Available online at http://www.journalcra.com

International Journal of Current Research
Vol. 7, Issue, 03, pp.13667-13673, March, 2015

INTERNATIONAL JOURNAL
OF CURRENT RESEARCH

ISSN: 0975-833X

RESEARCH ARTICLE

STUDIES ON THE EFFECTS OF VARIETY, INTRA-ROW SPACING AND NITROGEN FERTILISER RATES ON THE PERFORMANCE OF PEARL MILLET IN A SEMI-ARID AGRO-ECOLOGY IN NORTHERN GHANA

[1]Kanton, R. A. L. [1]Afribeh, D. [2,*]Inusah, I. Y. Baba, [1]Asungre, P. [1]Ansoba, E. Y. [1]Kusi, F. [2]Mawunya, M. [1] Sugri, I. [1]Lamini, S and [1]Yirzagla, J.

[1]CSIR-Savanna Agricultural Research Institute, P. O. Box 46, Bawku, Upper East Region, Ghana
[*2]CSIR-Savanna Agricultural Research Institute, P. O. Box 52, Nyankpala-Tamale, Northern Region, Ghana

ARTICLE INFO

Article History:
Received 24th December, 2014
Received in revised form
15th January, 2015
Accepted 23rd February, 2015
Published online 31st March, 2015

Key words:
Drought tolerance,
Early millet, nitrogen,
Row spacing,
Hunger gap,
Sudan savanna agro-ecological zone.

ABSTRACT

Field trials were conducted to investigate the effects of variety, intra-row spacing and nitrogen fertilizer rates on the performance of pearl millet in a semi-arid agro-ecology in north-eastern Ghana

The research was conducted at the Council for Scientific and Industrial Research (CSIR) - Savanna Agricultural Research Institute (SARI), Manga Agricultural Research Station near Bawku in the 2004 and 2005 cropping seasons.

The pearl millet varieties evaluated were Bongo Short Head and Tongo Yellow in 2004 and Bongo Short Head, Tongo Yellow and Arrow in 2005. The intra-row spacing adopted were 20 and 30 cm and the fertilizer levels were 20 and 40 kg/ha of nitrogen. The trial was established as a factorial in a randomised complete block design with 4 replications. Plot dimensions were 4.5 m x 6.0 m. Data was taken on all standard agronomic traits and analysed using GenStat software.

In 2004, panicle length was significantly ($P \leq 0.0001$) affected by millet variety; with Tongo Yellow producing longer panicles than Bongo Short Head. 100 -grain weight of pearl millet was not affected by any of the factors studied. Bongo Short Head produced the highest grain yield, though not significantly ($P \leq 0.05$) higher than Tongo Yellow. Similarly, closer spacing produced higher grain yield compared to wider spacing though the differences were not significant ($P \leq 0.05$). There was a general increase in millet yields with increase in nitrogen fertilizer application; with nitrogen fertilizer levels of 40 and 20 kg/ha significantly ($P \leq 0.013$) out-yielding the No Nitrogen treatment. In 2005, Tongo Yellow produced the highest grain yield. Planting at closer intra-row spacing produced higher grain yield than at wider spacing. Similarly millet yields were higher at 20 and highest at 40 kg N ha^{-1}.

The study enhanced the options available to pearl millet farmers in terms of improved agronomic practices and varietal choice.

INTRODUCTION

Pearl millet [*Pennisetum glaucum* (L.) R. Br.], often referred to as early millet, is one of the most important cereal crops in the Upper East Region (UER) of Ghana. Its uses are similar to those of sorghum but it is generally considered to be of higher nutritional value than the latter (Andrews and Kumar, 1992, 1996; Rai and Velu *et al.,* 2014; Munyaradzi Makoni, 2014). It also has the highest protein content of any cereal, of up to 22% (usually under conditions of extremely low grain yield), and a protein digestibility of about 95%, which makes an excellent source of protein. "Pearl millet grain has much higher levels of the critically important mineral micronutrients iron and zinc (Bouis *et al*., 2011; Pucher *et al.,* 2014; Rai, Govindaraj and Rao, 2012), which are vital to neurological and immune system development." commented Tom Harsh, pearl millet breeder at ICRISAT. More importantly, these mineral micronutrients (although not present in a highly available form), can improve blood iron levels when used in traditional pearl millet-based foods (Cercamondi *et al*., 2013a,b). Pearl millet grain, when fed to poultry, can provide a potentially important source of omega-3 fatty acids, which are also essential for normal neurological development (Collins *et al*., 1997). The crop is the staple food for more than 90 million people in parts of tropical Africa and India which are too hot, dry and sandy for sorghum production (Pearson, 1985; Andrews and Kumar, 1992; Andrews and Bramel-Cox, 1993). The stalks are used for thatching, as fuel and as a poor quality fodder. Decorticated and pounded into flour it is mostly consumed as a stiff porridge

Corresponding author: Inusah, I.Y. Baba,
CSIR-Savanna Agricultural Research Institute, P. O. Box 52, Nyankpala-Tamale, Northern Region, Ghana.

