Effective Nitrogen Fertilizer Management Practices for Hybrid Rice (Palethwe 1) at Yezin

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The thesis attached hereto, entitled **"**Nitrogen Management through the Use of Leaf Color Chart (LCC) and Chlorophyll Meter (SPAD) in Hybrid Rice (Palethwe1)**"** was prepared under the direction of the chairman of the candidate supervisory committee and has been approved by all members of that committee and board of examiners as a partial fulfillment of the requirements for the degree of **Master of Agricultural Science (Soil Science).**

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DECLARATION OF ORIGINALITY

This thesis represents the original work of the author, except where otherwise stated. It has not been submitted previously for a degree at any other University.

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DEDICATED TO MY BELOVED PARENTS,

U THAN AUNG AND DAW PU

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ABSTRACT

The pot experiments were conducted at Screen house, Department of Soil and Water Science during 2013 (1) to investigate the effective nitrogen fertilizer management practices for Palethwe1 (fixed time N management (FTMN) vs real time N management (RTMN)) (2) to analyze the effect of fixed time nitrogen management**,** SPAD and LCC based nitrogen management on growth, productivity and agronomic efficiency of Palethwe1 (110 days) (3) to determine the relationship of SPAD values and LCC scores with the grain yield of Palethwe1. The experiment was set in Randomized Complete Block Design (RCB) with 4 replications. The treatments were T_1 = Control (no N application), Fixed time nitrogen managements (FTMN); T_2 = 75 Kg N ha^{-1} and T_3= 150 Kg N ha^{-1} (basal, mid tillering , panicle initiation and flowering) respectively, real time nitrogen managements (chlorophyll meter and leaf color chart); T_4 = <SPAD (35), T_5 = < SPAD (37), T_6 = < LCC (3) and T_7 = < LCC (4). In the treatment T_4, T_5, T_6 and T_7 30 Kg N ha^{-1} was applied whenever the SPAD values and LCC values were lower than that in parenthesis of respective treatment.

The treatment T_7 (<LCC (4) with 30 KgNha^{-1} each time) resulted the highest grain yield, which was not statistically difference with treatment $T_{3,}$ however T_7 obtained the higher agronomic efficiency than T_3 Treatment in both seasons. T_4 (< SPAD (35) with 30 Kg N ha^{-1} each time) and T_6 (< LCC 3 with 30 Kg N ha^{-1} each time) obtained the same yield because they used the same dose of nitrogen and number of splits. T_4 (< SPAD (35) with 30 Kg N ha^{-1} each time) and T_6 (< LCC 3 with 30 Kg N ha^{-1} each time) not only saved 15 Kg N ha^{-1} but also obtained the higher grain yield than treatment T_2 (FTNM) in dry and wet seasons. Thus Grain yield can be increased in Palethwe 1 through the use of LCC and SPAD. In this study, all treatments using real time nitrogen management (LCC and SPAD) were higher in agronomic efficiency than those of the fixed-time nitrogen management in both seasons. SPAD and LCC mean values were positively and significantly correlated with mean grain yield of rice in both seasons. Therefore, the topdressing of N can be practiced based on the LCC and SPAD. If there is no LCC and SPAD, split application method (FTMN) is still effective nitrogen management in higher nitrogen level than lower level for farmers.

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CHAPTER I
INTRODUCTION

Rice is a staple food crop in the world, cultivated on about 146 million ha with a production of 520 million tons of grains. Rice is an important cereal crop of the world that provides the primary staple food for more than 2 billion people in Asia, the world's most densely populated region, and for hundreds of millions of people in Africa and Latin America. The crop occupies one-third of the world's total area planted to cereals and provides 35 - 60% of the calories consumed by 2.7 billion people (Guerra et al. 1998).

At the accelerating current growth rate of 1.8 percent of population, rice requirement by 2020 is estimated to be around 140 million tones. There is no scope for horizontal expansion of cultivable area. Therefore rice productivity and production have to be increased to meet the future demand. Among the various strategies proposed to improve rice productivity, exploitation of heterosis through the development of hybrid rice is one among them. Introduction of hybrid rice is an important step towards augmentation of rice yield. Hybrid rice yields about 15 - 20% more than the promising high-yielding commercial varieties (Chaturvedi 2005).

Hybrid rice was first developed in China in the 1970s and reached a maximum area of production of 17.6 million ha by 1991. In 2003, the area devoted to hybrid rice in Asia was about 16 million ha, of which China's hybrid rice area accounted for more than 90 percent. Hybrid rice (HR) has been cultivated on about 18 million acres across China and makes up 66% of the country's rice crop. Hybrid rice has also been expanded in other rice growing countries like Vietnam, India, Philippines, Bangladesh, and Myanmar, etc.

Myanmar started search on hybrid rice in 1997 and released its hybrid rice to fulfill the needs of consumption for the country (Grain 2005). Growing hybrid rice is a complex process since agronomic management of hybrid rice differs considerably from that of conventional inbred rice varieties in many respects (Ramesh and Chandrasekaran 2007). The life cycles of hybrid and inbred rice are almost similar, but hybrid rice is more vigorous in the vegetative phase, especially at seedling stage. Hybrid rice has higher seedling dry matter content, thicker leaves, larger leaf area and longer root system (BRRI 2000). Hybrid rice can give 10 - 15% yield advantage over modern inbred varieties through vigorous growth, extensive root system, efficient and greater sink size, higher carbohydrate translocation from vegetative parts to spikelets and larger leaf area index during the grain filling stage (Peng and Cassman 1998). The main reason for higher yield of hybrid rice is vigorous seedlings with tillers. The tillers that emerged in the seedbed produced more spikelets per panicle than the tillers that emerged after transplanting (Wen 1990).

Although rice is grown in different ecosystems, 78% of the world's rice is grown under irrigated or rainfed lowland conditions (IRRI 1997). Soils under these conditions are saturated, flooded, and anaerobic and its nitrogen (N) use efficiency is low. Under these situations, increasing rice yield per unit area through use of appropriate N management practices has become an essential component of modern rice production technology (Fageria and Baligar 2001). The major agronomic and environmental factors stagnating in growth and yield are thought to be mismanagement in the use of inputs such as nitrogen application, nutrient depletion, and poor quality seeds. Among these factors, nitrogen application is one of the most important variables affecting growth and yield to improve nitrogen use efficiency in rice fields, nitrogen application times should be adjusted as it is one of the key factors in achieving higher yield.

Nitrogen is an essential macronutrient needed by all plants to thrive. It is the most important nutrient for rice but it is the most limiting element in almost all soils. Also nitrogen is essential part of many compounds of plant, such as chlorophyll, nucleotides, proteins, alkaloids, enzymes, hormones and vitamins (Azarpor et al. 2011). It is an important component of many structural, genetic and metabolic compounds in plant cells. It is also one of the basic components of chlorophyll, the compound by which plants use sunlight energy to produce sugars during the process of photosynthesis. Leaf nitrogen status of rice is closely related to photosynthetic rate and biomass production, and it is a sensitive indicator of changes in crop nitrogen demand within a growing season.

When nitrogen application is non-synchronized with crop demand, nitrogen losses from the soil-plant system are large, resulting in its low nitrogen fertilizer use efficiency. Nitrogen use efficiency by flooded rice is less than 50% (Fageria and Baligar 2001, 2005). The low recovery efficiency of nitrogen is associated with its loss by leaching, denitrification, volatilization and soil erosion (Fageria and Baligar 2005). Nitrogen significantly improved yield of rice by improving yield components like panicle number, thousand grain weight, and reduced grain sterility (Fageria 1992, 2007).

In addition, nitrogen also improved grain harvest index, nitrogen harvest index and plant height which are positively associated with grain yield (Fageria 2007). Optimal nitrogen supply matching with the actual crop demand is thus vital for improving crop growth and maximizing production by environmentally friendly way. Deep placement of urea, split nitrogen application and the chlorophyll meter and leaf color chart techniques are some nitrogen management strategies that could improve fertilizer use efficiency in rice (Kumar et al. 2000).

There are two classes of techniques for foliar analysis of nitrogen content: destructive and non-destructive. Ramirez (2010) showed that plant nitrogen status can be accurately estimated using a destructive technique; in which foliar samples are analyzed using laboratory procedures. This technique is generally time consuming, costly and labor intensive (Sui et al. 2005). In contrast, non-destructive methods can be rapid and less expensive than destructive techniques, but are generally less accurate. There are a number of non-destructive methods available that vary in complexity and optimality. These include use of a Leaf Color Chart (LCC), which relies on visual comparison between leaf color and a color chart to assess the N status of certain plants. One of the most widely used digital tools is the chlorophyll meter (SPAD-502) and many authors suggested that, leaf color chart (LCC) and chlorophyll meter (SPAD) as important tools to diagnose the nitrogen status in rice to decide time of N top dressing (JhonKutti and Palaniappan 1996; Bijaysingh et al. 2002).

Leaf color chart (LCC) is a simple and inexpensive tool developed at IRRI, Manila, Philippines to determine the need for nitrogen application in rice (Furuya 1987). The leaf color chart is a plastic, ruler-shaped strip containing four panels that range in color from yellowish green to dark green. It is the cheapest, and has been widely used in rice, maize and sugarcane. It is an easy-to-use and inexpensive diagnostic tool for monitoring the relative greeness of a rice leaf as an indicator of the plant nitrogen status. The LCC can be used to rapidly assess leaf nitrogen status and thereby guide the application of fertilizer nitrogen to maintain an optimal leaf N content, which can be vital for achieving high rice yield with effective nitrogen management. Leaf color intensity is directly related to leaf chlorophyll content which in turn is related to leaf nitrogen status.

The chlorophyll meter, also known as SPAD (soil and plant analysis division) is a quick and non-destructive tool used for directly measuring leaf chlorophyll and indirectly assessing the proportional parameter of leaf, plant nitrogen status and finally, grain yield. This is a hand held device that estimates the chlorophyll content of leaves, as leaf chlorophyll content is closely correlated to leaf nitrogen concentration. Compared with the traditional destructive methods of chlorophyll extraction, the use of this equipment saves time, space, and resources.

Therefore, the experiment was carried out with the following objectives;

(1) To investigate the effective nitrogen fertilizer management practices for Palethwe 1 (fixed time nitrogen management, FTMN Vs real time N management , RTMN)

(2) To analyze the effect of fixed time nitrogen management, SPAD and LCC based nitrogen management on growth, productivity and agronomic efficiency of Palethwe 1

(3) To determine the relationship of SPAD values and LCC scores with the grain yield of Palethwe 1.

CHAPTER II

LITERATURE REVIEW

2.1 Importance of Rice

Rice (*Oryza sativa* L.) is the most important food crop and a major food grain for more than a third of the world's population (Zhao et al. 2011). Rice is eaten by about 3 billion people and is the most common staple food of the largest number of people on earth (Maclean et al. 2002). It is a major crop of 89 countries in the world and is the stable food for half of the world population (Nachimuthu et al. 2007). It is the most important food grain in the diets of hundreds of millions of Asians, Africans, and Latin Americans living in the tropics and subtropics. In these areas, population increases are high and will likely remain high at least for the next decade. Rice will continue to be their primary source of food.

