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Evaluation of the Effects of Different Sowing and Weed Control Methods on the Physiological Performance of NERICA 4 Rice Variety in Upland Ecology of Japan

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The experiment was established to determine the most yield enhancing combination of sowing method and weed control measure for the selected rice variety- NERICA 4. The experiment was conducted from March to November 2023, at the upland research field of JICA's Tsukuba International Center (TBIC), Japan. The experiment forms part of the fulfilment for the completion of

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a rice research technique fellowship in the Knowledge Co-Creation Program (KCCP) organized and funded by the Japan International Cooperation Agency (JICA). It consists of two sowing methods; Drilling (S1) and Dibling (S2)) as well as three methods of weed control; Chemical Weeding only at Sowing (CW), Chemical Weeding at sowing with once Hand Weeding at 60 DAS (CWHW) and Chemical Weeding at Sowing with Twice Hand Weeding at 60 and 90 DAS (CW2HW) which were combined to form six treatments. Treatments were laid in Randomized Complete Block Design (RCBD) with three replications of eighteen (18) plots. 8.9 g/plot of pendimethalin 2% (G0-G0-SAN) was used. Amaranthaceae, Cyperaceae and Poaceae were the prevalence weeds family identified. The treatment assigned to drilling and twice hand weeding in addition to chemical weeding at sowing (S1CW2HW) had the highest yield (3.95 tons/ha) while the treatment assigned to dibbling with the weeding control plot of only chemical weeding at sowing (S2CW) gave the lowest yield (2.5 tons/ha). There was significant difference at ($P<0.05$) amongst the mean yield values of all treatment combinations. However, the treatment assigned to same drilling but with once hand weeding (S1CWHW) had the highest profitability rank. This study concludes that sowing with drilling and weed management by pendimethalin and once hand weeding may be productively viable for the variety. This outcome may serve as a benchmark for further research within same thematic framework for increased productivity of rice farmers in the west African sub-region from where the first two authors were sent for the experiment in Japan.

Keywords: Dibbling; drilling; hand weeding; NERICA 4; pendimethalin, profitability.

1. INTRODUCTION

Dibbling is the most common method used for sowing rice on upland ecologies across the sub region (Nigeria and Ghana) of the first two authors while broadcasting is the most adopted alternative to it. The number of farmers who have tried drilling as a direct seeding method in West Africa between 2008 and 2018 represents a staggering two percentage of the total number of farmers documented within the period [1]. Lack of interest and willingness to adopt drilling as an alternative to broadcasting and dibbling by rice farmers in the sub-region has been majorly attributed to the reported strenuous and requirement of careful and higher number of weeding frequency [2]. There is a growing need for stakeholders in the West African sub region to establish optimal planting methods for each of the available rice varieties in order to ensure yield output that can encourage the cultivation of rice on upland ecologies in the two countries [1].This forms the background regional challenge which necessitated the participation of the first two authors in the research fellowship in order to determine the optimized sowing method for the rice variety in accordance with the theme of the fellowship program which was; Rainfed Rice Cultivation, Seed Production and Variety Selection under the supervision and mentorship of the third author.

A major challenge confronting direct seeding method was reported to be the weed pressure. If weeds are well managed, the crop may give a yield of about 3.70 ton/ha depending on the genetic and morphological characteristics of the variety [3]. In rain fed ecologies, weeds compete with rice plants for water, light, space and available soil nutrients. Under adverse conditions, weeds negatively affect leaf architecture, plants' physiological indices such as; plant growth cycle, tillering ability, as well as yield and yield attributes of rice [4]. Therefore, weed control in rice crop is becoming a greater challenge for successful crop production. Situ et al [5] reported that, weed competition is the major challenge limiting the yield and productivity of upland rice cultivation. Little or no information was however reported regarding the effects of both sowing method and weeding regime on the productivity of the selected variety in specific relation to the sub-region.

The objective of the experiment was to establish the most yield enhancing combination of sowing method and weed control measure for the selected rice variety (NERICA 4) which is usually grown by farmers of the countries of the first two investigators. NERICA 4 is however, the most widely adopted of the 18 improved upland rice varieties developed by AfricaRice Center's team led by Dr Monty Jones. Further research and development of NERICA rice varieties have been under the auspices of the Japan International Cooperation Agency, same agency which invited the first two investigators to Japan for the KCCP program from their respective countries of Nigeria and Ghana.

