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NITROGEN AND POTASSIUM USE EFFICIENCY OF BARIO RICE GROWN ON BEKENU SERIES

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NITROGEN AND POTASSIUM USE EFFICIENCY OF BARIO RICE GROWN ON BEKENU SERIES

By

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A Project Report Submitted in Partial Fulfillment of the Requirement
for the Degree of Bachelor of Bioindustry Science in the
Faculty of Agriculture and Food Sciences
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To Dad, Sulok Tawie

Mom, Agnes Tiong,

Beloved Brother and Sisters, Jefry, Sharon,

Priscilla and Steffi

Thank you for your love and support

Special Thanks to Eunice Herbert

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ABSTRACT

A pot study was carried with the following objectives: (i) To investigate N and K uptake of Bario rice on Bekenu series (Tipik Tualemkuts), and (ii) To investigate N and K use efficiency of Bario rice on Bekenu series. Treatments evaluated were: (i) Bario rice under fertilized condition (T1), and (ii) Bario rice under unfertilized condition (T0). The experiment was conducted in a glasshouse at Universiti Putra Malaysia Bintulu Campus, Sarawak, Malaysia. The type of soil used was Bekenu series. Altogether 18 pots were used having a completely randomized design (CRD) with 9 replications. Nitrogen and K were applied in the forms of urea (46 % N) and muriate of potash (60 % K_2O) at the rates of 0.52 g N and 0.60 g K_2O per pot respectively in split application while P was applied in the form of Christmas Island Rock Phosphate (36 % P_2O_5) at a rate of 0.54 g P_2O_5 per pot (also in split). At 65 days after planting, the Bario rice plants were sampled and partitioned into roots and stem. Their dry weight, N, and K concentrations determined using standard procedures. Soil sampling was done before and after fertilization. Soil total N was determined using the Kjeldahl method while exchangeable K, Ca, Na, and Mg were extracted using the double acid method and their concentrations determined using atomic absorption spectrophotometry. Dry ashing method was used for the determination of K, Ca, Na, and Mg concentrations in plant tissues while the Kjeldahl method was used to determine total N in plant tissues. The concentrations multiplied by the oven dried weight of roots and stem represented N, K, Ca, Na, and Mg uptake in these plant parts. The N and K use efficiencies were then calculated using the subtraction method. With the exception of Ca, urea and KCl (MOP)

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application significantly increased soil N, K, Mg, and Na concentrations. Total dry weight for both stem and roots showed no significant difference under T1 and T0. Except for Mg concentration in stem and roots, K concentration in stem and that of N in roots were significantly higher under T1 than under T0. The other comparisons showed no significant difference. Due to N and K fertilization, there was significant increase in plant height and number of panicles under T1 compared to T0. Nitrogen, K, Na, and Mg uptake in stem were significantly higher for T1 than T0. However, those of roots were not significantly different. The overall N and K use efficiencies of the Bario rice were 9.90 % and 4.23 % respectively, and were considered low, indicating that the rice grown within the time frame of this study did not efficiently utilize these nutrients. This was partly attributed to low N and K recovery during reduced condition and low organic matter status of Bekenu series as Bario rice is noted for being cultivated organically. Additionally, slow adaptation to inorganic fertilization and sudden climatic change involved in this study was not ruled out as one of the reasons for the low efficiency because the rice is traditionally cultivated in the highlands of Sarawak, Malaysia. However, with appropriate fertilization and soil maintenance (through research), Bekenu series could be used for Bario rice production. Probably supplementing inorganic fertilizers with organic ones may help to improve growth and development of this rice on Bekenu series. Future studies may consider mimicking or modifying the environment to suit Bario rice growth and development at lower elevations. Certainly, the quality of Bario rice at lower elevations should also be considered in future fertilization programmes or trials.

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ABSTRAK

Satu kajian dijalankan dengan objektif berikut: (i) menyiasat pengambilan N dan K oleh padi Bario dengan siri Bekenu (Tipik Tualemkuts), dan (ii) menyiasat penggunaan secara effisien N dan K dengan siri Bekenu. Rawatan yang dinilai adalah: (i) Padi Bario dalam keadaan pembajaan (T1), dan (ii) Padi Bario dalam keadaan tanpa pembajaan (T0). Eksperimen dijalankan dalam rumah hijau di Universiti Putra Malaysia Kampus Bintulu, Sarawak, Malaysia. Tanah yang diguna adalah siri Bekenu. Kesemuanya 18 pasu diguna yang mempunyai CRD dengan 9 replikasi. Nitrogen dan K diaplikasikan dalam bentuk urea (46 % N) dan muriate of potash (60 % K_2O) pada kadar 0.52 g N dan 0.60 g K_2O masing-masing setiap pasu dalam pembajaan secara pembahagian. Namun, P diaplikasikan dalam bentuk CIRP (36 % P_2O_5) pada kadar 0.54 g P_2O_5 setiap pasu (juga secara pembahagian). 65 hari selepas tanam, padi Bario disampel dan dibahagi kepada akar dan batang. Berat kering, kepekatan N, dan K ditentukan mengikut prosedur yang biasa. Pensampelan tanah dilakukan sebelum dan selepas pembajaan. Jumlah N tanah ditentukan menggunakan kaedah Kjeldahl sementara pertukaran K, Ca, Na, dan Mg diekstrak menggunakan kaedah *double acid* dan kepekatan dibaca dengan menggunakan AAS. Kaedah *dry ashing* digunakan untuk menentukan kepekatan K, Ca, Na, dan Mg di dalam tisu tanaman sementara kaedah Kjeldahl digunakan untuk menentukan jumlah N. Kepekatan yang diperoleh darab dengan berat kering oven akar dan batang memberi pengambilan N dan K oleh bahagian tumbuhan tersebut. Penggunaan effisien N dan K dikira menggunakan kaedah penolakan. Kecuali kepekatan Ca, aplikasi urea dan KCl (MOP) memberi peningkatan signifikan kepekatan

N, K, Mg, dan Na dalam tanah. Jumlah berat kering untuk kedua-dua akar dan batang menampakkan tidak signifikan dalam kedaaan T1 dan T0. Kecuali kepekatan Mg dalam akar dan batang, kepekatan K dalam batang, dan N dalam akar menunjukkan signifikan yang lebih tinggi dalam T1 dari T0. Perbandingan yang lain adalah tidak signifikan. Disebabkan pembajaan N dan K, terdapat peningkatan signifikan dalam tinggi dan jumlah pucuk padi dalam keadaan T1 berbanding T0. Pengambilan N, K, Na, dan Mg dalam batang memberi peningkatan signifikan yang lebih tinggi dalam T1 dari T0. Namun, untuk akar tidak signifikan. Keseluruhan penggunaan effisien N dan K oleh padi Bario masing-masing adalah 9.90 % dan 4.23 %, dan dianggap rendah, menunjukkan padi tumbuh pada sepanjang masa kajian tidak menggunakan nutrien tersebut secara effisien. Hal ini disebabkan oleh pemulihan N dan K yang rendah dalam keadaan yang sedikit dan status bahan organik yang rendah siri Bekenu untuk padi Bario yang sewajarnya ditanam secara organik. Adaptasi yang perlahan terhadap pembajaan tak organik dan perubahan iklim yang mendadak juga merupakan faktor bagi penggunaan effisien yang rendah kerana padi ini ditanam di kawasan tanah tinggi di Sarawak, Malaysia secara tradisional. Namun, dengan kadar pembajaan dan penjagaan tanah yang betul (melalui kajian), siri Bekenu boleh digunakan untuk produksi beras Bario. Mungkin dengan menambah baja tak organik dengan baja organik, pertumbuhan padi Bario atas siri Bekenu boleh dipertingkatkan. Kajian pada masa akan datang mungkin melibatkan perolahan atau persamaan keadaan persekitaran supaya sesuai untuk padi Bario tumbuh di kawasan tanah rendah. Sememangnya, kualiti beras Bario di tanah rendah juga akan diambil kira untuk kajian pada masa akan datang.

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I certify that this research project report entitled **"Nitrogen and Potassium Use Efficiency of Bario Rice Grown on Bekenu Series"** has been examined and approved as a partial fulfillment of the requirement for the degree of Bachelor of Bioindustry Science in the Faculty of Agriculture and Food Sciences, Universiti Putra Malaysia Bintulu Campus.