(called *Tuwo zafi* or *T.Z.),* gruel (*Koko*) or delicacy beverages (variously known as *Zim koom and Fura*) in northern Ghana.

Pearl millet's great merit is that it can grow on poor sandy soil in low rainfall areas and stores well (Purseglove, 1981; Andrews and Bramel-Cox, 1993). The crop has a pronounced strategic importance in UER because it serves to bridge the *hunger-gap* immediately after the long dry season when most farm-families would have exhausted their scanty harvest and even have difficulties in purchasing seed for the in-coming cropping season. The only cereal crop in the area that can be sown and harvested within two months is pearl millet (CSIR-SARI, 2009), (Figure 1). The most important characteristic of pearl millet is its unique ability to tolerate and survive under adverse weather conditions of low and erratic rainfall regime and continuous or intermittent drought as compared to most other cereals like maize and sorghum (Rachie and Majmudar, 1980; LCRI, 1997). The only pearl millet variety that was bred and released during Ghana's colonial era was Manga Nara which has since been cultivated extensively in this semi-arid agro-ecological zone of northern Ghana. Regrettably, this has been the only improved cultivar available to pearl millet farmers in the area since the country's independence in 1957 from British colonial rule.

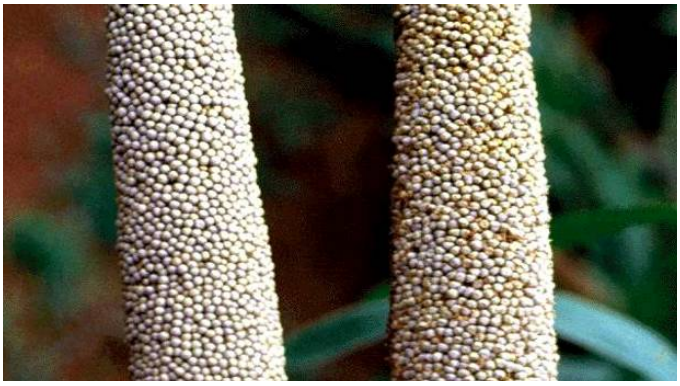

Figure 1. Pearl millet panicles (After Rob Williams/CAB International)

This situation has come about because pearl millet unlike its other cereal counterparts has never officially been regarded as an important crop in Ghana. In order to address this issue, the Council for Scientific and Industrial Research-Savanna Agricultural Research Institute (CSIR-SARI) instigated a millet breeding programme in the late 1990s. Researchers selected early maturing, pest- and disease-resistant pearl millet varieties, which are now being evaluated for subsequent release for enhanced productivity and production in Ghana. Adoption of improved pearl millet varieties tends to be slow in several cropping areas due a complex of factors such as seed availability, varietal performance or household preferences (Ndjeunga and Bantilan, 2005; Dalohou, van Mele and Weltzien, 2011; Rai and Velu *et al*., 2014). The ability of pearl millet to reliably produce on marginal lands and under low rainfall regimes makes it an attractive choice for sandy, low fertility and acidic soils (Menezes *et al.*, 1997). The introduction by CSIR-SARI, of 4 promising varieties of pearl millet into the zone is no doubt welcome news to the anxious smallholder farmers of the UER of Ghana. Indeed, over the years smallholders in the area have always ranked 'lack of early maturing, pest and disease resistant or tolerant varieties' as the most important constraint to enhanced productivity, barring 'low soil fertility' (CSIR-SARI, 2009). There is however, a paucity of information regarding the optimal spacing, plant population density and nitrogen fertilization for these promising varieties. Plant density is one of the most important factors affecting plant productivity (Ali, 2010) and the value of optimal nitrogen fertilization for cereals, for smallholders irking their livelihoods from largely marginal soils, has been underscored by several workers (Andrews and Bramel-Cox, 1993; Yirzagla *et al.,* 2013).

The present study set off to test the performance of selected promising pearl millet varieties and their responses to spacing and nitrogen fertilization for increased and stable yields in the UER.

MATERIALS AND METHODS

Field experiments were conducted at the CSIR-SARI, Manga Agricultural Research Station, near Bawku (11° 01' N, 0° 16' W, 249 m above sea level) in the 2004 and 2005 cropping seasons to evaluate the performance of three improved early millet varieties and their performance at two intra-row spacing and three fertilizer regimes. The research was conducted on a sandy loamy soil typical of the area, very poor in fertility and well drained (Adu, 1969; Aune and Lal, 1997). The millet varieties evaluated were Bongo Short Head (BSH), Tongo Yellow (TY) and Arrow (AR), all three being local materials improved by the research station. The trials were established as a factorial in a randomised complete block design, with four replications with a plot size was 4.5 m x 6 m = 27 m^2. The inter row spacing adopted was 75 cm between ridges. The two intra-row spacing adopted were 20 and 30 cm while the nitrogen fertilizer levels were N_0 = 0 kg N ha^{-1}, N_1 = 20 kg N ha^{-1} and N_2 = 40 kg N ha^{-1}.

