)	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
Nutrient sources				
S_1	0.69	290.76	33.86	185.66
S_2	0.67	183.39	32.31	164.34
S_3	0.63	161.21	28.57	184.72
S_4	0.68	274.26	28.38	164.97
S_5	0.68	177.49	33.62	160.01
Growth stages				
G_1	0.66	210.59	31.27	170.94
G_2	0.70	223.71	31.32	171.80
G_3	0.65	217.97	31.46	173.08
Interaction effects				
s_1g_1	0.64	245.65	36.39	176.50
s_1g_2	0.75	307.55	33.20	177.22
s_1g_3	0.68	319.07	32.00	203.25
s_2g_1	0.69	160.83	31.98	161.95
s_2g_2	0.73	198.80	33.04	165.59
s_2g_3	0.59	190.54	31.89	165.50
s_3g_1	0.58	162.27	28.49	187.84
s_3g_2	0.61	153.00	29.39	196.76
s_3g_3	0.70	168.35	27.84	169.58
s_4g_1	0.68	303.33	28.92	170.57
s_4g_2	0.69	288.02	27.04	157.35
s_4g_3	0.67	231.43	29.17	166.99
s_5g_1	0.69	180.86	30.55	157.85
s_5g_2	0.71	171.18	33.92	162.08
s_5g_3	0.69	180.45	36.38	160.11
Treatment mean	0.67	203.52	27.56	171.94
Control	0.67	195.79	33.06	157.29
SEm (±) : S	0.224	3.812	0.967	1.180
G	0.015	2.955	0.750	0.914
SG	0.036	6.419	1.612	3.981
CD (0.05) : S	-	11.044	2.804	3.420
G	-	8.554	-	-
SG	-	18.427	-	11.429
Treatment *Vs* Control	NS	S	NS	S

Table 25. Effect of nutrient sources, growth stages and their interaction on available Ca, Mg and S status of soil after the experiment, mg kg^{-1}

Treatments	Ca	Mg	S
Nutrient sources			
S_1	278.82	61.93	8.42
S_2	283.24	61.23	9.79
S_3	266.44	66.20	10.27
S_4	276.80	65.08	8.07
S_5	232.15	58.34	9.01
Growth stages			
G_1	262.37	62.80	9.20
G_2	272.75	63.69	9.44
G_3	267.33	61.18	8.69
Interaction effects			
s_1g_1	278.36	61.21	8.09
s_1g_2	267.10	62.81	8.80
s_1g_3	290.99	61.77	8.37
s_2g_1	261.25	59.16	9.94
s_2g_2	293.71	64.19	10.02
s_2g_3	294.76	60.33	9.43
s_3g_1	207.45	73.60	10.32
s_3g_2	290.28	62.71	10.67
s_3g_3	301.60	62.30	9.83
s_4g_1	309.94	60.64	8.24
s_4g_2	276.26	69.90	8.03
s_4g_3	244.19	64.72	7.93
s_5g_1	254.87	59.39	9.43
s_5g_2	236.43	58.83	9.69
s_5g_3	205.14	56.80	7.91
Treatment mean	267.48	62.55	9.11
Control	291.15	68.65	7.76
SEm (±) : S	2.552	1.072	0.389
G	1.978	1.860	0.301
SG	4.664	1.917	0.667
CD (0.05) : S	7.395	3.108	1.127
G	5.728	-	-
SG	13.388	5.505	-
Treatment *Vs* Control	S	S	NS

The interaction between nutrient sources and crop growth stages had significant effect on available soil magnesium.The treatment s_3g_1 (magnesium sulphate at booting stage) recorded the maximum available magnesium (73.60 mg kg^{-1}) and was at a par with s_4g_2 (19:19:19 complex at booting and flowering stages). As in the case of available calcium the available magnesium status of soil was also significantly higher in control (68.65 mg kg^{-1}) than treatment (62.55 mg kg^{-1}).

4.5.7 Available Sulphur

The results on the effect of nutrient sources, crop growth stages and their interaction on available sulphur content are presented in Table 25.

The nutrient sources alone had significant effect on available sulphur content. Flag leaf nutrition with magnesium sulphate @ 0.5 per cent (S_3) recorded the maximum available sulphur (10.27 mg kg^{-1}) and was at a par with S_2 (calcium nitrate).

The crop growth stages chosen for foliar nutrition and the interaction between nutrient sources and crop growth stages did not have any significant effect on the available sulphur status of soil. No significant difference was found between the treatments and the control.

4.6 ECONOMIC ANALYSIS

The data on the effect of nutrient sources, crop growth stages and their interaction on gross income, net income and benefit cost ratio are presented in Table 26.

4.6.1 Gross income

The nutrient sources alone had significant effect on gross income. Flag leaf nutrition with potassium nitrate (S_1) recorded the maximum gross income (₹ 1,35,127 ha^{-1}) followed by 19:19:19 complex (S_4). The crop growth stages chosen for foliar nutrition and the interaction between nutrient sources and crop growth stages failed to exert any significant effect on gross income. Significant difference was found between the treatments (₹ 99612 ha^{-1}) and the control (₹ 102280 ha^{-1}).

4.6.2 Net Income

Nutrient sources alone had significant effect on net income. Significantly higher net returns (₹ 70102 ha^{-1}) was recorded by application of potassium nitrate (S_1) followed by 19:19:19 complex (S_4). The crop growth stages chosen for foliar nutrition and the interaction between nutrient sources and crop growth stages failed to exert any significant effect on net income. Significant difference was found between the treatments (₹ 34309 ha^{-1}) and the control (₹ 40357 ha^{-1}).

4.6.3 Benefit Cost Ratio

As in the case of gross income and net income, benefit cost ratio also showed significant difference among the different nutrient sources. The highest benefit cost ratio (2.07) was recorded by application of potassium nitrate (S_1) followed by (1.65) recorded with 19:19:19 complex (S_4). The benefit cost ratio did not vary significantly among the three crop growth stages chosen for flag leaf nutrition. The effect of the interaction between nutrient sources and crop growth stages was also not significant. Significant difference was found between the treatments (1.52) and the control (1.65).

4.6.4 Return per Rupee Invested on Nutrient Sources Including Manures

The data on the effect of nutrient sources (including manures) on return per rupee invested are presented in Table 27.

Return per rupee invested on nutrients (including organic manures, chemical fertilizers and nutrient sources for FLN) was highest (₹ 3.30) when KAU POP was supplemented with FLN by potassium nitrate, followed by 19:19:19 complex (₹ 2.40). The control (KAU POP) gave ₹ 2.34 in return for every rupee invested on nutrient sources.

Table 26. Effect of nutrient sources, growth stages and their interaction on cost of cultivation, gross income, net income and BC ratio

Treatments	Cost of cultivation (₹ ha^{-1})	Gross income (₹ ha^{-1})	Net income (₹ ha^{-1})	BC ratio
Nutrient sources				
S_1	65025	135127	70102	2.07
S_2	65025	82135	17110	1.26
S_3	64825	86107	21282	1.32
S_4	65175	107845	42680	1.65
S_5	66475	86847	20372	1.30
Growth stages				
G_1	63614	99685	36077	1.56
G_2	65305	96666	31361	1.48
G_3	66996	102486	35490	1.53
Interaction effects				
s_1g_1	63474	131817	68343	2.07
s_1g_2	65025	140188	75163	2.15
s_1g_3	66576	133377	66801	2.00
s_2g_1	63474	81643	18167	1.28
s_2g_2	65025	79212	14187	1.22
s_2g_3	66576	85551	18975	1.28
s_3g_1	63374	90293	26919	1.42
s_3g_2	64825	82382	17557	1.27
s_3g_3	66276	85647	19371	1.29
s_4g_1	63549	99902	36383	1.57
s_4g_2	65175	100137	34962	1.53
s_4g_3	66801	123496	56694	1.84
s_5g_1	64199	94772	30573	1.47
s_5g_2	66475	81411	14936	1.27
s_5g_3	68751	84358	15607	1.22
Treatment mean	-	99612	34309	1.52
Control	61923	102280	40357	1.65
SEm (±) : S		3111.91	3113.00	0.047
G		2412.33	2413.17	0.037
SG		8784.13	8784.34	0.314
CD (0.05) : S		9014.90	9018.00	0.138
G		-	-	-
SG		-	-	-
Treatment *Vs* Control		S	S	S

Table 27. Effect of flag leaf nutrition on net returns per rupee invested on manures and fertilizers, ₹.₹$^{-1}$.

Treatments	Net returns per rupee invested
S_1 : KAU POP + potassium nitrate @ 0.5 per cent	3.30
S_2 : KAU POP + calcium nitrate @ 0.5 per cent	1.56
S_3 : KAU POP + magnesium sulphate @ 0.5 per cent	1.70
S_4 : KAU POP + 19 : 19 : 19 complex @ 0.5 per cent	2.40
S_5 : KAU POP + (S_2 + S_3 + S_4)	1.65
Control (KAU POP)	2.34

Discussion

5. DISCUSSION

The experiment entitled "Flag leaf nutrition for enhancing resource use efficiency in rice (*Oryza sativa* L.)" was undertaken to assess the effect of flag leaf foliar nutrition on partitioning of photosynthates, growth and productivity of rice and to work out the economics of the practice in lowland rice cultivation system. The results of the experiment are discussed briefly in this chapter.

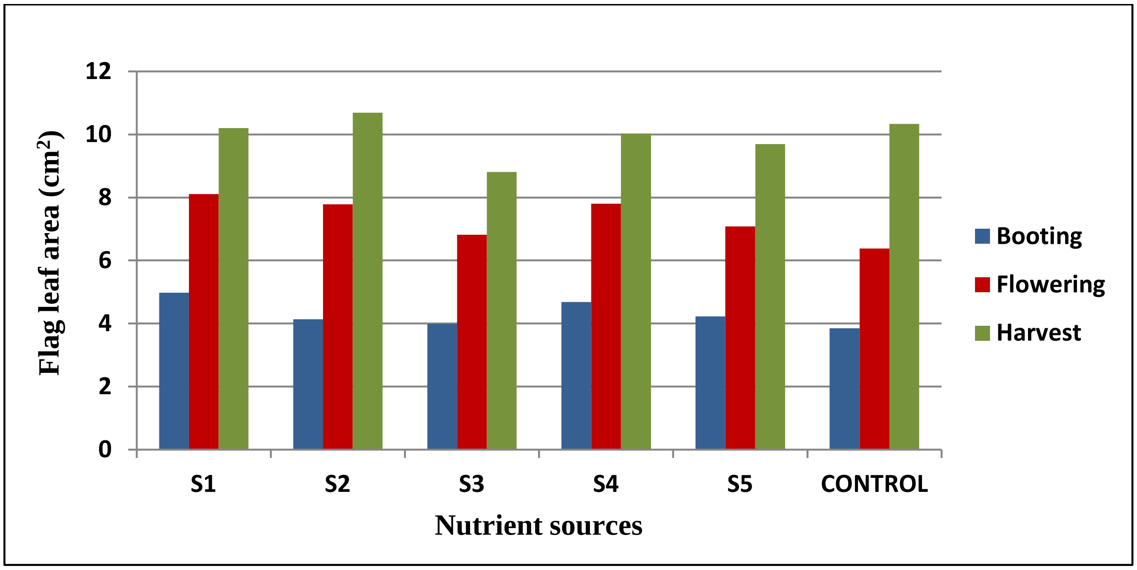
5.1 GROWTH AND GROWTH ATTRIBUTES

The data revealed that the growth and growth attributes, in general, varied more significantly with nutrient sources used for flag leaf nutrition (FLN), as compared to the growth stages chosen for flag leaf nutrition and the interaction between nutrient sources and growth stages.

Plant height exhibited significant variation with nutrient sources, crop growth stages and their interactions. The crop was significantly taller at booting stage when KAU POP was supplemented with 19:19:19 complex @ 0.5 per cent. Potassium nitrate @ 0.5 per cent resulted in taller plants at harvest stage. Among the three crop growth stages, FLN at booting + flowering + milk stages recorded significantly taller plants at harvest stage. The interaction effect showed that FLN with potassium nitrate (0.5 per cent) at booting and flowering stages (s_1g_2) was significantly superior with respect to plant height. No significant variation was observed between the treatment mean and the KAU POP (control). The effect of 19:19:19 complex on plant height could be attributed to the availability of all the three major nutrients, which might have improved the photosynthetic rate and carbohydrate translocation and in turn increased the dry matter production, as reported by Jagathjothi *et al*. (2012). The improvement in plant height under the effect of potassium nitrate might be due to the important role of potassium and nitrogen in crop growth. Potassium might have improved nutrient and sugar translocation in plant and helped in maintaining the turgor pressure of the plant cells thereby increasing the meristematic activity. The role of nitrogen in enhancing the vegetative growth of crops has been well documented. Similar results have been reported by Sarkar *et al*. (2007) and Hegazi *et al*. (2011). Effective absorption of nutrients at critical growth stages result in enhanced physiological activity leading to better growth (Kundu and Sarkar, 2009). This might be the reason for increased plant height by FLN at the different crop growth stages, among which booting and flowering stages are critical for rice.

