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**Research Paper**

# Improving soil nutrition for the efficiency of upland rice on acidic soil

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***Abstract.*** Inexact application of fertilizer by itself does not guarantee a steady increase in yields. It can lead to create environmental hazard and health problems. A study was conducted in two consecutive years of 2015 and 2016 during the rainy season (March to June) to assess the effect of inorganic fertilizer, poultry manure (organic fertilizer), and the combination of both fertilizers on the productivity of upland rice in acidic soils of Cameroon. Five treatments: 0N-0P-0K, 16N-8P-8K kgha$^{-1}$, 24N-12P-12K kgha$^{-1}$, 32N-16P-16K kgha$^{-1}$, 40N-20P-20K kgha$^{-1}$ for inorganic fertilizer, 5 treatments: $F_0$ (0 tha$^{-1}$), $F_1$ (2.5 tha$^{-1}$), $F_2$ (5 tha$^{-1}$), $F_3$ (7.5 tha$^{-1}$), $F_4$ (10 tha$^{-1}$) and 6 treatments: $C_0$ (0N-0P-0K kgha$^{-1}$), $C_1$ (2.5 tha$^{-1}$), $C_2$ ( 32N-16P-16K kgha$^{-1}$), $C_3$ (0.625 tha$^{-1}$ + 24N-12P-12K kgha$^{-1}$), $C_4$ (1.25 tha$^{-1}$ + 16N-8P-8K kgha$^{-1}$), $C_5$ (1.875 tha$^{-1}$ + 8N-4P-4K kgha$^{-1}$) for the combination of poultry manure and inorganic fertilizer were applied to NERICA 3 rice variety in a completely randomized block design with 4 replicates. The results revealed that the 32N-16P-16K Kgha$^{-1}$ dose of inorganic fertilizer, the 2.5 tha$^{-1}$ dose of poultry manure, and 1.875 tha$^{-1}$ + 8N-4P-4K Kgha$^{-1}$ dose of the combination was found to be best compared to control. Significant differences were observed in all treatments for leaf chlorophyll content and plant total biomass. The integration of these doses in soil offers a sustainable and comprehensive strategy for the management of acid soils in the tropics.

**Keywords:** Inorganic and organic fertilizer, soil toxicity, tropics.

## INTRODUCTION

Acid soils cover almost thirty percent 30% of the arable land of the world. In the tropics, Africa has 8.8 million km$^2$ of acidic land, or 29% of the continent (Eswaran and Beigroth, 1997). According to Von Uexkull and Mutert (1995), 67% of the acidic soils are found in forested areas, about 18% are covered by in savannas, prairie and steppe vegetation, only 4.5% is used in as cropland, and less than 1% under perennial crops. These types of land in Cameroon are composed of 75 to 100% of acid soil (Bindzi Tsala, 1987; Ngonkeu, 2009). The yield of rice is reduced in these soils due to toxicities of Al and Mn, low pH, and Ca, Mg, P and Mo deficiencies (Borrero *et al*., 1995; Kirk *et al.*, 2014). The worst effect of this soil acidity is on the inhibition of root development of plants which remains on a radius of 10 to 20 cm of soil that limits the absorption of water and nutrients on a large volume of soil (Kochian, 2012; Ojo *et al.*, 2018), ultimately reducing yield of more than 67% (The *et al.*, 2006; Petmi *et al.*, 2016). Futhermore to low soil fertility, the problem of food security in sub-saharan Africa is noted. Indeed, rice consumption in Cameroon has spread rapidly in recent years and the increase in their production cannot keep up the pace of growth for consumption. In addition, local rice production does not exceed 200.000 tons of paddy rice per year. Indeed, the production of local rice (140.170 tons) in 2020 has been

most lower than the estimated value for request (576.940 tons) (FAOSTAT, 2020). As a result, imports from Asia and North America are skyrocketing. Currently, the gap between supply and demand has widened to about 436.779 tons. On the other hand, to make up for this deficit, approximately 894 486 tons of white rice stored in cargoes were imported in 2019 for a value of $ 121713.544 billion, resulting in large foreign currency outflows (FAOSTAT, 2020).

Improved rice (NERICA) was developed by African researchers as a millennium crop to provide food security and livelihoods, because local varieties could not provide yields above 1 $tha^{-1}$ on acid soils (Zewdu *et al.*, 2020). Sometimes the unique use of improved variety does not achieve the expected yield. Hence, the rice yield has been increased by the application of phosphorus, bio-fertilizers, lime, organic matter into acid soil which can be reduced the stresses of soil acidity (Mafouasson *et al.*, 2018) and also improved the yield by use of the acid soil tolerant improved varieties. Phosphate fertilizers remain one of the most important fertilizers that influenced the rice yield because it is significantly affected the weight of 1000 grains which is related to achieve higher yield (Llyod, 1995). For better plant growth and profitable production, one ha area of acid soil might be corrected by the appplication of 4 to 10 tons of calcium carbonate (0-2 MM) during 2 to 3 years and the cost of this material is approximately 464.876 $ to 1162.190 $\$ha^{-1}$ at the rate of 38.739 $ a bag of 50 kg of lime (Petmi *et al*., 2016). This cost is very exorbitant for the average farmer who does not have enough income to support himself for his daily needs. Thus, the use of inorganic and organic inputs is essential as an alternative source for soil fertility to increase crop production (Alice *et al*., 2012). It is noted by the scientific community that the use of inorganic fertilizer has a significant effect on the different stages of rice growth and development. It is significantly increased the number of tillers per $m^2$, the number of fertile tillers, the number of grains, the weight of 1000 grains, the height of the plant and the percentage of filled grains (Alam *et al*., 2009; Alinajati and Mirshekari., 2011; Dastan *et al.*, 2012). An excess use of inorganic fertilizer contributed to increase the percentage of empty grains (Djomo *et al*., 2017).

Organic fertilizer have the potential to improve the chemical, physical and biological properties of soil, but their decomposition into nutrients favorable to crop production is slow, and its residual effect appears to be the most appropriate (Karbo *et al.*, 1999). Orluchukwu *et al.* (2018) reported that NERICA 5 was the best of the variety in terms of rennet production after application of fowl droppings and fungal substrate on upland rice varieties. Alice *et al.* (2012) found that intensive, continuous, long-term agricultural production and combined use of inorganic and organic fertilizer can significantly increase the crop production and maintain soil properties. Organic manure such as compost have been considered an excellent soil amendment that can provide N and enhance N availability to improve crop yields (Smith and Siciliano, 2015; Hu Cheng *et al.*, 2019). Poultry manure is an excellent organic fertilizer, which contains high nitrogen, phosphorus, potassium and other essential nutrients (Mehdizadeh *et al.*, 2013; Danmaigoro *et al*., 2019). In contrast to chemical fertilizer, it adds organic matter to soil that improves soil structures, nutrient retention, aeration, soil moisture- holding capacity and water infiltration (Deksissa *et al.*, 2008; Danmaigoro *et al.*, 2019).

Nevertheless, the inappropriate application of fertilizer does not guarantee a steady increase in yields. This may result in low nutrient use, cause environmental, and health problems. As a result, assessment of the comparative effectiveness of NERICA and different fertilizers are some options for managing soil acidity in cropping. This general assessment is dependent in detail on the interaction between fertilizer in inorganic, poultry manure, combined; soil, crop, climate. The aims of this study were, therefore, to test (1) the effect of inorganic fertilization on the productivity of upland rice; (2) the effect of poultry manure on upland rice production; and (3) the effect of the combination of inorganics fertilizer and poultry manure on the productivity of upland rice.

## MATERIALS AND METHODS

### Study area

The experiment was carried out in 2015 and 2016 in the experimental fields and laboratory of the Institute of Agricultural Research and Development Research Center Nkolbisson. This site is located in a humid forest zone with bimodal rainfall of Cameroon, altitude 748 m, 11° 27.542' longitude E, 3° 52.035' latitude N and brightness 62 lux. The average annual temperature is 23.53°C, bimodal rainfall with an annual average of 111.36 mm/year, relative humidity 83.2%. The vegetation is a deciduous or semi-deciduous forest; the soil is an oxysol with an argillaceous texture and a moisture content of 4.493% with a strong hydromorphic tendency.

