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Full Length Research Paper

Plant density effects on agromorphological traits and the yield of grain sorghum varieties in rainfed conditions in Burkina Faso

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Abstract

This study was conducted to evaluate the effect of plant density on agromorphological traits and yield of improved sorghum varieties and to identify the density that optimizes grain and straw yields. Eight improved sorghum varieties were field-tested in three plant densities (62,500, 83,500 and 93,750 plants.ha^{-1}) during the rainy seasons 2014 and 2015 at INERA Saria research station. The results showed that the factor "plant density" had a highly significant effect on most of the measured traits: increased density resulted in decreased stem diameter, leaf length and leaf width, panicle length, grain number per panicle, 1000 grain weight and crop index. On average, densities two and three yielded the highest grain yield with 3163 kg.ha^{-1} and 2909 kg.ha^{-1}, respectively as well as straw (6188 kg.ha^{-1} and 6438 kg.ha^{-1}). Sariaso 18, PSE07 S1/1-1Z-1 and PSE08 G2/46-1G-1 of guinea botanical race varieties were more efficient for straw production and Sariaso 14, Sariaso 15, Sariaso 16 and Sariaso 17 caudatum botanical race varieties for grain production, but with a high sensitivity of yield components to plants densities variations.

Key words: density, improved sorghum varieties, yield, yield components.

Introduction

Sorghum [*Sorghum bicolor* (L.) Moench] is the fifth cereal grown in the world in terms of area and grain production after wheat, maize, rice and barley; it is the second major cereal in Africa after maize with 26.8 million hectares (FAOSTAT, http://www.fao.org, 2010-2014). Due to its adaptive plasticity and its ability to tolerate biotic and abiotic stress (Reddy et al., 2009; Chantereau et al., 2013), sorghum is widely cultivated in many countries of the semi-arid and sub-humid zone such as Nigeria, Sudan, Burkina Faso and Ethiopia, where it provides food for many populations (FAOSTAT, http://www.fao.org. 2015).

In Burkina Faso, sorghum is a subsistence crop for over seven hundred thousand households (INSD, 2012); it is also the largest cereal in terms of area (44.3% of cereal area) and grain production (40% of cereal production). Between 1985 and 2014, the area for its cultivation increased by more than 103%, with yield increasing from 585 kg.ha^{-1} to 1130 kg.ha^{-1} (MARHASA, 2015). Despite this improvement, production remains largely influenced by rainfall (Ibrahim et al., 2014) and by the low soil content of major mineral elements (Hien, 2004).

Yoseph and Sorsa (2014), Buah and Mwinkaara (2009), Alderfasi et al. (2016) reported that the productivity of a crop not depends only of its genetic potential, but also on growing conditions such as mineral nutrients, agronomic management of culture and environmental factors (water, light, temperature). Among the agronomic techniques, the plant density is a parameter that influences crops yield. Blum (1970) and Fernandez et al. (2012) on sorghum, Gobeze et al.

(2012) on maize, Baloch et al. (2002) on rice, Beres et al. (2012) on wheat reported that increasing plant density per unit area is a factor for increasing yield, but it must be adapted to water supply. Other studies have reported the influence of density on the behaviour of plants in culture. Thus, Lafarge and Hammer (2002) found that the increase in density led to a decrease in the number of tillers; Moosavi (2012) found a decrease in stem diameter; Soleymani et al. (2012) showed a decreased in panicle length, while Ismaïl and Ali (1996) found a reduction in yield subsequent of the reduction of 100 grains weight above a density of 106,000 plants.ha^{-1}. For each variety, there is an optimum density that allows it to use the available resources of the growing environment (Hedge et al., 1976; Sangoi, 2000; Moosavi, 2012) beyond which, inter-plant competition for light, water and nutrients affects negatively yields (Tollenaar et al., 1997, Berenguer and Faci, 2001; Abuzar et al., 2011).

In Burkina Faso, to improve crop productivity, agronomic practices such as integrated soil fertility management have been experimented and disseminated (Zougmoré et al., 2003). However, information on plant density of improved sorghum varieties is out of dated and limited with a focus on grain yield. Arrivets (1970) reported that, in farmers' conditions in Burkina Faso, sorghum plant density varied widely above a minimum of 60,000 plants.ha^{-1}. The recommended densities for sorghum cultivation are derived from results of studies carried out between 1960 and 1966 in West African countries such as Senegal (IRAT/HV reports, 1960-1967). Thus, 93,750 plants.ha^{-1} were recommended to optimize grain yield, while the most widely cultivated varieties were guinea botanical race (Dumont, 1966). The sorghum breeding programme in Burkina Faso has developed new improved varieties to disseminate to farmers, getting information on their behaviour under cultivation is very important.

This study was conducted to assess the effect of plant density on improved caudatum and guinea botanical races varieties by considering agromorphological traits, grain yield and its components as well as straw yield. The objective is to identify the density that would allow to optimize yield according to the production objectives of farmers.

Material and methods

Plant material

Eight improved sorghum varieties belonging to two botanical races have been assessed: Sariaso 14, Sariaso 15, Sariaso 16 and Sariaso 17 (caudatum botanical race); Kapelga, Sariaso 18, PSE07 S1 / 1-1Z-1 and PSE08 G2 / 46-1G-1 (guinea botanical race).

Study area

The study was carried out during the rainy seasons 2014 and 2015 at INERA Saria research station (12° 16'N, 2°09'W, 300 m altitude) in Burkina Faso. Table 1 gives the characteristics of rain and soil of the study area.