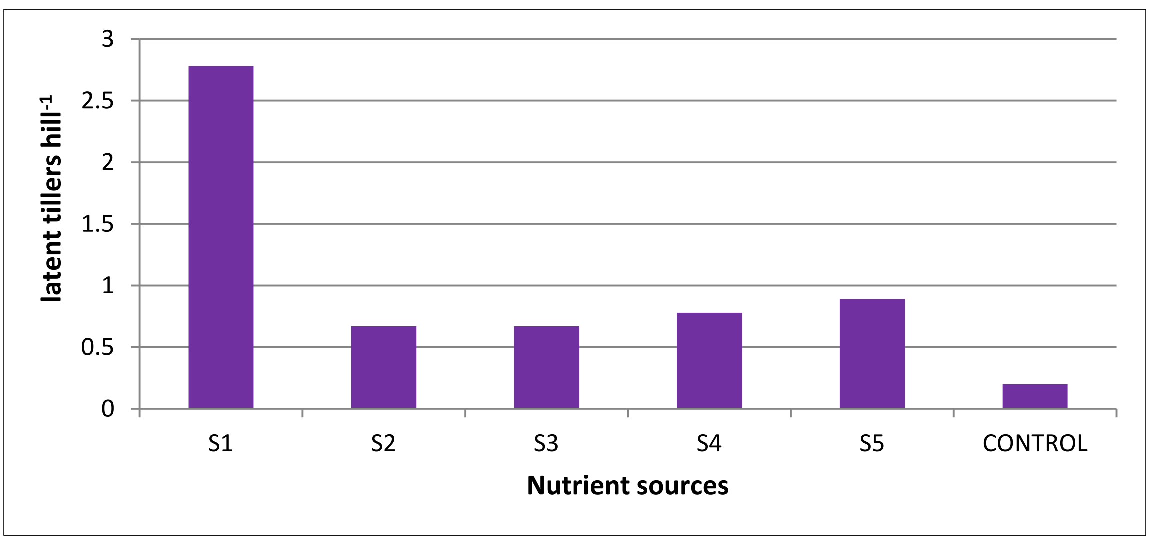
The nutrient sources, crop growth stages and their interaction failed to exhibit any significant effect on the number of tillers per hill and leaf area index. However, numerically, FLN with potassium nitrate @ 0.5 per cent was observed to record higher tiller count and leaf area index at the harvest stage.

In rice, the top three leaves especially the flag leaf plays an important role in the assimilation and translocation of assimilates and ultimately influence the grain yield (Ray *et al*., 1983; Misra, 1986). Thus the flag leaf area assumes paramount importance in photosynthesis contributing to grain yield. The nutrient sources had significant effect on flag leaf area, with potassium nitrate @ 0.5 per cent recording significantly higher flag leaf area at booting (4.98 cm^2) and flowering (8.11 cm^2) stages (Fig 3). It was at par with 19:19:19 complex at booting and flowering stages and calcium nitrate at flowering stage . The interaction effect was also significant. FLN with potassium nitrate @ 0.5 per cent registered a flag leaf area of 9.08 cm^2 at booting and flowering stages (s_1g_2) and it was 42.3 per cent greater than that registered by the control, KAU POP (6.38 cm^2). Although FLN with calcium nitrate at booting + flowering + milk stages (s_2g_3) proved superior at harvest stage, it remained at par with several other treatments including FLN with potassium nitrate at booting and flowering stages (s_1g_2). Supplementing the KAU POP with FLN at flowering, the most critical growth stage of rice was observed to increase the flag leaf area by 17.9 per cent. Foliar feeding of potassium nitrate and calcium nitrate might have resulted in better absorption and assimilation of nitrogen, resulting in higher flag



S1- Potassium nitrate, S2 - Calcium nitrate, S3 - Magnesium sulphate, S_4 - 19: 19: 19 complex,
S5- S2 + S3 + S4, CONTROL - (KAU POP)

Fig. 3. Effect of nutrient sources on flag leaf area (cm^2) at different crop growth stages



S1- Potassium nitrate, S2 - Calcium nitrate, S3 - Magnesium sulphate, S_4 - 19: 19: 19 complex,
S5- S2 + S3 + S4, CONTROL - (KAU POP)

Fig. 4. Effect of nutrient sources on latent tillers $hill^{-1}$

leaf area. Similar results have been reported by Chopra and Chopra (2004) and Sharief *et al*. (2006).

The number of days taken for panicle exsertion was not affected by the treatments and their interactions. No variation was observed between treatments and control. This finding is against the general belief that disturbing the paddy crop after panicle initiation might delay the panicle exsertion or result in partial exsertion of panicles.

Days to 50 per cent flowering was observed to be significantly more with FLN of magnesium sulphate @ 0.5 per cent. The other treatments including the control (KAU POP) showed only a variation of 4-5 days. The effect of magnesium sulphate might be due to its key role in the maintenance of plant pigments, especially chlorophyll. This might have prolonged the vegetative phase resulting in a slight delay in flowering. According to Tisdale *et al*. (1995), magnesium is the only mineral constituent in the chlorophyll molecule and chlorophyll formation alone account for about 15- 20 per cent of the total magnesium content of the plant. Further sulphur is also required for the synthesis of chlorophyll. The increase in chlorophyll content under the influence of magnesium sulphate might have prolonged the vegetative phase and delayed the flowering process. However the effect of magnesium sulphate in prolonging the 50 per cent flowering period has not reflected in any improvement in the grain yield of the crop.

5.2 PHYSIOLOGICAL STUDIES

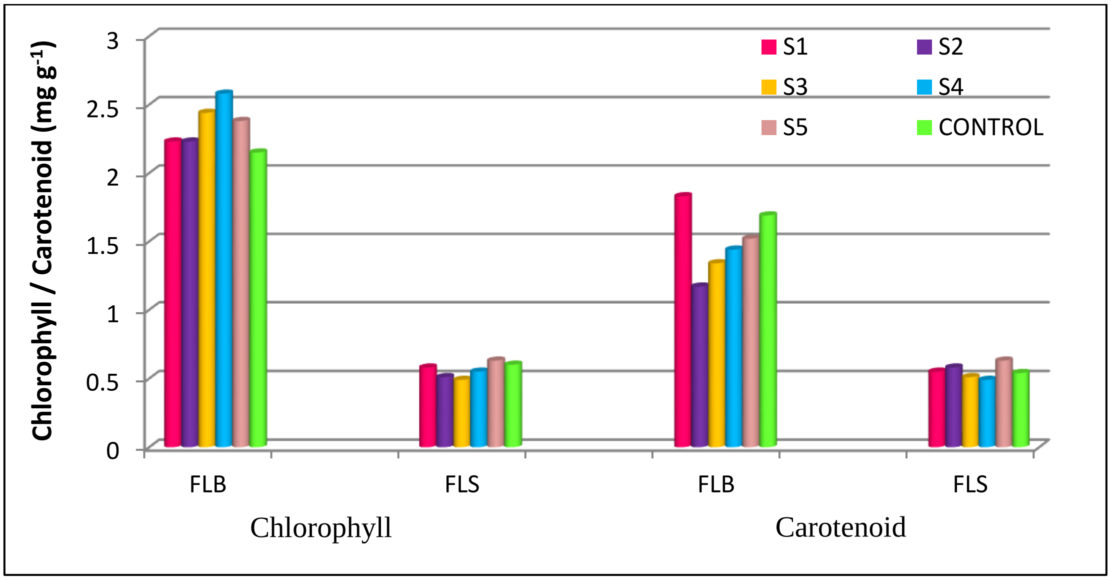
Yield is a complex feature which is a function of numerous physiological processes. Identification of growth and physiological indices in analysis of factors affecting yield and its components assumes paramount importance since its stability determines the dry matter production.

Leaf area duration was observed to be longest (41.88 days) when KAU POP was supplemented with FLN of calcium nitrate @ 0.5 per cent and was at par with all the other nutrient sources except potassium nitrate. Prevalence of Ca^{2+} cation plays a key role in cellular functions and enzyme activity (Bush, 1995) and result in more rational utilization of soil nitrogen and more active assimilation of NO_3- N in roots and leaves (Kondratev *et al.*, 1984), leading to delay in senescence as evidenced by better leaf area duration.

Specific leaf weight (SLW) is a vital variable related to physiological processes occurring in plants. The present study revealed significant variation in SLW with nutrient sources and with the interaction between nutrient sources and crop growth stages. SLW at flowering was higher (2.11 g m^{-2}) with S_5 (combination of calcium nitrate, magnesium sulphate and 19:19:19 complex) and at harvest (2.11 g m^{-2}) with 19:19:19 complex @ 0.5 per cent. In the case of interaction effect, application of potassium nitrate at booting stage recorded higher SLW. The better nutrient balance supported by the treatments might have contributed towards increasing the SLW. According to Braun and Wild (1984) and Field and Mooney (1986) specific leaf weight is very sensitive to plant nutrient status and nutrient application increases the specific leaf weight. Specific leaf weight, a measure of leaf thickness, has been reported to have a strong positive correlation with leaf photosynthesis of several crops as reported by Bowes *et al*. (1972). Dornhoff and Shibles (1970) presumed that higher SLW might be associated with higher cell surface to volume ratio and hence lower mesophyll resistance to CO_2 entry and increase in photoassimilates accumulation in soybean.

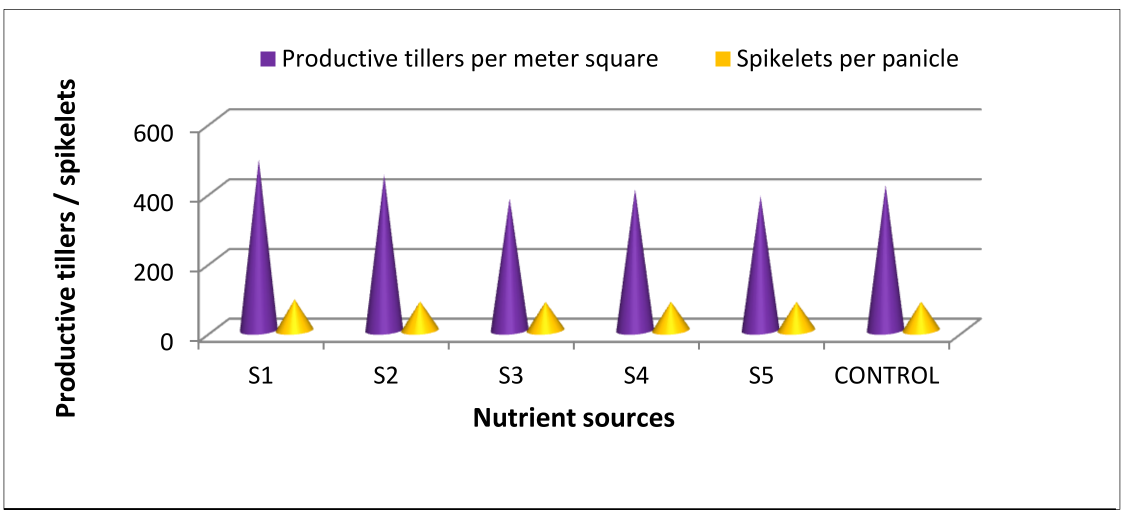
The nutrient sources exhibited significant effect on the relative growth rate and net assimilation rate. FLN with potassium nitrate @ 0.5 per cent recorded maximum relative growth rate at flowering (0.057 mg g^{-1} day^{-1}) and harvest stages (0.028 mg g^{-1} day^{-1}). Net assimilation rate recorded at booting (3.76 mg g^{-1} day^{-1}) and flowering stages (2.58 mg g^{-1} day^{-1}) were also significantly superior with FLN of potassium nitrate @ 0.5 per cent. The improvement in RGR and NAR under the influence of potassium nitrate could be traced to the importance of potassium and nitrogen in improving the growth and photosynthesis of the crops. Kundu and Sarkar (2009) have highlighted the role of potassium in photosynthesis, by directly increasing growth and leaf area index and hence carbon dioxide assimilation enhances outward translocation of more ATP essential for vigorous growth of plants. The nitrogen supplied by potassium nitrate might have also contributed to higher RGR and NAR. Nitrogen, in general, due to its role in production and translocation of cytokinin from the root to the shoots might have increased cell division rate and growth rate of rice. Similar results have been reported by Dasilva and Stutte (1981), Marschner (1995) and Timothy and Joe (2003). NAR represents plant photosynthetic efficiency. Higher net assimilation rate might be due to more dry matter production supported by FLN with potassium nitrate. The decrease in NAR at the later stages of growth could be attributed to an increase in the number of older leaves which lost photosynthetic activity (Pandey *et al.*, 1978).

Chlorophyll content is of particular significance as an indicator of photosynthetic activity. The chlorophyll and carotenoid contents of leaf blade was significantly affected by the different nutrient sources at flowering stage (Fig 5). The highest chlorophyll content was recorded with FLN of 19:19:19 complex @ 0.5 per cent and highest carotenoid was with potassium nitrate @ 0.5 per cent. The chlorophyll and carotenoid contents in the flag leaf sheath were maximum for S_5 (a combination of calcium nitrate, magnesium sulphate and 19:19:19 complex). The foliar nutrition might have resulted in better photosynthetic rate resulting in more pigment formation with increased leaf area. Nitrogen concentration in green vegetation is related to chlorophyll content, and therefore indirectly to one of the basic plant physiological processes: photosynthesis (Sabo *et al*., 2002; Bojovic and Stojanovic, 2005). Studies in rice (Tang, 2000) and wheat (Yang *et al*., 2002) showed that nitrogen fertilizer application increased the chlorophyll content of leaves,



S1- Potassium nitrate, S2 - Calcium nitrate, S3 - Magnesium sulphate, S_4 - 19: 19 : 19 complex, S5- S2 + S3 + S4, CONTROL - (KAU POP) FLB- Flag leaf blade FLS- Flag leaf sheath

Fig. 5. Effect of nutrient sources on plant pigments (mg g^{-1}) at flowering stage



S1- Potassium nitrate, S2 - Calcium nitrate, S3 - Magnesium sulphate, S_4 - 19: 19: 19 complex, S5- S2 + S3 + S4, CONTROL - (KAU POP)

Fig. 6. Effect of nutrient sources on productive tillers m^{-2} and spikelets $panicle^{-1}$

photosynthetic rate of rice flag leaf, electron transport capacity of PS I and PS II and extended the duration of photosynthetic duration in leaves. The effect of the combination treatment on the carotenoid content could be attributed to the effect of magnesium in enhancing the carotenoid content as reported by Liu *et al*. (2006) and Ding *et al*. (2008).