### Materials

Poultry manure of laying chicken has been taken from the Henry and Brothers Company. Analysis of the macronutrients, micronutrients and minerals in poultry and soil has been carried out at the IRAD laboratory of Nkolbisson Accreditation ISO 17025.

### Germplasm

Germplasm used as the seed was the improved variety

NERICA 3 from Africa Rice. This variety is adapted to all agro-ecological zones of Cameroon. This improved variety had the characteristics: early maturity (on average 100 days), resistance to drought, pests and diseases, high yields averaging 4 to 7 $tha^{-1}$ and protein content ranged from 8 to 10%.

**Experimental design**

The experiment was carried out on a total area of 225 $m^2$ subdivided into 4 blocks where the 1m alley separates each block and 16 elementary plots and each separated from each other by an alley of 1 m. Each elementary parcel had an area of 3 m × 3 m. The experimental setup was a completely randomized block design with 4 replicates where the 1st variable was the soil type: $T_O$ control for unfertilized soil (acidic soil) and treatment T corresponds to fertilized soil. The 2nd variable was the variety NERICA 3.

One week before sowing, a germination test of the rice kernels was done in a petri dish. In addition, the seeds were vanned to remove flakes. Subsequently, the seeds were soaked in water to remove unfilled seeds that float on the surface of the water as well, the filled seeds were dried. At the same time, plots were plowed and leveled. The proper seeding was carried out on 03 April 2015 for mineral and organic fertilization, on 03 April 2016 for the combination. Seeding was done in the pocket on a surface of 9 $m^2$ of each plot with a 25 cm × 20 cm rayonner (25 cm between 2 consecutive lines and 20 cm between consecutive pockets for a density of 550 $plantsha^{-1}$). Subsequently, about 6 grains of rice were introduced into each 3 cm deep pocket.

**Treatments and fertilizers application procedure**

Inorganic fertilizer treatments were $T_0$ (0N-0P-0K $kgha^{-1}$) for the unfertilized acid soil, $T_1$ (16N-8P-8K $kgha^{-1}$), $T_2$ (24N-12P-12K $kgha^{-1}$), $T_3$ (32N-16P-16K $kgha^{-1}$), $T_4$ (40N-20P-20K $kgha^{-1}$) treatments for fertilized soils, respectively. Thus, the NPK + Urea had been applied 2 weeks after sowing while the urea was applied in two phases: A first, 1 month after sowing and during the panicle initiation phase, a second, during the meiotic phase.

Poultry manure treatments were control $F_0$ (0 $tha^{-1}$) for untreated acidic soil and $F_1$ treatments (2.5 $tha^{-1}$); $F_2$ (5 $tha^{-1}$); $F_3$ (7.5 $tha^{-1}$), $F_4$ (10 $tha^{-1}$) for fertilized soils were calculated according to the method of Jonatan *et al.* (2014). The application of poultry manure was applied 2 weeks before sowing and after plowing.

Combination of inorganic fertilizer and poultry manure treatments were the control C0: 0N-0P-0K (acidic soil) and the treatments $C_1$: 2.5 $tha^{-1}$, $C_2$: 32N-16P-16K $kgha^{-1}$, $C_3$: 0.625 $tha^{-1}$+ 24N-12P-12K $kgha^{-1}$, $C_4$: 1.25 $tha^{-1}$+ 16N-8P-8K $kgha^{-1}$, $C_5$: 1.875 $tha^{-1}$+ 8N-4P-4K $kgha^{-1}$ for this test, poultry manure were applied 2 weeks before planting and NPK + Urea had been applied 2 weeks after sowing while urea was applied 1 month after sowing and during the panicle initiation phase and the meiotic phase.

**Data collection**

Data was taken on six randomly selected plants from all three replicates of each treatment and each elementary plot in a quadrat of $1m^2$. Data, namely the number of tillers and leaf chlorophyll content were measured at 36 days, 50 days, 64 days, 78 days after sowing (DAS). Leaf chlorophyll content was taken by chlorophyll meter LICOR Minolta SPAD-502°171.The data closely correlated with the yield: the weight of 30 panicles, the weight of no winnowed grain, the weight of grain, the % of the empty chaff, the weight on 1 $m^2$, the length of the grain, the weight of 1000 grains (kg), number of grains/panicles, number of panicles $m^{-2}$ were also collected. Parameters such as: number of plants $m^{-2}$ ($NPm^{-2}$), number of panicles/hills, number of grains/panicles (NG/PA), % of grains filled (%GF), the weight of 1000 grains ($P_{1000}$) calculated with a moisture content of 14% allowed to calculate the yield and the formula is as follows:

$$\boldsymbol{Y}\left(\frac{\boldsymbol{t}}{\boldsymbol{ha}}\right) = \frac{\mathbf{NP}}{\mathbf{m2}} \times \frac{\mathbf{NPA}}{\mathbf{PO}} \times \frac{\mathbf{NG}}{\mathbf{PA}} \times \%\,\boldsymbol{Gf} \times \mathbf{P1000} \times \mathbf{10^{-15}}$$

(Malaa *et al.*, 2013)

$NPm^{-2}$: number of plants $m^{-2}$; NPA/PO: number of panicles/hill; NG/P: number of grains/panicles; % GF% of grains filled; $P_{1000:}$ weight of 1000 grains calculated with at moisture content of 14%, DAS: days after sowing.

The data obtained was subjected to an analysis of variance by the software SAS.9.4 with the generalized linear procedure (GLM: General Linear Model) associated at the completely randomized block and 3 repetitions in order to test the effects of each treatment on the behavior of the NERICA 3. The Student Newman Keul test had allowed the comparison of averages with a probability of 5%.

$Yij = \mu + \alpha i + \beta j + \alpha\beta ij$
Yij: Performance of the individual
μ: Population mean
αi: Random effect of the ith repetition (i = 1, 2,3)
βj: Fixed effect of the NERICA 3 (j = 1)
(αβ)ij: Random effect of the repetition x genotype interaction.

**RESULTS AND DISCUSSION**

**Physical and chemical characterization of poultry manures and soil from the study site**

The soil of Nkolbisson is characterized by manganic

**Table 1.** Physico-chemical characteristic of soil.

| Soil characteristic | Mn | SR | pH | SOM | OC | N Total | P available | C/N | CEC | $Ca^{2+}$ | $Mg^{2+}$ | Ca/Mg | K | Mg/K |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Value** | 90.6 Cmol+ $kg^{-1}$ | 55.0 % | 4.49 | 42.548 $gkg^{-1}$ soil | 24.680 $gkg^{-1}$ | 1.741 $gkg^{-1}$ | 6.406 $mgkg^{-1}$ | 14.17 | 26.292 $Cmol_{+}kg^{-1}$ | 1.073 $mg.kg^{-1}$ | 0.311 $mg.kg^{-1}$ | 3.45 | 4.645 $mg.kg^{-1}$ | 0.067 |
| **Fertility standard** | 4-12.5 **(Mn Toxicity)** | 50-80 | 6-7 | * | > 5 | > 0.14 | ***** | >25 | > 40 | balance in Ca-Mg | | 1<Ca/Mg<5 | Deficiency | Mg/K>5 |

SOM: Soil Organic matter, OC: Organic Carbon, N: Nitrogen, CEC: Cation Exchange Capacity P: Phosphorus, K: Potassium, Ca: Calcium, Mg: Magnesium.

toxicity (90.6 $Cmol^{+}kg^{-1}$), a saturation rate (SR) of 55.02%, an acidic pH of 4.49. The C/N ratio of 14.17 shows that the soil is rich in nitrogen (Table 1). These results confirm those obtained on the same types of soil by previous authors (Ngonkeu, 2009; Petmi *et al*., 2016; Mballa *et al.*, 2018).

The results of poultry manures indicated that the pH was basic at 8.12 (Table 2), which might be favored for the development of the plant. Similar results were obtained by Orluchukwu *et al.* (2018) who reported that response of upland rice varieties (*Oryza sativa*) to poultry manure and depleted fungus substrate in humid agroecology of south-south, Nigeria and they also reported that the pH of a growing medium with a value > 6.2 contains a maximum of essentials elements, which are required for the proper plant growth (Stewart, 2006).