Collection of Biological Data and Analysis

Data were collected on the following: stand count at 2 weeks after sowing (WAS), at mid-season and at harvest, leaves per plant every 2 weeks, time to first head emergence (days) time to first flowering (days), time taken to reach 50% flowering (days), plant height at full panicle exertion (cm), stem girth (mm), panicle girth (mm), panicle length (mm), seeds per panicle,100- grain weight (g), straw and seed yield (kg ha^{-1}). Data obtained were subjected to statistical analysis using *GenStat* 9th edition software (Lawes Agricultural Trust - Rothamsted Experimental Station, 2007). Where statistical significance was detected, means were separated using the standard error or standard error of a difference between means.

Some agro-climatic conditions of study area

Long-term (1993-2007) and the 2004 and 2005 cropping seasons' rainfall data are presented in Figure 2. In summary, the long-term rainfall data presented indicates that there were fair amounts of rain in June (approximately 140 mm), but higher amounts in July, August and September. Rainfall distribution in 2004 cropping season was more or less even, with rains peaking rather early in May (at approximately 240 mm). The pattern in 2005 was more irregular with maximum amounts (approximately 320 mm) occurring in July (Figure 2).

RESULTS

All variables recorded varied significantly across years, hence the separation of the data to show the performance of the crop in both years. The effects of cultivar, spacing and nitrogen fertilizer on pearl millet stand count at establishment, mid-season, at harvest and days to panicle initiation at Manga Research Station for 2004 and 2005 are presented in Tables 1 and 2.

with the Bongo Short Head (BSH) recording significantly higher plant population than Tongo Yellow (TY). TY was the earliest to exert its panicle and BSH the latest.

Table 3 depicts time taken to reach 50% bloom (days), plant height (cm), downy mildew incidence (% of hills), panicle girth (mm) of pearl millet as affected by variety, spacing and nitrogen levels for 2004. Time taken to reach 50% bloom was significantly ($P \leq 0.029$) affected by pearl millet variety, whilst spacing and N level effects were not. Plant height was significantly ($P \leq 0.014$) affected by spacing, with closer spacing recording taller plants than wider (Table 3). Tongo Yellow however had slightly taller plants than Bongo Short Head.

Table 1. Effects of cultivar, spacing and nitrogen fertilizer on pearl millet stand count at establishment, mid-season, at harvest and days to panicle initiation at Manga Research Station in 2004

Variety	Stand count at 2 WAS	Stand count at mid-season	Stand count at harvest	Days to first panicle emergence
Bongo Short Head	95	93	87	45
Tongo Yellow	89	87	78	43
Mean	92	90	83	44
s.e.	3.25	3.33	2.70	0.5
Spacing (cm)				
20	103	102	91	44
30	82	78	74	45
Mean	93	90	83	45
s.e.	3.25	3.33	2.70	0.50
Nitrogen				
0	82	80	73	45
20	95	93	84	44
40	100	97	91	43
Mean	92.3	90	82.6	44
s.e.	3.98	4.08	3.31	0.61

Table 2. Effects of cultivar, spacing and nitrogen fertilizer on pearl millet time to first head emergence, time to reach 50% bloom, plant height and stem girth at Manga Research Station in 2005

Variety	Time to first head emergence (days)	Time to reach 50% flowering (days)	Plant height (cm)	Stem girth (mm)
Bongo Short Head	42	49	1.60	8.35
Tongo Yellow	40	49	1.70	8.51
Arrow	45	53	1.90	9.77
Mean	42.3	50.3	1.73	8.88
*s.e.*d	0.44	0.54	0.648	0.295
Spacing (cm)				
20	42	51	1.7	8.90
30	43	50	1.7	8.85
Mean	42.5	50.5	1.7	8.88
*s.e.*d	0.56	0.44	0.529	0.241
Nitrogen				
0	42	50	1.7	8.75
20	42	50	1.8	9.12
40	42	50	1.7	8.76
Mean	42	50	1.73	8.88
*s.e.*d.	0.44	0.54	0.648	0.295

Pearl millet stand count at establishment was affected significantly ($P \leq 0.01$) by both spacing and nitrogen but not variety. Closer spacing (20 cm) recorded significantly ($P \leq 0.000$) higher stand count compared to wider spacing (30 cm). Similarly, stand count at 40 kg N ha^{-1} was significantly ($P \leq 0.01$) higher than that recorded at 0 kg N ha^{-1}. At mid-season the trend in stand was similar to that at emergence with closer spacing and higher N level recording significantly ($P \leq 0.01$) higher number of plants than wider spacing and when no N was applied (Table 1). The trend was similar at harvest

