Lowland Rice Yield as Affected by Straw Incorporation and Inorganic Fertilizer Over Cropping Seasons in Fluvisol

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ABSTRACT

Grain yield stabilization of lowland rice over cropping seasons was explored using different compositions of inorganic fertilizers (NPK, NPKCa, NPKMg, NPKZn, NPKCaMg, NPKCaZn and NPKCaMgZn) and straw incorporation (3, 6, 9, 12 and 15 tha^{-1}). No fertilizer and no straw amended plot was the control in a split-plot design with three replications laid in a Fluvisol of Guinea savanna in Centre Cote d'Ivoire. Three weeks old nursery rice variety NERICA L19 was transplanted. No significant difference of grain yield was observed between the different treatments excluding the highest yields recorded for treatments NPKMg (5.09 tha^{-1}), NPKZn (5.15 tha^{-1}) and NPKCaéMg (5.31 tha^{-1}) compared with 12 (3.95 tha^{-1}) and 15 tha^{-1} (4.14 tha^{-1}) as straw rates respectively. Grain yield declining trend was more pronounced for mineral fertilizer treatments showing twice greater depressive effect of cropping cycle compared with the straw especially, for treatments characterized by highest grain yield in the first cropping season and similar grain yields were recorded for both sources of nutrient in the third cropping cycle. Of slowness of nutrients releasing by straw, highest grain yield was expected for this soil amender within a longer period of cultivation whereas, unbalance soil micronutrients should be relevant to studious declining yield under inorganic fertilizer effect. Nevertheless, the straw rate of 12 tha^{-1} supplying 0.58% of NPK as mineral fertilizer equivalent can be recommended for sustaining lowland rice production in the studied agro-ecosystems unless for three cropping seasons.

Keywords:

Luvisol, Inorganic fertilizer, rice straw, declining grain yield, yield stabilization, mineral fertilizer equivalency.

Academic Discipline And Sub-Disciplines

Agronomy, Crop Science

SUBJECT CLASSIFICATION

Rice Straw an Mineral Fertilizer Management, sustaining Rice production

TYPE (METHOD/APPROACH)

On-farm agronomy trial, site specific nutrient management, organic matter mineral fertilizer equivalent

INTRODUCTION

Whereas excess of applications of fertilizer and manure have damaged the environment in developed world, low use of inorganic fertilizer is one of the main causes of environmental degradation in Africa [1]: High cost of chemical fertilizer, unavailability of nutrient sources and haphazardly application are concerned.

However, the most productive lowland rice agro-ecosystem is prone to increasing soil nutrient deficiency in large spectrum across successive cropping seasons ([2];[3]) and some of the minor nutrients often missing in chemical fertilizer are also concerned. Moreover, declining levels of soil organic matter constitutes a threat to the sustainability of many agricultural systems in sub-Sahara Africa as consequence of high decomposition rates of soil organic matter due to the year-round high temperatures and, on the other hand, by poor organic matter management ([4]) hence, limiting the advantage of chemical fertilizer as nutrient source.

Techniques that promote soil organic carbon such as agro-forestry, the cultivation of green manures, optimal use of animal manure, and mulching are widely advocated but success has been limited in Africa ([4]). However, some cases reported beneficial effect of crop residues incorporation in aerobic soils ([5]; [6]) as they might contribute to enhance soil nutrient supplying, structure, water-holding capacity, and soil life [7]. In turn, there is narrow knowledge of such strategy for submerged soil condition in Africa whereas; the loss of chemical fertilizer in water circulation was observed in lowland rice fields [8] meanwhile, success of organic matter used in rice production was noticed in Asia depending to pedoclimate, the source and management (rate, application time and combining with inorganic fertilizer) of applied organic matter [9]. Because of the slowness of nutrient releasing by crop residues [10], combining chemical fertilizer was often recommended [11] ignoring the risk of humate bounding ($CaCO_3$-Ca^{++}) and disturbance of some equilibriums (C:N, C:S, N:S and monoester P: diester P) required for optimum mineralization of organic matter in wet soil ([12];[13]). Therefore, the effect of solely application of organic matter should be also explored in different agro-ecosystems for lowland rice production as holistic strategy of Integrated Soil Fertility Management.

Because of scarcity of organic material for agricultural purpose in Africa as mainly due to domestic use ([14];[15]), rice farmers can incorporate the harvested rice straw instead of burning after feeding livestock.

Indeed, greater amounts of K, Ca, Mg, Si, Fe, Mn and B removal remains in the straw in addition to 3:1 (grain: straw) ratios of N and P and equal proportions of S, Zn and Zn [16]. Hence, there is opportunity to return larger spectrum of nutrients to the soil than commercial inorganic fertilizer often characterized by limited chemical elements.

Comparative study of the effects of rice straw (3, 6, 9, 12 and 12 tha^{-1}) versus inorganic fertilizers (NPK, NPKCa, NPKMg, NPKZn, NPKCaMg, NPKCaZn and NPKCaMgZn) incorporations to the soil was conducted in irrigated lowland for rice production in Guinea savanna zone of Cote d'Ivoire. The aim was i) to explore their effects of rice yield and yield trend across cropping seasons respectively, ii) to recommend the optimum rate of straw for lowland rice production and, iii) to identify the equivalent mineral fertilizer of rice straw for sustainable rice production in the studied agro-ecology. A strategy of soil fertility management should be recommended for high and stable yield in intensified lowland rice production.