Soluble substances like soluble proteins reflect the ability of plants in making osmotic adjustments. Magnesium sulphate @ 0.5 per cent (S_3) recorded maximum total soluble protein content in flag leaf at booting (1.04 mg g^{-1}) and calcium nitrate @ 0.5 per cent (S_2) at flowering stage (1.97 mg g^{-1}). The increase in flag leaf soluble protein content might be due to better absorption of nutrients especially nitrogen, when applied as foliar nutrition. According to Minjun *et al*. (2002), the level of soluble protein is regarded as an important indicator of the degree of leaf senescence. The present study also revealed the role of soluble protein in delaying senescence of the flag leaf as evidenced by the higher leaf area duration recorded at harvest. The finding corroborate with those of Yan and Shi (2013).

Nutrient use efficiency assessed in terms of nitrogen use efficiency, agronomic efficiency and apparent recovery efficiency were significantly higher with potassium nitrate @ 0.5 per cent (S_1) followed by 19:19:19 complex @ 0.5 per cent (S_4). The effect of potassium nitrate in improving the nutrient use efficiency can be attributed to the role of potassium in increasing nutrient uptake and utilization as suggested by IPI (2014). The N: K balance and better absorption of the foliar applied nutrients at the critical growth stages, might have led to better nutrient use efficiencies thereby promoting better growth, partitioning of photosynthates and yield in rice . Among several strategies to improve NUE, balanced nutrition, particularly balancing N and K nutrition and tapping the synergistic effect between N and K, is important both in irrigated as well as rainfed production systems (Ganeshamurthy and Srinivasarao, 2001). Higher yields and crop quality can be obtained at optimal N:K nutritional ratios. Potassium is an essential macronutrient required for proper development of plants. In addition to activation of numerous enzymes, K plays an important role in the maintenance of electrical potential gradients across cell membranes and in the generation of turgor. It is also essential for photosynthesis, protein synthesis and regulation of stomatal movement, and is the major cation in the maintenance of cation-anion balances (Marschner, 1995).

5.3 YIELD ATTRIBUTES AND YIELD

Yield is a function of the yield attributes *viz*., productive tiller count, filled grains per panicle, sterility percentage and thousand grain weight. In the present study all the yield attributes were observed to respond significantly to flag leaf nutrition.

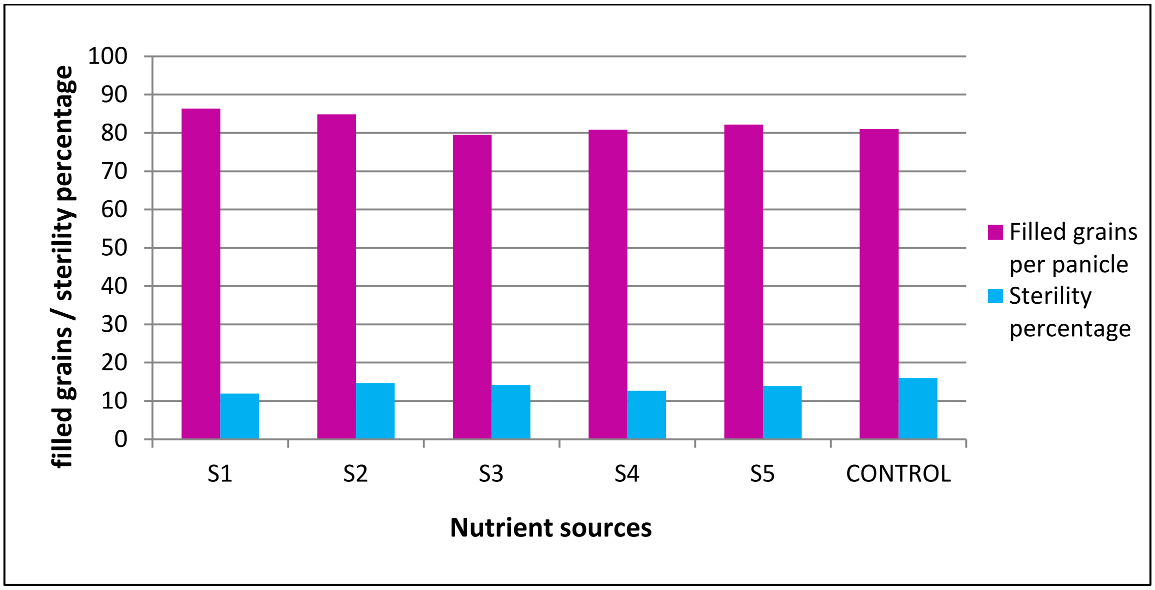
All the yield attributes *viz*. productive tiller count (490.19), grain weight panicle^{-1} (2.18 g), number of spikelets panicle^{-1} (89.11), filled grains panicle^{-1} and thousand grain weight (28.55 g) were significantly superior when KAU POP was supplemented with flag leaf nutrition of potassium nitrate @ 0.5 per cent (S_1). The control (KAU POP) recorded 417.24 productive tillers m^{-2}, 86.33 filled grains per panicle, 82.57 spikelets panicle^{-1}, 1.43 g grain weight panicle^{-1} and a thousand grain weight of 21.51 g (Fig 6). Further, sterility percentage was the lowest (11.94 per cent) with potassium nitrate @ 0.5 per cent, as compared to KAU POP (16.05 per cent) (Fig 7). The effect of potassium nitrate @ 0.5 per cent was at par with S_4 (19: 19: 19 complex) with respect to sterility percentage and thousand grain weight.

The effect of FLN with potassium nitrate can be viewed from two angles – the first being the effect of foliar nutrition and the second, with respect to the effect of potassium nitrate. Foliar fertilization provides more rapid utilization of nutrients and it can also compliment soil fertilization. Since root activity decreases towards the later stages of the reproductive phase, nutrient uptake may become insufficient to meet the demands for grain filling (Nelson *et al*., 2005). Fageria *et al*. (2009) reported that while crops respond to soil applied fertilizers in 5 to 6 days, the response is faster

(48 hours) in foliar application. Ali *et al*. (2007) suggested that major fraction of potash fertilizer directly applied to the soil may get fixed with the clay fraction and become unavailable to the crop. Potassium nutrition of plants through foliar application is well recognized and practiced in advanced countries.

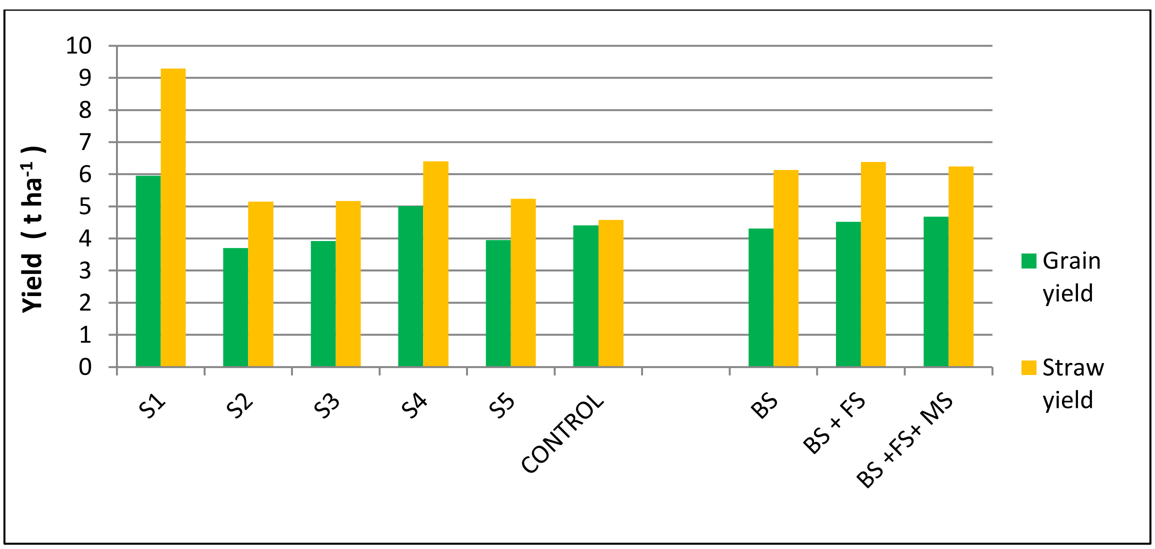
Flag leaf nutrition with potassium nitrate @ 0.5 per cent recorded significantly higher grain yield (5.95 t ha^{-1}) followed by 19: 19: 19 complex (5.01 t ha^{-1}). The control (KAU POP) recorded a grain yield of 4.41 t ha^{-1}. Straw yield was also significantly higher with potassium nitrate. Grain yield recorded with flag leaf nutrition at (G_2) booting + flowering stages (4.52 t ha^{-1}) and that (4.68 t ha^{-1}) at booting + flowering + milk stages (G_3) were at par (Fig 8).

The increase in yield with foliar KNO_3 spray could be credited to the increase in number of productive tillers m^{-2}, panicle length, grain weight $panicle^{-1}$ and thousand grain weight. Studies have showed that the panicle number per square metre is the most important factor in increasing the grain yield of rice and 89 per cent of yield changes is due to the effect of this factor (Miller *et al*., 1991). Potassium nitrate has the ability to supply both potassium and nitrogen. The effect of potassium can be explained as the role of potassium in helping photosynthesis, carbohydrate distribution and starch synthesis in the storage organs as described by Imas and Magen (2007). Son *et al*. (2012) also stated that foliar application of potassium nitrate at panicle initiation and flowering stages, improved grain filling and consequently the grain yield of rice. The results of Zhang *et al*. (2011) also revealed that nitrogen before anthesis followed by nitrogen fertilization at anthesis is necessary to increase post- anthesis dry matter accumulation, grain protein content and finally rice grain yield. These results suggested that nitrogen supply at late growth stages helped in attaining superior spikelets through better grain filling in rice, as observed in the present study. When compared to control (KAU POP), FLN with potassium nitrate recorded 35 per cent higher grain yield. The increase in grain yield over control could be attributed to the positive influence of foliar nutrition at the critical crop growth



S1- Potassium nitrate, S2 - Calcium nitrate, S3 - Magnesium sulphate, S_4 - 19: 19: 19 complex,
S5- S2 + S3 + S4, CONTROL - (KAU POP)

Fig. 7. Effect of nutrient sources on filled grains panicle^{-1} and sterility percentage



S1- Potassium nitrate, S2 - Calcium nitrate, S3 - Magnesium sulphate, S_4 - 19: 19: 19 complex,
S5- S2 + S3 + S4, CONTROL - (KAU POP) BS- Booting stage, FS- Flowering stage, MS- Milk stage

Fig. 8. Effect of flag leaf nutrition on yield, t ha^{-1}

stages of rice, *viz*., booting and flowering stages, in enhancing the yield contributing characters.

The increase in straw yield could be attributed to the fact that potassium plays a vital role in photosynthesis by directly increasing growth and leaf area index and hence the carbon dioxide assimilation enhance outward translocation of more ATP essential for vigorous growth of plants. The LAI and latent tiller production (Fig. 4) recorded with FLN of potassium nitrate @ 0.5 per cent might have contributed to higher straw yield.

Grain to straw ratio (0.80) and harvest index (0.44) were superior with 19: 19: 19 complex @ 0.5 per cent. Proper and balanced application of nutrients is one of the most important factors determining crop yield (Ali *et al*., 2007). The effect of 19:19:19 complex in registering a better harvest index and grain to straw ratio could be attributed to the fact that it contains all the three major nutrients, in addition to being 100 per cent water soluble. The presence of phosphorus in 19:19:19 complex might have also resulted in a better partitioning of photosynthates to economical parts (grain). Sufficient phosphorus at critical growth stages has been reported to be essential for accumulation of photosynthates. FLN with 19:19:19 complex resulted in 44 per cent of dry matter in the grains (Fig 9). The control (KAU POP) showed a better performance in terms of dry matter partitioning with 49 per cent of the total dry matter produced stored in the grain. In cereals like rice and wheat balanced nutrition is essential for maintaining the current photosynthetic activity of the plant since it is the major contributor for grain yield. Even within a crop source-sink balance varies based on nutrient availability (Venkateswarlu and Visperas, 1987). The balanced availability of the major nutrients might have favoured a better partitioning of dry matter towards the sink (grain) rather than the straw.

5.4 PLANT ANALYSIS

5.4.1 Index Leaf Analysis

The index leaf (flag leaf) varied significantly in its major nutrient (N,P,K) content under the influence of the different nutrient sources tested. Flag leaf nutrition with a combination treatment of calcium nitrate, magnesium sulphate and 19:19:19 complex (S_5) recorded the highest N content (1.85 per cent) and P content (0.73 per cent) and potassium nitrate @ 0.5 per cent recorded the highest K content (1.56 per cent) in the flag leaf. The increase in nutrient content in the flag leaf could be attributed to the effect of foliar nutrition, since foliar fertilization has been suggested to be an efficient way to supplement nutrients in readily available form, for effective fertilization (Girma *et al*., 2007). Further, in rice, Sperotto *et al*. (2013) have reported that flag leaves are a major source of remobilized minerals for the seeds. The combination treatment contained all the three major nutrients in a 100 per cent soluble form. Hence these nutrients might have been absorbed actively by the flag leaf resulting in higher contents. The higher K content observed with potassium nitrate can also be attributed to the effect of foliar application of potassium nitrate. Similar results have been reported by Ali *et al*. (2007) who observed an increase in potassium concentration with foliar nutrition of different potassium sources. The effect of FLN in increasing the nutrient concentration is also elucidated by the lower concentration of N (1.59 per cent), P (0.59 per cent) and K (1.25 per cent) content of the flag leaf in the control (KAU POP), in which no supplementary nutrient application was done.