Some minerals are incisive pollutants (heavy metal) that have a toxic impact on plants, on everyday consumer products and on human health. Their presence and accumulation in the soil has several origin, such as the intake and misuse of fertilizers based on these elements (Addis and Abebaw, 2017). Other minerals are essential to life (for example zinc and copper) at low concentrations, they are toxic at high doses while others are toxic even at very low doses, which is why the analysis of minerals concentrations in poultry manure is essential before application in the field. Thus, the results of minerals in poultry manure showed the absence of Cd (0 $mgkg^{-1}$), and Zn deduced with a higher content (599.525 $mgkg^{-1}$) than Mn (395.689 $mgkg^{-1}$), Cu (22.639 $mgkg^{-1}$), Ni (6.226 $mgkg^{-1}$), Pb (0.333 $mgkg^{-1}$). These results indicate that the level of contamination in the poultry manure applied to the soil was not high and the poultry manure was not polluted with toxic minerals (Cd and Pb). These results are similar to those obtained by Addis and Abebaw (2017). Therefore, these droppings were not harmful to the cultivation of upland rice. Chastain and *al* (1999) and Orluchukwu *et al.* (2018) confirmed that poultry fertilizer contains 13 essential elements for the plant. These include nitrogen, potassium, phosphorus, calcium, magnesium, sulfur, manganese, copper, zinc, chlorine, boron, iron, and molybdenum. In addition, the amount of elements contained in poultry manure depends on the quality of the feed, supplements, drugs (antibiotics) and water consumed by the poultry but the application rate is based on the 'nitrogen requirement by the plant. The presence of antibiotics in poultry manure has no impact on plant production since it is a antimicrobial action on the plant is also indirect, it is an application within a plant is effective for the fight against phyto-pathogens and their duration. Storage in the plant is very only for 20 to 30 days.

## Effect of inorganic fertilization on the productivity of upland rice

The effect of treatments $T_0$, $T_1$, $T_2$, $T_3$, $T_4$ on the number of tillers after 34, 50, 64 and 78 days had revealed a significant difference for all treatments and the number of tillers had evolved with time (Figure 1). The number of tillers after 78 days of sowing were $T_3$ (9.16), $T_1$ (7.77), $T_0$ (7.55), $T_2$ (7.16), $T_4$ (7.11), respectively. The treatment $T_1$ has been the best for the number of tillers of the plant compared to other treatments and the treatment $T_4$ has been the lowest for the number of tillering.

The number of tillers evolves with time (34, 50, 64 and 78 days) under the treatments $T_3 > T_1 > T_0 > T_2 > T_4$, respectively after 78 days of sowing. If the treatment $T_3$ (32N16P16K $kgha^{-1}$) was marked-down better for plant tillering compared to the

**Table 2.** Macronutrients, micronutrients and minerals in poultry manure.

| Nutrient | Unit | Poultry manure | Soil standard (Décision (UE) n° 2018/853) | Toxicity degree in soil | Standard in the plant (Darika *et al.*, 2011) | Toxicity degree in plant (Darika *et al.*, 2011) |
|---|---|---|---|---|---|---|
| Moisture content | % | 31.406 | * | * | * | * |
| pH | / | 8.12 | 7 | * | * | * |
| N | $gkg^{-1}$ | 0.0026 | > 0.14 | * | * | * |
| P | $gkg^{-1}$ | 0.0032 | * | * | * | * |
| K | $gkg^{-1}$ | 0.065 | * | * | * | * |
| Organic C | $gkg^{-1}$ | 48.214 | * | * | * | * |
| Zn | $mgkg^{-1}$ | 599.525 | * | 300 | 100 | 150-300 |
| Mn | $mgkg^{-1}$ | 395.689 | * | * | 200 | * |
| Cu | $mgkg^{-1}$ | 22.639 | 50 | 100 | 4-15 | >25 |
| Ni | $mgkg^{-1}$ | 6.226 | 3 | 50 | 0.5-5 | 30-75 |
| Pb | $mgkg^{-1}$ | 0.333 | <100 | 100 | 3 | 30-300 |
| Cd | $mgkg^{-1}$ | 0 | 1 | 3 | 0.2-0.8 | 5-30 |

Mn: Manganese; C: Carbon, N: Nitrogen, P: Phosphorus, K: Potassium, Ca: Calcium, Mg: Magnesium Cd: Cadmium, Zn: Zinc, Cu: copper, Ni: Nickel, Pb: Lead, *: no determined.

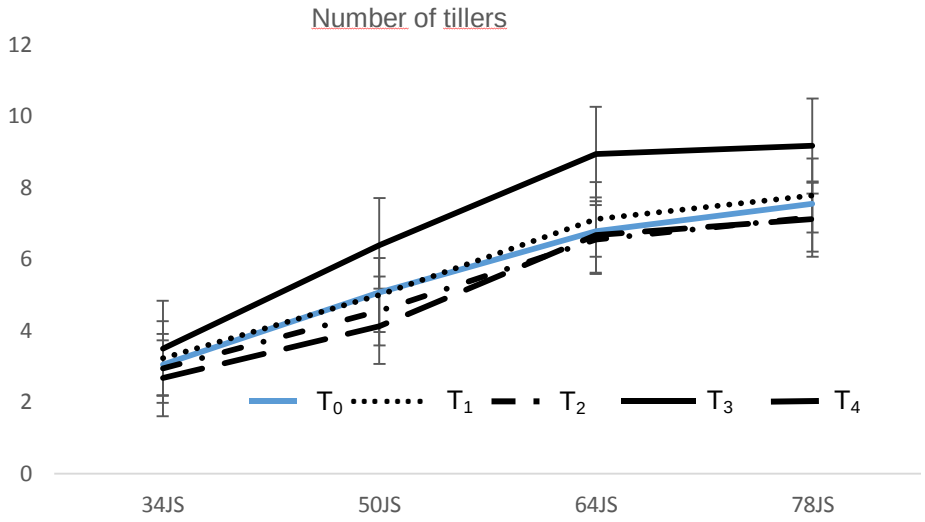


**Figure 1.** Effect of inorganic fertilizer doses on the number of tillers of upland rice.

others; which might be due to the application had a positive influence and the contribution of the NPK had enhanced the avaiability of water and nutrients to plants. These results are in perfect agreement with those of Saidu and Abayomi (2015) who found that potassium increases the tolerance of rice to pests of crops at various stages as well as the entry of water into the plant. In the same context, authors (Alam *et al.*, 2009; Alinajati and Mirshekari, 2011; Dastan *et al.*, 2012) certified that the use of fertilizers has a significant effect on the different stages of growth and development of rice. It significantly increases the number of tillers per $m^2$, the number of fertile tillers, the number of grains, 1000 grain weight, the height of the plant and grain filled percentage. Beyond, these results correspond with those obtained with Djomo *et al.* (2017). Treatment $T_4$ (40N20P20K $kgha^{-1}$) had shown the lowest number of tillers compared to control, however, Djomo *et al*. (2017) conducted research on the effect of different doses of NPK fertilizer on rice growth and yield in north west Cameroon; had used the same dose and obtained good tillers and heights compared to control. These contradictory results could be due to the impact of climate and soil on upland rice production. In all events, the application of fertilizers to optimize yield is not always positive. However, other studies have shown a high rate of nitrogen application of

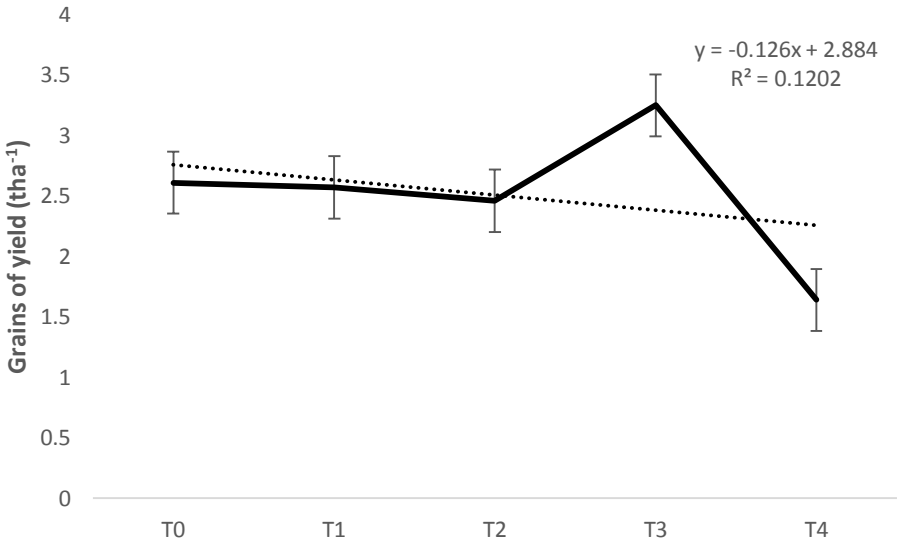


**Figure 2.** Effect of inorganic fertilizer doses on the yield of upland rice.

more than 225 kgha$^{-1}$ reduce the number of grains per panicle and probably the percentage of mature grains. Saidu and Abayomi (2015) agree that this regression of the number of grains observed in panicles was due to competition among tillers for the increase of metabolic reserves, thus reducing grain production.

