

Effect of *Tithonia diversifolia* (Hemsley) and Inorganic Fertilizers on Morpho-Agronomic Characteristics of Rice (*Oryza sativa* L.) Grown on Oxisols in Democratic Republic of Congo

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Abstract

Rice (*Oryza sativa*) is becoming a staplefood in many regions of DR-Congo. However, its production is still limited to the North Eastern part of the country and grain yield is low. A study was carried out in the city of Mbuji-Mayi located in the Central part of the DR-Congo to assess the effects of organic and inorganic fertilizers on morpho-agronomic characteristics of *O. sativa*. The trial was conducted during the 2021 agricultural season A using a completely randomized design with three replicates. The six treatments studied consisted of application of *T. diversifolia* biomass at a dose of 2 kg/4m² (BFT – 2 kg), 4 kg/4 m² (BFT – 4 kg), inorganic fertilizer consisting with NPK₁₇₋₁₇₋₁₇ + Urea (46% N) at a combined dose of 80 g/4 m² (NP), 1/2 of the combination (BFT – 2 kg + NP) and finally 1/2 of the combination (BFT – 4 kg + NP). The untreated plots were used as controls. Plants treated with 1/2 combination (BFT – 4 kg + NP), BFT – 4 kg, and NP showed similar height (100.93 cm, 99.03 cm, and 98.63 cm, respectively) that were significantly higher than control and other treatments [1/2 (BFT – 2 kg + NP, BFT – 2 kg)] For agronomic characteristics, days to 50% flowering varied between 73.00 and 74 days with an average of 74 days. The control and BFT – 4 kg showed significantly shorter panicles compared to other treatments. For yield components, 1/2 (BFT – 4 kg + NP) and the NP treatments generated a higher weight of 1000 grains. For yield per hectare, 1/2 (BFT – 4 kg + NP) induced significantly different levels of production than the control and other treatments, including 1/2 (BFT – 2 kg + NP), BFT – 4 kg + NP, BFT – 2 kg, BFT – 4 kg. The correlation coefficients between agronomic traits revealed that with the exception of the length of particle and

the abortion rates, all the yield components (panicles per plant, seeds per panicle, weight of 1000 grains, and grain yield per plot) were strongly correlated with grain yield per hectare.

Keywords

Rice, Fertilization, Mineral Fertilizer, Organic Fertilizer, Yield

1. Introduction

Rice is the world's largest cereal in terms of human food consumption [1] [2]. Once a luxury food and consumed during the festive season in the Democratic Republic of Congo (DRC), it is now the main staplefood in some provinces, but also in other least developed countries. Along with wheat, it is the most consumed cereal in the world [1]. However, rice cultivation in the DR-Congo is mainly rain-fed, although the country offers enormous potential for irrigated rice cultivation [2]. Despite the efforts made by the Government and partners to increase production through strategic development projects and improved varieties, domestic production of this commodity remains low [2]. Nevertheless, rice is the second most consumed cereal by the population in the DR-Congo, after maize [3]. In tropical regions, the crop is subject to drastic biotic and abiotic constraints, leading to threats of genetic erosion [4]. In addition, it has been pointed out that agricultural production on land in most African countries is being treated by population pressure, which is growing faster than in other regions [5]. In addition, poor land management practices subsequently lead to soil nutrient depletion [6]. It is the levels and types of soil elements during the crop cycle that determine the quality of plant mineral nutrition and largely the quantitative yields of crops [7]. Considering current socio-economic and environmental challenges, it is imperative to look for other sources of nutrients that can allow sustainable agriculture at a time when the import of agricultural products is breaking records due to low crop yields.