Calcium content of the index leaf did not vary significantly with the treatments or their interactions. Both nutrient sources and crop growth stages had significant effect on the magnesium and sulphur contents of the flag leaf. Among the nutrient sources, FLN with magnesium sulphate @ 0.5 per cent recorded the highest magnesium (0.273 per cent) and sulphur (0.084 per cent) contents in the flag leaf. This might be due to the absorption of magnesium and sulphur from the magnesium sulphate used for foliar nutrition. Similar effect of foliar nutrition with magnesium sulphate in increasing the magnesium content of plant tissue was reported by El-Zanaty *et al*. (2012). While the magnesium content of the flag leaf (0.233 per cent) was the highest with FLN at booting + flowering stages (G_2), the sulphur content (0.077 per cent) was the highest at G_3 (booting + flowering + milk stages). Sulphur has been reported to be a phloem mobile nutrient which when applied at critical growth stages can result in systemic effects with long term action (Fernandez *et al*., 2013). As in the case of major nutrients the content of secondary nutrients was also higher when the KAU POP (control) was supplemented with FLN. The interaction effect was significant only with respect to sulphur content, with FLN nutrition of magnesium sulphate at booting + flowering + milk stages recording the maximum value (0.094 per cent).

5.4.2 Nutrient Uptake

5.4.2.1 Uptake of Major Nutrients

The uptake of major nutrients was observed to vary significantly among the different nutrient sources. The uptake of all the three major nutrients *viz*., N, P and K was significantly superior when KAU POP was supplemented with FLN of potassium nitrate @ 0.5 per cent. Both the grain yield (5.95 t ha^{-1}) and straw yield (9.29 t ha^{-1}) were maximum with potassium nitrate, accounting for a total biological yield of 15.24 t ha^{-1} on dry weight basis. The higher total dry matter production recorded with FLN of potassium nitrate might have contributed towards the higher NPK uptake. The effect of growth stages and S x G were significant only for potassium uptake. FLN at booting +flowering + milk stages (G_3) and booting + flowering stages (G_2) remained at par with respect to potassium uptake. This could be attributed to a higher uptake on account of higher dry matter recorded by supplementing KAU POP with flag leaf nutrition at these two growth stages. Nutrient uptake is partly a function of dry matter production and concentration of nutrients in the plant. This is in accordance with the findings of Fageria and Baligar (2005) who have stated that nutrient accumulation pattern in plants followed dry matter accumulation. Among the interactions s_1g_1 (FLN with potassium nitrate at booting stage) recorded the highest K uptake which could be attributed to high grain and straw yields. Similar were the effects of s_1g_2 and s_1g_3. The high K uptake in the treatment combination s_4g_3 (19:19:19 complex at booting + flowering + milk stages) might have been due to higher grain yield clubbed together with a better uptake of K with 19:19:19 complex containing all the three major nutrients. Similar results have been reported by Rani *et al.* (2014). The treatments when compared against the control (KAU POP), exhibited significantly higher P uptake with FLN.

5.4.2.2 Uptake of Secondary Nutrients

Effect of nutrient sources was significant with respect to calcium uptake and sulphur uptake. While FLN with calcium nitrate @ 0.5 per cent recorded significantly higher calcium uptake (12.21 kg ha^{-1}), magnesium sulphate @ 0.5 per cent recorded the maximum sulphur uptake (10.59 kg ha^{-1}). This might be due to the fact that calcium and sulphur are phloem mobile nutrients which when applied at critical growth stages can result in systemic effects with long term action as reported by Fernandez *et al*. (2013). Sulphur uptake was significantly higher when FLN was given at booting + flowering + milk stages. The S x G interaction was significant for sulphur uptake with FLN of magnesium sulphate @ 0.5 per cent at booting + flowering stages (s_3g_2) recording the highest value (11.20 kg ha^{-1}). Significant increase in sulphur uptake with sulphur levels could be attributed to increase availability of sulphur with concomitant increase in grain yield. Similar observations have been made by Islam *et al*. (1997) and Vaiyapuri and Sriramachandrashekharan (2001). The increased response to foliar applied sulphur could also be attributed to reduced availability of S from soil due to poor drainage situation and consequent reduction of sulphur to sulphide form. Similar results have been reported by Rahman *et al*. (2007).

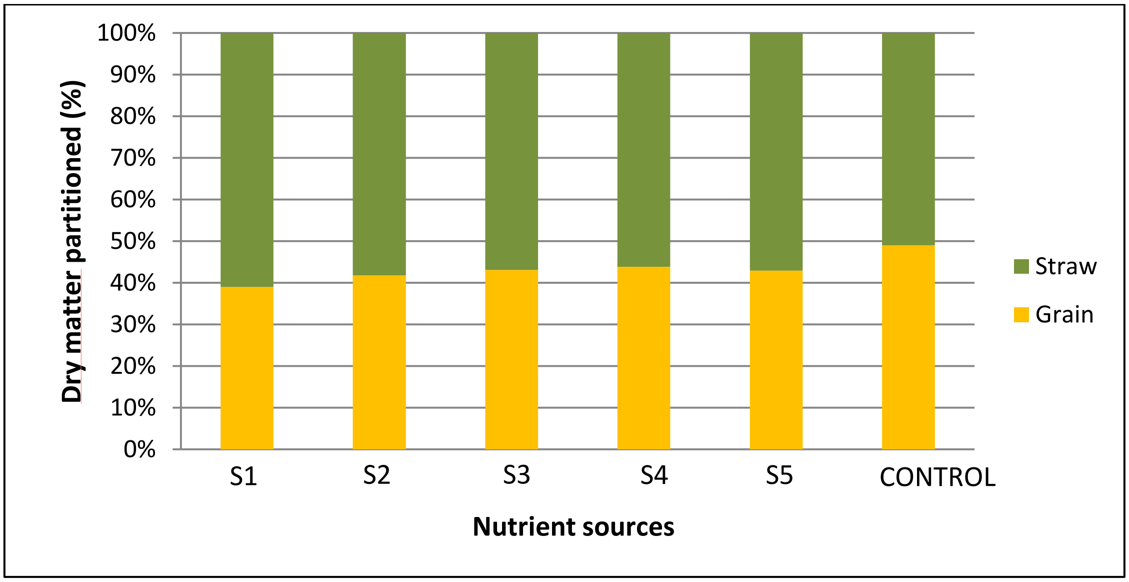
5.4.3 Crude Protein Content of Grain

Flag leaf nutrition with potassium nitrate @ 0.5 per cent (S_1) recorded the highest crude protein content (8.26 per cent). The interaction effect between nutrient sources and crop growth stages was significant with respect to the crude protein content of the grain. The crude protein content of the grain was significantly higher (8.34 per cent) when KAU POP was supplemented with flag leaf nutrition of 0.5 per cent potassium nitrate at booting + flowering stages (s_1g_2). The higher nitrogen uptake recorded by these treatments have contributed to the higher protein content as explained by Tisdale *et al*. (1995). Nishizawa *et al*. (1997) have reported that spraying nitrogen sources like urea on the rice leaves at the heading stage increased the grain protein content of rice. Perez *et al*. (1996) observed late nitrogen application at flowering as a management option for increasing the grain protein content of rice. Similar results have been reported by Juliano and Duff (1991).

5.5 SOIL ANALYSIS AFTER THE EXPERIMENT

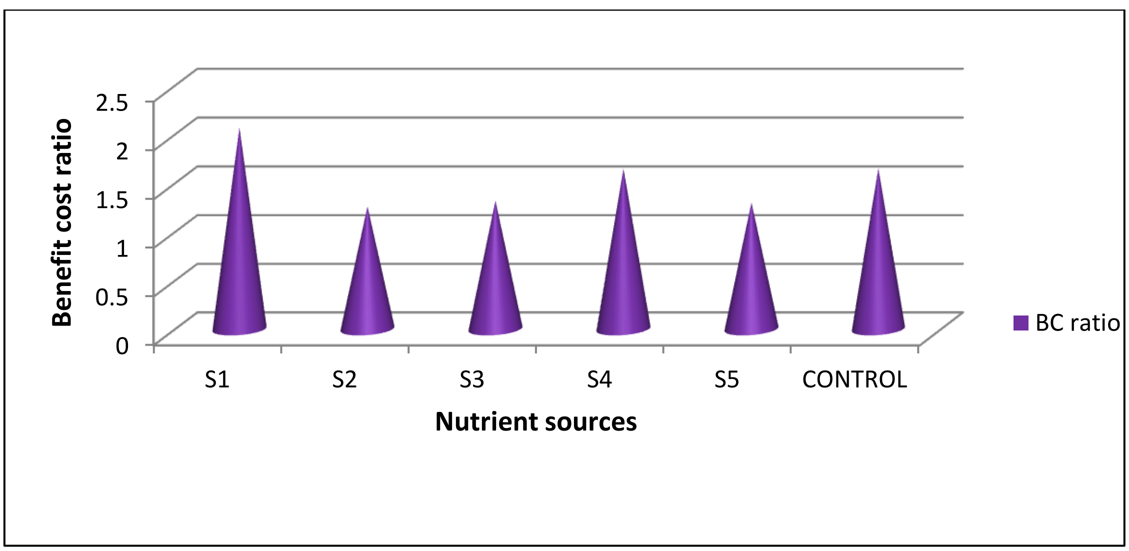
The soil organic carbon was not observed to vary significantly with nutrient sources, crop growth stages and their interactions.

The available N, P and K status of the soil was found to be significantly higher in treatments where the KAU POP was supplemented with FLN of potassium nitrate @ 0.5 per cent. Potassium nitrate might have satisfied the requirements of N and K of the plant at the later stages due to better absorption and utilization of the foliage applied nutrients. The positive N-K interaction might have also improved the phosphorus use efficiency. In general the available P content of the soil was observed to increase after the experiment. This might be due to dissolution of fixed P under the influence of near neutral pH caused by submergence of soil due to rains towards the harvest of the crop. The available N status of the soil was also observed to be significantly higher with FLN at booting + flowering stages and remained at par with



S1- Potassium nitrate, S2 - Calcium nitrate, S3 - Magnesium sulphate, S_4 - 19: 19: 19 complex,
S5- S2 + S3 + S4, CONTROL - (KAU POP)

Fig. 9. Effect of nutrient sources on percentage of dry matter partitioned towards grain and straw



S1- Potassium nitrate, S2 - Calcium nitrate, S3 - Magnesium sulphate, S_4 - 19: 19: 19 complex,
S5- S2 + S3 + S4, CONTROL - (KAU POP)

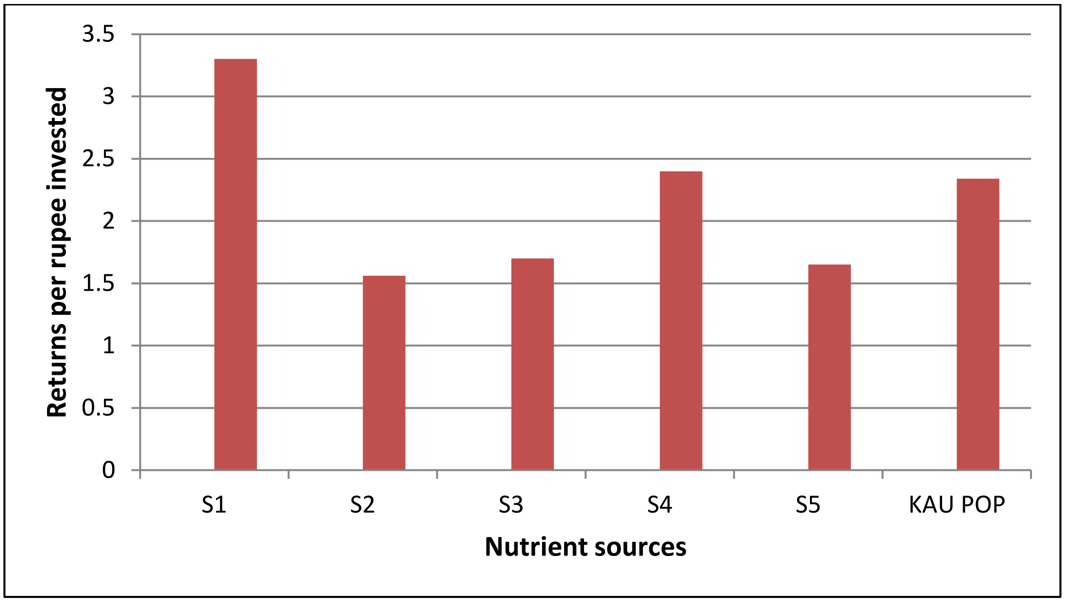
Fig. 10. Effect of nutrient sources on BC ratio

FLN at booting + flowering + milk stages. Supplementing KAU POP with FLN at the critical growth stages was observed to improve the nitrogen use efficiency, which is a measure of the quantity of yield produced per unit quantity of nitrogen applied. Thus the crop might have placed a less demand on the soil by satisfying its requirement of nitrogen from the foliar applied sources. This is also highlighted by the significantly higher N and K status of the soil observed with KAU POP supplemented with FLN compared to the control (KAU POP).

While the available Ca status of the soil was higher with supplementing KAU POP with FLN of calcium nitrate @ 0.5 per cent, the same was noted with FLN of magnesium sulphate @ 0.5 per cent in the case of available Mg and S status of the soil. This could also be attributed to the fact that the active absorption of the foliar applied nutrients might have reduced the demand on the available nutrients in the soil.

5.6 ECONOMIC ANALYSIS

The economic returns measure the profitability of a practice. Cost of cultivation was the highest (₹ 66475 ha^{-1}) when KAU POP was supplemented with FLN of a combination of calcium nitrate, magnesium sulphate and 19:19:19 complex (S_5), followed by FLN with 19:19:19 complex @ 0.5 per cent (₹ 65175 ha^{-1}). This resulted in low net income in S_5 (₹ 20372 ha^{-1}). The data on economics of FLN revealed that gross income, net income and benefit cost ratio were appreciably influenced by the flag leaf nutrition (Fig 10). Gross income (₹ 1,35,127 ha^{-1}), net income (₹ 70,102 ha^{-1}) and benefit cost ratio (2.07) were significantly higher in FLN with potassium nitrate @ 0.5 per cent, compared to KAU POP which recorded a BCR of 1.65. This could be attributed to the higher grain yield and straw yield recorded by FLN with potassium nitrate @ 0.5 per cent. The net income and gross income of control (KAU POP) and that of KAU POP supplemented with FLN



S1- Potassium nitrate, S2 - Calcium nitrate, S3 - Magnesium sulphate, S_4 - 19: 19: 19 complex, S5- S2 + S3 + S4

Fig. 11. Returns per rupee invested on organic manure (FYM) and chemical nutrient sources, ₹.₹$^{-1}$

of 19:19:19 (S_4) complex were almost equal. Both these treatments recorded the same BCR (1.65).

