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Fields Preparation Techniques for Rice Production: Impacts on Selected Soil Heavy Metals Concentration and Rice Yield in Lowlands of Southeastern Nigeria

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ABSTRACT

Field study was conducted in lowland research farm of Federal College of Agriculture, Ishiagu, in 2018 and 2019 to evaluate field preparation techniques effect on selected heavy metals concentration and rice yield in lowlands of Ebonyi State. A randomized complete block design was employed for the study. Field preparation employed include; Cleared, tilled, seedlings-transplanted and hand weeding (C/T/ST//HW) technique; Non-selective herbicide applied, cleared, tilled, seedlings-transplanted and herbicide for weeding (N-H/C/T/ST); Applied non-selective herbicide, cleared, broadcasted seeds and herbicide for weeding (N-H/C/B); Applied Non-selective herbicide, broadcasted and herbicide for weeding (N-H/B); Cleared, tilled, seedlings-transplanted and herbicides for weeding (C/T/ST/S); Applied Non-selective herbicide, cleared, tilled, seedlings-transplanted and hand weeding (N-Hw/C/T/ST/Hw). Results indicated field preparation with N-H/C/B produced the highest significant ($p < 0.05$) (1.94 mg Kg^{-1}) concentration of cadmium in first year, while plots with N-H/C/T/ST/Hw recorded the least (0.97 mg Kg^{-1}) concentration of cadmium. In second year, N-H/B plots gave highest concentration of cadmium level (2.71 mg Kg^{-1}), as plots with N-H/C/T/ST/Hw produced least (0.78 mg Kg^{-1}) concentration. Lead accumulation was significantly ($p < 0.05$) higher in N-H/C/T/ST and C/T/ST/S (0.05 mg Kg^{-1} and 0.053433 mgKg^{-1}), respectively, in first year over other plots. In the second year, lead concentration was significant (0.08 mg Kg^{-1}) in N-H/B plots. Yield results also showed that N-H/C/T/ST/Hw plots significantly improved the grain yield (8.40 t ha^{-1}) higher than the others in the second year. It is concluded that N-H/C/T/ST/Hw field preparation technique which recorded the least cadmium and lead concentration on top soil gave as well the best rice grain yield.

Keywords: Herbicides, transplanted, broadcasted, weeding, cadmium, lead concentration, rice grain yield

1. Introduction

Rice (*Oryza sativa*) is one of the main cereal crop as well as staple foods for most of the world's population, especially in Asian countries (Bird *et al.,* 2001). Approximately 600 million tons of rice is harvested worldwide annually (Chen *et al.,* 2012). Rice belongs to the grass family Poaceae, genus *Oryza* and tribe *Oryzaea*.

Nigeria is one of the many countries of the world with suitable ecologies for different rice varieties which can be harnessed to boost rice production to meet domestic demands and even have surplus for export. Nigeria produces about 1.35 metric tons of rice per hectare, which is below the world average of about 2 metric tons. The country is therefore deficient to the tone of a million tones making her a net importer of rice (WARDA, 2002).

Frequently, rice is eaten in cooked form by humans to obtain various nutrients, as well as to supplement their caloric intake (King *et al.,* 2011). Considering the heavy demand, contribution of rice and the scope of quality rice in the international market, interactive research work in almost all aspects of rice is needed, including the production practices as they affect the quality and health safety of the

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grain seed. Cadmium (Cd) is one of the most hazardous heavy metals, exerting toxic effects on the kidneys, and skeletal and respiratory systems, and classified as a human carcinogen by body inhalation (IPCS 1992, 2007; WHO 2010). There is a high bioaccumulation index of Cd in plants grown in soil, which causes no adverse influence on plant growth and development (Grant *et al.,* 1998). Accordingly, Cd can readily enter the food-chain via soil-crop systems, leading to potential food safety and human health risks (Liu *et al.,* 2006; Bernard 2008).

Contamination of soil by heavy metals through human activities such as pesticides and herbicide applications during cropping is of major concern because of their toxicity. Elevated levels of heavy metals in soils may lead to their uptake by plants, which depends not only on heavy metal contents in soils but is also determined by soil pH value, organic matter and clay contents, and influenced by the fertilization (Fytianos *et al.,* 2001). The fluctuation of the mentioned parameters cannot change the total amount of heavy metals in soil but can significantly affect their bioavailability (Ge *et al.,* 2000).