Table 1: ***Saria agroclimatic*** and experimental soils characteristics

Climate type of study area	Mean rainfall (2006-2015) mm	Rainfall duration	Soil characteristics	
North-Sudanian (700 - 900 mm)	849	June - October	Loamy-clay-sandy	Depth > 100 cm
			Organic matter (%)	1.03
			N (ppm)	410
			P (ppm)	2.37
			K (ppm)	44

Experimental design and field trial

The varieties were assessed in three densities [D1 (62,500 plants.ha^{-1}), D2 (83,500 plants.ha^{-1}), D3 (93,750 plants.ha^{-1})] in a randomized complete block design (RCBD) with four replications.

The plot per entry was three rows of 6 metres in length and the useful plot was the central line on which the data were collected. The sowing was carried out on the same date on July 9 in 2014 and 2015. The seedling spacing were 80 cm x 40 cm for the D1, 80 cm x 30 cm for the D2 and 80 cm x 40 cm for the D3. The seed holes were thinned to two-plants for densities D1 and D2 and to three plants for density D3. 1.5 t.ha^{-1} of compost and 75 kg.ha^{-1} of 14 (N), 23 (P_2O_5), 14 (K_2O) 6 (S) and 1 (B) were applied ten days after the seedling and 50 kg.ha^{-1} of urea at (46% N) at 35 days after seedling. The rainfall recorded during the crop cycle for each trial was 637 mm in 2014 and 728 mm in 2015.

Data collection

For each variety, data were collected for plant height (PH), leaves number (LEN), stem diameter (STD) measured at the internode under third leaf before the panicle, leaf length (LEL) and leaf width (LWD) measured on the third leaf under the panicle and panicle length (PANL) on six main plants in three random selected seed holes per repetition (four) for D1 and D2 and two seed holes for D3 excluding the first and the last seed hole. Measurements were made on the whole useful plot for the cycle length (DH) (number of days from sowing to 50% heading), the number of useful basal tillers (UT), the dry weight of straw (leaves and stems), the number of harvested panicles (NHPA), the dry weight of panicles (PADW), the dry weight of grain (GDW) and the weight of 1000 grains (1000GW). The grain yield per hectare (GY), the number of grain per panicle (GN/PA) and the straw yield (STY) were then calculated. The crop index (CI), grain yield/straw yield ratio was established.

Statistical analysis

Variance analysis was performed with thirteen agromorphological variables to evaluate the effect of variety and year on the expression of variables as well as the effect of densities on varieties. The equality between means was tested by the Fisher's “Least Significant Difference (LSD-test). The main effect of varieties (Genotype) plus variety by density interaction (Genotype-by-Environment) was established by the GGE Biplot (Yan and Kang, 2003), which determined common environments and best varieties in the three densities. The analysis was carried out using GenStat software 14.2.

Results

Variation of agromorphological traits in the density

The analysis of variance in each density revealed highly significant ($P < 0.01$) to very highly significant effects ($P < 0.001$) between varieties for all traits analysed (Table 2). The year effect was not significant in all densities for the cycle duration (DH), but very highly significant for plant height (PH), leaf number (LEN) and leaf width (LWD); it was significant in D1 for stem diameter (STD), in D1 and D3 for leaf length (LEL) and panicle length (PANL).

Variation of agromorphological traits between densities

The differences were highly significant to very highly significant between the densities for all measured traits except cycle length (DH) and plant height (HP) (Table 2). Statistically, D1 and D2 were identical for leaves number (LEN), leaf length (LEL), panicle length (PANL) but different from D3. Each density differs statistically from the other for the stem diameter (STD) and the leaves width (LWD).

The results showed that for each variety, the values of agromorphological traits tend to decrease from D1 (62,500 plants.ha^{-1}) to D3 (93,750 plants.ha^{-1}). These variations are well observed on leaf number (LEN), leaf length (LEL), leaf width (LWD), stem diameter (STD), panicle length (PANL).

In the three densities, the cycle length (DH) of varieties varied from 57.5 to 78.2 days; Kapelga was the earliest variety with 57.5 to 59.1 days, whereas Sariaso 17 was the latest variety with 75.6 to 78.2 days (Figure 1). The low plant heights were observed with caudatum varieties (173 - 195 cm) and the highest plant heights were observed with guinea varieties (261 - 328 cm). The mean number of useful tillers was low in all densities; it was 0,05; 0,02; 0,02 respectively in the D1, D2 and D3 for caudatum varieties and 0,13; 0,09; 0,07 for guinea varieties. Kapelga was the most tiller variety with an average number of 0.25 tillers in D1, 0.17 in D2 and D3; PSE07 S1 / 1-1Z-1 showed the lowest number of tillers with an average of 0.02 tillers in the D1 and 0.00 tiller in D2 and D3.