Return per rupee invested on nutrients (including organic manures, chemical fertilizers and nutrient sources for FLN) was highest (₹ 3.30) when KAU POP was supplemented with FLN by potassium nitrate, followed by 19:19:19 complex (₹ 2.40). The control (KAU POP) gave ₹ 2.34 in return for every rupee invested on nutrient sources (Fig 11).

The study revealed that supplementing the nutrient recommendation as per the KAU POP with flag leaf nutrition of potassium nitrate @ 0.5 per cent, twice, at 5 days prior to booting and 5 days prior to 50 per cent flowering stages respectively, resulted in significantly higher grain yield, nutrient uptake, nutrient use efficiency, net income and benefit cost ratio in lowland rice, variety Aiswarya.

Summary

6. SUMMARY

The experiment entitled “Flag leaf nutrition for enhancing resource use efficiency in rice (*Oryza sativa* L.)” was undertaken at the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, during June to October, 2014. The main objectives of the study were to assess the effect of flag leaf foliar nutrition on partitioning of photosynthates, growth and productivity of rice and to work out the economics of the practice in lowland rice ecosystem.

The field experiment comprised [(5x3)+1] treatment combinations, laid out in randomised block design with three replications, using PTB 52 (Aiswarya) as the test variety. The treatments were 0.5 per cent each of S_1 : potassium nitrate, S_2 : calcium nitrate, S_3 : magnesium sulphate, S_4 : 19 : 19 : 19 complex and S_5 : a combination $S_2 + S_3 + S_4$, sprayed at three crop growth stages *viz*., G_1 : Booting stage, G_2 : Booting + Flowering stages and G_3 : Booting + Flowering + Milk stages, as compared against control (KAU POP for medium duration rice). The flag leaf nutrition treatments (s_1g_1 to s_5g_3) were given, over and above the KAU POP.

The results revealed that the effect of nutrient sources used for flag leaf nutrition (FLN) was more significant, as compared to the effect of growth stages chosen for flag leaf nutrition and the interaction between nutrient sources and growth stages.

FLN with 19: 19: 19 complex @ 0.5 per cent recorded significantly taller plants at booting stage (85.47 cm) where as foliar nutrition of potassium nitrate @ 0.5 per cent (S_1) produced taller plants at harvest stage (113.73 cm). Flag leaf nutrition at booting + flowering + milk stages (G_3) recorded maximum plant height (106.15 cm). The interaction effect of nutrient sources and crop growth stages also exerted significance with the treatment s_1g_2 recording tallest plants (115.84 cm). The nutrient sources, crop growth stages and their interaction failed to exhibit any significant

effect on the number of tillers per hill and the leaf area index. However, numerically FLN with potassium nitrate @ 0.5 per cent was observed to record higher tiller count and leaf area index at the harvest stage. Flag leaf area was significantly higher at booting (4.98 cm^2) and flowering stages (8.11 cm^2) with potassium nitrate @ 0.5 per cent (S_1) which was at par with 19: 19: 19 complex @ 0.5 per cent. Significant difference was observed in the flag leaf area between the treatments and the control at flowering stage. The treatment effect was significantly superior (7.52 cm^2) to control (6.38 cm^2) at this stage. The number of days taken for panicle exsertion was not affected by the treatments and their interactions. This finding is against the general belief that disturbing the paddy crop after panicle initiation might delay the panicle exsertion or result in partial exsertion of panicles. However flag leaf nutrition with potassium nitrate resulted in earlier panicle exsertion (60.22 days). Crop fed with magnesium sulphate @ 0.5 per cent took longer to reach 50 per cent flowering stage (81.22 days). But this was not reflected in the yield. The latent tiller count was significantly higher (2.78) under foliar feeding with potassium nitrate @ 0.5 per cent.

Among the physiological studies leaf area duration was observed to be longest (41.88 days) with FLN of calcium nitrate @ 0.5 per cent and was at par with all nutrient sources except potassium nitrate. The nutrient sources used for flag leaf nutrition had significant effect on the specific leaf weight at flowering and harvest stages. Spraying a combination of calcium nitrate, magnesium sulphate and 19:19:19 complex @ 0.5 per cent (S_5) recorded the highest specific leaf weight at flowering (2.11 g m^{-2}) and foliar spraying of 19:19:19 complex @ 0.5 per cent (2.58 g m^{-2}) recorded the highest value at harvest stage. Flag leaf nutrition with potassium nitrate at booting stage (s_1g_1) was significantly superior in terms of specific leaf weight (2.57 g m^{-2}). The relative growth rate recorded at booting (0.174 mg g^{-1} day^{-1}), flowering (0.057 mg g^{-1} day^{-1}) and harvest stages (0.028 mg g^{-1} day^{-1}) was also superior with potassium nitrate @ 0.5 %. Net assimilation rate (NAR) recorded at booting stage was significantly higher for potassium nitrate (3.76 mg cm^{-2} day^{-1}). But at flowering stage, 19:19:19 complex had the same effect with a NAR of 2.58 mg cm^{-2} day^{-1}. The chlorophyll and carotenoid contents of the flag leaf sheath were significantly higher with a combination of calcium nitrate, magnesium sulphate and 19:19:19 complex at flowering. The chlorophyll and carotenoid contents of flag leaf blade was significantly affected by the nutrient sources. Highest chlorophyll was with 19:19:19 complex and carotenoid with potassium nitrate @ 0.5 per cent. Magnesium sulphate @ 0.5 per cent concentration (S_3) recorded the maximum total soluble protein (1.04 mg g^{-1}) at booting stage and was at par with S_2 (calcium nitrate) and S_4 (19:19:19 complex). At flowering stage the foliar spraying of calcium nitrate recorded the highest total soluble protein (1.97 mg g^{-1}) and was at par with S_5 (combination of calcium nitrate, magnesium sulphate and 19:19:19 complex), S_3 (magnesium sulphate) and S_4 (19:19:19 complex). Nutrient use efficiency assessed in terms of nitrogen use efficiency, agronomic efficiency, apparent recovery efficiency were significantly higher with potassium nitrate @ 0.5 per cent (S_1) followed by 19:19:19 complex @ 0.5 per cent (S_4).

All the yield attributes *viz*., productive tiller count (490.19), grain weight $panicle^{-1}$ (2.18 g), number of spikelets $panicle^{-1}$ (89.11), filled grains $panicle^{-1}$ and thousand grain weight (28.55 g) were significantly superior with flag leaf nutrition of S_1 (potassium nitrate @ 0.5 per cent) as compared to KAU POP which recorded 417.24 productive tillers m^{-2}, 82.57 spikelets $panicle^{-1}$, 1.43 g grain weight $panicle^{-1}$ and a thousand grain weight of 21.51 g. Further, sterility percentage was the lowest (11.94 per cent) with potassium nitrate @ 0.5 per cent, as compared to KAU POP (16.05 per cent). The effect of potassium nitrate @ 0.5 per cent was at par with that of S_4 (19: 19: 19 complex) with respect to sterility percentage and thousand grain weight.

Flag leaf nutrition with potassium nitrate @ 0.5 per cent recorded significantly higher grain yield (5.95 t ha^{-1}) followed by 19: 19: 19 complex (5.01 t ha^{-1}). Grain yield recorded with flag leaf nutrition at booting + flowering stages (G_2) (4.52 t ha^{-1}) and (G_3) booting + flowering + milk stages (4.68 t ha^{-1}) were at par. The control (KAU POP) recorded a grain yield of 4.41 t ha^{-1}. Straw yield was also significantly higher with potassium nitrate. Grain to straw ratio (0.80) and harvest index (0.44) were superior with 19: 19: 19 complex @ 0.5 per cent.

Index leaf (flag leaf) analysis revealed that FLN with a combination treatment of calcium nitrate, magnesium sulphate and 19:19:19 complex (S_5) recorded the highest N content (1.85 per cent). It was on a par with (S_1) potassium nitrate @ 0.5 per cent. Flag leaf nutrition with a combination treatment of calcium nitrate, magnesium sulphate and 19:19:19 complex (S_5) recorded the highest P content (0.73 per cent). Flag leaf nutrition with (S_1) potassium nitrate @ 0.5 per cent recorded significantly higher K content (1.56 per cent). The treatment magnesium sulphate (S_3) recorded the highest magnesium content (0.27 per cent) and also highest sulphur content (0.084 per cent). Flag leaf nutrition with potassium nitrate @ 0.5 per cent (S_1) recorded significantly higher NPK uptake. Flag leaf nutrition of (S_1) potassium nitrate @ 0.5 per cent recorded the maximum crude protein content (8.26 per cent), which remained at par (7.73 per cent) with 19:19:19 complex (S_4). Available NPK status after the experiment was significantly higher in FLN with potassium nitrate @ 0.5 per cent.

Gross income (₹ 1,35,127 ha^{-1}), net income (₹ 70,102 ha^{-1}) and benefit cost ratio (2.07) were significantly higher in flag leaf nutrition with potassium nitrate @ 0.5 % , compared to KAU POP with a BCR of 1.65.

The study revealed that KAU POP recommendation for high yielding medium duration wetland rice (FYM @ 5 t ha^{-1} + 90:45:45 kg NPK ha^{-1}) supplemented with flag leaf nutrition of potassium nitrate @ 0.5 per cent concentration, 5 days prior to booting and 50 per cent flowering stages, resulted in significantly higher grain yield, nutrient use efficiency and profitability, in the rice variety Aiswarya. However, the photosynthate partitioning efficiency, assessed in terms of harvest index and grain to straw ratio were observed to be superior with 19:19:19 complex @ 0.5 per cent.

FUTURE LINE OF WORK

Exploring the effect of flag leaf nutrition in upland rice using different varieties of rice.

Exploring the effect of novel customised and fortified nutrient sources for flag leaf nutrition in rice.

References

7. REFERENCES

Abbasi, H.R.A., Esfahani, M., Rabiei, B., and Kavousi, M. 2007. Effect of nitrogen fertilizing management on rice (cv. Khazar) yield and its components in a paddy soil of Guilan province. *J. Sci. Tech. Agric. Nat. Resour*. 1 : 21-28.

Ahmad, R. and Jabeen, R. 2005. Foliar spray of mineral elements antagonistic to sodium- a technique to induce salt tolerance in plant growing under saline conditions. *Pak. J. Bot*. 37(4): 913-920.

Alam, S.S., Moslehuddin, A.Z.M., Islam, M.R., and Kamal, A.M. 2010. Soil and foliar application of nitrogen for *boro* rice (BRRI dhan 29). *J. Bangladesh Agric. Univ*. 8 (2): 199-202.

Ali, A., Mahmood, I. A., Hussain, F., and Salim, M. 2007. Response of rice to soil and foliar application of potassic fertilizers. *Sarhad. J. Agric*. 23: 847-850.

Amberger, S. 1996. Effect of late-season N fertilization on photosynthesis and yield of transplanted and direct-seeded tropical flooded rice. *Res. J. Agric. Biol. Sci.* 4(1):648-652.

Ao, H.J., Wang, S.H., Zou, Y.B., Peng, S.B., Tang, Q.Y., Fang, Y.X., Chen,Y., Xiao, A.M., Chen, Y.M., and Xiong, C.M. 2008. Study on yield stability and dry matter characteristics of super hybrid rice. Sci. Agric. Sin. 41: 1927- 1936.

Asana, R.D. 1968. In quest of yield. *Indian J. Plant Physiol*. 11: 1-10.

Babu, S.D. 1996. Yield maximization of direct sown rice under puddled condition. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur, 112p.

Brar, M.S. and Brar, A.S. 2004. Foliar nutrition as a supplement to soil fertilizer application to increase yield of upland cotton (*Gossypium hirsutum*). *Indian. J. Agric. Sci.* 74(8):472-475.

Bhuyan, M.H.M., Ferdousi, M.R., and Iqbal, M.T. 2012. Foliar spraying of nitrogen fertilizer increases the yield of rice over conventional method. *ISRN Agron*. 10: 12-20.

Birsin, M.A. 2005. Effects of removal of some photosynthetic structures on some yield components in wheat. *J. Agric. Sci.* 11: 364-367.

Biswas, B., Dey, D., Pal, S., and Kole, N. 2013. Integrative effect of magnesium sulphate on the growth of flowers and grain yield of paddy : a chemist's perspective. *Rasayan J. Chem*. 6 (4): 300-302.

Bohri, A.R., Karaman, M.R., Topeas, M.T., Aktas, A., and Savasu, E. 2012. Effect of K and Mg fertilization on yield and nutrient content of rice crop growth on artificial siltation soil. *Turk. J. Agric. For*. 24: 429-435.

Bojovic, B. and Stojanovic, J. 2005. Chlorophyll and carotenoid content in wheat cultivars as a function of mineral nutrition. *Arch. Biol. Sci*. 57: 283-290.

Bouyoucos, C.J. 1962. Hydrometer method improved for making particle size analysis of soil. *Agron. J*. 54: 464-465.

Bowes G.W., Orgen, L., and Hageman R.H. 1972. Light saturated photosynthesis rate, RuBp carboxylase activity and specific leaf weight in soybean grown under different light intensities. *Crop Sci*. 12: 77-79.

Bradford, M.M. 1976. A rapid and sensitive method for the quantification of microgram quantities of protein utilizing the principles of protein dye binding. *Anal. Biochem*. 72: 248-254.

