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Responses of Sorghum Varieties to Climatic Variability — a Case Study Within the Risocas Project

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Introduction

Climate change is now a reality and not a hypothesis and will most likely have negative impacts on both agricultural and socio-economic development in the Sudano-Sahel region. Increased frequency of climate anomalies or adverse trends, as predicted by most climate change scenarios, may translate quickly into regional or local calamities, particularly in the Sahel and Sudan savannahs. Evidence of climate change such as a displacement of the 40 mm and 100 mm isohyets to the south and the disappearance of 1,200-mm isohyets from Mali and Burkina Faso exists (Paturel et al. 2003). Both the onset date and duration of the rainy season vary considerably among years, involving considerable uncertainty for agriculture. The use of genotypes that can fit into variable lengths of growing season as well as synchronize their maturity time with the end of the season could well increase ability to cope with this trend. In Mali, the length of growing season has decreased since the severe droughts of the 1970s, requiring farmers to help themselves with either technologies they possess or options that may be provided by development projects.

Sorghum [*Sorghum bicolor* (L.) Moench] ranks second in importance after maize in Africa with a mean yield of 0.8 t/ha from a cultivated area of about 24M ha (Maredia *et al*., 2000). It is an important staple grain produced by subsistence farmers mainly under rainfed conditions in Sub-Saharan Africa (SSA). Sorghum has been cultivated for millennia in West Africa, mainly in the seasonally moist Guinea savannah zone and parts of the drier Sudan savannah where the rainy season is frequently too short to produce satisfactory yields. Traditional sorghum cropping systems are based on the earliest possible date of sowing and the use of photoperiod sensitive cultivars that flower near the habitual end of the rainy season, whereas most modern (and potentially more productive) cultivars are relatively photoperiod insensitive. Photoperiod sensitivity (PPS), a singular trait for adaptation to environmental constraints, was believed to be a genetic constant that needed to be broken via breeding to better fit genotypes to the requirements of modern agriculture (Khush, 1977), has been found to also depend other factors, such as water availability and radiation (Dingkuhn and Asch, 1999). In the Sudano Sahelian zone, it allows for grouped flowering at the end of the rainy season for a wide range of sowing dates (Traore´ et al., 2000). Genotype and agronomic practice combinations that optimize performance and yield at one location may not perform as well at others due to interactions between plant, soil, and climatic factors. We focused on the testing of a few contrasting and rigorously screened cultivars of sorghum under a wide array of climate scenarios in this study to identify potential candidates and directions of crop breeding for coping with climate variability, a major feature of climate change.

Materials and Methods

The field studies were conducted under rainfed conditions at three sites in Mali along a latitudinal gradient representative of different agro-climatic zones. The sites were the Agronomic research stations of Institute d'economie Rurale (IER) at Cinzana (13°15'N; 5°52'W; 312 m as1; Sahel.) with a silty clay soil, Sotuba (12°17'N; 7°57'W; 364 m asl; Sudan Savannah.) with a loamy sand soil, and Farako (11°21'N, 5°41'W; 441 m as1, Guinea Savannah.) with a sandy loam soil. The sites naturally differed in the onset and amount of rainfall as well as in amplitude of photoperiod, as well as range of temperature and staggered sowing dates was used to create differences in the amount of moisture available to the crops. Three (July to September), four (June to

September), and five (June to October) monthly sowings were realized at Cinzana, Sotuba, and Farako respectively. Ten grain sorghum varieties, from an assortment of races and with differences in traits such as photoperiod sensitivity, height and adaptability, were used for the studies.

The factors were arranged in a split-plot (sowing date as main plots and genotype as subplot) and fitted in a Randomized Complete Block Design (RCBD) with three replicates at all the sites. Each subplot was 9 m wide (12 rows spaced 0.75 m apart) by 4 m long. The crops were thinned to 5 plants m^{-2} (1 plant $hill^{-1}$) in all the plots 10-14 days after sowing. Plots were kept free of weeds, whiles fertilizer and pesticides were applied to minimize nutrient and biotic stresses. Each subplot was divided into two batches of seven c and five consecutive ridges. The batch with seven ridges was used for routine destructive sampling. All data from non destructive sampling were recorded from 4 tagged plants within the batch of five ridges. Final yield was determined from the three inner ridges of the batch of five ridges on each subplot with a border of one hill at both ends.