Data from the stand points of the interactions of sowing and weeding regimes on rice variety as obtained from this study indicated appreciable alignment with reported data from different experimental locations.

2. MATERIALS AND METHODS

2.1 Description of Experimental Field

The field component was carried out on the annex field of the Tsukuba International Center (TBIC) and conducted from April to October, 2023 while the laboratory and workshop components were carried out using relevant laboratories and work spaces within TBIC. The experimental field was located on Latitude 36.0^{o} N, Longitude 140.1^{o} E and Altitude of 25m above sea level. The six treatments combination used for the experiment are as described in Table 1.

2.2 Experimental Design

The six treatment combinations were laid out in a Randomized Complete Block Design (RCBD) with three replications of eighteen (18) total plots. The gross plot size was 4 m x 3 m (12 m^2). Each block/ rep contained plots (6 plot block^{-1}×3 replications = 18 plots). Total area used for the experiment was 27.5 m × 10 m.

2.3 Land Preparation

The land was tilled twice on the 5th and 25th April, 2023 and leveled using a tractor mounted rotary tiller operated by TBIC technicians. Compost manure (Horse dung 1ton/10a) and Diazinon insecticide (6kg/10a) were both incorporated into the soil during the ploughing operation on the 8th of May, 2023.

2.4 Seed Preparation

Seeds were selected using specific gravity (1.00) of clean water to separate floating and sunken seeds. Sunk seeds were subjected to hot water seeds treatment method to avoid seed borne diseases. Seeds were placed inside a net bag and soaked in hot water at T 60^{oc} for 10 minutes. The treated seeds were immersed in cold water immediately after removal from the treatment basin after which the seeds were dried. The selected seeds were subsequently disinfected by soaking in Benlate-T (Thiruam 20%, Benomyl 20%) solution for 24 hours in order to prevent fungal diseases., the seeds were removed and dried for 24 hours after which seeds were coated with KIHIGENT (TMTD 80%, 1% of seed weight) to prevent seed picking by birds.

2.5 Sowing

Prior to sowing, inter row spacing of 45 cm was made using specified hand-held calibrated row spacing tool on each of the plots assigned to drilling (S1) while, inter row spacing of 20 cm × 30 cm was made using a calibrated hand-held fabricated row maker on each of the plots assigned to dibbling (S2) The 20 cm × 30 cm fabricated row maker was used to make shallow holes of 4cm deep on all the dibbling plots while drills of 4cm were opened on all drilling plots using a hoe. Five (5) seeds/hill were firstly sown at a depth of 2 cm to 3 cm after which the soil was covered and compacted with a fabricated hand-held rolling compacter. Thinning was subsequently done to adjust to 3 plant/stand. Equal seed rate of 36g/plot (3 kg 1000/m^2 as per Japanese standard) was used across all treatments in accordance with the modified method of Workneh *et a*l [6].

2.6 Fertilizer Application

Single element fertilizers; N as Ammonium sulphate (21% N), P as Superphosphate (17.5% P_2O_5) and K as Potassium chloride (61% K_2O) were in two (3) splits i.e. Basal (sowing day) and top dressing (70 DAS) using equal rate across all plots as described in Table 2.

Table 1. Description of experimental treatment

Treatment Description	Treatment Combination (Codes)
Sowing methods	S
Drilling	S1
Dibbling	S2
Weeds control methods	W
Chemical Weeding only at date of sowing.	CW
Chemical Weeding at date of sowing + Once Hand Weeding after 60 Days After Sowing (DAS).	CWHW
Chemical Weeding at date of sowing + Twice Hand Weeding at 60 DAS and 90 DAS.	CW2HW

Table 2. Design of fertilizer application

Type	Basal application kg ha^{-1}	Top dressing kg ha^{-1}	Total kg ha^{-1}
N(Nitrogen): 60 kg ha^{-1}	40	20	60
P (Superphosphate, P_2O_5):100kg ha^{-1}	100	0	100
K (Potassium K_2O) 75kg ha^{-1}	75	25	100

** Top dressing: applied at about 70 Days after Sowing (DAS)*

Table 3. Description of investigation

Investigated Parameter	Period of Investigation (DAS)
Seedling Establishment/ Germination count (%)	30
Plant Length (cm)	30,55,70 and102
Tiller Number (m^2 or hill)	30,55,70 and102
SPAD value	30,55,70 and102
Leaf Area Index	70 and 102
Weed Identification and Weed Dry Matter	60 and 90
Manual Weeding	65 and 95
Yield and Yield Components	135

2.7 Weed Management Approach

8.9g/plot of a Japanese brand of pendimethalin (GO-GO-SAN) was applied at equal rate of 8.9g/plot across all plots same day after sowing. While manual weeding control was done according to the treatment combination (Table 1) using a combination of Japanese hoe and hand removal of weed.