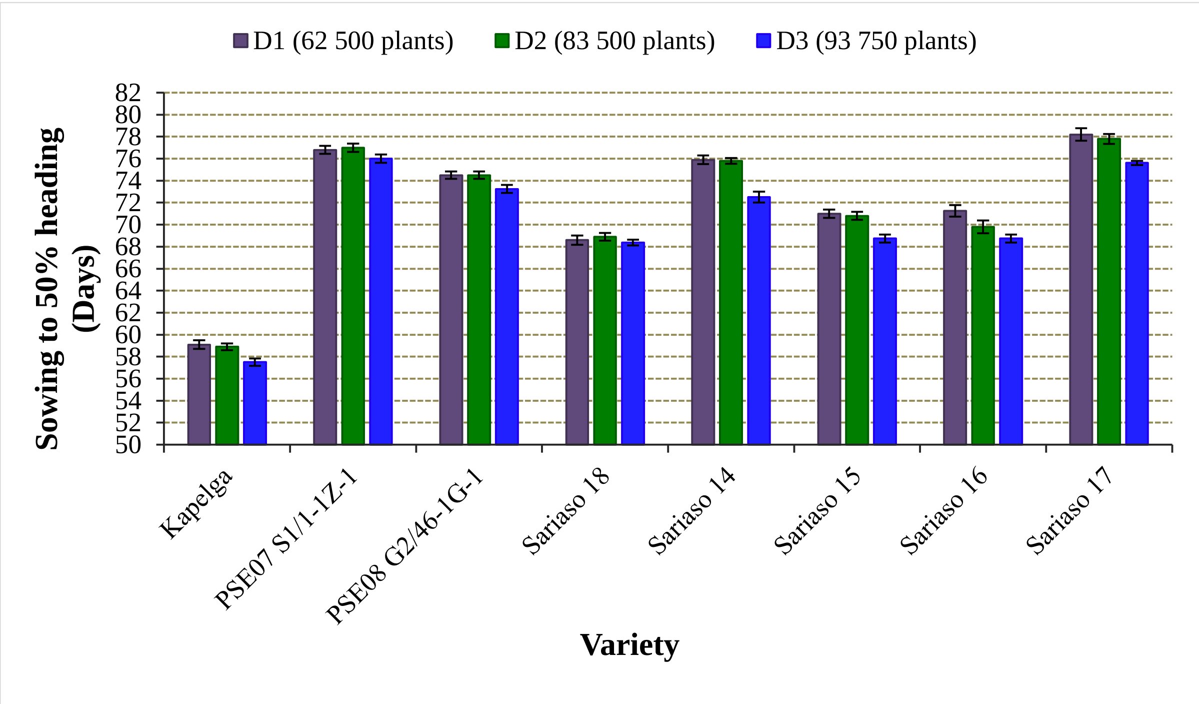

Figure 1: Variation of cycle length

Table 2: Variance estimates of agromorphological variables in each density and between densities

Density	Source of variation	D.f.	Parameters	DH (days)	PH (cm)	STD (mm)	LEN	LEL (cm)	LWD (cm)	PANL (cm)
D1	Variety	7	F value	267.6***	97.3***	9.8***	93.1***	15.4***	11.6***	108.5***
	Year	1		0.6 NS	13.5***	15.0***	26.9***	13.0***	45.9***	5.9*
	Variety x year	7		3.7**	1.8 NS	3.0*	2.4*	4.3**	4.8***	0.7 NS
			Mean ± s.e.d.	71.9 ± 0.5	235.7 ± 8.8	13.6 ± 0.6	20.8 ± 0.3	50.2 ± 2.2	7.3 ± 0.3	27.5 ± 0.9
D2	Variety	7	F value	299.7***	75.3***	14.9***	62.3***	21.4***	22.2***	168.2***
	Year	1		0.6 NS	27.8***	0.5 NS	45.2***	0.5 NS	15.0***	1.4 NS
	Variety x year	7		1.9 NS	3.7**	2.9*	1.8 NS	6.3***	6.9***	0.4 NS
			Mean ± s.e.d.	71.7 ± 0.5	243.2 ± 10.6	13.0 ± 0.5	20.8 ± 0.3	48.5 ± 1.9	6.9 ± 0.3	27.2 ± 0.7
D3	Variety	7	F values	321.3***	107.0***	8.0***	55.6***	15.5***	18.0***	113.5***
	Year	1		0.2 NS	22.4***	0.02 NS	58.4***	4.3*	41.0***	17.2***
	Variety x year	7		2.3*	5.1***	3.5**	3.2**	1.7 NS	3.9**	1.1 NS
			Mean ± s.e.d.	70.1 ± 0.5	243.0 ± 8.7	11.8 ± 0.5	20.0 ± 0.3	46.3 ± 2.1	6.5 ± 0.3	24.8 ± 0.8
Between Densities		2	F value	1.9 NS	0.3 NS	22.4***	3.9*	4.4*	11.0***	3.9*

NS (non significant),
* (significant effect of the factor at 0.05 α level),
** (highly significant effect of the factor at the 0.01 α level),
*** (very highly significant effect of the factor at the 0.001 α level)

Table 3: Variance estimates of productivity variables in each density and between densities

Density	Source of variation	D.f.	Parameters	GY ($kg.ha^{-1}$)	1000GW (gm.)	GN/PA	NHPA (ha)	STY ($kg.ha^{-1}$)	CI
D1	Variety	7	F value	69.5***	45.1***	38.5***	4.6***	16.4***	11.5***
	Year	1		0.4 NS	13.4***	14.0***	10.7**	7.8**	4.8*
	Variety x year	7		5.1***	2.2*	4.5***	2.8*	3.7**	4.3**
			Mean ± s.e.d.	2818 ± 94	22.3 ± 0.2	2109 ± 100	60092 ± 2097	5207 ± 242	0.55 ± 0.03
D2	Variety	7	F values	8.6***	32.4***	6.9***	2.4*	18.1***	4.1**
	Year	1		5.3*	6.0*	1.7 NS	11.3**	58.1***	4.0 NS
	Variety x year	7		1.3 NS	2.3*	1.0 NS	2.0 NS	3.1**	2.8*
			Mean ± s.e.d.	3163 ± 195	21.9 ± 0.3	1815 ± 151	79635 ± 2867	6188 ± 213	0.52 ± 0.04
D3	Variety	7	F value	19.8***	29.7***	5.2***	3.5**	29.7***	6.7***
	Year	1		1.0 NS	1.6 NS	23.3***	55.9***	56.4***	14.8***
	Variety x year	7		1.3 NS	4.2 **	0.5 NS	2.4*	1.4 NS	1.3 NS
			Mean ± s.e.d.	2909 ± 115	21.3 ± 0.3	1592 ± 133	86132 ± 2767	6438 ± 200	0.46 ± 0.02
Between Densities		2	F value	7.7***	10.4***	26.8***	347.6***	41.3***	4.7**

