FINAL TECHNICAL REPORT

INTEGRATING CROP RESIDUES FOR N, K, AND Si MANAGEMENT IN SUSTAINABLE RICE PRODUCTION IN MALAWI

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TABLE OF CONTENT

Project Executive Summary

Alabama A&M Greenhouse Experiment:

Abstract	1
Introduction	1
Methods	2
Results and Discussion	3
Conclusions	4
References	4
Data	6-8

Malawi Field Experiments:

Abstract	1
Introduction	1
Methods	3
Results and Discussion	5
Conclusion	7
References	8
Data	10-14

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PROJECT EXECUTIVE SUMMARY

An approach to integrated nutrient management will play an important role in sustainable crop production, particularly in developing countries. The recycling of crop residues as sources of plant nutrients, a novel approach was tried as part of developing sustainable rice (*Oryzae sative* L.) production. Rice is an important food crop in the world and ranked second to maize in cereal food crops in Malawi. The price of chemical fertilizers is rising and small scale, resource-poor, rice farmers in Malawi and in other developing countries can not afford to use them at the rates needed for sustaining productivity in their traditional paddy fields. Rice crop residues such as rice straw and rice hull (rice-hull ash) are rich in potassium, calcium, and silicon and are often wasted. In several developing countries, rice hull is used as a source of energy for domestic cooking (FAO, 1991). The resultant rice-hull ash collected from rice-hull fired stoves is rich in silicon and can be applied to rice nurseries as a silicon source.

A research project involving these local crop residues was conducted at Alabama A&M University and in Malawi, to accomplish the following objectives: 1) To study the effect of soil-applied rice-hull ash on the growth and nutrient composition of rice seedlings; 2) To investigate the effect of rice-hull ash, rice straw, and modified urea as sources of silicon, potassium, and nitrogen on the yield of transplanted rice; and 3) To develop an integrated nutrient management system for increasing and sustaining rice yields in Malawi.

The result of the greenhouse study showed that the rice-hull ash treated seedlings produced more dry matter (18%) than the untreated seedlings. The rice-hull ash treatment also reduced the nitrogen uptake by 16.4%, aluminum by 20% and manganese by 34%. However, the treatment increased the uptake of phosphorus by 7.7%, potassium by 20%, and silicon by 100%. These findings clearly

show the benefit of silicon applied through rice-hull ash to rice seedlings. The results of the three field studies in Malawi showed that incorporation of rice straw significantly increased the rice grain yield over control treatment. In general the application of rice straw, rice-hull ash (to rice nurseries), and nitrogen in the form of tablet at the rate of 100 kg/ha produced the best results.

In conclusion rice residues can be integrated with nitrogen and phosphorus fertilizers in rice production in Malawi. The incorporation of rice straws could be used as an alternative method of disposing them rather than burning which pollutes the air. The important strategy in Malawi in this regard should be the promotion and encouragement of the use of rice-hull stoves for domestic cooking and heating. Several prototypes and designs of these stoves are available in the literature (FAO, 1993). The dual usage of rice-hull, first for heat energy production and secondly, the application of collected rice-hull ash as a source of silicon and potassium in rice nurseries will result in greater rice grain yield.

EFFECT OF RICE HULL ASH SILICON ON RICE SEEDLINGS GROWTH

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ABSTRACT

Silicon (Si) promotes healthy development of rice plants. Research has shown that an adequate supply of Si to rice plants improves the plant resistance to abiotic and biotic stresses such as soil aluminum (Al) and manganese (Mn) toxicities and plant pest and diseases. Rice hull, a major by-product of rice milling, contains about 8% Si that can be recycled for use in a sustainable rice cultivation system. A greenhouse experiment was conducted to study the effect of Si from rice hull ash (RHA) on the growth of rice (*Oryza sativa* L.) seedlings. Rice hull ash was applied to two Malawian rice cultivars grown on three soil types at the rate of 0, 0.5, 1, and 2 kg/m^2. The RHA-treated seedlings produced (average of all treated seedlings) more dry matter (18%) over the untreated seedlings. The treated seedlings also reduced the uptake of N (16.4%), Al (20%), and Mn (34%), but increased uptake of P (7.7%), K (20%), and Si (100%) by shoots than the untreated seedlings. The effects of rice cultivars and soils on the seedling growth were not significant. The RHA application to rice nurseries seems to be an efficient way of recycling plant Si and have agronomic and environmental benefits, especially in developing countries.