The application of inorganic fertilizer on the rice plant for the yield parameter had shown a significant difference in all the treatments (Figure 2.). Yields in rice grains varied from $T_3$ (3.25 tha$^{-1}$), $T_0$ (2.62 tha$^{-1}$), $T_1$ (2.57 tha$^{-1}$), $T_2$ (2.46 tha$^{-1}$), $T_4$ (1.64 tha$^{-1}$), respectively, the highest yield of rice was observed with the treatment $T_3$ and the lowest yield was observed under the $T_4$ treatment. These results indicate that the dose of inorganic fertilization $T_3$ on the Nerica 3 plants were better than the other doses compared to control. Unlike plants fertilized on fallow soil, the control treatment ($T_0$) was marked-down with a high yield than $T_1$, $T_2$, $T_4$.

Sustained crop productivity relies on constant renewal when nutrient supply becomes a constraint to plant growth and development (Tilman *et al.*, 2011). In this context, the contribution of inorganic fertilizer to the production of upland rice yield were $T_3$ (3.25 tha$^{-1}$), $T_0$ (2.62 tha$^{-1}$) and $T_1$ (2.57 tha$^{-1}$), $T_2$ (2.46 tha$^{-1}$), $T_4$ (1.64 tha$^{-1}$), respectively. The highest yield of rice had been observed with the treatment $T_3$, which indicated the importance of fertilizers for the improvement of the productivity of Nerica. The best yield observed with the treatment $T_3$ (32N16P16K) of NERICA 3 was due to the balanced supply of all important plant nutrients. Similarly, Nascente and Kromocardi (2017) reported that application rates of N, P and K in upland rice achieved the highest grain yield of about 3 000 kgha$^{-1}$. In contrast to fertilized plants in acidic soil fallow, the treatment control ($T_0$) was marked-down with a high yield that $T_1$ (16N8N8K kgha$^{-1}$), $T_2$ (24N12PNK kgha$^{-1}$), $T_4$ (40N20P20K kgha$^{-1}$) and the lowest yield was observed under treatment $T_4$, which was the highest dose among all treatments. These results indicate that the organic matter contained in the control soil has been completely degraded and has provided sufficient nutrients available and favorable for the development of the rice plants. Lafond *et al.* (1992) state that the C/N ratio is used to evaluate the quality of organic matter in bedding as well as the estimation of the effectiveness of humification and mineralization processes acting in soils and the speed of mineralization of organic matter in the soil. According to Akselsson *et al.* (2005) the C/N ratio is a good indicator for assessing carbon sequestration in soils. A strong C/N ratio represents a low rate of carbon decomposition, since decomposer organisms use nitrogen, which rapidly becomes limiting. A low C/N ratio indicates a high nitrogen concentration and a high degree of decomposition. In addition, NERICA 3 had genes for resistance to manganese toxicity. By somewhere else, the high reduction of yield observed under treatment $T_4$ indicates that nutrient uptake in the plant has a threshold value. In fact, values above and below this threshold can induce specific stress and delay the growth and development of the plant. These results are similar to those obtained by Djomo *et al.* (2017) who claim that excess fertilizers increase the percentage of empty grains. In addition, when the panicles number is high, the energy required for their metabolism is insufficient, which could influence grains filling coupled with water stress, which has a negative impact on grains filling. In the same context, Sanogo *et al.* (2010) suggest that nutrients uptake and crops yield are the main factors that determine optimal fertilization practices. Therefore, it is very important to apply fertilizers in an adequate manner to minimize losses and improve the efficiency of nutrients used. Balanced fertilizers application is not only essential

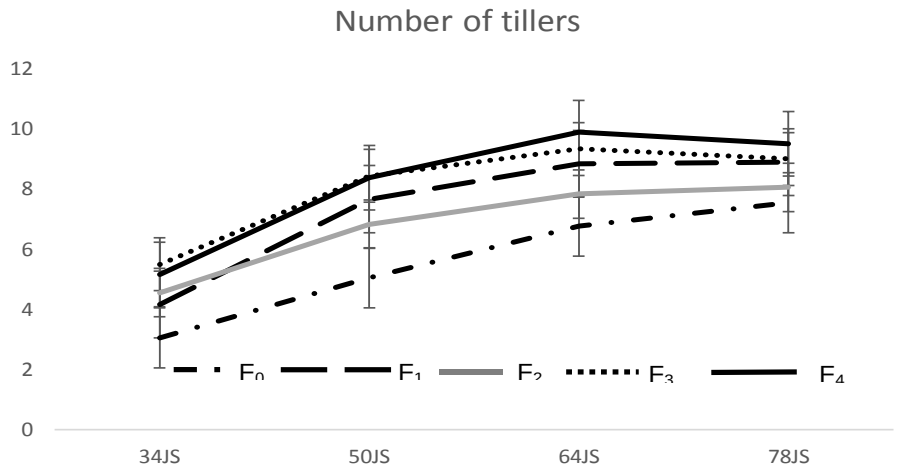


**Figure 3.** Effect of poultry manure on the number of tillers of upland rice.

to produce superior quality crops with high yields, but also for ensuring environmental sustainability.

## Effect of poultry manures on the productivity of upland rice

The effect of poultry manures with doses $F_0$, $F_1$, $F_2$, $F_3$, $F_4$ on the number of tillers after 34, 50, 64 and 78 days had deduced a significant difference for all treatments (Figure 3). The number of tillers after 78 days of sowing are $F_4$ (10.51), $F_3$ (9), $F_1$ (8.88), $F_2$ (8.05), $F_0$ (7.55), respectively and the number of tillers changed according to the time. The treatment $F_4$ stood out best for the number of tillers compared to control and other treatments; the control treatment ($F_0$) had the lowest number of tillers.

If the number of tillers plant had evolved according to the time after application of poultry manure, it is due to the fact that decomposition of organic matter takes a longer time (36 to 78 days) to release nutrients for the growth of the plant (Chastain *et al.*, 1999). In addition, treatment $F_4$ was marked-down better for tillering plant compared to other treatments because this treatment contains optimal phosphorus, which favors plant vegetative growth (Mengel and Kirby, 1979). These results are in agreement with those obtained by Orluchukwu and Adedokun (2014); Orluchukwu *et al*. (2018) who had asserted that the highest plant and number of tillers were also observed in treated plots with poultry manure. Poultry manure is an excellent organic fertilizer, as it contains high nitrogen, phosphorus, potassium and other essential nutrients (Mehdizadeh *et al.*, 2013; Danmaigoro *et al.*, 2019). In contrast to chemical fertilizer, it adds organic matter to soil, which improves soil structures, nutrient retention, aeration, soil moisture holding capacity and water infiltration (Deksissa *et al.*, 2008; Danmaigoro *et al*., 2019).

The application of poultry manure to the rice crop for the yield parameters had a significant difference for all the treatments (Figure 4). Grain yield of rice had been ranged from $F_1$ (3.92 $tha^{-1}$), $F_4$ (3.88 $tha^{-1}$), $F_3$ (3.84 $tha^{-1}$), $F_2$ (3.05 $tha^{-1}$), $F_0$ (2.62 $tha^{-1}$), respectively. The highest yield of rice was observed in the treatment $F_1$ and the lowest yield was observed under the treatment $F_0$.