2.8 Weed Identification

One (1) m^2 quadrat was used to measure weed species prevalence. The quadrat was randomly placed at three points in the middle diagonally on each of the plot. The weeds in each quadrat were then identified using a weed album and in accordance with the modified method of Krishnaprabu [7].

2.9 Data Collection

At 25 DAS, five (5) different spots containing seven (7) hills of plants were tagged with pegs as sample plants in each of the plots containing dibbling treatments while five different spots containing 50 cm of plants were tagged with pegs as sample plants on each of the plots containing drilling treatments. Data was obtained at intervals from the tagged samples. Additional two spots were added in each plot for the collection of harvest data. Borders rows were excluded during the selection of sample plants.

2.10 Investigated Items/Data Parameters

Data on physiological growth performance, were investigated at early growth stage, active tillering, maximum tillering, heading as well as harvest stages for yield and yield components parameters of the plant as presented in Table 3.

2.11 Data Analysis

Data collected was subjected to analysis by the statistical analysis software, Statistix 10 analytical package (2013) for windows. The analysis of variance (ANOVA) procedure for RCBD was used to determine significant differences among treatments. Tukey's Honesty Significant Difference (HSD) was also used for multiple comparison of treatment means that showed significant differences at 5% probability level. Economic analysis was also performed to determine the profitability of each experimental treatment.

3. RESULTS

3.1 Seedling Establishment

Fig. 1 shows the result of the rate at which the NERICA 4 seed used across each of the treatment combination established at 30 DAS. The rate of establishment ranged between 87% (S2CW) and 90% (S1CW2HW).

3.2 Plant Length

The effects of treatment combinations on the plant length of NERICA 4 at 30 DAS, 55 DAS, 70 DAS and 102 DAS is as presented in Fig. 2 wherein gradual increase of length was observed in all treatments though, with considerable variation from one growth stage to another. Specifically, at both maximum tillering and heading stages, highest plant length of 98 and 108 cm (S1CW2HW) were recorded while lowest plant length of 86 and 96 cm (S2CW) were obtained. At the heading stage, a significant difference ($P<0.05$) observed in the mean value of plant length amongst all treatments.

3.3 Tiller Number

The number of tillers (Fig 3) produced at different growth stages increasingly differ from one treatment to the other with highest count observed at 102 DAS for all treatment combinations. The treatment combination assigned to drilling combined with twice hand weeding (S1CW2HW) produced the highest tillers (53 tillers/30cm^2) while dibbling assigned to the control plot of weeding (S2CW) contained the lowest number of tillers (9/hill) at the final count (102 DAS). Significant difference at (P<0.05) was observed in the mean tiller count between the two sowing method groups at the heading stage.

3.4 SPAD Value

Fig 4 reveals the result obtained from the evaluation of the surface chlorophyll contents of the leaf of the plant across all evaluated treatment combinations. SPAD value however, increased in each treatment from the early growth stage to the maximum tillering stage before it started to decline at the heading stage (102 DAS). The dibbling treatment combined with twice hand weeding after chemical weeding (S2CH2HW) had the highest SPAD value (43.9) at 70 DAS while drilling assigned to the weeding control plot (S1CW) shows the lowest SPAD value (36.1) at 70 DAS. However, a significant different at (P<0.05) was observed in mean SPAD values between drilling and dibbling groups only at the heading stage.