MATERIAL AND METHODS

Site description

An on-farm trial was conducted in the irrigable valley of M'be II (8˚06N, 6˚00W, 180 m) about 24 km from the locality of Bouaké. The site is semi-developed lowland in the centre of Cote d'Ivoire including irrigation facility with minimum land leveling and missing drainage channel. The ecology is a Guinea savanna zone with a bimodal rainfall pattern including a specific dry, cool and dusty period of *harmattan* (December- February). The average annual temperature, rainfall and evapotranspiration were 28˚C, 1200 mm and about 100 mm respectively. Intensified rice-rice cropping is adopted by local farmers as two cycles per year with maximum yield of 3-4 tha^{-1}. The experiment was conducted in a second order lowland (100 – 120 m in wide) developed on granite-gneiss bed-rock with Fluvisol characterized by pH$_{water}$, C-organic and total-N of 5.5, 3.12 gkg^{-1} and 0.31 gkg^{-1} respectively. The content of available P (Olsen) was high (150 mgkg^{-1}) contrasting with the low content of K (0.08 cmolkg^{-1}). High contents of Ca (3.05 cmolkg^{-1}) and Mg (2.26 cmolkg^{-1}) are also determined for a CEC of 2.02 cmolkg^{-1}. The ratios of C:N and ((K:CEC)×100) account for 10.06 and 3.9. A five years old fallow dominated by *Lersiahexandra* (Poaceae) and *Frimbristulis* spp (Poaceae) was preceding the experiment.

Characteristics of Rice Cultivar Used

One of the popular lowland rice cultivar named NERICA L19 (New Rice for Africa Lowland 19) was used as interspecific (*O. glaberrima* × *O. sativa*) released by Africa Rice Center in 2008. Its relative high weight of grain is among the quality required by farmer in addition to its weed competitiveness resulting to its high vegetative growth. Panicle length is about 30 cm for a potential yield of 6 – 8 tha^{-1} in research station. The cultivar is tolerant to iron toxicity with high ratooning performance.

Characteristics of Nutrient Sources

The straw of newly harvested rice was keep for sun drying during 3-4 weeks. Dried straw was weighted in the basis of 3, 6, 9, 12 and 15 tha^{-1}. Straw concentrations of the studied nutrients are given in Table 1.

Table 1: Rice straw concentrations of N, P, K, Ca, Mg and Zn

Nutrient	Mean	Standard deviation (n=36)
N (gkg^{-1})	7.8	2.1
P (gkg^{-1})	0.8	0.3
K (gkg^{-1})	26.8	4.5
Ca (gkg^{-1})	3.0	0.7
Mg (gkg^{-1})	2.0	0.6
Zn (gkg^{-1})	0.12	0.07

Commercial mineral fertilizers were used as urea ($CO(NH_2)2$, 46% N), triple super phosphate ($Ca(H_2PO_4)2 \cdot H_2O$, 18–22% P), chloridic potassium (KCl ; 50% K), carbonate of calcium ($CaCO_3$; 40% Ca), sulfate of magnesium ($MgSO_4.H_2O$, 17% Mg) and sulfate of zinc ($ZnSO_4H_2O$, 36 % Zn).

Experiment Design

About 1200 m^2 of bush fallow was manually cleaned and debris was taking out of the plot before setting the experiment. Forty two (42) microplots of 3 × 5 m in individual dimension were laid and each of them was limited by 4 surrounding bounds with canals for irrigation and drainage. Different ratios (3tha^{-1}, 6tha^{-1}, 9tha^{-1}, 12tha^{-1} and 15tha^{-1}) of dried rice straw were laid randomly in specific microplot before applying slight irrigation. A week later, all the microplots were manually tilled incorporating the straw in 0 – 10 cm depth of soil and abandoned during two weeks before a second tillage preceded by mineral fertilizer application in other plots: 30 kgNha^{-1}, 60 kg Pha^{-1}, 50 kg Kha^{-1}, 50 kg Caha^{-1}, 50 kg Mgha^{-1} and 10 kg Znha^{-1} as basal fertilizers. Mineral fertilizer treatment was composed of NPK, NPKCa, NPKMg, NPKZn, NPKCaMg, NPKCaZn and NPKCaMgZn. The plot with no fertilizer and no incorporation of straw accounted for the control treatment. The experiment was laid in split-plot design (main plot: source of nutrients; sub-plot: rates). Twenty one days old nursery of NERICA L19 was transplanted per hill of two stands with 20 × 20 cm arrangement between rows and plants. At tillering and panicle initiation stages, hand weeding was done before applying 25 kgNha^{-1} respectively. Except the period of N application, the plot was maintain flooded with 3-5 cm water depth.The first trial was conducted in April 2012 and repeated every six months twice.

Data Collection

At rice maturity, the plots were drained before the harvest a week later: Rice was cut at soil level in 8 m^2 leaving 2 lines of the plot border.

The rice was threshed and the grains and straw were separately sundried and weighed. The moisture content of the grain was measured and grain yield (GY) was determined in the basis of 14% moisture content. Straw yield (SY) was also determined after the weighing.

Mineral fertilizer equivalent ratio (MFE) of organic manure was calculated testing two methods as that of [17] and [18].

[17] method was processed as: i) Mineral fertilizer treatment with similar yield compared with the recommendable rate of straw was identified, ii) Response curve equation of rice to mineral fertilizer was used to calculate mineral fertilizer equivalency (MFE) of organic manure,

$$FE = \frac{-b \pm \sqrt{b \times b} - 4ac}{2a} \text{ , where GY} = a \times FE^2 + b \times FE + c \quad \text{for mineral fertilizer} \quad (1)$$

and iii) MFE ratio was calculated as bellow:

$$MFE = \frac{FE}{\text{Amount of mineral fertilizer}} \times 100 \quad (2)$$

The method of [18] was based on the ratios of agronomy efficiencies (AE) of the different sources of nutrients as:

$$AE(MF) = \frac{GY_{NPK} - GY_{Control}}{\text{rate of NPK}} \quad (3)$$

Where, GY is the grain yield and MF is mineral fertilizer

$$AE(ST) = \frac{GY_{Straw} - GY_{Control}}{12 \, Straw \, tha-1} \qquad (4)$$

Where, ST is straw

$$MFE \, (\%) = \frac{AE(ST)}{AE(MF)} \times 100 \qquad (5)$$

Statistical Analysis

Analyze of variance was done to determine the mean values of grain yield each of the sources of nutrients. Similar method was applied for the determination of the mean values of rice grain and straw yields according to the different treatments of mineral fertilizer and straw which were described by polynomial regression. Furthermore, mean value of grain and straw yields were determined for each treatment according to the cropping cycles. Linear regression analysis was also tested for rice grain yield as described by the cropping cycle and mixed model analysis was processed to determine the difference of grain yield between the different treatments.