INTRODUCTION

Rice (*Oryza sativa* L.) is a popular staple food of most people in Asia and is fast becoming an important crop in Africa, South America, and in the United States. Rice is normally cultivated either by transplanting three-to-five week old seedlings prepared in a nursery or by direct seeding method. In either case, well-developed and healthy seedlings are prerequisites for a good crop stand and ultimately for good yield (DeDatta, 1981). Research has shown that silicon (Si) plays several physiological roles in rice plants. An adequate supply of Si improves the overall plant health by providing mechanical strength to the entire plant and by inducing resistance to abiotic stresses such as soil salinity and acidity and biotic stresses such as plant diseases and insect pests (Yoshida, 1975; Elawad and Green, 1979; Epstein, 1994). Although, the essentiallity of Si for plants has not been established (Epstein, 1994), many field trials have demonstrated that Si application to soil as silicate slags can significantly increase rice yields (Elawad and Green, 1979).

Rice hull (RH) is a major by-product of rice cultivation. Assuming that harvested rice composes 20% hull, the 519 million tons (t) of unmilled rice produced in the world in 1993 (FAO, 1993) would generate around 104 million t of RH and about 8 million t of Si. However, despite

its nutritional value as a Si source, RH has been wasted in many countries. Field studies demonstrate that RH can be effectively recycled. Rice farmers can use RH as a renewable on-farm source of energy for domestic cooking in developing countries (FAO, 1993). The resultant black-gray rice hull ash (RHA) collected from RH-fired stoves contained 60-70% amorphous SiO_2 (Savant and Stangel, 1996). Results of field experiments conducted in Sri Lanka have shown that the application of 740 kg/ha of RHA yielded an additional 1.0 - 1.4 t/ha of rice (Amarasiri, 1978). Recent reports suggest that the application of RHA (at 0.5 - 1.0 kg/m^2) to the seedbed has the potential to reduce the incidence of leaf blast at the nursery stage (Kumbhar et al., 1995) and stem borer after transplanting (Savant et al., 1994). Considering the high cost of Si fertilizer ($225/ha) reported by Alvarez (1992), the use of RHA seems to be an effective and affordable alternative on-farm source of available silicon for use in sustainable rice production, especially in developing countries. Similar conclusions were drawn by Savant et al. (1996).

Prompted by these encouraging results, field studies were conducted to integrate the use of plant Si sources (straw and hull) with efficient N and P fertilizer management in Malawi. Concurrently, a greenhouse experiment was conducted at Alabama A&M University to investigate the effect of soil-applied RHA on the growth and nutrient composition of rice seedlings. Results of the greenhouse experiment conducted in summer 1995 are reported here.

MATERIALS AND METHODS

A greenhouse experiment was conducted in 1995 at Alabama A&M University in 33 x 28 x 13 cm closed bottom plastic containers using three Alabama soils having similar properties to those of rice soils in Malawi. The taxonomic classification and general properties of these soils are given in Table 1. Two Malawian rice cultivars Senga (IE4094) and Chengu (IR1561-250-2-2) were used in this study.

Sufficient RHA was prepared by burning RH as a fuel in a Vietnamese stove called Lo Trau. The RHA thus formed was black-gray in color and contained 27% Si, mainly as amorphous silica (SiO_2). Rice hull ash was applied in four rates of 0, 0.5, 1.0, and 2.0 kg/m^2 to provide Si. The containers were filled with soil and mixed with the appropriate amount of RHA. Each container was divided into two sections by a vertical plastic sheet and each section was planted with one of the two rice cultivars. A basal application of 60 kg/ha of 13-13-13 (N, P_2O_5, and K_2O) fertilizer was applied to all containers. Each treatment was replicated three times and the experiment was carried out as a complete randomized block design. The soils were maintained at field capacity for the first two weeks and then flooded with 2-4 cm water level for the remaining period. Five-week old seedlings were harvested by pulling them gently from the soil, washed manually, and then

shoots and roots were separated and dried at 65° C for dry matter yield determination and chemical analyses.

Chemical Analyses:

Soil samples were air-dried, ground, passed through a 2-mm mesh stainless steel sieve, and analyzed for pH (1:1 soil/water ratio). Mehlich 3 extractant at a 1:10 soil/extractant ratio was used to measure the extractable nutrients (Mehlich, 1984). Total nitrogen was determined by using the Kjeldahl digestion procedure (salicylic acid modification) (Bremner, 1976). Mehlich 3 extractable phosphorus was determined by the Murphy-Riley method (1962). Plant tissue was digested with Sulfuric acid/Hydrogen Peroxide (H_2SO_4/H_2O_2) (Allen et al., 1974). The nutrient concentrations in both soil extracts and plant tissue digest were determined using Inductively Coupled Plasma Emission Spectroscopy. Plant tissue Si content was determined using the colorimetric method of Elliot and Snyder (1991). Deionized water was used to extract soil (1:5 ratio) for available Si and then measured colorimetrically.

Data were analyzed statistically by analysis of variance and the mean separation was done using Duncan's Multiple Range Test (DMRT).