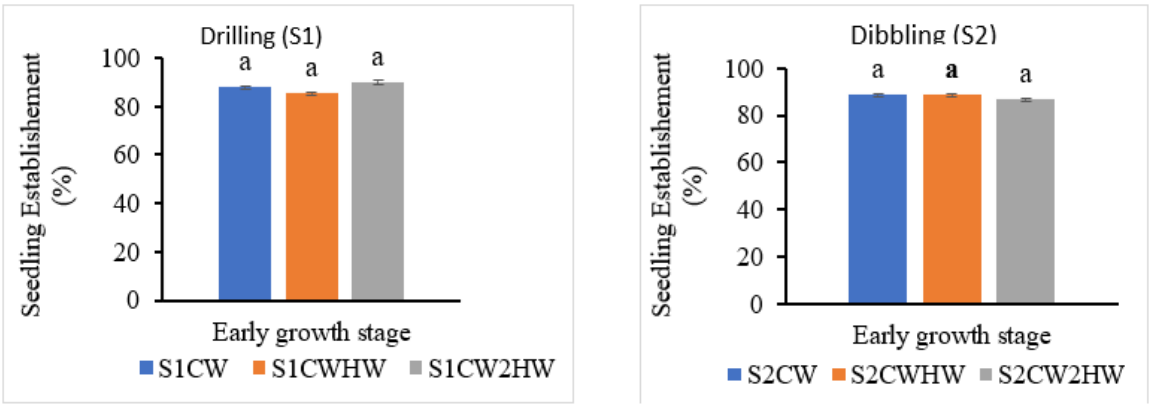

Fig. 1. Change in percentage of seedling establishment of NERICA 4 by treatment combination