To compensate for the decline in yields, several approaches can be considered, such as the use of organic fertilization and crop rotation [8] [9]. The use of mineral fertilization is cost prohibif due low rice farmer's income in the DR-Congo. The implementation of crop rotation requires knowledge of specific techniques. Several studies have suggested that producers adopt organic fertilizers as a crop management alternative aimed at reducing or eliminating chemical fertilizers. The decomposition of organic residues significantly improves the level of nutrients and organic matter in the soil [10]. However, the use of organic amendments such as organic waste is poorly documented in the Mbuji mayi region, even though they are an optimal source of nutrients and contain 50% to 90% organic matter. The mineral fertilization proposed as a solution remains fragile on soils such as oxisols with high mobility of aluminum and iron precipitating the other nutrients applied to the soil [8] [9] [11]. In addition, the low-income level of farmers in the region

and the lack of training in the application of mineral fertilizers often constitute obstacles to the use of mineral fertilizers. In addition, the increase in population has led to an intensification of agricultural practices and an extension of cultivated areas, which has resulted in a reduction in the fallow time. This situation not only accentuates soil erosion but also leads to a rapid depletion of its nutrients, particularly nitrogen, phosphorus and potassium [12].

The development of local resources that are not exploited, such as bat guano, *Tithonia diversifolia*, male inflorescences of oil palm, cow dung and chicken droppings are proposed [13]. These local resources are of interest to certain regions of the D. R. Congo in general, as they contain elevated amounts of plant nutrients [13]. *T. diversifolia* is rich in nitrogen, phosphorus and potassium and possesses other properties [14]-[17]. It decomposes rapidly after application, resulting in the improvement of soil physical, chemical and biological properties and in the increase of nutrient availability [15]. Hence, we hypothesize that the use of foliaceous biomass of *T. diversifolia* combined with NPK₁₇₋₁₇₋₁₇ + urea (46% N) would boost the rice yield compared to mineral fertilization with NPK₁₇₋₁₇₋₁₇ + urea (46% N) used without any combination with organic fertilizer in the edapho-climatic conditions of Mbuji mayi. The main objective of this study was to evaluate the effect of *T. diversifolia* and the mineral combination (NPK₁₇₋₁₇₋₁₇ + Urea (45% N)) on morpho-agronomic characteristics of rice (*Oryza sativa*).

2. Materials and Methods

2.1. Site Characterization

The study site was located in the City of Mbuji mayi in the Estestern Kasai in D.R. Congo (Figure 1). Specifically, the geographical GPS coordinates of this site were -6.122663, 23.583034 and between 500 and 1000 m above sea level. This site is located in a low-pressure region located 666 km from the equator. Because of this position, it rains heavily in this area with more than 1500 mm of rainfall recorded annually [12] [18]. Its climate is humid tropical and of the Aw3 type according to the köppen's classification, characterized by two dominant seasons, namely, the rainy season long of eight months and the dry season of four months. The rainy season includes a period of short dry period in January, resulting in two agricultural seasons from an agronomic point of view. Hence, campaign A runs from September-December and campaign B runs from January-April. The main dry season lasts 4 months and starts from May to August. The minimum temperature is 21 °C and the maximum is 30 °C, with an average of 25 °C. The annual rainfall is 1400 mm for the growing season B; and in November with 230.4 mm for the growing season, A. The relative humidity is 77.7%. The sandy-clay soil is composed of 85% sand, 15% clay, and little decomposing organic matter. The experimental field thus had sandy-clay soil with a pH of 6.7 [8] [9] [18].

2.2. Material

Rice variety Lioto was provided by INERA/Gandajika and the organic matter

consisting mainly of the leaves of *Tithonia diversifolia* was from the MBALA WA TSHITOLO ravine in the city of Mbuji Mayi. Mature *Tithonia diversifolia* plants are depicted in **Figure 2**. Its chemical composition is described in **Table 1**. Chemical fertilizers include NPK₁₇₋₁₇₋₁₇ and Urea 46% N were purchased locally in the city of Mbuji Mayi.

Table 1. Chemical composition of *Tithonia diversifolia*.

Chemical constituent	Cot	Nt	C/N	P	K	CA	Mg
% content	34.8	3.2	10.5	0.3	3.1	2.8	0.6
Quantity in Kg/per	640.32	58.88	10.87	5.52	57.04	51.5	11.04

Ot: Total Organic Carbon; Nt: Total nitrogen; CN: Carbon-to-Nitrogen Ratio, P: phosphorus, K: potassium, CA: calcium, Mg: Magnesium.