Data on six of the ten well characterized sorghum genotypes used in this study, representing different plant types available to farmers in West Africa, are presented. V1 is a semi-dwarf traditional Durra land race with slight photoperiod sensitivity and adapted to Sahel conditions collected from North western corner of Mali with a local name “Boiguel”, V2 is a tall, traditional, photoperiod sensitive Guinea landrace adapted to the Sudan savannah known as CSM 388, V3 is a tall and nearly day neutral Guinea landrace adapted to the Sahel known as CSM 63E, V4 is an improved semi-dwarf and slightly photoperiod sensitive Caudatum race called “Grinkan”, V5 is an improved dwarf and nearly day neutral Caudatum race known as “IRAT 204”, and V6 is a tall (up to 4.5 m), traditional, highly photoperiod sensitive Guinea landrace that was collected in southern Mali and known locally as “Dancouma”. Data on the effects of the factors studied on the length of plant cycle, number of leaves produced, plant height and yield for the two stations with the highest and lowest latitudes are presented in this paper.

Results and Discussion

Mean Plant height (PLTHT) was differentially influenced by site ($p<0.001$), date of sowing ($p<0.001$) and genotype ($p<0.001$). PLTHT for Farako (228 cm) was significantly higher than for Cinzana (198.5 cm). Responding to date of sowing, PLTHT reduced from 280.4 cm for S1 to 146.6 cm for S3.

Table 1 presents the main effects of site, date of sowing and genotype on the mean number of days from sowing to flagleaf ligulation (DTFLL), the mean number of leaves produced (NOL), and the mean plant height (PLTHT) recorded for scenarios involving two sites with extremes of latitude (Cinzana and Farako), sowings for July (S1) August (S2) and September (S3), and the six varieties.

The mean number of days from sowing to the appearance of the ligule on the flag-leaf (DTFLL), used as an index of the cycle of varieties, was differentially affected by the main effects of site ($p=0.048$), date of sowing ($p=<0.001$), and variety ($p<0.001$). For the mean effects of site, DTFLL increased from 57 days at Farako to 62 days at Cinzana, with plants at Cinzana being significantly later than those at Farako. The mean effects of date of sowing on DTFLL ranged from 54 (S3) to 69 (S1) days, with earlier sowing dates having significantly longer cycles than later ones. Between 47 (V3) and 80 (V6) days were recorded for the mean genotypic effects on DTFLL (Mean Plant height (PLTHT) was differentially influenced by site ($p<0.001$), date of sowing ($p<0.001$) and genotype ($p<0.001$). PLTHT for Farako (228 cm) was significantly higher than for Cinzana (198.5 cm). Responding to date of sowing, PLTHT reduced from 280.4 cm for S1 to 146.6 cm for S3.

Table 1). The mean effects on DTFLL, of the six scenarios involving site and date of sowing, were between 50 days (S3 at Farako) and 71 days (S1 at Cinzana) but these were not statistically different ($p=0.097$). Scenarios involving variations of both site and genotype had mean DTFLL ranging between 47 days (V4 at both sites) and 89 days (V6 at Cinzana), with the differences being significant ($p=0.028$). Differences between mean effects of the 18 scenarios involving date of sowing and genotypes on DTFLL, ranging between 40 days (S3V3) and 88 days (S1V6), were not significant ($p=0.088$).

For the mean number of leaves (NOL), statistical differences were observed between the main effects of site ($p=0.006$), date of sowing ($p<0.001$) and genotype ($p<0.001$). More leaves were produced at Cinzana (20) than at Farako (18). NOL reduced with delayed sowing from 23 leaves (S1) 15 leaves (S3), with the differences between any possible pair being significant. Genotypic effects on NOL ranged between 15 (V3) and 23 (V6).

The patterns and trends for NOL were very similar to that of DTFLL. The data revealed that both DTLL and NOL increased with latitude. The probably precursor of this trend is the increasing amplitude of photoperiod with increasing latitude. Photoperiod had a substantial effect on both DTFLL and NOL probably via the duration of the inductive or photoperiod-sensitive phase of V6 as seen in the reduction of DTFLL from 93 days (S1 at Cinzana) to 62 days (S3 at Farako) and the reduction of NOL from 27 days (S1 at Cinzana to 18 days (S3 at Farako). Craufurd and Aiming (2001) observed substantial effects of photoperiod on the duration of the photoperiod sensitive phase of sorghum in Nigeria.

