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Evaluation of the effect of types of fertilization, sowing methods and seed rates on the yield and plant density of fonio (*Digitaria exilis* Stapf) in Mali

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ABSTRACT: This study is a contribution to fonio's agroecological intensification cultivation. Objective is to propose innovative recommendation based on interaction between fertilization*seed rate *sowing arrangement to increase fonio yields. A factorial trial was set up in Mali. Paddy yield and plant density were evaluated. Treatment involving mineral fertilization was the most productive with 10% gain over those involving compost and 30% over those involving zero fertilizer. In zero fertilizer condition, the best treatment with 640 kg ha^{-1} yield paddy combine zero fertilization, 15 and 30 kg ha^{-1} seed rate and broadcast sowing. In mineral fertilization condition the best treatment with 1090 kg ha^{-1} combine mineral fertilizer, 15 and 30 kg ha^{-1} seed rate and broadcast sowing. In compost condition, the best treatment combine compost, 15 and 30 kg ha $^{-1}$ of seed rate and broadcast sowing and compost, 1 and 2 kg ha $^{-1}$ seed rate and line sowing, with an average paddy yield of 835 kg ha^{-1}. Doubling seed rate does not affect paddy yield, but affects essentially plant density for treatments involving broadcast sowing. Treatments involving broadcast sowing with 30 kg ha^{-1} of seed rate have plant density higher than 46%, 71% and 88% then treatments including broadcast sowing, 15 kg ha^{-1} seed rate, line sowing and hill dropping sowing at a seed rate of 2 kg ha$^{-1,}$ respectively.

KEYWORDS: broadcast sowing, hill dropping sowing, line sowing, mineral fertilizers, compost, interaction, yield and density.

1 INTRODUCTION

West African, fonio cultivation area was estimated more than 550,000 ha of land area per annum with production of 250,000 t/year and an average yield of 700 kg ha^{-1} [13] and yield is ranking between 0.2 t.ha^{-1} to 0.9 t.ha^{-1} [2], [7]. However, depending on cultivation conditions, some producer can reach 1200 kg ha^{-1} and even 2,000 kg ha^{-1}. In Guinea Conakry, top producer country across the word, cultivation area is about 459,563 ha and 479,985 t production in 2017 and yield is ranking between 605 and 847 kg ha^{-1} (SNA 2021). In Mali, fonio is growing mainly in Sahelian, North Guinea and Sudanese zones on around 40,533 ha, 22,000 t production which representing less than 2% of cereal cultivation area and less than 0.5% of cereal production [10]. Fonio land area per farm varies from 0.5 ha to 3 ha, with total available land area ranking from 5 to 13 ha. Yields are low, varying between 600 kg ha $^{-1}$ in Sahelian zone and 800 kg ha^{-1} in Sudanese zone [10]. Traditionally, fonio cultivation consist to a superficial work before sowing [23], and weeding to the demand. Sowing method on-farm is mainly broadcast and seed rate vary between 40 and 60 kg ha^{-1}. These rates, considered to be a waste of seed [18], while being a constraint to fonio growing areas extension, it's would help weeds control and reduce crop maintenance time. In Mali, the Institut d'Economie Rurale recommends 15 and 30 kg ha^{-1} of seed rate. However, in perspective to intensify fonio cultivation, 2 kg ha^{-1} seed rate is currently being tested on-farm. Traditionally, fonio don't benefited fertilization, although small quantities of mineral fertilizer are applied sparingly on -farm, particularly in northern Guinea zone, to compensate for growing deficits. In

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the sub-region, the mineral fertilizer rate initially proposed by fonio research is similar to sorghum and millet, i.e. 100 kg ha^{-1} of DAP and 50 kg ha^{-1} of urea. The Institut d'Economie Rurale (IER) has proposed smaller rates, i.e. 20 kg ha^{-1} of DAP and 10 kg ha^{-1} of urea (In press) which take into account fonio's low aerial biomass production relatively lower and nutrient requirements compare to millet and sorghum, and finally low income of producers.

Originally, fonio, for its early maturity period, was considered to be both a male and female crop, depending on agro-ecological zone. But following to maize introduction, which is also early but more productive, fonio became mainly a female crop in Sudanese and North Guinean zones, and remained a mixed crop in the Sahelian zone, with greater female involvement in harvesting and post-harvest operations.