World rice production must increase by approximately 1.5% annually to meet the growing demand for food that will result from population growth and economic development (Rosegrant et al. 1995). It has been estimated that in 2050 the world's population will have increased by a factor of 1.4 - 1.5 over the present level. This projected demographic increase will occur mostly in Asia, which is home to 60% of the world population where people depend on rice as their staple food. It is therefore crucial to increase rice production within a relatively short period (Mae 1997).

Agriculture in Myanmar, dominated by paddy rice cultivation, generates a direct or indirect economic livelihood for over 75% of the population. Rice is grown throughout the country by resource poor rural farmers and landless agricultural laborers on small farms averaging only 2.3 ha in size (Okamoto 2004). In the past 10 years, the growth of rice yield has dropped below 1% per year worldwide, but a rice yield increase of more than 1.2% per year will be required to meet the growing demand for food that will result from population growth and economic development in the next decade (Normile 2008).

2.2 Climatic Requirement for Rice

Rice crop is best suited to tropical and sub-tropical humid climate but it is grown in variety of climate except extreme cold temperate. The climatic factors that affect rice production are temperature, solar radiation and humidity (Yoshida 1981).

The atmospheric temperature has considerable effect on growth and development of rice plant. Rice needs relatively high temperature for their optimum growth and development. With irrigation, planting can be adjusted to take advantage of favorable climatic conditions such as optimum temperature and high solar radiation (Datta 1981).

Rice is needed the different temperature for different growth stages. For vegetative growth, a temperature range of 25˚C to 30˚C and for grain filling and ripening 20˚C to 25˚C temperature was reported best. For higher grain yield a day temperature of 25˚C to 32˚C and night temperature of 15 to 20˚C is preferable. Temperature beyond 35˚C affects not only pollen shedding but also grain filling. A higher mean temperature ranging between 25˚C to 32˚C per day would reduce the growth duration and accelerate flowering whereas a mean temperature of less than 15˚C would slow during vegetative growth and plants fail to flowers. Therefore, for vigorous vegetative growth moderately high temperature is required.

It is well known that mild temperature of night and clear sunny weather during day time is better for high yield of rice, but temperature less than 15˚C is not conducive for panicle initiation as well as for crop growth (Yoshida 1977, 1981). Solar radiation is essential for photosynthetic activity of rice plant. As such, the growth, development and yield of rice plants are affected by the level of solar radiation (Nguyen 1998). If irrigation water is available, rice can be grown in the dry season and the grain yield will be higher than in the wet season because of the higher intensity of solar radiation (Datta 1981).

2.3 Soils Requirement for Rice

Rice is adaptable to all kinds of soils and practically all soil types are found in the world's rice growing areas. The suitability of a soil for rice cultivation depends more on the conditions under which the plants are grown than upon the nature of the soil itself. Rice is grown in all types of soils; the best soils are clay loams, the characteristic of deltas. These soils become soft to very soft on puddling and crack deep when dry. The semi aquatic nature of the crop necessitates a heavy soil through which the irrigation or rain water will not be easily drained away because the demands of rice are more precise for water than soil conditions. Rice is able to tolerate a wide range of soil reaction but it may have a preference for acidic soils. The crop has preference to 5.5 to 6.5 pH. Red soils, black soils and laterite soils are also suitable.

2.4 Impacts of Hybrid Rice

Hybrid rice can be produced by crossing two inbred, genetically fixed varieties of a particular crop. These hybrids are special, because they have heterosis or hybrid vigor. If two parents which are genetically distinct from each other are crossed, the offspring will be superior and produce higher yields. This effect is known as heterosis and it disappears after the first generation (F_1). Therefore farmers cannot save the seeds produced from hybrid crops. They need to purchase new F_1 seeds in every planting season to make use of the heterosis effect (Kuyek et al. 2000).

Hybrid technology was successfully developed in China during 1964 to 1975. Today, hybrid rice covers around 50% of the rice area (30 million ha) in China. Other countries are successively catching up. This hybrid rice technology is being developed in about 20 countries worldwide. Vietnam, India, the Philippines, Bangladesh, Indonesia, Myanmar and the USA are the most important countries which use this technology and in total it covers around 800,000 ha of arable land. Hybrid rice has proven to be more suitable for scare land, large population, and cheap labor areas. Commercial exploitation of hybrid vigor is one of the most important applications of genetics in agriculture. Heterosis of hybrid rice is credited for large increases in production per unit area, thus sparing large amounts of land for other uses such as environmentally begnin nature preserves. Thus hybrid rice technology is very important for the food security (FAO 2004).

Hybrid rice differs from HYVs in many of the following aspects: seed rate of hybrids is 65-70% less than that of HYVs. Hybrid rice is more responsive to fertilizers than HYVs. Average spikelets per panicle produced in hybrids are generally more than that of HYVs. During vegetative growth stage, hybrid rice accumulates more dry matter which results in more spikelets per panicle, whereas in HYVs spikelets per panicle is governed by the accumulation of assimilates after heading. About 90% of grain carbohydrates come from photosynthetic assimilation after heading in early maturing HYVs, while in hybrid rice 30 - 40% of the grain carbohydrate comes from assimilation before heading and remaining 60 - 70% comes after heading. Hybrids and HYVs have similar grain filling percentage at suboptimal and optimal plant densities. However, at higher plant density, it is comparatively low in hybrids.

2.5 Nitrogen Sources

The earth's atmosphere consists of 78 percent nitrogen and is the ultimate source of nitrogen. In most areas of the world, the nitrogen found in soil minerals is negligible. Nitrogen may be added to or lost from soil by a number of processes. In the soil, nitrogen can undergo a number of transformations. Rainfall adds about 10 pounds of nitrogen to the soil per acre per year. The nitrogen oxides and ammonium that are washed to earth are formed during electrical storms, by internal combustion engines and through oxidation by sunlight. Some scientists also believe that some of the gaseous products that result from the transformation of nitrogen fertilizers may cause a depletion of the ozone (O_3) layer around the earth. The extent of this possible damage has not been substantiated. Crop residues decompose in the soil to form soil organic matter. This organic matter contains about 5 percent nitrogen. An acre-foot of soil having 2 percent organic matter would contain about 3,500 pounds of nitrogen. Generally, about 1 to 3 percent of this organic nitrogen is converted per year by microorganisms to a form of nitrogen that plants can use.

Legumes fix atmospheric nitrogen through their symbiotic association with *Rhizobium* bacteria. If plant roots are well nodulated, the legume plant does not benefit from the addition of fertilizer nitrogen. Perennial legumes, such as alfalfa, can fix several hundred pounds of nitrogen per acre per year. Manure contains an appreciable amount of nitrogen. Most of this nitrogen is in organic forms: protein and related compounds. Cattle manure contains about 10 to 40 pounds of nitrogen per ton. About half of this nitrogen is converted to forms available to plants during the first growing season. Lesser amounts are converted during succeeding seasons. Each ton of applied manure is equal to about 5 to 20 pounds of commercial fertilizer nitrogen.

Commercial fertilizer nitrogen comes in three basic forms: gas, liquid and dry. All forms are equally effective when properly applied. Once applied, fertilizer nitrogen is subject to the same transformations as other sources of nitrogen. There is no difference between the ammonium (NH_4^+) or nitrate (NO_3^-) that enters the plant from commercial fertilizer and that produced from natural products such as manure, crop residues or organic fertilizers. (Barbarick 2013)

2.6 Functions of Nitrogen in Plant

It is not only an essential component of amino acids, all proteins but also an essential component of nucleic acids, and therefore needed for all cell division and reproduction. Enzymes are specialized proteins, and serve to lower energy requirements to perform many tasks inside plants. Nitrogen is contained in all enzymes essential for all plant functions. Nitrogen has greater influence on and yield of crop plants than any other essential plant nutrient. It plays a pivotal role in many physiological and biochemical processes in plants. It is a constituent of the chlorophyll molecule, which plays an important role in plant photosynthesis. Many enzymes are proteinaceous; hence, nitrogen plays a key role in many metabolic reactions. Nitrogen is also a structural constituent of cell walls.

Of all mineral nutrients, nitrogen is quantitatively the most important for plant growth. Uptake of N from the soil is mainly in the form of ammonium (NH_4^+) and nitrate (NO_3^-). An important factor for regulation of nitrogen uptake is also the carbohydrate production and delivery to the roots. Nitrogen nutrition influences leaf growth and leaf area duration and the number and size of vegetative and generative storage organs (Lawlor et al. 1989; Hageman and Below 1990; Wullschleger and Oosterhuis 1990).

2.7 Nitrogen Deficiency Symptom

Nitrogen(N) is highly soluble and highly mobile and also rapid transformation into leachable forms. Nitrogen deficiency symptoms first appear in the lower or older leaves. The nitrogen deficiency symptoms first start in the tips and margins of the leaves. Symptoms include poor plant growth, and leaves that are pale green or yellow because they are unable to make sufficient chlorophyll. Leaves in this state are said to be chlorotic. Lower leaves (older leaves) show symptoms first, since the plant will move nitrogen from older tissues to more important younger ones.

Nitrogen-deficient plant leaves are yellowish and pale in color due to a loss of chlorophyll. In cases of severe deficiency, whole leaf becomes yellow and dry.

Nitrogen-deficient plants grow slowly, and their leaves are small. Nitrogen deficiency also decreases leaf area index (LAI), lowers radiation use efficiency, and lowers photosynthesis activity in plants (Muchow 1988; Sinclair and Horie 1989; Fageria and Baligar 2005). A significant positive association has been reported between the light saturation rate of photosynthesis of a leaf and its nitrogen content (Evans 1989; Poorter and Evans 1998).

The reason for this strong relationship is the large amount of leaf organic nitrogen (up to 75%) present in the chloroplasts, most of it in the photosynthetic machinery (Evans and Seemann 1989; Poorter and Evans 1998). Seeds are small and yields are reduced in cereals and legume crops under N-deficient conditions. The reduction in yield and quality are directly related to the severity of the N deficiency.

2.8 Sulphur and Nitrogen Interaction in Soil

Because of central role of sulphur (S) and nitrogen (N) in the synthesis of proteins, the supplies of these nutrients in plants are highly inter-related. Sulphur and nitrogen relationships were established in many studies (Zhao et al., 1993; McGrath and Zhao 1996; Ahmad et al. 1998; and Jamal et al. 2005, 2006, 2010) in terms of dry matter and yield in several crops. An intensive agriculture with use of improved cultivars and high analysis fertilization offers conditions of nutrients exhaustion resulting in nutrient imbalance in soils. Fazili et al. (2008) reported that lack of sulphur (S) limits the efficiency of added nitrogen; therefore, sulphur addition becomes necessary to achieve maximum efficiency of applied nitrogenous fertilizer. Kowalenko and Lowe (1975) noticed that a high N: S ratio (produced by addition of N) resulted in a decrease in mineralization of S in the soil sample during incubation. Janzen and Bettany (1984) indicated the optimum ratio of available N to available S to be 7:1. Ratios below 7 gave the reduced seed yields.

2.9 Losses of Nitrogen from Fertilizer Applied to Rice

Nitrogen is lost from the soil system in several ways such as leaching, runoff and erosion losses, volatilization and Denitrification.