Grain yield and yield components

In each density, the difference between varieties was highly significant for grain yield (GY), weight of 1000 grain (1000GW), grain number per panicle (GN/PA) and number of harvested panicles (NHPA) (Table 3). The year effect was highly significant in all densities for the number of harvested panicles (NHPA); it was significant in the D1 for 1000GW and GN/PA, in the D2 for GY and 1000GW and in the D3 for GN/PA.

Between densities, the difference was significant for grain yield and its components. The D1 (2818 $kg.ha^{-1}$) and the D3 (2909 $kg.ha^{-1}$) are statistically identical and differ from the D2 (3163 $kg.ha^{-1}$). The yield varied from 1689 $kg.ha^{-1}$ to 3431 $kg.ha^{-1}$ in D1, from 2242 $kg.ha^{-1}$ to 3531 $kg.ha^{-1}$ in D2 and from 2104 $kg.ha^{-1}$ to 3207 $kg.ha^{-1}$ in D3 (Figure 2). Sariaso 17 gave the best yield in the D1 and Sariaso 14 in the D2 and D3. Kapelga was the least productive variety in all densities. Apart from Sariaso 17 which was more productive in the D1, all the other varieties gave their best yield in the D2. The GGE [Genotype main effect (G) and Genotype-by-Environment (GE) interaction] analysis showed two distinct environments (Figure 3): D2 and D3 which are very close and constitute a mega-environment and D1 which constitute another environment. Sariaso 14, Sariaso 17, Sariaso 16, Sariaso 15 and Sariaso 18 gave an above average grain yield in the three densities; PSE08 G2/46-1G-1 is at the average level, while Kapelga and PSE07 S1/1-1Z-1 were below the average.

For the 1000 grain weight (1000GW), the densities D1 and D2 differed significantly from the D3 with respectively an average weight of 22.3 g, 21.9 g and 21.3 g. The 1000GW was 22.8 g, 21.8 g and 21.6 g respectively in the three densities for guinea varieties (decrease of 5.3%) and 22.8 g, 22.0 g and 21.0 g for the caudatum varieties (decrease of 7.9%). All densities differed significantly from each other for the grain number per panicle (GN/PA) with respectively 2109 grains for D1, 1815 grains for D2 and 1592 grains for D3. The grain number per panicle was 1822, 1627 and 1482 for the guinea varieties (decrease of 18.7%) and 2396, 2003 and 1701 for caudatum varieties (decrease of 29.0%).