Fonio cultivation faces a lot of constraints divide to production and post-harvest challenges. Production constraints include lack and poor application of good agronomic practice and poor application of technical itineraries recommended by research (Eric et al, 2007), lack of effective seed system [3], [4] and availability of improve seed, low yield. We can add biotic and abiotic stresses. Biotic stress include weeds like *Kyllinga squamulata*; phytophagy parasite and sucker flower and paddy at early maturing stage like *Lytta vesicatoria* and disease [2], [14], [17]. Abiotic stresses including terminal drought stress even fonio's crop have good recovery capacity during vegetative stage. Initial soil fertilizer can affect also fonio's production even fonio is less susceptible to low fertility compare to other crops. Post-harvest challenges including grain small size, threshing, winnowing, shelling and whitening [21]. Despite its status of called minor and neglected crop, fonio has remained part of farming systems over the years, as producers quickly recognized the role plays in improving soil structure, food security and nutrition [25]. It is also recommended in the diets of diabetics and obese people [11].

This study is a contribution to fonio's agroecological intensification cultivation. Objective is to propose innovative recommendation based on interaction between three types of fertilization, two types of seed rate and four types of sowing method in factorial trial to increase fonio yields. Paddy yield and density have been valued. Use new sowing methods like hill dropping and on line will allow mechanization and reduce seed rate. The study will provide responses to the following research questions: Are there significant differences between treatments in terms of paddy yield and plant density? What treatment should be proposed in different fertilization contexts? What is the impact of sowing arrangement and seed rates on yield and plant density?

2 MATERIAL AND METHOD

2.1 EXPERIMENTAL SITES

The work was carried out at Cinzana and N'Tarla Agricultural Research Stations and at Farako Agricultural Research Sub-station of the Institut d'Economie Rurale (IER) during the 2020-2021 raining season (**Figure 1**). The locations and main characteristics of these structures are listed in Table1.

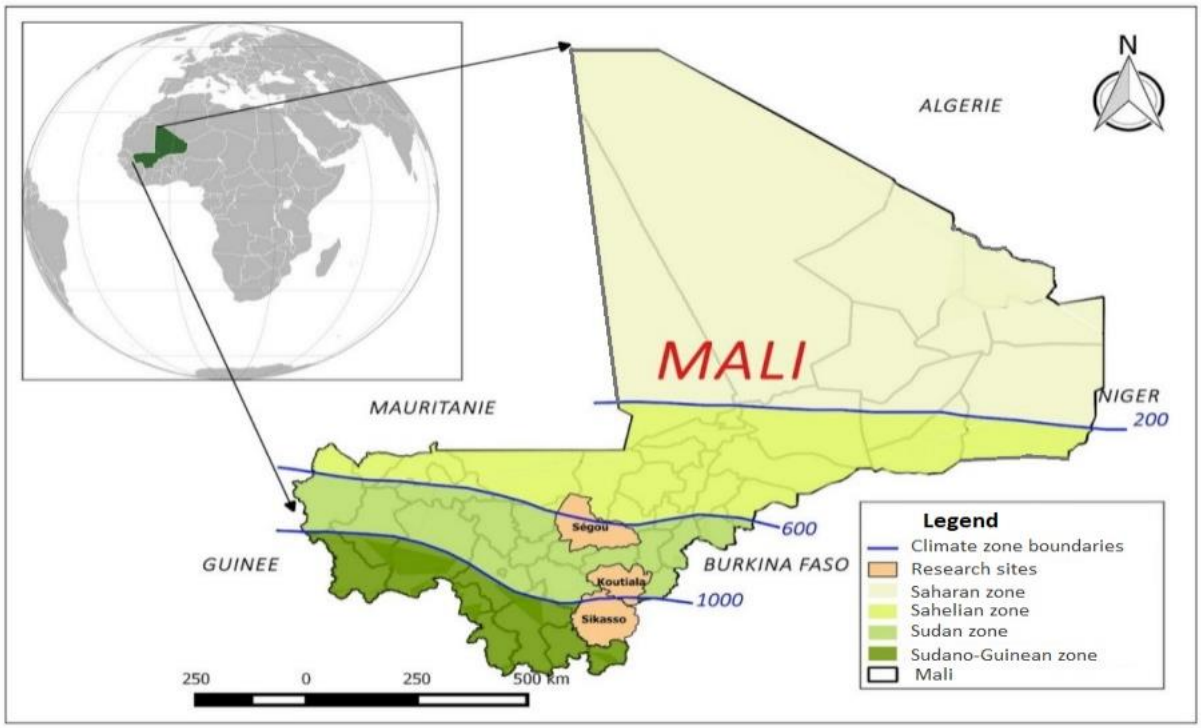

Fig. 1. Map of Mali with the different intervention zones

Table 1. Location and characterization of experimental sites

	SRA Cinzana	**SSRA Farako**	**SRA N'Tarla**
Administrative region	Ségou	Sikasso	Koutiala
Agro-ecological zone	Sahelian	North Guinean	Sudanese
Longitude and latitude	5 57' et 13*15'N	-5*48 W et 11*21N	5*42' et 12*35*
Average rainfall	700 mm	1100 mm	850 mm
Soil structure	Tropical ferruginous depleted, ruby modal	Leached tropical ferruginous	silty-clay-sandy
Average sand content horizon 0-20 cm		84%	72%
Texture	Silty sand	Silty sand	Silty sand
Previous crop	Cowpea	Maize	Sorghum