RESULTS AND DISCUSSION

Statistical analyses of the plant growth data indicated that there were no significant differences between the two rice cultivars (Senga and Chengu) with regard to the RHA application or soil type; hence, varietal averages are reported.

Dry Matter:

A significant increase in shoot and total (shoot + root) dry matter occurred at all RHA rates compared to control but not in root dry matter (Table 2a). Total dry matter increased significantly with increasing RHA rates, except for 0.5 and 1.0 kg/m^2 rates. Seedlings treated with RHA were significantly taller and looked healthier than control. However, increasing the rate of RHA did not significantly affect the seedling height. Leaf numbers per plant were not affected by RHA application (Table 2a). Rice seedlings grown on Decatur soil produced least amount of root dry weight but significantly taller seedlings compared to others (Table 2b).

Nutrient Uptake:

The shoot Si content of the RHA treated seedlings was significantly higher than the non-treated seedlings (Table 3). Similar observations for Indian cultivars under field conditions were reported by Savant et al. (1994) and Kumbhar et al. (1995). The increase in RHA rate also significantly increased the shoot Si content of the rice seedlings (Table 3). The shoot Si content and the shoot dry matter increased with an increase in RHA rates. This indicates the importance of RHA as the Si source for rice seedlings (Table 2a and 3). The increase in Si content in rice also

corresponded with the decrease in Al and Mn contents and increase in P and K uptake (Table 3). This relationship can be useful in reducing the negative effects of Al and Mn in acidic soils for rice cultivation. These observations are consistent with earlier reports. Barcelo et al. (1993) reported inhibition of monomeric Al species by Si in maize plants (*Zea mays* L. spp mexicana) grown in nutrient solution at pH 4. Alleviation of Mn toxicity by Si in rice plants cultured in nutrient solution has been reported by Horiguchi (1988).

CONCLUSIONS

These data have shown that Si through the application of RHA to seedbed improves Si content in rice seedlings and consequently their dry matter. Utilization of RHA for providing Si to rice plants can also serve the dual purpose of providing energy for cooking in rural area. This would help reduce the dependence on forests for firewood needs, thus may help save forest (FAO, 1991). The reduced Al and Mn uptake by the RHA-treated seedlings suggests that acid soils with high levels of Al and Mn which normally induce toxicity could be used by farmers for growing healthy rice seedlings with possible reclamation benefits.

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Table 1. Initial chemical analysis of the soils used in greenhouse experiment.

Soil Type	pH	% total N	Mehlich 3 Extractable Nutrients (mg/kg)								
			P	K	Ca	Mg	Zn	Fe	Mn	Al	Si*
Guthrie	4.0	0.2	64.5	5.5	83.2	6.7	0.3	8.7	16.2	96.4	20.0
Waverly	5.0	0.1	4.7	9.8	46.4	12.1	0.2	11.8	57.3	133.8	30.0
Decatur	4.7	0.2	29.7	4.6	107.3	11.1	0.4	26.5	29.2	101.3	40.0

Guthrie: typic fragiaquults, fine-silty, Siliceous, Thermic.
Waverly: rhodic hapludoxs clayey, Kaolinite, Thermic.
Decatur: rhodic hapludoxs, clayey, Kaolinitic, Thermic.
* Water Extractable

Table 2a. Effect of rice hull ash (RHA) application on growth parameters of rice seedlings. [a]

Rice Hull Ash kg/m^2	Shoot Dry Wt. g/100 seedlings	Root Dry Wt. g/100 seedlings	Total Dry Wt. g/100 seedlings	Leaf No.	Plant Height cm
0.0	16.6 c *	3.4 a	20.0 c	4.2 a	44.5 b
0.5	18.7 b	4.4 a	23.1 b	4.0 a	48.5 a
1.0	18.8 b	3.7 a	22.5 b	4.2 a	52.8 a
2.0	20.9 a	4.3 a	25.2 a	4.2 a	51.8 a

Table 2b. Effect of soil type on growth parameters of rice seedlings. [b]

Soil	Shoot Dry Wt. g/100 seedlings	Root Dry Wt. g/100 seedlings	Total Dry Wt. g/100 seedlings	Leaf No.	Plant Height cm
Guthrie	19.1 a *	4.8 a	23.9 a	3.9 a	48.5 b
Waverly	18.6 a	3.6 ab	22.1 a	4.3 a	47.8 b
Decatur	18.7 a	3.3 b	22.0 a	4.3 a	53.3 a

[a] Data points represent the average of two rice cultivars, three soils and three replicates.
[b] Data points represent the average of two rice cultivars, four rates of RHA and three replicates.
* Means followed by the same letters in each column are not significantly different at the 5% level (DMRT).