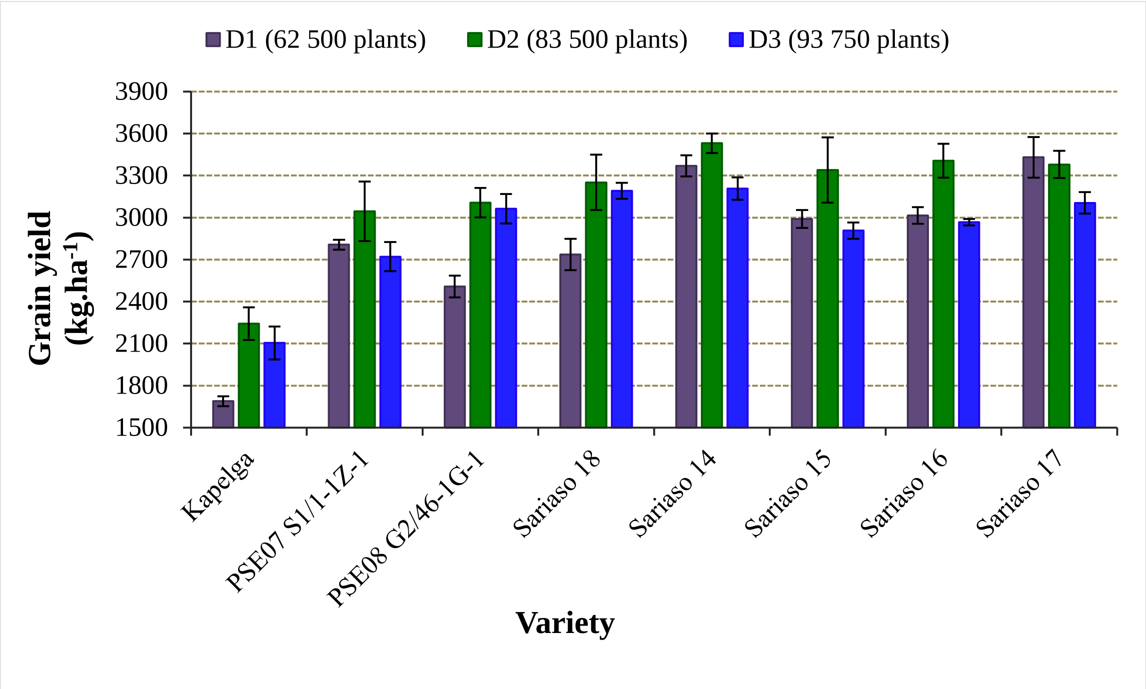

Figure 2: Grain yield of the varieties evaluated in 2014 and 2015

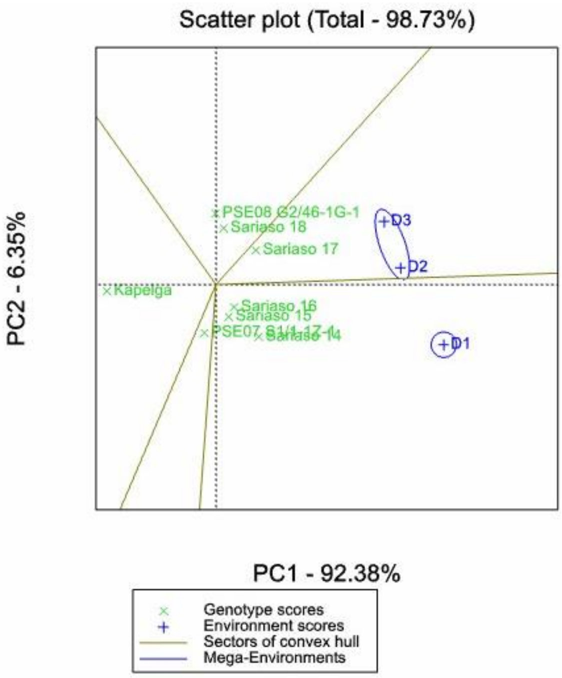

Figure 3: GGE Biplot, mega-environments for grain yield

Straw yield

The three densities were significantly different for the straw yield (STY) (Table 3). This difference is induced by density D1 (5207 kg.ha^{-1}) which differed statistically from densities D2 (6188 kg.ha^{-1}) and D3 (6438 kg.ha^{-1}). The yield ranged from 3659 kg.ha^{-1} to 5737 kg.ha^{-1} in D1, from 4877 kg.ha^{-1} to 6945 kg.ha^{-1} in D2 and from 5110 kg.ha^{-1} to 7331 kg.ha^{-1} in D3. PSE07 S1/1-1Z-1 gave the highest yield in D1 and PSE08 G2/46-1G-1 in D2 and D3; only Kapelga was the least productive in the group of guinea varieties in all densities (Figure 4).

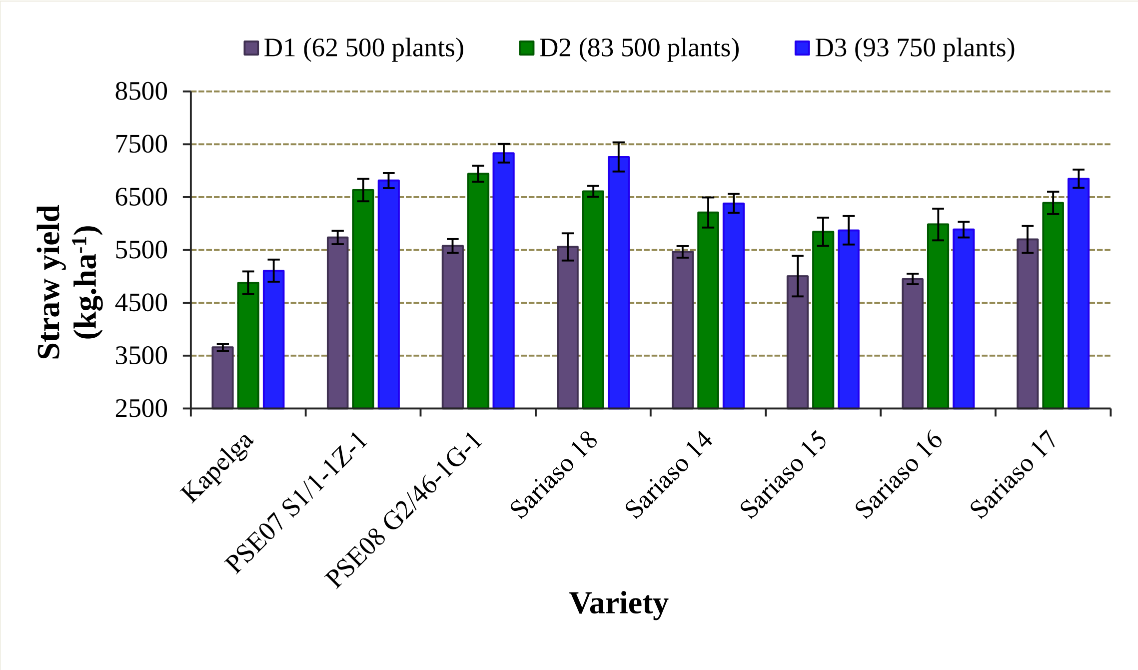

Figure 4: Straw yield of the varieties evaluated in 2014 and 2015

Crop index

The variety effect is highly significant for the crop index (CI) in each density (Table 3). The differences were also significant between the densities. Statistically densities D1 and D2 were identical and differed from density D3.On average, the crop index was 0.55 in D1, 0.52 in D2 and 0.46 in D3; it varied from 0.45 to 0.62 in D1, from 0.45 to 0.58 in D2 and from 0.40 to 0.51 in D3. Among the varieties, it was caudatum varieties, Sariaso 14 and Sariaso 15 which gave the best index in the D1 (0.62). In the group of guinea varieties, Sariaso 18 was better with indices of 0.50, 0.49, and 0.44; PSE08 G2/46-1G-1 showed the lowest indices in the three densities (0.45, 0.45, 0.42) (Figure 5).