Figure 1. Location of experimental sites (a) Democratic Republic of Congo (red) on a map of Africa; (b) Details on the map of Democratic Republic of Congo. The arrow indicates the site (Mbuji Mayi) where the study was conducted. Adapted from Google Map, accessed in June 2023.

2.3. Method

The experimental setup was a completely randomized design with three replicates. The experimental units (plot) each measured 2×2 m or 4 m^2 , with a separating area of 0.5 m between the plots, and one meter between the repetitions. The total area of the experimental trial was 139.5 m^2 or 15.5×9 m. The six treatments used include the control with no fertilization, foliaceous biomass of *T. diversifolia* applied at a dose of $2 \text{ kg}/4 \text{ m}^2$ (BFT – 2 kg), foliaceous biomass of *T. diversifolia* applied at a dose of $4 \text{ kg}/4 \text{ m}^2$ (BFT – 4 kg), the inorganic fertilizer NPK₁₇₋₁₇₋₁₇ + Urea (46% N) at the combined dose of $80 \text{ g}/4 \text{ m}^2$ (NP), combination of 1/2 (BFT – 2 kg + NP) and finally the combination of 1/2 (BFT – 4 kg + NP).

2.3.1. Observed Variables

To evaluate the effect of organic matter, mineral manure, and their combinations, several morpho-agronomic characteristics were measured. They include the diameter at the tiller, the height of the plants, taken from the collar to the panicle recorded using a tape measure; and finally, the number of tillers per plant counted from flowering tillers at the clump flowering stage, and useful tillers indicating the number of tillers bearing panicles. As far as the production variables are concerned, we have analyzed for this study, the number of days to 50% flowering by counting the days from sowing to the time when half of the plot was in flowering; the day to 50% maturity recorded by counting the days, from sowing to the day when 50% of plant maturity; the weight of 1000 grains measured with a precision scale; the length of the panicles which recorded with a tape measure; the number of panicles per pocket, based on direct counting of panicles harvested from ten plants. An average per plant was also determined. The plot production of paddy was determined at the time of harvest, after drying, threshing and winnowing. It consisted of weighing the weight of the rice paddy harvested in each plot, in order to compare the production within different treatments of a replicate. Finally, the paddy (grain) yield was extrapolated in tonnes (t/ha) using the following formula:

$$\text{Yield (Kg} \cdot \text{ha}^{-1}) = \frac{\text{Production per plot}}{\text{Plot size}} \times 1000 \text{ m}^2$$

2.3.2. Statistical Analysis of the Data

Statistical analysis of the data was performed using Statistix 8.0 software. To compare the means of the different treatments, the analysis of variance (ANOVA), supplemented by the LSD test at the probability level of $P \leq 0.05$ was used to identify the treatment(s) that differ significantly from the others.



Figure 2. Mature *Thitonia diversifolia* plants.

3. Results

The results for morphological and agronomic characteristics are presented in

Tables 2-3. The effects of organic and inorganic fertilization were observed based the selected parameters studied. After statistical analysis of the data collected in the field, it is observed that the combination 1/2 (BFT – 4 kg + NP) generated similar diameter at the collar as the NP mineral fertilizer with 4.33 cm and 4.16 cm, respectively. Nevertheless, this diameter at the collar was significantly greater than those (between 3 cm and 3.33 cm) observed under control and other treatments tested inputs. The same trend was observed on almost other vegetative parameters such as plant height and the number of tillers per pocket (**Table 2**). Indeed, plants treated with 1/2 combination (BFT – 4 kg + NP), BFT – 4 kg, and NP showed similar height (100.93 cm, 99.03 cm, and 98.63 cm, respectively) that were significantly higher than control and other treatments [1/2 (BFT – 2 kg + NP, BFT – 2 kg)] (**Table 2**). Higher number of tillers/pocket (6.33) was also observed in plants treated with (BFT – 4 kg + NP), BFT – 4 kg, and NP compared to the control and other organic and inorganic treatments.

Table 2. Effects of *Tithonia diversifolia* (organic fertilizer) and inorganic fertilizer on morphometric characteristics of rice (*Oryza sativa*) in dry land in Mbuji Mayi, DR-Congo.