Table 3. Nutrient composition of the rice seedlings treated with rice hull ash. [a]

Rice Hull Ash kg/m^2	N %	P %	K mg/kg	Zn mg/kg	Fe mg/kg	Mn mg/kg	Al mg/kg	Si %
				Shoot				
0.0	3.53 a	0.39 c	27.5 c	0.08 a	0.39 a	4.10 a	0.51a	1.92 d
0.5	3.09 b	0.38 bc	28.9 c	0.08 a	0.43 a	3.27 b	0.45 ab	3.08 c
1.0	3.15 b	0.42 ab	33.6 b	0.10 a	0.39 a	2.88 c	0.41 ab	3.86 b
2.0	2.61 c	0.45 a	36.6 a	0.09 a	0.34 a	1.94 d	0.33 b	4.53 a
				Root				
0.0	1.49 b	0.36 a	11.21 b	0.20 c	25.26 a	2.85 a	17.38 a	3.4 c
0.5	1.81 ab	0.40 a	13.58 b	0.30 b	23.38 ab	2.13 a	15.78 ab	3.6 bc
1.0	2.16 a	0.41 a	17.22 a	0.43 a	23.14 ab	2.61 a	14.68 ab	4.1 ab
2.0	1.44 b	0.38 a	19.69 a	0.49 a	18.20 b	2.85 a	12.61 b	4.6 a

[a] Data points represent the average of two rice cultivars, three soils and three replicates.

* Means followed by the same letters in each column with in shoots or roots are not significantly different at the 5% level (DMRT).

INTEGRATING RICE HULL ASH, RICE STRAW, AND METHOD OF NITROGEN APPLICATION INTO A SUSTAINABLE RICE PRODUCTION SYSTEM

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ABSTRACT

Rice is the staple food for nearly 40% of the world's population. In Malawi, rice is ranked second to maize as a cereal food crop. In rainfed areas, grain yields average 1.0-1.5 t/ha, potential yield is 4-5 t/ha. To bridge the gap between potential and current yields, several novel nutrient management systems were studied. Many research reports indicate that rice responds to silicon (Si) and potassium (K) application. Rice crop residues (straws and hulls) are rich in Si and K, but are not utilized in rice production. The effect of rice-hull ash (RHA), rice straw (RS), and method of N application as prilled urea (PU) and urea briquette (UB) on a transplanted rice crop was studied in Malawi through field experiments. In the 1995 winter experiment, application of UB produced significantly greater rice grain yields than N application in the form of prilled urea. Incorporation of RS significantly increased grain yields over the control treatment in three consecutive years, but, no significant increase in yield was observed over treatments that received N and P without straw. Rice-hull ash (RHA) did not significantly increase rice grain yield. however, combination of RS and RHA significantly increased grain yields in 1996 winter.

INTRODUCTION

Since rice (*Oryza sativa* L.) is one of the most important food crops in the world, the need for developing sustainable rice production systems can not be overemphasized. Cassman et al. (1995) reported the declining trend in rice yields due to soil-related factors. Flinn and DeDatta (1984) explained that the decline in rice production may be due to decrease in available phosphorus (P) and potassium (K) in intensive cropping systems. Recent studies suggest that depletion of plant-available silicon (Si) in soils under intensive rice cultivation may reduce yield (Savant et. al 1996; DeDatta, 1981).

Essentiality of Si as a plant nutrient is still not clear. However, many studies have indicated that an adequate supply of Si improves the overall plant health by providing mechanical strength to the entire plant and by inducing resistance to abiotic stresses such as soil acidity and biotic stresses such as plant diseases and insect pests (Yoshida, 1975; Edward and Green, 1979; Epstein, 1994; Sistani et al. 1997). Many field experiments have demonstrated that Si application to soil as silicate slags can significantly increase rice yields (Edward and Green, 1979). However, the beneficial role of Si in an integrated nutrient management system for sustainable rice production has not received adequate attention. Failure to notice the importance of Si is due to several factors such as (a) Si is a nonessential nutrient and (b) being abundant in the earth's crust (28%). It is generally believed that Si deficiency would not be a problem in soil. However, under intensive rice farming and short fallow periods the availability of Si will decrease rapidly. The reason that Japanese rice farmers are able to sustain high yields despite their intensive cultivation is probably due to the routine application of silicate slag ($CaSiO_3$) at 1.5 to 2 t/ha (Kono, 1969; Takahashi and Miyake, 1977; DeDatta, 1981).

Rice hull (RH) and rice straw (RS) are major by-products of rice milling and cultivation, respectively. These rice crop residues are rich in Si and K and normally are not utilized in rice production. In several developing countries, RH is used as a

renewable on-farm source of energy for domestic cooking (FAO, 1991). The resultant rice hull ash (RHA) collected from RH-fired stove contains 60-70% amorphous SiO_2 (Savant and Stangel, 1996). Studies have shown that application of RHA at the rate of 0.5-1.0 kg/m^2 to rice nurseries has the potential to produce strong and healthy seedlings with high resistance to diseases and high yields (Kumbnar, 1995; Savant et al., 1994).

