ASSESSMENT OF NITROGEN AND POTASSIUM FERTILIZATION ON RICE YIELD IN MAUBIN TOWNSHIP

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A thesis submitted to the post-graduate committee of the Yezin Agricultural University as a partial fulfillment of the requirements for the degree of Master of Agricultural Science
(Soil and Water Science)

Department of Soil and Water Science
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The thesis attached hereto, entitled **"Assessment of Nitrogen and Potassium Fertilization on Rice Yield in Maubin Township"** 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 and Water Science).**

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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 ZAW WIN AND DAW KHIN MAR WIN

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ABSTRACT

To assess the effect of different levels of nitrogen fertilization with and without potassium fertilizer on the yield and yield components as well as agronomic efficiency of Thee Htat Yin rice variety, the field experiments were conducted in Maubin township during 2015 and 2016 of dry season. Four levels of nitrogen and potassium fertilizer treatments with four replications included in the experiment using RCB experimental design. The eight treatments of experiment were control (no fertilizer), P (only phosphorus), N_1P (58 kg N ha^{-1}), N_1PK_1 (58 kg N ha^{-1} and 31 kg K ha^{-1}), N_2P (116 kg N ha^{-1}), N_2PK_2 (116 kg N ha^{-1} and 63 kg K ha^{-1}), N_3P (174 kg N ha^{-1}) and N_3PK_3 (174 kg N ha^{-1} and 94 kg K ha^{-1}). The routine rate of phosphorus fertilizer (12 kg P ha^{-1}) was applied in all treatments except control.

According to the experimental results, different rates of N and K fertilizer application had significant effects on plant height, number of tillers, number of panicles, number of spikelets and grain yield. The grain yield and yield components of rice responded to N fertilizer application. However, the higher values of these results were observed from balanced fertilization of N with K as compared to N without K fertilizer application treatments in both seasons. The highest grain yield obtained from N_2PK_2, and thus fertilizer level of 116 kg N ha^{-1} and 63 kg K ha^{-1} could be optimum for achieving higher grain yield. Relative to treatments without K, nitrogen use efficiency (NUE) of balancing N with K fertilizer treatments showed an increase in ratio ranging from 6.7% to 38.25% for first season and from 10.83% to 28.57% for second season experiment. Yield increment by the application of N fertilizer with K indicated the need of K application in rice cultivation related to yield response. Higher fertilizer rate beyond certain level may not increase the grain yield of rice. Application of N with K would prevent soil K mining to sustain soil productivity and crop yield in the long run.

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CHAPTER I
INTRODUCTION

Rice (*Oryza sativa* L.) is the most important food crop of the world and the staple food of more than 3 billion people or more than half of the world's population. Rice is grown in more than one hundred countries with a total harvested area of about 160 million hectares, producing more than 700 million tons every year (IRRI 2010). Once dried, rice can be stored for a very long time and, therefore, in case of famine, can be a lifesaving food source. For increasing world population, rice represents a primary source of nourishment. Due to its adaptability, rice can be grown almost anywhere, and can be easily distributed to any part of the world (Expo Milano 2015). Myanmar is the world's sixth-largest rice producing country. Rice is the country's most important crop and is grown on over 8 million hectares, or more than half of its arable land (GRiSP 2013). In Myanmar, rice has been cultivated since antiquity and continues to be the most important staple as well as dominating the country's cropped acreage, rural employment and utilization of fresh water (Expo Milano 2015). From 1995 to 2009, the country's total rice consumption increased by more than 60% due to increasing in population size (GRiSP 2013). According to Myanmar launches national strategic plan to increase rice acreage and production (2015), Myanmar has exported around 1.7 million tons of rice in 2014-2015, up to about 40% from around 1.2 million tons exported in 2013-2014. Since rice is the major crop for both food security and economy of the country, efficient rice production is important for the country.

Fertilizers are currently responsible for 40 to 60 percent of the world's food supply (www.tfi.org 2008). The major nutrients such as nitrogen (N), phosphorus (P) and potassium (K) occur naturally in the environment. However, these nutrients are removed by the harvested crop and provide for nutritional value of these crops. Human intervention, e.g. introduction of mineral fertilizer or increase of cropping intensity may cause unbalanced nutrient cycles resulting in decreased fertility and lower yield in the long run. Therefore, even if the yields of without nutrient plots do not indicate the need to apply fertilizer, maintenance fertilizer application is necessary to prevent soil fertility from being mined over time (Wopereis et al. 2009).

Growing of high-yielding varieties (HYV) may become deficient in soil nutrients because they are more demanding in nutrient requirements than local varieties. Furthermore, declines in crop yield are strongly related to soil quality degradation, particularly nutrient depletion (Roy et al. 2003). Proper fertilization is necessary to maintain global crop productivity at present and will be even more crucial if yields are to be increased (Roberts 2009). Among plant nutrients, nitrogen (N), phosphorus (P), and potassium (K) are needed in large quantities for plant growth. Nitrogen makes up 1 to 4 percent, potassium makes up 1 to 4 percent and phosphorus makes up 0.1 to 0.4 percent of dry matter of the plant (FAO and IFA 2000). As nitrogen is the essential constituent of proteins, it is involved in all the major processes of plant development and yield formation. In addition, a good supply of nitrogen for the plant is important for the uptake of other nutrients. Phosphorus plays a key role in the transfer of energy, and thus is essential for photosynthesis, helping in seed germination and water use efficiency of plant. Potassium plays a key role in carbohydrate and protein synthesis. Other aspects of plant health influenced by potassium include the growth of strong stalks, protection from extreme temperatures, and the ability to fight stress and pests (www.tfi.org 2008).

Sustainable farming systems require soil fertility status to be maintained at a level that supports satisfactory plant growth while minimizing nutrient loss to the environment. However, in most cases, farmers apply excess amount and imbalance fertilizer rates resulting to significant soil fertility as well as soil quality degradation (Betteridge et al. 2008). According to previous study, the increase in rice production has been achieved by the use of improved germplasm, associated with increased application of N and P fertilizers, but without a corresponding increase in the use of K fertilizer. This lack of K has been exacerbated by the practice of resource poor farmers who remove nutrients from their fields, especially K, in the form of straw for fuel and cattle feed (Wihardjaka et al. 1999; Yaday 1998).

Nitrogen (N) is the major limiting nutrient for lowland rice production among given major nutrients (N, P and K). Application of N significantly increased yield components and consequently the grain yield of rice whereas P and K fertilizers have no visual response to their applications (Wanyama et al. 2015). However, farmers have a financial cost for buying and applying fertilizer and the cost has been great recently for N, P and K fertilizers (Johnston and Milford 2012). Over application of N combined with inadequate application of K is a serious problem in modern intensive agriculture system. Imbalanced use of fertilizers reduces soil fertility and crop yield resulting in mining of soil nutrients in the long run. High N fertilizer application hastens soil K decline by producing larger plants with bigger root systems. Although N fertilizer consumption is increasing quantitatively, the corresponding increase in yield per unit of nutrient input has diminished compared to previous years leading to ineffectiveness of applied fertilizers (Rao 2007). Therefore, improving in utilization of N is the most important in agronomic, economic and environmental points of view.

In the field, N uptake and utilization is better with sufficient K application. This means K improved N utilization and produced higher yields. Crop response to higher K levels when N is adequate and greater response in yield to N fertilizer occurs when K is adequate (Armstrong 1998). Several strategies to increase the efficiency of N fertilizer include balanced N and K fertilization (Zheng 1998). Because of synergetic effect between N and K for uptake and assimilation, crops can be beneficial from balanced N and K nutrition (Milford and Johnston 2007).

According to Liao et al. (2010), the requirement to increase K-supplying potential capacity of paddy soils is solved by adequate K application. It will also lead to increase rice crop yields and sustain K fertility of paddy soils. Moreover, K fertilizer application is a traditional agricultural measure to sustain rice crop yield in the rice-rice cropping system (Zheng et al. 1989). In addition, Leikam (2010) pointed out that by making the farmers understand how nutrients work, they can optimize production and investment in fertilizer, while minimizing excess application of nutrients that could result to negative impact to the environment. Potassium (K) and nitrogen (N) are two vital nutrients that create greater benefits when combine together than applying individually.

In Maubin township, rice is commonly grown by direct seeding using Thee Htat Yin rice variety during dry season. For fertilizer application, farmers usually apply blanket doses of phosphorus fertilizer as basal. In addition, about 247 kg ha^{-1} of urea (114 kg N ha^{-1}) was also applied. However, only 31 kg ha^{-1} of potash fertilizer (16 kg K ha^{-1}) is mostly applied for their rice production. Although the use of N fertilizer has been increased, the application of K has not followed the same trend as that of N. In addition to being cheaper than K fertilizer, N fertilizer shows great response to the growth and yield of rice crop, and thus famers mostly apply N and has applied higher rates than P and K. The rate and type of fertilizer depend on the financial status of farmers and the farmers made the choice for fertilizer application without considering soil nutrient conditions and balance.

Due to a strong interaction between the two nutrients (N and K) in crop growth, more application of N to increase yield requires more available K in the soil and without K, the crop response to N will be limited (Johnston and Milford 2012). Moreover, most farmers in the study area believed that maximization of fertilizer utility may benefit for higher yield. Farmers are not practicing balanced fertilization and data related to the balancing on N and K applications are limited. Therefore, the experiment was conducted with the following objectives;

(1) To determine an optimum N and K fertilizer level in increasing fertilizer use efficiency
(2) To compare the effect of N and K balanced fertilization on the growth and yield of rice crop
(3) To point out the need of K applied together with N for increasing the growth, yield and nitrogen use efficiency (NUE) of rice crop

CHAPTER II
LITERATURE REVIEW

2.1 Importance of Rice

Cereal grains are the principal food source for growing human population. Approximately 50% of calories consumed by the whole human population depend on wheat, rice and maize (Gnanamanickam 2009). Although rice is the second crop due to planted area, it serves as the most important food source for Asian countries especially in south-east parts where it is grown on millions of hectares as an economic crop by farmers and workers throughout the area (Gomez 2001). According to IRRI (2007), rice is the major food source of more than 2.7 billion people, most of them are poor and this number will grow up to 3.9 billion people by the year 2025. Since rice is important for food security of so many poorest countries, there should be an emphasis on rice production to alleviate poverty and meet food demands of still increasing urbanized population. Moreover, rice also plays an important role as a “wage” commodity for workers in the cash crop or non-agricultural sectors. In many countries, both developed and developing, rice is considered as a “strategic” commodity and has consequently remained subject to a wide range of government controls and interventions (Calpe 2006).

Rice grows in a wide range of environment and is productive in many situations where other crops would fail. Geographically, Asia occupies 90 % of world rice production mainly in South, South-east and East Asia (Bouman et al. 2007). This area is subject to an alternate wet and dry seasonal cycle and also contains many of the world’s major rivers, each with its own vast delta. Annually, during raining season, areas of flood and low-lying agricultural land are flooded in these regions. Rice adapt readily to production under these conditions of saturated soil and high temperatures (Maclean et al. 2002).

Being a major source of energy, rice provides 21% of global human per capita energy and 15% of per capita protein. One hundred grams of raw white rice provide 361 k cal and 6 g of protein (Calpe 2006). Although rice protein ranks high in nutritional quality among cereals, protein content is modest. Rice also provides minerals, vitamins, and fiber, although all constituents except carbohydrates are reduced by milling (Memon 2013).

The world average rice consumption in 1999 was 58 kg, with the highest intake in some Asian countries (Maclean et al. 2002). In Myanmar, rice is the main staple food, and people eat more rice compared to other Asian countries. Myanmar people has consumed less rice over time that is the per capita rice consumption in kg was 212, 215, 208, 206, 205, 202 and 196 in 1997, 1998, 1999, 2000, 2001, 2002 and 2003 respectively. However, rice consumption rate of Myanmar people is still high, compared with other Asian countries (Tin Maung Shwe and Thida Chaw Hlaing 2011).

Besides rice is the most important staple food of the world people, there are several important useful things of rice (Toungos 2016). Rice straw is used as cattle feed, used for thatching roof and in cottage industry for preparation of hats, mats, ropes, sound absorbing, straw board and used as litter material. Rice husk is used as animal feed, as well as for paper making and as fuel source. Rice bran is used as cattle and poultry feed. The defatted bran, which is rich in protein, can be used in the preparation of biscuits and cattle feed. Rice bran oil is used in soap industry. Refined oil can be used as a cooling medium like cotton seed oil or corn oil. Rice bran wax, a byproduct of rice bran oil, is used in industries. In addition, ready to eat products which have long shelf life eg. popped and puffed rice, instant or rice flakes, canned rice and fermented product are produced.

In the future, rice production continues to grow at least as rapidly as the populations to meet the food demand of growing population. National Rice Development Strategy (NRDS) (2009) claimed that the promotion of domestic rice production is a key element in the strategies for improving food security, stimulate economic growth and increase rural income. Therefore, rice research that develops new technologies for all farmers has a key role to play in meeting this need and contributing to global efforts directed at poverty alleviation.

2.1.1 Rice production in Myanmar

Rice production is critical for the economic livelihood and food security of the population in Myanmar. Rice is grown throughout the country by resource poor rural farmers and landless agricultural labourers on small farms averaging only in size of 2.3 ha (Okamoto 2004). As a major staple crop, rice is grown in monsoon and summer seasons with cultivated acres of 19 million or 33% of total crop sown areas.

Monsoon rice is grown in 16 million acres and summer rice is grown in 3 million acres (Sein Win Hlaing 2014). According to interview results from farmers, monsoon rice crop yields were typically in the range of 1.8 to 2.8 MT ha^{-1}, whereas summer (dry season) rice crop yields were mostly in the range of 2.7 to 3.1 MT ha^{-1}. The key information is summer crop yields may be somewhat higher (De Denning et al. 2013).

According to Myanmar Rice Sector Development Strategy (2015), Myanmar's rice-growing areas can be divided into two agroecosystems namely, favorable lowlands, which accounts for 68% and unfavorable rainfed, which comprises 32% of the total rice sown area. These two agro-ecosystems are subdivided into seven rice sub-ecosystems. The favorable lowland is comprised of the rainfed lowlands (48%) and irrigated lowlands (20%). The unfavorable rainfed area is subdivided as drought prone, deep-water, submerged, salt affected and uplands. The major rice producing regions of Myanmar are Ayeyarwady, Bago and Yangon regions which make up almost half of the country's harvested rice area (MOAI 2011). These areas are naturally provided with fertile deltaic alluvial soil and abundant monsoon rainfall (Tin Aye Aye Naing et al. 2008).

In the fertilizers (N, P and K) utilization, 63% of interviewed rice farmers in the delta or coastal area and 76% in the dry zone applied inorganic fertilizer. Corresponding fertilizer application rates were higher in dry season than in monsoon season. As organic fertilizer, farmyard manure (FYM) was usually used, but 78 % of the farmers cannot use animal manure in the present condition because they do not posses enough animals (Tin Aye Aye Naing et al. 2002).

Rice production is estimated to increase by 5% from 12 million metric ton (MMT) in 2013-14 to 12.6 MMT in 2014-15. This is due to increase use of high yielding rice varieties (HYV) and an expansion of the irrigated dry season rice crop production (Swe Mon Aung 2015). In 2015-16, rice production is decreased by 3 percent to 12.2 MMT. This is mainly due to flooding during the main rice crop growing season and insufficient water supplies for the dry season rice crop (Swe Mon Aung 2016).

2.2 Rice Growth and Development

Rice is an annual grass with round, hollow, jointed culms; narrow, flat, sessile leaf blades joined to the leaf sheaths with collars; well-defined, sickle-shaped, hairy auricles; small acute to acuminate or two cleft ligules and terminal panicles. The agronomic phases of rice plant may be divided into three growth stages:

(1) Vegetative (germination to panicle initiation),

(2) Reproductive (panicle initiation to flowering), and

(3) Ripening (flowering to mature grain).

All these stages are quite important because they influence the three main yield components that determine grain yield are number of panicles per unit land area, the average number of grain produced per panicle and the average weight of the individual grains (Olembo et al. 2010). The number of panicles per unit land depends on the average number of tillers per plant. The number of grains panicle^{-1} is influenced throughout the season from panicle initiation through head emergence by environmental, nutritional, and plant conditions. The average weight of individual grains is also affected by environmental and plant conditions (Beighley 2010).

The vegetative growth phase is characterized by active tillering, a gradual increase in plant height and leaf emergence at regular intervals. The length of this phase primarily determines the growth duration of cultivars. The reproductive phase is characterized by culm elongation, a decline in tiller number, booting, emergence of the flag leaf, heading and flowering. The reproductive phase usually lasts approximately 30 days in most cultivars. The grain filling and ripening or maturation phase follows ovary fertilization and is characterized by grain growth. During this period, the grain increases in size and weight as the starch and sugars are translocated from the culms and leaf sheaths where they have accumulated, the grain changes color from green to gold or straw color at maturity and the leaves of the rice plant begin to senesce (Moldenhauer and Slaton 1999).