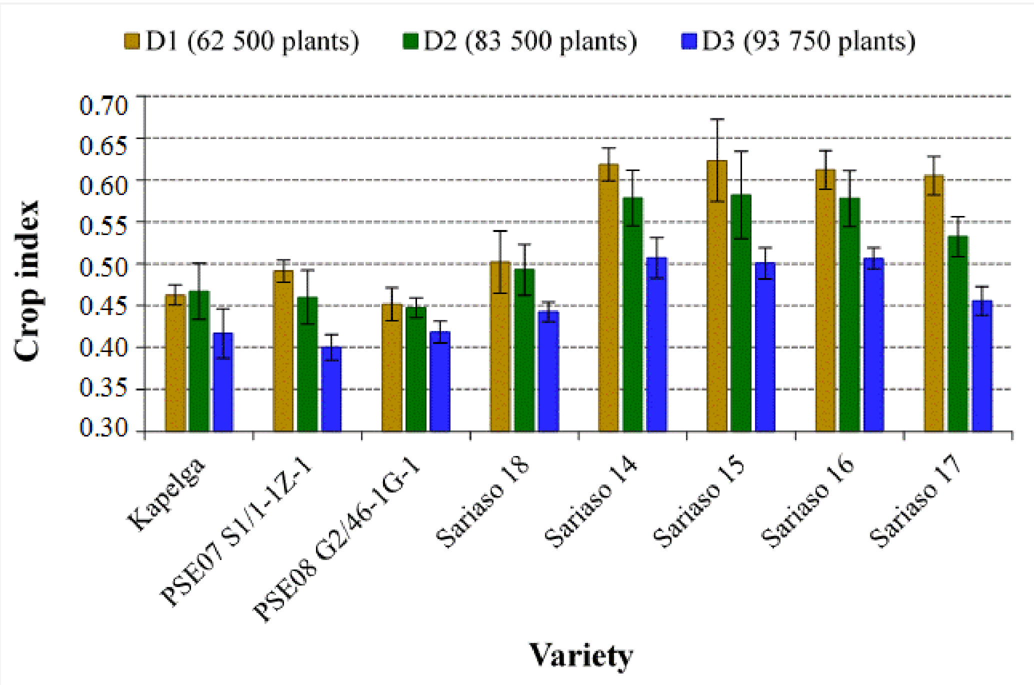

Figure 5: Crop index of the varieties evaluated in 2014 and 2015

Discussion

Effect of plant density on agromorphological traits

The year factor showed an absence of variation for the cycle duration [sowing-50% heading (DH)] in each density. Clerget (2004) reported that for the tropical sorghum, the cycle duration is influenced by sowing date, the length of the day and the temperature. For this study, the two experiments were sown at the same date on July 9 in 2014 and in 2015, the parameters that can modify the cycle duration were similar from one year to the next, which resulted in a quasi-stability of the vegetative phase. This result would also be linked to the highly inheritable character of the cycle [(0.80 ≤ h² ≤ 0.98), (Tamini, 2014).

For the rest of traits, the density had an effect on the size of stem diameter (STD), leaf number (LEN), leaf length (LEL), leaf width (LWD) and Panicle length (PANL) with a more significant decrease in D3. Different authors reported that when the growing resources become limiting in the environment the competition between plants grows under high density conditions. Azam-ali et al. (1984) observed on millet water deficits that slowed the growth of the whole plant, however the development of the ears continued with a decrease in the weight of the dry matter. Jettner et al. (1998) and Lemerle et al. (2004) showed that a high density leads to low radiation on the leaves with a decrease in photosynthesis and therefore a decrease in grain yield. Kim et al. (2010) also reported that low radiation and inadequate temperature can affect the availability of carbohydrates and their deficiencies in high stands affect plant growth and development. In this study, the decrease in the size of certain some agromorphological traits would be probably linked to water or even nutrients deficiencies that would have induced competition effects between plants; particularly those of density D3 (93,750 plants) would have been more affected. The decrease in the size of agromorphological traits was also observed on sorghum by other authors in high plant densities. Lafarge et al. (1998) and Clerget (2004) reported a reduction in the number of leaves related to the slowing down of the plastochrome during the run-up phase. Moosavi (2012) reported a decrease in stem diameter and tiller number from 2.3 to 0.27 in high plant densities; the reduction in the tillers number according to Lafarge and Hammer (2002) is linked to an earlier termination of tillering. Zand et al. (2014) found a decrease in the weight of grains and the number of grains per panicle when the density increases.

Effect of plant density on grain yield and yield components

The eight varieties of this study showed differences in behaviour in the three densities for grain yield (Figure 3). This result is similar to that observed by Hegde et al. (1976) on sorghum hybrids. Overall, the best results were obtained with the D2 where the caudatum varieties were better. The three components of the yield, namely the number of panicles (NHPA) per hectare, the grain number per panicle (GN/PA) and the weight of 1000 grains (1000GW) contribute to the adjustment of varieties yield to density variations. In all densities, the number of panicles (NHPA) per hectare and the weight of 1000 grains (1000GW) were the major components of the yield of guinea varieties; whereas, the number of grains per panicle (GN/PA) contributed most to the yield of caudatum varieties. In response to the increase in density, the grain weight was the most stable of yield components in guinea and caudatum varieties. Adjustment to densities was mainly due to the other two components, although the guinea varieties were much more stable than the caudatum varieties for the number of grains per panicle and also for the number of harvested panicles (NHPA) per hectare. This lower stability of yield components in caudatum varieties may be due to a susceptibility to support the water deficit, their root system is less developed than that of guinea varieties (Kouressy 2008). Vadez et al. (2011) reported that caudatum varieties have a higher transpiration efficiency compared to guinea varieties and this may reflect differences in roots function. In this study, the caudatum varieties presented larger leaves than those of the guinea varieties that could increase the evaporative demand with the risk that it would not be satisfied.