Thereby, fertilization with poultry manure had an effect on the development of NERICA 3. These results Were supported by the work of Obi and Ebo (1995), who had reported that poultry manure improve the chemical and biological properties of soil and alternatively increases the productivity of the plants. Organic manure such as poultry manure and compost has been considered an excellent soil amendment that can provide N and enhance N availability to improve crop yields (Smith and Siciliano, 2015; Hu Cheng *et al.*, 2019). Orluchukwu *et al.* (2018) had signaled that Nerica 5 was the best variety in terms of yield when treatments of poultry manure and exhaust mushroom substrates had been applied on varieties of upland rice. This same trend had been achieved by Ezeibekwe *et al.* (2009) where poultry manure had favored flowering and a high yield. The positive response of treatment $F_1$ for the efficiency of NERICA 3 plant in acidic soil was contradictory with those obtained by Danmaigoro *et al.* (2019). These authors had achieved on growth and yield of direct seeded upland rice varieties as influenced by weed management and organic manure application that application of 10 $tha^{-1}$ of poultry manure gave significantly greater grain yield of upland rice varieties (NERICA and FARO 48) than the lowest rates (0 and 5 $tha^{-1}$).

## Combination of inorganic and organic fertilization under upland rice

The combinations of poultry manure with inorganic fertilizer doses ($C_0$, $C_1$, $C_2$, $C_3$, $C_4$, $C_5$) influence the number of tillers after 34, 50, 64 and 78 days had shown a significant difference for all treatments (Figure 5). The

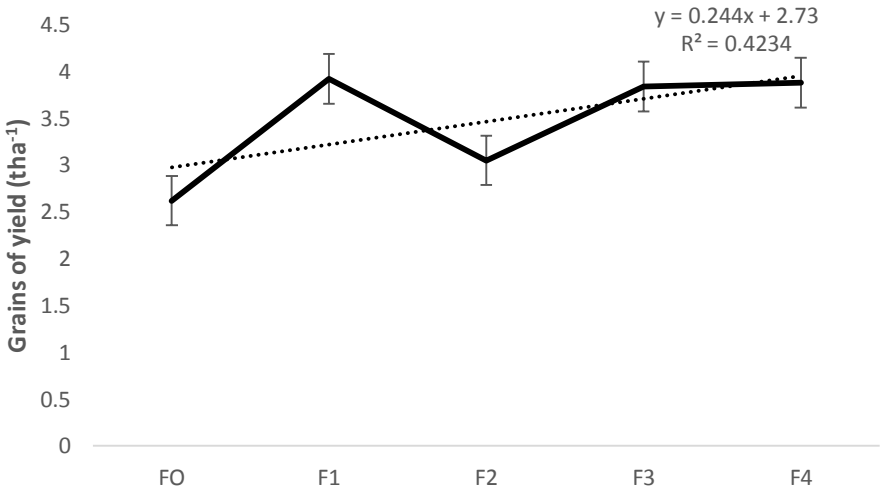


**Figure 4.** Effect of poultry manure on the yield of upland rice.

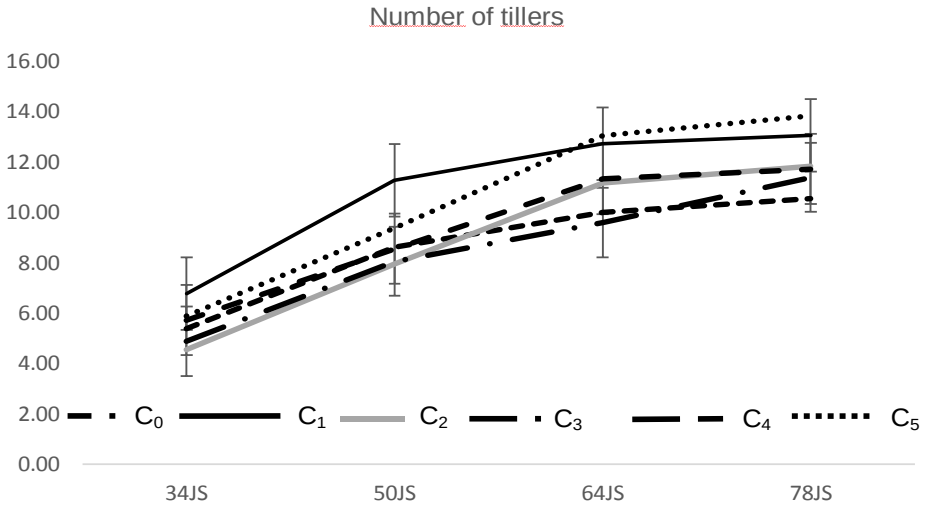


**Figure 5.** Effect of combination of poultry manure and inorganic fertilizer on the number of tillers of upland rice.

number of tillers after 78 days were $C_5$ (13.83), $C_1$ (13.05), $C_2$ (11.83), $C_4$ (11.72), $C_3$ (11.38), $C_0$ (10.55), respectively and the number of tillers changed with time. $C_5$ treatment had been best for the number of the tillers for the plant compared to other treatments. The control had the lowest tillers.

The effect of the combination of poultry manure with inorganic fertilizer on the development of the rice plants had indicated a significant difference for the yield parameters for all treatments (Figure 6). Yields of rice grains ranged from $C_1$ (6.82 $tha^{-1}$), $C_5$ (5.45 $tha^{-1}$), $C_3$ (4.77 $tha^{-1}$), $C_2$ (4.48 $tha^{-1}$), $C_0$ (4.31 $tha^{-1}$), $C_4$ (4.01 $tha^{-1}$) respectively, the highest yield of rice was observed in treatment $C_1$. The best combination for the yield of rice grains was $C_5$ and the lowest yield was observed under the $C_4$ combination.

These results are contradictory to that obtained by Alice *et al.* (2012) on the effect of inorganic fertilizer supplementation with organic fertilizer on the growth and yield of mixed rice-cowpea crops. However, in this study, treatment $C_1$ (6.82 $mtha^{-1}$ poultry manure alone) was better in terms of yield than treatments $C_2$ (4.48 $mtha^{-1}$ inorganics fertilizers alone), treatments combination between inorganic and organic fertilizers; $C_5$ (5.45 $tha^{-1}$), $C_3$ (4.77 $tha^{-1}$), $C_4$ (4.01 $tha^{-1}$) and control $C_0$ (4.31 $tha^{-1}$). The best combination was treatment $C_5$ (1.875 $tha^{-1}$ + 8N-4P-4K $kgha^{-1}$). This result obtained with the combination $C_5$ (1.875 $tha^{-1}$ + 8N-4P-4K $kgha^{-1}$) proves that its effect on the production of upland rice was more effective than those plants, which had received the inorganic nutrition as well as that of control plants. A similar trend was observed by the study of Hu Cheng *et al.* (2019). Alice *et al.* (2012) support this theme that for intensive and continuous agricultural production in the