2.3 Soil Requirement for Rice

Rice is grown in almost all types of soils with varying productivity. Under high temperature, high humidity with sufficient rainfall and irrigation facilities, rice can be cultivated in any types of soil (Kumar 2013). However, soils have good water holding capacity such as heavy neutral soils (clay, clay loam and loamy) are most suited for its cultivation. The most important group of soils for successful rice cultivation include alluvial soils, red soils, laterite soils and black soils (Tripathi et al. 2011). The main rice growing soil groups of Myanmar classified by Soviet soil scientists are Gleysols, Fluvisols, humic Planosols and pallic Vertisols (Khin Win 1991). De Denning et al. (2013) stated that delta regions fall under alluvial and swampy soils, whereas vertisols are more important in the irrigated rice land of the dry zone. Rice is grown normally in soils with a pH ranging from 5 to 8, The optimum soil pH for rice growth is 5.5 to 6.5 in dry conditions. It may rise from 7.0 to 7.2 under flooded conditions (Somado et al. 2008).

2.4 Climatic Requirements of Rice

Rice can be grown in different locations under various climatic conditions. From a crop physiologist's point of view, crop period, productivity, and stability are major aspects of rice cultivation. Climatic factors affect each of them in different ways. Temperature, solar radiation, and rainfall influence rice yield by directly affecting the physiological processes related to grain production, and indirectly through diseases and insects (Yoshida 1981).

2.4.1 Temperature

Temperature has a favourable and in some cases unfavourable effects on the development, growth and yield of rice. Extreme temperatures are destructive to plant growth, and thus depending on the environment under which the life cycle of the rice crop can be completed (Tripathi et al. 2011; Yoshida 1981). Since rice is a tropical and subtropical plant, it requires a fairly high temperature. The critically low and high temperatures range from 20°C to 40°C. The optimum temperature of 30°C during day time and 20°C during night time is subject to be more favourable for the development and growth of rice crop (Tripathi et al. 2011).

Rice cultivation is conditioned by temperature parameters at the different growth stages of crop. Temperature influences the grain yield by affecting tillering, spikelet formation and ripening, and it affects the growth rate just after germination and increases almost linearly with increasing temperature within a range of 22–31°C (Yoshida 1981). The critical mean temperature for flowering and fertilization ranges from 16 to 20°C, whereas, during ripening, the range is from 18 to 32°C. Temperature beyond 35°C affects grain filling (Hamjah 2014).

2.4.2 Solar radiation

Solar radiation is very essential and most important energy source for crop growth and development. The solar radiation of rice crop varies from one growth stage to another. The rice yield is influenced by solar radiation particularly during ripening periods (Tripathi et al. 2011). Shading during the vegetative stage only slightly effects yield and yield components. However, shading during reproductive stage has a significant effect on number of spikelets and, hence, on yield. It reduces grain yield considerably during ripening due to a decrease in the percentage of filled spikelets (Yoshida 1978). Therefore, Tunde et al. (2011) stated that rice yield is directly related to the solar radiation at reproductive and ripening phases. The effect of solar radiation is better where water, temperature and nitrogenous nutrients are not limiting factors. Bright sunshine with low temperature during ripening period of the crop helps in the development of carbohydrates in the grains (Tripathi et al. 2011).

2.4.3 Rainfall

The amount and distribution of rainfall is the most important weather element in rain fed rice ecosystem (upland, lowland and flood prone). It affects indirectly on irrigated rice ecosystem through availability of water for irrigation from sources (tank, canal, well etc.) as well as on evapotranspiration of the crop through changes in temperature and solar radiation. Daily rainfall is more critical than monthly or annual rainfall. Availability of about 200-300 mm of water per month is considered minimum to produce good crop of rainfed rice (Sridevi and Chellamuthu 2015). Water stress at any growth stage may reduce the yield. The rice plant is most sensitive to water deficit from the reduction division stage to heading (Awan 2012). There should be no water at maturity stage. Narayanan (2004) reported that wet spells are detrimental to rice crop from flowering to maturity.

2.5 Effects of Submergence on Soil Properties

Rice fields surrounded by bunds to retain rain and irrigation water, and ensure soil submergence are one of the world’s agricultural ecosystems. Soil volume primarily comprises solid matter, water and air. When the soil is submerged, most of its pore space volume is occupied by water. Therefore, the supply of oxygen is quickly depleted due to the displacement of oxygen contained in the pore space (Inglett et al. 2005). The loss of oxygen is the most significant effect of submerging soil and results in physical, biological, chemical changes.

Oxygen in the atmosphere dissolves in the water covering the submerged soil and penetrates only a thin layer of soil. This soil layer has aerobic properties and is sometimes referred to as a thin aerobic surface layer (IRRI 2009). Submergence retards gas exchange between soil and air, stabilizes soil temperature, causes swelling and destruction of soil aggregates and reduces permeability. Standing water favors rice by eliminating water stress, controlling weeds, reducing the soil, and increasing the availability of nutrients. Rice can grow in reduced soils because it has an oxygen transport system from shoot to roots (Ponnamperuma 1981). Rice roots have large air spaces which are connected to culm and leaves, constituting an efficient air passage system from shoot to root, to get oxygen down to cells in root tissue (Yoshida 1981). Saturated soil conditions support microbial populations adapted to anaerobic environments. Aerobic microbial populations are restricted to zones where oxygen is available (Inglett et al. 2005).

Unlike a well drained soil, submerged soil is in a reduced state. Except for the thin, brown, oxidized layer at the surface, a submerged soil is gray or greenish, has a low oxidation-reduction potential, and contains the reduced counterparts of NO_3^-, SO_4^{2-}, Mn^{4+}, Fe^{3+} and CO_2: NH_4^+, H_2S, Mn^{2+}, Fe^{2+} and CH_4. Reduction of the soil is a consequence of anaerobic respiration by soil bacteria. During anaerobic respiration organic matter is oxidized and soil components are reduced (Ponnamperuma 1972). As a result of flooding, the pH of acidic soils increases and alkaline soils decreases. Soil pH is an important chemical property since it influences nutrients availability to plants. The overall, pH of most soils tends to change toward neutral with an equilibrium pH range 6.5 to 7.5 after flooding (Patrick and Reddy 1978; Fageria et al. 2011).

2.6 Nitrogen Transformation in Submerged Soils

The relative magnitude of the N forms, particularly nitrate (NO_3^-) and ammonium (NH_4^+), and N transformation are markedly affected by the oxidation status of soil. Nitrogen takes nine different forms in soil corresponding to different oxidative states (Robertson and Groffman 2007). Nitrate is the dominant form of inorganic N in drained, aerated soils; whereas ammonium is the dominant form of inorganic N that accumulates in submerged soils. The main N transformation processes in submerged soils are mineralization, immobilization, nitrification, denitrification, ammonia (NH_3) volatilization, and biological N_2 fixation (Buresh et al. 2008).

Mineralization is the biological conversion of organic N to ammonium which supplies plant-available N in submerged agricultural soils. Net release of NH_4^+ during mineralization and immobilization processes in anaerobic system is dependent on the N requirements of anaerobic microbial populations, nature of organic material, and several soil and environmental factors. The ultimate NH_4^+ formation is controlled by mineralization and immobilization balance in submerged soils, which can be related to the C: N ratio of the decomposing residues (Reddy and Patrick 1984).

Nitrification is the biological conversion of NH_4^+ to NO_3^-, and it is regulated by the availability of O_2, and NH_4^+ concentration in the aerobic zones. Oxygen availability is typically the most limiting factor of nitrification in submerged agricultural soils. Nitrate formed by nitrification is stable within an aerobic zone, but it does not accumulate in the anaerobic zone and is reduced to gaseous endproducts of nitrous oxide (N_2O) and nitrogen gas (N_2) called denitrification. It is mediated by heterotrophic microorganisms, and the rate is regulated by NO_3^- concentration and available C. The supply of NO_3^- originating from the aerobic zones is typically the factor limiting denitrification in submerged soils (Aulakh et al. 2000).

Ammonia volatilization is now recognized as a major process by which fertilizer N is lost from rice fields with submerged or saturated soils. Urea, a common fertilizer for rice in Asia, is rapidly hydrolyzed within the week after application to submerged soils (Fillery et al. 1984). Ammoniacal N originating from the hydrolyzed urea accumulates in floodwater. High concentrations of ammoniacal N together with high floodwater pH and temperature favor loss of added fertilizer N by NH_3 volatilization (Vlek and Stumpe 1978; Cai 1997).

2.7 Forms of Potassium in Soils

Potassium exists in soils mainly in three forms which are unavailable, slowly available or fixed, readily available or exchangeable.

Unavailable potassium: Depending on soil type, approximately 90-98% of total soil K is found as unavailable form. Feldspars and micas are minerals that contain most of the K. Plants cannot use the K in this crystalline-insoluble form. Over long periods of time, these minerals weather and K is released. This process, however, is too slow to supply the full K needs of field crops. As these minerals weather, some K moves to the slowly available pool. Some also moves to the readily available pool.

Slowly available potassium: This form of K is thought to be trapped between layers of clay minerals and is frequently referred to as being fixed. Growing plants cannot use much of the slowly available K during a single growing season. It can also serve as a reservoir for readily available K. While some slowly available K can be released for plant use during a growing season, some of the readily available K can also be fixed between clay layers, and thus converted into slowly available.

The amount of K fixed in the slowly available form varies with the type of clay that dominates in the soil. Montmorillonite clays fix K when soils become dry because K is trapped between the layers in the clay mineral. However, this K is released when the soil becomes wet. Illite clays also fix K between layers when they become dry, but do not release all of the fixed K when water is added. This fixation without release causes problems for management of potash fertilizers for crop production in the region.

Readily available potassium: Potassium that is dissolved in soil water (water soluble) plus that held on the exchange sites on clay particles (exchangeable K) is considered readily available for plant growth. The exchange sites are found on the surface of clay particles. Plants readily absorb the K dissolved in the soil water. As soon as the K concentration in soil water drops, more is released into this solution from the K attached to the clay minerals. The K attached to the exchange sites on the clay minerals is more readily available for plant growth than the K trapped between the layers of the clay minerals (Rehm and Schmitt 1997). The factors that affect availability of K in the soil and resulting plant uptake are soil factors, plant factors, fertilizer and management practices (Armstrong et al. 1998).

2.8 Importance of Fertilizer Nutrients in Rice

Nutrition may be defined as the supply and absorption of chemical elements needed for growth and metabolism, and the chemical elements required by an organism are termed nutrients (Fageria and Baligar 2005). It is recognized that sustainable high yield systems require both adequate nutrient supplies to growing crops as well as continual improvements to the soil’s nutrient status and quality (De-ren and Wan-fang 1998). Clearly, low soil fertility and inadequate nutrient management are among the major factors limiting the rice yield level (Gebrekidan and Seyoum 2006). Increase in yield attributing characters is associated with better nutrition and increased nutrient uptake which result in better and healthy plant growth and development (Kumar and Rao 1992; Thakur 1993).

Among the major nutrients, nitrogen, phosphorus and potassium are the most limiting nutrients in plant growth (Wopereis et al. 2009). However, one-sided or unbalanced nitrogen fertilizer application may be justified on soils rich in plant-available phosphate, potassium and all other necessary secondary and microelements. Since higher yields will also take up greater amounts of the other nutrients (mainly phosphorus and potassium) from the soil, increased yields through application of nitrogen alone deplete the soils of the other plant nutrients. IRRI research suggests that under intensive rice-rice cropping systems the demand for phosphorus and potassium increases over time. Research showed that, without phosphorus and potassium application, nitrogen efficiency declined, whereas when all nutrients were applied together, phosphorus and potassium efficiency increased steadily, thereby indicating interactions between these nutrients. Therefore, for optimum fertilizer use efficiency, balanced fertilization is necessary (FAO and IFA 2000).

2.8.1 The role of nitrogen in rice

Nitrogen is the most rice yield limiting nutrient in all rice growing soils of the world (Fageria 2010). It is taken up during early growth stages of rice plant and accumulated in the vegetative parts of the plant and then utilized for the formation of grain. During differentiation, a large protein of nitrogen is absorbed by the plant, and is present in leaves and stems (Abou-khalifa 2012). Nitrogen provides dark green appearance of plant parts as a component of chlorophyll, promotes rapid growth or increased plant height and number of tillers as well as increases the size of leaves and grains (De Datta 1981). Nitrogen fertilization increased the number of tillers and panicles per square meter and the total number of spikelets, reflecting on grain productivity (Dastan et al. 2012). Rice plants require a large amount of nitrogen during tillering stages to ensure maximum number of panicles. At panicle initiation stage, the supply of nitrogen may increase number of spikelets panicle^{-1}. Little amount of nitrogen is also required at the ripening stage (De Datta 1981).

2.8.2 Deficiency and excess of nitrogen in rice

Nitrogen deficiency is common in all rice-growing soils where modern varieties are grown without sufficient mineral N fertilizer. It usually occurs at critical growth stages of rice crop, such as tillering and panicle initiation at which the demand for nitrogen is large. N deficiency may also accur where a large amount of N fertilizer has been applied at the wrong time or the wrong way. Soils particularly favour for nitrogen deficiency include soils with very low soil organic matter, particular constraints to indigenous N supply, and a high potential for NH_3 volatilization losses. Causes of N deficiency include: (1) low soil N-supplying power, (2) insufficient application of mineral N fertilizer, (3) low fertilizer N use efficiency (losses from volatilization, denitrification, incorrect timing and placement, leaching and runoff), (4) permanently submerged conditions that reduce indigenous soil N supply, (5) N loss due to heavy rainfall, (6) temporary drying out of the soil during the growing period, and poor biological N_2 fixation because of severe P deficiency (Dobermann and Fairhurst 2000).

On the other hand, to maximize grain yield, farmers often apply a higher amount of N fertilizer than the minimum requirement for maximum crop growth. The relatively cheap price of N fertilizer and the lack of knowledge of farmers on the correct amount and management of N application relative to their target yield have also stimulated excessive N application. Excess use of N reduces the profit of rice farmers by increasing production costs and reducing grain yield. Moreover, high N loss has many environmental consequences (Mew et al. 2003). Luxuriant growth of the crop due to excessive N attract more insects and susceptible to diseases (Kulagod et al. 2011). Too much N can lead to lodging at maturity (especially in direct-seeded rice), high levels of sterility and reduced yield (Dunn 2010).

2.8.3 Fertilizer nitrogen use efficiency

Nitrogen is typically the major limiting nutrient in the lowland rice production, and application of N fertilizer is vital for the sustained production of sufficient rice to meet demand. About 20% of the global production of fertilizer N is applied in rice production systems that experience soil submergence. The fertilizer nitrogen use efficiency (NUE) by the crop is typically low, due to losses of the applied fertilizer N arising from unique features of submerged soils as compared with aerated soils (Buresh et al. 2008). Numerous nitrogen-response experiments have shown that the nitrogen recovery efficiency of rice crop seldom exceeds 30-40%. Even with the best agronomic practices and strictly controlled conditions, it is seldom more than 60-65% (De Datta et al. 1968). De Datta (1981) stated that the soil and climatic conditions that favor rice growth adversely affect the recovery of nitrogen from the soil and are responsible for its rapid loss. Low nutrient recovery efficiency not only increases the cost of crop production but also causes environmental pollution.

In lowland rice, losses of applied N take place through ammonia volatilization, denitrification, leaching, and runoff. Ammonia loss was generally greater when broadcast to young rice within 3 weeks after transplanting than to older rice near the panicle initiation stage. At 10 to 21 days after transplanting, broadcasting of nitrogen as urea into floodwater caused 27 to 56% ammonia loss of applied urea (Fillery et al. 1984; Fillery and De Datta 1986; De Datta et al. 1989). However, ammonia loss at panicle initiation represented only 10 to 15% of the applied urea N (Fillery et al. 1984). The characteristic of submerged soils with important implications for N cycling is the adjoining presence of aerobic zones where nitrification occurs and anaerobic zones where denitrification occurs. Nitrogen loss by coupled processes of simultaneous nitrification and denitrification is consequently a unique feature of submerged soils (Reddy and Patrick 1986; Buresh et al. 2008).

Worldwide, crops do not directly utilize about half of the fertilizer N use and the overall NUE has declined with increasing applied N fertilizer. This trend seems to continue in many developing countries. Interventions to increase NUE and reduce N losses to the environment must be accomplished at the farm level through a combination of improved technologies, and careful to promote the adoption of improved N management practices while sustaining yield increases (Dobermann 2005).