Effect of plant density on straw yield

The results showed clearly that the increase in density resulted in an increase in straw yield for each variety. The guinea varieties produced the highest yields in D3 because of their high stem and their higher level of tillering; however, in terms of fodder nutritional values, their lignin content is often higher than that of caudatum varieties, hence ruminants preference for caudatum straw (Sohoro et al., 1994). In Burkina Faso, cereal straw in particular those of sorghum, are very important source of feed for livestock during the dry season. These results on straw are therefore interesting to consider for farmers who have different production objectives.

Effect of plant density on crop index

One of the important criteria for breeding is the improvement of crop index. In this study caudatum varieties showed a better index compared to guinea varieties, but the increase in plant density resulted in a decrease in the crop index for all varieties. Sariaso 18, a variety resulting from participatory variety selection in the Centre-North region presented the best crop index among guinea varieties in all densities, showing that the improvement of grain yield in relation to straw is possible in guinea varieties.

Conclusion

This study on sorghum density showed that the increase in plant density has an impact on the agromorphological traits, grain yield and its components as well as the straw yield of the varieties. It also showed that in rainfed conditions inter-plant competition is higher in the density D3 (93,750 plants.ha^{-1}) compared to the density D1 (62,500 plants.ha^{-1}) resulting in a decrease in the size of the agromorphological traits. The increase in density provides an advantage for grain and straw yields (D2 and D3). The best grain yields and crop index were observed with caudatum varieties, while the best straw yields were observed with guinea varieties. The Kapelga variety that was the earliest showed its genetic limits for both grain yield and straw yield. It appears that if the production objective is grain, the caudatum varieties are more efficient with density D2, but if the objective is straw production the guinea varieties (excepted Kapelga) are recommended with density D3. The densities D2 or D3 may be appropriate for a dual purpose.

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References

Abuzar MR, Sadozai GU, Baloch MS, Baloch AA, Shah IH, Javaid T, Hussain N (2011). Effect of plant population densities on yield of maize. The Journal of Animal & Plant Sciences, 21(4): 692-695.

Alderfasi AA, Selim MM, Alhamma BA (2016). Evaluation of Plant Densities and Various Irrigation Regimes of Sorghum (*Sorghum bicolor* L.) under Low Water Supply. Journal of Water Resource and Protection, 8: 1-11. DOI.org/10.4236/jwarp.2016.81001.

Arrivets J (1970). Exigences minérales du sorgho étude d'une variété voltaïque à grande tige. Agronomies tropicale, 33(1): 29-46.

Azam-Ali SN, Gregory PJ, Monteith JL (1984). Effects of planting density on water use and productivity of pearl millet (Pennisetum typhoides) grown on stored water. I. Growth of roots and shoots. II. Water use, light interception and dry matter production. Expl. Agric., 20(3): 215-224. DOI: https://doi.org/10.1017/S0014479700017786.

Baloch AW, Soomro AM, Javed MA, Ahmed M, Bughio HR, Bughio MS, Mastoi NN (2002). Optimum Plant Density for High Yield in Rice (O*ryza sativa* L.). Asian Journal of Plant Sciences, 1: 25-27.

Berenguer MJ, Faci JM (2001). Sorghum (*Sorghum bicolor* L.) yield compensation processes under different plant densities and variable water supply. Eur. J. Agron. 15: 43-55. DOI: 10.1016/S1161- 0301(01)00095-8.

Beres BL, McKenzie RH, Càrcamo HA, Dosdall LM, Evenden ML, Yang RC, Spaner DM (2012). Influence of seeding rate, nitrogen management, and micronutrient blend applications on pith expression in solid-stemmed spring wheat. Crop Sci., 52: 1319-1329.

Blum A (1970). Effect of Plant Density and Growth Duration on Grain Sorghum Yield under Limited Water Supply. Agronomy journal, 62: 333-336. DOI: 10.2134/agronj1970.00021962006200030007x.

Buah SSJ, Mwinkaara S (2009). Response of Sorghum to Nitrogen Fertilizer and Plant Density in the Guinea Savana Zone. Journal of Agronomy, 8(4): 124-130. http://dx.DOI.org/10.3923/ja.2009.124.130.

Chantereau J, Cruz J-F, Ratnadass A, Trouche G (2013). Le sorgho. Agriculture tropicales en poche, ed Quae, www. presseagro.be, ISSN: 1778-6568. 245 p.

Clerget B (2004). Effect of photoperiod-sensitivity on yield and yield components of three sorghum varieties grown in West Africa. Thesis, Institut National Agronomique Paris-Grignon, 103 P.

Dumont C (1966). La sélection du sorgho à grain en Haute-Volta. African soils, 11(1 & 2): 301-320.

Fernandez CJ, Fromme DD, Grichar WJ (2012). Grain Sorghum Response to Row Spacing and Plant Populations in the Texas Coastal Bend Region. International Journal of Agronomy, article ID 238634, 6 pages. DOI: 10.1155/2012/238634.