Downy mildew incidence (DMI) was significantly influenced by both variety and spacing at ($P \leq 0.029$) and ($P \leq 0.012$) respectively (Table 3). DMI was higher on Bongo Short Head than on Tongo Yellow. Similarly downy mildew incidence (or number of 'green ears' recorded) was higher at 20 cm than at 30 cm intra-row spacing. Furthermore, the occurrence of 'green ears' increased with an increase in nitrogen fertilizer application (Table 3). Pearl millet panicle girth was significantly ($P \leq 0.0001$) affected by variety, with BSH recording broader panicles than TY. Variety and Nitrogen interaction effect on panicle girth was also significant (P≤0.020).

In 2004, panicle length was significantly (P≤0.0001) affected by pearl millet variety; with Tongo Yellow producing longer panicles than Bongo Short Head. 100-grain weight of the millet was not affected by any of the factors studied.

Bongo Short Head produced the highest grain yield, though not significantly (P≤0.05) higher than Tongo Yellow. Similarly, closer spacing produced higher grain yield compared to wider spacing though the differences were not significant (P≤0.05). There was a general increase in pearl millet yields with increase in nitrogen fertilizer application, with nitrogen fertilizer levels of 40 and 20 kg/ha significantly (P≤0.013) out-yielding the No Nitrogen treatment (Table 3).

Table 3. Time to reach 50% flowering, plant height, panicle girth and downy mildew incidence of pearl millet as affected by variety, spacing and nitrogen levels at Manga Research Station in 2004

Variety	Time to reach 50% flowering (days)	Plant height (cm)	Panicle girth (mm)	Downy mildew incidence (% of hills)
Bongo Short Head	53	143	36.1	29
Tongo Yellow	52	149	26.7	31
Mean	52.5	146	31.4	30
s.e.	0.47	2.23	0.36	1.68
Spacing (cm)				
20	52	151	31.4	34
30	53	142	31.4	26
Mean	52.5	146.5	31.4	30
s.e.	0.47	2.23	0.36	1.68
Nitrogen				
0	53	144	30.8	26
20	53	146	31.6	30
40	52	149	31.8	34
Mean	52.7	146.3	31.4	30
s.e.	0.58	2.74	0.44	2.06

Table 4. Panicle length, 100-grain weight, grain and biomass yield as affected by variety, spacing and nitrogen fertilizer levels at Manga Research Station in 2004

Variety	Panicle length (cm)	100-grain weight (g)	Grain yield (kg ha^{-1})	Biomass yield (t ha^{-1})
Bongo Short Head	9.8	1.67	700	7.20
Tongo Yellow	16.7	1.81	600	5.10
Mean	13.7	1.74	650	6.20
s.e.	0.33	0.06	470	0.28
Spacing (cm)				
20	12.8	1.68	700	6.50
30	13.7	1.81	600	5.90
Mean	13.3	1.75	650	6.20
s.e.	0.33	0.06	47.0	0.28
Nitrogen				
0	12.9	1.71	510	5.40
20	13.7	1.67	660	6.10
40	13.1	1.87	780	7.00
Mean	13.2	1.75	650	6.20
s.e.	0.40	0.08	0.58	0.34

Table 5. Panicle length, number of panicles harvested, 100-grain weight, grain and biomass yield as affected by variety, spacing and nitrogen fertilizer levels at Manga, 2005

Variety	Panicle length (cm)	Number of panicles harvested	100-grain weight (g)	Grain yield (kg ha^{-1})	Biomass yield (t ha^{-1})
Bongo Short Head	11.4	189	1.52	1053	7.80
Tongo Yellow	17.2	188	1.68	1069	7.40
Arrow	27.9	92	1.41	627	8.30
Mean	18.8	156	1.54	916	7.80
s.e.d.	0.593	5.26	0.096	57.6	0.72
Spacing (cm)					
20	18.6	172	1.53	986	8.20
30	19.0	141	1.54	847	7.50
Mean	18.8	124	1.54	916	7.85
*s.e.*d.	0.484	4.3	0.078	47.0	0.59
Nitrogen					
0	18.3	153	1.56	813	7.10
20	18.7	160	1.57	1035	8.30
40	19.5	155	1.47	903	8.20
Mean	18.8	156	1.53	917	7.86
*s.e.*d.	0.593	5.26	0.096	57.6	0.72

Biomass yield was significantly (P≤0.0001) affected by variety, with Bongo Short Head producing significantly higher biomass than Tongo Yellow. There was a significant (P≤0.09) interaction between variety, spacing and nitrogen. Tables 4 are 5 summarise data on seeds per panicle, 100-grain weight (g), grain and biomass yield (kg ha^{-1}) as affected by variety, spacing and nitrogen fertilizer levels at Manga Research Station for 2004 and 2005 cropping seasons. In 2005, Tongo Yellow produced significantly (P≤0.001) longer panicles compared to Bongo Short Head (Table 5).