Fertilizer NUE is controlled by many factors such as crop demand for N, supply of N from the soil, fertilizer and manure application and losses of N from the soil-plant system. Imbalanced and inappropriate use of N and other nutrients such as K in agro-ecosystems can affect NUE since NUE normally depends on the extent of deficiency of K. The application of both N and P failed to improve the NUE in the absence of applied K. A positive relationship between N and K exists for the uptake and utilization of N by plants to form protein and amino acids which ultimately affect the quality and yield of crops. Balanced use of N and K fertilizers will be more profitable for farmers as well as reduced environmental degradation (Brar et al. 2011).

2.8.4 Functions of potassium in plants

Out of all the mineral nutrients, potassium (K) plays a particularly critical role in plant growth and metabolism. Although K is not a constituent in chemical structure of plants, it plays many important regulatory roles in plant development. Potassium “activates” at least 60 different enzymes involved in plant growth. It changes the physical shape of the enzyme molecule, exposing the appropriate chemically active sites for reaction. The amount of K present in the cell determines the enzymes that can be activated and the rates at which chemical reactions can proceed (Armstrong et al. 1998).

Another function of K is to regulate the opening and closing of stomata through which leaves exchange carbon dioxide (CO_2), water vapor, and oxygen (O_2) with the atmosphere. Proper functioning of stomata is essential for photosynthesis, water and nutrient transport, and plant cooling (Armstrong et al. 1998). Potassium is essential for photosynthesis, protein synthesis (i.e., nitrogen use), nitrogen fixation, starch formation and the translocation of sugars. Potassium also plays a major role in the transport of water and nutrients throughout the plant in the xylem. It enhances crop quality and increases root growth (Brar and Imas 2014). It contributes greatly to the survival of plants that are under various biotic and abiotic stresses (Pettigrew 2008).

2.8.5 The role of potassium in rice

Potassium (K) is a macronutrient taken up by plants in large quantities with total aboveground uptake in mature crops. In rice plants about 75% of plant K remains in leaves and stems, and the rest is translocated to grains (Espino 2012).

Modern high-yielding rice cultivars absorb K in larger quantities than any other essential nutrient. In farmers' fields across Asia, a crop producing 5 t ha^{-1} of grain have total K uptake rates in the range of 100 kg ha^{-1}, more than 80% of which are concentrated in the straw at maturity (Dobermann and Fraihurst 2000). For yields greater than 8 t ha^{-1}, total K uptake may even exceed 200 kg ha^{-1} (Dobermann et al. 1998).

Proper potassium nutrition in rice promotes tillering, panicle development, spikelet fertility, nutrient uptake of nitrogen and phosphorus, leaf area and leaf longevity, root elongation and thickness, culm thickness and strength, rice plant tolerance to diseases and pests, and resistance to lodging (Haifa 2014). Dong et al. (2010) showed that a strong positive relationship between K fertilizer input and grain yield. However, there is gradual reduction in soil test K values with time because of intensive cropping and the cultivation of high yielding varieties that remove more soil K, and thus higher soil K levels may even require for producing optimum yield (Slaton et al. 1995).

2.8.6 Potassium deficiency in rice

Although K does not have a pronounced effect on tillering, it increases the number of spikelets $panicle^{-1}$, percentage of filled grains, and grain weight. Potassium improves the rice plant's tolerance of adverse climatic conditions, lodging, insect pests and diseases. Deficiency symptoms tend to occur in older leaves first, because K is very mobile within the plant and is translocated to young leaves from old senescing leaves. Often yield response to K fertilizer is observed only when the supplies of other nutrients, especially N and P, are sufficient (Armstrong and Griffin 2002).

The signs and symptoms of K deficiency include: (1) rusty brown spots on tips of older leaves that later spread over the whole leaf causing it to turn brown and dry if K deficiency is severe, (2) irregular necrotic spots may also occur on panicles, (3) stunted plants with smaller leaves, short and thin stems, (4) reduced tillering under very severe deficiency, (5) greater incidence of lodging, (6) early leaf senescence, leaf wilting, and leaf rolling when temperature is high and humidity is low, (7) large percentage of sterile or unfilled spikelets, (8) unhealthy root system (many black roots, reduced root length and density), causing a reduction in the uptake of other nutrients, (9) poor root oxidation power, causing decreased resistance to toxic substances produced under anaerobic soil conditions, and increased incidence of diseases, where inappropriate amounts of fertilizers are used. K deficiency damage is important throughout the growth cycle. It is becoming increasingly important throughout Asia (Dobermann and Fairhurst 2000).

2.8.7 Causes of potassium deficiency

In agroecosystem, K is contributed by many sources like animal manure, crop residue, compost, rice burning residue, irrigation water and rain etc. Similarly, besides crop K removal, K is lost to deeper layers by rain or irrigation water by leaching (Srinivasarao et al. 2011).

K deficiency commonly occurs: (1) when N and P fertilizers are used excessively, but application of K fertilizer is not adequate, (2) where straw is completely removed, and (3) when recovery efficiency of applied K fertilizer is low due to high K fixation capacity or leaching losses. Soils which are particularly prone to K deficiency include: (1) coarse-textured soils with low cation exchange capacity (CEC) and small K reserves, and (2) highly weathered acid soils with low CEC and low K reserves, e.g., acid upland soils and degraded lowland soils. Soils on which K uptake is inhibited include: (1) lowland clay soils with high K fixation, (2) soils with a large K content but very wide (Calcium + Magnesium): K ratio, (3) leached, "old" acid sulfate soils with a small base cation content, (4) poorly drained and strongly reducing soils, and (5) organic soils (Histosols) with small K reserves (Dobermann and Fairhurst 2000).

2.8.8 A balance supply of nitrogen and potassium in rice

The relationship between nitrogen and potassium in crops is known to be of special importance and their interaction in crop productivity can be either antagonistic or synergistic. Because of this relationship, scientists view potassium as a major factor in adjusting nitrogen supply for crops (Bo et al. 2003).

Nitrogen being *‘the motor of plant growth’* will usually show its efficiency soon after application: the plants develop a dark green colour and grow more vigorously. However, unbalanced, excess nitrogen in rice may result in lodging, greater weed competition and pest attacks, with substantial losses of rice production. In addition, the nitrogen not taken up by the crop is likely to be lost to the environment (FAO and IFA 2000). Moreover, K deficiency has become a limiting nutritional factor for increasing rice yield with intensive cropping and increased application of N and P fertilizers in recent years (Dobermann and Fairhurst 2000; Yang et al. 2004). Rice needs higher K application as compared to other cereals, as about 56-112 kg of K is taken out from the soils by each harvest of 4-8 t ha^{-1} and annual K demand for irrigated rice would be 9-15 × 10^6 t by 2025 (Rahman 2015).

There is positive N and K interaction in rice. The benefit is in the form of increase yield with higher N levels and with less or low levels of K application but more significant with higher levels of K application. There is better utilization of applied N at high levels of balanced N and K application (Mondal 1982).

An improved nitrogen use efficiency (NUE) means that farmers may apply less N fertilizer without affecting yield. Therefore, savings of N fertilizer are achieved with higher profits to the farmer and enhanced environmental maintenance. Many trials conducted by International Potash Institute (IPI) demonstrate the role and scale effect of K on NUE. In these experiments, a typical K application of 30-150 kg K_2O ha^{-1} increases NUE by approximately 10-40% (Brar and Imas 2014). Simultaneous application of N and K in different years have significantly affected on performance of rice grain yield and dry matter (Zhang and Wang 2005).

Application of N promotes vegetative growth and plant height, and regular applications of N without supplemental K are not conducive to strong plant stands. The application of K can reduce the incidence of lodging in the presence of high N supply. Application of K significantly improved root growth and hence anchorage, reducing the incidence of lodging. Increased and timely N supply, promoting vigorous vegetative growth and increased panicle size and weight, may result in lodging. Similarly, insufficient K levels in plant tissues increases lodging incidence. Consequently, N nutrition and K availability are key factors in isolating the cause of lodging in rice production systems (Bhiah et al. 2010).

High N application resulted to softer stem growth in rice, which is more susceptible to plant diseases. However, high K application increases tolerance to diseases. In rice, the lesion length of bacterial leaf blight grew with increases in levels of applied N both at low and medium levels of applied K. However, the high level of

K significantly reduced lesion length even at the highest level of applied N (Ismunadji and Partohardjono 1979).

Moreover, without adequate K, NO_3 accumulates in the roots and a feedback mechanism to the root cells stops further NO_3 uptake. Consequently, NO_3 remains in the soil and is at risk of being lost to the environment, either when leached into surface and groundwater or denitrified and lost to the atmosphere as nitrogen gas or nitrous oxide, a greenhouse gas. On the other hand, with an adequate K supply, increased yields with N are accompanied by larger amounts of N in the crop and thus smaller residues of NO_3 in the soil at harvest. Less residual N means less potential risk of contamination of groundwater. Therefore, balanced fertilization with K increases crop yields and profits while enhancing NUE for the protection of the environment (Brar and Imas 2014).

CHAPTER III
MATERIALS AND METHODS

The first field experiment was conducted from February to May 2015 and the second experiment from December 2015 to March 2016. Both experiments were carried out during dry season.

3.1 Experimental Site

The experiments were conducted at the field of Let Khoke Pin village, Tar Pat (West) village tract, Maubin Township, Ayeyarwady Region. The area is situated at 16.73 latitude and 95.65 longitude with the elevation of 11 meters above the sea level. The experimental site of the second season was about 0.8 km far from that of the first season in the same village.

3.2 Experimental Design and Treatments

The experiment was laid out in Randomized Complete Block Design (RCBD). There were 32 experimental plots comprising 8 treatments and 4 replications. The tested cultivar was Thee Htat Yin. Nitrogen and potassium fertilizers were applied as treatments. Phosphorus fertilizer was applied with the same rate in all treatments except in control. The amounts of fertilizers applied in each treatment are presented in table 3.1.

3.3 Soil Sampling and Analysis

The soil samples were collected randomly at 0-15 cm depth. The composite soil sample was air-dried, and ground to pass through a 2 mm sieve. The soil sample was analysed for some physicochemical properties such as soil texture, soil pH, electrical conductivity (EC), available N, available P, available K, organic matter % and cation exchange capacity (CEC) at the Department of Agricultural Research and bulk density was analysed at the Department of Soil and Water Science, Yezin Agricultural University. The physicochemical properties of experimental soils for both seasons are described in table 3.3 and 3.4.

Table 3.1 Treatments of the experiment

Treatments	kg ha^{-1}		
	N	**P**	**K**
T_1 - Control	0	0	0
T_2 - P	0	12	0
T_3 - N_1P	58	12	0
T_4 - N_1PK_1	58	12	31
T_5 - N_2P	116	12	0
T_6 - N_2PK_2	116	12	63
T_7 - N_3P	174	12	0
T_8 - N_3PK_3	174	12	94

Urea, Triple Super Phosphate and Muriate of Potash were used as fertilizers.

Table 3.2 Soil analysis methods

Analytical Item	Analytical Method
Soil Texture	Pipette method
Soil pH	1:5 (soil: water)
Electrical Conductivity (EC)	1:5 (soil: water)
Available N	Alkaline permanganate method
Available P	Olsen’s method
Available K	1N Ammonium acetate extraction method
Cation Exchange Capacity (CEC)	Leaching method
Organic Matter	Tyurin’s method
Bulk Density	Bulk density measurement of disturbed soil

Table 3.3 Physicochemical properties of the experimental soil for the first experiment

Properties	Results
Soil Texture	Silt Loam
Soil pH	5.5 (moderately acid)
Electrical Conductivity (EC)(dSm^{-1})	0.2
Available N (mg kg^{-1})	60 (low)
Available P (mg kg^{-1})	18 (medium)
Available K (mg kg^{-1})	137 (low)
Cation Exchange Capacity(cmol(+) kg^{-1})	23
Organic Matter (%)	4.1 (high)
Bulk Density (gcm^{-3})	1.21

Table 3.4 Physicochemical properties of the experimental soil for the second experiment

Properties	Results
Soil pH	6.1 (slightly acid)
Electrical Conductivity (EC)(dSm^{-1})	0.29
Available N (mg kg^{-1})	59 (low)
Available P (mg kg^{-1})	2 (low)
Available K (mg kg^{-1})	142 (low)
Cation Exchange Capacity(cmol(+) kg^{-1})	34
Organic Matter (%)	4.3 (high)
Bulk Density (gcm^{-3})	1.27

The soil of the experimental site was silt loam in texture, acidic in reaction. The pH of the second season experimental soil was slightly higher than that of the first season. For both seasons, the soil was low in available N and K, but high in organic matter content. Available P was medium level in the soil of first season, and low level in that of second season experiment.

3.4 Land Preparation and Crop Management

The field used was previously grown monsoon rice. The land preparation was done mechanically. The whole size of the experimental area was (26.5 x 41) m^2 and each plot size was (5 x 4) m^2. Double bunds were constructed 1m apart between plots and 1.5 m between blocks to prevent other contamination that effect on treatments such as mixing fertilizers during irrigation or drainage. Seedlings were raised in nursery and then twenty-five days old seedlings were transplanted with two plants $hill^{-1}$ at the spacing of 20 cm x 15 cm. The experimental field was fenced round with fishnet at panicle initiation stage until harvesting to prevent rodents. Weed control was done regularly, especially at the early stages of growth. The plots were irrigated whenever necessary.

3.5 Fertilizer Application

In fertilizer application, the whole required amount of phosphorus fertilizer was applied as basal. Nitrogen and potassium fertilizers were added in 3 equal splits; one third was applied at recovery stage (9 DAT), one third at active tillering stage (25 DAT), and the remaining one third at panicle initiation stage (45 DAT). All fertilizers were applied by broadcast method.

3.6 Measurement Parameter for Growth

Growth parameters such as plant height and number of tillers $hill^{-1}$ were recorded from 10 randomly selected hills for each plot. Plant height was measured from the base to uppermost growing point of the plant. The number of tillers $hill^{-1}$ was recorded at 2-week intervals from 14 days after transplanting (DAT) until heading stage.

3.7 Measurement Parameter for Yield and Yield Components

The crop was harvested at physiological maturity. The grain yield was determined from a central 5 m^2 harvested area in each plot. After harvest, the grains were hand threshed, winnowed and sun dried. The dried grains from each plot were weighted and grain yield was adjusted to 14% moisture content.

Two sites of four opposite hills along the diagonal of each harvested area were selected to assess the yield component parameters such as number of panicles $hill^{-1}$, number of spikelets $panicle^{-1}$, filled grain% and 1000 grain weight. Rice panicles with spikelets were cut and collected, and then total panicles for every sample were counted. After that dried spikelets or grains were separated from the panicle into two groups, unfilled grains and filled grains. From here, 1000 grain weight and filled spikelets percentage were recorded.

3.8 Agronomic Efficiencies of Nitrogen and Potassium

Nitrogen use efficiency (NUE) was calculated by using the following formula;

$$\text{NUE} \qquad \frac{GY_{+N} - GY_{0N}}{FN}$$

Where, GY_{+N} = grain yield in a treatment with N application (kg ha^{-1})

GY_{0N} = grain yield in a treatment without N application (kg ha^{-1})

FN = the amount of fertilizer N applied (kg ha^{-1})

Potassium use efficiency (KUE) was calculated by using the following formula;

$$\text{KUE} = \frac{GY_{+K} - GY_{0K}}{FK}$$

Where, GY_{+K} = grain yield in a treatment with K application (kg ha^{-1})

GY_{0K} = grain yield in a treatment without K application (kg ha^{-1})

FK = the amount of fertilizer K applied (kg ha^{-1})

(Dobermann and Fairhurst 2000)

3.9 Weather Data

Climate influences the rice crop distribution over different regions of the world, while weather influences the corresponding rice crop production potential. Among abiotic stress, weather plays the significant role in influencing the growth and yield of rice. All weather data for the seasons of both experiments were obtained from Department of Agriculture, Maubin district (Appendix 1).

The monthly average temperature and the amount of rainfall for two experimental growing periods are shown in Figure 3.1. In the periods from February to May 2015 (first experiment), the maximum temperature ranges from 34°C (February) to 37°C (March and April), and the minimum temperature ranges from 15°C (February) to 21°C (April and May). From December 2015 to March 2016 (second experiment), the maximum temperature ranges from 29°C to 35°C, and the minimum temperature ranges from 16°C to 22°C in January and March respectively.

During periods of the first experiment, there were rainy days in April and May, and the amount was 28.96 and 189.48 mm respectively. However, there was no rainy day during ripening periods of the second experiment and the amount of rainfall in January 2016 was 52.07 mm. Viswambaran et al. (1989) stated that there was a negative correlation between grain yield and number of rainy day during maturity phase.