2.9.1 Leaching

Leaching losses involve the movement of water downward through a soil below the root zone. This loss most frequently occurs with nitrate (NO_3^-) in areas of high rainfall, under excessive irrigation and with coarse-textured (sandy) soils. Losses of nitrogen through leaching reduce the amount of nitrogen available to crops and may potentially contaminate shallow water wells and aquifers.

Kudeyaruov (1989) resulted that leaching losses of 3 - 9% in Russia. Irrespective of the N source, the concentration of N in the leachates was higher where the entire N was applied as basal instead of split dressings (Mahajan and Tripathi 1992). Katyal et al. (1985) reported that leaching losses for the loss of N and poor performance of the urea super granules placed below the soil surface of highly percolating soil with low Cation exchange capacity (CEC). Similar findings were indicated by Vlek et al. (1980) for a greenhouse experiment.

2.9.2 Runoff and erosion losses

It may include nitrate (NO_3^-), ammonium (NH_4^+), and organic nitrogen. The negatively charged NO_3^- ion remains in the soil water and is not held by soil particles. If water containing dissolved NO_3^- or NH_4^+ runs off the surface, these ions move with it. Although ammonium-nitrogen can be strongly fixed to clay particles and is less at risk to leaching than nitrate, under normal conditions ammonium-N in the soil is rapidly converted to nitrate. Nitrate is the form of N that can be leached when precipitation (or irrigation) exceeds the soil’s ability to hold water in the crop root zone.

Annual nitrogen loss through erosion was 18.3 kg ha^{-1} from upland rice fields in china (Peng et al. 1995). Ma (1997) also observed that the annual loss of N via drainages of surface water prior to transplanting rice seedling and via runoff was 9.3 and 19.8 kg ha^{-1}, respectively in rice wheat rotation in China. Craswell and Velk (1982) concluded that the degree of outflow of water from rice field was variable, depending on the site, season, and degree of water control and water management. They also reported runoff losses in the ranges of 4 - 16 Kg N ha^{-1} in Japan, 19 - 30 Kg N ha^{-1} in the Philippines and California.

2.9.3 Denitrification

Denitrification occurs in the flooded rice soils following the nitrification of ammonium into nitrate (NO_3^-). Nitrification occurs at a distance of 0 - 2 mm from root surface while denitrification occurs at a distance of 1.5 - 5.0 mm (Arth and Frenzel, 2000). In this process, NO_3^- is reduced by a series of steps to nitric oxide (NO), nitrous oxide (N_2O), and nitrogen (N_2) gases, which are then released into the atmosphere (Reddy and Patrick 1986). Nitrogen in the NH_4^+ form is not subject to this loss. Management alternatives are available if denitrification losses are a potential problem. Linquist et al. (2006) reported that shortly after flooding for planting, most nitrate is lost from the soil plow layer and most mineral nitrogen is in the form of ammonium. The nitrate present prior to flooding the fields for planting would most likely have been lost via denitrification (Buresh and De Datta 1991).

Gaseous N losses due to denitrification from applied fertilizer N have been reported as being about 10% in lowland rice (De Datta et al. 1991). Cai et al. (2002) also reported that denitrification loss was not a significant pathway of N loss from N fertilizer applied to submerged rice during the rice growth period. In some cases, a high mitigation rate of N_2O emission was observed when using slow-released fertilizers. (Delgado and Mosier 1996; Akiyama et al. 2000, Hou et al. 2000, Yan et al. 2000)

2.9.4 Ammonia Volatilization

Ammonia volatilization is the loss of nitrogen to the atmosphere as ammonia gas. Ammonia production and loss is typically associated with urea hydrolysis in soils. Upon hydrolysis of urea the pH around the urea particle is increased drastically and the proportion of nitrogen in the ammonium form is shifted towards ammonia. Ammonia is then released into the atmosphere and no longer available to the plant. Ammonia loss may be as great as 60% of the nitrogen applied as urea. Several factors affect the volatile loss of ammonia.

Ammonium ions in the soil solution enter into an equilibrium reaction with NH_3 in the soil solution. The soil-solution NH_3 is, in turn, subject to gaseous loss to the atmosphere. Soil pH and concentration of NH_4 in the soil solution are important. As soil pH increases above 6.0 the NH_3 form, as a fraction of soil-solution NH_4 plus soil-solution NH_3 , increases by an order of magnitude; thus, increasing the loss of soil-solution NH_3 to the atmosphere.

Significant losses from some surface-applied N sources can occur through the process of volatilization**.** In this process, N is lost as the ammonia (NH_3) gas. Nitrogen can be lost in this way from manure and fertilizer products containing urea. Ammonia is an intermediate form of N during the process in which urea is transformed to NH_4^+. Loss of N from volatilization is greater when soil pH is higher than 7.3, the air temperature is high, the soil surface is moist, and there is a lot of residue on the soil.

Ammonium loss was an important pathway of N loss from N fertilizer applied to rice (30 - 39%) applied N (Cai et al. 2002). Cai (1997) also resulted that ammonia loss was the dominant pathway of N loss from soil and accounted for up to 40%. Fillery et al. (1984) reported that ammonia loss accounted for a 30 - 50% of nitrogen applied to floodwater 2 - 3days after transplanting. Ammonia loss from well-developed rice canopies occurred in the range of 11 - 13% N applied as urea and ammonium sulphate after panicle initiation (Frenay et al. 1981; Fillery et al. 1984).

2.10 Ways to Minimize Nitrogen Losses

2.10.1 Fertilizer deep placement (FDP)

Deep placement of urea eliminates nitrogen losses due to volatilization, denitrification and floodwater run-off, allowing farmers to realize a 30% increase in yields over the same nitrogen when conventionally applied (Bowen et al. 2005). Deep placement of fertilizers, particularly urea, has resulted in improved yields and lower nitrogen and phosphorus losses from flooded rice fields (Kapoor et al. 2008; Bowen et al. 2005). Deep placement also ensures nitrogen availability beyond the flowering stage due to reduced early tillering and more available nitrogen encourages algal biological nitrogen fixation because of low floodwater nitrogen concentration and reduces weed competition (Singh 2005). Paddy yields, labor requirements and production costs were compared for deep placement versus conventional urea application (Thompson and Sanabria 2009).

2.10.2 Slow and Controlled Release Fertilizers

Slow and controlled release fertilizers have been defined as fertilizers that are formulated to either delay nutrient availability after application or result in a longer period of plant availability over time compared to conventional fertilizers, such as urea and ammonium nitrate (Subbarao et al. 2006). These forms of N fertilizers are designed with chemical and physical properties that regulate or slowly release N into soil solution to meet plant needs, reduce NH_4^+ availability to nitrifying bacteria, and subsequently reduce NO_3^- leaching or gaseous loss as N_2O or NO. Urea or other nitrogen source is coated with a polymer so that the N release pattern is regulated to match crop N demand.

Examples of these fertilizer products include urea-formaldehyde based fertilizer, sulfur-coated urea, and polymer-coated/encapsulated products (Subbarao et al. 2006). Among the possible advantages of these fertilizers are that they may decrease the rate of nitrogen release at times when potential for nitrogen loss (i.e. leaching, runoff and gaseous loss) is high (e.g. wet conditions); they may improve the timing of fertilizer nitrogen release to match crop N requirements over the growing season thereby increasing Recovery Efficiency of Nitrogen (RE_N); and they may decrease the potential for salt injury allowing the fertilizer to be placed closer to plants which may also increase (RE_N).

Control release nitrogen fertilizer is highly efficient in use, because of its regulated nitrogen release and its ease of placement with seed that enhances crop nitrogen uptake (Shoji et al. 2001). Control release nitrogen fertilizer produced more grain yield per unit of nitrogen applied (26 to 45 kg additional grain per kg N in dry season and 12 to 20 in wet season) than conventional split N application with AE_N values of 19-22 for DS and 7-15 for WS. However, the high cost of CRNF prevents its widespread use by farmers.

2.10.3 Nitrification Inhibitors

Nitrification inhibitors (NI) are chemicals that slow down, delay, or restrict the nitrification process, thereby decreasing the risk of nitrate that will occur before the fertilizer nitrogen is utilized by plants. These chemicals inhibit the metabolism of *Nitrosomonas* bacteria involved in the nitrification process. Therefore, they can potentially reduce the amount of nitrate that can be leached out of the rooting zone or transformed into N_2O gas through denitrification. Among the common nitrification inhibitors are nitrapyrin (N-Serve, Dow Chemical Co., Midland, MI) and dicyandiamide (Guardian, Conklin Co., Shakopee, MN).

Urease inhibitors (UI) reduce the rate at which urea is hydrolyzed and converted to ammonium by inhibiting the activity of urease, a common enzyme in soil (Subbarao et al**.** 2006). By delaying this hydrolysis, volatile losses of ammonia which occur primarily at the soil surface can be reduced. Ammonia volatilization losses due to surface application of urea range from 5 to 20% and can be as high as 50% under extreme conditions (Gioacchini et al. 2002 and Laboski 2006).

Conditions favoring ammonia volatilization from urea or urea-based fertilizers include surface-application of the fertilizer, relatively high surface soil pH, high amounts of surface residue, warm and windy weather, high relative humidity and adequate soil water content (Bouwmeester et al. 1985 and Gehl 2007). Additional possible benefits of use of urease inhibitors to delay urea hydrolysis include possible reductions in nitrate leaching losses and lower N_2O losses (Prakash et al. 1999). Urease inhibitors also decreased damage to germinating seeds and seedlings caused by released ammonia and nitrite when urea is band placed close to seed (Malhi et al. 2003).

2.11 Nitrogen Management Strategies

Two major strategies followed in N management are:

- 2.11.1 Blanket-fertilizer nitrogen recommendations
- 2.11.2 Crop-need-based nitrogen management.

2.11.1 Blanket-fertilizer nitrogen recommendations.

Blanket-fertilizer nitrogen recommendations generally take into account crop response to applied N as basis to calculate the amount of N required to achieve a targeted yield. It provides a recommendation for the total fertilizer N requirement (kg/ha) and a plan for the splitting and timing of applications in accordance with crop growth stage, cropping season, variety used, and crop establishment method. These recommendations do not consider variability in soil N supply and changes in crop demand. Farmers generally apply too much N (and little P and K and other nutrients) that results in high incidence of pests and diseases, besides lodging. The consequence of high N application is high pesticide use to control pests, more expenditure on pesticides and reduced yield and poor grain quality due to lodging. In addition, excess N is leached into water sources that get polluted over time. Farmers suffer from more pesticide-related health risks.

2.11.2 Crop-need-based nitrogen management

Crop-need-based nitrogen management approach takes into account variability in soil nitrogen supply and crops additional requirement for nitrogen fertilizer. This means that rice crops in different fields require different amounts of nitrogen input. Before leaf color chart (LCC) and chlorophyll meter (SPAD) was developed fixed time split application based on crop growth stages (basal, mid tillering, panicle initiation (PI) and flowering) was used. However being need-based, it can treat deficiency on a timely basis but requires careful periodic monitoring of crop nitrogen status. The main tool used for periodic monitoring of nitrogen status are chlorophyll meter (SPAD) and the leaf color chart (LCC).