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LIST OF ABBREVIATIONS TERMS

1 **CEC** – Cation Exchange Capacity
2 **N** – Nitrogen
3 **P** – Phosphorus
4 **K** – Potassium
5 **Ca** – Calcium
6 **Mg** – Magnesium
7 **Na** – Sodium
8 **OPF** – Optimum Preflood Fertilizer
9 **RSP** – Reductant-Soluble Phosphate
10 **AAS** – Atomic Absorption Spectrophotometry
11 **SAS** – Statistical Analysis System
12 **KCl** – Potassium Chloride
13 **T1** – Fertilized Treatment
14 **T0** – Unfertilized Treatment
15 **DAP** – Days After Planting
16 **MOP** – Muriate of Potash
17 **DW** – Dry Weight
18 **CIRP** – Christmas Island Rock Phosphate

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CHAPTER 1

INTRODUCTION

Rice is one of the most important cereal crops in the world and ranks second after wheat (Brohi, 1998). In Malaysia, the area of rice production is not sufficient; as a result, rice such as Bario is grown in the highlands of Sarawak. Bario rice is produced by the Kelabit farmers in Sarawak. It is home-grown rice, planted and harvested entirely by hand using old and traditional methods. In the fertile valleys of the highlands, the rice is grown at 1200 meters above sea level and irrigated by the cool and clean mountain streams. Bario rice is produced without the usage of pesticides and chemical fertilizers, probably due to logistics of transporting these materials to the highlands. Even if the pesticides and fertilizers get there, they are expensive for the local farmers to afford. Therefore Bario rice has all the attributes of organic rice with the added flavour and distinguished taste derived from the cool, pristine and unpolluted environments where it is grown. Bario rice is from the Adan variety and the market price ranges from RM 8 (US$ 2.30) to RM 9 (US$ 3.00) per kilogram. Even though the Bario rice is popular with good price in Sarawak, the optimum yield (potential yield) has not been attained. One of the reasons could be lack of adequate use of nutrients such as N, P, and K. Besides, the cultivation of this rice has not been tested on low land acid soils such as Bekenu series to enable wide cultivation to meet the current demand.

Since the rice cultivar is commonly planted in high hilly areas, this experiment will exposed it to the local Bintulu, Sarawak soil type such as the Bekenu series. The

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Bekenu series is a member of the Bekenu family which is fine *loamy, siliceous, isohyperthermic, red-yellow to yellow Tipik Tualemkuts* (Paramanathan, 2000). It typifies the family and is developed over mixed sedimentary rocks. Soils of the Bekenu series are defined as being characterized by their deep, well drained profiles with brownish yellow to yellow subsoil colours dominating the subsoil. These soils have an argilic horizon with fine sandy clay loam textures and ECECclay of less than 24 cmol (+) kg^{-1} clay in all subhorizons (between 25 to 100 cm depth). They have weak medium to coarse subangular blocky and consistence is friable. In terms of suitability for agriculture, the Bekenu series has low fertility status and the terrain on which these soils occur are the main limiting factors for the use of these soils. However, with proper fertilization and soil conservation measures, a wide range of crops such as upland rice could be cultivated on these soils (Paramanathan, 2000).

The experiment had graded levels of NPK (nitrogen, phosphorus and potassium) fertilizers to determine appropriate fertility management strategies for the two soils, and understanding how this should be refined with the Bario rice cultivar that was used in this experiment. It should also indicate changes in input-response pattern and any nutrient deficiencies, which may develop over time. Proper fertility management is important to avoid large withdrawal of plant nutrient from soil, thereby accentuating the problem of nutrient disorders and affecting crop yield.

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1.1 Objectives

The objectives of this study were: (i) To investigate N and K uptake of Bario rice grown on Bekenu series, and (ii) To investigate N and K use efficiency of Bario rice grown on Bekenu series.

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CHAPTER 2

LITERATURE REVIEW

2.1 Global Rice Production

The continuous growth in world rice production has further elevated its eminence as a staple, with importance equal to that of wheat. In many areas of the developing world, rice is gaining popularity as a preferred source of caloric supply (Brohi, 1998). For instance rice covers about 148 million hectares of the earth surface and the production has been estimated to be 522 tons in the world (Brohi, 1998). On an average basis, rice produces a higher grain yield than wheat or maize and can support more people per hectare of land.

2.2 Bario Rice

Bario rice is regarded by the 'Orang Ulu' tribe and natives as the finest and best rice from the highlands of Sarawak. It is grown on cool climates at an elevation above 1,200 meters. According to the natives, the rice is only eaten by the longhouse chief on special occasion. It has long been regarded as one of the finest rice grains of the world. It is famous for its soft texture, fine and elongated grains with mild aromas and splendid taste. The rice is a home-grown, laboriously planted and harvested by hands using age-old traditional methods. It is perfect for health conscious consumers. Bario rice is air-flown out of Bario and Ba'kelalan highlands to enable the rest of Malaysians to sample the finest rice derived from the Land of the Hornbills (Sarawak Tourism Board, 2006).

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2.3 Bekenu Series

The Bekenu series is a member of the Bekenu family which is fine *loamy, siliceous, isohyperthermic, red-yellow to yellow Tipik Tualemkuts.* In terms of suitability for agriculture, the Bekenu series low fertility status and the terrain on which these soils occur are the main limiting factors for the use of these soils. However, with proper fertilization and soil conservation measures a wide range of crops such as upland rice could be cultivated on these soils (Paramanathan, 2000). Although the Bekenu series has low fertility status, low water holding capacity, and high erodibility, with much fertilization and maintenance, they could be used for rice production (Paramanathan, 2000).

2.3.1 Horizon Description

In the AB horizon (0 – 12 cm), the soil is described as yellowish brown (10YR5/6) sandy loam; weak medium to fine subangular blocky; very friable; many medium to fine roots; few coarse; few fine charcoal fragments; moderate biological activity diffuse boundary (Paramanathan, 2000).

2.3.2 Range in Characteristics

In the past in Sarawak, soils of the Bekenu series were mapped as Red-Yellow Podzolic soils which can either have a cambic, kandic or argilic horizon with hues of 10YR or 2.5Y with any CECclay value. They are redefined here as soils having only an argilic horizon with red-yellow to yellow colour class and a CECclay of less than 24 cmol (+) kg^{-1} in all subhorizons between 25 cm to 100 cm depth (Paramanathan, 2000).

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Little is known about the range in characteristics of the Bekenu series. They generally occur on rolling, hilly to steep terrain. On the steeper terrain the profiles become moderately deep and are no longer the Bekenu series. Textures in this soil are uniformly fine sandy clay loam and colours are brownish yellow, yellow to olive yellow. Structure is generally weak medium to coarse subangular blocky and consistence friable. Patchy clayskins are often present. Only the deep soils are retained as belonging to the Bekenu series in this redefinition. CECclay values are higher than 16 but less than 24 cmol (+) kg^{-1} clay. In some profiles a few subhorizons may have a CECclay of less than 16 cmol (+) kg^{-1} in the 25 to 100 cm depth (Paramanathan, 2000). Soils of the Bekenu series typically occur on rolling and hilly terrain (slopes of 12 – 38 % or 6 – 20 ^{o}) at elevations of less than 1,000 metres (3,300 feet) (Paramanathan, 2000).

2.3.3 Principal Associated Soils

In the lowlands, soils of the Bekenu series to-date have been mapped in association with soils of the Nyalau and Merit series. On the steeper slopes moderately deep and shallow equivalents have also been mapped. These soils are distinguished using the particle-size class and the diagnostic horizon. To-date soils of the Bekenu series have only been mapped in Sarawak. The actual extent of these soils is not fully known (Paramanathan, 2000).

2.4 Nitrogen Behaviour, Fertilization, and Nutrition

The flooded environment in which rice is grown has such a profound impact on its N fertilizer uptake efficiency that rice can be the most efficient or inefficient of the

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agronomic crops in this respect, depending on how the N fertilizer is applied and managed. Rice is capable of taking up the N fertilizer consistently with a 65 to 75 % efficiency when the N fertilizer is applied utilizing the split or Optimum Preflood Fertilizer (OPF) application methods and managed properly (Wilson *et al.*, 1994; Guindo *et al.*, 1994a,b; Bufogle *et al.*, 1997a,c).

The N fertilizer rate required to produce the best grain and milling yields of rice is dependant on the rice cultivar, stand density, previous crop, straw management, soil texture and permeability, N fertilizer application method, water management, soil pH, N fertilizer source, and possibly, tillage (Roberts *et al.*, 1993; Norman *et al.*, 1996; Bufogle *et al.*, 1997b).

2.4.1 Nitrogen and Plants

Plants absorb most of their nitrogen from the soil as ammonium or nitrate, with nitrite usually being present only in minor quantities in well-aerated soils. However, both trees and herbaceous plant species have the ability to take up certain organic N forms, especially when they are associated with mycorrhizal fungi (Chalot *et al.*, 2002).

The amount of N consumed by plants varies greatly from one species to another, and for any given species, the amount varies with genotype and the environment. Also, considerable variations exist in the relative amount of the N contained in the different plant parts (grain, stems, leaves, roots, etc.) (Tisdale *et al.*, 2005; Marschner, 1995; Mengel and Kirkby, 1996; Brady and Weil, 2002).