3.10 Statistical Analysis

All the collected data were analysed using ANOVA with Statistix 8 software. The differences in treatment means were separated by Least Significant Difference (LSD) at 5 percent probability level. For combined analysis of variance, IRRISTAT software was used.

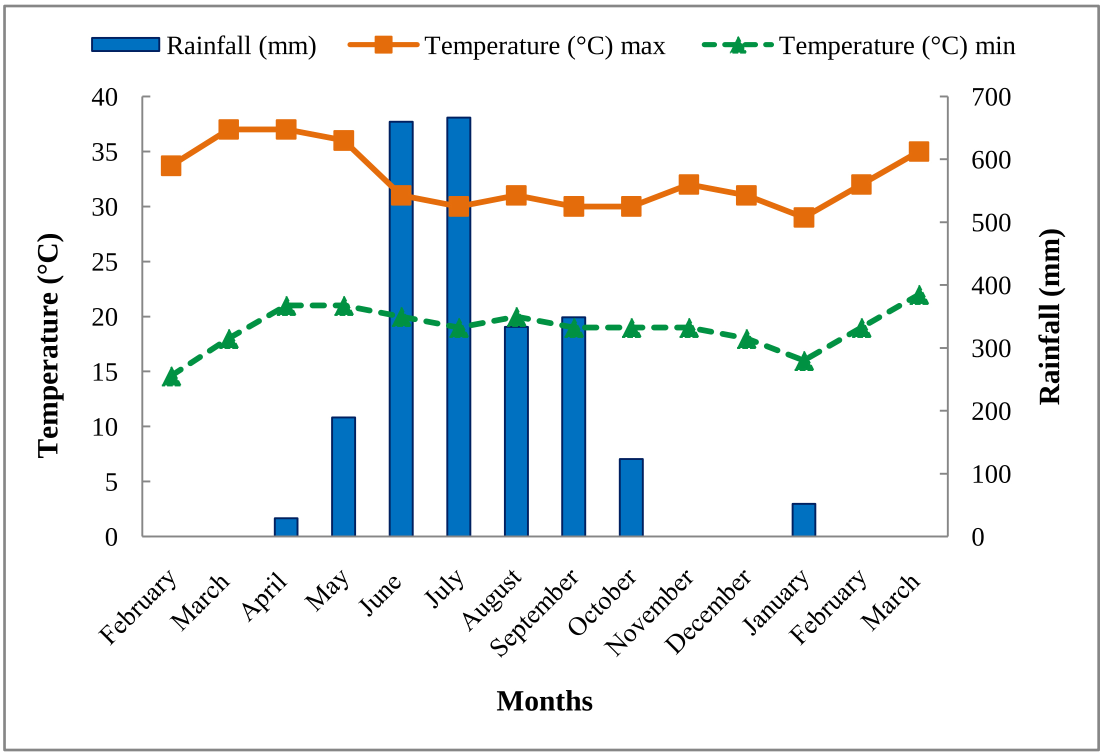


Figure 3.1 Monthly average rainfall, minimum and maximum temperature during experimental periods in Maubin (February 2015 - March 2016)

CHAPTER IV
RESULTS AND DISCUSSION

4.1 First Experiment (Dry season, 2015)

This experiment was conducted during the dry season from February to March 2015 to identify the effect of nitrogen and potassium fertilization on yield and fertilizer use efficiency of Thee Htat Yin rice variety. The experimental results are presented and discussed in this chapter.

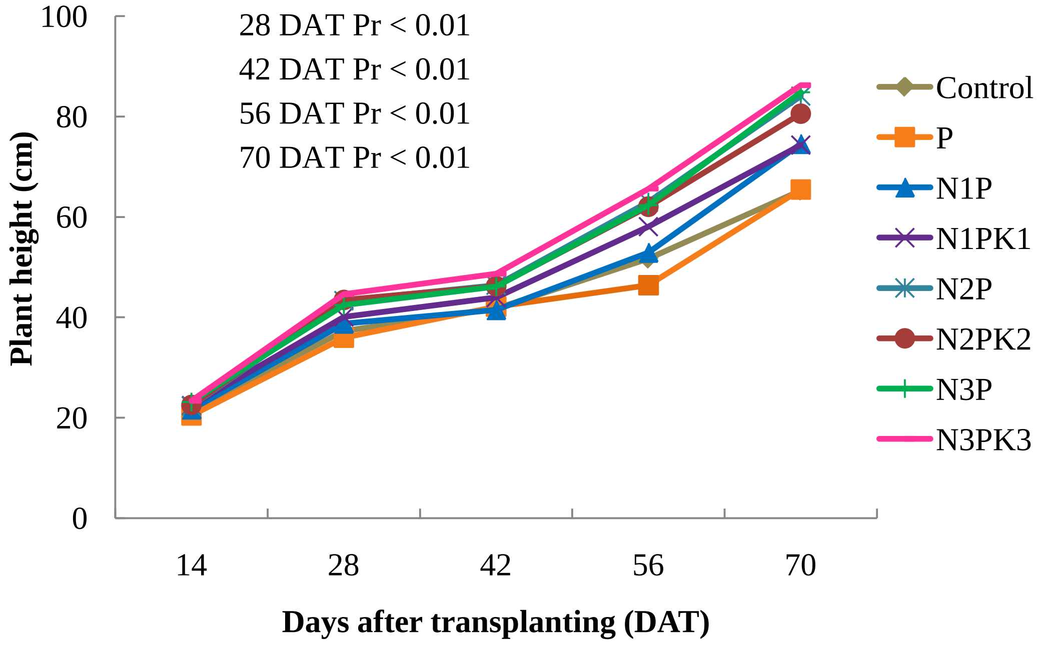
4.1.1 Effect of nitrogen and potassium fertilization on growth parameters

4.1.1.1 Plant height (cm)

The plant height was measured at 2-week intervals starting from 14 days after transplanting (DAT) to 70 DAT. The plant height increased progressively up to 86.28 cm at 70 DAT starting from 20.48 cm at 14 DAT (Figure 4.1). It was observed that the rates of nitrogen exerted significant influence on plant height. Except 14 DAT, all the plant height among the treatments were highly significant different at 1% level.

At 28, 42, 56 and 70 DAT, the maximum plant height was produced by N_3PK_3 (174: 12: 94 kg ha^{-1}) which was statistically similar to that of N_2P (116: 12: 0 kg ha^{-1}), N_2PK_2 (116: 12: 63 kg ha^{-1}) and N_3P (174: 12: 0 kg ha^{-1}). Only P treatment gave the minimum plant height at 28 DAT and 56 DAT. The shortest plant heights at 42 DAT and 70 DAT were recorded from control. Plant heights were higher in higher nitrogen rate treatments. However, within the same amount of nitrogen application, potassium application did not increase plant height significantly. Nitrogen influenced cell division and cell elongation and ultimately increases plant height (Mannan 2005).

In all different observed data from 14 DAT to 70 DAT, all the highest plant height were obtained from N_2P (116: 12: 0 kg ha^{-1}), N_2PK_2 (116: 12: 63 kg ha^{-1}), N_3P (174: 12: 0 kg ha^{-1}) and N_3PK_3 (174: 12: 94 kg ha^{-1}) while N_3PK_3 got the highest data of mathematical value. Most of the shortest plant heights were resulted from P alone and control treatments. At 70 DAT, the maximum plant height obtained from N_3PK_3 (174: 12: 94 kg ha^{-1}) treatment was 86.28 cm and the minimum plant height from control treatment was 65.25 cm. Although plant height is not a yield component, it implies the influence of nutrients on plant metabolisms. Bhiah et al. (2010) discussed that application of nitrogen promotes vegetative growth and plant height, and regular



DAT	**14**	**28**	**42**	**56**	**70**
LSD$_{0.05}$	**0.47**	**0.59**	**1.91**	**2.20**	**1.74**

Figure 4.1 Mean value of plant height as affected by nitrogen and potassium fertilization on Thee Htat Yin rice variety in Maubin township during the dry season, 2015

Control – (no fertilizer), **P** – (0: 12: 0 kg ha^{-1}),

N$_1$P – (58: 12: 0 kg ha^{-1}), **N$_1$PK$_1$** – (58: 12: 31 kg ha^{-1}),

N$_2$P – (116: 12: 0 kg ha^{-1}), **N$_2$PK$_2$** – (116: 12: 63 kg ha^{-1}),

N$_3$P – (174: 12: 0 kg ha^{-1}), **N$_3$PK$_3$** – (174: 12: 94 kg ha^{-1})

application of nitrogen with supplemental potassium are conductive to strong plant stands.

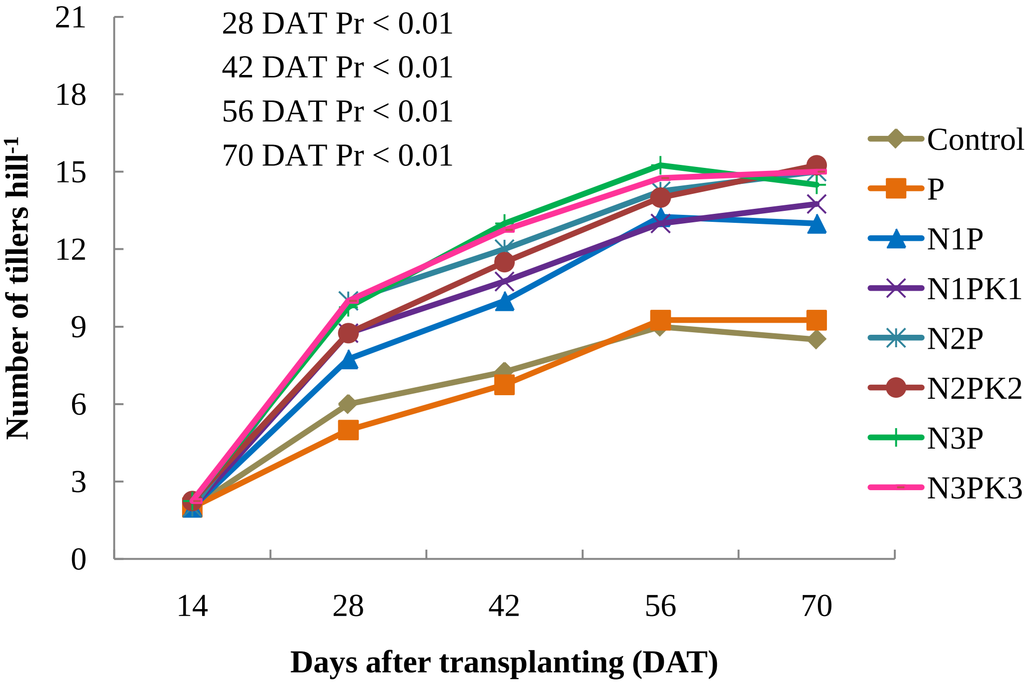
Highest fertilizer rate treatments, N_3P (174: 12: 0 kg ha^{-1}) and N_3PK_3 (174: 12: 94 kg ha^{-1}), were not further increased significantly in plant height at all growth stages. The highest level of nitrogen i.e. 160 kg ha^{-1} did not increased plant height (Kumar et al. 1995; Singh et al. 2014).

4.1.1.2 Number of tillers hill^{-1}

The number of tillers hill^{-1} was recorded 2-week intervals from 14 days after transplanting (DAT) to 70 DAT which was analysed and has been presented in Figure 4.2. The nitrogen level played an important role in increasing number of tillers hill^{-1}. The results showed that the number of tillers hill^{-1} increased due to increasing level of nitrogen from 28 DAT to 70 DAT.

The significant difference in number of tillers hill^{-1} was observed at 28, 42, 56 and 70 DAT at 1% level of significance. At 42 DAT and 56 DAT, the highest number of tillers hill^{-1} (13.00 and 15.25 respectively) were recorded from N_3P (174: 12: 0 kg ha^{-1}), and the lowest number of tillers (7.25 and 9.00 respectively) were produced by control. The second and third most number of tillers hill^{-1} were obtained from N_3PK_3 (174: 12: 94 kg ha^{-1}) (12.75 at 42 DAT and 14.75 at 56 DAT), and N_2P (116: 12: 0 kg ha^{-1}) (12.00 at 42 DAT and 14.25 at 56 DAT) treatments respectively.

The maximum number of tillers hill^{-1} (15.25) was observed in N_2PK_2 (116: 12: 63 kg ha^{-1}) at 70 DAT whereas the minimum (8.50) in control. The number of tillers hill^{-1} of N_2PK_2 (116: 12: 63 kg ha^{-1}) was statistically identical with that of N_2P (116: 12: 0 kg ha^{-1}) and N_3PK_3 (174: 12: 94 kg ha^{-1}) with the value of 15. The increase in number of tillers hill^{-1} was observed with increased nitrogen level up to 116 kg N ha^{-1}. The application of nitrogen enhanced the development of tillers (Hussain et al. 2013). If nitrogen requirement would not supply, plant would encounter reduction in growth, photosynthesis, and number of tillers. Ntanos and Koutroubas (2002) reported that nitrogen produces more dry matter and yield by affecting size and longevity of the leaf, as well as formation and survival of tiller. However, the highest nitrogen rate (174 kg N ha^{-1}) did not produce additional tillers, and thus it seems to reach its maximum since the nitrogen rate (116 kg N ha^{-1}).



DAT	**14**	**28**	**42**	**56**	**70**
$LSD_{0.05}$	**0.47**	**0.59**	**1.91**	**2.20**	**1.74**

Figure 4.2 Mean value of number of tillers hill^{-1} as affected by nitrogen and potassium fertilization on Thee Htat Yin rice variety in Maubin township during the dry season, 2015

Control – (no fertilizer), **P** – (0: 12: 0 kg ha^{-1}),
N_1P – (58: 12: 0 kg ha^{-1}), **N_1PK_1** – (58: 12: 31 kg ha^{-1}),
N_2P – (116: 12: 0 kg ha^{-1}), **N_2PK_2** – (116: 12: 63 kg ha^{-1}),
N_3P – (174: 12: 0 kg ha^{-1}), **N_3PK_3** – (174: 12: 94 kg ha^{-1})

4.1.2 Effect of nitrogen and potassium fertilization on yield and yield components

4.1.2.1 Number of panicles hill^{-1}

Mean data regarding the number of panicles hill^{-1} as affected by different nitrogen and potassium fertilization are presented in Table 4.1. The number of panicles hill^{-1} was highly significant different among the treatments. The mean number of panicles varied from 5.00 to 10.25. The highest number of panicles hill^{-1} was found in highest nitrogen rate treatment N_3P (174: 12: 0 kg ha^{-1}), which was statistically similar to those recorded in the treatments N_3PK_3 (174: 12: 94 kg ha^{-1}), N_2P (116: 12: 0 kg ha^{-1}), and N_2PK_2 (116: 12: 63 kg ha^{-1}) with the values of 9.75, 9.25 and 9.00 respectively. The lowest number of panicles hill^{-1} was resulted from control. The number of panicles hill^{-1} was increased with increased rates of nitrogen fertilizer. The nitrogen application can be increasingly effected dry matter, panicle length and number of panicles m^{-2} which are correlated with grain yield (Bahmaniar and Ranjbar 2007).

Tillering in rice is an important agronomic trait for number of panicles per unit land area as well as grain production (Moldenhauer and Gibbons 2003). However, excessive tillering leads to high tiller abortion, poor grain setting and small panicle size, and further reduction in grain yield (Peng et al. 1994; Ahmad et al. 2005). Therefore, panicle bearing tiller rate influences the grain yield of rice (Wang et al. 2007). However, in this experiment, the number of panicles hill^{-1} followed a trend similar to that obtained for the number of tillers. The higher number of panicles hill^{-1} was due to higher number of tillers hill^{-1}. In addition, it was observed that the increase in number of panicles hill^{-1} was mainly due to increasing rates of nitrogen application, and application of potassium was not significantly affected the number of panicles. Hashem et al. (2016) stated that the effect of nitrogen application on number of panicles m^{-2} is attributed mainly to the stimulation effect of nitrogen on effective tillers formation.

4.1.2.2 Number of spikelets panicle^{-1}

Based on the results, it was revealed that the number of spikelets panicle^{-1} varied significantly due to the different levels of nitrogen and potassium application at 1% level (Table 4.1). Nitrogen fertilization significantly increased the number of spikelets panicle^{-1} up to the applied level of 116 kg ha^{-1} and application of more than

Table 4.1 Yield and yield components as affected by nitrogen and potassium fertilization in Maubin township during the dry season, 2015

Treatments	Number of panicles hill^{-1}	Number of spikelets panicle^{-1}	1000- grain weight (g)	Filled grain %	Grain Yield (t ha^{-1})
Control	5.00 d	82.43 e	19.55	77.50	2.30 c
P	6.25 d	86.78 de	20.08	80.00	2.88 c
N_1P	8.25 bc	92.57 cd	20.58	78.00	4.00 b
N_1PK_1	8.00 c	103.33 ab	20.60	80.50	4.65 ab
N_2P	9.25 abc	97.90 bc	20.30	76.75	4.80 ab
N_2PK_2	9.00 abc	110.98 a	20.40	81.25	5.50 a
N_3P	10.25 a	95.65 bcd	21.00	81.75	5.28 a
N_3PK_3	9.75 ab	98.35 bc	20.60	81.50	5.48 a
LSD $_{0.05}$	1.710	9.910	0.948	8.918	0.973
Pr>F	**	**	ns	ns	**
CV%	14.15	7.02	3.16	7.61	15.17

Means followed by different letters in the same column are significantly different by LSD test at 5% level.