2.11.2.1 Fixed time split application

Split nitrogen (N) fertilizer applications can play an important role in a nutrient management strategy that is productive, profitable and environmentally responsible. Dividing total nitrogen application into two or more treatments can help growers enhance nutrient efficiency, promote optimum yields and mitigate the loss of nutrients. This practice minimizes the risk of placing all the nitrogen at the time of seeding. It reduces the exposure of nitrogen in saturated soils where the potential for losses such as leaching and denitrification are increased. By more specifically synchronizing nitrogen supply with a plant’s ability to utilize nutrients, split application can be an important component of 4R Nutrient Stewardship - right source, right rate, right time and right place.(The Fertilizer Institute 2014.)

2.11.2.2 Real time nitrogen management

Use of N in excess of crop requirement and inefficient splitting of N applications are the main reasons for low N use efficiency in rice. Farmers generally apply nitrogen fertilizer in several splits, but the number of splits, amount of nitrogen applied per split, and the time of applications are not as per requirement as well as not as per recommended. The apparent flexibility of rice farmers in adjusting the time and amount of fertilizer application offers potential to synchronize nitrogen application with the real-time demand of the rice crop. Since improving the synchrony between crop N demand and the N supply from soil and/or the applied N fertilizer is likely to be the most promising strategy to increase N use efficiency, the split application of fertilizer N is going to remain an essential component of fertilizer N management strategies in rice. Real-time N management is based on periodic assessment of plant N status, and the application of fertilizer N is delayed until N deficiency symptoms start to appear. The main tools for real time nitrogen management are leaf color chart (LCC) and chlorophyll meter (SPAD). (Amir Hossian 2011)

2.11.2.2.1 Leaf Color Chart (LCC)

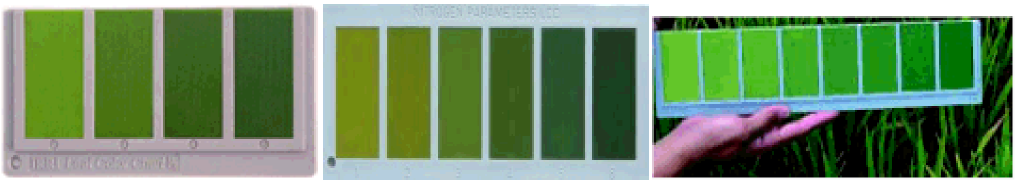
Leaf color is a good indicator for plant health and nutrition. Different types of stress may cause different symptoms and a comparative analysis can yield information about the type of stress. Nitrogen deficient leaves turn to pale or yellowish green rather than dark green and farmers generally prefer to keep leaves of the crop dark green. The LCC is made of high impact plastic. The color strips are fabricated with veins resembling rice leaves. It is inexpensive (at approximately US$1 a piece), simple and easy to use. It measures leaf color intensity related to leaf N status.

LCC is an ideal tool for individual farmers to optimize N use in rice at high yield levels irrespective of the source of N applied, i.e., organic manure, biologically fixed N, or chemical fertilizers. Figure (2.1) shows three different types of LCC. Standardized LCC with four colours shade from pale (No.2) to dark green (No.5). Six- panel LCC was an improved version (Figure 1b) (IRRI, 1996; Singh et al. 2010).Recently, researchers at the University of California developed another eight-panel LCC (UCD-LCC) (Figure 2.1c) with scale of eight green color shades (1–8). It has mainly been applied to rice crops.

2.11.2.2.2 Chlorophyll Meter (SPAD)

Minolta Co. (Japan) developed the chlorophyll meter (SPAD-502) or SPAD meter. This instrument weighs 225 g, has a 0.06 cm^2 measurement area, and calculates an index in SPAD units. The SPAD meter estimates the relative chlorophyll concentration in a leaf by measuring the differential transmittance of light through it. Within a small chamber (2 - 3 mm) in which part of a leaf is being held, the meter emits light from two diodes, one producing a peak wavelength near 650 nm (red), which is absorbed by chlorophyll and the other, a peak near 940 nm (infrared), which is transmitted through leaves and serves as an internal reference to compensate for leaf thickness and moisture content (Shapiro et al. 2006).

More red lights are absorbed by leaves when more chlorophyll is present. Thus, the chlorophyll concentrations of leaves are correlated with SPAD meter values. It measures the relative greenness or chlorophyll content of leaves (Turner and Jund 1994) because leaf chlorophyll content is closely related to leaf N concentration (Balasubramanian et al. 1999), this meter has been used to assess foliar N content. It makes simple, rapid, and nondestructive measurements to provide a relative indication of leaf chlorophyll concentration compared to the extraction method (Yadava 1986; Marquard and Tipton 1987; Yamamoto et al. 2002).



(a) (b) (c)

Figure 2.1 (a) LCC with four color shades (b) LCC with six color shades (c) LCC with eight color shades

Figure2.2 A chlorophyll meter (SPAD-502).

CHAPTER III

MATERIALS AND METHODS

Two successive pot cultivation experiments were carried out. Pot experiment I was conducted from February 2013 to June 2013 and experiment II was carried out from July 2013 to October 2013.

3.1 Experimental Site

The experiment was conducted at screen house, Department of Soil and Water Science in Yezin Agricultural University which is located at (15º 52'N and 96º 07'E) with the elevation of 213 meters above sea level.

3.2 Experimental Design

Experiment was laid out as in Randomized Complete Block Design (RCB) with 4 replications.

3.3 Treatments

T_1	C	- Control (no N application)
T_2	FTNM	- 75 Kg N ha^{-1} (basal, midtillering , PI and flowering stage)
T_3	FTNM	- 150 Kg N ha^{-1} (basal, mid tillering , PI and flowering stage)
T_4	<SPAD 35	- < SPAD (35) with 30 Kg N ha^{-1} each time
T_5	<SPAD 37	- < SPAD (37) with 30 Kg N ha^{-1} each time
T_6	<LCC 3	- < LCC (3) with 30 Kg N ha^{-1} each time
T_7	<LCC 4	- < LCC (4) with 30 Kg N ha^{-1} each time

Treatment T_2 and T_3 were fixed time nitrogen managements (FTMN) in which 75 and 150 Kg N ha^{-1}applied as basal and 3 equal splits. Real time nitrogen managements are treatment T_4, T_5, T_6 and T_7. In treatment T_4 and T_5, 30 Kg N ha^{-1} were applied whenever the SPAD values were observed lower than 35 and 37. In treatment T_6 and T_7, 30 Kg N ha^{-1} were applied whenever the LCC values were observed lower than 3 and 4.

3.4 Experimental Soil

Soil samples for site characterization were collected at 0 to 15 cm depth from different locations in the Yezin Agricultural University field. The sample was air-dried, ground and sieved through a 2 mm sieve. Some physicochemical properties of soil such as soil texture, soil pH, available N, available P, available K, organic matter %, and cation exchange capacity (CEC) of soil sample were analyzed at the Department of Agricultural Research before growing the plant.

Table 3.1 Physicochemical properties of experimental soil

Properties	Values
Soil Texture	sandy loam
Soil pH	6.17
Available N	60 ppm (medium)
Available P	10 ppm (medium)
Available K	44 ppm (low)
Bulk density	1.5 gcm^{-3}
Organic matter	1.6% (low)
Cation Exchange Capacity	6.8 (low)

3.5 Pot Preparation

The size of the pots was 26 cm in height, 30 cm diameter at the top and 21.3 cm at the bottom. The soil was filled from the bottom of the pot up to 23 cm and it was submerged about two weeks. 18.53 kg of soil was put in each pot. According to the recommended rate from Yuan Longping. and Fu (1995) and Department of Agricultural Research, a dose of 70 kg of P_2O_5 ha^{-1} and 120 kg of K_2O ha^{-1} and 8 kg of S ha^{-1} and 3.36 kg of Zn ha^{-1} was applied into the soil as basal. 30kg of Nha^{-1} was used as basal except T_1 (control). The total amount of P as triple super phosphate, K as KCL, S as gypsum, Zn as zinc sulfate were applied immediately before transplanting. Twenty days old seedlings of Palethwe 1 were transplanted 15cm x

1cm with 2 plants per pot in February, 2013 in dry season and July, 2013 in wet season. Water was applied as needed.

3.6 Chlorophyll Meter and Leaf Color Chart Measurement

The SPAD reading was taken by a chlorophyll meter (SPAD-502, Minolta Co., Japan), starting from 14 days after transplanting until 50% flowering. From each hill, SPAD readings were taken from the uppermost fully expanded leaf, one side of the midrib of the leaf blade, midway between the leaf base and tip.

In addition to SPAD, the LCC jointly developed by International Rice Research Institute (IRRI) and Philippine Rice Research Institute (Phil Rice)consisting of four green shades (2 - 5) from yellowish green to dark green, showing increasing greenness with increasing number, was used in this study. From each hill topmost fully expanded leaf was selected and LCC readings were taken by placing the middle part of the leaf on the chart and the leaf color was observed by keeping the sun blocked by body as sun light affects leaf color reading.

3.7 Test Cultivar

Palethwe 1, Hybrid rice (110 days) was used in this experiment.

3.8 Data Collection

Growth parameter such as plant height and number of tillers hill^{-1} was recorded one week interval. Plant height was measured from the surface of the soil to the tip of the topmost leaf. The number of tillers hill^{-1} was recorded until the heading stage. LCC scores and SPAD values were recorded weekly intervals from 14 days after transplanting until 50% flowering.

3.9 Measurement Parameter for Yield and Yield Components

The spikelets number panicle^{-1}, panicle length, filled grain %, unfilled grain % and 1000 grain weight were measured at harvest. The grain was harvested from the pot area and hand threshed, winnowed and sun dried. The dried grains from each treatment were weight and computed to gram per plant.

3.10. Agronomic Efficiency will be calculated by the following equation.

$$\text{Agronomic efficiency (AE)} = \frac{\text{Grain yield (g plant}^{-1}\text{) in N pot - control}}{\text{Quantity of N fertilizer applied in N fertilized pot}}$$

(Peng and Cassman et al. 1998)

3.11 Pest and Disease Management

Hand weeding was done whenever necessary in both seasons. Although there was no found insect pest damage in the dry season, the incidence of stem borer was found in the wet season. Therefore, carbosulfan was used for stem borer.

3.12 Data Analysis

The data were analyzed by using GenStat (9th version) and differences between means were compared by using least significant difference test at 5% level. SPSS program was utilized for correlation analysis.

3.13 Weather Data

All weather data for both seasons were obtained from meteorological station at Department of Agricultural Research, Yezin .