2.2 EXPERIMENTAL DESIGN

Trials were hand sown in a factorial design with 3 replications and 3 factors comprising 3 fertilization levels x 2 seed rates x 4 sowing arrangements, i.e. 24 entries, was set up. The main factor includes 3 levels of fertilization: compost made from cow dung and fonio and millet straws. It was applied at 1000 kg ha^{-1}; mineral fertilizers (Di Ammonium Phosphate at a rate of 20 kg ha^{-1} and 10 kg ha^{-1} of urea) and zero fertilization (control). The secondary factor concerned sowing rates: single and double rates of seed rate. The single rate is 1 kg ha^{-1} for hill dropping and line sowing, and 15 kg ha^{-1} for broadcast sowing (control 1). The double rate is 2 kg ha^{-1} for the first two sowing methods and 30 kg ha^{-1} for broadcast sowing (Control 2). The tertiary factor, concern sowing arrangements: in hill dropping at distances of 15 cm x 40 cm, hill dropping at distances of 30 cm x 40 cm, line sowing at a distance of 40 cm between lines and broadcast sowing.

Experimental design is divided in 3 blocs for main factor (compost, mineral fertilization and zero fertilization). Each bloc is divided in two sub-blocs for secondary factor (simple and double seed rate). In each sub bloc we had 3 repetitions and each repetition contain 4 plots with 4-m large and 6-m long. Each plot contain sowing method randomized.

2.3 PLANT MATERIAL

The plant material used was the Solosso variety, an ecotype from San region of Mali. An overview of the 24 treatments is given in Table 2.

Table 2. Overview of the 24 Treatments

Treatment	Fertilization	Type of planting	Sowing arrangement	Seed quantity
T1	Compost	Hill	15 x 40 cm	1 kg ha-1
T2	Compost	Hill	15 x 40 cm	2 kg ha-1
T3	Compost	Hill	30 x 40 cm	1 kg ha-1
T4	Compost	Hill	30 x 40 cm	2 kg ha-1
T5	Compost	Line	40 cm interline	1 kg ha-1
T6	Compost	Line	40 cm interline	2 kg ha-1
T7	Compost	Broadcast		15 kg ha-1
T8	Compost	Broadcast		30 kg ha-1
T9	Mineral fertilizer	Hill	15 x 40 cm	1 kg ha-1
T10	Mineral fertilizer	Hill	15 x 40 cm	2 kg ha-1
T11	Mineral fertilizer	Hill	30 x 40 cm	1 kg ha-1
T12	Mineral fertilizer	Hill	30 x 40 cm	2 kg ha-1
T13	Mineral fertilizer	Line	40 cm interline	1 kg ha-1
T14	Mineral fertilizer	Line	40 cm interline	2 kg ha-1
T15	Mineral fertilizer	Broadcast		15 kg ha-1
T16	Mineral fertilizer	Broadcast		30 kg ha-1
T17	Zero fertilizer	Hill	15 x 40 cm	1 kg ha-1
T18	Zero fertilizer	Hill	15 x 40 cm	2 kg ha-1
T19	Zero fertilizer	Hill	30 x 40 cm	1 kg ha-1
T20	Zero fertilizer	Hill	30 x 40 cm	2 kg ha-1
T21	Zero fertilizer	Line	40 cm interline	1 kg ha-1
T22	Zero fertilizer	Line	40 cm interline	2 kg ha-1
T23	Zero fertilizer	Broadcast		15 kg ha-1
T24	Zero fertilizer	Broadcast		30 kg ha-1

2.4 CONDUCTING THE TRIAL

A flat plough followed by levelling was carried out before sowing. Sowing was carried out in wet soil, without mixing fonio seed with sand and without fungicide treatment. For broadcast sowing, seeds were spread over the plots. In hill dropping and line sowing, hill and line were marked out before and followed by seeds sowing. Seeds are buried very superficially with a daba to prevent them being eaten by granivorous birds or plundered by ants. DAP and compost were broadcast and ploughed in at sowing time. Urea was spread as soon as flag leaves appeared on moist soil. Conditions of realization were carried out are shown in Table 3.