****Significant difference at 1% level, ns non-significant difference

Control – (no fertilizer), **P** – (0: 12: 0 kg ha^{-1}),
N_1P – (58: 12: 0 kg ha^{-1}), **N_1PK_1** – (58: 12: 31 kg ha^{-1}),
N_2P – (116: 12: 0 kg ha^{-1}), **N_2PK_2** – (116: 12: 63 kg ha^{-1}),
N_3P – (174: 12: 0 kg ha^{-1}), **N_3PK_3** – (174: 12: 94 kg ha^{-1})

116 kg N ha^{-1} reduced the number of spikelets panicle^{-1}. This may be caused by vigorous vegetative growth resulting in heavy drain on soluble carbohydrate, and thus reduced its availability for spikelets formation or possibly due to an increase competition for metabolic supply among tillers leading to decreased production of spikelets (Hasegawa et al. 1994; Wu et al. 1998; Gebrekidan and Seyoum 2006).

The number of spikelets panicle^{-1} due to different treatments ranged from 82.43 to 110.98. The maximum number of spikelets panicle^{-1} was obtained from N_2PK_2 (116: 12: 63 kg ha^{-1}) which was statistically similar to those observed in N_1PK_1 (58: 12: 31 kg ha^{-1}) with the value of 103.33. The minimum number of spikelets panicle^{-1} was resulted from control. In addition, it was found that the number of spikelets panicle^{-1} recorded from N_1PK_1 (58: 12: 31 kg ha^{-1}), N_2PK_2 (116: 12: 63 kg ha^{-1}) and N_3PK_3 (174: 12: 94 kg ha^{-1}) were more than that of N_1P (58: 12: 0 kg ha^{-1}), N_2P (116: 12: 0 kg ha^{-1}) and N_3P (174: 12: 0 kg ha^{-1}) treatments respectively. Therefore, the same amount of nitrogen fertilizer treatments with potassium application gave higher number of spikelets panicle^{-1} than that of nitrogen fertilizer treatments without potassium application. Abd El-Hadi et al. (2013) and Ding et al. (2015) concluded that nitrogen fertilizer significantly increases number of spikelets in rice and the utilization of applied nitrogen fertilizer was improved by potassium fertilization.

4.1.2.3 1000 grain weight (g)

In this experiment, the application of nitrogen and potassium fertilizers did not significantly increased 1000 grain weight of Thee Htat Yin rice variety (Table 4.1). The grain weight varied from 19.55 to 21 g. The maximum 1000 grain weights were obtained from fertilizer treatments N_3P (174: 12: 0 kg ha^{-1}), N_3PK_3 (174: 12: 94 kg ha^{-1}), N_1PK_1 (58: 12: 31 kg ha^{-1}) and N_1P (58: 12: 0 kg ha^{-1}). Control gave the minimum 1000 grain weight. The result was in agreement with the findings of Bahmaniar and Ranjbar (2007), Islam et al. (2008) and Masum et al. (2013). Weight of 1000 grain was not significantly influenced by nitrogen and potassium application because it is mostly governed by genetic makeup of the variety.

4.1.2.4 Filled grain %

The response of filled grain % to nitrogen and potassium fertilization ranged from 76.75% to 81.75% is presented in Table 4.1. There was no statistically significant effect on filled grain % among different treatments. The highest filled grain % was obtained from N_3P (174: 12: 0 kg ha^{-1}) and the lowest filled grain % from N_2P (116: 12: 0 kg ha^{-1}) but the values were statistically similar among different treatments. It was found that most of the highest filled grain % values were resulted from nitrogen and potassium balanced fertilization. Potassium fertilizer increased the number of filled grains, and the improved grain filling under potassium application was due to increased photosynthetic activity, as potassium stimulates some biochemical processes (Mathews 2005).

4.1.2.5 Grain yield (t ha^{-1})

The grain yield responded significantly to nitrogen and potassium balanced fertilization at 1% level and results are presented in Table 4.1. The grain yield of rice ranged from 2.3 to 5.5 t ha^{-1} due to different treatments. The maximum grain yield was produced by N_2PK_2 (116: 12: 63 kg ha^{-1}) treatment which was statistically identical to those resulted from N_3PK_3 (174: 12: 94 kg ha^{-1}) and N_3P (174: 12: 0 kg ha^{-1}) treatments with the values of 5.48 t ha^{-1} and 5.28 t ha^{-1} respectively. The minimum grain yield was given by control (no fertilizer) treatment. Addition of only phosphorus did not provide a significant yield increase (2.88 t ha^{-1}) over the control. The application of nitrogen and potassium fertilizers increased grain yield in comparison with no application of both fertilizers (Farrokh et al. 2012).

The grain yields of N_1PK_1 (58: 12: 31 kg ha^{-1}) (4.65 t ha^{-1}), N_2PK_2 (116: 12: 63 kg ha^{-1}) (5.5 t ha^{-1}), and N_3PK_3 (174: 12: 94 kg ha^{-1}) (5.48 t ha^{-1}) were higher than that of N_1P (58: 12: 0 kg ha^{-1}) (4 t ha^{-1}), N_2P (116: 12: 0 kg ha^{-1}) (4.8 t ha^{-1}) and N_3P (174: 12: 0 kg ha^{-1}) (5.28 t ha^{-1}) treatments. In N_1P, N_2P and N_3P treatments, potassium was omitted comparing with corresponding treatments of N_1PK_1, N_2PK_2 and N_3PK_3 while applying the same amounts of nitrogen and phosphorus fertilizers. Therefore, it was found that all of the higher grain yields were obtained from nitrogen and potassium balanced fertilization treatments. Rahman (2015) reported that potassium doses had significant effect on the grain yield of transplanted rice. Brar and Imas (2014) also pointed out that when nitrogen and potassium are applied together the increase in grain yield is greater than that applied individually.

Although the highest fertilizer rates were applied in both cases of N_3P (174: 12: 0 kg ha^{-1}) and N_3PK_3 (174: 12: 94 kg ha^{-1}), there was no further increasing in grain yield. Increasing the N fertilizer rate for rice plants does not always increase grain yield due to diminishing returns (Bohlool et al. 1992). Over application of nitrogen and potassium does not lead to further yield increments (Brar et al. 2011).

4.1.3 Percent increase in grain yield over control during 2015

The percent grain yield increase over control was influenced by the application of nitrogen and potassium (Figure 4.3). The grain yield increased 73.91%, 108.70% and 129.27% when nitrogen application rates were increased to 58, 116 and 174 kg ha^{-1} respectively. When potassium fertilizer was applied together, the grain yield increased 102.17%, 139.13% and 138.26% over control. The higher percent grain yield increases over control were observed by the combined application of nitrogen with potassium. The highest grain yield increase 139.13% was observed in N_2PK_2 (116: 12: 63 kg ha^{-1}) and it was lowest in P treatment. Khan et al. (2007) stated that application of potassium (60 kg K_2O ha^{-1}) treatment increased the grain yield by 50% over control.

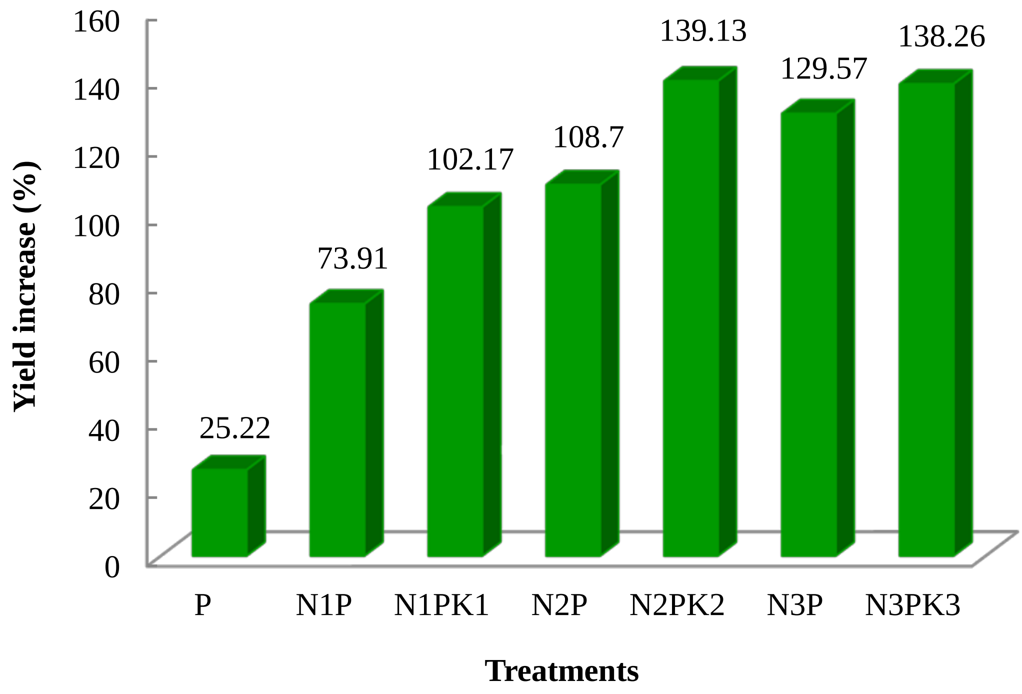


Figure 4.3 Yield increase (%) of rice over control as affected nitrogen and potassium fertilization in Maubin township during the dry season, 2015

P – (0: 12: 0 kg ha^{-1}), **N$_1$P** – (58: 12: 0 kg ha^{-1}), **N$_1$PK$_1$** – (58: 12: 31 kg ha^{-1}),
N$_2$P – (116: 12: 0 kg ha^{-1}), **N$_2$PK$_2$** – (116: 12: 63 kg ha^{-1}),
N$_3$P – (174: 12: 0 kg ha^{-1}), **N$_3$PK$_3$** – (174: 12: 94 kg ha^{-1})

4.1.4 Agronomic efficiencies of nitrogen and potassium

4.1.4.1 Nitrogen use efficiency (NUE)

The NUE of Thee Htat Yin rice variety as influenced by different levels of nitrogen and potassium fertilizers is presented in Table 4.2. The NUE was highest in N_1PK_1 (58: 12: 31 kg ha^{-1}) (40.52) followed by N_1P (58: 12: 0 kg ha^{-1}) (29.31), N_2PK_2 (116: 12: 63 kg ha^{-1}) (27.59), N_2P (116: 12: 0 kg ha^{-1}) (21.55), N_3PK_3 (174: 12: 94 kg ha^{-1}) (18.28) and the lowest in N_3P (174: 12: 0 kg ha^{-1}) treatment (17.13). The higher nitrogen rate treatments (N_2P, N_2PK_2, N_3P and N_3PK_3) were lower in NUE than N_1P and N_1PK_1 where the rate of applied nitrogen was low as compared to those treatments. The poor nitrogen use efficiency (NUE) of rice could be partially due to high nitrogen input (Peng et al. 2002; Peng et al. 2006). The use of excessive fertilizers could reduce the nitrogen use efficiency. However, the reduction in NUE due to added fertilizer was lower with combined application of nitrogen with potassium than with only nitrogen application, which illustrated the importance of potassium in rice for increasing NUE. Therefore, adequate and balanced application of fertilizer nutrients is one of the most common practices for improving the efficiency of nitrogen fertilizer.

The NUE of balancing the nitrogen application with potassium fertilizer treatments were greater than that of nitrogen without potassium fertilizer treatments under the same amount of nitrogen application. The NUE of N_1PK_1 (58: 12: 31 kg ha^{-1}) was 38.25% greater than that of N_1P (58: 12: 0 kg ha^{-1}), treatment N_2PK_2 (116: 12: 63 kg ha^{-1}) was 28.03% greater than N_2P (116: 12: 0 kg ha^{-1}) and treatment N_3PK_3 (174: 12: 94 kg ha^{-1}) was 6.7% greater than N_3P (174: 12: 0 kg ha^{-1}). These results are in line with the findings of Brar and Imas (2014) who reported that potassium improves NUE because it allows better nitrogen uptake and utilization resulting in higher yield.

4.1.4.2 Potassium use efficiency (KUE)

Nutrient use efficiency is also called nutrient to grain ratio (i.e. kg grain per kg K applied). Potassium use efficiency (KUE) of Thee Htat Yin rice variety during dry season 2015 ranged from 2.13 to 20.97 (Table 4.2). The highest KUE was obtained from N_1PK_1 (58: 12: 31 kg ha^{-1}) (20.97) followed by N_2PK_2 (116: 12: 63 kg ha^{-1}) (11.11) and the lowest from N_3PK_3 (174: 12: 94 kg ha^{-1}) (2.13). It was found that the lowest rate of potassium application gave the maximum KUE and the highest

Table 4.2 Effect of nitrogen and potassium fertilization on nitrogen use efficiency (NUE) and potassium use efficiency (KUE) of Thee Htat Yin rice variety in Maubin township during the dry season, 2015

Treatments	NUE (kg grain kg^{-1} N)	KUE (kg grain kg^{-1} K)
Control	-	-
P	-	-
N_1P	29.31	-
N_1PK_1	40.52	20.97
N_2P	21.55	-
N_2PK_2	27.59	11.11
N_3P	17.13	-
N_3PK_3	18.28	2.13

Control – (no fertilizer), **P** – (0: 12: 0 kg ha^{-1}),
N_1P – (58: 12: 0 kg ha^{-1}), **N_1PK_1** – (58: 12: 31 kg ha^{-1}),
N_2P – (116: 12: 0 kg ha^{-1}), **N_2PK_2** – (116: 12: 63 kg ha^{-1}),
N_3P – (174: 12: 0 kg ha^{-1}), **N_3PK_3** – (174: 12: 94 kg ha^{-1})

potassium application gave the minimum KUE, although the grain yield of N_1PK_1 (58: 12: 31 kg ha^{-1}) was lower than that of N_2PK_2 (116: 12: 63 kg ha^{-1}) and N_3PK_3 (174: 12: 94 kg ha^{-1}). The higher application of fertilizers could reduce the nutrient use efficiency of both nitrogen and potassium (N'Guessan Diby et al. 2011). Roberts (2008) stated that much higher nutrient efficiencies could be achieved simply by sacrificing yield, but that would not be economically effective or feasible for the farmer. Dibb (2000) described this relationship between yield and nutrient efficiency where nutrient use efficiency is high at low yield level, because any small amount of nutrient applied could give a large yield response. Despite yields continue to increase with the increase in rate of nutrient application, nutrient use efficiency typically declines. However, the extent of the decline will be dictated by the best management practices, soil and climatic conditions.

4.1.5 Correlation and regression analysis

There was a highly significant correlation between grain yield with number of panicles hill^{-1} (r = 0.9499**) and number of spikelets panicle^{-1} (r = 8544**) in dry season 2015 (Appendix 6). The positive linear relation was observed between number of panicles hill^{-1} and number of spikelets panicle^{-1} with grain yield (R^2= 0.902 and R^2= 0.73 respectively). The results showed that the grain yields were significantly increased with increasing in number of panicles hill^{-1} (Figure 4.4). The correlation coefficient of this regression model is high having the correlation coefficient as high as 0.9499 with the degree of fitness of 90.2%. Fageria (1989) reported that panicles m^{-2} had the highest correlation among the yield components, and thus this parameter was responsible for a higher contribution to the grain yield. The optimum rice yield could not be attained without optimum panicle density of uniform maturity (Gravois and Helms 1992). Spikelets panicle^{-1} also significantly increased the grain yield having correlation coefficient 0.8544 with the degree of fitness of 73% (Figure 4.5). The grain yield exhibits significantly positive correlation with the number of spikelets panicle^{-1} (Akinwale et al. 2011). Li et al. (2014) also stated that number of panicles m^{-2} and number of spikelets m^{-2} were significantly and positively correlated with grain yield.