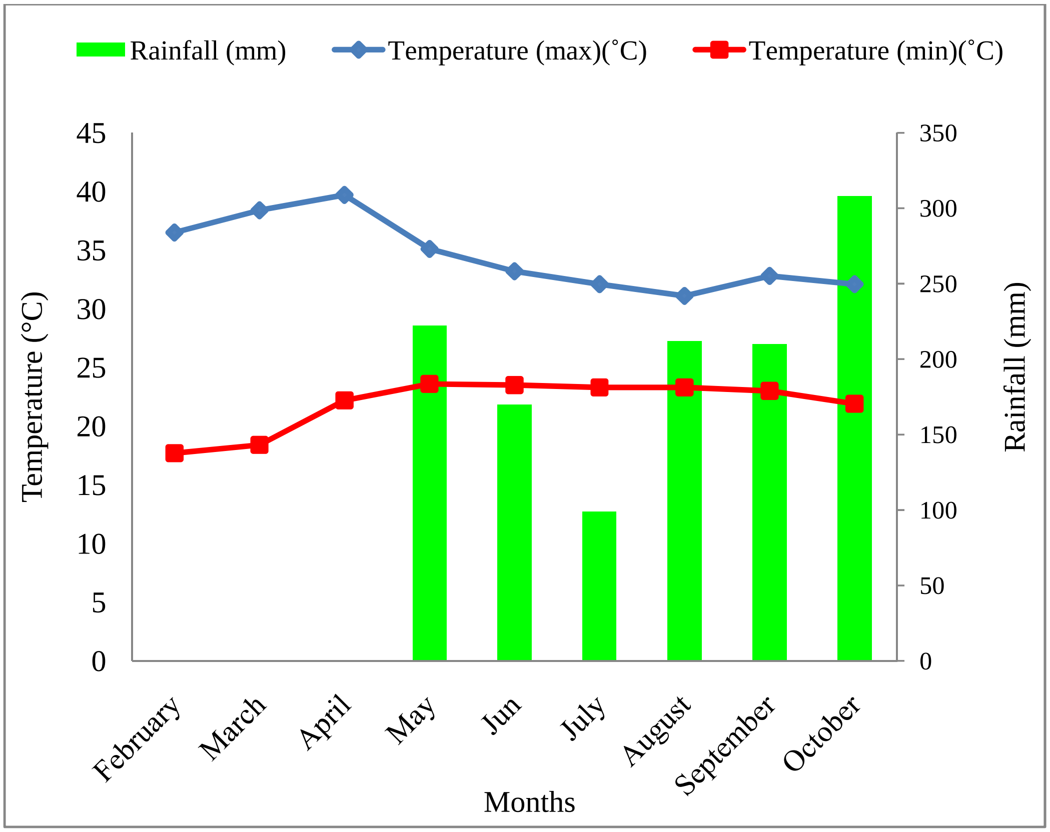


Figure 3.1: Monthly rainfall, average minimum and maximum temperature during experimental period (February- October, 2013).

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Experiment I (dry season, 2013)

This experiment was performed to compare the effect of fixed time nitrogen management, SPAD and LCC based nitrogen application on the response of hybrid rice during dry season from February to June.

4.1.1 Effect of fixed time nitrogen management, SPAD and LCC based nitrogen application on growth parameter and yield and yield components of hybrid rice (Palethwe 1) during dry season , 2013

4.1.1.1 Plant height (cm)

The plant height was measured at 7 days interval from 14 to 70 Days after transplanting (DAT). Plant height at 14, 21, 28, 35, 42, 49, 56, 63 and 70 days after transplanting (DAT) were shown in Figure 4.1. The plant height in all treatments increased continuously from 14 DAT to 70 DAT. Plant height among the treatments were not significantly different at 14, 21, 56, and 70 DAT. There was significant difference in plant height at 35 and 63 DAT. The highly significant difference in plant height among the treatments was occurred at 28, 42 and 49 DAT.

At 28, 35, 42 and 49 DAT, the highest plant height was obtained from T_7 (<LCC (4) with 30KgNha^{-1} each time) and the T_1 (untreated control) gave the lowest plant height. Balasubramanian et al. (1999) observed that increase in growth and yield parameters with the SPAD and LCC based nitrogen management.

At 63 DAT, the highest plant height value was also recorded from T_3 (150 kg N ha^{-1}; basal, mid tillering, PI and flowering stage) and the lowest values in T_1 (control).

The increase in plant height due to application of increased level of nitrogen might be due to associate with stimulating effect of nitrogen on various physiological process including cell division and cell elongation of the plant. Manzoor et al. (2006) reported that the increase in plant height with increased N application might be primarily due to enhanced vegetative growth with more nitrogen supply to plant.

4.1.1.2 Number of tillers per hill

The tiller numbers were counted at 7 days interval from 14 to 70 Days after transplanting (DAT). The number of tillers per hill as affected by fixed time nitrogen management, SPAD and LCC based nitrogen application was not significantly different at all growth stages except 56, 63 and 70 DAT which were highly significant at 1 % level.

At 56 DAT, 63 DAT and 70 DAT, the greatest number of tillers per hill were recorded from T_7 (<LCC (4) with 30Kg Nha^{-1} each time) and the lowest tiller numbers were produced from T1 (control) respectively.

The second most tiller numbers were produced by T_3 (150 kg N ha^{-1} (basal; mid tillering stage, PI and flowering stage) in all stages. T_7 was also used 150 Kg of nitrogen per hectare. Yosef Tabar (2012) observed that 150 kg/ha nitrogen treatment gave the maximum tillers. This might be due to favorable effect of N on cell division and tissue organization that ultimately improved tiller formation at tillering stage (Huang et al. 2008).

4.1.1.3 Number of panicles per hill

At harvest, the number of panicles per hill was presented in (Table 4.1). The number of panicles per hill was significantly different at 1% level. The number of panicles per hill due to the effect of fixed time nitrogen management, SPAD and LCC based nitrogen application was in the range of 18.75 to 25. Rice plants produced the highest number of panicles per hill (25) at T_7, which was not statistically different from T_3 (23.38) and T_5 (22.88). T_1 (untreated control) obtained the lowest panicle number (19.75).

More panicles per hill in experiment might be due to the more availability of nitrogen that played vital role in cell division. These results are in accordance with the findings of Manzoor et al. 2006.

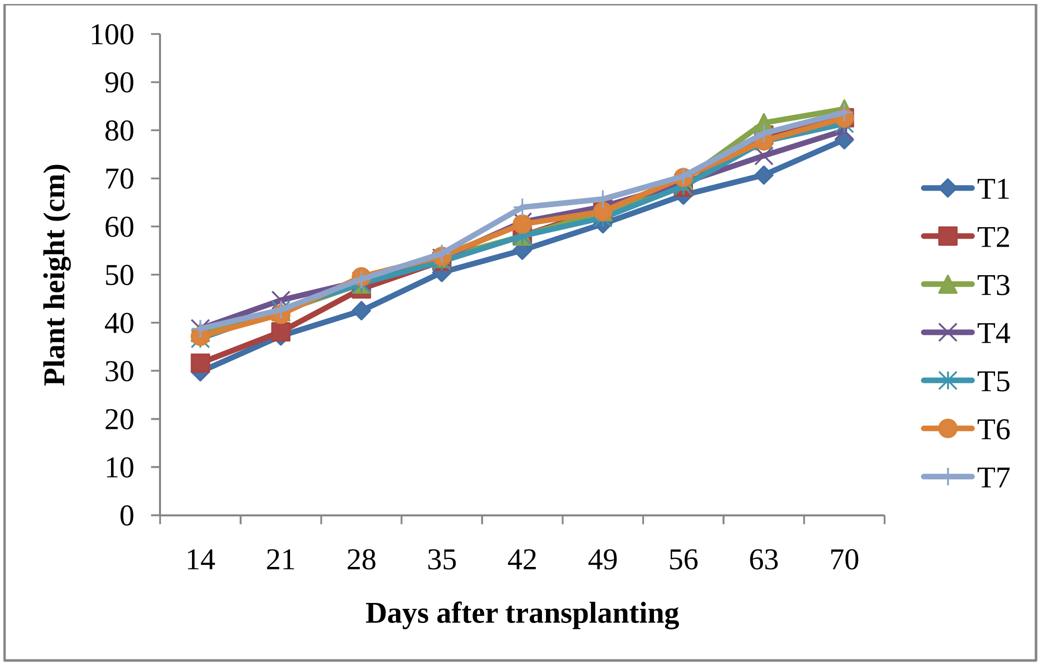


Figure 4.1: Mean values of plant height as affected as by fixed time nitrogen management, SPAD and LCC based nitrogen application in hybrid rice (Palethwe 1) during dry season, 2013

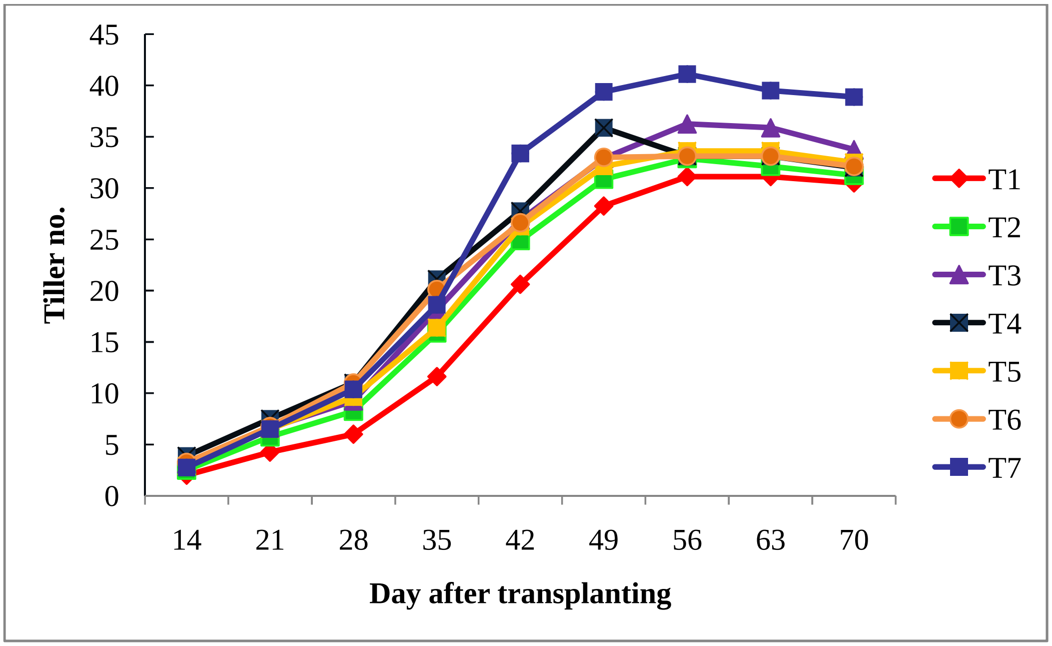


Figure 4.2: Mean values of tillers number per hill as affected as by fixed time nitrogen management, SPAD and LCC based nitrogen application in hybrid rice (Palethwe 1) during dry season, 2013

4.1.1.4 Number of spikelets per panicle

The number of spikelets per panicle, one of the yield component parameters was exhibited in (Table 4.1). In general, the number of spikelets per panicle is more or less directly correlated with rice grain yield .Number of spikelets per panicle was significantly difference among the different nitrogen levels at 5 % level. The largest number of spikelets per panicle was obtained from T_7 (<LCC (4) with 30 Kg Nha^{-1} each time). The untreated control treatment produced the lowest number of spikelets per panicle among the different nitrogen levels.

De Datta (1978) suggested that the N absorbed by the plant from tillering to panicle initiation tends to increase the number of tillers and panicles and that absorbed during panicle development (from panicle initiation to flowering) increases the number of filled spikelets per panicle.