RESULTS

Cropping Season Effects in Different Sources of Nutrient

Fig. 1 shows the average rice grain yield for the treatments of mineral fertilizer and straw according the three cropping cycles: Greater grain yields accounted for the mineral fertilizer in the cropping cycle 1 and 2 compared with that of the straw effect meanwhile, the grain yields are very closed in the cropping cycle 3 for both sources of nutrients. There is also highest decreasing of rice grain yield for mineral fertilizer ongoing cropping while the yield recorded in cropping cycle 2 did not significantly differed with those the cycle 1 and 3 for straw treatment. The yield loss in cropping cycle 3 is almost half of the initial yield recorded in cropping cycle 1.
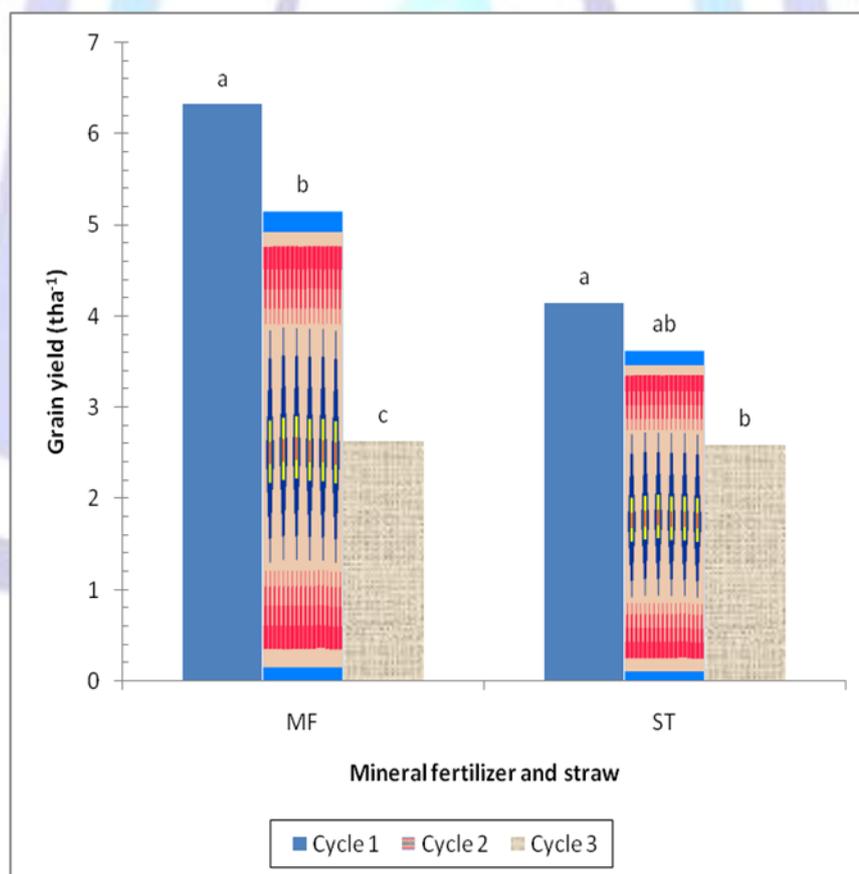
Fig. 1: Average rice grain yield as affected by treatments of mineral fertilizer (MF) and Straw (ST) according to cropping cycle (Cycle 1, 2 and 3).

However, variance of these trends can be observed among the different treatments for each of the sources of nutrients (Tables 2 and 3):

No significant decreasing of rice grain yield is observed for treatments NPKCaZn and NPKMg in spite of yield reduction of about half in the third cropping cycle (Table 2).

Table 2: Mean value of rice grain yield for different mineral fertilizer treatments according to cropping cycles

	Grain yield (tha^{-1})							
	T1	T2	T3	T4	T5	T6	T7	Control
Cycle 1	5.58a	5.90a	7.68a	6.09a	6.83a	7.21a	6.25a	4.98a
Cycle 2	3.91ab	5.46a	5.15ab	5.12a	5.62a	5.41ab	5.49a	4.67ab
Cycle 3	2.48b	2.68a	3.09b	2.49a	2.61a	2.79b	2.23a	2.75b
GM	3.98	4.68	5.31	4.70	5.02	5.15	4.68	4.13
P>F	0.030	0.120	0.023	0.003	0.033	0.028	0.136	0.075

Letters a and b are indicating the mean values of significant difference; GM : Grand mean; **T1**: NPK; **T2**: NPKCa; **T3**: NPKCaMg; **T4**: NPKCaZn; **T5**: NPKMg; **T6**: NPKZn; **T7**: NPKCaZnMg

In contrast, the grain yield of the treatment NPKCaMg is significantly reduced from 7.68 tha^{-1} to 3.09 tha^{-1} in the period of three cropping. Nevertheless, almost the grain yields recorded were ranging under 3tha^{-1} during the third cropping cycle for the other mineral fertilizer treatments.

In other hand, the grain yield is significantly (*P* = 0.012) decreased early in the second cropping cycle for the treatment of 12 tha^{-1} of straw while this fact occurs later in the third cropping cycle with treatment 15 tha^{-1} (Table 3). No significant yield decreasing accounts for the lower rates of straw (< 12 tha^{-1}).

Table 3: Mean value of rice grain yield for different ratios of straw treatments according to cropping cycles

	Grain yield (tha^{-1})					
	Control	3 tha^{-1}	6 tha^{-1}	9 tha^{-1}	12 tha^{-1}	15 tha^{-1}
Cycle 1	3.50a	3.89a	3.95a	3.99a	4.91a	4.90a
Cycle 2	3.45a	3.74a	2.85a	3.69a	3.84b	4.32ab
Cycle 3	2.80a	2.67a	2.50a	3.12a	3.07b	3.21b
GM	3.25	3.50	3.10	3.58	3.55	4.13
P>F	0.136	0.796	0.178	0.883	0.012	0.114

Letters a and b are indicating the mean values of significant difference; GM : Grand mean

The declining trend of rice grain yield is linearly more pronounced with the mineral fertilizer according to the negative value of the slope (-1.83) and that of R^2 (0.54) compared with characteristics recorded for the straw (Table 4). Depressing effect of cropping cycle is twice greater with mineral fertilizer than the straw (-1.83 *vs* – 0.57).