The effects of spacing and nitrogen were however not significantly different (P≤0.05). Pearl millet variety did not also have any significant (P≤0.05) effect on number of panicles harvested. The number of pearl millet panicles harvested at 20 cm spacing was significantly (P≤0.001) higher than those harvested at 30 cm. Similarly, the number of panicles harvested when no fertilizer was applied was not significantly different from those that received fertilizer (Table 5). 100 –grain weight of TY was significantly (P≤0.05) higher than that of BSH. The effect of spacing and nitrogen fertilisation did not significantly affect 100 - grain weight of pearl millet varieties. TY produced the highest grain yield and Arrow the lowest. Both TY and BSH significantly (P≤0.05) out-yielded Arrow. The latter (Arrow), however produced the highest straw yield and Tongo Yellow the least (Table 5). Sowing at wider intra-row spacing (30 cm) produced longer panicles, relative to closer intra row (20 cm) sowing. Grain and straw yields at closer spacing were also greater than for wider planting distance.

The grain and biomass yields of Bongo Short Head in 2004 were 700 and 7200 kg/ha respectively, which were significantly higher than those of Tongo Yellow. These same values for the variety in 2005 were 1053 and 7800 kg/ha and not much different statistically from those of Tongo Yellow .Grain yield for the cultivar was over 40% higher than that of Arrow and generally much higher than in the previous year.
Close intra row spacing of 20 cm proved a better option than wider spacing of 30 cm in both years of study as far as numbers of panicles harvested; grain and biomass yields were concerned. The highest grain yield over the two seasons was recorded when 20 kg N per hectare was applied, which was significantly higher than for the treatments where 0 and 40 kg N per were applied.

DISCUSSION

The mean annual rainfall for the study area is 925 mm. The quantity and distribution of rain recorded in 2004 and 2005 (with early peaks in both years respectively) were typically far from ideal though fairly favourable for pearl millet production (Purseglove, 1981; LCRI, 1997; Haussmann and Rattunde et al., 2012). The rainfall in the 2005 cropping season was similar in distribution to the long term pattern. The amount of rain in the growing season and distribution in this year appeared better than for the 2004 thereby resulting in better crop performance in 2005 than in the former year. Pearl millet is often planted early- to mid- June and usually harvested in August to supplement farmers' depleted food stock *(bridging hunger gap)* in the current cropping season.

The higher plant densities (at all major phenological stages) associated with Bongo Short Head compared to Tongo Yellow might be ascribed to its inherent genetic properties. Variations in plant height, panicle length and girth together with time taken to reach 50% flowering to a large extent, are all attributable to inherent genetic traits of the pearl millet cultivars (Clayton and Renvoize, 1982; Kumar and Andrews,1993) although Mass, Haanna and Mullinix (2007) (underscoring environmental influence) have reported that planting date and row spacing affects grain yield and height of pearl millet.

Close intra-row spacing (20 cm) normally would result in higher plant stands than a wider spacing (30 cm) but the superior stand counts recorded with increase in nitrogen fertilizer levels can be attributed to better nutrition and a subsequently enhanced survival and growth environment under the higher rates of nitrogen in the study (Menezes *et al.,* 1997). Earliness in the exertion of panicles in pearl millet is synonymous with early maturity. Pearl millet plants that received high N fertilizer amounts also exerted their panicles earlier than those that received no N or low N fertilizer. Enhanced soil fertility status under fertilized treatments would contribute to better root and above ground plant development of most cereal crops usually resulting in earlier maturity than in non fertilized treatments as supported by the works of other researchers in this area (Brunken, Wet and Harlan, 1977; Wilson *et al*., 2008; Ali, 2010).

That intra-row spacing and nitrogen did not interact in the present study is supported by earlier findings by Mass *et al.,* (2007). The panicles of Bongo Short Head are much shorter than those of Tongo Yellow, which make BSH more likely to be accepted by Guinea Savanna zone farmers than Tongo Yellow. Indeed, Wilson *et al., (*2008) reported that smaller panicles tend to be preferred in Ghana, whereas relatively much longer panicles are favoured in Niger. Downy mildew "green ears" are formed when the downy mildew pathogen (fungi) systemically infects the developing panicle so that the host plant's reproductive structures are replaced by leaf-like structures containing the oospore that are involved in survival of the pathogen in the soil from one cropping season to the next. Pearl millet yield loss from this fungal infection is often very severe, up to 50% of potential yield being reported in many parts of sub- Saharan Africa (Singh and Gopinath, 1985; Jones, Breese and Shaw, 2001; Breese, Hash and Devos *et al.,* 2002; Nutsugah, Atokple and Rao, 2002; Wilson *et al.,* 2008).
The occurrence of 'green ears' increased with an increase in nitrogen fertilizer application and close intra row spacing in this work. Singh in 1974 reported that incidence of downy mildew in pearl millet increased as the N levels were raised from 0 to 40 kg/ha; but between 40 and 80 kg/ha N, no significant increase was detected. In the main, enhanced levels of nitrogen fertilizer and high plant densities have severally been associated by some researchers with higher incidences of fungal disease attack in susceptible cereal cultivars (Long, Lee and TeBeest, 2000; Walters and Bingham, 2007; Sester, Raveloson *et al.,* 2014).