4.1.1.5 1000 grain weight (g)

There was no significant difference in 1,000 grain weight (g) due to the responses of different nitrogen (Table 4.1). In fixed time nitrogen management, SPAD and LCC based nitrogen application, there was no significant effect on 1,000 grain weight (g) of Palethwe 1(hybrid rice). The maximum 1,000 grain weight (24.7 g) was produced by T_7 which was statistically similar with other treatments.

There is no significantly different in 1,000 grain weight due to the application of nitrogen. (Shivay and Singh 2003). Yoshida (1981) confirmed that the individual grain weight is usually a stable varietal character and the management practice has less effect on its variation.

4.1.1.6 Filled grain %

The response of filled grain % to the fixed time nitrogen management, SPAD and LCC based nitrogen application was clearly demonstrated in (Table 4.1). In this experiment, there was highly significant difference in filled grain % among treatments. T_7 gave the highest filled grain % and T_1 also gave the lowest value.

Dobermann and Fairhurst (2000) also stated that nitrogen increases panicles number, spikelets number per panicle and filled spikelets. Alagesan and Babu (2011) found that levels of N and time of application manifested favorable effect on the number of filled grain per panicle during the periods of study large number of filled grain in a panicle was recorded with the application of 160 kg N ha^{-1}.

4.1.1.7 Grain yield

According to the dry season results, grain yields as affected by fixed time N management and real time N management were shown in (Table 4.1). It can be clearly observed that there were statistically significant on grain yield of hybrid rice due to the effect of fixed time N management and real time N management. The highest grain yield was produced by T_7 (<LCC (4) with 30 Kg Nha^{-1} each time). The control plots produced the lowest grain yield among all other treatments during dry season. All treatments which received nitrogen application exceed the seed yield over control.

At the T_5 treatment (<SPAD (37) with 30KgNha^{-1} each time), grain yield was higher than T_4, T_6, T_2 and T_1 (control) except T_3 and T_7. The SPAD value-based N application can increase grain yield and N use efficiency of both hybrid and inbred varieties and hybrid can give an advantage of 6.5 % due to heterosis over the inbred varieties (Peng et al. 1998). Shukla et.al (2004) also reported that N application in recommended splits is not based on indigenous N supply.

The yield of T_7 was 30% greater than control, 21 % greater than T_2, 8 % greater than T_3, 10 % greater than T_4, 8 % greater than T_5, 12 % greater than T_6 in dry season. The same result was reported by the other researchers that N management based on LCC shade 4 could produce yield of hybrid PHB – 71 higher to those obtained in fixed schedule recommended N (Shukla et al. 2004).

4.1.1.8 Agronomic efficiency (AE)

The results (Table 4.2) suggested that the agronomic efficiency (AE) was the greatest in the treatment T_4, followed by T_6, T_5, T_7, T_3, and T_2. Kumar et al. (2001) and Velu et al. (2002) observed higher AE for SPAD based N application compared to the conventional method of N fertilization.

The treatment T_4 was 65% superior to treatments with fixed N splits, T_2 56% greater than T_3. The AE was higher 52% and 40% than T_2 and T_3 by treatment $T_{5.}$ The AE in the treatment T_6 was 61% and 40% larger than treatments with fixed N splits, T_2 and T_3 .Treatment T_7 was 41%and 26% bigger than T_2 and T_3

4.1.1.9 LCC and SPAD values with grain yield

The LCC and SPAD mean values from LCC 21, LCC 42, SPAD 21 and SPAD 42 were positively correlated with mean grain yield of rice. LCC 63 and SPAD 63 mean values were found positively and significantly correlation with mean grain yield of rice (Table 4.4). The “r” values of grain yield with LCC ranged from 0.375 – 0.774** while that of SPAD ranged from 0.418–0.776**. The significant and positive correlations of these parameters indicate that the topdressing of N can be practiced based on the LCC and SPAD. Therefore, using SPAD chlorophyll meter and leaf color chart (LCC) could provide an indirect assessment of leaf N status.

Table 4.1 Yield and yield components as affected by fixed time nitrogen management, SPAD and LCC based nitrogen application in hybrid rice (Palethwe 1) during dry season, 2013.

Treatments		Number of panicle hill^{-1}	Number of spikelets panicle^{-1}	1000 grains weight	Filled grain %	Grain yield (g/plant)
T_1	C	18.75 c	129.00 d	24.52	75.32 c	50.98 c
T_2	FTNM	22.62 b	137.50 cd	24.62	77.78 c	57.36 c
T_3	FTNM	23.38 ab	155.75 ab	24.55	87.03 ab	67.04 ab
T_4	<SPAD 35	21.62 bc	149.20 abc	24.62	81.13 bc	65.48 b
T_5	<SPAD 37	22.88 ab	154.50 ab	24.52	86.83 ab	66.95 ab
T_6	<LCC 3	21.88 bc	140.00 bcd	24.62	79.80 c	64.00 b
T_7	<LCC 4	25.00 a	160.50 a	24.70	89.82 a	72.43 a
$LSD_{0.05}$		2.31	15.59	5.00	5.81	6.55
Pr> F		0.001	0.013	0.356	<0.001	<0.001
CV %		7.0	7.1	5.0	5.0	7.0

Treatment means followed by common letters in column are not significantly different within treatments by LSD at 0.05. T_1(C) - Control (no N application), T_2 (FTNM) - 75 Kg N ha^{-1} (basal, midtillering , PI and flowering stage), T_3 (FTNM) - 150 Kg N ha^{-1} (basal, mid tillering , panicle initiation and flowering stage), T_4 (<SPAD 35)- < SPAD (35) with 30 Kg N ha^{-1} each time, T_5 (<SPAD 37)- < SPAD (37) with 30 Kg N ha^{-1} each time, T_6 (<LCC 3) - < LCC (3) with 30 Kg N ha^{-1} each time, T_7 (<LCC 4)- < LCC (4) with 30 Kg N ha^{-1} each time. Data represents the mean of four replications.

Table 4.2: Effect of fixed time nitrogen management, SPAD and LCC based nitrogen application on agronomic efficiency of hybrid rice (Palethwe 1) during dry season, 2013.

Treatments		Agronomic efficiency
T_1	C	-
T_2	FTNM	10.63
T_3	FTNM	13.38
T_4	<SPAD 35	30.2
T_5	<SPAD 37	22.20
T_6	<LCC 3	27.10
T_7	<LCC 4	18.00

Table 4.3: Nitrogen dose, number of split application, date of fertilizer application and grain yield of hybrid rice (Palethwe 1) during dry season, 2013.

Treatment		N dose (kg ha^{-1})	No.of split	Date of fertilizer application (Days after transplanting DAT)	Yield (g/plant)
T_1	C	-	-		50.98 c
T_2	FTNM	75	4	Basal, 21, 40, 63	57.36 c
T_3	FTNM	150	4	Basal, 21, 40, 63	67.04 ab
T_4	<SPAD 35	60	2	Basal ,56	65.48 b
T_5	<SPAD 37	90	3	Basal, 35, 63	66.95 ab
T_6	<LCC 3	60	2	Basal, 56	64.00 b
T_7	<LCC 4	150	5	Basal, 14, 21, 42, 63	72.43 a

T_1(C) - Control (no N application), T_2 (FTNM) - 75 Kg N ha^{-1} (basal, mid tillering , panicle initiation and flowering stage), T_3 (FTNM) - 150 Kg N ha^{-1} (basal, mid tillering , panicle initiation and flowering stage), T_4 (<SPAD 35) - < SPAD (35) with 30 Kg N ha^{-1} each time, T_5 (<SPAD 37)- < SPAD (37) with 30 Kg N ha^{-1} each time, T_6 (<LCC 3) - < LCC (3) with 30 Kg N ha^{-1} each time, T_7 (<LCC 4) - < LCC (4) with 30 Kg N ha^{-1} each time. Data represents the mean of four replications.

Table 4.4: The relationship of LCC and SPAD at mid tillering, panicle initiation and flowering stage of hybrid rice (Palethwe 1) with grain yield during dry season, 2013

	LCC21	LCC42	LCC63	SPAD21	SPAD42	SPAD63	Yield
LCC21	1						
LCC42	.791*	1					
LCC63	.732	.873*	1				
SPAD21	.913**	.883**	.778*	1			
SPAD42	.957**	.817*	.799*	.882**	1		
SPAD63	.675	.809*	.977**	.755*	.737	1	
Yield	.375	.482	.771*	.418	.582	.776*	1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

4.2 Experiment II (wet season, 2013)

This experiment was carried out as the same layout of experiment I to compare the effect of fixed time nitrogen management, SPAD and LCC based nitrogen application on the performance of hybrid rice during wet season from July 2013 to October 2013.

4.2.1 Effect of fixed time nitrogen management, SPAD and LCC based nitrogen application on growth parameter and yield and yield components of hybrid rice (Palethwe 1) during wet season , 2013

4.2.1.1 Plant height (cm)

The plant height was measured at 7 days interval from 14 to 70 days after transplanting (DAT). Plant height at 14, 21, 28, 35, 42, 49, 56, 63 and 40 DAT were presented in Figure 4.3. In all treatments, plant height increased progressively from 14 DAT to 70 DAT. There was no significant difference in plant height among the treatments at 14, 21, 28, 35 DAT. The significantly difference in plant height among the treatments was occurred at 42, 49, 56, 63 and 70 DAT.

At 42 DAT and 49 DAT, the highest plant height was resulted from T_7. The T_1 (untreated control) gave the lowest plant height. Nitrogen affects on cytokinins synthesis and improves cell division; as a result, it is increasing of plant height, tiller number and leaf area of rice crop (Abdulrahman and Hai 2000).

T_3 treatment produced the highest plant height at 56, 63 and 70 DAT. This result is similar to that of Hakoomat et al. (2004) who reported that increases in plant height was consistent with increase in the nitrogen rates. He also stated that plant height is a function of the combined effect of genetic make-up, environmental influences and nutritional status of the soil.

4.2.1.2 Number of tillers per hill

The number of tillers per hill was counted at 7 days interval from 14 to 70 days after transplanting (DAT) (Table 4.5). The number of tillers per hill was significant difference at 14, 28 DAT at 5% level. However, the highly significant difference in tillers number among the treatments was observed at 21, 35, 42, 49, 56, 63 and 70 DAT at 1% level.

Among the treatments, T_7 (<LCC (4) with 30 KgNha^{-1} each time) produced the highest number of tiller per hill at all growth stages. Yuan Longping and Fu (1995) reported that fast growth of tiller in the vegetable stage and the maintenance of strong tillering ability until heading appear to be characteristics of F_1 rice hybrid**.** The treatment T_1 (control) was also obtained the lowest value at all growth stages. Number of tillers per unit area is the most important component of yield. The more the number of tillers, especially fertile tillers, the more will be the yield.

4.2.1.3 Number of panicles per hill

The number of panicles per hill was presented in Table 4.5. Highly significant difference in panicles number per hill among the treatments was observed in wet season. According to the wet season result, the highest number of panicles per hill (14.00) was also recorded from T_7. The second largest value was observed by T_3 (13.12). The lowest panicle number was produced from T_1 (control). Yoshida et al. (1972) reported that increases the amount of nitrogen absorbed by the crop, increased the number of panicles per square meter. Dobermann and Fairhurst (2000) also stated that nitrogen increases panicles number per hill.