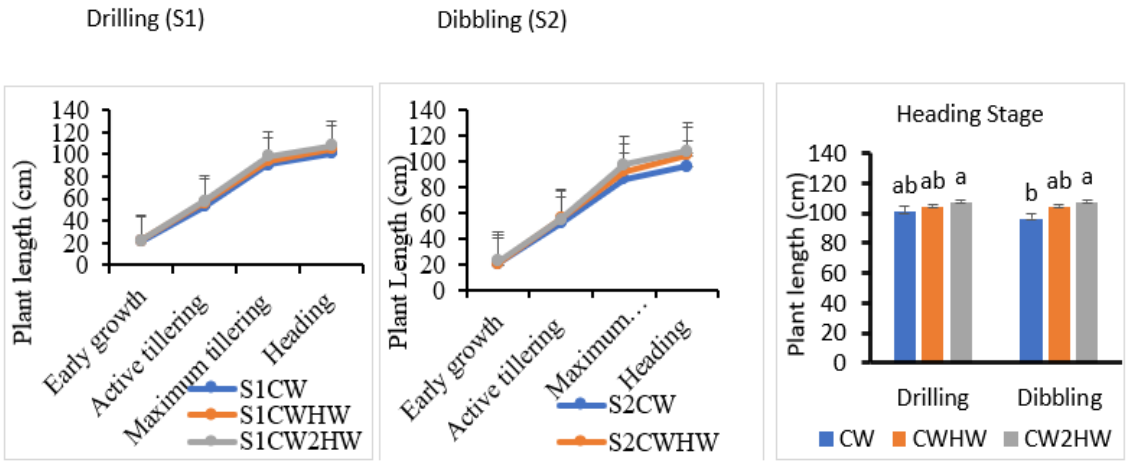

Fig. 2. Change in plant length of NERICA 4 by treatment combination

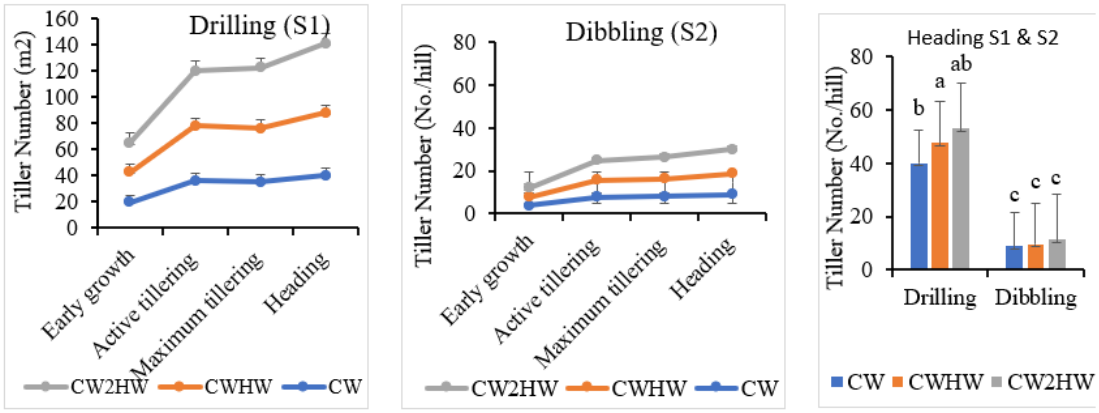

Fig. 3. Change in tiller number of NERICA 4 by treatment combination

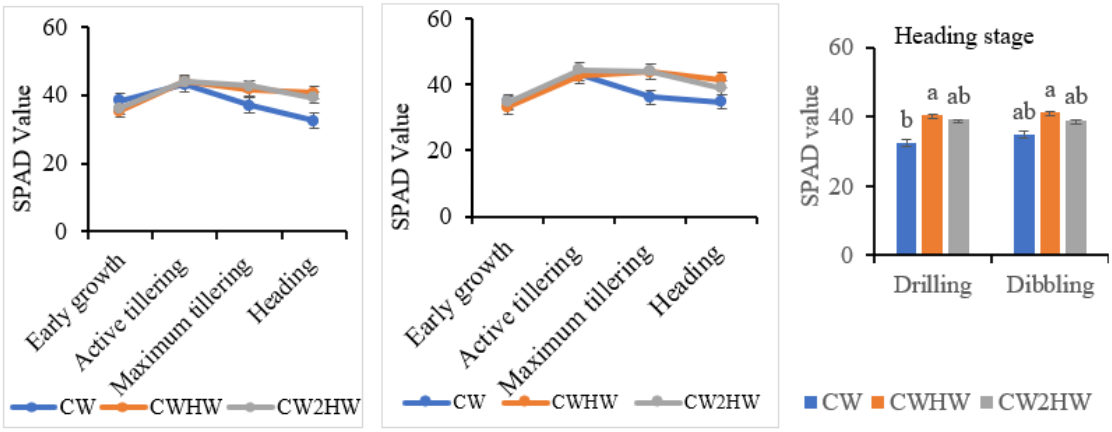

Fig. 4. Change in SPAD Value of NERICA 4 by Treatment Combination

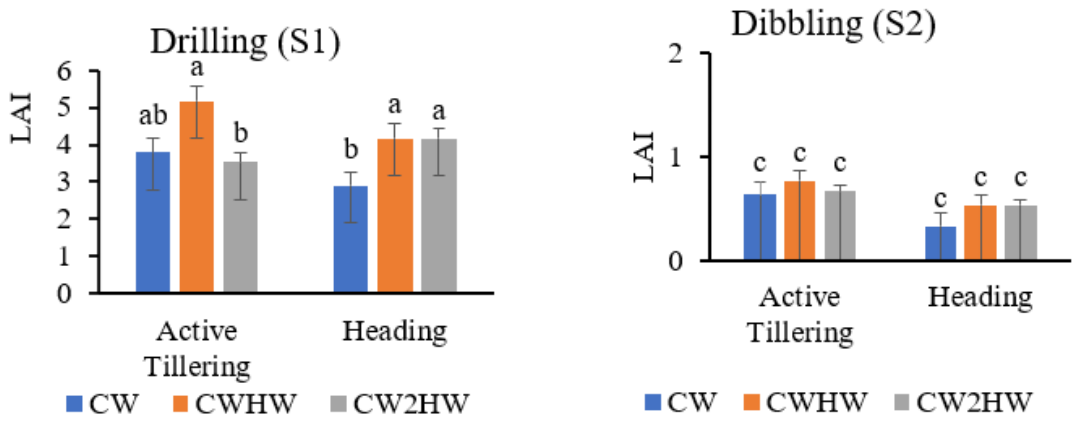

Fig. 5. Change in LAI of NERICA 4 by Treatment Combination

3.5 Leaf Area Index (LAI)

Presented in Fig 5 as evaluated at the maximum stage of plant tillering and the heading stage (70 DAS and 102DAS). The treatment assigned to drilling and one hand weeding (S1CWHW) possesses the highest LAI (5.2 and 4.2) at both stages of evaluation while the treatment assigned to dibbling with the control plot of weeding (S2CW) has the lowest LAI (0.6 and

0.3). The LAI values as well as weights of their dry matter show significant difference at (P<0.05) between the two sowing methods at both stages of evaluation.