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2.4.2 Total N Determination

The Kjeldahl is the most common method for total N determination. The advantages for using the Kjeldahl method are first, it is easy to run multiple analyses and second, it is applicable to samples low in N (Tan, 1996). It must be emphasized that the difference between Kjeldahl-N and total-N in soils is usually very small, as a result mainly due to the presence of nitrate-N in the total-N determination. Because of this, the Kjeldahl method takes into account nitrate-N fraction in soil samples by first reducing it during the distillation process (Tan, 1996).

2.5 Potassium Behaviour, Fertilization, and Nutrition

Conceptually, K exists in the soil in four basic forms: (1) solution, (2) exchangeable, (3) non-exchangeable or clay fixed, and (4) primary and secondary minerals. These four forms of K are all in a state of dynamic equilibrium. The availability of K to rice increases after flooding, due to exchangeable K^+ being displaced from the soil exchange complex into the soil solution by NH^+_4 from early N fertilization and by Fe^{3+} and Mn^{4+}, which are reduced to the more soluble Fe^{2+} and Mn^{2+} forms with soil reduction (Patrick *et al.*, 1985).

2.6 Potassium Uptake

Nutrient depletion studies suggest that K uptake kinetics differs among rice cultivars (Marschner 1995; Mengel and Kirkby, 1996). However, a limited amount of field research has failed to document significant cultivar differences in tissue K concentration, total K uptake, or yield response to K fertilization.

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The rice plant's concentration of K is highest during the seedling stage and gradually declines with plant development or increasing dry matter accumulation. The cation K occurs in several forms in the soil that differ in their availability to plants. The most readily plant-available fraction is that in the soil solution, followed by the exchangeable fractions, which replenishes the soil solution if nutrients are removed by either plant uptake or leaching. Potassium fixed in clay interlayers becomes available at a time scale from hours to weeks. The least available forms are various primary and secondary soil minerals, which release the perspective nutrients upon weathering (Brady and Weil, 2002).

2.7 Nutrient Efficiency

As a comparative measure of the ability of plant species or varieties to grow and produce yields on nutrient-limited soils, agronomists have developed the concept of *nutrient efficiency* (Marschner, 1995). A crop species or variety A is said to be more nutrient efficient than a species or variety B if A reaches a satisfactory level of productivity at a lower nutrient supply than B, even if both have the same productivity when nutrients are not limiting. Being more nutrient efficient, A can be grown on a less-fertile soil and with less fertilizer input than B. The concept can also be applied to specific yield components, such as grain, instead of total biomass (Marschner, 1995).

Nutrient efficiency has two components: the *efficiency of nutrient acquisition* by the roots as measured by total nutrient uptake per plant, and the efficiency of nutrient utilization within the plant, which is called *nutrient-use efficiency* and is defined as the

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dry matter produced per unit nutrient in the dry matter. Efficient nutrient translocation within the plant and low nutrient requirements on the cellular level are factors that increase the nutrient-use efficiency. Alone or in combination, such characteristics tend to increase the productivity of plants when grown in soil with low nutrient availability (Marschner, 1995).

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CHAPTER 3

MATERIALS AND METHODS

3.1 Experimental Site and Method of Planting

The experiment was a pot study and conducted in a glasshouse at the Universiti Putra Malaysia Bintulu Campus, Sarawak. The type of soil used in this study was Bekenu series. The test crop in this study was Bario rice. Based on the soils' bulk density, plastic pots measuring 36 cm (height) x 30 cm (diameter) were filled with soil samples until the bulk density of this soil was attained. The soil in the plastic pots were flooded to 5 cm water above the soil surface and the rice seedlings seeded at a rate equivalent to 25 kg/ha. It should be noted that for a good establishment, seeds were soaked for 24 hours in sacks. Planting involved two distinct operations – dibbling plant holes and sowing the seed. Dibbling was done with a staff or dibble – stick which was flared out slightly towards the base. The dibble – stick was dibbled into the soil and removed with a slight twisting action usually leaving well – formed planting holes 2 cm in diameter. The depth of the planting holes ranged from 2 – 4 cm. Sowing was done by hand – broadcast and regulated by the number of seeds per throw. Seeds were sown directly in each planting hole. The planting holes were partially covered by loose soil from the surface so to allow quick emergence of the seeds. There were 12 seeds per pot.

Before the start of the experiment, the soil was analyzed for bulk density, pH, total N, exchangeable K, Mg, Ca, and cation exchange capacity (CEC).

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3.2 Soil Bulk Density

Soil bulk density is referred to as the mass (weight) of soil per unit volume of undisturbed soil or bulk soil volume whereas particle is defined as the mass (weight) of a unit volume of only particles (no air and water). In this research, coring method was used to obtain the bulk density of the soil (Tan, 1996). The bulk density of Bekenu series was 1.25 g/cm^3 and was typical of this soil series.

3.3 pH of Soil

Soil pH indicates the degree of acidity or alkalinity of soils. There are various ways to determine soil pH but in this research only the most common procedure which is the potentiometric method was used. To determine the pH in water and pH in 1 N KCl, pH meter and pH buffer solutions were used. Ten grams of soil samples were used in determining pH in water and 1 N KCl (soil to water or 1 N KCl of 1:2). The pH of the soil in water was 4.5 while that in 1 N KCl, was 3.5 and they were consistent with the pH of acid soils of Malaysia.

3.4 Determination of Total N in Soil and Plant

Total N was determined using micro-Kjeldahl method (Bremner, 1965). About 0.5 gram of soil, stem and roots were separately weighed into 50 mL Kjeldahl digestion tubes and treated with 5 mL concentrated sulphuric acid and one tablet of Kjeldahl catalyst (mixture of high selenium and sodium sulphate anhydrous) put in each tube. The samples were shaken and allowed to equilibrate for 30 minutes after which they were digested on a digestion block in a fume chamber. The samples were initially

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heated at 180 °C for 1 hour and then to 320 °C for 5 hours until samples became colourless, and they were then allowed to cool down. Afterwards, the samples were transferred into 50 mL volumetric flasks, diluted to volume using distilled water, and then filtered through Whatman filter paper number 2. Ten mL of the filtrates were distilled with 10 mL of 40 % NaOH and the ammonium collected into 50 mL Erlenmeyer flask containing 10 mL of 2 % boric acid-indicator mixture (bromocresol green-methyl red). Total N was determined by titrating the distillates with 0.01M HCl. The total N was found to be 0.25 % and was typical of Bekenu series.

Percentage of nitrogen in the soil or plant parts were calculated as:

% N = [(V-B) x M x R x 14.01/ Wt x 1000] x 100

Where: V = Volume of 0.01 M HCl or H_2SO_4 titrated for the sample (mL)

B = Digested blank titration volume (mL)

M = Molarity of HCl solution

14.01 = Atomic weight of N

R = Ratio between total volume of the digest and the digest volume used for distillation

Wt = Weight of air-dry soil or plant sample (g)

3.5 Determination of K, Ca, Mg, and Na in Soil

In this research, the double acid method (Tan, 1996) was used to extract the exchangeable K, Ca, Mg, and Na in soil. Forty mL of 0.05 M HCl:0.025 M H_2SO_4 and another 40 mL of distilled water were separately added to 10 g of soil samples in plastic vials. The samples in the plastic vials were shaken for 10 minutes in an orbital shaker at

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180 rpm. The samples were then filtered into new sets of plastic vials and filtered using Whatman paper number 2. The solutions were then analyzed for the exchangeable K, Ca, and Mg using the Atomic Absorption Spectrophotometry (AAS) and their concentrations were 6.82, 6.54, and 35.48 mg/kg. The K and Ca contents were typical of Bekenu series but for no apparent reason, that of Mg was high.

3.6 Determination of K, Ca, Mg, and Na in Plant

Dry ashing (single dry ashing) (Cottenie, 1980) was adopted for the extraction of K, Ca, Mg, and Na in the plant tissues. Some samples of stem and roots were initially oven dried for 24 hours at a temperature of 60 °C after which they were cooled in a desicator and 0.5 g weighed into crucibles and placed in a muffle furnace and initially ashed at 300 °C for 1 hour. The temperature was raised to 520 °C for 5 hours. Few drops of distilled water were added to the samples, followed by 2 mL concentrated HCl. Samples were evaporated to dryness in a fume chamber. Ten mL of 20 % HNO_3 was added to the samples and heated on a hot plate in a fume chamber for 1 hour. The samples were filtered through Whatman filter paper number 2 into 100 mL volumetric flasks, and diluted to volume. The filtrates were analyzed for K, Ca, Mg, and Na using AAS.