Braun, P. and Wild, M. 1984. The influence of brassinosteroid on growth and parameters of photosynthesis of wheat and mustard plants. *J. Plant Physiol*. 116: 189-196.

Bush, D.S. 1995. Calcium regulation in plant cell and its role in signaling. *Annu. Rev. Plant Biol*. 46: 95-122.

Cassman, K.G., Gines, D.C., Dizon, M.A., Samon, M.I., and Alcantara, J.M. 1996. Nitrogen use efficiency in tropical low land rice systems: contributions from indigenous and applied nitrogen. *Field Crops Res.* 47: 1-12.

Cassman, K.G., Kropff, M.J., Gaunt, J., and Peng, S. 1993. Nitrogen use efficiency of rice reconsidered: What are the key constraints? *Plant Soil* 155/156: 359-362.

Cassman, K.G., Peng, S., Olk, D.C., Ladha, J.K., Reichardt, W., Dobermann, A., and Singh, U. 1998. Opportunities for increased nitrogen-use efficiency from resource improved management in irrigated rice systems. *Field Crops Res*. 56: 7-39.

Channabasavanna, A.S., Setty, R.A., and Hanumaretti, N.G. 1996. Studies on response of paddy to water regimes and f levels under deep black soils of TBP. *Farming Syst.* 12 (1 &2): 26-29.

Chesnin, I. and Yien, C.H. 1950. Turbidimetric determination of available sulphates. *Proc. Soil. Soc. America*. 15: 149-151.

Chopra, N.K. and Chopra, N. 2004. Seed yield quality of Pusa 44 rice (*Oryza sativa*) as influenced by nitrogen fertilizer and row spacing. *Indian J. Agric. Sci*. 74: 144-146.

Dasilva P.R.F. and Stutte, C.A. 1981. Nitrogen loss in conjunction with translocation from leaves as influenced by growth stage, leaf position and N supply. *Agron. J*. 73: 38-42.

De Datta, S.K. 1970. Effect of time of harvest and nitrogen level on yield and grain breakage in transplanted rice. *Agron. J*. 62: 468-474.

De Datta, S. K. 1981. *Principles and Practices of Rice Production*. John Wiley and Sons, New York, 618p.

Ding, Y.F., Wang, Q.S., and Zhao, C.H. 2003. Effect of application stage of panicle fertilizer on rice grain yield and the utilization of nitrogen. *J. Nanjing Agric. Univ.* 26: 5-8.

Ding, Y.C., Chang, C.R., Lou, W., Wu, Y.S., Ren, X.L., Wang, P., and Xu, G.H. 2008. High potassium aggravates the oxidative stress induced by magnesium deficiency in rice leaves. *Pedosphere* 18 (3): 316-327.

Dingyi, Z. and Dang, J. 2007. Regulative effect of nitrogen fertilization on grain yield, quality and photosynthesis of flag leaves in different wheat varieties. *Plant Nutr. Fertil. Sci*. 13(4): 535-542.

Donald, C.M. and Hamblin, J. 1976. Biological yield and harvest index of cereals as agronomic and plant breeding criteria. *Adv. Agron*. 28: 361-405.

Dornhoff, G.M. and Shibles, R.M. 1970. Varietal differences in net photosynthesis of soybean leaves, *Crop Sci*. 10: 42-45.

Duan, W.W., Zhao, H.M., Guo, C.J., Xiao, K., and Li, Y.M. 2007. Responses of photosynthesis characteristics to nitrogen application rates in summer maize (*Zea mays* L.). *Acta Agron Sin.* 33(6): 949-954.

Dutta, R.K., Miam, B.M.A., and Khanam, S. 2002. Plant architecture and growth characteristics of fine grain and aromatic rices and their relation with grain yield. *IRC Newsl*. 51: 51–56.

El-Zanaty A.A., El-Nour, A., and Shaaban, M.M. 2012. Response of wheat plants to magnesium sulphate fertilization. *Am. J. Plant Nutr. Fertil. Technol.* 2: 56-63.

Fageria, N.K. and Baligar, V.C. 2005. Enhancing nitrogen use efficiency in crop plants. *Adv. Agron.* 88 : 97-185.

Fageria, N.K., Filho, M.B.P., Moreira, A., and Guirmar~aes, C.M. 2009. Foliar fertilization in crop plants. *J. Plant Nutr*. 32 : 1044-1064.

Fageria, N.K. 2007. Yield physiology of rice. *J. Plant Nutr*. 30: 843-879.

Fernandez, V., Sotiropoulos, T., and Brown, P. 2013. *Foliar Fertilization: Scientific Principles and Field Practices*. International Fertilizer Industry Association, Paris, France, 144 p.

Field, C. and Mooney, H.A. 1986. The photosynthesis-nitrogen relationship in wild plants. In : Givnich, T.V. (ed.), *The Economy of Plant Form and Function*. Cambridge University Press, New York, USA, pp. 25-55.

Friessen, D.K., Miller, M.H., and Juo, A.S.R. 1980. Liming and lime-phosphorus-zinc interaction in two Nigerian ultisols. *Soil Sci. Soc. Am. J*. 44: 1221-1226.

Ganeshamurthy, A.N. and Srinivasarao, C. 2001. Interaction of potassium with other nutrients. In: Pasricha, N.S. and Bansal, S.K. (eds), *Potassium in Indian Agriculture*. Proceedings of International Symposium on Importance of Potassium in Nutrient Management for Sustainable Crop Production in India, International Potash Institute, Switzerland and Potash Research Institute of India, Gurgaon, India. pp. 159-174.

Gao, L., Mao-Bing, Y., Lang-Lai, X., and Wen-Biao, S. 2007. Factors affecting on the rise of aminopeptidases activity in wheat leaves during aging. *Acta Agric. Boreali-occidentalis Sin*. 16(5): 72-74.

Girma, K., Martin, K.L., Freeman, K.W. Mosali, J., Teal, R.K., Raun, W., Moges, R.S.M., and Arnall, D.B. 2007. Determination of optimum rate and growth for foliar applied phosphorus in corn. *Commun. Soil Sci. Plant Anal.* 38: 1137-1154.

Gomez, A.K. 1972. *Techniques for Field Experiments with Rice*. International Rice Research Institute, Los Banos, Philippines, 633p.

Gooding, M. J. and Davis, W. P. 1992. Foliar urea fertilization of cereals: a review. *Fertil. Res.* 32: 209-222.

Gregersen, P.L., Holm, P.B., and Krupinska, K. 2008. Leaf senescence and nutrient remobilisation in barley and wheat. *Plant Biol.* 10: 37-49.

Guo, T.C., Feng, W., Zhao, H. J., Xue, G. D., Wang, H. C., Wang, Y. H., and Yao, Z. J., 2004. Photosynthetic characteristics of flag leaves and nitrogen effects in two winter wheat cultivars with different spike type. *Acta Agron Sin*. 30: 115-121.

Habibi, M., Nouri, M., Nasiri, M., and Momeni, A. 2014. Effects of foliar application of nitrogen and potassium on dry matter remobilization of rice. *Adv. Environ. Biol.* 8(9): 910-913.

Hallmark, W.B., Brown, L.P., and Hawkins, G.L. 1997. Use of calcium chloride to reduce the nitrogen requirements of sugarcane. *Louisiana Agric*. 40:30-31.

Hasegawa, P., Bressan, R.A., Zhu, J.K., and Bohnert, H.J. 2000. Plant cellular and molecular responses to high salinity. *Annu. Rev. Plant Mol. Biol*. 51: 463–499.

Hegazi, E.S, Samira, I., Mohamed, M., El-Sonbaty, M.R., El-Naby, K.M.A., and El-Sharony, T.F. 2011. Effect of potassium nitrate on vegetative growth, nutritional status yield and fruit quality of olive. *J. Hort. Sci. Ornamental Plants* 3 (3): 252-258.

Imas, P. and Magen, H. 2007. Management of potassium nutrition in balanced fertization for yield and quality. In: Vyas, A.K. and Imas, P. (eds), *Proceedings of Regional Seminar on Recent Advances in Potassium Nutrition Management in Cropping Systems*, 28-29 September, 2007, Indore. National Research Centre for Soybean, Indore, pp. 1-20.

Inoue, T., Inanaga, S., Sugimoto, Y., An, P., and Eneji, A.E. 2004. Effect of drought on ear and flag leaf photosynthesis of two wheat cultivars differing in drought resistance. *Photosynthetica* 42 : 559-565.

IPI [International Potash Institute] 2014. *Potassium and Nitrogen Use Efficiency*. International Potash Institute, Horgen, Switzerland, 20 p.

Islam, R., Hossain, M.S.A., Howladar, A.S., Islam, A.R., and Haq, S.M.I. 1997. Effect of S on rice under flooded condition. *Int. J. Trop. Agric*. 5 (2): 93-101.

Jackson, M.L. 1973. *Soil Chemical Analysis*. Prentice Hall of India Pvt. Ltd., New Delhi, 498p.

Jagathjothi, N., Muthukrishnan, P., and Amanullah, M.M. 2012. Influence of foliar nutrition on growth and yield of transplanted rice. *Madras Agric. J.* 99 (4-6): 275-278.

Jamal, Z., Hamayun, M., Ahmad, N., and Chaudhary, M.F. 2006. Effect of soil and foliar application of different concentrations of NPK and foliar application of ammonium sulphate on different parameters in wheat. *J. Agron*. 5(2): 251-256.

Jiang, L., Dai, T., Jiang, D., Cao, W., Gan, X., and Wei, S. 2004. Characterizing physiological N-use efficiency as influenced by nitrogen management in three rice cultivars. *Field Crops Res*. 88: 239-250.

Juliano, B. O. and Duff, B. 1991. Setting priorities for rice grain quality research. In: Naewbanij, B.O. (ed.), *Grain Postharvest Research and Development: Priorities for the Nineties*. Proceedings of the 12th ASEAN Seminar on Grain Postharvest Technology, Surabaya, Indonesia, pp. 201-211.

KAU [Kerala Agricultural University] 2011. *Package of Practices Recommendations: Crops.* (14^{th} Ed.). Kerala Agricultural University, Kerala, Thrissur, 360 p.

Khalifa, A.A.B., Misra, A.N., and Salem, A. E. 2008. Effect of leaf cutting on physiological traits and yield of two rice cultivars. *African J. Plant Sci*. 2: 147-150.

Kondratev, M.N., Konch, K.M.F., and Treatyakov, N.N. 1984. Role of Ca:K ration in soil, in uptake and assimilation of nitrate by maize. *Investiya Timiryazav skoi sel Skohozya istrennot Akademi*, 3 : 113-117.

Kundu, C. and Sarkar, R. K. 2009. Effect of foliar application of potassium nitrate and calcium nitrate on performance of rainfed lowland rice (*Oryza sativa* L.). *Indian J. Agron*. 54: 428-432.

Lina, J., Cuhnxi, L., and Ximei, D. 1999. Effect of different nitrogen application on the physiological activity of flag leaf at the later stage of wheat. *J. Shenyang Agric. Univ*. 30(6): 609-612.

Liu, H., Chen, X., Chen, R., Song, S., and Sun, G. 2006. Effects of magnesium deficiency on growth and photosynthesis of flowering chinese cabbage. In: Lumpkin, T.A. and Warrington, I.J. (eds), *Horticultural Plants in Urban and Periurban Life.* Proceedings of the XXVII International Horticulture Congress – IHC-2006, Seoul, Korea, 767p.

Li, B., Feng, Z., Xie, M., Sun, M., Zhao, Y., and Liang, L. 2011. Modulation of the root-sourced ABA signal along its way to the shoot in *Vitis ripariax x Vitis labrusca* under water deficit. *J. Exp. Bot*. 62:1731-1741.

Loss, S.P. and Siddique, K.H.M. 1994. Morphological and physiological traits associated with wheat yield increases in Mediterranean environments. *Adv. Agron*. 52 : 229-276.

Luo, C., Branlard, G., Griffen, W.B., and McNeil, D.L. 2000. The effect of nitrogen and sulfur fertilization and their interaction with genotype on wheat glutenins and quality parameters. *J. Cereal Sci.* 31: 185-194.

Mae, T. 1997. Physiological nitrogen efficiency in rice – nitrogen utilization, photosynthesis and yield potential. *Plant Soil* 106 : 201-210.

Mahmood N. and Chowdhry, M.A. 1997. Removal of green photosynthetic structures and their effect on some yield parameters in bread wheat. *Wheat Inf. Serv.* 85: 14-20.

Makino, A., Mae, T., and Ohira, K. 1985. Relation between nitrogen and ribulose-1, 5-bisphosphate carboxylase in rice leaves from emergence through senescence. *Plant Cell Physiol*. 25: 429.

Mackill, D. J., Coffman, W. R., and Garrity, D. P. 1996. *Rainfed Lowland Rice Improvement*. International Rice Research Institute, Los Banos, Philippines, 76p.

Marschner H. 1995. *Mineral Nutrition of Higher Plants*. Academic Press, London, 105 p.

Matsushima, S. and Tanaka, T. 1967. Decreasing basal dressing of nitrogen in accordance with increasing plant density of rice. *Agric. Hort*. 42 (2): 373-374.

Miller, B.C., Hill, J.E., and Roberts, S.R. 1991. Plant population effect on growth in water seeded rice. *Agron. J*. 83: 291-297.

Mingzhu, S. 1996. Preliminary Report of the corn leaf nitrate reductase. *Agric. Sci*. 1: 25-26.

Minjun, X., Guiru, L., Xueju, Y., and Lijun, W. 2002. The influence of water stress to protein metabolism of winter wheat cultivars with different drought resistance ability. *Agric. Res. Arid Areas* 20(3): 85-88.

Misra, A.N. 1986. Effect of temperature on senescing I. photoelectron transport activity of chloroplast. *Plant Sci.* 46: 1-4.

Misra, A.N., Sahu, S., Misra, M., Mohapatra, P., Meera, I., and Das, N. 1997. Sodium chloride induced changes in leaf growth and pigment and protein contents in two rice cultivars. *Biol. Plant* 39: 257 – 262.