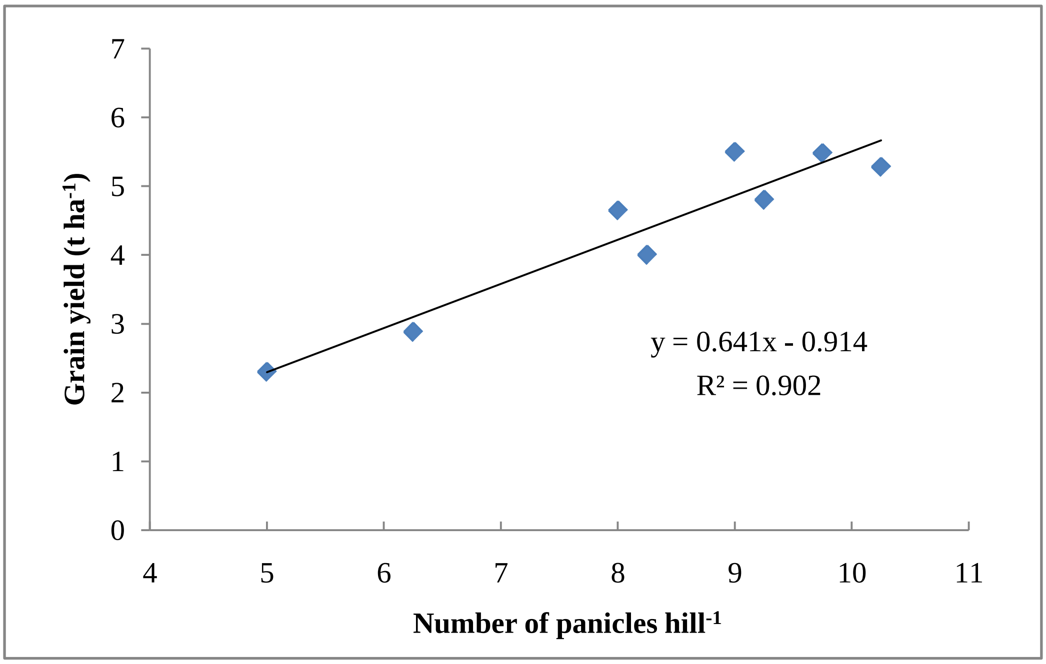


Figure 4.4 Relationship between grain yield (t ha^{-1}) and number of panicles hill^{-1} of Thee Htat Yin rice variety during the dry season, 2015

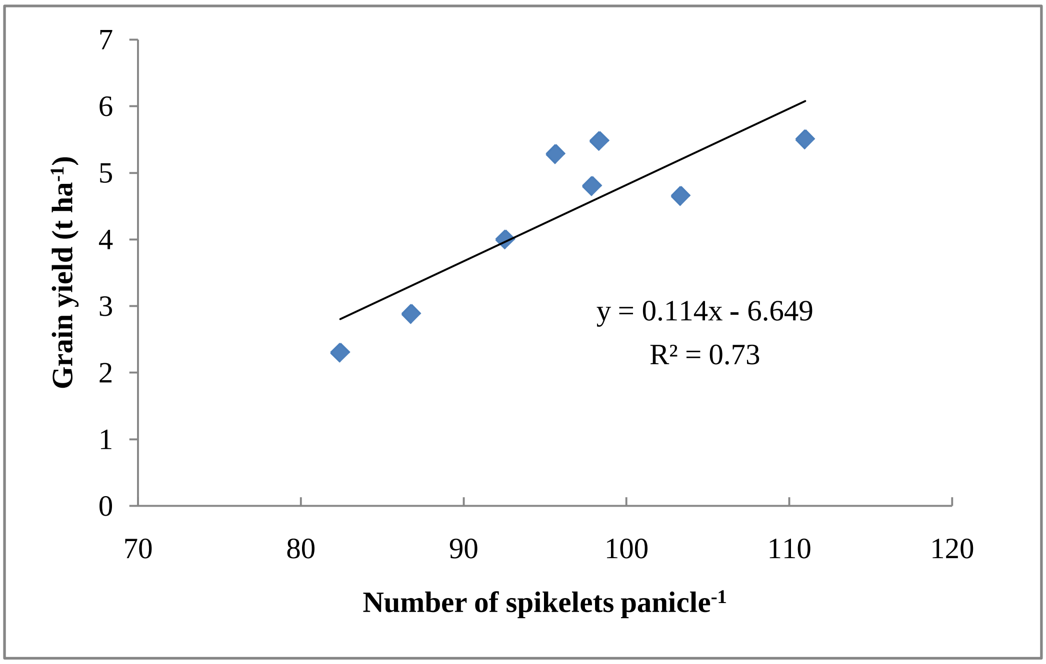


Figure 4.5 Relationship between grain yield (t ha^{-1}) and number of spikelets panicle^{-1} of Thee Htat Yin rice variety during the dry season, 2015

4.2 Second Experiment (Dry season, 2016)

The second dry season experiment was carried out as the same procedures of first experiment in different place of the same village to examine the effect of nitrogen and potassium fertilization on rice yield and its fertilizer use efficiency during dry season from December 2015 to March 2016. The results of this study are described and discussed in this section.

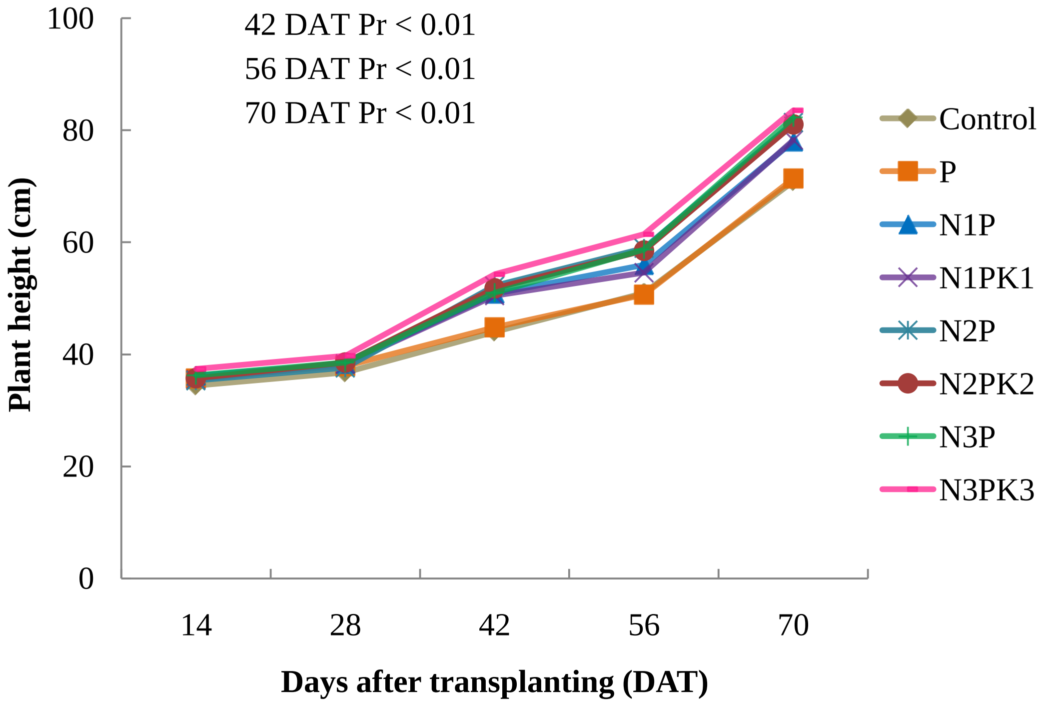
4.2.1 Effect of nitrogen and potassium fertilization on growth parameters

4.2.1.1 Plant height (cm)

Plant height data recorded at 2-week intervals started from 14 days after transplanting (DAT) to 70 DAT are presented in Figure 4.6. It was found that plant height in all treatments increased continuously from 14 DAT to 70 DAT and the rates of nitrogen significantly influenced plant height of Thee Htat Yin rice variety.

Except 14 DAT and 28 DAT, significant difference in plant heights among different nitrogen and potassium rates were observed at 1% level of significant. At 42 DAT, the maximum plant height was recorded from N_3PK_3 (174: 12: 94 kg ha^{-1}) which was statistically identical with N_1P (58: 12: 0 kg ha^{-1}), N_1PK_1 (58: 12: 31 kg ha^{-1}), N_2P (116: 12: 0 kg ha^{-1}), N_2PK_2 (116: 12: 63 kg ha^{-1}) and N_3P (174: 12: 0 kg ha^{-1}) treatments. The minimum plant height was observed in control. At 56 DAT, the tallest plant height (61.42 cm) was resulted from N_3PK_3 (174: 12: 94 kg ha^{-1}) which was followed by that of N_2P (116: 12: 0 kg ha^{-1}), N_3P (174: 12: 0 kg ha^{-1}) and N_2PK_2 (116: 12: 63 kg ha^{-1}) treatments. The shortest plant height (50.65 cm) was obtained from sole P treatment.

Plant height at 70 DAT was varied from 70.90 cm to 83.55 cm. The highest nitrogen and potassium rates treatment N_3PK_3 (174: 12: 94 kg ha^{-1}) gave the maximum plant height which was not significant different with that of N_3P (174: 12: 0 kg ha^{-1}), N_2P (116: 12: 0 kg ha^{-1}) and N_2PK_2 (116: 12: 63 kg ha^{-1}) treatments. The minimum plant height was produced by control. It was found that shorter plant heights were observed in low nitrogen rates, and taller plant height in high rates of nitrogen and potassium. Chaturvedi (2005) stated that the application of nitrogen fertilizers increased in plant height significantly. Because potassium contributes in nitrogen use efficiency, highest plant height resulted from highest application of potassium combination with highest nitrogen rate (Gething 1993; Tatar et al. 2010).



DAT	**14**	**28**	**42**	**56**	**70**
LSD$_{0.05}$	**3.51**	**3.55**	**4.80**	**4.26**	**3.15**

Figure 4.6 Mean value of plant height as affected by nitrogen and potassium fertilization on Thee Htat Yin rice variety in Maubin township during the dry season, 2016

Control – (no fertilizer), **P** – (0: 12: 0 kg ha^{-1}),
N$_1$P – (58: 12: 0 kg ha^{-1}), **N$_1$PK$_1$** – (58: 12: 31 kg ha^{-1}),
N$_2$P – (116: 12: 0 kg ha^{-1}), **N$_2$PK$_2$** – (116: 12: 63 kg ha^{-1}),
N$_3$P – (174: 12: 0 kg ha^{-1}), **N$_3$PK$_3$** – (174: 12: 94 kg ha^{-1})

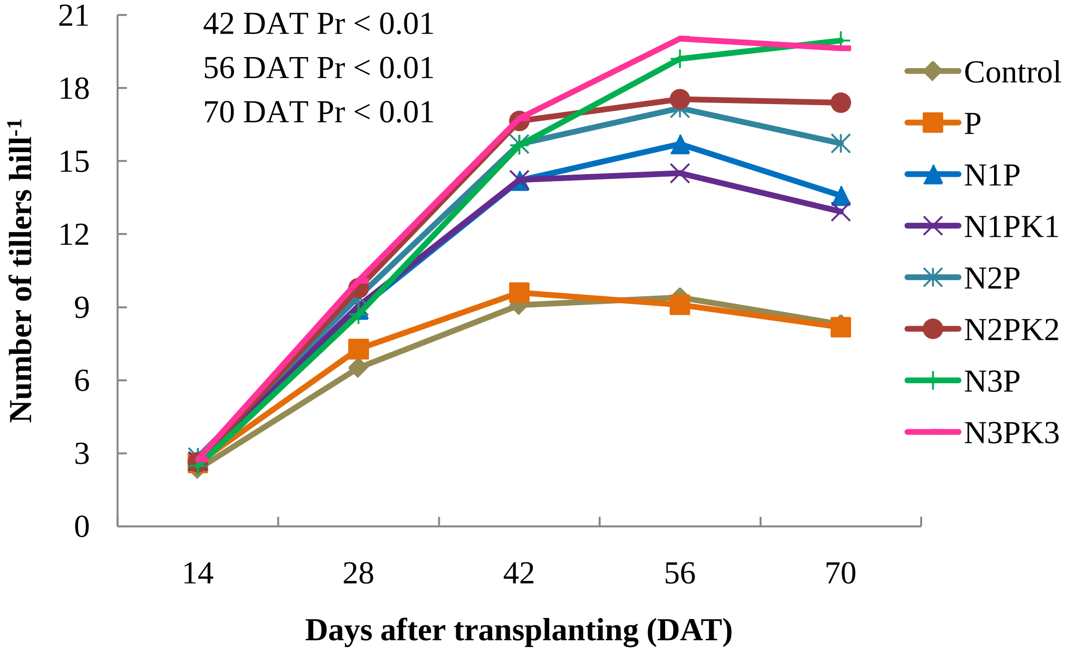
4.2.1.2 Number of tillers hill^{-1}

The data on number of tillers hill^{-1} counted at 2-week intervals started from 14 DAT to 70 DAT are illustrated in Figure 4.7. There was no significant difference in number of tillers hill^{-1} at 14 DAT and 28 DAT. At 42, 56 and 70 DAT, the number of tillers hill^{-1} was highly significant different among various rates of nitrogen and potassium fertilizer treatments.

The highest number of tillers hill^{-1} at 42 DAT was resulted from N_3PK_3 (174: 12: 94 kg ha^{-1}) (16.75) which was statistically similar to that of N_2PK_2 (116: 12: 63 kg ha^{-1}), N_2P (116: 12: 0 kg ha^{-1}), N_3P (174: 12: 0 kg ha^{-1}), N_1PK_1 (58: 12: 31 kg ha^{-1}) and N_1P (58: 12: 0 kg ha^{-1}) and the values were 16.65, 15.70, 15.65, 14.23 and 14.2 respectively. The lowest number of tillers (9.08) was recorded from control.

At 56 DAT, increased nitrogen and potassium supply enhanced tillering. The highest number of tillers hill^{-1} (20.03) was observed in N_3PK_3 (174: 12: 94 kg ha^{-1}) and the lowest (9.1) in P only treatment. The number of tillers hill^{-1} ranged from 8.18 to 19.95 at 70 DAT. The maximum number of tillers was achieved from N_3P (174: 12: 0 kg ha^{-1}) which was statistically similar with that of N_3PK_3 (174: 12: 94 kg ha^{-1}) (19.63). P alone treatment gave the minimum number of tillers hill^{-1}.

It was found that the number of tillers hill^{-1} increased significantly with increased levels of nitrogen fertilizer. The number of tillers hill^{-1} was increased with increasing nitrogen rates and reduced nitrogen consumption reduces tillering (Hosseinniya and Kamrani 2013). Among the treatments, N_3PK_3 (highest rates of nitrogen and potassium fertilizers) produced the highest number of tillers hill^{-1} at all growth stages of crop except at 70 DAT. However, within the same amount of nitrogen fertilizer, potassium application was not significantly increased the number of tillers hill^{-1}. Bagheri et al. (2011) also reported that the total tillers hill^{-1} was not affected by the rates of potassium.



DAT	**14**	**28**	**42**	**56**	**70**
LSD$_{0.05}$	**0.72**	**0.73**	**3.52**	**2.99**	**2.26**

Figure 4.7 Mean value of number of tillers hill^{-1} as affected by nitrogen and potassium fertilization on Thee Htat Yin rice variety in Maubin township during the dry season, 2016

Control – (no fertilizer), **P** – (0: 12: 0 kg ha^{-1}),
N$_1$P – (58: 12: 0 kg ha^{-1}), **N$_1$PK$_1$** – (58: 12: 31 kg ha^{-1}),
N$_2$P – (116: 12: 0 kg ha^{-1}), **N$_2$PK$_2$** – (116: 12: 63 kg ha^{-1}),
N$_3$P – (174: 12: 0 kg ha^{-1}), **N$_3$PK$_3$** – (174: 12: 94 kg ha^{-1})

4.2.2 Effect of nitrogen and potassium fertilization on yield and yield components

4.2.2.1 Number of panicles hill^{-1}

The number of panicles hill^{-1}of Thee Htat Yin rice variety as affected by different rates of nitrogen and potassium fertilizer application is shown in Table 4.3. The results showed that the number of panicles hill^{-1} increased due to increasing level of nitrogen and potassium application and was significantly different at 1% level.

The number of panicles hill^{-1} ranged from 5.54 to 12.51 among different treatments. The maximum number of panicles was recorded in N_3PK_3 (174: 12: 94 kg ha^{-1}) and control gave the minimum number of panicles hill^{-1}. Adequacy of nitrogen probably enhanced the cellular activities during panicles formation and development which led to increase number of panicles hill^{-1} especially at higher levels of applied nitrogen (Iqbal Hussain et al. 2015).

Although the number of panicles hill^{-1} among treatments of nitrogen with potassium and without potassium application were not statistically significant different, rice plant produced more number of panicles hill^{-1} in combined application of nitrogen with potassium treatments as compared to that applied only nitrogen fertilizer treatments especially in higher rates. Singh et al. (2015) revealed that one of the yield attribute parameter, number of panicles hill^{-1} increased significantly with the application of potassium up to 99 kg K ha^{-1}.