3.7 Cation Exchange Capacity Determination

Cation exchange capacity of the soil samples was determined using the ammonium acetate (leaching) method (Cottenie, 1980). Ten gram of each soil samples were weighed into leaching tubes covered with broth at the base and Whatman filter

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paper number 2 at both ends. The soil samples were leached with 1 M NH_4OAc for 6 hours. The samples were then washed with 95 % of ethanol and the ethanol discarded after collection. The soils were then leached with 100 mL of 0.1 M K_2SO_4 and the leachate collected in 100 mL volumetric and made up to volume. Ten mL of the samples were pipetted into distillation apparatus and 10 mL of 40 % NaOH added. Distillates were distilled and collected in 10 mL of 2 % boric acid-indicator solution until 50 mL conical flask containing the distillate twice the original volume (20 mL) was obtained. The colour changed from purple to green during distillation. The distillates were then titrated with 0.01 M HCl until the colour changed from green to purple (end point). The CEC was 10.70 cmol/kg soil and was typical of Bekenu series.

3.8 Fertilizer Rate, Soil Analysis and Harvesting

The fertilizer rate (Table 1) of 50 N kg/ha, 40 P kg/ha and 30 K kg/ha for the Bario rice variety was followed (recommendation of Semengok Agriculture Research Centre, Kuching). The fertilizers used were urea (46% N), Christmas Island Rock Phosphate (36% P_2O_5) and Muriate of Potash (60% K_2O). The plants were monitored for 65 days. After 65 days, soil samples were taken and analyzed for N, K, Ca, Mg, Na, organic matter, pH, and CEC. Nitrogen, and K uptake and yield of the rice variety were determined. The details of the split fertilizer application are presented in Table 1.

Table 1: Split fertilizer application

Application	Days after seeding
1st application (1/3)	20-25
2nd application (1/3)	45-55
3rd application (1/3)	65-75

At 65 days after planting, the plants were harvested and partitioned into roots and stem. Standard procedures were used to dry these parts, and determination of their dry weights.

3.9 Nitrogen and K Use Efficiency

The concentrations of N and K in the plant parts multiplied by their dry matter gave the amount of N and K taken up by the plant parts. Nitrogen and K use efficiency were calculated using the subtraction method (Pomares-Gracia and Pratt, 1987). Nitrogen and K use efficiency were calculated using the formula:

Example:

% N use efficiency

$$= \frac{\text{Total N uptake in fertilized plots} - \text{Total N uptake in unfertilized plots}}{\text{Total amount of N fertilizer applied}} \times 100\%$$

3.10 Experimental Design and Statistical Analysis

The experimental design was a completely randomized design with nine replications. Data was analyzed statistically by independent and paired t-test to detect treatment effect. The statistical software used was the Statistical Analysis System (SAS) version 9.1 (SAS, 2001).

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CHAPTER 4

RESULTS

4.1 Effect of Treatments on CEC and pH

The CEC and pH after harvest for the fertilized and unfertilized conditions are presented in Table 2. The treatment mean of the CEC for without fertilizer (T0) was 11.56 cmol (+)/kg while that of with fertilizer (T1) was 12.56 cmol (+)/kg. The treatment mean of T0 for pH in KCl, was 3.98 while that of T1 was 4.18. As for the treatment mean of T0 for pH in water, it was 4.82 and that of T1 was 4.99. Regardless of treatment, CEC and pH values were typical of Bekenu series. The outcome of the statistical comparisons of treatment means (Table 2) were: (i) CEC of the soil of T0 and CEC of the soil of T1 – no significant increase, (ii) pH in KCl of T0 and pH in KCl of T1 – significant increase, and (iii) pH in water of T0 and pH in water of T1 – significant increase.

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Table 2: Effect of fertilized (T1) and unfertilized (T0) conditions on CEC and pH

Treatment	Value
(a) CEC (cmol/kg)	
(T0)	11.56[a]
(T1)	12.56[a]
(b) pH in KCl	
(T0)	3.98[a]
(T1)	4.18[b]
(c) pH in Water	
(T0)	4.82[a]
(T1)	4.99[b]

Note: Means with different alphabets within column indicate significant difference between treatments by independent t-test at $p \leq 0.05$.

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4.2 Effect of Treatments on Soil Total N, Exchangeable K, Ca, Na, and Mg

The total N, exchangeable K, Ca, Na, and Mg in soil for with and without fertilization are shown in Table 3. The treatment mean of T0 for total N was 0.44 % and that of T1 was 0.62 %. The treatment means of T0 for K, Ca, Na, and Mg were 38.19, 73.86, 28.38, and 20.31 mg/kg respectively while those of T1 for K, Ca, Na, and Mg were 117.27, 89.22, 33.24, and 22.55 mg/kg respectively. The outcome of the statistical comparisons of treatment means (Table 3) were: (i) Total N in soil of T0 and T1 – significant increase, (ii) Exchangeable K in soil of T0 and T1 – significant increase, (iii) Exchangeable Ca in soil of T0 and T1 – no significant increase, (iv) Exchangeable Na in soil of T0 and T1 – significant increase, and (v) Exchangeable Mg in soil of T0 and T1 – significant increase.

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Table 3: Total N, exchangeable K, Ca, Na, and Mg in soil under fertilized and unfertilized conditions

Without Fertilizer (T0)					With Fertilizer (T1)				
N	K	Ca	Na	Mg	N	K	Ca	Na	Mg
%	mg/kg				%	mg/kg			
0.44[a]	38.19[a]	73.86[a]	28.38[a]	20.31[a]	0.62[b]	117.27[b]	89.22[a]	33.24[b]	22.55[b]

Note: Means with different alphabets within row indicate significant difference between treatments by independent t-test at $p \leq 0.05$.

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4.3 Effect of Treatments on N, K, Ca, Mg, and Na Concentrations in Bario Rice

The N, K, Ca, Mg, and Na concentrations in Bario rice roots and stem for unfertilized and fertilized conditions are presented in Table 4. For roots, the treatment means of T0 for N, K, Ca, Na, and Mg were 0.52, 0.15, 0.004, 0.08, and 0.05 % respectively while that of T1 for N, K, Ca, Na, and Mg were 0.70, 0.17, 0.01, 0.06, and 0.06 % respectively. As for stem, the treatment means of T0 for N, K, Ca, Na, and Mg were 1.34, 0.74, 0.11, 0.04, and 0.05 % respectively while that of T1 for N, K, Ca, Na, and Mg were 1.59, 1.19, 0.07, 0.03, and 0.06 % respectively. The outcome of the statistical comparison of treatment means (Table 4) were: (i) Nutrient concentrations in roots for T0 and T1 conditions – no significant increase in K, Ca, and Na but significant increase for N and Mg, and (ii) Nutrient concentrations in stem for T0 and T1 conditions – no significant increase in N, Ca, and Na but significant increase for K and Mg.

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Table 4: Nitrogen, K, Ca, Mg, and Na concentrations in roots and stem of Bario rice under fertilized and unfertilized conditions

Treatment	N	K	Ca	Na	Mg
	------------------------------	------	%------	------	------------------------------
(a) Roots					
(T0)	0.52[a]	0.15[a]	0.004[a]	0.08[a]	0.05[a]
(T1)	0.70[b]	0.17[a]	0.01[a]	0.06[a]	0.06[b]
(b) Stem					
(T0)	1.34[a]	0.74[a]	0.11[a]	0.04[a]	0.05[a]
(T1)	1.59[a]	1.19[b]	0.07[a]	0.03[a]	0.06[b]

Note: Means with different alphabets within column indicate significant difference between treatments by independent t-test at $p \leq 0.05$.

4.4 Effect of Treatments on Average Height and Panicles of Bario Rice

The average height and panicles of Bario rice per pot from Day 20 to Day 60 are presented in Figures 1 and 2. The average height of paddy for T0 in ascending order (Day 20 to Day 60) were 33.61, 35.67, 37.61, 39.33, 41.61, and 44.44 cm while those of T1 in ascending order (Day 20 to Day 60) were 33.94, 37.56, 39.94, 43.22, 44.11, and 56.89 cm. The average numbers of panicles of the paddy for T0 from Day 20 to Day 60 were 4, 4, 4, 4.38, 4.38, and 4.88. The average numbers of panicles of the paddy for T1 from Day 20 to Day 60 were 4, 4, 4.44, 5.05, 5.29, and 7.11. The results of the comparison of treatment means were: (i) Height of Bario rice for T0 and that of T1 – no significant increase on Day 20 and Day 48 and significant increase on Days 27, 34, 41,

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and 60, and (ii) Number of panicles of Bario rice for T0 and that of T1 – no significant increase from Day 20 to Day 34 and significant increase from Day 41 to Day 60.

Figure 1 shows an increase in the height of Bario rice from Day 20 to Day 60 for both treatments (T0 and T1). Also noticeable is that the plant height of T1 which was higher than T0 starting from Day 27 until Day 60. As for Figure 2, it shows a constant number of panicles from Day 20 to Day 34 for T0 and then gradually increased with time from Day 34 to Day 60 while for T1, a constant number of panicles from Day 20 to Day 27 followed by a gradual increased with time from Day 27 to Day 48 and a sharp increased from Day 48 to Day 60 can be seen in Figure 2. Figure 3 shows the height and number of panicles of the fertilized and unfertilized Bario rice. The growth of the fertilized plants was clearly better than those of the unfertilized plants.