Table 3. Test conditions at the Cinzana, Farako and N'Tarla sites

Parameter	Cinzana	N'Tarla	Farako
Previous crop	Cowpea	Millet	Sorghum
Date of planting	June 26, 2021	June 28, 2021	June 28, 2021
Total rainfall received during the trial	331 mm	457.5 mm	489 mm

2.5 AGRO-MORPHOLOGICAL MEASUREMENTS.

Two agro-morphological measurements were done including plant density and paddy weight (kg ha^{-1}). Paddy consists of the husks surrounding the grains. They are removed by mechanical hulling.

2.5.1 DENSITY ESTIMATION

Plant density was determined 20 days after plant emergency. In broadcast plots, 10 squares of 20 cm x 20 cm were placed at random. In each square, all plants were removed and counted. The plants in the 10 squares were averaged to determine by extrapolation number of plants per hectare. In plots sown in continuous line, number of plants was determined in the same way as for broadcast sowing, but with squares placed along sowing line. In hill sowing plots, 10 hills were randomized, and plants were removed and counted. Based on the average of the number of plant in 10 hills, the density per hectare was determined by extrapolation.

2.5.2 YIELD ESTIMATION

At physiological maturity, a portion of aerial biomass including panicles was harvested approximatively 30 cm above the ground by sickle and stored in heap on tarpaulins with panicle exposed to the sun. After drying, aerial biomass is threshed with sticks to remove paddy. And after winnowing, plot paddy weights were determined with balance of precision called Kern ffn and paddy yield is determined by extrapolation.

3 RESULTS

3.1 PADDY YIELD (KG HA-1)

Higher yield was recorded at Cinzana, followed by both Farako and N'Tarla. At Cinzana, yield is ranking between 399 and 1005 kg $ha^{-1,}$ with 775 kg ha^{-1} average yield and 0.55 coefficient of repeatability. The best treatment is an interaction between zero fertilizer*seed rate at 2 kg ha^{-1}*line sowing with 1005 kg ha^{-1} average yield was highly significantly different (Table 4). Yield average analysis in relation with types of fertilization reveals that all treatments including compost were highly significantly more productive with 860 kg ha^{-1} an average yield. They were followed by all treatments including zero fertilizer (control) and all treatments including mineral fertilizer, both had 735 kg ha^{-1} of average yield. This performance of treatments including zero fertilizer is probably due to the after-effect of cowpea, which was the previous crop (Table 1). Yields average analysis in relation with seed rates reveals that all treatments including simple seed rate were significate more productive with 880 kg ha^{-1} compared to all treatments including double sowing rate with 652 kg ha^{-1}. Yields average analysis in relation with sowing arrangements reveals that all treatments including line sowing were not significantly different to those including all broadcast sowing treatments with respectively an average yield of 880 kg ha^{-1} and 830 kg ha^{-1}. But both were significantly different than those including all hill dropping sowing (15x40 cm and 30x40 cm) treatments with 695 kg ha^{-1}.

At Farako, yield is ranking between 212 and 1424 kg $ha^{-1,}$ with 710 kg ha^{-1} average yield and 0.85 coefficient of repeatability (Table 4). Three following treatments were highly significantly more productive: mineral fertilizer*2 kg ha^{-1}seed rate*line sowing, mineral fertilizer*15 kg ha^{-1} seed rate*broadcast sowing and mineral fertilizer*30 kg ha^{-1}seed rate* broadcast with 1390 kg ha^{-1} yield paddy. Yield average analysis in relation with fertilization types reveals highly significant difference. All treatment including mineral fertilizers with 1015 kg ha^{-1} yield paddy are the best. They were followed by all treatments including compost with 725 kg ha^{-1} and all treatment including zero fertilizer with 350 kg ha^{-1}. Yield average analysis in relation with sowing rates reveals no significant difference between all treatments including double sowing rate with 744 kg ha^{-1} and all treatment including single sowing rate with 652 kg ha^{-1}. Yield average analysis in relation with sowing arrangements reveals highly significant difference. All treatments including broadcast sowing with 870 kg ha^{-1} are more productive following by all treatments including line sowing, with 709 kg ha^{-1} and all treatments including hill dropping sowing (15x40 and 30x40) with 605 kg ha^{-1}.