This study was designed, (1) to investigate the effect of RHA, RS, and modified urea (U) as sources of Si, K, and N respectively, on the yield of transplanted rice, and (2) to develop an integrated nutrient management system for increasing and sustaining rice yields in Malawi.

MATERIALS AND METHODS

Field experiments were conducted at the Lifuwu Rice Research Station in Malawi during the 1995 winter, 1996 summer, and 1996 winter seasons. The soils are vertisols with 45% clay, 45% exchange capacity, pH 8.3, 1.62% organic matter, 0.6% total N, 16 ppm P, and K, Ca, Mg of 0.4, 24.9, 5.5 meq/100 g soil respectively. All the trials were conducted under irrigated.

Sixteen treatments (Table 1) comprising various nutrient sources were compared under the irrigated conditions on rice cultivar Senga. Randomized complete block design with 3 replications were used inall the three seasons.

Table 1. Experimenta treatments.

T1	$A_0 S_0 N_0$	(control)	T11	$A_0 S_1 N_{32}$	(UB)
T2	$A_0 S_0 N_{32}$	(U)	T12	$A_0 S_1 N_{60}$	(UB)
T3	$A_0 S_0 N_{60}$	(U)	T13	$A_0 S_1 N_{100}$	(UB)
T4	$A_0 S_0 N_{100}$	(U)			
T5	$A_0 S_0 N_{32}$	(UB)	T14	$A_1 S_0 N_0$	
T6	$A_0 S_0 N_{60}$	(UB)	T15	$A_1 S_1 N_{60}$	(U
T7	$A_0 S_0 N_{100}$	(UB)	T16	$A_1 S_1 N_{60}$	(UB)

T8	$A_0 S_1 N_{32}$	(U)
T9	$A_0 S_1 N_{60}$	(U)
T10	$A_0 S_1 N_{100}$	(U)

A= rice-hull ash; U= prilled urea; S= rice straw; UB= urea briquette (tablet)
One (1) or zero (0) denote either the treatment was applied or not, respectively.

Rice hull ash contained approximately 27% Si, mainly as amorphous silica (SiO_2); made by burning RH in the open air. The ash was applied to the nursery beds and mixed with the soil to a depth of 6 cm, before sowing rice seeds at the rate of 1 kg/m^2.

Rice straw was chopped into small pieces (about 5 cm) length, incorporated to a depth of 22-27 cm after puddling at the rate of 2.5 kg/plot.

Three UB sizes, small (1.49 g), medium (1.88 g), and large (2.8 g) containing U fortified with diammonium phosphate (DAP) were custom made to provide the right rates of N by the International Fertilizer Development Center (IFDC), Muscle Shoals, AL USA. Urea briquettes were placed in the center of four hills at a 10 cm depth one day after transplanting and the hole was closed after the placement of UB to reduce N losses.

Line transplanting technique was used to achieve a 20 x 20 cm spacing and a 25 cm of traffic lane for workers to pass during transplanting and tablet placement. On plots which received PU and regular DAP, half the rate of N and all the P were applied on the same day at the begining of the season (Table 2). The remaining half of the N was applied at tillering stage as topdress.

Two hills were randomly selected in each plot for tiller counting and plant height measurements at 20 day intervals beginning 20 days after transplanting until flowering. A net plot area of 6.25 m^2 was harvested for grain yield. Harvesting was done by hand. The data were analyzed statistically, using the Duncan Multiple

Range Test (DMRT) for mean separation. Orthagonal contrasts were made to compare the appropriate treatment combinations.

Table 2. Dates of field operations.

Season	Sowing	Transplanting	Straw application	Prilled Urea and Urea Briquette Application	Top dress Application Prilled Urea	Harvest
1995 (Winter)	6/16/95	7/18/95	7/17/95	7/19/95	8/27/95	11/6/95
1996 (Summer)	1/11/96	2/1/96	1/31/96	2/6/96	3/21/96	5/10/96
1996 (Winter)	6/11/96	7/16/96	7/15/96	7/17/96	8/25/96	11/7/96

RESULTS AND DISCUSSION

Since the major goals of this study were to investigate the effects of RHA, RS, and method of N application, we will discuss the results by the effect of these factors on main agronomic parameters. Since there was significant interaction between treatments and seasons, each season was analyzed independently.