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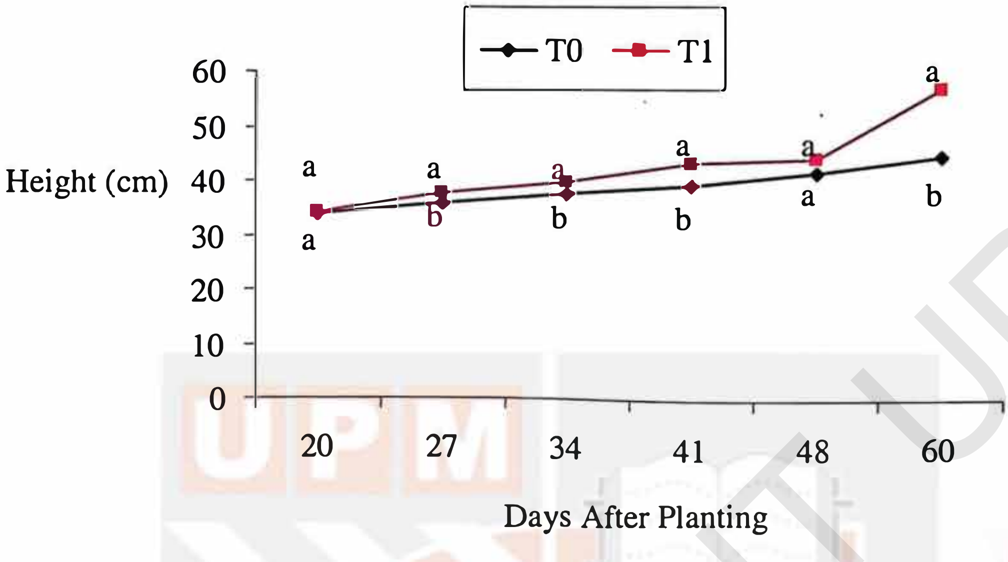

Figure 1: Effect of fertilized and unfertilized conditions on paddy height with time

Note: Means with different alphabets indicate significant difference between treatments by independent t-test at $p \leq 0.05$.

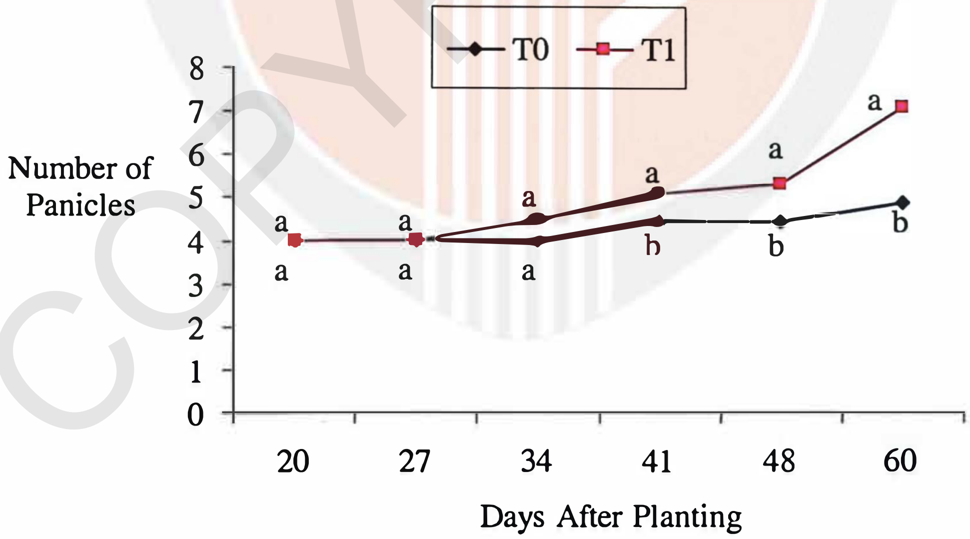

Figure 2: Effect of fertilized and unfertilized conditions on paddy panicles with time

Note: Means with different alphabets indicate significant difference between treatments by paired t-test at $p \leq 0.05$.

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Figure 3: Comparison between fertilized and unfertilized paddy

4.5 Effect of Treatments on Dry Weight and Nutrient Uptake

The dry weight of Bario rice roots and stem for T0 and T1 are presented in Table 5. The total dry weight (roots and stem) of T0 and T1 were 4.31 g and 6.87 g respectively. In terms of parts, the dry weight production (roots and stem) regardless of treatment was not significant. The total nutrients uptake for T0 and T1 respectively were: N = 0.03 g and 0.08 g; K = 0.02 g and 0.04 g; Ca = 0.001 g and 0.002 g; Na = 0.003 g and 0.004 g; and Mg = 0.003 g and 0.004 g. Irrespective of treatment, K and Ca distribution was higher in the stems than in the roots. In the case of Na, the distribution was higher in roots than in stem. As for N, the distribution was higher in roots than in stem for T0. In the case of T1, it was higher in stem than in roots. For Mg, the distribution was higher in roots than stem for T0 while for T1, the distribution in roots and stem was similar. The results of the statistical comparisons of treatment means (Table 5) were: (i) T0 and T1 – no significant increase in dry weight (DW), N, K, Ca, Na, and Mg uptake in roots, and (ii) No significant increase in dry weight (DW), and Ca uptake but significant increase in N, K, Na, and Mg uptake in stem.

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Table 5: Dry weight (DW), N, K, Ca, Mg, and Na uptake in roots and stem under fertilized and unfertilized conditions

	Without Fertilizer (T0)						With Fertilizer (T1)					
Parts	DW	N	K	Ca	Na	Mg	DW	N	K	Ca	Na	Mg
	------------------------------ (g) ------------------------------						------------------------------ (g) ------------------------------					
Roots	3.23[a]	0.02[a]	0.01[a]	0.0001[a]	0.003[a]	0.002[a]	4.19[a]	0.04[a]	0.01[a]	0.0003[a]	0.003[a]	0.002[a]
Stem	1.08[a]	0.014[a]	0.01[a]	0.001[a]	0.0004[a]	0.001[a]	2.68[a]	0.04[b]	0.03[b]	0.002[a]	0.001[b]	0.002[b]
Total	4.31	0.03	0.02	0.001	0.003	0.003	6.87	0.08	0.04	0.002	0.004	0.004

Note: Means with different alphabets within row indicate significant difference between treatments by independent t-test at $p \leq 0.05$.

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4.6 Nitrogen and K Use Efficiency

The results of the N and K use efficiency in roots and stem are shown in Table 6. For roots, the percentage for N was 4.466 and that of K was 0.067 while for stem, the percentage for N was 5.437 and that of K was 4.167. The overall N and K use efficiencies of the Bario rice were 9.90 % and 4.23 % respectively.

Table 6: Nitrogen and K use efficiency in roots and stem of Bario rice

Treatments	N	K
	%	
Roots	4.466	0.067
Stem	5.437	4.167
Total	9.903	4.234

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CHAPTER 5

DISCUSSION

5.1 CEC and pH of Soil

The insignificant difference between the CEC of T0 and T1 at harvest suggests that fertilization did not affect the exchange property of the soil within the time frame of this study (Table 2). This observation was expected as organic matter that usually affects soil CEC was not included in this study and no leaf decomposition in the experimental pots as the plant grew was observed. However, the pH of T1 in both water and KCl were greater than those of T0 (Table 2) probably due to addition of fertilizers particularly urea which is noted for increasing soil pH rapidly at the soil microsites (Ahmed *et al*., 2006). Anhydrous ammonia, urea, diammonium phosphate, and nitrogen solutions, when first applied, greatly but temporarily increase soil pH in the zone of application (Wilson *et al*., 2001).

5.2 Total N, Exchangeable K, Ca, Na, and Mg in Soil

The significant increase in soil N, K, Mg, and Na concentrations (Table 3) for the fertilized condition (T1) could be attributed to the addition of urea and KCl (MOP). This finding was consistent with that of Nand (2000) who observed that the patterns of the availability of N and K were affected by continuous fertilizer use.

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5.3 Nitrogen, K, Ca, Mg, and Na Concentrations in Plant Parts

The general insignificant difference in nutrient concentrations in roots and stem (Table 4) may be ascribed to dilution effect (Marschner, 1995; Mengel and Kirby, 1996). Lack of significant effect on N uptake may be partly due to ammonia volatilization and denitrification under reduced condition or under submerged conditions of rice (Prasertsak *et al.*, 2001; Cai *et al.*, 2002). Upon application, urea-N changes rapidly to NH_4^-N and therefore is readily available to plants on application to the soil. Urea presents another problem, in that when it is surface-applied, significant quantities of nitrogen as ammonia may be lost through volatilization which cause low N uptake in plants (Prasertsak *et al.*, 2001; Cai *et al.*, 2002). This occurs because the urea dissolves, be in contact with the soil for conversion to volatile nitrogen, and easily escapes to the atmosphere due to its proximity to the soil surface (Nambiar, 1994; Prasertsak *et al.*, 2001; Cai *et al.*, 2002).