4.2.2.2 Number of spikelets panicle^{-1}

It was observed that the number of spikelets panicle^{-1} was highly significant among different treatments from the analysed data (Table 4.3). The highest number of spikelets panicle^{-1} (116.41) was produced by N_3P (174: 12: 0 kg ha^{-1}) which was statistically similar with that obtained from N_3PK_3 (174: 12: 94 kg ha^{-1}) and N_2PK_2 (116: 12: 63 kg ha^{-1}) with the values of 115.06 and 112.75 respectively. The lowest number of spikelets panicle^{-1} (79.29) was recorded in control. The more number of spikelets panicle^{-1} obtained in treatments receiving higher nitrogen rates were probably due to better nitrogen status of plant during panicle growth period (Awan et al. 2011; Ronanki et al. 2014).

At nitrogen levels of 58 kg ha^{-1} and 116 kg ha^{-1}, the number of spikelets panicle^{-1} was higher in the treatments that applied nitrogen and potassium fertilizers

Table 4.3 Yield and yield components as affected by nitrogen and potassium fertilization in Maubin township during the dry season, 2016

Treatments	Number of panicles hill^{-1}	Number of spikelets panicle^{-1}	1000- grain weight (g)	Filled grain %	Grain Yield (t ha^{-1})
Control	5.54 d	79.29 f	21.48	78.31	2.96 d
P	6.63 d	87.53 ef	21.66	79.42	3.02 d
N_1P	9.66 bc	98.93 de	21.91	80.16	4.99 c
N_1PK_1	9.54 c	100.95 cd	22.05	82.84	5.57 bc
N_2P	11.13 abc	104.36 bcd	21.66	82.18	6.28 ab
N_2PK_2	11.60 ab	112.75 abc	21.68	83.74	6.64 a
N_3P	12.32 a	116.41 a	21.85	79.63	5.79 abc
N_3PK_3	12.51 a	115.06 ab	21.83	82.33	6.43 ab
LSD $_{0.05}$	2.009	12.004	0.583	9.855	0.882
Pr>F	**	**	ns	ns	**
CV%	13.85	8.01	1.82	8.27	11.51

Means followed by different letters in the same column are significantly different by LSD test at 5% level.

******Significant difference at 1% level, ns non-significant difference

Control – (no fertilizer), **P** – (0: 12: 0 kg ha^{-1}),
N_1P – (58: 12: 0 kg ha^{-1}), **N_1PK_1** – (58: 12: 31 kg ha^{-1}),
N_2P – (116: 12: 0 kg ha^{-1}), **N_2PK_2** – (116: 12: 63 kg ha^{-1}),
N_3P – (174: 12: 0 kg ha^{-1}), **N_3PK_3** – (174: 12: 94 kg ha^{-1})

together. Esfahani et al. (2005) also stated that the number of spikelets panicle^{-1} increased by the application of nitrogen and potassium.

4.2.2.3 1000 grain weight (g)

According to the results, it was indicated that the effects of nitrogen and potassium on 1000 grain weight were not significant (Table 4.3). Increase in fertilizer application rates did not effect on the 1000 grain weight and it ranged from 21.48 to 22.05 g among the treatments. The maximum 1000 grain weight was observed in N_1PK_1 (58: 12: 31 kg ha^{-1}) and the minimum grain weight was found in control which was not significantly different among each other. Since 1000 grain weight is a genetical character fixed by an individual variety, it was not significantly affected by fertilizer treatments (Wilson et al. 1996; Bahmanyar and Mashaee 2010).

4.2.2.4 Filled grain %

The filled grain % was not significantly influenced by nitrogen and potassium fertilizer application (Table 4.3). The filled grain % ranged from 78.31 to 83.74% depending on the rates of fertilizer application. The highest filled grain % was observed in N_2PK_2 (116: 12: 63 kg ha^{-1}) (83.74%) followed by N_1PK_1 (58: 12: 31 kg ha^{-1}) (82.84%) and N_3PK_3 (174: 12: 94 kg ha^{-1}) (82.33%). The lowest filled grain % was recorded from control (78.31%). According to the results, it was revealed that plots receiving potassium had a higher filled grain % when compared to corresponding treatments which received no potassium. Dedatta and Mikkelson (1985) and Bahmanyar (2004) showed that potassium fertilization has positive effect on the percentage of filled grain of rice while its deficiency results in the pollen sterility and lower number of filled grains.

4.2.2.5 Grain yield (t ha^{-1})

The results of ANOVA showed that nitrogen and potassium levels had significant effects on grain yield at 1% level (Table 4.3). The grain yield increased steadily with the increase in the level of nitrogen up to 116 kg ha^{-1} and decreased with further increase of applied nitrogen fertilizer (174 kg N ha^{-1}).

The grain yield ranged from 2.96 to 6.64 t ha^{-1}. The highest grain yield was obtained from treatment N_2PK_2 (116: 12: 63 kg ha^{-1}). This could be mainly due to the increase in the number of panicles hill^{-1} and number of spikelets panicle^{-1}. Improvements in grain yields attributed to increments in yield components which are associated with better nutrition, plant growth and increased nutrient uptake (Behera 1998; Kumar and Rao 1992; Thakur 1993; Pramanik and Bera 2013). The highest grain yield that resulted from N_2PK_2 (116: 12: 63 kg ha^{-1}) (6.64 t ha^{-1}) was statistically similar with that of N_3PK_3 (174: 12: 94 kg ha^{-1}) (6.43 t ha^{-1}) and N_2P (116: 12: 0 kg ha^{-1}) (6.28 t ha^{-1}). The lowest grain yield was observed in control (2.96 t ha^{-1}) which was statistically identical with that of only P fertilizer treatment (3.02 t ha^{-1}).

In the case of high rates of fertilizer application, nitrogen addition did not increase grain yield in the treatment N_3P (174: 12: 0 kg ha^{-1}) as compared to the treatment that received potassium N_3PK_3 (174: 12: 94 kg ha^{-1}). Singh et al. (1995) and Gebrekidan and Seyoum (2006) stated that a decrease in grain yield of rice with application of high doses of N fertilizer. Furthermore, at all rates of nitrogen application, the treatments receiving potassium had produced higher grain yield than corresponding treatments receiving no potassium. Witt et al. (2004) pointed out that the need for potassium application in rice not only to increase yield but also to prevent soil potassium mining to sustain soil productivity and grain yield.

4.2.3 Percent increase in grain yield over control during 2016

Yield increase over control varied with different levels of nitrogen and potassium (Figure 4.8). The results indicated that increase in grain yield over control was progressive up to 116 kg N ha^{-1} and 63 kg K ha^{-1} and thereafter, it declined. Mahajan et al. (2010) showed that further increase in rates of nitrogen fertilizer beyond certain level had no effect on crop response to fertilizer. The highest increase in yield over control was achieved in N_2PK_2 (116: 12: 63 kg ha^{-1}) (124.32%) followed by N_3PK_3 (174: 12: 94 kg ha^{-1}), N_2P (116: 12: 0 kg ha^{-1}), N_3P (174: 12: 0 kg ha^{-1}), N_1PK_1 (58: 12: 31 kg ha^{-1}) and N_1P (58: 12: 0 kg ha^{-1}) with 117.23%, 112.16%, 95.61%, 88.18% and 68.58% additional yield respectively. The lowest grain yield increase over control was observed in P (2.03%). Therefore, balancing nitrogen with potassium at the rate of 116 kg N ha^{-1} and 63 kg K ha^{-1} could be optimum for achieving higher yield response.

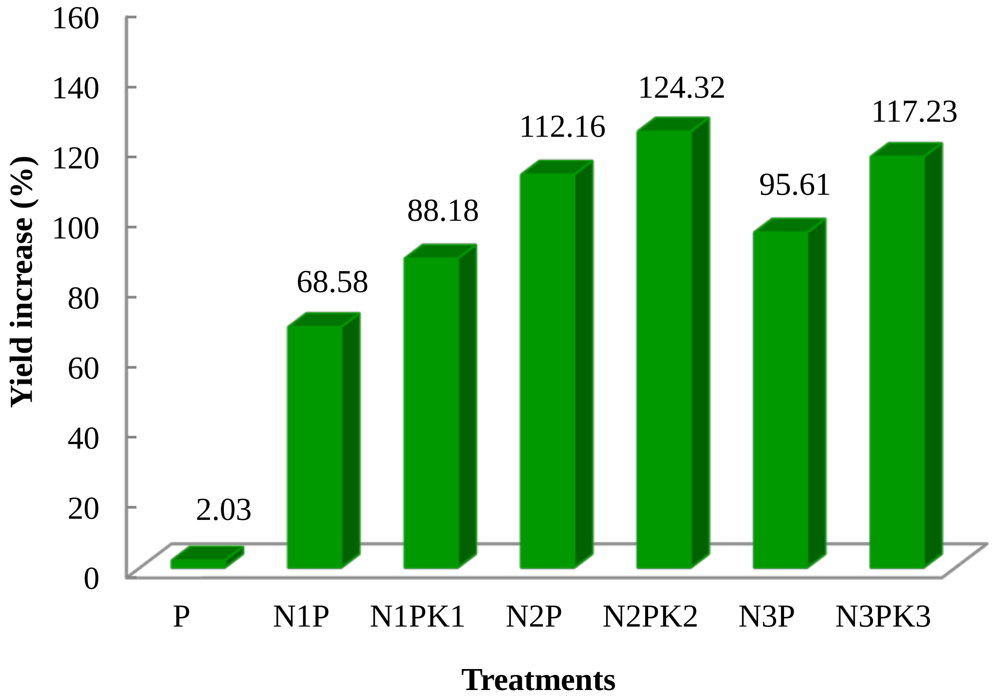


Figure 4.8 Yield increase (%) of rice over control as affected nitrogen and potassium fertilization in Maubin township during the dry season, 2016

P – (0: 12: 0 kg ha^{-1}), **N$_1$P** – (58: 12: 0 kg ha^{-1}), **N$_1$PK$_1$** – (58: 12: 31 kg ha^{-1}),
N$_2$P – (116: 12: 0 kg ha^{-1}), **N$_2$PK$_2$** – (116: 12: 63 kg ha^{-1}),
N$_3$P – (174: 12: 0 kg ha^{-1}), **N$_3$PK$_3$** – (174: 12: 94 kg ha^{-1})

4.2.4 Agronomic efficiencies of nitrogen and potassium

4.2.4.1 Nitrogen use efficiency (NUE)

Nitrogen use efficiency (NUE) can be defined as the production of additional yield for each kg of nitrogen applied (Dobermann and Fairhurst 2000). The NUE for Thee Htat Yin rice variety during dry season of 2016 is shown in Table 4.4. The calculated results of NUE revealed that potassium fertilization improved the utilization of added nitrogen fertilizer. The NUE reached 45.00, 31.72 and 19.94 by the combination of nitrogen and potassium in N_1PK_1 (58: 12: 31 kg ha^{-1}), N_2PK_2 (116: 12: 63 kg ha^{-1}) and N_3PK_3 (174: 12: 94 kg ha^{-1}) treatments respectively. The highest NUE was obtained from N_1PK_1 (58: 12: 31 kg ha^{-1}) (45.00) and lowest value was resulted from N_3P (174: 12: 0 kg ha^{-1}) (16.26) treatment. It was observed that NUE gradually decreased with increasing nitrogen rate.

Grain yield typically increased with increasing rates of nitrogen as well as potassium, and gradually approached a maximum yield level. At low levels of nitrogen and potassium supply, rates of increase in yield were large because the applied nutrients were the primary factors limiting crop growth and final yield. As nitrogen and potassium supplies increased, incremental yield gains became smaller because yield determinants other than applied nutrients became more limiting as the maximum yield potential was approached. Similar results were reported by Dobermann (2005).

Within the treatments of the same nitrogen rate, combined application of nitrogen with potassium gave higher NUE than that with no potassium fertilizer. Srinivasarao (2010) stated that nitrogen utilization depends on several agronomic factors including balanced and proper nutrient use; where balancing the nitrogen fertilizer application with potassium fertilizer is important for improving the utilization of added nitrogen fertilizers. Relative to N_1P (58: 12: 0 kg ha^{-1}), the NUE of N_1PK_1 (58: 12: 31 kg ha^{-1}) treatment showed an increase in ratio of 28.57%. Relative to N_2P (116: 12: 0 kg ha^{-1}), the NUE of N_2PK_2 (116: 12: 63 kg ha^{-1}) treatment showed an increase in ratio of 10.83%. Relative to N_3P (174: 12: 0 kg ha^{-1}), the NUE of N_3PK_3 (174: 12: 94 kg ha^{-1}) treatment showed an increase in ratio of 22.63%. Balancing the fertilizer nitrogen application with potassium fertilizer is an urgent requirement for achieving higher NUE (Brar et al. 2011).

Table 4.4 Effect of nitrogen and potassium fertilization on nitrogen use efficiency (NUE) and potassium use efficiency (KUE) of Thee Htat Yin rice variety in Maubin township during the dry season, 2016

Treatments	**NUE (kg grain kg^{-1} N)**	**KUE (kg grain kg^{-1} K)**
Control	-	-
P	-	-
N_1P	35.00	-
N_1PK_1	45.00	18.71
N_2P	28.62	-
N_2PK_2	31.72	5.71
N_3P	16.26	-
N_3PK_3	19.94	6.81

Control – (no fertilizer), **P** – (0: 12: 0 kg ha^{-1}),
N_1P – (58: 12: 0 kg ha^{-1}), **N_1PK_1** – (58: 12: 31 kg ha^{-1}),
N_2P – (116: 12: 0 kg ha^{-1}), **N_2PK_2** – (116: 12: 63 kg ha^{-1}),
N_3P – (174: 12: 0 kg ha^{-1}), **N_3PK_3** – (174: 12: 94 kg ha^{-1})

4.2.4.2 Potassium use efficiency (KUE)

Potassium use efficiency (KUE) or potassium agronomic efficiency (KAE) refers to the crop yield increase per unit potassium applied. KUE as affected by different levels of potassium application during dry season 2016 is presented in Table 4.4. The values varied from 5.71 to 18.71. The maximum value of KUE was resulted from N_1PK_1 (58: 12: 31 kg ha^{-1}) (18.71) which was followed by N_3PK_3 (174: 12: 94 kg ha^{-1}) (6.81) and the minimum KUE value was observed from N_2PK_2 (116: 12: 63 kg ha^{-1}) (5.71). The KUE of N_3PK_3 (174: 12: 94 kg ha^{-1}) was greater than that of N_2PK_2 (116: 12: 63 kg ha^{-1}) but the values were not much different. The lowest rate of K gave the highest KUE. According to Naseem et al. (2014), the N and K use efficiencies were reduced although the application of fertilizer enhanced yields. The different values for KUE were related to the amount of applied fertilizer and how much increase in grain yield by potassium application.

4.2.5 Correlation and regression analysis

Grain yield was significantly correlated with number of panicles (r = 0.9491**) and number of spikelets panicle^{-1} (r = 0.9189**) in dry season 2016 (Appendix 7). The number of spikelets panicle^{-1} was observed to be highly significant correlation with number of panicles hill^{-1} (r = 0.9866**). The relation between number of panicles hill^{-1} and number of spikelets panicle^{-1} with grain yield were positive and linear (R^2= 0.9 and R^2= 0.844 respectively). Figure 4.9 illustrated that the grain yield was significantly increased with the increased of number of panicles. The number of spikelets panicle^{-1} also highly correlated with grain yield (Figure 4.10). The grain yield was significantly increased with increased number of spikelets. The variability in grain yield was 90% due to number of panicles hill^{-1}, and 84.4% due to number of spikelets panicle^{-1}. The grain was strongly determined by these two parameters. The results were in line with the findings of Ottis and Talbert (2005) who stated that there was a high relation (R^2> 0.85) between yield and panicle density. Dokuyuch and Akkaya (1999) reported that the grain yield had a positive significant correlation with number of spikelets panicle^{-1}. Grain yield positively correlated with number of panicles hill^{-1} and number of spikelets panicle^{-1} which were increased by nitrogen and potassium fertilizers application (Esfahani et al. 2005).