4.2.1.4 Number of spikelets per panicle

Number of spikelets per panicle was not significantly different among the different nitrogen levels in wet season. However, the maximum number of spikelets per panicle was obtained from T_7 (178.25) followed by T_3 (175.25), T_5 (166.25), T_4 (162.50), T_6 (158.00) and T_2 (154.50). The untreated control treatment produced the lowest number of spikelets per panicle among the different nitrogen levels. The more number of spikelets per panicle was obtained in treatments receiving higher nitrogen levels than in treatments with lower and little nitrogen levels throughout the growing period.

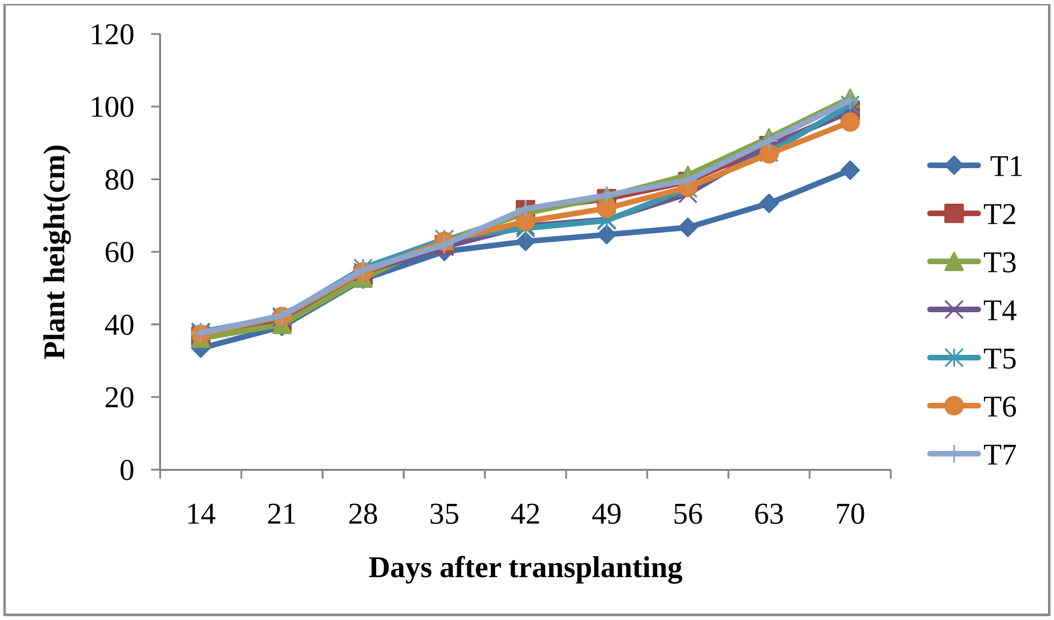


Figure 4.3: Mean values of plant height as affected as by fixed time nitrogen management, SPAD and LCC based nitrogen application in hybrid rice (Palethwe 1) during wet season, 2013

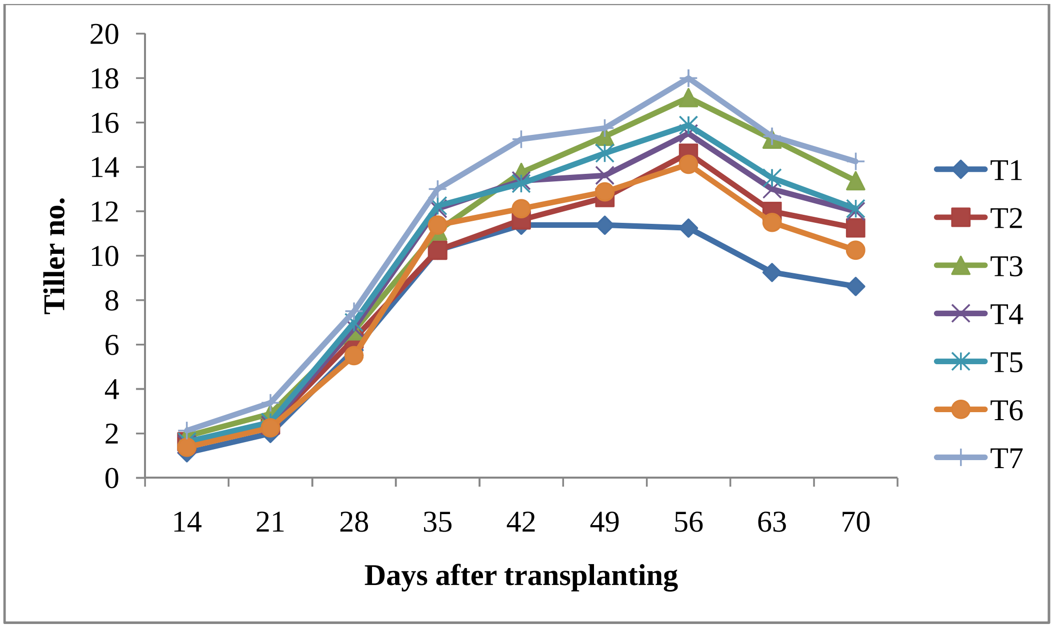


Figure 4.4: Mean values of tillers number per hill as affected as by fixed time nitrogen management, SPAD and LCC based nitrogen application in hybrid rice (Palethwe 1) during wet season, 2013

4.2.1.5 1000 grain weight (g)

According to wet season result**,** there was no significant difference in 1,000 grain weight (g) due to fixed time nitrogen management, SPAD and LCC based nitrogen application (Table 4.5). The maximum 1,000 grain weight (27.2g) was produced by T_7 which was not statistically different from the other treatments.

The weight of thousand grain of rice was not significantly influenced by N level as it is mostly governed by genetic makeup of the variety (Islam et al. 2008). Among the yield components, 1000 grain weight was less influenced by the treatment combinations because it is more or less genetically controlled characteristics.

4.2.1.6 Filled grain %

The statistical result of filled grain % to the fixed time nitrogen management, SPAD and LCC based nitrogen application was presented in (Table 4.5). In this experiment, there was significant difference in filled grain % among nitrogen levels at 5% level. The superior filled grain % was obtained from T_7 and T_1 also was given the lowest value.

Yang et al. (2008) discussed that grain filling played an important role in grain weight, which is an essential determinant of grain yield in cereal crops, and is characterized by its duration and nitrogen rate.

4.2.1.7 Grain yield

In the wet season experiment, there was significant difference among fixed time nitrogen management, SPAD and LCC based nitrogen application at 1% level (Table 4.5). The highest paddy yield (48.11 g per plant) was produced from T_7 followed by T_3 , T_5, T_4 , T_6, T_2 .The lowest paddy yield was obtained from T_1 (26.41). Kenchaiah et al. (2000) also found higher grain yield under LCC based N management than the blanket recommendation.

The yield of T_7 was 45 % greater than control, 30% greater than T_2 and 13.09 % greater than T_3, 33% greater than T_4, 27% greater than T_5 and 38 % greater than T_6. Application of fertilizer nitrogen based on leaf color chart was found effective to maintain optimal leaf nitrogen which resulted in better crop growth and high rice grain yield (Sathiya and Ramesh 2009). The SPAD meter- based N management appeared to be more efficient to produce similar grain yield (Miah and Ahmed 2002). Application of nitrogen in split according to the crop needs was the reason for better rice growth parameter (Sathiya and Ramesh 2009).

4.2.1.8 Agronomic efficiency (AE)

Agronomic efficiency (AE) for wet season was presented in (Table 4.6). In the wet season, the highest agronomic efficiency (AE) was obtained from the treatment T_4, followed by T_6, T_5, T_7, T_3, T_2 T_4 was 44 % more than treatments with fixed N splits, T_2 and also 43.5% larger than T_3 .The AE in the treatment T_5 was 25% and 24.5% higher than treatments with fixed N splits, T_2 and T_3. AE was higher 30% and 29.5% than T_2 and T_3 by treatment T_6. T_7 was 26%and 25.5% bigger than T_2 and T_3. Saleque et al. (2004) reported that AE is usually greater at low dose of nitrogen fertilizer application that obtained with the high dose.

4.2.1.9 LCC and SPAD Values vs. Grain Yield

The SPAD 21 and SPAD 63 were positively correlated with mean grain yield of rice. LCC 21, LCC42, LCC63 and SPAD 42 mean values were found positive and significant correlation with mean grain yield of rice in the wet season (Table 4.8). The “r” values of grain yield with LCC ranged from .843* -.885** while that of SPAD ranged from .523-.813*. The significant positive correlations of these parameters indicate that the topdressing of N can be practiced based on the LCC and SPAD.

Table 4.5: Yield and yield components as affected by fixed time nitrogen management, SPAD and LCC based nitrogen application in hybrid rice (Palethwe 1) during wet seasons, 2013.

Treatment	Number of panicle hill^{-1}	Number of spikelets panicle^{-1}	1000 Grain weight	Filled Grain %	Grain yield (g/plant)
T_1	8.37 e	153.50 ab	26.25	85.34 c	26.41 e
T_2	9.75 d	154.50 b	26.60	85.47 bc	35.69 d
T_3	13.12 ab	175.25 ab	27.05	91.15 ab	45.06 ab
T_4	11.12 c	162.50 ab	26.84	85.35 bc	39.65cd
T_5	12.25 bc	166.25 ab	27.00	90.30 ab	41.20 bc
T_6	9.50 de	158.00 ab	26.42	87.01 abc	37.02 cd
T_7	14.00 a	178.25 a	27.20	92.62 a	48.11 a
$LSD_{0.05}$	1.178	23.58	2.718	5.992	5.431
Pr>F	<0.001	0.270	0.984	0.019	<0.001
CV %	7.1	9.7	6.8	4.6	10.3

Treatment means followed by common letters in column are not significantly different within treatments by LSD at 0.05. T_1(C) - Control (no N application), T_2 (FTNM) - 75 Kg N ha^{-1} (basal, midtillering , PI and flowering stage), T_3 (FTNM) - 150 Kg N ha^{-1} (basal, mid tillering , PI and flowering stage), T_4 (<SPAD 35) - < SPAD (35) with 30 Kg N ha^{-1} each time, T_5 (<SPAD 37), < SPAD (37) with 30 Kg N ha^{-1} each time, T_6 (<LCC 3) , < LCC (3) with 30 Kg N ha^{-1} each time, T_7 (<LCC 4) , < LCC4 with 30 Kg N ha^{-1} each time. Data represents the mean of four replications.

Table 4.6: Effect of fixed time nitrogen management, SPAD and LCC based nitrogen application on agronomic efficiency of hybrid rice (Palethwe 1) during wet season, 2013.

Treatments		Agronomic efficiency
T_1	C	-
T_2	FTNM	15.47
T_3	FTNM	15.54
T_4	<SPAD 35	27.5
T_5	<SPAD 37	20.5
T_6	<LCC 3	22.1
T_7	<LCC 4	18

Table 4.7: Nitrogen dose, number of split application, date of fertilizer application and grain yield of hybrid rice (Palethwe 1) during wet season, 2013.