Grain Yield

Rice-hull ash, and RS had significantly higher grain yields than the control. There were no significant difference between PU and UB application at lower N rates (32 and 60 kg/ha). However, at highest N rate UB application produced significantly higher grain yields than PU in 1995 and 1996 winter seasons, treatments 7 vs 4 (Tables 3 and 7). Incorporation of RS along with different N application did not result in significantly different yield responses. Only the high level of N applied as UB plus RS significantly increased the yields in the 1995 and 1996 winter seasons (treatment 8, 9, 10 vs 11, 12, and 13). Urea briquettes application in combination with RHA and RS (treatment 16) was significantly better than PU in combination

with RHA and RS (treatment 15) in 1995 (Table 3 and 7). The best treatment in two out of three experiments was treatment 13 which contained N at high rates in the form of UB with incorporation of rice straw.

Incorporation of RS significantly increased the grain yield over the control in all the three experiments [treatments 8 through 13 vs 1 (Tables 3 and 7)]. There were significant differences with regard to rice yields among treatments receiving RS and UB application than treatments receiving no RS in 1995 winter season, treatments 11, 12, and 13 vs 2, 3, and 4. However, this trend did not continue to the next two seasons. This may be due to initial low soil K and the residual K effect after RS application in 1995.

Many researchers have reported that application of RHA to rice nurseries during the seed bed preparation increased the rice grain yields (Amarasiri, 1978, Savant and Stangel, 1996). However, in this study, treatments that received RHA increased the rice grain yields by maximum of 480 kg/ha, which was not significantly greater than no ash treatments (Tables 3 and 7). In all three experiments application of RHA along with incorporation RS and N increased the rice yield significantly over the treatments that received only RHA (treatments 15 and 16 vs 14). Application of RHA in combination with UB produced more rice grain yield than RHA in combination with prilled urea. The increase was significant in the 1995 experiment, but not in the 1996 summer and 1996 winter experiments (treatment 16 vs 15).

Plant Height and Number of Productive Tillers

Method of N application did not significantly affect the other agronomic factors such as number of productive tillers, plant height, number of grains per tiller, and 1000 seed weight (tables 4, 5, and 6). Rice straw application increased plant

height significantly over the control in all treatment combinations for all three experiments (Tables 4, 5, and 6). However, there was no specific trend observed with other parameters.

Number of Grain per Tiller and Weight of 1000 Grain

Rice-hull ash effect on other agronomic parameters such as number of productive tillers, plant height, and number of grain per tiller followed the same trend as with grain yields (Tables 4-6).

CONCLUSION AND DISCUSSION

Results of the three field experiments conducted over two years demonstrated that incorporation of rice residues including RS and RHA had beneficial effect on rice plants and improved the rice grain yields. The increase in yield was enhanced when N and P were also applied at optimum levels in an integrated nutrient management system. Conventionally, in many developing countries RS are burned and the RH are wasted. This study clearly indicated that rice farmers in those countries would benefit from using these renewable on-farm resources. This would also help to sustain optimum production from the soil. Application of N in a form of a briquette in combination with P was significantly superior, in one out of the three experiments, to traditionally broadcasting PU and P fertilizers.

We also agree with many other researchers including FAO in encouraging the rice farmers in rice producing countries to make a dual use of RH, first, to burn the hulls to produce heat energy for cooking and other useages, secondly apply the collected RHA, as source of Si to rice nurseries to produce strong healthy seedlings which result in greater rice yields.

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Table 3. Rice (variety Senga) grain yield response to method of N application, rice-hull ash, and rice straw. Lifuwu, Malawi.

Treatments	Seasons		
	1995 (Winter)	1996 (Summer)	1996 (winter)
1 Control	2149 i*	2032 h	1620 h
2 $A_0S_0N_{32}$ (U)	3531 gh	2869 fg	3560 g
3 $A_0S_0N_{60}$ (U)	4960 ef	3365 def	5232 de
4 $A_0S_0N_{100}$ (U)	6373 cd	4480 ab	6876 ab
5 $A_0S_0N_{32}$ (UB)	3995 gh	3136 efg	3972 g
6 $A_0S_0N_{60}$ (UB)	5685 de	3920 abcde	4835 ef
7 $A_0S_0N_{32}$ (UB)	7333 ab	4379 abc	6031 cd
8 $A_0S_0N_{32}$ (U)	3749 gh	3237 ef	4210 fg
9 $A_0S_0N_{60}$ (U)	4048 gh	3584 cdef	5889 cd
10 $A_0S_1N_{100}$ (U)	6757 bc	4779 a	7107 a
11 $A_0S_1N_{32}$ (UB)	4496 fg	3152 efg	3942 g
12 $A_0S_1N_{60}$ (UB)	6112 cd	3733 bcdef	5426 cde
13 $A_0S_1N_{100}$ (UB)	7936 a	4629 a	6202 bc
14 $A_1S_0N_0$	2128 i	2309 gh	1718 h
15 $A_1S_1N_{60}$ (U)	5045 ef	3973 abcde	5549 cde
16 $A_1S_1N_{60}$ (UB)	6249 cd	4181 abcd	5861 cd

*Means followed by the same letter within each column are not significantly different at 5% level (DMRT).
Note: See table 1 for treatment identification.