The erratic response of the pearl millet varieties to Nitrogen fertilizer treatments over the period can be associated with the agro-climatic conditions that prevailed (Figure 2). The amount and distribution of rainfall appeared to be more favourable for the pearl millet crop in 2005 than in the previous year (Fig. 2) and plots with low fertilizer rates applied (in 2005) were clearly more beneficial in terms of grain and stover yield than high fertilizer treatment plots. It can therefore be inferred that careful choice of optimum planting dates for pearl millet is of great importance since in the year 2004 which was characterized by relatively even distribution, too early peaking and relatively low amounts of rain, pearl millet yields were generally depressed across board (600 - 700 kg/ha) compared to the more favourable 2005 when grain yields ranged from 627 to 1069 kg/ha.

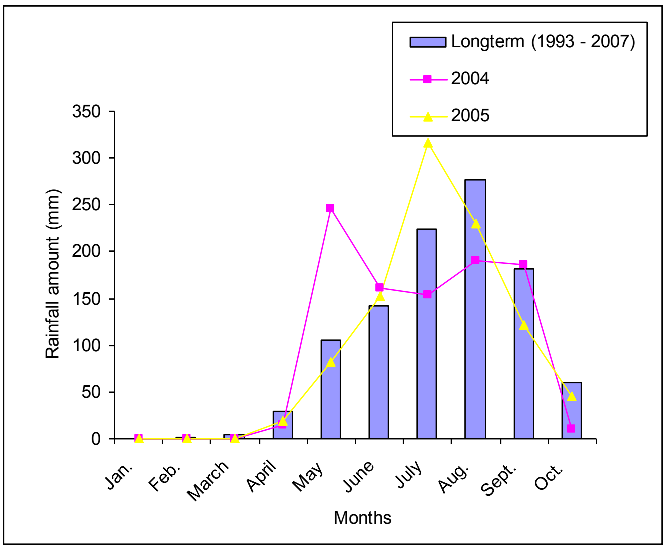

Figure 2. Long-term, 2004 and 2005 rainfall at the Manga Agricultural Research Station, CSIR-SARI

A very important by-product of any cereal crop in northern Ghana is stover which serves several purposes, not least of which is fuel wood. The release of Bongo Short Head, Tongo Yellow and Arrow by the CSIR-SARI for use by farmers opens for them several choices of in terms of varieties. For early croppers and pearl millet farmers operating along the banks of streams and rivers (hydromorphic fringes), they would prefer the longer maturing higher grain yielding Bongo Short Head or Tongo Yellow, which have been shown to have relatively longer vegetative growth periods and are expected to require water for longer periods (Andrews and Kumar, 1992; Mass *et al.,* 2007). On the other hand, late croppers or those farming in typically 'drier' upland conditions of the Sudan Savanna zone with a view of timely bridging the *hunger gap* and/or obtaining a fairly good harvest of both grain and fuel wood - they also have an opportunity to choose a shorter duration Arrow.

Conclusion

Bongo Short Head produced consistently higher grain yields as compared to the other pearl millet varieties evaluated in the study. Close spacing of pearl millet plants resulted in better yields than their more widely spaced counterparts. Similarly, with the application of 20 kg/ha nitrogen, pearl millet either performed comparatively with the 40 kg/ha nitrogen treatment or even out-performed it. These findings would have serious implications for pearl millet production and productivity particularly in the semi-arid regions in Africa with similar weather conditions to those in north-eastern parts of Ghana.

Acknowledgements

The authors of the article gratefully acknowledge the kind permission of the Director of the CSIR-SARI, for permission to publish this work. The work is particularly dedicated to the memory of our late colleague, breeder David. Afribeh. We are also grateful to the Field Technicians of the Manga Research Station for field establishment and data collection.

NB: Text highlighted in yellow are corrections or new insertions. Text highlighted in Blue should be deleted

REFERENCES

Adu, S. V. 1969. Soils of the Navrongo - Bawku area, Upper East Region, Ghana. *Memoir Number 5.* CSIR-Soil Research Institute, Kumasi, Ghana.