5.4 Average Height and Panicles of Paddy

Although there was general increase in plant height and number of panicles with time irrespective of treatment, there was significant increase in these variables with time (Figures 1 to 3) under the fertilized condition (T1) compared with the unfertilized condition (T0) to fertilization and this could be partly associated with K and N fertilization.

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5.5 Total Dry Weight and Nutrient Uptake

There was no significant difference between root dry weight and N, K, Ca, Na, and Mg under T0 and T1. In the case of stem, the difference in dry weight of the treatment was not significant but in terms of uptake, except for Ca, N, K, Na, and Mg uptake under T1 were statistically higher than under T0. Obviously, addition of urea and KCl fertilizers explains the higher uptake of N and K in the stem under the fertilized condition compared to the unfertilized condition. Different rates of N and K applied to rice plant under greenhouse conditions significantly increased the uptake of macro and micro-nutrients in rice grain (Rafey et al., 1989).

5.6 Nitrogen and K Use Efficiency

Regardless of treatment, the low percentages of N and K indicate that the N and K uptake by the plants even though significant in stem, the general nutrient use by Bario rice on Bekenu series was low or inefficient. The low fertility status and the terrain on which these soils occur could be some of the limiting factors for the use of these soils. However, with proper addition of organic fertilizers as supplement of inorganic fertilizers and soil conservation measures, the N and K use efficiency may be improved (Paramanathan, 2000).

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CHAPTER 6

CONCLUSIONS AND RECOMMENDATION

Application of N and K fertilizers significantly increased N, K, Mg, and Na accumulation on Bekenu series soil. Roots and stem dry weight of Bario rice showed no significant difference under T0 and T1. Application of urea and MOP had significant effect on N and K uptake in stem. However, the N and K use efficiencies (10 % for N and 4 % for K) of Bario rice on Bekenu series were low.

As the results showed inefficient nutrient use, series of trials on Bekenu series on the interaction between inorganic and organic fertilizers (e.g. compost) should be carried out. This is essential because Bario rice seems to grow well under organic fertilization. Probably supplementing inorganic fertilizers with organic fertilizers may help in good growth and development of Bario rice on Bekenu series since it may be difficult and expensive to mimic the climatic conditions under which Bario rice grows well.

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REFERENCES

Ahmed, O.H., H. Aminuddin, and M.H.A. Husni, 2006. Reducing ammonia loss from urea and improving soil-exchangeable ammonium retention through mixing triple superphosphate, humic acid and zeolite. *Soil and Management* **22:** 315-319.

Brady, N.C. and R.R. Weil. 2002. The nature and properties of soils. 13th edn. New Jersey: Prentice Hall.

Bremner, J.M. 1965. Total nitrogen. In *Methods of Plant Analysis. American Society of Agronomy. Monograph* **9:** 1149-1178.

Brohi, 1998. Effect of nitrogen and phosphorus fertilization on the yield and nutrient status of rice crop grown on artificial siltation soil from the Kelkit river. *Turkey Journal of Agriculture and Forestry* **22:** 585-592.

Bufogle, A., Jr., P. K. Bollich, J. L. Kovar, C. W. Lindau, and R. E. Macchivelli. 1997a. Rice variety differences in dry matter and nitrogen accumulations as related to plant stature and maturity group. *Journal of Plant Nutrition* **20:** 1203-1224.

Bufogle, A., Jr., P. K. Bollich, J. L. Kovar, C. W. Lindau, and R. E. Macchivelli. 1997b. Rice plant growth and nitrogen accumulation from midseason application. *Journal of Plant Nutrition* **20:** 1191-1201.

Bufogle, A., Jr., P. K. Bollich, R. J. Norman, J. L. Kovar, C. W. Lindau, and R. E. Macchivelli. 1997c. Rice plant growth and nitrogen accumulation in drill-seeded and water-seeded culture. *Soil Science Society of American Journal* **61:** 832-839.

Cai, G.X., Chen, D.L., Ding, H., Pacholski, A., Fan, X.H. & Zhu. Z.L. 2002. Nitrogen losses from fertilizers applied to maize, wheat and rice in the North China Plan. *Nutrient Cycling in Agroecosystems* **63:** 187-195.

Chalot, M., Javelle, A., Blaudez, D., Lambilliote, R., Cooke, R., Sentenac, H., Wipf, D., and Botton, B. 2002. An update on nutrient transport processes in ectomycorrhizas. *Plant and Soil* **244:** 165-175.

Cottenie, A. 1980. Soil testing and plant testing as a basis of fertilizer recommendation. *FAO Soils Bulletin* **38:** 70-73.

Guindo, E., R.J. Norman, and B.R. Wells. 1994a. Accumulation of fertilizer nitrogen-15 by rice at different stages of development. *Soil Science Society of American Journal* **58:** 410-415.

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Guindo, E., B.R. Wells, and R.J. Norman. 1994b. Cultivar and nitrogen rate influence on nitrogen uptake and partitioning in rice. *Soil Science Society of American Journal* **58:** 840-845.

Marschner, H. 1995. Mineral nutrition of higher plants. 2nd edn. London: Academic Press.

Mengel, K. and E.A. Kirkby. 1996. Principles of plant nutrition. 4th edn, p. 147-9. New Delhi: Panina Publishing Corporation.

Nambiar, K.K.M. 1994. Soil fertility and crop productivity under long-term fertilizer use in India. New Delhi, India: Indian Council of Agricultural Research.

Nand, R. 2000. Long-term effects of fertilizers on rice-wheat-cowpea productivity and soil properties in a Mollisols. In *Long-term Soil Fertility Experiments in Rice-Wheat Cropping Systems*, ed. Abrol, I.P., Bronson, K.E., Duxbury, J.M. and Gupta, R. K., p. 50-55. *Rice-Wheat Consortium Paper Series 6*, New Delhi, India: Rice-Wheat Consortium for the Indo-Gangetic Plains.

Norman, R.J., C.E. Wilson, Jr., P.K. Bollich, K.A. Gravois, and B.R. Wells. 1996. Nitrogen uptake of selected rice cultivars. *Proc. 26th Rice Tech. Work. Group* **1996:** 173.

Paramanathan, S. 2000. Soils of Malaysia: Their characteristics and identification. Volume 1, Akademi Sains Malaysia, p. 121, 124 and 384.

Patrick, W.H., D.S. Mikkelson, and B.R. Wells. 1985. Plant nutrient behavior in flooded soils. In *Fertilizer Technology and Use*, ed. Engelstad. 3rd edn. *Soil Science Society of American Journal*, p. 197-228. Madison, WI.

Pomares-Gracia, F. and P.F. Pratt. 1987. Recovery of 15N-labelled fertilizer from manured and sludged-amended soils. *Soil Science Society of American Journal* **42:** 717-720.

Prasertsak, P., Freney, J.R., Saffiga, P.G., Denmead, O.T. & Prove, B.G. 2001. Fate of urea nitrogen applied to a banana crop in the wet tropics of Queensland. *Nutrient Cycling in Agroecosystems* **59:** 65-73.

Rafey, A., Khan, P.A. and Srivastava, V.C. 1989. Effect of N on growth, yield and nutrient uptake of upland rice, *Indian Journal of Agronomy* **34(1):** 133-135.

Roberts, S.R., J.E. Hill, D.M. Brandon, B.C. Miller, S.C. Scardaci, C.M. Wick, and J.F. Williams. 1993. Biological yield and harvest index in rice: Nitrogen response of tall and semidwarf cultivars. *J. Prod. Agric* **6:** 585-588.

Sarawak Tourism Board. 2006, http://www.sarawaktourism.com/content.cfm/ID/54CACAAF-61B7-4677-A843E8A399B8EF8F visited on 23/07/2006.

SAS 2001. SAS/STAT *software*. SAS Institute NC, USA.

© COPYRIGHT UPM

Tan, K. H. 1996. Soil sampling preparation, and analysis. New York: Marcel Dekker, Inc.

Tisdale, S.L., Havlin, J.L., Beaton, J.D., and W.L. Nelson. 2005. Soil fertility and fertilizers. 7th edn. New York: McMillan Publication Co., Inc.

Wilson, C. E., Jr., B.R. Wells, and R.J. Norman. 1994. Fertilizer nitrogen uptake by rice from urea-ammonium nitrate solution vs. granular urea. *Soil Science Society of American Journal* **58:** 1825-1828.

Wilson, C. E., N. A. Slaton, R. J. Norman, and D. M. Miller. 2001. Efficient use of fertilizer. In *Rice Production Handbook*, ed. N.A. Slaton, p. 51-74. Univ. Ark. Coop. Ext. Serv. Publ. MP-192.