At N'Tarla, yields is ranking between 350 and 1121 kg $ha^{-1,}$ with 699 kg ha^{-1} average yield and 0.78 coefficient of repeatability (Table 4). The best treatment is an interaction between mineral fertilizers* 30 kg ha^{-1}seed rate*broadcast sowing with 1121 kg ha^{-1}paddy yield. Yield average analysis in relation with fertilization types reveals that average yield of all treatments including mineral fertilizers had the highest significate average yield with 849 kg ha^{-1}. They were followed by those including compost with 725 kg ha^{-1} and those including zero fertilizer with 501 kg ha^{-1}. Yield average analysis in relation with seed rate reveals that there is not significantly different between treatments including double seed rate with 730 kg $ha^{-1}$and treatment including single seed rate with 652 kg ha^{-1}. Yield average analysis in relation with sowing arrangement reveals a highly significant difference in favor of all treatments including broadcast sowing with 870 kg ha^{-1}. They were followed by treatments including all line sowing with 709 kg ha^{-1} and those including hill dropping sowing (15x40 and 30x40 cm) with 630 kg ha^{-1} paddy yield.

Table 4. Summary of analysis of variance results for paddy yields (kg ha^{-1}) at Cinzana, Farako and N'Tarla sites, 2021

	Cinzana (kg ha^{-1})	Farako (kg ha^{-1})	N'Tarla (kg ha^{-1})
Trial mean	775	697	692
High Yield	1005	1370	1121
Low yield	399	212	350
Worst treatment	T11	T23	T19
Best treatment	T6 et T22	T14, T15, T16	T16
Repeatability	0.54	0.78	0.85
LSD (5%)	400	598	301
CV%	15.56	25.88	13.12
Fertilization * Rate	S	HS	HS
Fertilization * Arrangement	HS	HS	HS
Arrangement*Rate	HS	NS	HS
Fertilization * Rate *Arrangement	HS	HS	HS

Multisite analysis in relation with fertilization types revealed highly significate difference. Treatments involving mineral fertilizers were the most productive (Figure 2), with an average yield of 863 kg ha^{-1} and 10% higher than treatments involving compost (770 kg ha^{-1}) and 30% higher than treatments involving zero fertilizer (502 kg ha^{-1}). However, in mineral fertilization context, the two best treatments combined mineral fertilizer*15 kg ha^{-1} seed rate*broadcast sowing, and mineral fertilizer*30 kg ha^{-1} seed rate* broadcast sowing. In compost condition the best treatment are those combining compost*2 kg ha^{-1}of seed rate*line sowing, and compost *30 kg ha^{-1} of seed rate*broadcast sowing. In zero fertilizer context, the best treatment combined zero fertilizer*15 kg ha^{-1} seed rate*broadcast sowing, and zero fertilizer*30 kg ha^{-1} seed rate*broadcast sowing.

Multisite analysis involving sowing methods reveals highly significate difference. Best yields were obtained by treatments including broadcast sowing (figure 2) with an average of 846 kg ha^{-1} followed by treatments including line sowing with 751 kg ha^{-1} and treatments including hill dropping sowing with 643 kg ha^{-1} (15x40 cm and 30x40 cm), either 10% and 30% gains respectively. In broadcast sowing context the best treatments combining broadcast sowing, mineral fertilizer and 15/30 kg ha^{-1}seed rates. Their average yield is 1090 kg ha^{-1}. In line sowing context, best treatment to be recommended combine line sowing and mineral fertilizer with 15 and 30 kg ha^{-1} of seed rate with 910 kg ha^{-1} average yield.

Multisite analysis involving seed rates reveals that doubling seed rate does not affect yield (figure 2). The yield gain caused by doubling seed rate is very low, at 0.04%.