Table 4: Characteristics of the linear regressions of rice grain yield as affected by cropping cycle according to the different sources of nutrients

		Slope (tha^{-1})	*P* > ltl
Mineral fertilizer	Intercept	8.37	<0.0001
	Cycle	-1.83	<0.0001
	R^2		0.54
Straw	Intercept	4.74	<0.0001
	Cycle	-0.57	0.003
	R^2		0.15

However, no significant difference is observed between the grain yields of the different treatments as mineral fertilizer and straw rates across the cropping cycles (Fig. 2 a, b and c): The grain yields of mineral fertilizer treatments out stand in the higher range of 8 – 6 tha^{-1} in the cropping cycle 1 while the yields of 3, 6 and 9 tha^{-1} of straw rates are very closed to that of the control plot and twice low than that of the treatment NPKCaMg (Fig.2a). Similar results are observed in subsequent cropping cycle 2 but the yield of the treatment NPK drops in the same range of that of the control plot (4 tha^{-1}) contrasting with the yield of the other mineral fertilizer ranging about 6 tha^{-1} (Fig. 2b). The similarity of rice grain yield is increased in the cropping cycle 3 but almost of the yields of the mineral fertilizer treatments are closer to that of the control plot except

the treatment NPKCaMg inducing about 3 tha^{-1} which also characterized the treatments of straw, especially, that of 9, 12 and 15 tha^{-1} as straw (Fig. 2c).
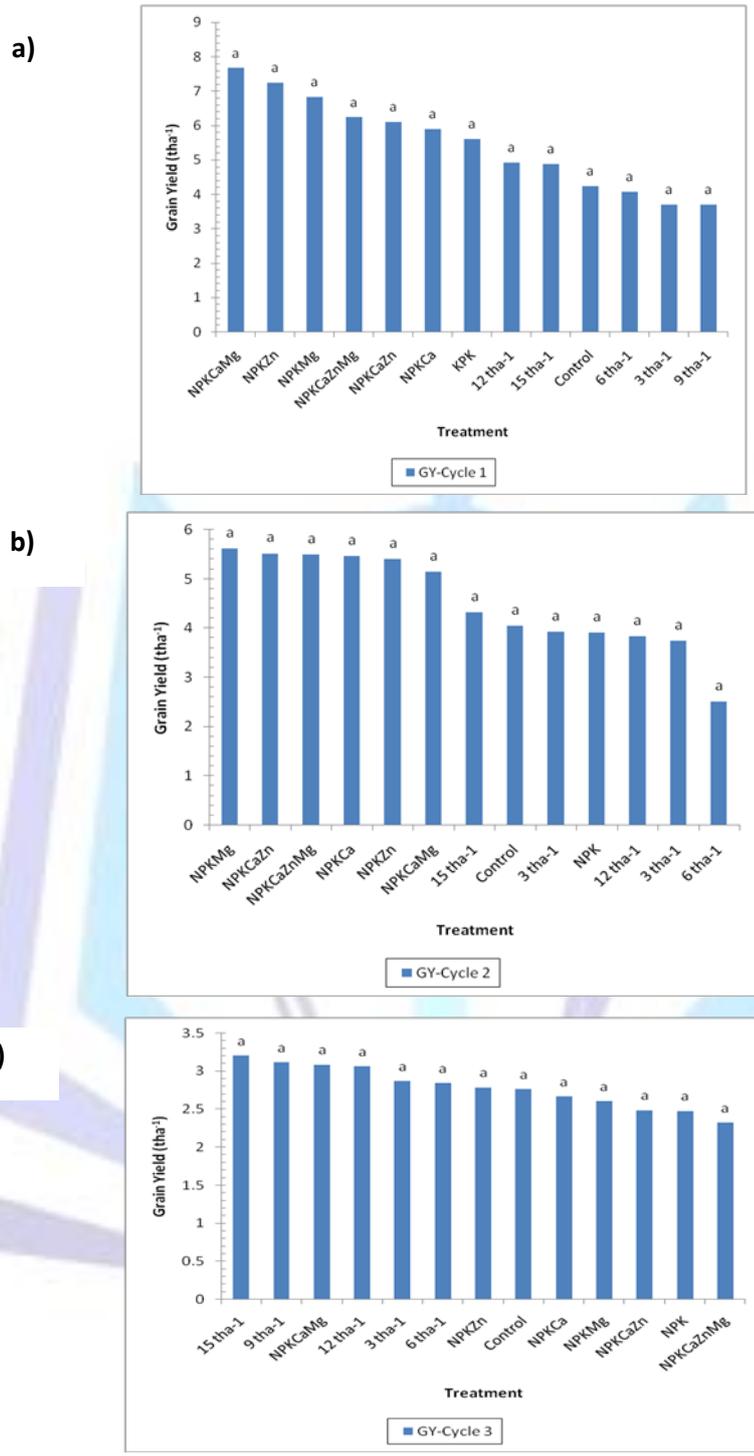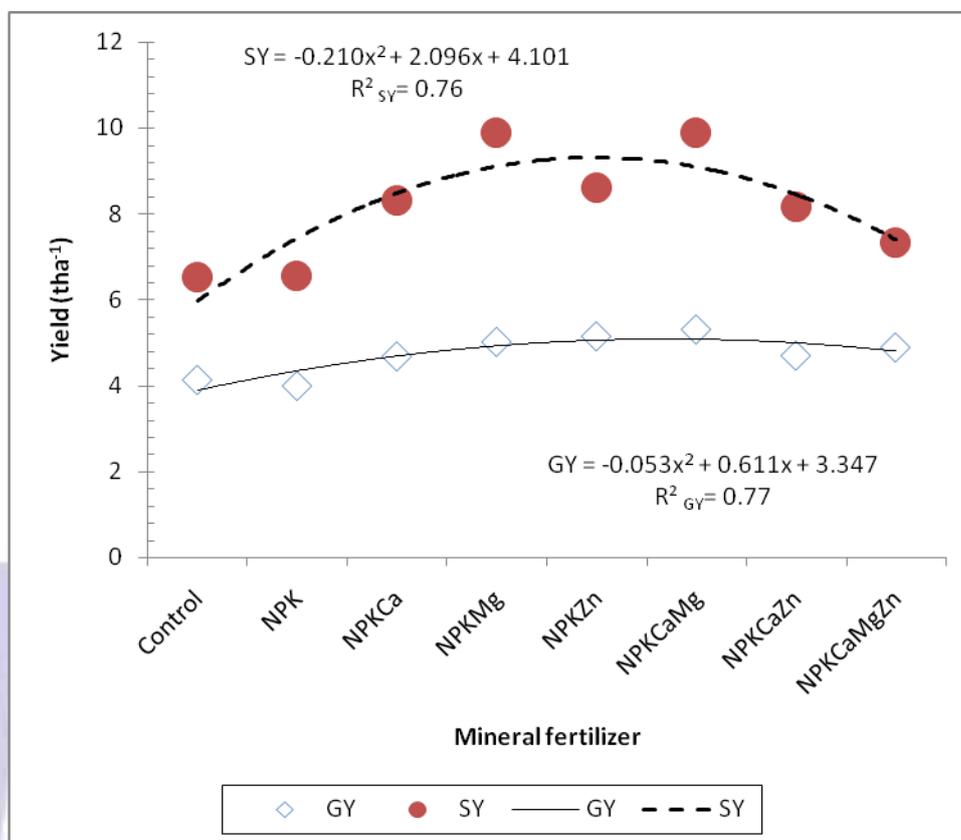
a)