Muraleedharan, P. and Jose, A.I. 1993. Effect of application of magnesium and sulphur on the growth, yield and uptake in rice. *J. Tropic. Agric*. 31: 24-28.

Nair, N.P. 1995. Status and availability of sulphur in the major paddy soils of Kerala and the response of rice to sulphatic fertilizers. Ph. D thesis, Kerala Agricultural University, Thrissur, 185p.

Nair, V.G. 2011. *Compendium on Crop Varieties of Kerala*. Kerala Agricultural University, Mannuthy, Thrissur, p.23.

Narayan, N.N., Vasconcelos, M.W., and Grusak, M.A. 2007. Expression profiling of *Oryza sativa* metal homeostasis genes in different rice cultivars using a cDNA macroarray. *Plant Physiol. Biochem.* 45: 277–286.

Nelson, K.A., Motavalli, P.P., and Nathan, M. 2005. Response of no- till soyabean to timing of pre plant and foliar potassium applications in a clay pan soil. *Agron. J.* 97: 832-838.

Nishizawa, N., Kitahara, I., Noguchi, T., Hareyama, S., and Honjyo, K. 1997. Protein quality of high protein rice obtained by spraying urea on leaves before harvest. *Agric. Biol. Chem*. 41: 477-485.

Olszewski, M., Makowska, A., Pszczolkowska, A., Okorski, A., and Bieniaszewski, T. 2014. The effect on nitrogen fertilization on flag leaf and ear photosynthesis and grain yield of spring wheat. *Plant Soil Environ*. 60 (12): 531 – 536.

Ottis, B.V., Harrell, D.L., Gerard, P.D., Bond, J.A., and Walker T.W. 2008. Hybrid rice response to nitrogen fertilization for midsouthern United States rice production. *Agron. J*. 100: 381-386.

Padmaja, R.S. 1991. Influence of source and sink on the production of high density grain and yield in rice. *Indian J. Plant Physiol.* 34: 339-348.

Pandey, R., Krishnapriya, V., and Bindraban, P.S. 2013. *Biochemical Nutrient Pathways in Plants Applied as Foliar Spray : Phosphorus and Iron.* Virtual Fertilizer Research Centre, Washington DC, USA, 17p.

Pandey, R. K., Saxene, M. C., and Singh, V. B. 1978. Effect of moisture stress on growth, yield and yield component of field grown sorghum variety having glossy and non-glossy leaf. *Indian J. Agric. Sci.* 53: 428-430.

Panse, V.G. and Sukhatme, P.V. 1985. *Statistical Methods for Agricultural Workers* (4th Ed.). Indian Council of Agricultural Research, New Delhi, India, 347 p.

Pearce, R.B., Brown, R.H., and Balster, R.F. 1968. Photosynthesis of alfalfa leaves as influenced by age and environment. *Crop Sci*. 6: 677-680.

Peng, S., Khush, G.S., and Cassman, K.G. 1993. Evolution of new plant ideotytpe for increased yield potential. In: Cassman, K.G. (ed.), *Breaking the Yield Barrier*. Proceedings of Workshop on rice yield potential in favourable environments, International Rice Research Institute, Manila, Philippines, pp. 5-20.

Perez, C.M., Juliano, B.O., Liboon, S.P., Alcantara, J.M., and Cassman, K.G. 1996. Effects of late nitrogen fertilizer application on head rice yield, protein content and grain quality of rice. *Cereal Chem*. 73 (5): 556-560.

Perkin-Elmer Corporation 1982. *Analytical Methods for Atomic Absorption Spectrophotometry.* Perkin Elmer Corporation, Norwalk, Connecticut, USA, pp. 1-5.

Rahman, M.H., Ali, M.H., Ali, M.M., and Khatun, M. M. 2007. Effect of different levels of nitrogen on growth and yield of transplant aman rice cv. BRRI dhan 32. *Int. J. Sustain. Crop Prod.* 2(1): 28-34.

Rahman, M.N., Sayam, S.M., Alam, M.K., Islam, M.S., and Mondol, A.T.M.A.I. 2007. Influence of sulphur on nutrient content and uptake by rice and its balance in old Brahmaputra floodplain soil. *J. Soil Nature* 1 (3): 5-10.

Raj, A. and Tripathi, M.P. 2000. Varietal variations in flag leaf area and yield in deep water rice. *Indian J. Plant Physiol.* 5: 293-295.

Rani, S.B., Krishna, G.T., and Munirathnam, P. 2014. Studies on the effect of foliar fertilization in combination with conventional fertilizers on yield, economics and nutrient uptake of rice (*Oryza sativa* L.) under K.C. canal ayacut area of Andhra Pradesh. *Indian Agric. Sci. Digest* 34 (1) : 15-20.

Rao, S.D. 1997. Flag leaf a selection criterion for exploiting potential yields in rice. *Indian J. Plant Physiol*. 25(3): 265-268.

Ray, S.W., Mondal, A., and Choudhuri, M.A. 1983. Regulation of leaf senescence, grain-filling and yield of rice by kinetin and abscissic acid. *Plant Physiol*. 59: 343-346.

Riaz, R. and Chowdhry, M.A. 2003. Genetic analysis of some economic traits of wheat under drought condition. *Asian J. Plant Sci.* 2: 790-796.

Sabo, M., Teklic, T., and Vidovic, I. 2002. Photosynthetic productivity of two winter wheat varieties (*Triticum aestivum* L.). *Rostlinna Vybroba* 48: 80-86.

Sahai, V.N. 2004. *Fundamentals of Soil*. (3rd Ed.). Kalyani Publishers, New Dehli, India. pp:151-155.

Salvagiotti, F. and Miralles, D. 2008. Radiation interception, biomass production and grain yield as affected by the interaction of nitrogen and sulphur fertilization in wheat. *Eur. J. Agron.* 28: 282-290.

Sarkar, R.K., Deb, N., and Parya, M.K. 2007. Effect of seed treatment and foliar nutrition on growth and productivity of spring sunflower (*Helianthus annuus*). *Indian J. Agric. Sci*. 77 (3): 191-194.

Sharief, A.E., El- Kalla, S.E., El-Kassaby, A.T., Ghonema, M.H., and Abdo, G.M.Q. 2006. Effect of Bio-chemical fertilization and times of nutrient foliar application on growth, yield and yield components of rice. J. Agron. 5 (2): 212-219.

Sharpley, A.N., Chapra, S.C., Wedepohl, R., Sims, J.T., Daniel, T.C., and Reddy, K.R. 1994. Managing agricultural phosphorus for protection of surface waters: issues and opinions. *J. Environ. Qual.* 23: 437-451.

Shen, A.L., Liu, C.Z., Zhang, F.S., Huangpu, X.R., and Kun, Z.L. 1997. Effects of different application rate of NPK on the growth of rice and N fertilizer utilization ratio underwater leakage and non-leakage conditions. *Chinese J. Rice Sci*. 11(4): 231−237.

Siddiq, E.A. 2000. Yawning productivity gaps. *The Hindu Survey of Indian Agriculture.* 2000 : 39 – 44.

Simpson, J.E., Adair, C.R., Kohler, G.O., Dowson, E.H., Dobald, H.A., Kester, E.B., and Klick, J.J. 1965. *Quality Evaluation Studies of Foreign and Domestic Rices*. Technical Bulletin No1331, USDA, 186 p.

Singh, M., Singh, R.P., and Gupta, M.L. 1993. Effect of sulphur on rice (*Oryza sativa* L.) 30: 315-317.

Singh, P. and Ghosh, D.C. 1990. Effect of cultural practices on growth and yield of rice. *Indian J. Agron*. 35: 83-87.

Singh, T. and Ghosh, A.K. 1981. Effect of flag leaf on grain yield of transplanted rice. *IRRN* 6: 5.

Sisie, A.S. and Mirshekari, B. 2011. Effect of phosphorus fertilization and seed bio fertilization on harvest index and phosphorus use efficiency of wheat cultivars. *J. Food Agric. Environ.* 9(2): 388-397.

Snedecor, G.W. and Cochran, W.G. 1967. *Statistical Methods* (16^{th} Ed.). Oxford and IBH Publishing Co., Calcutta, pp. 349-351.

Son, T.T., Anh, X.L., Ronen, Y., and Holwerda, H.T. 2012. Foliar potassium nitrate application for rice. *Better Crops* 96: 29-32.

Sperotto, R.A., Ricachenevsky, F.K., de Waldow, V.A., Muller, A.L.H., Dressler, V.L., and Fett, J.P. 2013. Rice grain Fe, Mn and Zn accumulation : how important are flag leaves and seed number ?. *Plant Soil Environ*. 59 (6): 262-266.

Spiertz, J.H. and Vos, J. 1985. Grain growth of wheat and its limitation by carbohydrate and nitrogen supply. In: Day, W. and Atkin, R.K. (eds), *Wheat Growth and Modelling.* NATO ASI series. Series A, Plenum Press, New York, pp.129-141.

Strong, W. M. 1982. Effect of late application of nitrogen on the yield and protein content of wheat. *Aust. J. Exp. Agric. Anim. Husb.* 22: 54–61.

Subbiah, D.V. and Asija, G.L. 1956. Rapid procedure for estimation of available nitrogen in soil. *Curr. Sci*. 25: 259-260.

Tambussi, E.A., Bort, J., Guiamet, J.J., Nogués, S., and Araus, J.L. 2007. The photosynthetic role of ears in C3 cereals: metabolism, water use efficiency and contribution to grain yield. *Crit. Rev. Plant Sci.* 26: 1-16.

Tang, X.R. 2000. Effect of N supply on yield and on protein content and its mechanism in hybrid rice. *Hybrid Rice* 15 (2): 34-37.

Tari, D.B., Gazanchian, A., Perdashti, H.A., and Nasiri, M. 2009. Flag leaf morphophysiological response to different agronomical treatments in a promising line of rice (*Oryza sativa* L.). *American-Eurasian J. Agric. Environ. Sci*. 5: 403-408.

Timothy, W. and Joe, E. 2003. *Rice Fertilization*. Information sheet No. 1341, Mississippi Agricultural and Forestry Experiment Station, USA, 4p.

Tisdale, S. L., Nelson, W. L., Beaton, J. D., and Havlin, L. 1995. *Soil Fertility and Fertilizers* (5^{th} Ed.). Mc. Millan Publishing Co., New York, USA, 733p.

Traore, A. and Maranville, J.W. 1999. Nitrate reductase activity of diverse grain sorghum genotypes and its relationship to nitrogen use efficiency. *Agron. J*. 91: 863-869.

Turner N.C. 1997. Further progress in crop water relationship. *Adv. Agron*. 58: 293-338.

Vaiyapuri, V. and Sriramachandrasekharan, M.V. 2001. Integrated use of green manure and sulphur on nutrient uptake and rice yield. *J. Ecobiol*. 13 (3): 223-227.

Venkateswarlu, B. And Visperas, R.M. 1987. *Source-sink Relationships in Crop Plants*. International Rice Research Institute, Los Banos, Manila, Philippines, 20p.

Wang, S., Zhu, Y., Jiang, H., and Cao, W. 2005. Positional differences in nitrogen and sugar concentration of upper leaves related to plant nitrogen status in rice under different nitrogen rated soils. *Field Crops Res*. 96 (2-3): 224-234.

Watson, D.J. 1947. Comparative physiological studies on the growth of field crops: variation in net assimilation rate and leaf area between species and varieties and within and between years. *Ann. Bot*. 11: 47-76.

Williams, R.F. 1946. The phenology of plant growth with special reference to the concepts of net assimilation rate. *Ann. Bot*. 10: 41-72.

Wilson, D.R., Reid, J.B., Zyskowski, R.F., Maley, S., Pearson, A.J., Armstrong, S.D., Catto, W.D., and Stafford, A.D. 2006. Forecasting fertiliser requirements of forage brassica crops. *Proc. New Zealand Grassland Assoc*. 68: 205-210.

Xusheng, S., Lin, Q., and Li, L. 2008. Effects of nitrogen supply on photosynthetic characteristics at later developing stages and yield in superhigh- yield winter wheat. *Plant Nutr. Fertil. Sci*. (5): 84-84.

Yan, L. and Shi, Y. 2013. Effect of nitrogen application rate on the enzyme activity of flag leaf after anthesis. *Adv. J. Food Sci. Technol*. 5: 738-742.

Yang, J.C., Zhang, J.H., Wang, Z.Q., and Zhu, Q.S. 2003. Hormones in the grains in relation to sink strength and post anthesis development of spikelets in rice. *Plant Growth Regul*. 41:185-195.

Yang, Q., Li, Y.M., Xiao, K., and Dou, Y.H. 2002. Effect of different amount of nitrogen on flag leaf senescence and yield components of wheat. *J. Heibei Agric. Univ*. 25 (4): 20-24.

Yoshida, S., Forno, D.A., Cock, J.H., and Gomez, K.A. 1976. *Laboratory Manual for Physiological Studies of Rice* (3rd Ed.). International Rice Research Institute, Los Banos, Philippines, 83p.

Zhang, X.C. and Shangguan, Z.P. 2007. Effect of nitrogen fertilization on photosynthetic pigment and fluorescence characteristics in leaves of winter wheat cultivars on dryland. *J. Nucl. Agric. Sci*. 21(3): 299-304.

Zhang, Z.X., Zhing, L.I., Chen, J., Qi-Song, L.I., and Chen, L.H. 2011. Effects of nitrogen management on protein expression of flag leaves at grain filling stage in large panicle rice. *Acta Agron. Sin*. 37: 842-854.

Zeigler, R.S. 2012. Cutting-Edge Rice Science for Food Security, Economic Growth and Environmental Protection in India and Around the World [Coromandel lecture]. 26th November, 2012; NASC, New Delhi, 10p.

Flag Leaf Nutrition for Enhancing Resource use Efficiency in Rice

(*Oryza sativa* L.)