In recent years, the rural labour had migrated towards the industrial sector, which had led to the non-availability of laborers for transplanting of rice at the appropriate time in areas of rice production leading to delayed transplantation of rice as per the schedule, thereby resulting in yield reductions. The transplanting method also results in drudgery among the rice workers (Budhar and Tamilselvan, 2001). Transplanting of paddy seedlings is common method of crop establishment in the irrigated and rain-fed rice systems of Nigeria but labour intensive (30 persons/ha/day) (Bhuiyan *et al.,* 1995). The problems associated with transplanting method have led to the adoption of zero tillage or reduce tillage establishment of rice (broadcasting method of rice) using various kinds of herbicides for clearing vegetation cover and field weed control, which is used widely around the study area; and this practice according to Piggin *et al.,* (2002) has potential to allow savings in time, energy, water and labour during rice establishment.

In many developing nations, current agricultural methods follow unsustainable practices which have resulted in a huge amount of toxic effluents being emitted directly or indirectly into the soil, air, and water (Yáñ ez *et al.,* 2002). The advent of nanotechnology and nanomaterials has further complicated the scenario of soil inputs and their degradation (Mishra *et al.,* 2018; Mishra *et al.,* 2017). Currently, various agrochemicals (i.e., herbicides, fungicides, insecticides, nematicides, molluscicides, rodenticides, chemical fertilizers are being used non-judiciously (Meena *et al.,* 2016) which have adversely affected beneficial soil (micro) biota.

Weeds and insects are the major reducing biotic factors in agriculture and hamper crop yield, productivity, and resource use efficiency (Oliveira *et al.,* 2014). Therefore, herbicides (type of pesticide that kills specifically targeted herbs) and insecticides (type of pesticide that kills specifically targeted insects) are being used indiscriminately for ensuring higher production by eliminating or suppressing pest population (Meena *et al.,* 2016).

In the past years, a large number of herbicides have been introduced as pre and post-emergence weed killers in many countries of the world. In Nigeria, herbicides have since effectively been used to control weeds in agricultural systems (Sebiom *et al.,* 2011). As farmers continue to realize the usefulness of herbicides, larger quantities are applied to the soil. But the fate of these compounds in the soils is becoming increasingly important since they could be leached; in which case groundwater is contaminated or immobile, and persists on the top soil (Ayansina *et al.,* 2003). These herbicides could then accumulate to toxic levels in the soil and become harmful to microorganisms, plants, wild life and man (Sebiomo *et al.,* 2011). There is an increasing concern that herbicides not only affect the target organisms (weeds) but also the microbial communities present in soils, and these non-target effects may reduce the performance of important soil functions (Hutsch, 2001).

Glyphosate (G) herbicides and pesticides have recently been the subject of a controversy between agencies such as the International Agency for Research on Cancer (IARC) of the World Health Organization (WHO) and the European Food Safety Agency (EFSA) (Portier *et al.,* 2016). The IARC classified Glyphosate as a probable carcinogen (Guyton *et al.,* 2017), while EFSA did not (EFSA, 2015). According to their detailed reports, this was probably because of the different toxicity profiles of the full formulations and Glyphosate alone.

The objective of the study is to determine the effect of different field preparation (agronomic) practices on selected soil heavy metals and grain yield of lowland rice.

2. Materials and Methods

The study was carried out at the inland valley rice field at Federal College of Agriculture, Ishiagu, Ebonyi State, Nigeria, during the 2018 and 2019 cropping seasons. The field was under rice cultivation by the Institution before the study. The area is located within latitude 05° 56' N and longitude 07° 41' E. The mean annual rainfall and mean monthly temperature have been reported as 1350 mm and 30° C respectively. The area lies within the derived savanna vegetative zone of South Eastern Nigeria. There are two reported distinct seasons, the dry season which spans November to March, at times extend to April, and the rainy season which spans April to October (Nwite *et al.,* 2008).

Geologically, the area is underlain by sedimentary rock derived from the successive deposits of the cretaceous and tertiary periods and lies within Asu River Group (Lekwa *et al.,* 1995). The location lies within the Asu River Group and consists of Olive brown sandy shale, fine grained micaeous sandstones and mudstones deposited in an alternating sequence. Generally, Ebonyi State lies mostly in the Ebonyi (Aboine) river Basin and Cross River plains. The area contains two main geological formations. The soil is hydromorphic and belongs to the order Ultisol. It has been classified as a typic Haplustut (FDALR, 1985).

2.1 Agronomic Practices

2.1.1 Land Preparation

The land used was prepared according to the specifications outlined in each treatment. The plot size measured 2.6 m x 3.4 m.