FAO (Food and Agriculture Organization) (2016). Statistical, yearbooks, food and agriculture data 2010-2015. http://www.fao.org.

Gobeze YL, Ceronio GM, Van Rensburg LD (2012). Effect of Row Spacing and Plant Density on Yield and Yield Component of Maize (Zea mays L.) under Irrigation. Journal of Agricultural Science and Technology, 263-271.

Hedge BR, Major DJ, Wilson DB, and Krogman KK (1976). Effects of row spacing and population density on grain sorghum production in southern Alberta. Can. J. Plant Sci, 56: 31-37.

Hien E (2004). Dynamique du carbone dans un Acrisol ferrique du Centre Ouest Burkina: Influence des pratiques culturales sur le stock et la qualité de la matière organique. Thèse, Ecole Nationale Supérieure Agronomique de Montpellier, 137 P.

Ibrahim B, Karambiri H, Polcher J, Yacouba H, Ribstein P (2014). Changes in rainfall regime over Burkina Faso under the climate change conditions simulated by 5 regional climate models. Climate Dynamics, Springer Verlag, 42: 1363-1381. DOI: 10.1007/s00382-013-1837-2.

INSD (Institut national de la statistique et de la démographie) (2012). Annuaire statistique, 411 P.

Jettner R, Loss SP, Siddique KHM, Martin LD (1998). Response of faba bean to sowing rates in southwestern Australia. I. seed yield and economic optimum plant density. Australian Journal of Agriculture Research, 49: 989-998.

Kim HK, van Oosterom E, Dingkuhn M, Luquet D, Hammer G. 2010. Regulation of tillering in sorghum: environmental effects. Annals of Botany, 106: 57–67.

Kouressy M (2007). Agro-ecological adaptation and potential of short-statured, photoperiod-sensitive sorghums in Mali. Thesis, University of Montpellier II, 161 P.

Lafarge T, De Raïssac M, Tardieu F (1998). Elongation rate of sorghum leaves has a common response to meristem temperature in diverse African and European environmental conditions. Field Crops Research, 58: 69-79.

Lemerle D, Causens RD, Gill LS, Peltzer SJ, Moerkerk M, Murphy CE, Collins D, Cullis BR (2004). Reliability of higher seeding rates of wheat for increased competitiveness with weeds in low rainfall environment. Journal of Agriculture Science, 142: 395- 409.

MARHASA (Ministère de l'Agriculture, des Ressources Hydrauliques, de l'Assainissement et de la Sécurité Alimentaire) (2015). Statistiques agricoles du Burkina Faso 1985-2014.

Moosavi SG (2012). Effect of density plant and planting pattern on yield, yield components and morphological traits of forage sorghum in the second cultivation. Int J. Agri Crop Sci. 4(1): 28-32.

Reddy BVS, Ramesh S, Reddy PS, Kumar AA (2009). Genetic Enhancement for Drought Tolerance in Sor-ghum. Plant Breeding Reviews, 31: 189-222. DOI: 10.1002/9780470593783.ch3.

Sohoro A, Taonda SJB, Dickey JR (1994). Performance des variétés de sorgho et de niébé à double usage en milieu réel, une évaluation agronomique par les chercheurs et les producteurs. In Recherche intégrée en production agricole et en gestion des ressources naturelles. Purdue University and Winrok international, 153-163.

Sangoi L (2000). Understanding plant density effects on maize growth and development: an important issue to maximize

grain yield, Ciência Rural, Santa Maria, 31(1): 159-168.
Soleymani A, Almodares A, Shahrajabian MH (2012). Changes in seed yield and yield components of two cultivars of sweet sorghum in different plant populations. International Journal of Agriculture and Crop Sciences. 4(4): 175-178.
Tamini M (2014). Evaluation de l’effet de la densité de plantes sur la productivité de nouvelles variétés de sorgho [*Sorghum bicolor* (L.) Moench] du Burkina Faso. Université de Ouagadougou, Centre Universitaire Polytechnique de Dédougou, 53 P.
Tollenaar M, Aguilera A, Nissanka SP (1997). Grain yield is reduced more by weed interference in an old than in a new maize hybrid. Agronomy Journal, Madison, 89(2): 239-246.
Vadez V, Krishnamurthy L, Hash CT, Upadhyaya HD, Borrell AK (2011). Yield, transpiration efficiency, and water-use variations and their interrelationships in the sorghum reference collection. Crop & Pasture Science, 62: 645-655.
Yan W, Kang MS (2003). GGE Biplot Analysis: a Graphical Tool for Breeders. Geneticists and Agronomists. CRC Press, Boca Raton.
Yoseph T, Sorsa Z (2014). Evaluation of Sorghum (*Sorghum bicolor (*L.) Moench) Varieties, for Yield and Yield Components at Kako, Southern Ethiopia. Journal of Plant Sciences*.* 2(4): 129-133. DOI: 10.11648/j.jps.20140204.12.
Zand N, Shakiba MR, Moghaddam-Vahed M, Dabbagh-Mohammadai-nasab A (2014). Response of Sorghum to Nitrogen Fertilizer at Different Plant Densities. International Journal of Farming and Allied Sciences, 3: 71-74.
Zougmoré R, Zida Z, Kambou NF (2003). Role of nutrient amendments in the success of half-moon soil and water conservation practice in semiarid Burkina Faso. Soil & Tillage Research, 71: 143–149.