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APPENDICES

APPENDIX A

Bulk density, pH (in water and KCl), CEC, N, K, Ca, and Mg concentrations of Bekenu series before planting

Replicate	Bulk Density g/cm^3	pH Water	pH KCl	CEC Cmol(+)/kg	N %	K mg/kg	Ca mg/kg	Mg mg/kg
1	-	5.00	3.90	12.00	0.28	4.14	6.86	33.30
2	-	4.90	4.10	13.00	0.28	6.30	13.27	45.40
3	1.3248	4.60	4.00	13.00	0.28	5.91	4.64	38.00
4	-	4.70	4.00	12.00	0.28	6.41	3.05	34.10
5	1.1167	4.80	4.10	12.00	0.28	5.09	1.97	24.30
6	1.0326	4.90	4.10	7.00	0.14	4.86	1.71	29.20
7	1.3816	4.40	3.80	6.00	0.14	7.75	1.93	28.30
8	1.3148	4.40	3.80	6.00	0.28	8.48	2.23	32.50
9	1.2887	4.80	4.10	12.00	0.28	8.42	23.22	54.20
10	1.3238	5.30	4.90	14.00	0.28	10.86	-	-
Average	1.2547	4.78	4.08	10.70	0.25	6.82	6.54	35.48

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APPENDIX B

Soil moisture content of Bekenu series before planting

Crucible (g)	Wet soil (g)	Dried soil (g)	Water content (g)	% of water content (wet basis)	% of water content (dry basis)
42.77	20	17.77	2.23	11.15	12.55
42.18	20	17.94	2.06	10.30	11.48
42.92	20	17.61	2.39	11.95	13.57
43.26	20	17.37	2.63	13.15	15.14
38.43	20	16.79	3.21	16.05	19.12
40.21	20	16.91	3.09	15.45	18.27
43.42	20	16.89	3.11	15.55	18.41
46.65	20	17.09	2.91	14.55	17.03
40.86	20	17.09	2.91	14.55	17.03
44.33	20	17.81	2.19	10.95	12.29
	Average		2.67	13.37	15.49

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APPENDIX C

Fertilizer calculation

Radius of each pot = 0.15 m = 0.025 m^2

For Urea,

Urea = 46 %

50 kg N Urea/ha

46 kg N = 100 kg Urea

Amount of Urea needed for a pot = (100 x 50)/46 = 108.70 kg Urea

10000 m^2 = 108.70 kg

0.071 m^2 = (108.7 x 0.071)/10000 = 7.72 x 10^{-4} kg = 0.772 gram

Note: 0.52 g of urea used because paddy was fertilized twice in split application (per application = 0.52 g).

For Phosphorus (P_20_5), 36 %, 40 kg/ha,

36 kg P_20_5 = 100 kg CIRP

91.6 kg P_20_5 = (100 x 91.6)/36 = 254.44 kg CIRP

10000 m^2 = 254.44 kg

0.071 m^2 = (254.44 x 0.071)/10000 = 1.81 x 10^{-3} kg = 1.81 gram

Note: 1.20 g of CIRP used because paddy was fertilized twice in split application (per application = 1.20 g).

For Potassium (K_2O), 60 %, 30 kg/ha,

60 kg K_2O = 100 kg MOP

72 kg K_2O = (100 x 72)/60 = 120 kg MOP

10000 m^2 = 120 kg MOP

0.071 m^2 = (120 x 0.071)/10000 = 8.52 x 10^{-4} kg = 0.85 gram

Note: 0.60 g of MOP used because paddy was fertilized twice in split application (per application = 0.60 g).

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APPENDIX D

pH of Bekenu series after harvest

Treatments	pH in KCl	pH in water
T_1R_1	4.13	4.98
T_1R_2	4.68	5.33
T_1R_3	3.98	4.90
T_1R_4	4.21	5.00
T_1R_5	4.07	4.87
T_1R_6	4.34	5.09
T_1R_7	3.99	4.83
T_1R_8	3.93	4.82
T_1R_9	4.30	5.13
T_0R_1	3.99	4.90
T_0R_2	4.02	4.93
T_0R_3	3.93	4.86
T_0R_4	3.98	4.73
T_0R_5	3.97	4.77
T_0R_6	3.97	4.76
T_0R_7	3.96	4.83
T_0R_8	4.01	4.88
T_0R_9	3.95	4.74

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APPENDIX E

CEC of Bekenu series after harvest

Treatments	cmol (+)/kg soil
T_1R_1	12
T_1R_2	10
T_1R_3	10
T_1R_4	14
T_1R_5	13
T_1R_6	12
T_1R_7	14
T_1R_8	12
T_1R_9	16
T_0R_1	10
T_0R_2	13
T_0R_3	10
T_0R_4	12
T_0R_5	10
T_0R_6	13
T_0R_7	14
T_0R_8	11
T_0R_9	11

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APPENDIX F

Total N, exchangeable K, Ca, Na, and Mg in Bekenu series after harvest

Treatments	N (%)	K (mg/kg)	Ca (mg/kg)	Na (mg/kg)	Mg (mg/kg)
T_1R_1	0.56	98.76	63.20	34.18	22.32
T_1R_2	0.56	85.80	85.28	33.83	25.20
T_1R_3	0.28	133.72	89.96	26.45	20.00
T_1R_4	0.56	152.68	83.64	34.11	20.40
T_1R_5	0.56	124.68	95.52	32.36	23.76
T_1R_6	0.84	89.56	125.52	31.47	23.52
T_1R_7	0.84	131.48	83.52	33.19	22.88
T_1R_8	0.84	129.24	110.60	39.45	22.80
T_1R_9	0.56	109.48	65.76	34.14	22.08
T_0R_1	0.56	38.59	81.80	25.95	19.44
T_0R_2	0.56	37.81	86.00	29.86	17.76
T_0R_3	0.56	28.90	71.84	22.73	20.72
T_0R_4	0.28	37.83	77.32	30.07	20.08
T_0R_5	0.28	41.72	58.20	28.47	21.20
T_0R_6	0.56	37.30	80.48	30.60	18.88
T_0R_7	0.28	33.94	71.92	25.90	21.04
T_0R_8	0.56	43.84	75.12	30.82	22.00
T_0R_9	0.28	43.80	62.04	31.04	21.68

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APPENDIX G

Nitrogen, K, Ca, Na, and Mg concentrations in stem

Treatments	N (%)	K (%)	Ca (%)	Na (%)	Mg (%)
T_1R_1	1.12	1.07	0.07	0.03	0.07
T_1R_2	0.56	1.09	0.07	0.03	0.06
T_1R_3	0.84	1.19	0.05	0.03	0.05
T_1R_4	2.24	1.31	0.06	0.04	0.05
T_1R_5	2.24	1.37	0.06	0.03	0.08
T_1R_6	1.40	1.24	0.09	0.05	0.08
T_1R_7	2.24	1.10	0.06	0.03	0.05
T_1R_8	1.12	1.26	0.07	0.03	0.08
T_1R_9	2.52	1.06	0.09	0.03	0.07
T_0R_1	1.40	0.66	0.07	0.04	0.04
T_0R_2	1.68	0.63	0.07	0.03	0.05
T_0R_3	1.12	0.82	0.08	0.05	0.05
T_0R_4	1.40	0.74	0.06	0.03	0.05
T_0R_5	1.40	0.74	0.07	0.04	0.06
T_0R_6	0.84	0.78	0.47	0.03	0.05
T_0R_7	1.40	0.80	0.07	0.05	0.05
T_0R_8	1.40	0.81	0.06	0.03	0.05
T_0R_9	1.40	0.69	0.08	0.04	0.04

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APPENDIX H

Nitrogen, K, Ca, Na, and Mg concentrations in roots

Treatments	N (%)	K (%)	Ca (%)	Na (%)	Mg (%)
T_1R_1	0.70	0.15	0.01	0.05	0.05
T_1R_2	0.67	0.14	0.01	0.05	0.06
T_1R_3	0.67	0.15	0.01	0.06	0.06
T_1R_4	0.73	0.16	0.01	0.06	0.06
T_1R_5	0.76	0.20	0.01	0.08	0.07
T_1R_6	0.64	0.13	0.01	0.05	0.06
T_1R_7	0.76	0.14	0.01	0.11	0.05
T_1R_8	0.67	0.10	0.01	0.04	0.06
T_1R_9	0.70	0.16	0.01	0.06	0.07
T_0R_1	0.42	0.17	0.001	0.10	0.04
T_0R_2	0.42	0.18	0.001	0.09	0.05
T_0R_3	0.36	0.17	0.001	0.08	0.05
T_0R_4	0.53	0.15	0.004	0.07	0.06
T_0R_5	0.63	0.19	0.005	0.09	0.05
T_0R_6	0.56	0.16	0.004	0.06	0.05
T_0R_7	0.56	0.18	0.007	0.09	0.04
T_0R_8	0.73	0.10	0.007	0.06	0.04
T_0R_9	0.48	0.19	0.005	0.07	0.06