b)

c)

Fig. 2: Average grain yield of different treatments in the cropping cycles 1 (a), 2 (b) and 3 (c). Letter is indicating the mean values with no significant difference.

## Overall Effects of Different Sources of Nutrient

Roughly, there are polynomial trends of grain and straw yields when adding nutrients as mineral fertilizer treatments (Fig.3). Highest straw yield accounts for the treatments NPK including Mg or both Mg and Ca while the addition of Ca or Zn along to NPK results in straw yield reduction.

Plot annotations:
$$SY = -0.210x^2 + 2.096x + 4.101$$
$$R^2_{SY} = 0.76$$
$$GY = -0.053x^2 + 0.611x + 3.347$$
$$R^2_{GY} = 0.77$$

Y-axis: Yield (t ha^{-1}); X-axis categories: Control, NPK, NPKCa, NPKMg, NPKZn, NPKCaMg, NPKCaZn, NPKCaMgZn; X-axis label: Mineral fertilizer; Legend: ◇ GY, ● SY, —— GY, – – – SY

Fig. 3: Straw and grain yields as affected by increasing mineral fertilizer composition

Grain yields are twice lower than the straw yields and it is greater for treatment NPKCaMg over Zn compound fertilizers which can do better in NPKZn however. Combining Zn to Mg and Ca with NPK is likely inducing depressive effect in rice grain and straw yields while Zn along with NPK only adverse the straw yield.

Polynomial trends are also observed for grain and straw yields with the increase of rice straw incorporation into the soil in 1/2 ratio of straw/grain except for the control plot (Fig. 4). However, studious increasing of straw yield is observed with applying straw rate within 0 - 9 t ha^{-1} while contrasting with the low increasing trend of the grain yield. In turn, further increasing the rate of applied straw underlined the reversed scenario: the straw remained almost stable contrasting with the increase of the grain yield. Nevertheless, the grains yields of the treatments of 12 t ha^{-1} and 15 t ha^{-1} are much closed.
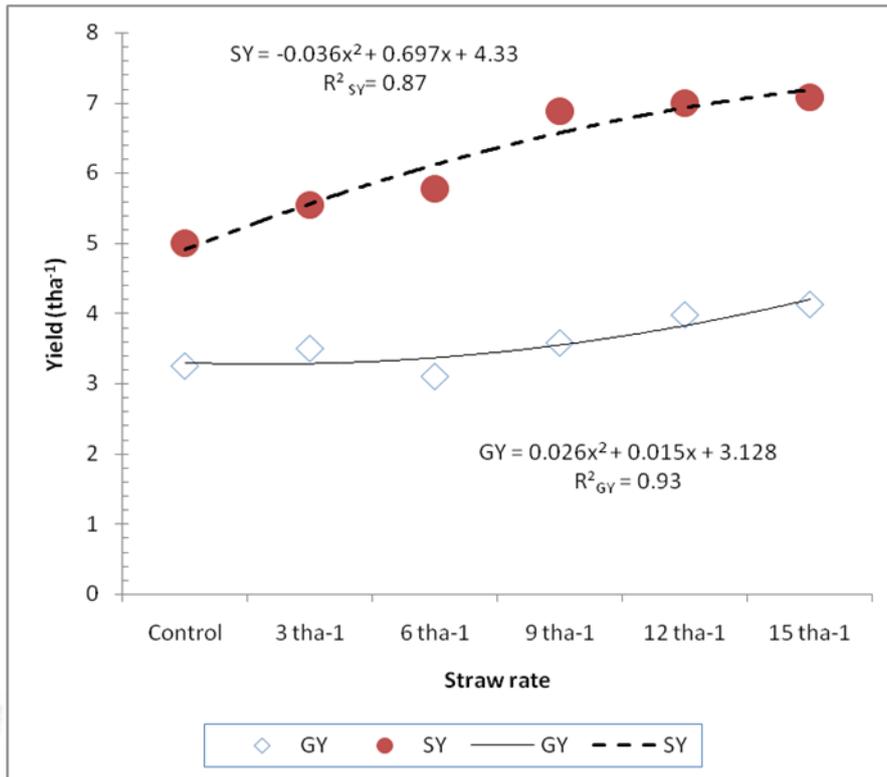
Fig. 4: Grain and straw yields as affected by increasing rate of rice straw