Treatment		N dose (kg ha^{-1})	No.of split	Date of fertilizer application (Days after transplanting DAT)	Yield (g/plant)
T_1	C	-	-		26.41 e
T_2	FTNM	75	4	Basal, 22, 43, 63	35.69 d
T_3	FTNM	150	4	Basal, 22, 43, 63	45.06 ab
T_4	<SPAD 35	60	2	Basal , 42	39.65cd
T_5	<SPAD 37	90	3	Basal, 42 , 63	41.20 bc
T_6	<LCC 3	60	2	Basal, 42	37.02 cd
T_7	<LCC 4	150	5	Basal, 14, 28, 42, 63	48.11 a

T_1(C) - Control (no N application), T_2 (FTNM) - 75 Kg N ha^{-1} (basal, midtillering , panicle initiation and flowering stage), T_3 (FTNM) -150 Kg N ha^{-1} (basal, mid tillering , PI and flowering stage), T_4 (<SPAD 35)- < SPAD (35) with 30 Kg N ha^{-1} each time, T_5 (<SPAD 37)- < SPAD (37) with 30 Kg N ha^{-1} each time, T_6 (<LCC 3) - < LCC (3) with 30 Kg N ha^{-1} each time, T$_7$ (<LCC 4) - < LCC (4) with 30 Kg N ha^{-1} each time. Data represents the mean of four replications.

Table 4.8: The relationship of LCC and SPAD at mid tillering, panicle initiation and flowering stage of hybrid rice (Palethwe 1) with grain yield during wet season, 2013.

	LCC21	**LCC42**	**LCC63**	**SPAD21**	**SPAD42**	**SPAD63**	**Yield**
LCC21	1						
LCC42	.637	1					
LCC63	.933**	.820*	1				
SPAD21	.567	.191	.332	1			
SPAD42	.782*	.869*	.938**	.029	1		
SPAD63	.786*	.509	.842*	.018	.840*	1	
Yield	.860*	.843*	.885**	.523	.813*	.676	1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

CHAPTER V
CONCLUSION

Grain yield and nitrogen use efficiency can be increased in rice through the use of LCC and SPAD. The concurrent optimization of grain yield and nitrogen use in rice is possible by matching nitrogen supply with crop nitrogen demand. Monitoring rice plant nitrogen status is an important subject with improving the balance between crop nitrogen demand and nitrogen supply from soil and applied fertilizer. The LCC based nitrogen management assures high yields consistent with efficient use of nitrogen in rice. SPAD meter is a reliable tool that is used to determine the right time for nitrogen topdressing and identify N levels for more precise N management in rice.

The treatment T_7 (<LCC (4) with 30 KgNha^{-1} each time) resulted the highest grain yield, which not statistically different with treatment $T_{3,}$ however T_7 obtained the higher agronomic efficiency than T_3 Treatment in both seasons. T_4 (< SPAD (35) with 30 Kg N ha^{-1} each time) and T_6 (< LCC 3 with 30 Kg N ha^{-1} each time) obtained the same yield because they used the same dose of nitrogen and number of splits. T_4 (< SPAD (35) with 30 Kg N ha^{-1} each time) and T_6 (< LCC 3 with 30 Kg N ha^{-1} each time) not only saved 15 Kg N ha^{-1} but also obtained the higher grain yield than treatment T_2 (FTNM) in dry and wet seasons. Thus grain yield can be increased in Palethwe 1 through the use of LCC and SPAD. In this study, all treatments using real time nitrogen management (LCC and SPAD) were higher in agronomic efficiency than those of the fixed-time nitrogen management in both seasons. SPAD and LCC mean values were positively and significantly correlated with mean grain yield of rice in both seasons. Therefore, the topdressing of N can be practiced based on the LCC and SPAD. If there is no LCC and SPAD, split application method (FTMN) is still effective nitrogen management in higher nitrogen level than lower level for farmers.

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Appendix 1. Total rainfall, temperature and relative humidity % data at Yezin during two experiments (2013)

Month	Temperature (˚C)		Rainfall (mm)	Relative Humidity (%)
	Maximum	Minimum		
February	36.5	17.7	0	43
March	38.4	18.4	0	45
April	39.7	22.2	0.06	55
May	35.1	23.6	222	60
June	33.2	23.5	170	73
July	32.1	23.3	99	72
August	31.1	23.3	212	72
September	32.8	23	210	66
October	32.1	21.9	308	62

Appendix 2 Effect of fixed time nitrogen management and SPAD and LCC based nitrogen management on plant height of hybrid rice (Palethwe 1), dry season, 2013

Treatments	Plant height (cm)								
	14DAT	21DAT	28DAT	35DAT	42DAT	49DAT	56DAT	63DAT	70DAT
T_1	30.88	34.25	40.44	48.46	53.06	58.56	65.5	74.69	79.39
T_2	31.62	36.12	47.02	52.81	58.04	63.62	69.5	79	82.6
T_3	38.75	42.69	48.08	53.43	58	63.06	70.19	81.56	84.41
T_4	38	42.31	48.69	53.48	60.96	64.12	69.06	74.7	79.95
T_5	36.69	42.62	48.12	52.75	58.06	61.81	68.38	77.69	82.58
T_6	37.19	41.75	49.06	53.81	60.5	63.12	69.44	77.81	79.73
T_7	38.81	44.69	49.56	54.38	64	65.69	70.19	75.38	83.04
LSD 0.05	6.617	7.163	4.491	2.991	4.073	1.560	3.919	4.564	4.453
Pr>F	0.086	0.056	0.008	0.013	0.001	0.009	0.229	0.045	0.176
CV%	12.4	11.9	6.4	3.8	4.7	3.5	3.8	4.0	3.7

Appendix 3. Effect of fixed time nitrogen management and SPAD and LCC based nitrogen management on plant height of hybrid rice (Palethwe 1)wet season, 2013

Treatment	Plant height (cm)								
	14DAT	21DAT	28DAT	35DAT	42DAT	49DAT	56DAT	63DAT	70DAT
T_1	36.3	38.44	50.44	60.12	65.88	67.75	69.75	76.38	85.5
T_2	36.69	40.55	53.5	62	71.62	74.62	79.38	89.25	99
T_3	36.19	40	52.75	63.12	70.62	75.25	81.12	91.44	102.38
T_4	37.62	41.88	54.38	61.38	67.12	68.88	76	89.12	101.75
T_5	37.94	42.21	55.56	63.5	66.5	68.62	77.5	87.31	98.62
T_6	37.31	42.19	54.5	62.88	68.38	72	79.75	90.62	100.5
T_7	37.62	42.46	55.06	62	71.88	75.62	77.75	87	95.75
LSD 0.05	2.612	2.404	3.751	2.401	2.121	3.989	4.163	5.428	5.829
Pr>F	0.028	0.081	0.543	0.111	<0.001	<0.001	<0.001	<0.001	<0.001
CV%	4.8	3.9	4.7	2.6	2.1	3.8	3.6	4.2	4.1

Appendix 4. Effect of fixed time nitrogen management and SPAD and LCC based nitrogen management different nitrogen levels on tiller numbers of hybrid rice (Palethwe 1), dry season, 2013

Treatments	Tiller numbers								
	14DAT	21DAT	28DAT	35DAT	42DAT	49DAT	56DAT	63DAT	70DAT
T_1	2.00	4.25	6.00	11.62	20.62	28.25	31.12	31.12	30.50
T_2	2.50	5.75	8.25	15.88	24.88	30.87	32.88	32.12	31.25
T_3	3.12	6.62	9.25	18.12	26.88	32.88	36.25	35.88	33.75
T_4	3.88	7.50	11.00	21.12	27.75	35.88	33.12	33.12	32.00
T_5	2.88	6.50	9.62	16.38	26.25	32.12	33.62	33.62	32.50
T_6	3.25	6.75	11.00	20.12	26.62	33.00	33.12	33.12	32.12
T_7	2.75	6.50	10.38	18.62	33.38	39.38	41.12	39.50	38.88
LSD 0.05	1.588	2.787	3.974	7.589	7.194	7.331	3.542	3.515	3.533
Pr>F	0.318	0.357	0.162	0.225	0.066	0.105	<0.001	0.002	0.002
CV%	36.4	30.2	28.9	29.6	18.2	14.9	6.9	6.9	7.2

Appendix 5. Effect of fixed time nitrogen management and SPAD and LCC based nitrogen management on tiller numbers of hybrid rice (Palethwe 1), wet season, 2013

Treatments	Tiller numbers								
	14DAT	21DAT	28DAT	35DAT	42DAT	49DAT	56DAT	63DAT	70DAT
T_1	1.12	2.00	5.75	9.00	11.38	11.38	11.25	9.25	8.62
T_2	1.62	2.37	6.25	10.25	11.62	12.62	14.62	12.00	11.25
T_3	1.87	2.88	7.00	12.25	13.75	15.38	17.12	15.25	13.38
T_4	1.50	2.37	6.62	11.38	13.25	13.62	15.50	13.00	12.00
T_5	1.62	2.50	6.75	12.12	13.38	14.62	15.88	13.50	12.12
T_6	1.37	2.25	5.50	11.12	12.12	12.88	14.12	11.50	10.25
T_7	2.12	3.37	7.50	13	15.25	15.75	18.00	15.38	14.25
LSD 0.05	0.55	0.50	1.14	1.43	1.72	2.22	2.07	1.80	1.58
Pr>F	0.028	<0.001	0.022	<0.001	0.002	0.006	<0.001	<0.001	<0.001
CV%	22.9	13.3	11.9	8.5	9.0	10.9	9.2	9.3	9.1

Appendix6. General guideline for using LCC

1. Start LCC readings from 14 days after transplanting (DAT) for transplanted rice or 21 days after seeding (DAS) for direct wet-seeded rice. The last reading is taken when the crop just starts heading.

2. Randomly select at least 10 disease-free rice plants or hills in a field with uniform plant population.
3. Select the topmost fully expanded leaf from each hill or plant.
4. Place the middle part of the leaf on top of the chart and compare the leaf color with the LCC shades. When the leaf color falls between two shades, the mean value is taken as the reading, e.g. 2.5 for color between 2 & 3. *Do not detach or destroy the leaf.*
5. Measure the leaf color under the shade of your body (Figure 2), because direct sunlight affects leaf color readings. If possible, the same person should take LCC readings at the same time of the day every time.
6. Repeat the process every 7 to 10 days intervals (see below) or at critical growth stages (early tillering, active tillering, panicle initiation, and first heading) and apply N as needed .

Appendix 7. General guidelines for measuring SPAD values in the field

SPAD readings are taken at 7- to 10-d intervals, starting from 14 d after transplanting (DAT) for transplanted rice (TPR) and 21 d after seeding (DAS) for wet direct-seeded rice (DSR). Periodic readings continue up to the first (50%) flowering. The youngest fully expanded leaf of a plant is used for SPAD measurement. Readings are taken on one side of the midrib of the leaf blade, midway between the leaf base and tip. In early growth stages, when leaves are too narrow to allow SPAD measurements on one side of the midrib, the leaf tip can be used for measuring SPAD values. It is recommended that SPAD readings be taken under the shade and at the same time of day, if possible. A mean of 10-15 readings per field or plot is taken as the measured SPAD value. Whenever SPAD values fall below the set critical values, N fertilizer should be applied immediately to avoid yield losses from N deficiency.