3.6 Dry Weight of Leaf Area Index (LAI)

The dried weight of Leaf Area Index (LAI) was obtained at 60 and 90 DAS as presented in Fig 6 and ranged between 31.7-57.9. Significance Difference was observed amongst the treatments at both stages of evaluation.

3.7 Dry Weight of Weed

Varying weights of dried matter of weeds isolated from each plot were derived and analyzed at 60 DAS and 90 DAS prior to weeding activity. The result is as presented in Table 4, the weed control plot assigned to dibbling (S2CW) had the highest weed dry matter (124 g/m^2) at 90 DAS while the lowest was recorded on the drilling plot assigned to twice hand weeding (S1CW2HW) which had 52 g/m^2 at 90 DAS.

3.8 Weed Identification

A total number of seven different weed species were found at varying spots and different stages during the lifespan of the plant. Two different species of broad leaf Amaranthaceaa (*Chenopodium album* and *Dyphania pumilio)* exerted highest dominance on the field. However, sedges and grass types of weeds were also identified with varying degrees of prevalence on the field as described in Table 5.

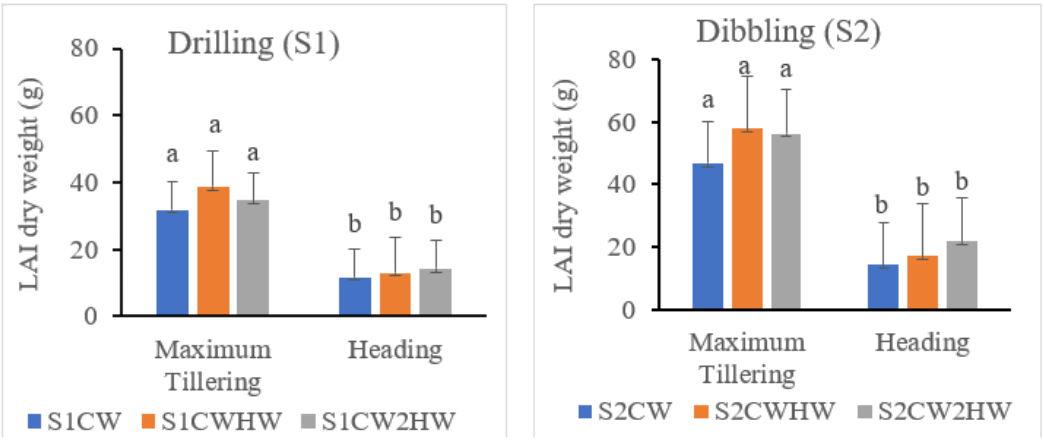

Fig. 6. Change in dry Weight of LAI of NERICA 4 by Treatment Combination

Table 4. Change in dry weight of weeds found in NERICA 4 by treatment combination

Sowing Methods	Weeds Control Methods	Weeds dry weight at maximum (g/m^2)	Weeds dry weight at Heading (g/m^2)
Drilling (S1)	CW	2.9	111ab
	CWHW	1.9	35ab
	CW2HW	1.4	21b
Dibbling (S2)	CW	2.0	124a
	CWHW	5.0	54ab
	CW2HW	2.4	52ab
Sowing Method	S1	2.1	55.8
	S2	3.1	76.6
Weeding	CW	2.4	118a
	CWHW	3.4	37.3b
	CW2HW	1.9	43.5b
Sowing		n.s	n.s
Weeding		n.s	*
Sowing+Weeding		ns	*

*with same superscripts in each column are not significantly different at 5%Tukey test (HSD). *significant at 5%*

Table 5. Identity and prevalence of weed on NERICA 4 experimental field

Scientific Name	Morphological type	Family	Prevalence
Chenopodium album	Broad leaf	Amaranthaceae	+++++
Cyperus microiria	Sedge	Cyperaceae	+++
Digitaria ciliaris	Grass	Poaceae	+++
Dyphania pumilio	Broad leaf	Chenopodioideae	+++++
Eleusine indica	Grass	Poaceae	+++
Galinsoga quadriadiata	Broad leaf	Asteraceae	+
Solanum carolinense	Broad leaf	Solanaceae	+