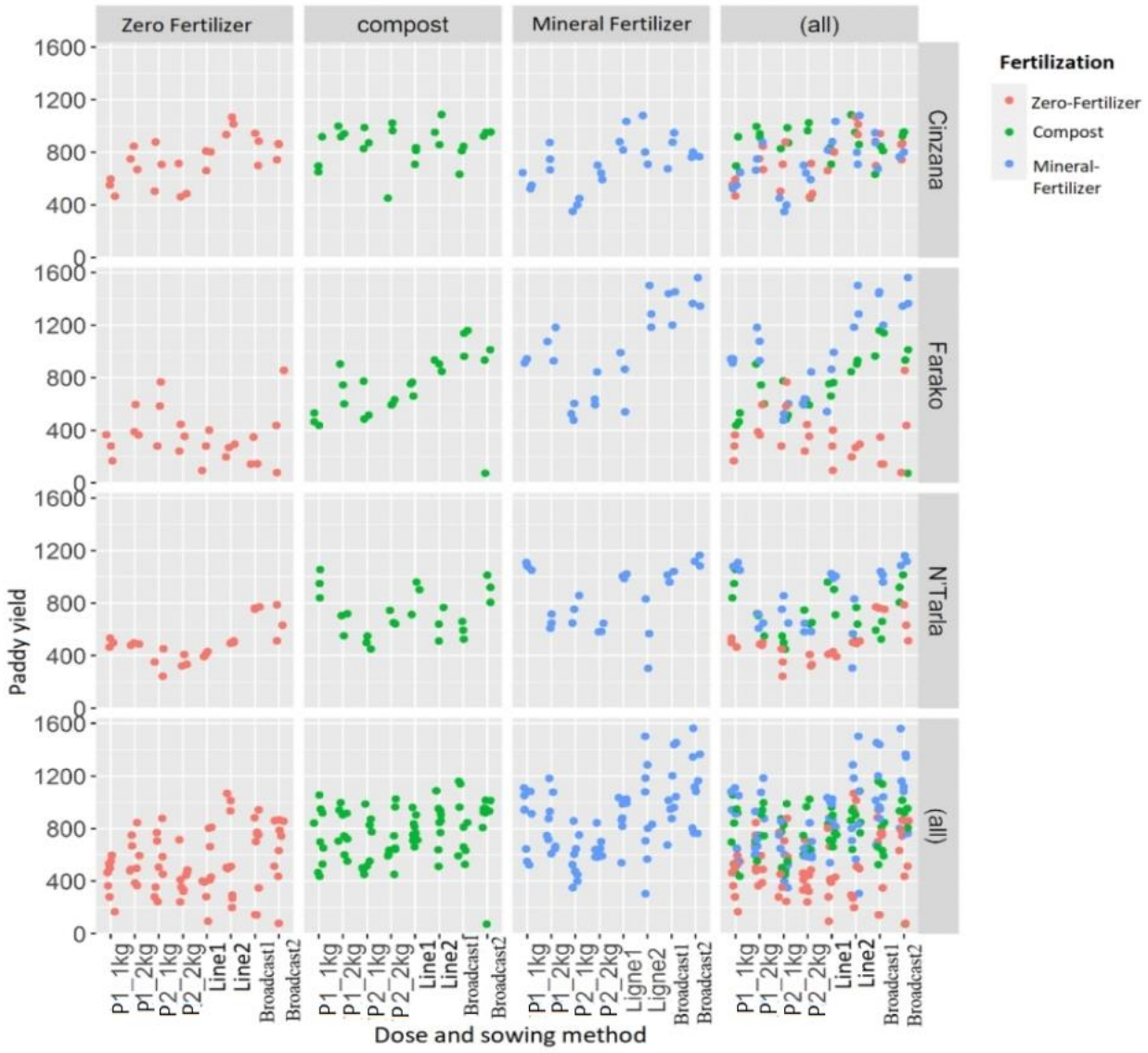

Fig. 2. Distribution of yields at different sites according to fertilization, sowing methods and rates

3.2 PLANTS DENSITY

Densities average varied from site to site with the highest at Cinzana, followed by Farako and N'Tarla (Table 6). At Cinzana, it's was 3,615,470 plants ha^{-1}, with 83% coefficient of repeatability. The highest density, 18,037,037 plants ha^{-1} was obtained by treatment combining mineral fertilizers*30 kg ha^{-1} of seed rate*broadcast sowing. Densities analysis in relation with sowing rate reveals highly significate difference in favor of treatments including double sowing rate with 4,429,571 plants ha^{-1} were the densest, compared to 2,801,369 plants ha^{-1} obtained by treatments combining single sowing rate. Densities analysis in relation with sowing method reveals highly significate difference. The densest were treatments including broadcast sowing, with 10,543,210 plants ha^{-1}. These were followed by treatments combining line sowing with 2,617,283 plants ha^{-1}, and those including hill dropping sowing (15x40, 30x40 cm) with 650,693 plants ha^{-1}.

At Farako, density average was 1,438,340 plants ha^{-1} with 64% coefficient of repeatability. There is highly significate difference. Highest density was obtained by treatment combining zero fertilizer*30 kg ha^{-1}seed rate*broadcast sowing. Density analysis in relation with sowing method reveals that treatments including broadcast sowing with 2,669,753 plants ha^{-1} were the densest followed by treatments combining treatment including line sowing with 1,979,938 plants ha^{-1} and those including hill dropping sowing with 551,833 plants ha^{-1}. Density analysis in relation with sowing rate reveals that treatments including double sowing rate were the densest with 1,635,368 plants/ha, followed by treatments combining single sowing rate with 1,051,611 plants ha^{-1}.