Rice fields preparation techniques employed for the study and their descriptions include the following;

I. Clear, tilled and seedlings-transplanted + use of hand weeding (C/T/ST/HW). The plots involved were cleared, tilled manually with a native hoe, and followed by transplanting. Hand weeding was adopted during weeding operation.

II. Non-selective herbicide was applied, cleared, tilled and seedlings-transplanted + use of herbicide for weeding (N-H/C/T/ST). A branded name non-selective herbicide (Uproot) was applied to kill the grasses in the affected plots; after two weeks of application, the plots were cleared of the dead grasses, later tilled with native hoe and rice seedlings transplanted. During the weeding operation, a branded name – orizo plus selective herbicide was applied in the designated plots.

III. Non-selective herbicide (Uproot) was applied, cleared, broadcast + use of herbicide for weeding (N-H/C/B). A branded name non-selective herbicide (Uproot) was applied at the rate of 150 mls a.i./20 litres of water to kill the grasses in the affected plots; after two weeks of application, the plots were cleared of the dried grasses, re-touched with the same herbicide at the rate of 100 mls a.i/20 liters of water. This was followed by the broadcasting of rice seeds at the rate of 40 kg/ha. Weeding of the plots was carried out using orizo-plus selective herbicide at the rate of 150 mls a.i./20 liters of water.

V. Non-selective herbicide was applied and rice seeds broadcast + use of herbicide for weeding (N-H/B).

VI. Clear, tilled and seedlings-transplanted + use of orizo-plus selective herbicide for weeding (C/T/T/S). The plots involved were cleared, tilled manually with native hoe, and followed by transplanting. During weeding operation, orizo-plus selective herbicide was used for weeding.

VII. Non-selective herbicide was applied, clear, tilled and seedlings-transplanted + uses hand weeding (N-Hw/C/T/ST/ Hw). A branded name non-selective herbicide (Uproot) was applied to kill the grasses in the affected plots; after two weeks of application, the plots were cleared of the dried grasses, later were tilled with native hoe and rice seedlings transplanted. Hand weeding was used during weeding operations in the affected plots.

Inorganic fertilizer (NPK 20:10:10) combined with rice husk dust was applied basally at 200 kg/ha and 5 t/ha, respectively, in all the plots. The rice husk dust was applied to those plots where seeds broadcasting were carried out at the time of the broadcasting, while the rice husk dust was applied and incorporated to the tilled and transplanted plots at the period of tillage operation. The NPK 20:10:10 was applied two weeks after germination or two weeks after transplanting as the case may be.

2.1.2 Planting

I. Broadcasting method: The test crop was rice (*Oryza sativa* –FARO 57 variety). The plots where rice seeds broadcasting were adopted as a method had no determined plant spacing but were thinned 2 weeks after germination where they were found to be crowded. The broadcasted rice seeds started germinating after 4 days. The plots were ponded with water after one month of germination.

II. Transplanting: Nursery bed was established for these plots where the rice transplanting method was practiced. In this regard, a raised bed was made, followed by the broadcasting of rice seeds on the raised bed. The seed rate in transplanting is 30kg/ha as against 40kg/ha in broadcasting method. The prepared nursery was ready for transplanting into field at the age of 3 weeks, as transplanting of seedlings at a later age reduces tillering rates. Transplanting was done by uprooting the seedlings and washing-off the attached soil particles on the roots and transplanted with the aid of fork-sticks. Planting space of 20 cm x 20 cm was used in the transplanted plots to give a plant population of 221 stands/plots and a total of 250,000 stands/ha.

2.1.3 Weeding

Weeding operation was carried out manually by hand or with herbicides according to the treatments' specifications at the right time.

2.2 Data collection

The grain yield data was determined by weighing the rice grain after harvest and threshing, using a weighing balance.

2.3 Soil sampling and laboratory techniques

At the commencement of the experiment, a composite soil sample from random points was collected from the site using a soil auger at 0-20cm depth. Core soil sample collection was also carried out for determination of soil bulk density. At the end of the harvest, another set of auger and core samples was collected from all the identified sampling points on each of the plots from the top (0-20cm) soil depth for laboratory analysis.

The augured top soil samples were air-dried and sieved through 2mm sieve. Soil fractions less than 2mm from individual samples were then analyzed for cadmium and lead using the following methods.

I. Lead: The lead concentration was determined by using an instrumentation laboratory 1l251 atomic absorption spectrophotometer equipped with two hollow cathode lamp holders and Rank-Hilger slotted cathode lamps (Munter, 1990).