Treatment	Diameter at collar (cm)	Plant height (cm)	Number of Tillers/Pocket
Control	3.00 b	78,10 d	4.00 b
BFT – 2 kg	3.13 b	86.80 c	4.33 b
BFT – 4 kg	3.33 b	99.03 ab	5.00 ab
NP	4.16 a	98.63 ab	5.33 ab
1/2 (BFT – 2 kg + NP)	3.33 b	94.70 b	4.66 b
1/2 (BFT – 4 kg + NP)	4.33 a	100.93 a	6.33 a
AVERAGE	3.55	93.03	4.94
CV (%)	7.71	3.59	15.95

In the columns, the means followed by the same letter are not significantly different at the 5% threshold following the LSD test.

Table 3. Effects of *Tithonia diversifolia* (organic fertilizer) and inorganic fertilizers on agronomic characteristics of rice (*Oryza sativa* L.) in a dry land in Mbuji Mayi (RD Congo).

Treatments	Days to flowering 50%	Days to maturity 50%	Number of panicles/pocket	Panicle length (cm)	Number of Seeds/Panicles	1000 grain weight (g)	Seed abortion rate (%)	Grain production per plot (g)	Grain yield per ha Kg/ha
Control	74.33 a	84.33 a	4.00 b	23.66 c	100.67 b	32.00 c	2.66 a	348.67 c	1540 c
BFT – 2 kg	74.00 ab	83.33 b	4.33 b	27.83 a	105.67 ab	32.33 c	1.66 a	366.33 bc	1630 bc
BFT – 4 kg	73.33 bc	84.66 a	4.66 b	26.43 b	105.33 ab	37.33 b	2.33 a	413.67 bc	1803 bc
NP	73.00 c	84.00 ab	5.00 ab	27.83 a	107.00 ab	42.00 a	3.66 a	431.00 ab	1910 ab
1/2 (BFT – 2 kg + NP)	73.66 abc	83.33 b	4.66 b	28.00 a	107.00 ab	32.33 c	2.66 a	360.33 bc	1600 bc
1/2 (BFT – 4 kg + NP)	73.00 c	84.00 ab	6.00 b	28.26 a	111.67 a	42.66 a	2.33 a	499.00 a	2210 a

Continued

Means	73.55	83.94	4.77	27.00	106.22	36.44	2.55	403.17	17.90
CV (%)	0.59	0.60	13.05	2.63	3.96	6.71	69.14	10.32	10.32

In the columns, the averages followed by the same letter are not significantly different at the 5% threshold following the LSD test.

For agronomic characteristics, days to 50% flowering varied between 73.00 and 74 days with an average of 74 days. There were no clear significant differences among treatments for days to 50% flowering, days to 50% maturity and the length of panicles (Table 3). The length of the panicles varied between 24 and 29 cm with an average of 27.00 cm. The control and BFT – 4 kg showed significantly shorter panicles compared to other treatments. For yield components, 1/2 (BFT – 4 kg + NP) and the NP treatments generated a higher weight of 1000 grains. For yield per hectare, 1/2 (BFT – 4 kg + NP) induced significantly different levels of production than the control and other treatments including 1/2 (BFT – 2 kg + NP), BFT – 4 kg + NP, BFT – 2 kg, BFT – 4 kg. This is depicted in Figure 3. The rate of seed absorption was very low in all the treatments, an indication of the good growing conditions and genetic attribute of the Lioto variety used.