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APPENDIX I

Average height of paddy per pot from 20 DAP to day 60 DAP

Average height of paddy per pot	Day 20 (After the first NPK application) [cm]	Day 27 [cm]	Day 34 [cm]	Day 41 [cm]	Day 48 [cm]	Day 60 [cm]
T_0R_1	32	35	37.5	38	39	40
T_0R_5	38	39.5	40	43	43	47
T_1R_2	35	38.5	40	41	41	63
T_1R_1	32	39	40	48	48	62
T_0R_2	32	35	36	36.5	39	43
T_1R_7	37	38.5	42	48	49.5	72
T_0R_3	31.5	33	34	37.5	38	40
T_1R_3	32	39	40	41	42	52
T_1R_4	31	35.5	41.5	42.5	43	47.5
T_1R_6	32	37.5	39	44	45	56.5
T_0R_6	32.5	36	38.5	41	43	45.5
T_0R_9	34.5	37	43	47	49	55
T_1R_8	36	37	38.5	41.5	43	56
T_0R_4	33	34.5	35	35.5	37.5	40.5
T_1R_9	34.5	36	40	42	43.5	44
T_0R_8	34	35	37	37.5	47	48
T_1R_5	36	38	39	41	42	59
T_0R_7	35	36	37.5	38	39	41

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APPENDIX J

Average number of paddy panicles per pot from day 20 to day 60

Average number of paddy panicles per pot	Day 20 (After the first NPK application) [cm]	Day 27 [cm]	Day 34 [cm]	Day 41 [cm]	Day 48 [cm]	Day 60 [cm]
T_0R_1	4	4	4	4	4	4
T_0R_5	4	4	4	4	4	5
T_1R_2	4	4	4	4	5	7
T_1R_1	4	4	5	5	6	7
T_0R_2	4	4	4	4	4	4
T_1R_7	4	4	5	5	5	7
T_0R_3	4	4	4	4	4	4
T_1R_3	4	4	4	4	4	6
T_1R_4	4	4	5	5	4	6
T_1R_6	4	4	5	5	5	7
T_0R_6	4	4	4	4	4	4
T_0R_9	4	4	5	5	5	6
T_1R_8	4	4	4	5	5	7
T_0R_4	4	3	3	3	3	4
T_1R_9	4	4	4	5	5	5
T_0R_8	4	4	4	4	4	4
T_1R_5	4	4	4	4	4	7
T_0R_7	4	4	4	4	4	4

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APPENDIX K

Comparison of the treatment means of the average height and panicles of paddy per pot under with and without fertilizer conditions from Day 20 to Day 60

Treatment	Day 20	Day 27	Day 34	Day 41	Day 48	Day 60
(a) Height (in cm)						
(T0)	33.61[a]	35.67[a]	37.61[a]	39.33[a]	41.61[a]	44.44[a]
(T1)	33.94[a]	37.56[b]	39.94[b]	43.22[b]	44.11[a]	56.89[b]
(b) Panicle						
(T0)	4.00[a]	4.00[a]	4.00[a]	4.38[a]	4.38[a]	4.88[a]
(T1)	4.00[a]	4.00[a]	4.44[a]	5.05[b]	5.29[b]	7.11[b]

Note (Height): Means with different alphabets within column indicate significant difference between treatments by independent t-test at $p \leq 0.05$.

Note (Panicle): Means with different alphabets within column indicate significant difference between treatments by paired t-test at $p \leq 0.05$.

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APPENDIX L

Fresh and dry weight of Bario rice stem

Treatments	Fresh weight (g)	Dry weight (g)
T_1R_1	17.655	4.441
T_1R_2	7.701	2.139
T_1R_3	5.391	1.433
T_1R_4	5.827	1.569
T_1R_5	13.699	2.866
T_1R_6	7.900	1.932
T_1R_7	23.840	5.334
T_1R_8	14.032	3.391
T_1R_9	4.972	1.044
T_0R_1	2.301	0.808
T_0R_2	2.393	1.226
T_0R_3	1.656	0.640
T_0R_4	2.518	0.739
T_0R_5	2.973	1.086
T_0R_6	4.232	1.205
T_0R_7	3.826	1.071
T_0R_8	5.126	1.078
T_0R_9	7.096	1.881

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APPENDIX M

Fresh and dry weights of Bario rice roots

Treatments	Fresh Weight (g)	Dry Weight (g)
T_1R_1	40.469	8.693
T_1R_2	11.773	2.077
T_1R_3	7.637	1.341
T_1R_4	8.343	1.457
T_1R_5	13.521	2.721
T_1R_6	10.790	1.737
T_1R_7	61.279	12.270
T_1R_8	18.129	4.041
T_1R_9	12.401	3.398
T_0R_1	8.081	1.497
T_0R_2	12.408	3.899
T_0R_3	16.616	5.488
T_0R_4	6.526	1.197
T_0R_5	15.406	3.439
T_0R_6	13.817	3.075
T_0R_7	11.976	2.142
T_0R_8	10.189	1.885
T_0R_9	20.581	6.464

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APPENDIX N

Dry weight (DW), N, K, Ca, Mg, and Na uptake in stem

Treatments	DW (g)	N (g)	K (g)	Ca (g)	Na (g)	Mg (g)
T_1R_1	4.44	0.05	0.05	0.003	0.001	0.003
T_1R_2	2.14	0.01	0.02	0.001	0.001	0.001
T_1R_3	1.43	0.01	0.02	0.001	0.0004	0.001
T_1R_4	1.57	0.04	0.02	0.001	0.001	0.001
T_1R_5	2.87	0.06	0.04	0.002	0.001	0.002
T_1R_6	1.93	0.03	0.02	0.002	0.001	0.002
T_1R_7	5.33	0.12	0.06	0.003	0.002	0.003
T_1R_8	3.39	0.04	0.04	0.002	0.001	0.003
T_1R_9	1.04	0.03	0.01	0.001	0.0004	0.001
T_0R_1	0.81	0.01	0.01	0.0006	0.0002	0.0004
T_0R_2	1.23	0.02	0.01	0.001	0.0004	0.0006
T_0R_3	0.64	0.01	0.01	0.001	0.0003	0.0003
T_0R_4	0.74	0.01	0.01	0.0004	0.0002	0.0004
T_0R_5	1.09	0.02	0.01	0.001	0.0004	0.001
T_0R_6	1.21	0.01	0.01	0.006	0.0004	0.001
T_0R_7	1.07	0.02	0.01	0.0008	0.0004	0.001
T_0R_8	1.08	0.02	0.01	0.001	0.0003	0.001
T_0R_9	1.88	0.03	0.001	0.0001	0.001	0.001

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APPENDIX O

Dry weight (DW), N, K, Ca, Mg, and Na uptake in roots

Treatments	DW (g)	N (g)	K (g)	Ca (g)	Na (g)	Mg (g)
T_1R_1	8.69	0.06	0.01	0.0005	0.004	0.004
T_1R_2	2.08	0.01	0.003	0.0001	0.001	0.001
T_1R_3	1.34	0.01	0.002	6.84×10^{-5}	0.001	0.001
T_1R_4	1.46	0.01	0.002	0.0001	0.001	0.001
T_1R_5	2.72	0.02	0.01	0.0002	0.002	0.002
T_1R_6	1.74	0.01	0.002	0.0001	0.001	0.001
T_1R_7	12.27	0.10	0.02	0.001	0.01	0.01
T_1R_8	4.04	0.03	0.004	0.0003	0.002	0.003
T_1R_9	3.40	0.02	0.01	0.0002	0.002	0.002
T_0R_1	1.49	0.01	0.003	8.00×10^{-6}	0.001	0.001
T_0R_2	3.89	0.02	0.01	4.52×10^{-5}	0.003	0.002
T_0R_3	5.49	0.02	0.01	3.73×10^{-5}	0.004	0.003
T_0R_4	1.20	0.01	0.002	4.79×10^{-5}	0.001	0.001
T_0R_5	3.44	0.02	0.01	0.0002	0.003	0.002
T_0R_6	3.08	0.02	0.005	0.0001	0.002	0.002
T_0R_7	2.14	0.01	0.004	0.0001	0.002	0.001
T_0R_8	1.89	0.01	0.002	0.0001	0.001	0.001
T_0R_9	6.46	0.03	0.01	0.0003	0.005	0.004

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PUBLICATION OF THE PROJECT UNDERTAKING

This is to certify that I have no objection to publish the project entitled **"Nitrogen and Potassium Use Efficiency of Bario Rice Grown on Bekenu Series"** by the supervisor in a joint authorship. However, it has to be evaluated by the Faculty of Agriculture and Food Sciences, University Putra Malaysia Bintulu Campus and published in form approved by the Faculty.

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Kevin Muyang Tawie Anak Sulok

Date: 3rd May 2007