II. Cadmium: It was analyzed in the laboratory using atomic energy dispersive x-ray fluoresce Spectrophotometer (AED-XRFS), MiniPAL4 Model (C) 2005 (Munter, 1990).

2.4. Statistical Analysis

Data collected were subjected to analysis of variance (ANOVA) for a randomized complete block design (RCBD). Treatment means were separated and compared using Fisher's least significant difference (F-LSD) and all inference were made at 5 % level of probability according to Obi, (2002).

3. Results and Discussion

3.1. Initial soil characteristics of the studied soil (0 – 20 cm depth)

Table 1 showed the initial characteristics of the studied soil. It was obtained that the pH and cation exchange capacity (CEC) of the soil is low with a pH value of 4.8 and 10.40 cmol/kg value of cation exchange capacity (CEC) (Nwite *et al.,* 2014). There is likelihood that these situations might help to increase the concentration of heavy metals especially cadmium and lead in the soil on a long term. Nwite *et al.,* (2014), and Sharma and Agrawal (2005) reported that heavy metals retentions in the soil is associated with decreased soil pH and cation exchange capacity (CEC). The authors went further to submit that, at high soil pH, heavy metals are retained in soils if the buffering capacity is high enough to resist the acidic input solution and at low levels of soil pH, cation exchange capacity becomes the more dominant process in heavy metals retention. The initial concentrations of cadmium and lead in the soil were observed to be 0.834 mg/kg and 0.034 mg/kg, respectively. Fytianos *et al.,* (2001) submitted that elevated levels of heavy metals in soils are determined by soil pH value, organic matter and clay contents.

Table 1: Initial soil characteristics of the studied soil (0 – 20 cm depth)

Soil Properties	Values
Clay (g/kg)	200
Silt	230
Fine sand	530
Coarse sand	40
Textural class	Sandy clay
Organic carbon	11.4
Total nitrogen	0.84
pH (H_2O)	4.8
Silicon (mg/kg)	0.216
Cadmium (mg/kg)	0.834
Lead (mg/kg)	0.034
Exchangeable bases (cmol/kg)	
Sodium (Na^+)	0.03
Potassium (K^+)	0.06
Calcium (Ca^{2+})	1.80
Magnesium (Mg^{2+})	1.20
Cation exchange capacity (CEC)	10.40
Available phosphorous (mg/kg)	4.66
Exchangeable acidity (cmol/kg)	2.0

3.2. Effects of fields preparation techniques on selected heavy metals concentration

Results on cadmium (Table 2) showed that in the first year of the study, plots with N-H/C/B recorded the highest significant ($p < 0.05$) level (1.939200 mg/kg) of cadmium. This was followed by plots with N-H/C/T/ST (1.75 mg/kg) preparation techniques, while N-H/C/T/ST/Hw technique gave the least (0.97 mg/kg) significant concentration of cadmium in the studied soil. In the second year of the study, N-H/B field preparation technique significantly ($p < 0.05$) increased higher (2.71463 mg/kg) cadmium concentration on the top soil, while the same H/C/T/ST/Hw plots recorded the least (0.77600 mg/kg) concentration. Generally, the concentrations of the cadmium among the field preparation methods in both the first and the second year of the study except H/C/T/ST/Hw plots of second year (Table 2) were higher than the average soil Cd concentration (0.82 mg kg^{-1}) according to an investigation by Du *et al.,* (2006). However, the Cd values obtained in various field preparation techniques or practices were lower than the 3.0 mg/kg World Health Organization Maximum Permissible Standard as published in Doka *et al.,* (2020), but might increase above this permission level at a long term basis. The continued increased level of the cadmium in the studied soil if left unchecked might be unsafe to the human body if eroded into drinking stream waters, even when plants grown in the area uptakes it and were consumed. Accordingly, the Cd contamination of soil in this area if left unchecked will be severe, making it necessary to evaluate the food safety of the crops from these fields and carry out remediation for the Cd contamination. Raj *et al.,* (2013) submitted that heavy metals are much toxic and have a tendency to accumulate in the body and may result in chronic damage. They also reported that the natural concentration of metals in fresh water varies depending upon the metal concentration in the soil and the underlying geological structures, the acidity of the water, its humus content and particulate matter concentration.