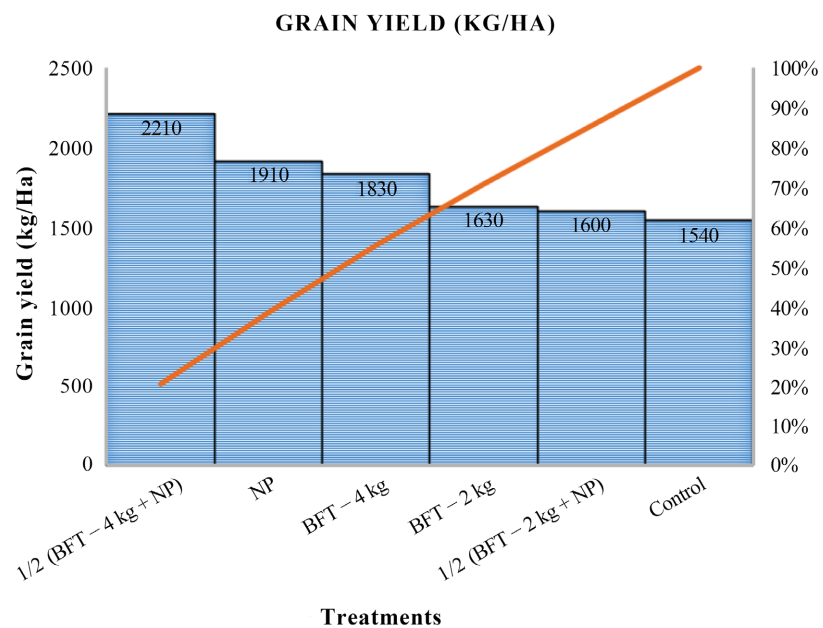


Figure 3. Rice grain yield in plots treated with different concentrations of organic and inorganic fertilizers in Mbuji Mayi (DR Congo).

The correlation coefficients between agronomic traits revealed that with the exception of length of particle and the abortion rates, all the yield components (panicles per plant, seeds per panicle, weight of 1000 grains, and grain yield per plot) were strongly correlated with grain yield per hectare (Table 4). In fact, the Pearson correlation values varied from 0.81 to 0.99 for these traits and the grain yield and only 0.41 for length of panicles and the abortion rate.

Table 4. Correlation coefficients between agronomic traits in rice fertilization trial in Mbuji Mayi (DR-Congo).

	#Panicles/ plants	Panicle length (cm)	#Seeds/ panicles	Weight of 1000 grains	Abortion rate (%)	Grain yield/plot (g)	Grain yield ha (Kg)
Panicles/plant	1	0.57	0.92	0.82	0.10	0.94	0.95
Panicle length (cm)		1	0.83	0.36	0.01	0.41	0.41
# Seeds/plant			1	0.67	-0.02	0.79	0.81
Weight of 1000 seeds				1	0.45	0.92	0.91
Abortion rate (%)					1	0.11	0.11
Grain yield/plot (g)						1	0.99
Grain yield/ha (Kg)							1

4. Discussion

The results obtained in this study show that in relation to vegetative variables such as emergence rate, plant height in cm, and number of tillers/pocket, the treatment based on the 1/2 combination (BFT – 4 kg + NP) was better, although not significantly different from rice under the addition of the chemical fertilizer NP. This can be justified by the fact that mineral fertilizer releases nutrients quickly and is used excessively by the plant, compared to organic fertilizer, which takes time to break down and maintain optimum nutrients that stimulate plant growth in the long term. De Ridder and Van Kaulem [19] and Muyayabantu *et al.* [20] reported that the use of inorganic and organic fertilizers often leads to synergy and improved efficiency in nutrient and water use. This could be the case for certain soil inputs such as the 1/2 combination (BFT – 4 kg + NP) which similarly increased the diameter at the collar as the NPK mineral input with 4.33 cm and 4.16 cm, respectively. Nevertheless, this diameter at the collar is significantly greater than those (between 3 cm and 3.33 cm) observed under control and other inputs to the ground, with no significant difference between them. The same trend was maintained on almost other vegetative parameters such as the height of the plants and the number of tillers per pocket. Indeed, rice under-treatment based on the 1/2 combination (BFT – 4 kg + NP) significantly shows better growth in height (100.93 cm) and a good number of tillers (6.33) compared to rice under other soil inputs. Rice under NP and BFT – 4 kg comes in second place, while the lowest height was found in rice that was not fertilized (control), although it generated a similar number of tillers to rice under other treatments. The variability in height observed during this study is likely due to soil variability.