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ABSTRACT

The experiment entitled "Flag leaf nutrition for enhancing resource use efficiency in rice (*Oryza sativa* L.)" was undertaken at the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram, during June to October, 2014. The main objectives of the study were to at assess the effect of flag leaf foliar nutrition on partitioning of photosynthates, growth and productivity of rice and to work out the economics of the practice in lowland rice ecosystem.

The field experiment comprised [(5x3)+1] treatment combinations, laid out in randomised block design with three replications, using PTB 52 (Aiswarya) as the test variety. The treatments were 0.5 per cent each of S_1 : potassium nitrate, S_2 : calcium nitrate, S_3 : magnesium sulphate, S_4 : 19 : 19 : 19 complex and S_5 : a combination S_2 + S_3 + S_4, sprayed at three crop growth stages *viz*., G_1 : Booting stage, G_2 : Booting + Flowering stages and G_3 : Booting + Flowering + Milk stages, as compared against a control (KAU POP for medium duration rice). The flag leaf nutrition treatments (s_1g_1 to s_5g_3) were given, over and above the KAU POP.

The effect of nutrient sources used for flag leaf nutrition (FLN) was more pronounced than the growth stages chosen for FLN. Flag leaf area was significantly higher at booting (4.98 cm^2) and flowering stages (8.11 cm^2) with S_1 (potassium nitrate @ 0.5 %), which was at par with S_4 (19: 19: 19 complex). Foliar spraying of potassium nitrate @ 0.5 per cent at booting and flowering stages (s_1g_2) recorded the highest flag leaf area (9.08 cm^2) at flowering stage and s_2g_3 resulted in the highest flag leaf area (11.65cm^2) at harvest stage. FLN had no significant effect on the number of days taken for panicle exsertion. Latent tiller production (2.78 $hill^{-1}$) was significantly higher with potassium nitrate @ 0.5 %. The relative growth rate recorded at booting (0.174 mg g^{-1} day^{-1}), flowering (0.057 mg $g^{-1}day^{-1}$) and harvest stages (0.028 mg g^{-1} day^{-1}) was also superior with potassium nitrate. Net assimilation rate (NAR) recorded at booting stage was significantly higher for potassium nitrate

(3.76 mg cm^{-2} day^{-1}). But at flowering stage, 19:19:19 complex had the same effect with a NAR of 2.58 mg cm^{-2} day^{-1}. FLN with 19:19:19 complex (S_4) registered significantly higher chlorophyll content (2.58 mg g^{-1}) in flag leaf blade at flowering stage. However, the carotenoid content was significantly superior (1.83 mg g^{-1}) with potassium nitrate.

All the yield attributes *viz*. productive tiller count (490.19), grain weight $panicle^{-1}$ (2.18 g), number of spikelets $panicle^{-1}$ (89.11), filled grains $panicle^{-1}$ and thousand grain weight (28.55 g) were significantly superior with (potassium nitrate @ 0.5 %) as compared to KAU POP which recorded 417.24 productive tillers m^{-2}, 82.57 spikelets $panicle^{-1}$, 1.43 g grain weight $panicle^{-1}$ and a thousand grain weight of 21.51 g. Further, sterility percentage was the lowest (11.94 per cent) with S_1 compared to KAU POP (16.05 per cent). The effect of potassium nitrate was at par with 19: 19: 19 complex, with respect to sterility percentage and thousand grain weight.

FLN with potassium nitrate @ 0.5 per cent recorded significantly higher grain yield (5.95 t ha^{-1}) followed by 19: 19: 19 complex (5.01 t ha^{-1}). The treatment combination, s_1g_1 (potassium nitrate at booting stage) recorded the highest yield of 6.28 t ha^{-1}. The KAU POP recorded a grain yield of 4.41 t ha^{-1}. Straw yield was also significantly higher with potassium nitrate. Grain yield recorded with flag leaf nutrition at booting + flowering stages (G_2) (4.52 t ha^{-1}) and booting + flowering + milk stages (G_3) (4.68 t ha^{-1}) were at par. Grain to straw ratio (0.80) and harvest index (0.44) were superior with 19: 19: 19 complex @ 0.5 per cent.

Index leaf (flag leaf) analysis recorded significantly higher N and P contents with S_5 and K content with S_1. The treatment s_3g_3 recorded the highest sulphur content in flag leaf. The treatment combination, s_1g_2 recorded significantly higher crude protein content (8.34 per cent) in grain. FLN had no effect on the incidence of pests and diseases.

FLN with potassium nitrate @ 0.5 per cent (S_1) recorded significantly higher N, P and K uptake. The treatment combination, s_3g_2 recorded significantly higher sulphur uptake. Nutrient use efficiency assessed in terms of nitrogen use efficiency, agronomic efficiency and apparent recovery efficiency were significantly higher with S_1 followed by 19: 19: 19 complex. Gross income (₹ 1,35,127 ha^{-1}), net income (₹ 70,102 ha^{-1}) and benefit cost ratio (2.07) were significantly higher with S_1, compared to KAU POP with a BCR of 1.65.

The study revealed that KAU POP recommendation for high yielding medium duration wetland rice (FYM @ 5 t ha^{-1} + 90:45:45 kg NPK ha^{-1}) supplemented with FLN of potassium nitrate @ 0.5 per cent concentration, 5 days prior to booting and 50 per cent flowering stages, resulted in significantly higher grain yield, nutrient use efficiency and profitability, in the rice variety Aiswarya. However, the photosynthate partitioning efficiency, assessed in terms of harvest index and grain to straw ratio were observed to be superior with 19:19:19 complex @ 0.5 per cent.

സംഗ്രഹം

കൊതുമ്പോല പത്രപോഷണത്തിലൂടെ നെൽകൃഷിയിൽ വിഭവ ഉപയോഗ കാര്യക്ഷമത വർദ്ധിപ്പിക്കുന്നതിനായിട്ടുള്ള ഒരു പരീക്ഷണം 2014 ജൂൺ മുതൽ ഒകടോബർ വരെയുള്ള കാലയളവിൽ വെള്ളായണി കാർഷിക കോളേജിലുള്ള ഇൻസ്ട്രക്ഷണൽ ഫാമിലെ നെൽപ്പാടത്ത് നടത്തുക യുണ്ടായി. കൊതുമ്പോല പത്രപോഷണത്തിലൂടെ നെല്ലിന്റെ വളർച്ച, വിളവ്, സാമ്പത്തിക ലാഭം എന്നിവയിലുണ്ടാകുന്ന മാനങ്ങളെക്കുറിച്ച് പഠിക്കുക എന്നതായിരുന്നു പ്രധാന ലക്ഷ്യം.

പ്രസ്തുത പരീക്ഷണത്തിന് റാൻഡമൈസ്ഡ് ബ്ലോക്ക് ഡിസൈൻ എന്ന പഠന രീതിയാണ് അവലംബിച്ചത്. പിന്ദിബി 52 (ഐശ്വര്യ) എന്ന നെല്ലിനമാണ് പഠന വിധേയമാക്കിയത്. കൊതുമ്പോല പത്ര പോഷണം ഉൾപ്പെടുന്ന 15 പരിചരണ മുറകളാണ് പരീക്ഷിക്കപ്പെട്ടത് – 0.5 ശതമാനം വീതം പൊട്ടാസ്യം നൈട്രേറ്റ് (S_1), കാൽസ്യംനൈട്രേറ്റ് (S_2), മഗ്നീഷ്യം സൾഫേറ്റ് (S_3), 19:19:19 കോംപ്ലക്സ് (S_4), $S_2+S_3+S_4$ (S_5), എന്നീ പോഷക മൂലക സ്രോതസ്സുകൾ നെല്ലിന്റെ മൂന്ന് വർച്ചാദശകളിൽ (പൊതിപ്പരുവം G_1,) പൊതിപ്പരുവം+കതിർനിരക്കൽ -G_2, പൊതിപ്പരുവം+ കതിർനിരക്കൽ+ നെൽമണികളിൽ പാൽ പരു വം -G_3) തളിക്കുകയുണ്ടായി. മേൽ സൂചിപ്പിച്ച 5x3 പരിചരണ മുറകൾ മധ്യകാല മൂപ്പുള്ള നെല്ലിനങ്ങൾ ക്കുവേണ്ടി കേരള കാർഷിക സർവ്വകലാശാലയുടെ പാക്കേജ് ശുപാർശ യുമായി താരതമ്യപ്പെടുത്തുകയും ചെയ്തു. കൊതുമ്പോല പത്രപോഷണ ഇടപെടലുകളെല്ലാം തന്നെ ശുപാർശ ചെയ്തിട്ടുള്ള വളപ്രയോഗത്തിന് ഉപരിയായിട്ടാണ് നൽകിയത്.

പോഷകമൂലക സ്രോതസ്സുകളുടെ സ്വാധീനം കൊതുമ്പോല പത്രപോഷണത്തിനായി തിരെഞ്ഞെടുത്ത നെല്ലിന്റെ വളർച്ചാ ദശകളേക്കാൾ കൂടുതലായിരുന്നു. കൊതുമ്പോല പത്രപോഷണം മൂലം കതിർനിരക്കുന്ന സമയത്തിൽ ഒരു വ്യത്യാസവും രേഖപ്പെടുത്തിയിട്ടില്ല. എന്നാൽ 0.5 ശതമാനം പൊട്ടാഷ്യം നൈട്രേറ്റ് തളിച്ച പ്ലോട്ടുകളിൽ പൂർണ്ണ വളർച്ചയെ ത്താത്ത ചിനപ്പുകളുടെ എണ്ണം കൂടുന്നതായി കാണുകയുണ്ടായി.

നെൽകൃഷിയിൽ വിളവിന്റെ മാനദണ്ഡങ്ങളായ കതിരായ ചിനപ്പുകളുടെ എണ്ണം, ഓരോ കതിരുലുമുള്ള മണികളുടെ എണ്ണം, മണികളുടെ തൂക്കം, പതിരിന്റെ എണ്ണം, ആയിരം നെൽമണികളുടെ തൂക്കം –എന്നിവയെല്ലാം തന്നെ 0.5 ശതമാനം പൊട്ടാസ്യം നൈട്രേറ്റ് കൊതുമ്പോല പത്രപോഷണത്തിനായി ഉപയോഗിച്ചപ്പോൾ പാക്കേജ് ശുപാർശയെക്കാൾ വർദ്ധിച്ചതായി രേഖപ്പെടുത്തുകയുണ്ടായി. പ്രസ്തുത പരിചരണമുറ നെല്ലിന്റെ വിളവും അറ്റാദായവും വർദ്ധിപ്പിക്കാൻ സഹായിച്ചു.

മധ്യകാല മൂപ്പുള്ള നെല്ലിനമായ ഐശ്വര്യയ്ക്ക് ശുപാർശ ചെയ്യപ്പെട്ടിട്ടുള്ള പോഷക മൂലകസ്രോതസ്സുകൾക്ക് (ഹെക്ടറിന് 5 ടൺ കാലിവളം, 90കി. നൈട്രജൻ, 45കി. ഫോസ്ഫറസ്, 45കി. പൊട്ടാസ്യം) ഉപരിയായി രണ്ട് തവണ 0.5 ശതമാനം വീര്യത്തിൽ പൊട്ടാസ്യം നൈട്രേറ്റ് (പൊതിപ്പരുവത്തിനും കതിർ നിരക്കുന്നതിനും 5 ദിവസംമുൻപ്) തളിക്കുന്നത് കൂടുതൽ വിളവും, മൂലക ഉപയോഗ കാര്യക്ഷമതയും ലാഭവും നൽകുന്നതായി രേഖപ്പെടുത്തി.

Appendices

APPENDIX- I

Weather data for the cropping period

(June 2014 to October 2014)

Standard week	Temperature (^{o} C)		Bright Sunshine hours	Rainfall (mm)	Relative humidity (%)	
	Maximum	Minimum			Maximum	Minimum
25	31.1	25.7	9.3	19.4	92.3	77.7
26	30.5	25.0	9.5	33.9	92.7	79.1
27	30.4	24.7	9.2	7.6	90.9	79.0
28	29.7	24.2	8.7	24.2	92.9	80.4
29	30.1	24.2	9.3	19.4	90.4	76.7
30	29.9	24.2	9.3	14.6	91.6	73.6
31	29.2	23.5	8.6	94.2	95.3	85.9
32	29.4	23.5	8.7	88.7	88.6	77.3
33	29.7	24.0	8.9	4.0	89.7	79.6
34	29.8	24.0	8.1	219.0	94.0	80.9
35	29.9	23.9	8.7	206.6	87.6	84.1
36	29.2	23.9	8.8	80.0	96.1	79.3
37	30.1	24.5	9.2	94.2	89.3	74.1
38	30.5	24.6	9.7	0.0	85.0	75.6
39	31.1	24.1	7.5	74.4	93.3	84.9
40	30.7	23.9	8.6	9.0	95.4	73.6
41	30.7	24.2	8.9	20.6	90.0	85.7
42	30.3	23.7	7.0	163.0	92.4	82.4

APPENDIX- II

Average input cost and market price of produce

Sl. No	Items	Cost
	INPUTS	
A	Seed (Breeder seed)	₹ 45 per kg
B	Labour	
1.	Women	₹ 350 per day
2.	Men	₹ 588 per day
C	Cost of manures, fertilizers and nutrient sources for FLN	
1.	Farm yard manure (FYM)	₹ 5 per kg
2.	Lime	₹ 15 per kg
3.	Urea	₹ 8 per kg
4.	Rock phosphate	₹ 10 per kg
5.	Muriate of potash (MOP)	₹ 17 per kg
6.	Potassium nitrate	₹ 150 per kg
7.	Calcium nitrate	₹ 150 per kg
8.	Magnesium sulphate	₹ 110 per kg
9.	19:19:19 complex	₹ 180 per kg
	OUTPUT	
A	Market price of grain	₹ 15 per kg
B	Market price of straw	₹ 5 per kg