It was obtained that lead concentration significantly ($p < 0.05$) varied among the treatments in both the first and the second year of study. Lead (Pb) was significantly increased higher (0.05 mg/kg) in N-H/C/T/ST plots than other plots, while N-H/B plot gave the least (0.01 mg/kg) concentration of lead in the first year of study. In the second year, the highest level (0.08 mg/kg) of concentration was recorded in the N-H/B plots whereas C/T/ST/HW field practice had the least (0.03 mg/kg) accumulation of lead. The concentration of Pb was less than the established standards of 1.0 mg/100 g of dry soil (FAO/WHO, 1996) published in: Kacholi and Sahu (2018).

Table 2: Effects of rice fields preparation techniques on selected heavy metals concentration

Treatments applied	Cadmium concentration		Lead concentration	
	Year 1	Year 2	Year 1	Year 2
C/T/ST/S	1.551300	1.63433	0.053433	0.053433
C/T/ST/HW	1.551233	0.96900	0.040200	0.026700
N-H/B	1.63400	2.71463	0.013500	0.080167
N-H/C/B	1.939200	1.74517	0.040267	0.026733
N-H/C/T/ST	1.745200	1.35733	0.053467	0.053467
N-H/C/T/ST/ Hw	0.969000	0.77600	0.026767	0.066800
Grand mean	**1.486556**	**1.53274**	**0.037939**	**0.051217**
F-LSD 0.05	**0.0007695**	**0.001124**	**0.0002946**	**0.0000879**

N-H/C/T/ST = Apply non-selective herbicides, clear, till and transplant + selective herbicide; C/T/ST/HW= clear, till and transplant + hand weeding; N-H/C/B = Apply non-selective herbicides, clear and broadcast + selective herbicide; N-H/B = Apply non-selective herbicides, broadcast+ selective herbicide; C/T/ST/S = Clear, till and transplant + selective herbicide; N-H/C/T/ST/Hw = non-selective herbicides, clear, till and transplant + hand weeding; F-LSD=Fisher's least significant difference

3.3 Effects of field preparation techniques on grain yield

The rice grain yield in the first year did not significantly ($p < 0.05$) improve due to the different field preparation techniques employed in the study. However, it was obtained that C/T/ST/HW field practice recorded the highest (5.89 t/ha) grain yield, whereas N-H/B fields gave the lowest (3.93 t/ha) of rice grain yield. In the second year of study, the results (Table 3) revealed that N-H/C/T/ST/ Hw field treatment yielded significantly ($p < 0.05$) higher (8.40 t/ha) grains of rice than other field preparations used. This was followed by C/T/ST/HW fields with a mean value of 7.66 t/ha, while N-H/B field preparation technique recorded the least (3.45 t/ha) grain yield in the study. Generally, it was observed that the second year yield performance appreciated higher than the first year of the study, except in N-H/B fields where its yield was reduced by 0.48 t/ha. It was recorded that in N-H/C/T/ST/ Hw field method, the difference in yield between year 1 and year 2 of the study was 20.2% yield difference.

Table 3: Effects of rice field preparation techniques on grain yield of rice (t ha^{-1})

Treatments applied	Rice Grain yield (tons/hectare)	
	Year 1	Year 2
C/T/ST/S	4.18	4.88
C/T/ST/HW	5.89	7.66
N-H/B	3.93	3.45
N-H/C/B	5.54	5.60
N-H/C/T/ST	5.07	5.87
N-H/C/T/ST/ Hw	5.58	8.40
Grand mean	**5.03**	**5.98**
F-LSD 0.05	**NS**	**2.141**

N-H/C/T/ST = Apply non-selective herbicides, clear, till and transplant + selective herbicide; C/T/ST/HW= clear, till and transplant + HAND WEEDING; N-H/C/B = Apply non-selective herbicides, clear and broadcast + selective herbicide; N-H/B = Apply non-selective herbicides, broadcast+ selective herbicide; C/T/ST/S = Clear, till and transplant + selective herbicide; N-H/C/T/ST/Hw = non-selective herbicides, clear, till and transplant + HAND WEEDING; F-LSD=Fisher's least significant difference

4. Conclusion

The study reveals that N-H/C/T/ST/ Hw recorded the lowest concentration of cadmium in both the first and second years of study. The results equally indicated that this N-H/C/T/ST/ Hw field preparation method which gave the least concentration of cadmium in the field also gave the highest significant rice grain yield in the study, while the N-H/B plot that recorded the highest cadmium concentration gave the least rice grain yield. This implies that as the concentration of cadmium increases in the soil, rice grain yield performance decreases.

Further research should consider whether there is a significant build-up of this cadmium in the rice seeds, to determine the safety or quality of the rice grain, i.e., whether this is problematic or not, as it is considered toxic to plants.

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