3.9 Yield and Yield Components

The effects of treatment combinations of sowing (Drilling and Dibbling) and weeding method (CW, HW and 2HW) on yield components and yield were as summarized in Table 6. Highest number of panicles, spikelet, weight of thousand grain and ripening ratio (240 m^2, 99 m^2, 29 g and 48.7 %) respectively were recorded in the drilling treatment assigned to twice hand weeding (S1CW2HW) which correspondingly led to the highest yield of 3.95 tons/ha in the same treatment. However, the dibbling plot assigned to the control plot of weeding (S2CW) had the lowest mean yield value of 2.5 tons/ha with corresponding lowest values of investigated yield components. The harvest index which ranged between 0.43 (S2CW) to 0.61(S1CW2HW) follows same trend from the least yielded treatment (S2CW) to the most yielded (S1CW2HW). However, a significant difference at ($P<0.05$) was observed in the yield mean values across all treatments. A combined interaction of sowing methods and weeding regime was also observed in the yield and most of the yield components with the exception of weight of a thousand grain and ripening percentage.

3.10 Economic Analysis

The ranking order of potential profitability of each treatment condition to farmers is as provided in Table 7. Ranking was based on the monetary value of revenue from each treatment (USD) which resulted from the subtraction of the total cost of production from the monetary value of yield. The total cost of production was a summation of each cost component (seed, fertilizers, herbicides, labour charge, etc) after conversion to the actual situation based on the experimental quantities. S1CWHW (drilling with once hand weeding) had the highest profit rank (1) while S2CW had the lowest (6).

Table 6. Yield and Yield components of NERICA 4

Sowing Methods	Weeds Control Method	No. of panicles (m^{-2})	No. spikelet's/panicle	1000 grain weight (g)	Ripening Percentage (%)	Paddy Yield (t ha^{-1})	Harvest Index
	CW	188^{ab}	76^{c}	27.7^{a}	53.1^{a}	2.65^{b}	0.42^{b}
Drilling (S1)	CWHW	238^{a}	87^{bc}	28.6^{a}	53.9^{a}	3.87^{a}	0.58^{a}
	CW2HW	240^{a}	99^{abc}	29.0^{a}	48.7^{a}	3.95^{a}	0.61^{a}
	CW	131^{b}	96^{abc}	28.7^{a}	57.0^{a}	2.50^{b}	0.43^{b}
Dibbling (S2)	CWHW	159^{b}	119^{a}	27.7^{a}	50.7^{a}	3.36^{a}	0.53^{a}
	CW2HW	181^{ab}	109^{ab}	28.9^{a}	55.6^{a}	3.79^{a}	0.57^{a}
Weeds Control	CW	159.3^{a}	85.83^{a}	28.20^{a}	55.05^{a}	2.58^{b}	0.55^{a}
	CWHW	198.3a	102.7a	28.18a	52.3a	3.58a	0.72a
	CW2HW	210.7a	104.2a	28.95a	52.15a	3.88a	0.76a
Sowing Method	S1	222.0a	87.2a	28.4a	51.9a	3.5a	0.77a
	S2	156.89b	107.9b	28.4a	54.4a	3.2a	0.58b
Weeds control		n.s	n.s	n.s	n.s	*	n.s
Sowing methods		*	*	n.s	n.s	n.s	*
Sowing+Weeding		*	*	n.s	n.s	*	*

Values with same superscripts in each column are not significantly different at 5%Tukey test (HSD).

- *Refers to significant difference at ($P<0.05$)*

n.s Refers to no significant difference at ($P<0.05$)

Table 7. Production economy of treatments combinations

Treatments	Cost of land preparation/ ha (USD)	Cost of seed/ha (USD)	Cost of fertilizer/ha (USD)	Cost of herbicide/h a (USD	Cost labour for weeding/person/h. (USD)	Cost of labour for sowing/person/h. (USD)	Total production cost (USD)	Yield (tons/ha)	Price of brown rice t/ha (USD)	Value of yield (USD)	Revenue (USD	Profitability ranking
S1CW	18.1	1.7	1.7	103.2	0.2	96.7	220.1	2.7	436.3	1156.2	936.1	5
S1CWHW	18.1	1.7	1.7	103.2	144.1	96.7	364.0	3.9	436.3	1688.5	1324.5	1
S1CW2HW	18.1	1.7	1.7	103.2	288.0	96.7	508.0	4.0	436.3	1723.4	1215.4	2
S2CW	18.1	1.7	1.7	103.2	0.2	159.9	283.3	2.5	436.3	1090.8	807.5	6
S2CWHW	18.1	1.7	1.7	103.2	144.1	159.9	427.2	3.4	436.3	1466.0	1038.7	4
S2CW2HW	18.1	1.7	1.7	103.2	288.0	159.9	571.2	3.8	436.3	1653.6	1082.4	3