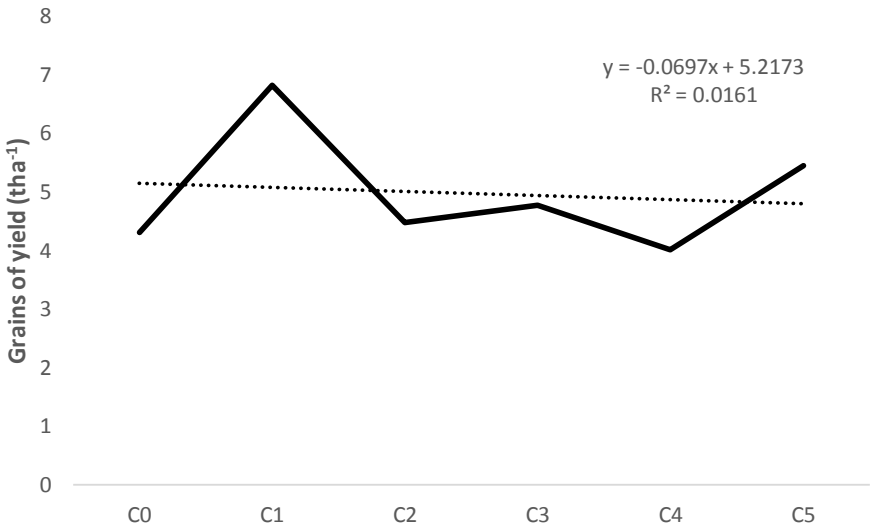


**Figure 6.** Effect of the combination of poultry manure and inorganic fertilizer on the yield of upland rice.

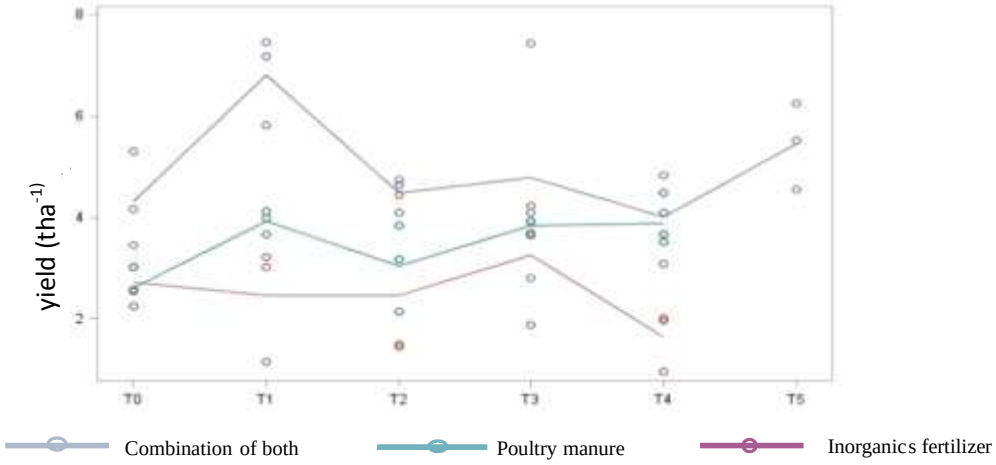


**Figure 7.** Interaction effect of different fertilizers on the yield of upland rice.

long term, combined use with inorganic and organic fertilizer can significantly increase production and maintain soil properties. If the control plants had a high production that some plants having received two fertilizers it is because residues of organic substances contained in fallow soil had the beneficial effect on the productivity of NERICA 3. These results indicated that NERICA 3 can be grown on acidic soil, Moreover, the application of fertilizers above or below the threshold value of a nutrient response leads to a regression of production.

## Interaction between different fertilizers

In the environment, the overall analysis of poultry manure, inorganic fertilizer and a combination of both fertilizers had revealed that the combination of both found better of all fertilizers to optimize the productivity of rice crop followed by poultry manure and inorganic fertilizer (Figure 7).

The all analysis of poultry manure, inorganic fertilizer and combination in environment revealed that combination of both fertilizers found a best in terms of performance, might be due to the amendment of poultry manure during the growth and development of the rice plants, which resulted in higher retention of water and made the environment conducive for better productivity. These findings are also supported by Alice *et al.* (2012) and reported that combination of poultry manure and inorganic fertilizers can significantly increase the production and maintain the soil properties.

The application of inorganic fertilizer, poultry manure and combined fertilizers had a positive effect on the

**Table 3**. Effect of treatments on vegetative biomass and yield.

| Inorganic fertilizer | | | Poultry manure | | | Combination | | |
|---|---|---|---|---|---|---|---|---|
| **Treatments** | **Vegetative biomass (g)** | **Yield ($tha^{-1}$)** | **Treatments** | **Vegetative biomass (g)** | **Yield ($tha^{-1}$)** | **Treatments** | **Vegetative biomass (g)** | **Yield ($tha^{-1}$)** |
| $T_0$ | $15.31^a$ | $2.61^a$ | $F_0$ | $15.27^a$ | $2.62^a$ | $C_0$ | $6.52^a$ | $4.31^a$ |
| $T_1$ | $13.28^a$ | $2.57^a$ | $F_1$ | $13.35^a$ | $3.92^c$ | $C_1$ | $8.57^a$ | $6.82^c$ |
| $T_2$ | $17.71^a$ | $2.46^a$ | $F_2$ | $13.77^a$ | $3.05^a$ | $C_2$ | $6.67^a$ | $4.48^a$ |
| $T_3$ | $15.36^a$ | $3.25^b$ | $F_3$ | $18.73^a$ | $3.84^b$ | $C_3$ | $10.13^a$ | $4.77^b$ |
| $T_4$ | $14.47^a$ | $1.64^c$ | $F_4$ | $20.06^a$ | $3.88^b$ | $C_4$ | $7.06^a$ | $4.01^a$ |
| | | | | | | $C_5$ | $10.79^a$ | $5.45^b$ |

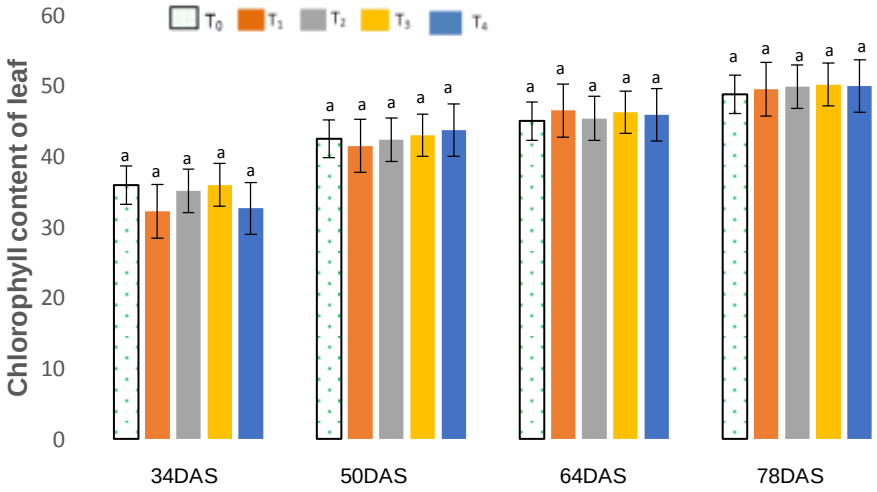


**Figure 8.** Effect of inorganic fertilizer doses on the chlorophyll content of leaf rice.

vegetative biomass. Treatments $T_2$ (17.71 g) of inorganic fertilizer and $F_4$ (20.06 g) of poultry manure, which had a high vegetative biomass but did not have a high yield. Only the treatment $C_5$ of the combination showed a high vegetative biomass and yield (Table 3). This result revealed that vegetative biomass had an effect on the yield. The yield may-be estimated through the vegetative biomass if the rice plant did not attain maturity.

Firstly, Treatment $T_2$ (17.71 g) of inorganic fertilizer and $F_4$ (20.06 g) of poultry manure with high vegetative biomass didn't have a high yield because these fertilizers doses were above ($F_4$) or below the threshold, ($T_2$) respectively, expected to affect the photosynthesis, which had favored abundant vegetative growth as grains filling. Saidu and Abayomi (2015) agree that regression of the number of grains per panicle may be to competition among the tillers for the increase of metabolic reserves thus reducing grain production. However, other studies (Djomo and *al*., 2017) had shown a high rate of nitrogen application (more than 225 $kgha^{-1}$) reduced the number of grains per panicle and probably the percentage of mature grains. On the other hand, treatment $C_5$ of combination had shown the high vegetative biomass and yield could be due to the beneficial effect on acidic soil, vegetable biomass and yield. This implies that combination fertilizers (inorganic and poultry manure) amendment are very beneficial on red ferrasols, which are low in pH and have low availability of major plant nutrients, such as P and some exchangeable cations. Zhu *et al.* (2015) also reported that biochar + NPK amendment of a red soil increased maize total biomass by 2.7-3.5 and 1.5-1.6 times compared to that of NPK and biochar amendments, respectively.

The average chlorophyll content of leaf measured during the crop growth period was significant for all treatments of inorganic, poultry manure and combination fertilizers. All treatments had green color but green coloring was darker for the treatment of poultry manure and combination fertilizers (Figures 8, 9 and 10). These results assert that all fertilizers applied on acidic soil had a positive effect on the photosynthesis, growth and development of the plant.