At N'Tarla, density average was 861,525 plants $ha^{-1,}$ with 40% coefficient of repeatability. There is significate difference. Highest density was obtained by following treatments with an average density of 2,319,444 plants ha^{-1}: zero fertilizer*30kg ha^{-1} seed rate*broadcast sowing, and mineral fertilizer*30 kg ha^{-1}seed rate*broadcast sowing. Density analysis in relation with sowing rates reveals highly significate difference in favor to treatments including double sowing, with 998,991 plants ha^{-1}. These were followed by all treatments combining single seed rate with 724,058 plants ha^{-1}. Density analysis in relation with sowing method reveals significate difference and treatments including broadcast sowing with 1,487,654 plants ha^{-1} was the densest. These are followed by treatments combining line sowing with 909,464 plants $ha^{-1,}$ and those including hill dropping sowing (15x40 cm and 30x40 cm) with 524,490 plants ha^{-1}

Table 5. Summary of results of analysis of variance of densities at Cinzana, Farako and N'Tarla sites, 2021

	Cinzana	Farako	N'Tarla
Trial mean	3 615 470	1 438 340	861 525
High density	18 037 037	4 046 296	2 333 333
Low density	484 027	390 555	194 444
Worst treatment	T20	T11	T21
Best treatment	T16	T24	T16 T24
Repeatability of plot value	83	64	40
Ppds (5%)	402524	116518	99464
CV%	25	30	36
Fertilization * Arrangement	HS	HS	HS
Fertilization * Seed rate	NS	NS	NS
Arrangement*Seed rate	HS	HS	HS
Fertilization*Seed rate*Arrangement	HS	HS	HS

Multisite analysis in relation with sowing arrangement reveals highly significate differences in favor of treatments involving broadcast sowing (Table 8). Following densities averages were obtain: 575,672 plants/ha for treatments involving hill dropping sowing (15x40 and 30x40cm), 1,835,562 plants ha^{-1} for all treatments involving line sowing and 4,900,205 plants ha^{-1} for treatments involving broadcast sowing, which achieved gains of 78% and 62% compared with the treatments involving respectively hill dropping and line sowing. A deeply analyze reveal that among broadcast sowing there is a significant difference between 30 and 15 kg ha^{-1} seed rate. But among line sowing with 1 and 2 kg ha^{-1} seed rate and hill dropping sowing with the same rates there is no significant difference between 1 and 2 kg ha^{-1} seed rate. So, seed rate doubling affected only density of treatments including broadcast sowing. Ratios densities among sowing methods and seed rates are mention in Table 8.

Table 6. Comparison of plant densities according to sowing method and sowing rate

Mode	Rate (kg ha^{-1})	Average density	ratio with 15 kg (%)	ratio with 30 kg (%)
Line	2	1,883.058	45.00	71.00
Line	1	1,788,065	47.00	72.00
Hill	2	733,717	78.00	89.00
Hill	1	733,271	78.00	88.00
Broadcast	15	3,411,522		46
Broadcast	30	6,388,888		
Line	2	1,883,058	45.00	71.00

4 DISCUSSION

In terms of yield, significant differences were recorded in favor of treatments involving mineral fertilizers, with 361 kg ha^{1} difference compared to treatments involving zero fertilization (control). The purchase price of 20 kg of DAP and 10 kg of urea was 7,500 FCFA (approximatively $15) for non-subsidized fertilizers and 15,000 CFA (approximatively $30) for subsidized fertilizers. Depending on selling period, the price per kg paddy can vary from 150 CFA (approximatively $0.3) at harvest September to 200 CFA (approximatively $0.4) in December and reaching 300 CFA (approximatively $0.6) in June. Selling price of 361 kg supplement at 200 f/kg is 72,200 F (approximatively 144$) and 108,300 FCFA (approximatively 217 $) when 1kg paddy is sold at 300 FCFA. When fertilizer is subsidized, gross profits are respectively 64,500 FCFA (approximatively 129 $) and 100,800

FCFA (approximatively 216 $). On the other hand, when fertilizer is not subsidized, gross profits are 57,000 FCFA (approximatively 114 $) and 93,300 FCFA (approximatively 187$) respectively.

Studies achieved in West Africa have been focus on mineral, organic and organic-mineral fertilizations impact on paddy yield and rarely on factorial trial combining fertilization types, seed rates and sowing methods. Otherwise, fertilization rate recommended on fonio crop in West Africa is similarly to those applied on millet and sorghum [18], [24] contrary to the small rates that we applied in this study. When we take into account the above-ground biomass produced by millet and fonio, we can deduce that there is overdosing with application of fertilizer rates for tall cereals on fonio. Furthermore, the low income of small producers and the high cost of mineral fertilizers mean that the recommendations made with high rates cannot be adopted by farmers. Studies in sub-region concluded on the agronomic profitability of fertilization compared to zero fertilization but without making a financial profitability analyze. Our agronomics results are similar with those obtained by [15]. They conclude a good response of Flooded Lowland Rice when we applied moderate fertilization rate.