Exchange Rate: 1USD-151.31Japanese Yen, 1USD-806.77 Nigeria Naira and 1USD-11.84 Ghana Cedis

4. DISCUSSION

The experiment was designed to investigate the possible effects of drilling and dibbling methods of directly sown rice as well as the effects of three different levels of weed control measures on the growth and yield of NERICA 4 rice variety. Obvious variation in growth parameters between the two sowing methods was only noticeable at the heading stage. This situation may be attributed to the impact of plant population which was reportedly higher in the drilling plots compared to the dibbling plots. This finding regarding increase in these traits especially plant length and tiller count is in agreement with data reported by Farshid and Hamid [8]. Moreover, maximum plant length found in S1CW2HW and the minimum in S2CW is a clear indication of the combined interactive effects of higher plant population in drilling and the effectiveness of two hand weeding over other weeding regimes. Twice hand weeding has been previously reported to impact tallness of plant height with positive consequence on tiller count and grain size [5].

It is evident that higher concentration of weeds found in the weeds control treatments of sowing factors; drilling (S1CW) and dibbling (S2CW) was not significantly higher than the rest of the treatments until around 60 DAS which was beyond the active tillering stage. This situation as revealed by the result of the weed dry weight may be attributed to the prolonged activity of pendimethalin (GO-GO-SAN). This scenario may as well be an evidence-based justification to support the effectiveness of its specific active ingredient as a pre-emergence capable of inhibiting the growth of weeds seeds in rice fields for up to 60 DAS. The life span of pendimethalin on rice fields has been reported to be above 40 DAS [7]. Although, the concentration of dry weight of weeds in this experiment is higher than that reported by Muhammad [9].

The variation in yield as observed in this study is directly proportional to the difference in the number of panicles per m^2 and number of spikelets per panicle. Consistent interaction of both sowing and weed control measures with the two parameters evidently led to maximum yield in S1CW2HW and lowest yield in S2CW. The improved performance of combined indices of growth (plant height, tiller count etc.) and yield attributes (panicle number, spikelet number) in S1CW2HW might have resulted to its superior, yet enhanced rice grain yield. Similar results were however, reported by Krishnaprabu [7] for rice planted with another method but managed with same weed regimen. Meanwhile, despite the variation in yield and yield components occasioned by treatment conditions in this trial, the yield of NERICA 4 across all treatments generally falls within ranges previously reported by Workneh *et al* [6] and Tsedalu *et al* [10] for the variety in the same location in Japan. The highest yield obtained in the drilling treatment in this experiment is somewhat in contravention of its potential in economic profitability wherein drilling with just one hand weeding returned highest profitability following economic analysis of production. This may be attributed to the lack of significant difference in the mean of yields between one hand weeding and two hand weeding as observed in the yield data [11].

5. CONCLUSION

In this study, all comparative data (from broadcast, sowing, selective herbicides etc.) required to establish all effects of sowing methods and weed regimen were not exhausted. Nonetheless, the investigation concludes that drilling is a yield enhancing sowing method for the cultivation of NERICA 4 rice variety in rain-fed ecologies. It also concludes that the use of pendimethalin as pre-emergence herbicide supported with two hand weeding could be adjudged as an effective weed control measure for the evaluated variety. A combination of both techniques may therefore be more effective in promoting enhanced grain yield of NERICA 4 for farmers in the sub-region. However, this trial needs to be repeated and adapted to the savannah ecologies of the two countries of the first two authors.

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COMPETING INTERESTS DISCLAIMER

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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APPENDIX

Weed Album

I. *Chenopodium album*
II. *Dyphania pumilio*
III. *Cyperus microiiria*
IV. *Digitaria ciliaris*
V. *Eleusine indica*
VI. *Galinsoga quadriadiata*
VII. *Solanum*

Field Activities

SPAD meter usage

Data on tiller Number

Comparing Weeded vs Control plots

Sampling weeds with quadrant

Data on plant length

Field overview

Field day

LAI Data Sampling

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