Chlorophyll content, an indicator of photosynthetic activity, was related to the N content in green plants and serves as a measure of the response of crops to N fertilizer application and soil nutrient status (Minotta and Pinzauti, 1996). In this study, the average leaf chlorophyll measured during the crop growth period was significant

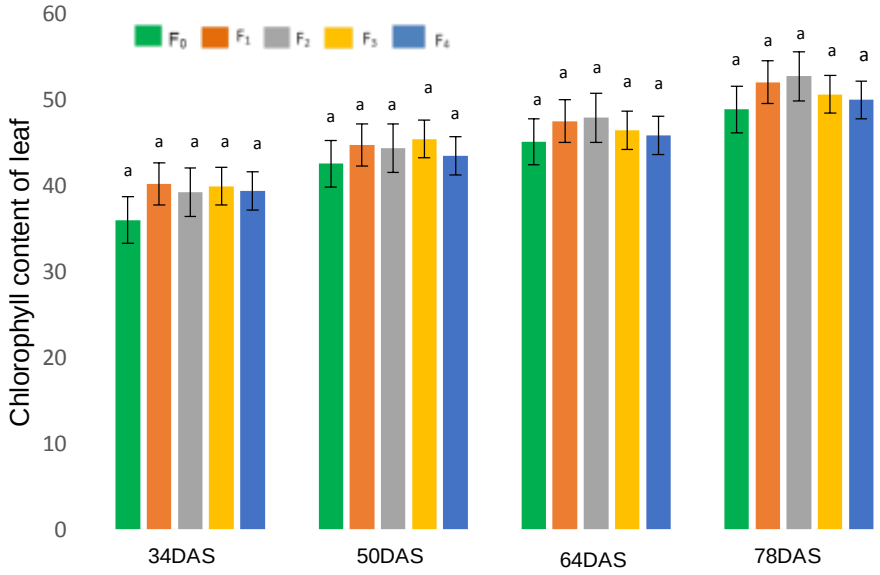


**Figure 9.** Effect of poultry manure on the chlorophyll content of leaf rice.

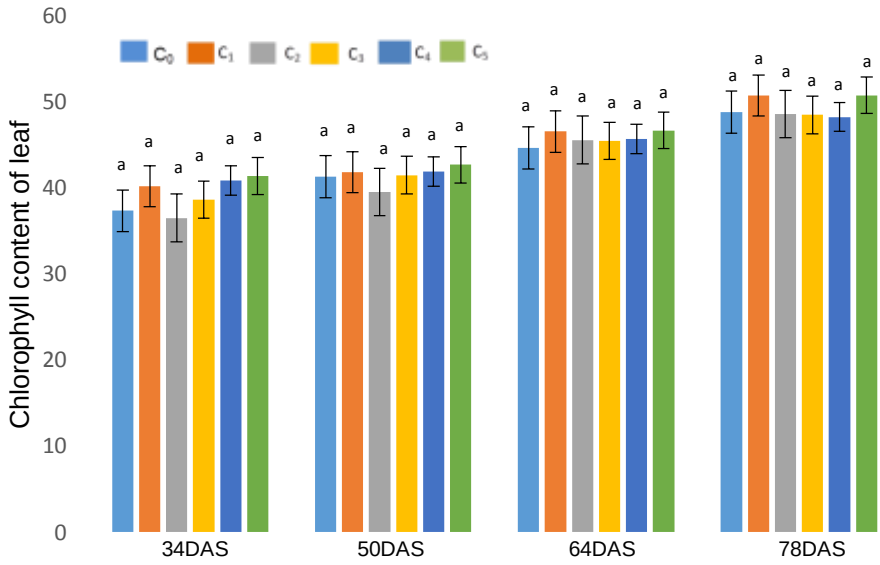


**Figure 10.** Effect of the combination of poultry manure and inorganic fertilizers on the chlorophyll content of leaf rice.

for all treatments of inorganic fertilizer, poultry and combination fertilizer. These results assert that all fertilizers applied on acidic soil had a beneficial effect on the photosynthesis, growth and development of the plant. Doan *et al.* (2015) and Zhang *et al.* (2016) mentioned the fertilizer important for improving long-term soil fertility and crop yield. Green coloring was darker in the treatment of poultry and combination fertilizers than treatment of inorganic fertilizer because of higher in-leaf chlorophyll content with plant age suggests increased availability of nutrient and water over time due to organic amendments. Other authors have shown that the application of biochar and compost with fertilizer significantly increased the leaf chlorophyll content of crops compared to fertilizers alone (Adekayode and Olojugba, 2010; Agegnehu *et al.*, 1998).

## CONCLUSION

This initiative aims to cope with a large and growing rice production to make agriculture an exponential beacon for development. At the end of this study, the doses of inorganic fertilizer 32N16P16K kgha$^{-1}$, 2.5 tha$^{-1}$ of poultry manure and the combination of 1.875 tha$^{-1}$ + 8N-4P-4K

$kgha^{-1}$ are the best treatments for a upland rice production. The integration of these doses in the soil offers a sustainable, intensive and comprehensive strategy for the management of acidic soils in the tropics.

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### REFERENCES

**Adekayode F, Olojugba M (2010).** The utilization of wood ash as manure to reduce the use of mineral fertilizer for improved performance of maize (*Zea mays L.)* as measured in the chlorophyll content and grain yield. J. Soil Sci. Environ. Manage. 1, 40-45.

**Agegnehu G, Bird M, Nelson P (1998).** The ameliorating effects of biochar and compost on soil quality and plant growth on a Ferralsol. Soil Res. 53:1-12.

**Akselsson CB, Berg V, Meentemeyer OW (2005).** Scaling up carbon sequestration rates in organic layers of boreal and temperate forest soils example Sweden. Global Ecol. Biogeogr., 14:77-84.

**Alam MM, Hassanuzzaman M, Nahar K (2009).**Tiller dynamics of three irrigated rice varieties alfisol. *Nigeria J. Soil Res*. 2:15-20.

**Alice AA, Shuichi M, Nobumitsu K (2012).** Effet de la supplémentation en engrais inorganique avec des engrais organiques sur la croissance et le rendement des cultures mixtes riz-niébé. Plant Prod. Sci. 15(2):109-117.

**Alinajati S, Mirshekari B (2011).** Effect of phosphorus fertilization and seed biofertilization on harvest index and phosphorus use efficiency of wheat cultivars. J. Food Agric. Environ. 19(2):388-397.

**Bindzi Tsala J (1987).** Les sols rouges du Cameroun. Communication à la 8ème Réunion du sous-comité Ouest et Centre africain de corrélation des sols pour la mise en valeur des Terres, Mesires- FAO, Yaoundé, 201 p.

**Borrero JC, Pandey S, Ceballos H, Magnavaca R, Bahia AFC (1995).** Genetic variances for tolerance to soil acidity in tropical maize population. *Maydica* 40:283-288.

**Chastain JP, Camberato JJ, Skewes P (1999).** Poultry manure production and nutrient content. NRAES, pp.1-17.

**Danmaigoro O, Halilu AG, Izge AU (2019).** Growth and yield of direct seeded upland rice varieties as influenced by weed management and organic manure application. J. Res. Weed Sci. 2:103-114.

**Dastan S, Siavoshi M, Zakavi D, Ghanbaria-malidarreh A, Yadi R, Ghorbannia DE, Nasiri AR (2012).** Application of nitrogen and silicon rates on morphological and chemical lodging related characteristics in rice (*Oryza. sativa* L.) North of Iran. J. Agric. Sci. 4(6):34-37.

**Deksissa T, Short I, Allen J (2008).** Effect of Soil Amendment with Compost on Growth and Water Use efficiency of Amaranth. In: Proc. the UCOWR/NIWR Annual Conference*:* International Water Resources: Challenges for the 2st Century and Water Resources Education. July 22-24, 2008, Durham, North Carolina.

**Djomo SH, Mbong GA, Malla DK, Suh C (2017).** Effet de différentes doses d'engrais NPK sur la croissance et rendement du riz à Ndop, au nord-ouest du Cameroun. Afr. J. Agric. Res. 12(15):1244-1252.

**Doan TT, Henry-des-Tureaux T, Rumpel C, Janeau JL, Jouquet P (2015).** Impact of compost, vermicompost and biochar on soil fertility, maize yield and soil erosion in northern Vietnam: a three years mesocosm experiment. Sci. Total Environ. 514:147-154.