Although no significant difference accounts between the mean values of grain yields, the yields of Ca compound fertilizers are much closer to that of the control and slightly lower yield accounts for the treatment of NPK. But, the addition of Mg to calcium compound fertilizer (NPKCa) can increase the yield as observed in the treatment NPKCaMg when Zn is omitted (Fig. 5a). One can also enquiringly observed yield gap between straw treatments of 6 tha[-1] and 3 tha[-1] showing more depressive effect of 6 tha[-1] (Fig. 5b).

b)
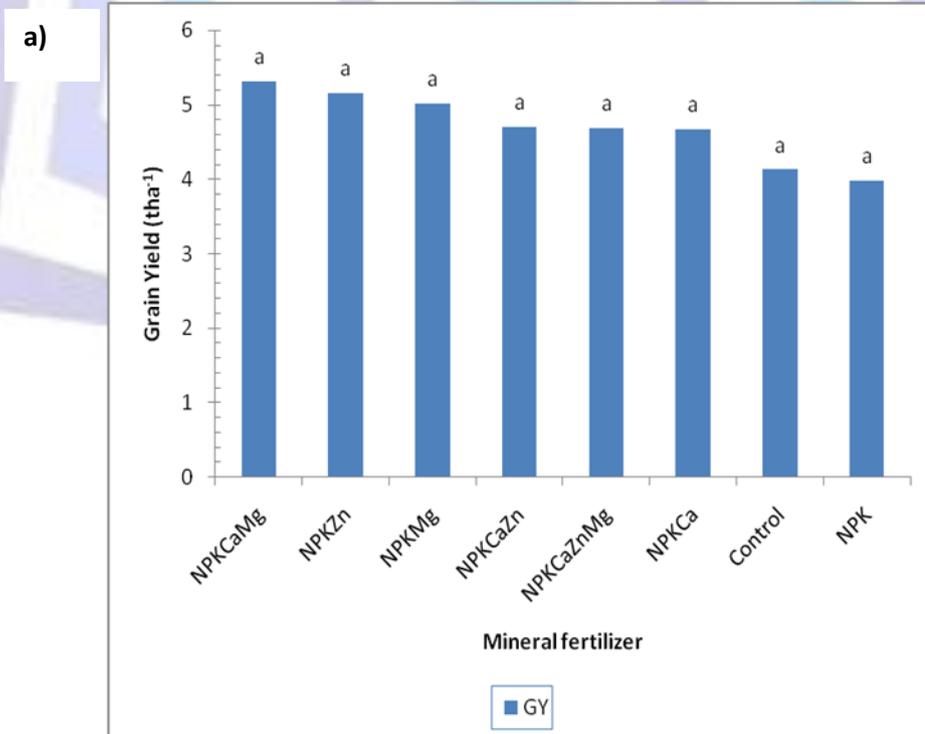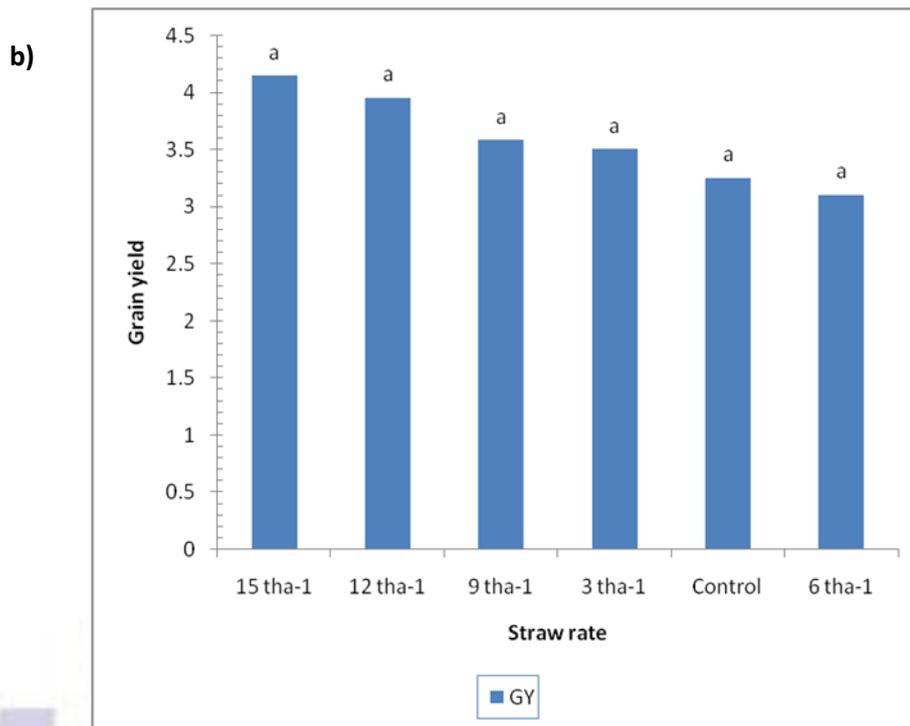
Fig. 5: Grain yield in decreasing order according to mineral fertilizer (a) and straw treatments (b). Letter is indicating mean values with no significant difference

There is insight of straw effect versus mineral fertilizer effect in rice grain yield and grain sterility ($P > 0.05$) in Table 5: Only 12 and 15 tha^{-1} of straw are showing yields in the same range observed with almost the mineral fertilizer treatments and about 5 tha^{-1} is achieved in treatment NPKCaMg characterized by 23% grain sterility in similar range with that of the other treatment while the straw rate of 6 tha^{-1} induces low yield of 3.10 tha^{-1}.