Mean Plant height (PLTHT) was differentially influenced by site ($p<0.001$), date of sowing ($p<0.001$) and genotype ($p<0.001$). PLTHT for Farako (228 cm) was significantly higher than for Cinzana (198.5 cm). Responding to date of sowing, PLTHT reduced from 280.4 cm for S1 to 146.6 cm for S3.

Table 1 Main effects of Site, Date of Sowing and Genotype on mean Days to flagleag ligulation (DTFLL), Number of leaves (NOL) and plant height (PLTHT). Means under the same column under a heading followed by the same letter are not significantly different ($lsd_{0.05}$).

Source	DTFLL	NOL	PLTHT
Site			
Farako	58a	18b	228a
Cinzana	62b	20a	199b
Month Sown			
July	69a	23a	280a
August	58b	18b	213b
September	54c	15c	147c
Variety			
V1	61b	22a	190d
V2	60b	19b	277b
V3	47d	15d	230c
V4	62b	20b	148e
V5	54c	17c	130f
V6	80a	23a	330a
Grand Mean	60.19	18.93	213.3
CV (%)	12.6	11.5	12.3

Genotypic differences were also observed with regard to PLTHT which ranged between 130 cm (V5) and 330 cm (V6), with the difference between any pair of varieties being significant. Similar but reversed patterns and trends were observed for plant height as for DTFLL and NOL with regards to all the scenarios involving site. For example, whiles DTFLL and NOL were higher at Cinzana than at Farako, plants at Farako were taller than those at Cinzana. Etiolation from competition for light at Farako (with more cloud cover) could most probably be the cause of this. For site and date of sowing scenarios, PLTHT ranged from 112.7 cm for S3 at Cinzana to 282.8 cm for S1 at FarakoPLTHT of between 129.2 cm for V5 at Cinzana and 388.9 cm for V6 at Farako were recorded for the different scenarios involving site and genotypes, with very highly significant differences ($p<0.001$).PLTHT of between 104.2 cm (S3V4) and 442.9 cm (S1V6) were recorded for scenarios involving the different combinations of date of sowing and genotype.

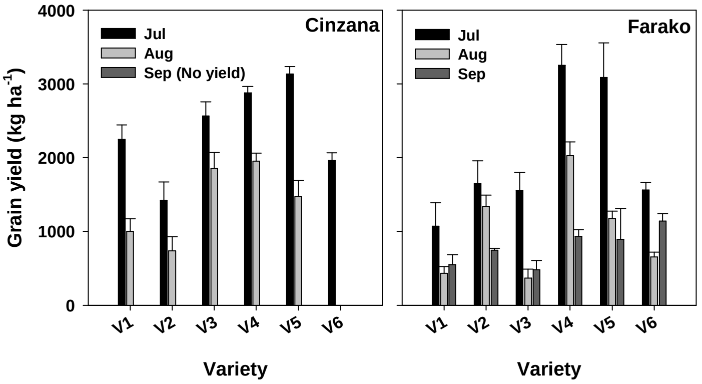


Figure 1: Grain yield response of genotypes to sowing date at Cinzana and Farako

Grain yield is the ultimate goal for sorghum cropping in the Sudano-Sahel ecology and other areas in the semi-arid tropics.