Depending on fertilization context, producers who apply zero fertilization, choice of sowing method and seed rate did not affect yield. However, at Cinzana site with cowpea as previous crop, zero fertilization associated with broadcast sowing with 30 kg ha ^{1} seed rate had a similar yield to that involving mineral fertilizers application. In agro-ecological context, cowpea rotation with fonio can be a good and sheep alternative to mineral fertilizers utilization in context of rarefaction and higher prices of mineral fertilizers. For producers who use compost, the best treatments combine broadcast sowing with seed 15 kg ha ^{1} seed rate and line sowing with a seed rate of 2 kg ha ^{1}. For producers who apply mineral fertilizers, the best productive treatments combine broadcast sowing with 15 and 30 kg ha ^{1} seed rate.

Sowing rates impact evaluation on paddy yields showed no significant difference on yield. Doubling seed rate did not increase significantly yield paddy, whatever fertilization type and sowing method. Work carried out in the sub-region on the comparison of seed rates has focused on broadcast sowing, line sowing and hill dropping sowing.

Sowing methods impact evaluation on paddy yield reveal significant difference in favor of treatments including broadcast sowing and treatments including hill dropping sowing were least productive. Work carried out in the sub-region based solely on the comparison of line and broadcast sowing produced divergent results. Reference [19], found significant differences in favor of line sowing while [23] found significant differences in favor of broadcast sowing followed by line and hill dropping. In these various studies, authors used either the same quantities of seed for line sowing and broadcast sowing, or higher rates for line sowing [20] those choices can penalize performance of line sowing due to high competition between the plant on the same line. In our study 1 and 2 kg ha ^{1} seed rate were used for line and hill dropping sowing and 15 and 30 kg ha ^{1} for broadcast sowing. Reference [16] recommended 15 and kg ha ^{1} for broadcast sowing. Reference [16] also mentioned lower seed rates of 5-10 kg ha ^{1} for line sowing. In Benin, recent work with line sowing increase paddy yield of around 150 kg to 200 kg ha ^{1} compared with broadcast practice [19].

Plant density evaluation revealed that highest densities were obtained by treatments involving broadcast sowing, followed by treatments involving line sowing and hill dropping sowing, with density gains of 56% over line sowing and 90% over hill dropping sowing. The high densities of treatments involving broadcast sowing are due to the higher seed rate used, 15 and 30 kg ha ^{1} rate against 1 and 2 kg ha ^{1} rates for line and hill dropping sowing. Density evaluation in sub-region showed that broadcast sowing obtained the highest plant densities, followed by line sowing and hill dropping sowing [23] (Siena L.A C et al,) 2020, [18] C. Kanlindogbe et al, 2020; [16] Gueye M.M (2016).

5 CONCLUSION

Study allowed to identify the bests treatments and to make specific recommendations according to different production context in relation with fertilization type, sowing arrangement and seed rate. In agro-ecological intensification context, Cinzana's results highlighted the role of cowpea in increasing fonio yields. A rotation cowpea with fonio could be an alternative to mineral fertilizers utilization.

The best productive treatments combine mineral fertilizers, broadcast sowing with 15 and 30 kg ha^{-1} rates effects. Densities and yields for treatments including hill dropping sowing and line sowing were significantly lower than those including broadcast sowing, respectively with 89% for density and 30% for yield concerning hill dropping sowing and 72% for density and 10% for yield treatments including line sowing (Table 8). This means that the probability to increase line sowing yield is three time greater than hill dropping sowing yield. Density is generally correlated with yield, adjustments in seed quantity for line sowing are necessary to achieve significantly higher yields than treatments including broadcast sowing. Increases of seed rate is 72% for line sowing, either 1.44 kg ha^{-1}. These adjustments give us 3.44 kg ha^{-1} for line sowing. This rate can be adjusted to 4 kg ha^{-1}. This suggestion is close to 5 at 10 kg ha^{-1} recommended by [19] for line sowing. To minimize intra-line competition, spacing between lines can be reduced by 10 cm, either 30 cm between lines instead of 40 cm to increase line number by hectare. This

new spacing is better suited to use human-drawn Indian hoe for weeding. Further research are needed to facilitate recommendations disseminate. The first will be focus on line sowing yield evaluation with spaced at 30 cm at 4 kg ha^{-1} seed rate. The second will focus on the development of suitable line sowing equipment and weeding fonio. Equipment can be manual or animal-drawn. Whatever the type of equipment should be multi-line to minimize time spending to sowing and weeding. Finally, the third will quantify the after-effect of legumes (peanut and cowpea) on fonio yield in legume rotation with fonio.

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