Table 5: Average grain yield and grain sterility for the treatments of both sources of nutrients

Treatment	Grain yield (tha^{-1})	Sterility (%)
NPKCaMg	5.31a	22.78a
NPKZn	5.15a	25.67a
NPKMg	5.09a	27.00a
NPKCaZnMg	4.69a	26.33a
NPKCa	4.68a	20.33a
15 tha^{-1}	4.14a	22.90a
NPK	3.99a	22.33a
12 tha^{-1}	3.95a	24.22a
Control	3.69a	24.83a
9 tha^{-1}	3.58a	25.11a
3 tha^{-1}	3.50a	24.22a
6 tha^{-1}	3.10a	24.11a
GM	4.22	24.20
P>F	0.142	0.999

More than 1 tha^{-1} accounts significantly for the difference between the yield of treatment NPKCaMg and that of treatments 12 tha^{-1} ($P < 0.05$) and 15 tha^{-1} ($P < 0.10$) respectively as well as between that of NPKMg and 12 tha^{-1} ($P < 0.10$). Although not significant, the treatments of 12 tha^{-1} and 15 tha^{-1} are yielding over the control plot with differences of 250 – 471 kgha^{-1}. Similarly, leaser difference (0.04 tha^{-1}) is observed between the yields of the treatments NPK and 12 tha^{-1} of straw (Table 6). Hence, mineral fertilizer equivalency of straw is determined as 4.17% and 0.58% (Table 7).

Table 6: Average difference of rice grain yield between the treatments of mineral fertilizer and the greatest rates of straw (12 and 15 tha^{-1})

	Grain yield difference (Straw *vs.* mineral fertilizer)			
	12 tha^{-1} of Straw		15 tha^{-1} of straw	
	Dif (tha^{-1})	*P* >l t l	Dif (tha^{-1})	*P* >l t l
NPK	-0.04	0.865	0.14	0.519
KPKCa	-0.75	0.295	-0.56	0.339
NPKCaMg	-1.56	0.050	-1.17	0.065
NPKZn	-1.20	0.060	-1.00	0.116
NPKCaZn	-0.75	0.259	-0.56	0.376
NPKMg	-1.07	0.090	-0.55	0.155
NPKCaMgZn	-0.74	0.240	-0.54	0.391
Control	0.25	0.555	0.44	0.471
P> F				0.0003

Table 7: Mineral fertilizer equivalency of rice straw according to two methods

	According to [17]	
Parameter	**Result**	**Observation**
Grain yield response curve for mineral fertilizer treatments	0.053 FE^2 +0.611 FE +3.347	According to Figure 6-7
Similar grain yield (tha^{-1}) for NPK and 12 tha^{-1} of straw	3.99	According to Table 6-12 to be converted for 8m^2
Equation to be solved	0.053 **FE^2** +0.611 **FE** − 0.643 = 0	For grain yield of 3.99 tha^{-1}
FE $_1$ = $\dfrac{-b + \sqrt{b \times b - 4ac}}{2a}$	0.97	First solution adopted as 0.776 kg grain for 8m^2
FE $_2$ = $\dfrac{-b - \sqrt{b \times b - 4ac}}{2a}$	-12.50	Second solution rejected for negative value
Amount of NPK (kg)	18.58	Addition of the quantities
MFE (%) = $\dfrac{FE1}{\text{Amount of NPK}} \times 100$	4.17	4.17 kg NPK for 100 kg of straw
	According to [18]	
AE(MF) = $\dfrac{GY_{NPK} - GY_{Control}}{\text{rate of NPK}}$	4.28	Agronomy efficiency of mineral fertizer for average rate of 100 kg Nha^{-1}, 60 kgPha^{-1} and 50 kg Kha^{-1} (70 kgNPKha^{-1})
AE(ST) = $\dfrac{GY_{Straw} - GY_{Control}}{12 \text{ Straw tha} - 1}$	0.025	
MFE (%) = $\dfrac{AE(ST)}{AE(MF)} \times 100$	0.58	0.58 kg NPK for 100 kg of straw

DISCUSSION

Rice Productivity with Inorganic Fertilizer

The soil of the experimental site was poor in organic C (3.12 gkg^{-1}) resulting low organic matter statue coupled with low exchangeable K (<0.10 $cmolkg^{-1}$) content which was not deficient on the basis of K:CEC ratio [19] however. Total N (0.31 gkg^{-1}) deficiency was likely the most concerned in the studied agro-ecosystem characterized by slightly low C:N ratio for a tropical soil whereas, the acidity was moderate as suitable for the availability of large spectrum of micronutrients, especially for Boron (Bo), manganese (Mn), iron (Fe), cooper (Cu) and Zn [20]. In the light of this analysis, rice response to mineral fertilizer was expected unless for N and K applications when, there was scant evidence of this fact during the experiment (Fig. 2) in spite of 47% of grain yield increasing in treatment NPKCaMg compared with the control plot (3.69 tha^{-1}). In contrast, the rates of 80 $kgNha^{-1}$, 10 kg Pha^{-1} and 75 kg Kha^{-1} were recommended in the same valley for significant high yielding (2.34 – 2.26 tha^{-1}) of NERICA L19 [21] while the current treatment NPK (100 $kgNha^{-1}$, 60 kg Pha^{-1} and 50 kg Kha^{-1}) has induced an average grain yield of 3.99 tha^{-1} over that recorded during the previous study. However, there was opportunity to increase rice grain yield when applying greater rate of K fertilizer than 75 $kgKha^{-1}$ whereas, only 50 kg Kha^{-1} was currently applied and was advocated for recapitalizing the amount of K exported by rice and sustaining rice production over cropping seasons. Furthermore, 80 $kgN ha^{-1}$ was deemed as optimum rate in lowland of Guinea savanna (Becker and Johnson, 2001) emphasizing the excess of N during the actual experiment and resulting antagonistic effects with almost the tested nutrients including K and Ca [22]. In fact, Ca fertilizer compounds were characterized by a grain yield closer to that of the control plot (Fig. 2a). However, this threat was likely mitigated when adding Mg to NPKCa (5.31 tha^{-1}) or applying NPKZn (5.15 tha^{-1}) contrasting with the treatment of NPKCaMgZn (4.69 tha^{-1}) failing to do much.