Table 4. Agronomic data of rice grown in a field experiment in Malawi, 1995.

treatment #	treatment description	number of productive tillers	Plant height (cm.)	number of grains per tiller	1000 grain weight (g.)	yield (kg/ha)
1	control	5 e**	65.3 e	110 f	20.7 a	2149 i
2	$A_0S_0N_{32}$ (PU)*	8 cde	72.3 cd	128 cde	21.0 a	3531 h
3	$A_0S_0N_{60}$ (PU)	9 bcde	72.7 cd	131 cde	20.7 a	4960 ef
4	$A_0S_0N_{100}$ (PU)	5 a	76.7 bc	136 bcd	21.7 a	6373 cd
5	$A_0S_0N_{32}$ (UB)	8 bcde	74.3 cd	119 ef	20.7 a	3995 gh
6	$A_0S_0N_{60}$ (UB)	12 ab	71.7 cd	149 ab	21.0 a	5685 de
7	$A_0S_0N_{100}$ (UB)	14 a	83.3 a	148 ab	21.3 a	7333 ab
8	$A_0S_1N_{32}$ (PU)	9 bcde	72.3 cd	126 de	21.0 a	3749 gh
9	$A_0S_1N_{60}$ (PU)	11 abc	76.0 bc	136 bcd	20.7 a	4048 gh
10	$A_0S_1N_{100}$ (PU)	15 a	77.0 bc	140 bcd	21.0 a	6757 bc
11	$A_0S_1N_{32}$ (UB)	12 abc	73.3 cd	118 ef	21.7 a	4496 fg
12	$A_0S_1N_{60}$ (UB)	10 bcd	75.3 cd	139 bcd	21.3 a	6112 cd
13	$A_0S_1N_{100}$ (UB)	14 a	83.7 a	158 a	20.7 a	7936 a
14	$A_1S_0N_0$	6 de	70.3 d	119 ef	20.7 a	2128 i
15	$A_1S_1N_{60}$ (PU)	12 abc	74.7 cd	143 bc	20.7 a	5045 ef
16	$A_1S_1N_{60}$ (UB)	12 abc	81.0 ab	136 bcd	21.0 a	6299 cd

* PU: regular urea; UB: urea briquette;
A: rice-hull ash; S: rice straw; N: nitrogen;
0: no application; 1: treatment was applied;

** Within columns, means followed by the same letter are not significantly different (P>0.05) DMRT.

Table 5. Agronomic data of rice grown in a field experiment in Malawi, 1996 Summer.

treatment #	treatment description	number of productive tillers	Plant height (cm.)	number of grains per tiller	1000 grain weight (g.)	yield (kg/ha)
1	control	7 de**	67.8 f	145 cd	21.3 ab	2032 h
2	$A_0S_0N_{32}$ (PU)*	10 cde	77.2 de	150 bcd	21.0 abc	2869 fg
3	$A_0S_0N_{60}$ (PU)	14 abc	80.2 bcde	156 abcd	20.7 abc	3365 def
4	$A_0S_0N_{100}$ (PU)	17 ab	88.o abc	168 abc	21.3 ab	4480 ab
5	$A_0S_0N_{32}$ (UB)	14 abc	78.3 cde	142 d	20.7 abc	3136 efg
6	$A_0S_0N_{60}$ (UB)	12 bcd	85.0 bcd	160 abcd	21.7 ab	3920 abcde
7	$A_0S_0N_{100}$ (UB)	17 ab	85.7 aabcd	172 ab	21.0 abc	4379 abc
8	$A_0S_1N_{32}$ (PU)	10 cde	80.2 bcde	173 ab	21.3 bc	3237 ef
9	$A_0S_1N_{60}$ (PU)	10 cde	77.7 de	165 abcd	21.3 ab	3584 cdef
10	$A_0S_1N_{100}$ (PU)	13 abc	85.8 abcd	159 abcd	21.7 ab	4779 a
11	$A_0S_1N_{32}$ (UB)	11 cde	80.8 bcde	159 abcd	19.7 c	3152 efg
12	$A_0S_1N_{60}$ (UB)	13 abcd	87.o abcd	164 abcd	21.0 abc	3733 bcdef
13	$A_0S_1N_{100}$ (UB)	18 a	95.7 a	178 a	21.0 abc	4629 a
14	$A_1S_0N_0$	6 e	72.3 ef	157 abcd	21.0 abc	2309 gh
15	$A_1S_1N_{60}$ (PU)	12 bcd	89.5 ab	174 ab	21.0 abc	3973 abcde
16	$A_1S_1N_{60}$ (UB)	13 abcd	89.3 ab	174 ab	21.0 abc	4181 abcd

* PU: regular urea; UB: urea briquette;
A: rice-hull ash; S: rice straw; N: nitrogen;
0: no application; 1: treatment was applied;

** Within columns, means followed by the same letter are not significantly different (P>0.05) by Duncan's Multiple Range Test.