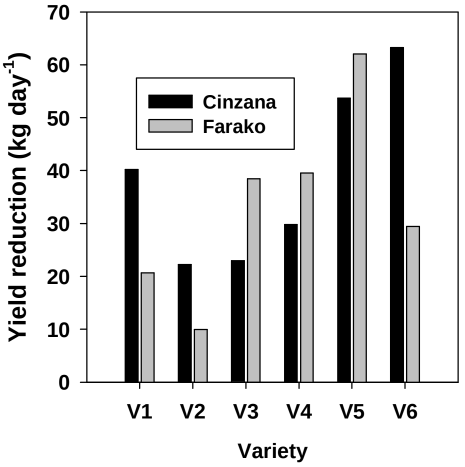
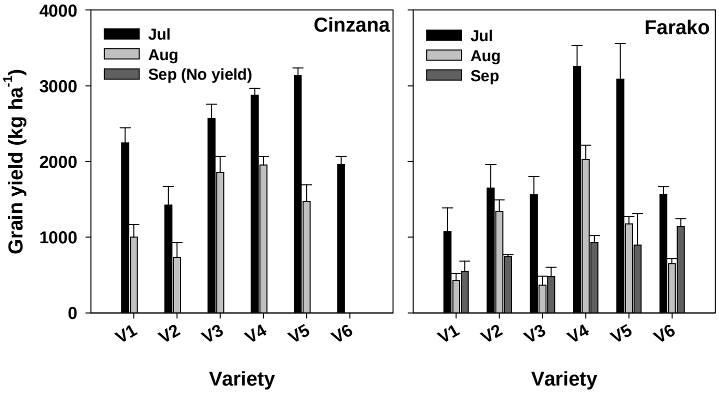


Figure 2: Genotypic variations in yield reduction due to delayed sowing from July to September at Cinzana and Farako.

The data for grain yield presented here are for S1 and S2 at Cinzana and for S1, S2, and S3 at Farako since nothing was harvested from the S1 at Cinzana. However data for main effects of genotype only has been shown in this paper and all discussions refer to S1 and S2 since these were common for all sites. Sorghum yield responses were statistically similar ($p=0.168$) at Cinzana (1720 kg ha^{-1}) and Farako (1542 kg ha^{-1}). In response to date of sowing, mean grain yields were 2090 kg ha^{-1} and 1172 kg ha^{-1} for S1 and S2 respectively, and the differences were very highly significant ($p<0.001$). The rates of yield reduction due to delaying sowing from July to August ranged between 16 kg day^{-1} (V2) and 58 kg day^{-1} (V5).

Very highly significant genotypic differences ($p<0.001$) in yield were also observed in this study, with yield range of 1044 kg ha^{-1} (V6) to 2528 kg ha^{-1} (V4) (Figure 1). In response to the interactive effects of site and date of sowing, yield ranged from 1151 kg ha^{-1} (S2 at Farako) to 2247 kg ha^{-1} (S1 at Cinzana), though the differences were not significant ($p=0.078$). Yield reduction due to delayed sowing from July to August ranged from 10 kg day^{-1} (V2 at Farako) to 63 kg day^{-1} (V6 at Cinzana) (Figure 2).



Differences in the interactive effects of site and genotype on grain yield were highly significant ($p<0.001$) with mean grain yield figures ranging between 753 kg ha^{-1} (V1 at Farako) and 2640 kg ha^{-1} (V4 at Farako).

V1, V3 and V5 (adapted to arid environments and/or nearly day neutral) produced more at Cinzana than at Farako. On the other hand, V2, V4 and V6 (adapted to humid environments and/or photoperiod sensitive) performed better at Farako than at Cinzana.

With the exception of S1 at Cinzana, when V5 had slightly higher yields, V4 recorded the highest absolute yields under all the scenarios reported here (Figure 1).In response to the interactive effects of date of sowing and genotype, grain yields ranged from 326 kg ha^{-1} (S2V6) to 3111 kg ha^{-1} (S1V5). The differences among these figures were very highly significant ($p=0.002$). For all the scenarios presented, the highest yield was recorded for V4 sown in July at Farako, whiles the lowest was recorded for V6 sown in August at Cinzana.

Using a benchmark or threshold of 1500 kg ha^{-1} -130 kg below the grand mean- the data showed that V1 performed well under the scenario "S1 at Cinzana" only; V2 performed well under the scenario "S1 at Farako"; V3 performed well under all scenarios, except "S2 at Farako"; V4 perfromed well under all the scenarios; V5 and V6 performed well under S1 only at both sites.

Conclusions and Outlook

It is possible to create different climatic scenarios by selecting sites along a latitudinal gradient and varying sowing dates within sites. The study revealed that latitude influences adaptation of sorghum cultivars, changing climates will affect the performance of sorghum, delayed sowing reduces crop cycle, number of leaves, plant height and grain yield. The frequency of sowing was so coarse that differences related to timeframes shorter than one month could have eluded us. Further studies involving the use of sowing dates with shorter intervals is required for effective selection of cultivars.

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