Ali, E. A. 2010. Grain yield and nitrogen use efficiency of pearl millet as affected by plant density, nitrogen rate and splitting in sandy soil. American-Eurasian Journal of Agriculture and Environmental Science 7, 327-335.

Andrews, D. J and, Kumar, K.A. 1992. Pearl millet for food, feed and forage. In: Advances in Agronomy. Ed. Sparks, D.L. Academic Press 48, 90-139.

Andrews, D. J. and Bramel-Cox, P. 1993. Breeding cultivars for sustainable crop production in low-input dryland agriculture in the tropics. In: Buxton DR, Shibles R, Forsberg RA, Blad BL, Asay KH, Paulsen GM, Wilson RF (eds), International Crop Science 1. Madison, Wisconsin, USA: Crop Science Society of America, 211-222.

Andrews, D.J. and Kumar, K.A. 1996. Use of West African pearl millet cultivar Iniadi in cultivar development. Plant Genetic Resources Newsletter 1051, 5-22.

Aune, J.B. and Lal, R. 1997. Agricultural productivity in the tropics and critical limits of properties of oxisols, ultisols and alfisols. Tropical Agriculture 74(2), 96–103.

Bouis, H.E., Holtz, C., McClafferty B., Meenaski, J.V. and Pfeiffer, W. 2011. Biofortification: A new tool to reduce micronutrient malnutrition. Food and Nutrition Bulletin, vol. 32, no. 1 supplement: S31-S40.

Breese, W.A., Hash, C.T., Devos, K.M. and Howarth, C.J. (2002). Pearl millet genomics and breeding for resistance to downy mildew. In: Leslie, J.F. (ed), Sorghum and Millets Diseases. Ames, Iowa, USA: Iowa State University Press 243-246

Brunken, J., de Wet, J.M.J. and Harlan, J.R. 1977. The morphology and domestication of pearl millet. Economic Botany 31,163-174.

Cercamondi, Colin I., Ines M. Egli, Mitchikpe, E., Tossou, F., Hessou, J., Zeder, C., Hounhouigan, J.D. and Hurrell, R.F. (2013a). Iron bioavailability from a lipid-based complementary food fortificant mixed with millet porridge can be optimized by adding phytase and ascorbic acid but not by using a mixture of ferrous sulphate and sodium iron EDTA. *The Journal of Nutrition*. doi: 10.3945/jn.113.175075

Cercamondi, Colin I., Ines M. Egli, Mitchikpe, E., Tossou, F., Zeder, C., Hounhouigan, J,D. and Hurrell, R.F. 2013b. Total iron absorption by young women from iron-biofortified pearl millet composite meals is double that from regular millet meals but less than that from post-harvest iron-fortified millet meals.The Journal of Nutrition. doi: 10.3945/jn.113.176826.

Clayton, W. D. & Renvoize, S. A. 1982. Pennisetum. In: Polhill RM (ed.), Flora of tropical East Africa. Gramineae (Part 3). Rotterdam, Netherlands: A A Balkema, 672-673.

Collins, V.P., Cantor, A.H., Pescatore, A.J., Stra, M.L. and Ford M.J.(1997). Pearl millet in layer diets enhances egg yolk omega-3 fatty acids. Poultry Science 76(2): 326-330. doi: 10.1093/ps/76.2.326.

Council for Scientific and Industrial Research - Savanna Agricultural Research Institute (CSIR-SARI) 2009. Annual Report. Accra, Ghana. Pp122-125.

Dalohou, D/N., van Mele, P., Weltzien, E., Diallo. D., Guindo, H. and vom Brocke, K. 2011. Mali: When Government gives entrepreneurs room to grow. In: van Mele, P., Bentley, J.W. and Guie, R.G. (eds). African Seed Enterprises: Sowing the Seeds of Food Security. Wellingford. Oxfordshire,UK. CABI 65-88 DOI: http://dx.doi.org/10.1111/j.1439-037X.2012.00526.x.

Hanna, W. W. 1989. Characteristics and stability of a new cytoplasmatic nuclear male-sterile source in pearl millet. Crop Science 29, 1457-1459.

Hash, C.T., Witcombe 2002. Gene management and breeding for downy mildew resistance. In: Leslie, J.F. (ed), Sorghum and Millets Disease. Ames, Iowa, USA: Iowa State University Press 27-36

Haussmann, B. I. G., Rattunde, H. F., Weltzien, E., Traoré P.S.C., vom Brocke, K. and Parzies, H.K. 2012. Breeding Strategies for Adaptation of Pearl Millet and Sorghum to Climate Variability and Change in West Africa. *Journal of Agronomy and Crop Science* http://dx.doi.org/10.1094/PDIS.2000.84.4.403.