Table 6. Agronomic data of rice grown in a field experiment in Malawi, 1996 Winter.

treatment #	treatment description	number of productive tillers	Plant height (cm.)	number of grains per tiller	1000 grain weight (g.)	yield (kg/ha)
1	control	10 e**	52.2 h	92 c	20.7 b	1620 h
2	$A_0S_0N_{32}$ (PU)*	17 de	62.2 efg	104 bc	21.3 ab	3560 g
3	$A_0S_0N_{60}$ (PU)	21 abcd	70.5 abcd	120 abc	21.0 b	5232 de
4	$A_0S_0N_{100}$ (PU)	28 a	71.2 abc	118 abc	22.0 ab	6876 ab
5	$A_0S_0N_{32}$ (UB)	23 abcd	60.7 g	102 bc	21.3 ab	3972 g
6	$A_0S_0N_{60}$ (UB)	23 abcd	64.7 def	108 bc	20.7 b	4835 ef
7	$A_0S_0N_{100}$ (UB)	25 abcd	68.3 bcde	128 ab	22.0 ab	6031 cd
8	$A_0S_1N_{32}$ (PU)	18 cd	65.5 cdefg	101 bc	21.0 b	4210 fg
9	$A_0S_1N_{60}$ (PU)	19 cd	67.0 bcdef	123 ab	22.7 a	5889 cd
10	$A_0S_1N_{100}$ (PU)	28 ab	75.0 a	142 a	20.7 b	7107 a
11	$A_0S_1N_{32}$ (UB)	20 bcd	61.7 fg	113 bc	22.0 ab	3942 g
12	$A_0S_1N_{60}$ (UB)	26 abc	64.2 efg	110 bc	22.0 ab	5426 cde
13	$A_0S_1N_{100}$ (UB)	28 a	71.8 ab	127 ab	21.3 ab	6202 bc
14	$A_1S_0N_0$	10 e	54.0 h	104 bc	21.0 b	1718 h
15	$A_1S_1N_{60}$ (PU)	19 cd	72.7 ab	128 ab	21.3 ab	5549 cde
16	$A_1S_1N_{60}$ (UB)	25 abc	68.0 cde	125 ab	21.7 ab	5861 cd

* PU: regular urea; UB: urea briquet;
A: rice-hull ash; S: rice straw; N: nitrogen;
0: no application; 1: treatment was applied;

** Within columns, means followed by the same letter are not significantly different (P>0.05) by Duncan's Multiple Range Test.

Table 7. Combination treatment contrasts

Treatment Contrast			Yield	Probability
			1995 Winter	
Control (1)[a]	vs vs	Rest (2-16)	2149 vs 5230	<0.01
Urea (2,3,4,8,9,10,15)	vs	Urea Briquette (5,6,7,11,12,13,16)	4923 vs 5979	<0.05
Straw (8-13)	vs	No straw (2-7)	5516 vs 5312	NS[b]
Ash (14,15,16)	vs	No Ash (1,3,6)	4491 vs 4265	NS
Straw+Ash (15 and 16)	vs	No Straw No Ash (3 and 6)	5672 vs 5322	NS
			1996 Summer	
Control (1)	vs vs	Rest (2-16)	2032 vs 3715	<0.01
Urea (2,3,4,8,9,10,15)	vs	urea briquette (5,6,7,11,12,13,16)	3755 vs 3876	NS
Straw (8-13)	vs	No straw (2-7)	3852 vs 3691	NS
Ash (14,15,16)	vs	No Ash (1,3,6)	3488 vs 3106	NS
Straw+Ash	vs	No Straw No Ash	4077 vs 3642	NS
			1996 Winter	
Control (1)	vs vs	Rest (2-16)	1620 vs 5094	<0.01
Urea (2,3,4,8,9,10,15)	vs	Urea Briquette (5,6,7,11,12,13,16)	5489 vs 5182	NS
Straw (8-13)	vs	No straw (2-7)	5463 vs 5084	NS
Ash (14,15,16)	vs	No Ash (1,3,6)	4376 vs 3896	NS
Straw+Ash (15 and 16)	vs	No Straw No Ash (3 and 6)	5705 vs 5033	<0.05

[a] numbers in the parenthesis indicate the treatment number
[b] NS means not significant at 5% level