**Eswaran H, Reich P, Beigroth F (1997).** Global distribution of soils with acidity. In Plant Soil Interactions at Low pH. Ed. A C Monitz. Brazilian Soil Science Society, Campines Brazil. pp. 159-164.

**Ezeibekwe IO, Ogbonnaya CI, Onuoha CI (2009).** Comparative effects of poultry manure and urea on the growth and yield of maize (*Zea mays*). Report and Opinion 1(4): 37-40.

**FAOSTAT. (2020).** Food and agriculture organization of United nation, Statistics division; 2020. Available: http://faostat.fao.org/site/567/ Desktop Default.aspx?PageID=567#ancor.

**Hu C, Xia XG, Chen YF, Qiao Y, Liu DH, Fan J, Li SL (2019).** Yield, nitrogen use efficiency and balance response to thirty-five years of fertilization in paddy rice-upland wheat cropping system. Plant Soil Environ. 65:55-62.

**Jonatan GB, Sengli JD, Jamuda MS, Chairul M (2014).** Effect of Soil Tillage Method, Organic Materials and Varieties on Growth and Production of Upland Rice in the Area of Immature Rubber Plantation. Int. J. Sci Technol. Res. 3(11):62-68.

**Karbo N, Bruce J, Otchere EO (1999).** The role of livestock in sustaining soil fertility in northern Ghana. *ILEIA newsletter* 15 (1/2): 49-50.

**Kirk GJD, Greenway BJ, Atwell BJ, Ismail AM, Colmer TD (2014).** Adaptation of rice to flood soils*. In Progress in Botany*, Vol 75, eds Lüttge U., Beyschlag W. Cushman Springer Berlin; Heidelberg. doi: 10.1007/978-3-642-38797-5_8. Retrieved 18/05/2016.

**Kochian L (2012).** Cellular mechanism of aluminium toxicity and resistance in plants. Annu. Rev. Plant Physiol. 88:619-625.

**Lafond R, Claude C, Ducruc JP (1992).** Pédologie forestière, *Mont-Royal (Québec*): *Modulo*, p. 146.

**Llyod R (1995).** Soil nutrient management for sustained food crop production in upland farming systems in the tropics. *Soil and crop sciences Department College station*, Tennesse 77843 USA, pp. 46.

**Mafouasson HNA, Gracen V, Yeboah MA, Ntomboh-Ntsefong G, Tandzi LN, Mutengwa CS (2018).** Genotype-by-Environment Interaction and Yield Stability of Maize Single Cross Hybrids Developed from Tropical Inbred Lines. Agronomy 2018,8, 62; doi:10.3390/agronomy8050062.

**Malaa KD, Magloire K, Tsafack BS, Tite B, Woin N, Agboh-Noameshie R, Beye A, Cromme N (2013).** Aspect genre et préférence des caractéristiques biophysiques du riz au Cameroun. *Proceding 3ème Congrès du Riz en Africa 2013*, 21-24 Octobre 2013 Yaoundé, Cameroun. p. 146.

**Mballa TAN, Malaa DK, Ngonkeu ELM, Mouen J, Meppe P, Feyem MNM, Mbiade E, Petmi C, Tekeu H, Woin N (2018).** Potential role of groundnut stover in soil nutrient management for a sustainable rainfed upland rice production in bimodal rain forest zone of Cameroon**.** *Annu. Res. Rev. Biol*. 22(1): 1-13, 2018; Article no. ARRB. 35131. ISSN: 2347-565X, NLM ID: 101632869.

**Mehdizadeh M, Izadi Darbandi E, Naseri Rad H, Tobeh A (2013).** Growth and yield of tomato (*Lycopersicon esculentum Mill*.) as influenced by different organic fertilizers. *IJAPP*. 4:734-738.

**Mengel K, Kirby EA (1979).** Principles of plant nutrition. 2nd edition. *International Potash Institute*, *Berns, Switzerland*. 30-35.

**Minotta G, Pinzauti S (1996).** Effect of light and soil fertility on growth, leaf chlorophyll content and nutrient use efficiency of beech (*Fagus sylvatica L*.) seedling*.* For. Ecol. Manag. 86:61-71.

**Nascente AS, Kromocardi R (2017).** Genotype selection and addition of fertilizer increases grain yield in upland rice in Suriname. *Acta Amazonica*. 47(3):185-194.

**Ngonkeu MEL (2009).** Tolérance de certaines variétés de maïs aux sols à toxicité aluminique et manganique du Cameroun et diversité moléculaire et fonctionnelle des mycorhizes à arbuscules. *Thèse de Doctorat PhD d'Université de Yaoundé I*. pp 22465.

**Obi ME, Ebo PO (1995).** The effects of organic and inorganic soil amendments on soil physical properties and maize production in a severely degraded sandy loam soil in Southern Nigeria. Resour. Technol. 51:117-1-23.

**Orluchukwu JA, Adedokun OM (2014).** Comparable effects of poultry and spent mushroom substrate on the growth and yield of pineapple (*Ananas comosus*) in Nigeria. Afr. J. Agric. Res. 9(26):2041-2044.

**Orluchukwu JA, Chinonyelum U (2018)**. Response of upland rice (*Oryza sativa*) varieties to poultry manure and spent mushroom substrate in humid agro-ecology of south-south, Nigeria. *IJAAR*. 12(5):9-18.

**Petmi CL, Ngonkeu ELM, Tandzi NL, Ambang Z, Boyomo O, Bell JM, Tekeu H, Mafouasson H, Malaa D, Woin Noe (2016).** Screening of Maize (*Zea mays L.*) Genotypes for Adaptation on Contrasted Acid Soils in the Humid Forest Zone of Cameroon. Int. J. Exp. Agric. pp. 1-15.

**Saidu A, Abayomi Y A (2015).** Interactive effects of organic and inorganic fertilizers on the performance of Upland Rice (*Oryza sativa L.*) Cultivars. Int. J. Agric. Sci. 5(2):399-406.

**Sanogo S, Camara M, Zouzou M, Keli Z, Messoum F, Sekou A (2010).** Effets de la fertilisation minérale sur des variétés améliorées de riz en condition irriguée à Gagnoa, Côte d'Ivoire. *J. Appl. Biosci.* 35:2235-2243.

**Smith LED, Siciliano G (2015).** A comprehensive review of constraints to improved management of fertilizers in China and mitigation of diffuse water pollution from agriculture. Agric. Ecosyst. Environ, 209:15-25.

**Stewart Dean P C (1995).** The effect of spent mushroom compost on soil conditions and plant growth. The Lincoln University publications.http://hdl.handle.net/10182/1550.

**The C, Calba H, Zonkeng C, Ngonkeu MEL, Adetimirin VO, Mafouasson HA, Meka SS, Horst WL (2006).** Response of maize grain yield to changes in acid Characteristics after soil amendments. Plant and Soil 284:45-57.

**Tilman D, Balzer C, Colline J, Befort BL (2011).** La demande alimentaire mondiale et l'intensification durable de l'agriculture. Proc. Natl. Acad. Sci. 108: 20260-20264.

**Von Uexkull HR, Mutert E (1995)**. Global extent, development and economic impact of acidsoils. pp 5-19. In Data RA, *et al*. (eds.) Plant-soil interaction at low pH: Principles and management. Kluver Academic Publishers, Dardrecht, The Netherlands Maize. Crop Sci. 34:1511-14.

**Zewdu Z, Abebe T, Mitiku T, Worede F, Dessie A, Berie A, Atnaf M (2020).** Performance evaluation and yield stability ofupland rice (*Oryza sativa L.)* varieties in Ethiopia. Cogent Food Agric 6:1842679**.** *https://doi.org/10.1080/23311932.2020.1842679*.

**Zhang D, Pan G, Wu G, Kibue GW, Li L, Zhang X, Zheng J, Cheng K, Joseph S (2016).** Biochar helps enhance maize productivity and reduce greenhouse gas emissions under balanced fertilization in a rainfed low fertility inceptisol. Chemosphere 142:106-113.

**Zhu Q, Peng X, Huang T (2015).** Contrasted effects of biochar on maize growth and N use efficiency depending on soil conditions. Int. Agrophys. 29(2):257-266.