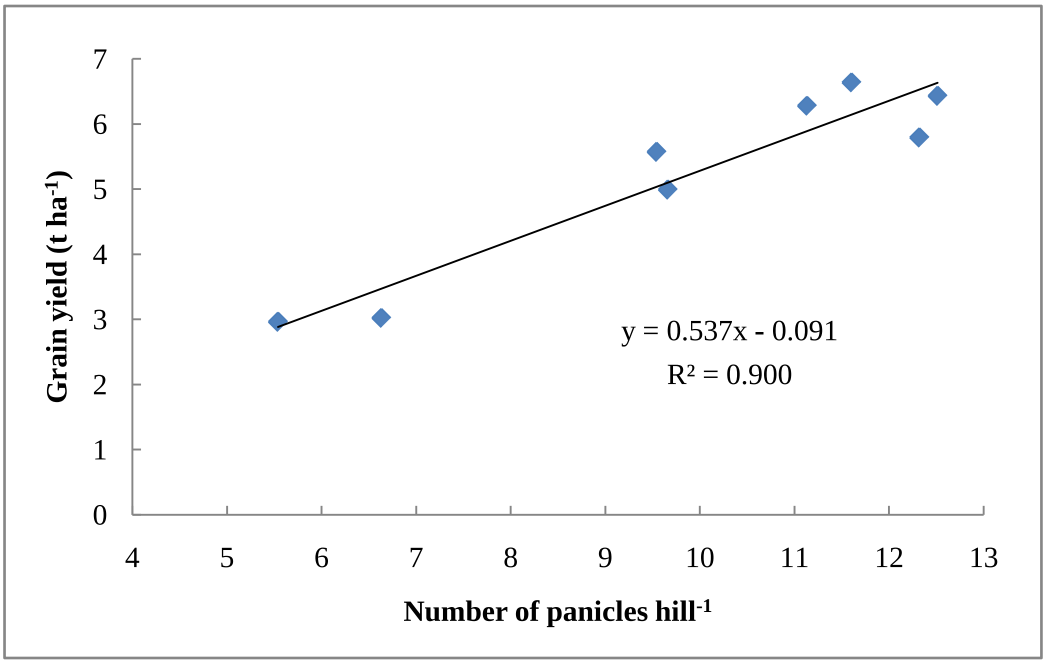


Figure 4.9 Relationship between grain yield (t ha^{-1}) and number of panicles hill^{-1} of Thee Htat Yin rice variety during the dry season, 2016

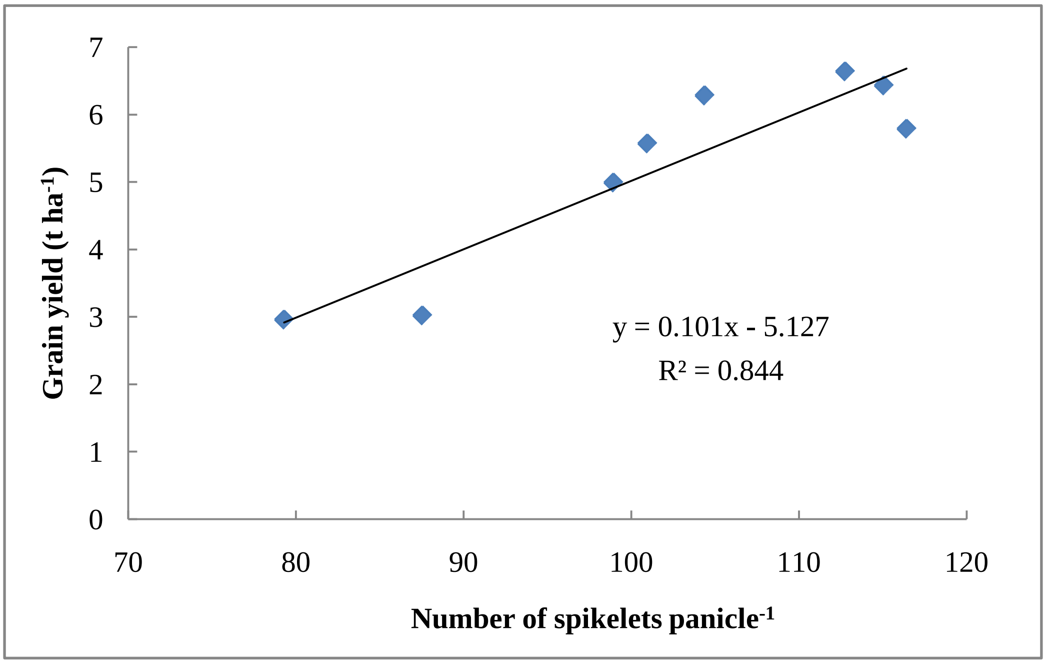


Figure 4.10 Relationship between grain yield (t ha^{-1}) and number of spikelets panicle^{-1} of Thee Htat Yin rice variety during the dry season, 2016

4.2.6 Combined analysis of variance for yield and yield components of rice across seasons

Results for the combined analysis of variance for yield and yield components of rice during the dry season of 2015 and 2016 are shown in table 4.5. There were highly significant differences in number of panicles, number of spikelets, 1000 grain weight and grain yield among the two growing seasons. Temperature and rainfall differences between the two growing seasons were the probable cause of variation in these parameters. Among treatments, the results showed significant differences for number of panicles, number of spikelets and grain yield at 1% level while significant difference for 1000 grain weight was observed at 5% level. Different rates of nitrogen and potassium had significant effects on yield and yield components of Thee Htat Yin rice variety. Jalali-Moridani and Amiri (2014) stated that nitrogen and potassium have positive impacts on yield and yield components of rice. Results from treatment x season interaction showed that there were no significant differences in yield and yield related traits except in number of spikelets which was significantly different at 5% level.

Table 4.5 Combined analysis of variance for yield and yield components of rice as affected by nitrogen and potassium fertilization across seasons

Source of Variation	Mean Square				
	Number of panicles	Number of spikelets	1000 grain weight	Filled grain %	Grain yield
Season (S)	42.41**	561.27**	30.51**	38.16	11.35**
Replication	1.61	34.45	0.38	116.11*	0.95
Treatment (T)	37.89**	878.60**	0.68*	21.04	14.12**
T x S	1.59	152.11*	0.19	9.85	0.32
Error	1.65	59.99	0.28	37.55	0.40
CV%	14.2	7.8	2.5	7.6	13.2

* Significant difference at 5% level, ** Significant difference at 1% level

CHAPTER V

CONCLUSION

The field experiment assessed the balancing on the application of N and K as well as optimum fertilizer rates to achieve higher grain yield and nutrient use efficiency.

In the present study, different rates of N application increased plant height, number of tillers, number of panicles, number of spikelets and grain yield for both seasons. Also, number of spikelets, filled grain% and grain yield were increased by the combined application with K. The grain yield and yield components of Thee Htat Yin rice variety responded to N fertilizer application. However, the highest grain yield and greater magnitude of increase in yield were observed in combined application of N with K fertilizers. The maximum grain yield was resulted from N_2PK_2 treatment where 116 kg N ha^{-1}, 12 kg P ha^{-1} and 63 kg K ha^{-1} were applied. Further increasing the rate of N and K fertilizer application did not provide additional yield increase. According to the observed results from the present study, it can be suggested that a high fertilizer rate beyond certain level may not increase the grain yield of rice.

The agronomic efficiency of N also pointed out the impact of K in promoting the grain yield of rice. The NUE of rice crop was increased with the application of N fertilizer together with K in both seasons. Relative to without K treatments, NUE of balancing N with K fertilizer treatments showed an increase in ratio ranging from 6.7% to 38.25% for the first season and from 10.83% to 28.57% for the second season experiment. Yield increment due to K application indicated the need for K application in rice cropping related to yield response. Application of N with K would prevent soil K mining to sustain soil productivity and crop yield in the long run.

The results revealed that even the same amount of N were applied, K application gave the higher grain yield of rice over no K application. Although N is the most common rice yield limiting nutrient, the yield response to N fertilization was dependent on balanced fertilization with K. The sole P treatment did not showed any significant effect in this short-term experiment. Combined application of 116 kg N ha^{-1} and 63 kg K ha^{-1} could be optimum level to achieve higher grain yield.

Traditionally, most farmers do not return rice straw to the fields and application of K fertilizer was low in the study area. Therefore, balanced fertilization is important to ensure sustainable productivity of land in this area. Further investigation for the application of different levels of K with the optimum nitrogen rate and rice straw management research should be carried out to be able to conserve soil nutrient reserves in the long-term. Fertilizer management practices should also be done with the efficient methods of fertilization to prevent losses of plant nutrients from the soil.

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APPENDICES

Appendix 1. Monthly rainfall, monthly average values of maximum and minimum temperature at Maubin township during the two experimental growing periods (February 2015 – March 2016)

Month	Temperature (°C)		Rainfall (mm)
	Maximum	Minimum	
February	34	15	0
March	37	18	0
April	37	21	28.96
May	36	21	189.48
June	31	20	659.89
July	30	19	666.50
August	31	20	333.50
September	30	19	348.74
October	30	19	123.44
November	32	19	0
December	31	18	0
January	29	16	52.07
February	32	19	0
March	35	22	0

Appendix 2. Effect of nitrogen and potassium fertilization on plant height of Thee Htat Yin rice variety in Maubin township, dry season 2015

Treatments	Plant height (cm)				
	14 DAT	28 DAT	42 DAT	56 DAT	70 DAT
Control	21.47	37.26 cd	41.71 c	51.68 bc	65.25 b
P	20.48	35.97 d	42.17 c	46.42 c	65.46 b
N_1P	21.68	38.79 cd	41.50 c	52.93 bc	74.60 ab
N_1PK_1	22.47	40.15 bc	43.98 bc	58.11 ab	74.34 ab
N_2P	22.35	43.35 ab	46.42 ab	62.98 a	84.10 a
N_2PK_2	22.58	43.47 a	46.20 ab	62.05 a	80.56 a
N_3P	23.18	42.45 ab	46.17 ab	62.33 a	84.84 a
N_3PK_3	23.40	44.65 a	48.74 a	65.64 a	86.28 a
$LSD_{0.05}$	2.095	3.254	3.672	8.110	12.930
Pr>F	ns	**	**	**	**
CV%	6.42	5.43	5.60	9.55	11.43

Means followed by different letters in the same column are significantly different by LSD test at 5% level.

** Significant different at 1% level, **ns** non significant difference

Control – (no fertilizer), **P –** (0: 12: 0 kg ha^{-1}),
N_1P – (58: 12: 0 kg ha^{-1}), **N_1PK_1** – (58: 12: 31 kg ha^{-1}),
N_2P – (116: 12: 0 kg ha^{-1}), **N_2PK_2** – (116: 12: 63 kg ha^{-1}),
N_3P – (174: 12: 0 kg ha^{-1}), **N_3PK_3** – (174: 12: 94 kg ha^{-1})

Appendix 3. Effect of nitrogen and potassium fertilization on number of tillers hill^{-1} of Thee Htat Yin rice variety in Maubin township, dry season 2015

Treatments	Number of tillers hill^{-1}				
	14 DAT	**28 DAT**	**42 DAT**	**56 DAT**	**70 DAT**
Control	2.00	6.00 c	7.25 d	9.00 c	8.50 c
P	2.00	5.00 c	6.75 d	9.25 c	9.25 c
N_1P	2.00	7.75 b	10.00 c	13.25 ab	13.00 b
N_1PK_1	2.00	8.75 ab	10.75 bc	13.00 b	13.75 ab
N_2P	2.00	10.00 a	12.00 ab	14.25 ab	15.00 a
N_2PK_2	2.25	8.75 ab	11.50 abc	14.00 ab	15.25 a
N_3P	2.25	9.75 a	13.00 a	15.25 a	14.50 ab
N_3PK_3	2.25	10.00 a	12.75 a	14.75 ab	15.00 a
LSD $_{0.05}$	0.471	1.588	1.912	2.204	1.740
Pr>F	ns	**	**	**	**
CV%	15.30	13.09	12.38	11.67	9.08

Means followed by different letters in the same column are significantly different by LSD test at 5% level.

** Significant difference at 1% level, **ns** non significant difference

Control – (no fertilizer), **P** – (0: 12: 0 kg ha^{-1}),
N_1P – (58: 12: 0 kg ha^{-1}), **N_1PK_1** – (58: 12: 31 kg ha^{-1}),
N_2P – (116: 12: 0 kg ha^{-1}), **N_2PK_2** – (116: 12: 63 kg ha^{-1}),
N_3P – (174: 12: 0 kg ha^{-1}), **N_3PK_3** – (174: 12: 94 kg ha^{-1})

Appendix 4. Effect of nitrogen and potassium fertilization on plant height of Thee Htat Yin rice variety in Maubin township, dry season 2016

Treatments	**Plant height (cm)**				
	14 DAT	**28 DAT**	**42 DAT**	**56 DAT**	**70 DAT**
Control	34.42	36.76	44.04 b	50.94 d	70.90 c
P	35.70	37.93	44.84 b	50.65 d	71.37 c
N_1P	36.19	38.29	50.84 a	55.97 bc	78.03 b
N_1PK_1	35.46	38.27	50.48 a	54.56 cd	78.22 b
N_2P	35.32	37.58	52.22 a	58.94 ab	81.39 a
N_2PK_2	35.77	38.57	51.80 a	58.53 abc	81.05 ab
N_3P	36.28	38.54	51.02 a	58.71 abc	82.27 a
N_3PK_3	37.39	39.74	54.28 a	61.42 a	83.55 a
LSD $_{0.05}$	3.505	3.55	4.801	4.264	3.153
Pr>F	ns	ns	**	**	**
CV%	6.66	6.32	6.54	5.16	2.74

Means followed by different letters in the same column are significantly different by LSD test at 5% level.

** Significant difference at 1% level, **ns** non significant difference

Control – (no fertilizer), **P –** (0: 12: 0 kg ha^{-1}),
N_1P – (58: 12: 0 kg ha^{-1}), **N_1PK_1 –** (58: 12: 31 kg ha^{-1}),
N_2P – (116: 12: 0 kg ha^{-1}), **N_2PK_2 –** (116: 12: 63 kg ha^{-1}),
N_3P – (174: 12: 0 kg ha^{-1}), **N_3PK_3 –** (174: 12: 94 kg ha^{-1})

Appendix 5. Effect of nitrogen and potassium fertilization on number of tillers hill^{-1} of Thee Htat Yin rice variety in Maubin township, dry season 2016

Treatments	**Number of tillers hill^{-1}**				
	14 DAT	**28 DAT**	**42 DAT**	**56 DAT**	**70 DAT**
Control	2.35	6.50 c	9.08 b	9.40 d	8.30 f
P	2.60	7.28 bc	9.60 b	9.10 d	8.18 f
N_1P	2.70	8.90 abc	14.20 a	15.70 bc	13.58 de
N_1PK_1	2.68	9.05 abc	14.23 a	14.50 c	12.93 e
N_2P	2.83	9.43 ab	15.70 a	17.18 abc	15.73 cd
N_2PK_2	2.63	9.78 ab	16.65 a	17.55 ab	17.40 bc
N_3P	2.48	8.70 abc	15.65 a	19.20 a	19.95 a
N_3PK_3	2.75	10.08 a	16.75 a	20.03 a	19.63 ab
LSD $_{0.05}$	0.725	2.727	3.521	2.986	2.265
Pr>F	ns	ns	**	**	**
CV%	18.77	21.28	17.12	13.24	10.65

Means followed by different letters in the same column are significantly different by LSD test at 5% level.

Significant difference at 1% level, **ns non significant difference

Control – (no fertilizer), **P –** (0: 12: 0 kg ha^{-1}),
N_1P – (58: 12: 0 kg ha^{-1}), **N_1PK_1 –** (58: 12: 31 kg ha^{-1}),
N_2P – (116: 12: 0 kg ha^{-1}), **N_2PK_2 –** (116: 12: 63 kg ha^{-1}),
N_3P – (174: 12: 0 kg ha^{-1}), **N_3PK_3 –** (174: 12: 94 kg ha^{-1})

Appendix 6. Correlation between yield and yield components of rice as affected by nitrogen and potassium fertilization during the dry season, 2015

	No. of panicles hill^{-1}	**No. of spikelets panicle^{-1}**	**1000-grain weight**	**Filled grain %**	**Yield**
No. of panicles hill^{-1}	1				
No. of spikelets panicle^{-1}	0.6791	1			
1000 grain weight	0.8775**	0.5653	1		
Filled grain %	0.4613	0.4837	0.5910	1	
Yield	0.9499**	0.8544**	0.8065*	0.5595	1

* Significant difference at 5% level, ** Significant difference at 1% level

Appendix 7. Correlation between yield and yield components of rice as affected by nitrogen and potassium fertilization during the dry season, 2016

	No. of panicles hill^{-1}	No. of spikelets panicle^{-1}	1000-grain weight	Filled grain %	Yield
No. of panicles hill^{-1}	1				
No. of spikelets panicle^{-1}	0.9866**	1			
1000 grain weight	0.4778	0.4904	1		
Filled grain %	0.6463	0.6352	0.3904	1	
Yield	0.9491**	0.9189**	0.4554	0.8224*	1

* Significant difference at 5% level, **Significant difference at 1% level