Jones, E.S., Breese, W.A. and Shaw, D.S. 2001. Inoculation of pearl millet with the downy mildew pathogen, *Sclerospora graminicola*: chilling inoculum to delay zoospore release and avoid spray damage to zoospores. Plant Pathology 50(3): 310-316

Kumar, K. A. and Andrews, D. J. 1993. Genetics of qualitative traits in pearl millet: a review. Crop Science 33, 1-20.

Lake Chad Research Institute (LCRI) 1997. *Extension Guide No. 8* on the production of millet.

Lawes Agricultural Trust (Rothamsted Experimental Station) (2007). GenStat 9th Ed. GenStat Procedure Library. Release PL17.1; *VSN International*, 5. The Waterhouse, Waterhouse Street, Hemel Hempstead, Hertfordshire HP1 1ES, UK.

Long, D.H., Lee, F.N. and TeBeest, D.O. 2000. Effect of nitrogen fertilization on disease progress of rice blast on susceptible and resistant cultivars. Plant Disease 84, 4: 403-409

Mass, A.L., Haanna, W.W. and Mullinix, B.G. 2007. Planting date and row spacing affects grain yield and height of pearl millet Tifgrain 102 in Southeastern Coastal Plain of the United States of America.

Menezes, R.S.C., Gascho, G. J., Hanna, W. W., Cabrera, M. L. and Hook, J. E.1997 Subsoil nitrate uptake by grain pearl millet. *Agronomy Journal* 89, 189-194..

Munyaradzi Makoni 2014. "Biofortified Pearl millet 'can combat iron deficiency'". *SciDev Net*. Retrieved 9 September 2014.

Ndjeunga, J. and Bantilan, M.S.C. 2005. Toward understanding household preference for consumption charateristics of pearl millet varieties. A case study from Western Niger. Agriculture Economics 32,151-165.

Nutsugah, S.K., Atokple, I.D.K., Rao, V.P. 2002. Identification of resistance to downy mildew and smut of pearl millet in Ghana. In: Leslie JF (ed), Sorghum and Millets Diseases. Ames, Iowa, USA: Iowa State University Press 43-45.

Pearson, C.J. 1985. Pearl millet, special issue. Field Crops Research, 11(2, 3),111-290. Plant Pathology 63, 10.1111/ppa (2): 373-381.

Pucher, A., Høgh-Jensen H., Gondah J., Hash, C.T. and. Haussmann, B.I.G. 2014. Micronutrient density and stability in West African pearl millet – Potential for biofortification. Crop Science 54(4): 1709-1720. doi: 10.2135/cropsci2013.11.074

Purseglove, J.W. 1981. Tropical Crops. Monocotyledons. Longman. NY.

Rachie, K.O. and Majmudar, J.V. 1980. Pearl millet. University Park, USA: Pennsylvania State University Press.

Rai, K.N., Govindaraj, M and Rao, A.S. 2012. Genetic enhancement of grain iron and zinc content in pearl millet. Quality Assurance and Safety of Crops & Foods 4: 119-125.

Rai, KN., Velu, G., Govindrai, M., Upadhyaya, H.D., Rao, AS., Shivade, H. and Reddy, K.N. 2014. In idai Pearl millet germplasm as a valuable genetic resource for high grain iron and zinc densities. Plant genetic Resources: Characterization and Utilization. DOI:10.1017/S1479262114000665.SATeJournal/ejournal.icrisat.org 5, 1-4.

Sester M., Raveloson, H., Tharreau, D., and Dusserre, J. 2014. Conservation agriculture cropping system to limit blast disease in upland rainfed rice

Singh, S.D. 1974. Studies in pearl millet disease *Sclerospora graminicola* (Sacc). Schoet, bajra. *Pennisetum typhoides* (Burm D) Stapf. (E. Hubb). PhD. thesis, Indian Agricultural Research Institute, New Delhi, India. 126p.

Singh, S.D. and Gopinath. R, A. 1985. Seedling inoculation technique for detecting downy mildew resistance in pearl millet. Plant Diseases 69; 582-584

WaIters, D.R. and Bingham, I.J. 2007. Influence of nutrition on disease development caused by fungal pathogens: implications for plant disease control. *Annals of Applied Biology* 151, 10.111/aab (3): 307-324.

Wilson, J.P., Sanogo, M.D. Nutsugah, S.K., Angarawal. I., Fofana, A., Traore, H., Ahmadou, I. and Muuka, F.P. 2008. Evaluation of pearl millet for yield and downy mildew resistance across seven countries in sub-Saharan Africa. *African Journal of Agricultural Research* 3 (5): 377-378.

Yirzagla, J., Padi, F. K., Akromah, R. & Dawuda, M. M. 2013. Evaluation of Cowpea Genotypes for Maize-based Additive Series Intercropping in the Guinea and Sudan Savanna Zones of Ghana. *Journal of Advances in Agricultural Science and Technology* 1 (1): 001- 008.

****