The combination of organic (*T. diversifolia*) and inorganic (NP) nutrient [1/2 (BFT – 4 kg + NP)] sources resulted in higher grain yields than all other treatments. This is likely due to increased nitrogen and phosphorus availability as well as improvements in other soil parameters. These results are consistent with the findings reported by Steiner *et al.* [21]. These studies concluded that replenishment of the nutrients available to the plants by the addition of mineral fertilizers alone is not satisfactory to maintain soil fertility in freely drained soils. In addition, as reported

in many studies, the integration of organic and inorganic nutrient inputs increases the efficiency of the use of these fertilizers and provides a more balanced supply of nutrients to crops. Gao *et al.* [22] reported significant increases in maize yield following the application of green manures. Leaves incorporated into the soil (as green manure) at the beginning of the season decomposed and would have released nutrients, especially nitrogen, which improved crop performance. It should be noted that the amount of nutrients provided by organic matter is highly dependent on the amount of organic matter applied [21] [22]. In all the cases, the untreated plot always yielded lower grain production compared to organic and inorganic fertilisers.

As for the weight of 1000 grains, it appears at the same pace as for the number of grains per panicle. The soil contribution of the 1/2 combination (BFT – 4 kg + NP) further confirms its superiority with a weight of 1000 grains of rice (42.66), although statistically similar to the intake of NP (42.00), remains, however, significantly high to that of rice under other treatments. The lowest weight of 1000 rice grains was recorded under control, which remained similar to the intake of BFT – 2 kg and BFT – 1/2 (2 kg + NP). On the other hand, the greater the weight of 1000 grains, the more seed to be used per hectare, which could have a positive impact with the varieties that are evolving, given the low income of farmers in the region. However, rice under 1/2 combination (BFT – 4 kg + NP) gave a plot production (499.00 g) statistically ($p = 0.05$) compared to rice under other treatments followed by the addition of NP chemical fertilizers (431.0 g). Unfertilized rice gave a significantly lower return (348.67 g). As the yield is derived from the extrapolation of plot production, the same tenadance is maintained. Indeed, rice under 1/2 (BFT – 4 kg + NP) significantly retains its superiority over other treatments, with a yield of $2.21 \text{ t}\cdot\text{ha}^{-1}$. The control rice was the one that gave the lowest possible yield, significantly lower ($1.54 \text{ t}\cdot\text{ha}^{-1}$) than the rice under other treatments, which remained intermediate. These results corroborate with those found at INERA Yangambi, in a controlled environment, the variety used in our study (Lioto) produced between 2000 and 3000 kg/ha; and in peasant areas, it produced between 1500 kg/ha and 2000 kg/ha. According to Nziguheba *et al.* [23], *Tithonia diversifolia* is used alone as a fertilizer, but combined with phosphorus fertilizers, can double or even triple the harvests. In the same given environment, the interactions of plants are dependent on a complex whole, it can also be noted that the good yield in rice could not be due solely to the application of fertilizers. The absence of attacks, diseases, predators and good climatic conditions have also made it possible to have the best yields in this environment. The soil of the City of Mbuji mayi is a sandy-clay soil made up of 15% clay. However, this rice would be best suited to a soil that can buffer climatic variations having a good water-holding capacity, contains a roughly equal proportion of clay, sand, silt and a pH varying between 4.5 and 8.7 [24]. However, the other constraint is the retention of soil moisture, which is important because upland rice depends above all on water can be major constraints for rice production.

Overall, the effects of *T. diversifolia* observed in this rice trial are consistent with data observed in other crops. Setyowati *et al.* 2018 demonstrated that *Tithonia* compost increase plant height, plant dry weight, curd diameter, as well as curd weight of cauliflower. Ewané *et al.* [25] showed that *T. diversifolia* leaves and stems treatment increases the number of shoots, the height and the diameter of shoots as well as the area of shoots leaves compared to the control in plantain crops. Dayo-Olagbende *et al.* [26] showed that the application of tithonia mulch improved growth, and yield indices of maize as well as soil physical and chemical properties. Likewise, Muyayabantu *et al.* [8] demonstrated that the combination of NP with *T. diversifolia* or *E. abyssinica* leaves resulted in the highest increase in maize grain yields in Gandajika. These authors later showed that the use of *T. Diversifolia* resulted in the highest monetary advantage index (MAI) compared to the use of inorganic fertilizers and crop mixtures [9].

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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