Results of the actual study were most affected by N and K managements which could have contributed to alleviated yield difference between treatments (excess of N) and deepened soil nutrient (K) depletion ongoing cropping seasons coupled with declining yield (Table 3), even though, the overall grain yields recorded were similar to that of different inland valleys in Guinea savanna [23]: Significant declining yield occurred in the treatments characterized by greatest yield during the first cropping season when that of NPKMg were statistically similar across seasons even with 61% of yield reduction. Similar fertilizer composition was advocated for sustaining rice production in continuous cropping in tropical agro-ecosystems [24] but our finding also revealed NPKZn and NPKCaMg as much for this purpose (Fig.5a) emphasizing the used of NPKCaMg as better fertilizer practice (Fig. 2). Nevertheless, cumulative effect of SO_4 as component of Zn and Mg fertilizers could also accounted for declining rice grain yield because of the adverse effect of H_2S consecutive to flooding duration [25]. This matter should be more explored by further study.

Alternative Use of Straw Incorporation into Lowland Rice Soil

Lack of significant difference between the grain yields of mineral fertilizer treatments and straw rates (Fig. 2 and Table 5) underlined the ability of crop residues to substitute mineral fertilizer in some extend and even, the rate of 15 tha^{-1} as straw has induced supplemental grain yield of 140 $kgha^{-1}$ compared with the treatment NPK. In fact, widest spectrum of nutrients (including Si, Cu, Fe and Mn) was expected from straw mineralization as organic source [26] compared with the mineral fertilizers tested. Meanwhile, about 20 kg N, 11 kg P_2O_5, 30 kg K_2O, 3 kg S, 7 kg Ca, 3 kg Mg, 675 g Mn, 150 g Fe, 40 g Zn, 18 g Cu, 15 g B, 2 g Mo and 52 kg Si are required for the production of 1 tone of paddy (rough rice) according to [24]. Hence, the inorganic fertilizers tested could have limited the supplying capacity of micronutrient contributing to highest depletion of soil nutrient. Consequently, higher declining rate (-1.83) of grain yield in continuous cropping was observed for inorganic fertilizer than straw incorporation (-0.51) in the Table 4 and the yields were similar in third cropping season for both sources of nutrients (Fig. 1). However, yield stabilization in straw treatment was likely limited to 9 tha^{-1} and declining rice grain yield occurred for further increase (Table 3). Accumulation of intermediate produces as aliphatic and phenolic acids as well as ethylene derivatives could be relevant of declining rice grain yield as phytoxines [27] in straw amending soils, especially for highest rates (12 – 15 tha^{-1}) which were characterized by stabilization of straw yield while the grain yield was slightly increased compared with the lowest rates (Fig. 4). Moreover, N as most limiting nutrient for crop production in the studied agro-ecology [28] is more prone to immobilization when the increase of the concentrations of K^+, Fe^{2+}, Mn^{2+} and P in soil solution was reported consecutively to incorporation of rice straw into flooded soil ([29]; [30]) even though, N can be released later in subsequent cropping seasons. This pathway in N dynamic could account for the lower yields of straw treatment in the first and second cropping seasons compared the effects of inorganic fertilizer respectively (Fig.1): In fact, N supplying capacity of straw incorporation could be low during the cropping seasons 1 and 2 contrasting with the cropping season 3 characterized by similar yields of organic and inorganic sources of nutrients. Probably, the availability of N for rice plant was increased after two cropping cycles of NERICA L19 (over 150 days of straw incubation) while such process was occurring about 85 days in Asia agro-ecologies [29] as shortest period of N-immobilization. Furthermore, there was scant evidence of positive effect of the wide spectrum of micronutrient in the straw referring to the decreasing trend of grain yield which was yet often lowest: Relatively, higher grain yields were for the rates of 12 tha^{-1} and 15 tha^{-1} among straw treatments and negligible difference (-40 $kgha^{-1}$) was recorded exclusively with the yield of treatment NPK comparing with that of 12 tha^{-1} of straw (Table 6) which could supply an equivalent of 0.50% of NPK (Table 7). No equivalence was possible with inorganic fertilizer treatments including Ca, Mg or Zn attesting no or slight supplying of these nutrients by straw incorporation within a period of three cycles of NERICA L19. Well, such cations should be complexed by soil organic matter as labile and available reservoir (Zech *et al.* 1997), but, they were not released as much for yield increasing during three cropping duration of actual study. Hence, immobilization of these cations was likely longer than that of N in contrast with previous knowledge ([31]; [32]).

However, 69.6 kg NPK ha^{-1} was equivalently released by 12 tha^{-1} of straw according to the method of [18] while 70 kgha^{-1} of inorganic NPK was applied and the lack of significant difference between the grain yields recorded during the study is advocating straw incorporation instead of inorganic fertilizer application in the basis of fertilizer net return concept [33]. Due to the slowness of nutrients released by straw in paddy soil, we can expect yield increasing in longer cultivation duration while, similar yields were observed in the third cropping season for both sources of nutrients yet.

Thus, there is insight of sustaining lowland rice cultivation using rice straw as organic source of nutrients but further study is required in longer period in order to generate mitigating methods of the adverse effects of phytotoxic intermediate produces as well as that of nutrient immobilization.

Accessory, the current study points out a method for calculation of mineral fertilizer equivalency in organic matter in relation with complex fertilizer, meanwhile, existing methods were known only for single nutrient fertilizer ([17]; [18]).

CONCLUSION

Nitrogen and K managements were the most concerned for sustaining rice production in Fluvisol of Guinea savanna. Significant declining yield occurred in the treatments characterized by greatest yield during the first cropping season likely consecutive to unbalance of nutrient removal even for the usually recommended NPKMg characterized by 61% of yield reduction in spite of no significant difference across cropping seasons. The current study also revealed NPKZn and NPKCaMg fertilizers as much for yield stabilization emphasizing the used of NPKCaMg as better fertilizer practice. However, highest grain yields were observed for inorganic fertilizer with highest declining rate (-1.83) in continuous cropping except for the third cropping season characterized by similar yields of both sources of nutrients. Due to slowness of nutrients released by straw incorporation, yield increasing was expected for longer cropping period but further investigations are required for managing intermediate toxic produces. Nevertheless, 12 tha^{-1} of straw incorporation can supply 69.6 kg NPK ha^{-1} in three cropping season. Therefore, straw management is recommended lowland rice production for net return increasing within three cropping duration and for highest yield stabilization is expected in longer cultivation period.

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