African Journal of Agricultural Research Vol. 7(32), pp. 4526-4535, 21 August , 2012
Available online at http://www.academicjournals.org/AJAR
DOI: 10.5897/AJAR11.1569
ISSN 1991-637X ©2012 Academic Journals

Full Length Research Paper

Evaluation of five pearl millet varieties for yield and forage quality under two planting densities in the Sahel

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Accepted 21 May, 2012

In the Sahel that is typified by an agro-pastoral system and a long dry season between rains, the availability of animal feed is a very serious constraint. The objectives of this study were to identify pearl millet varieties with high forage productivity under rainfed conditions in the Sahel; to identify best planting densities and to find physiological mechanisms conducive to high forage productivity in pearl millet. The experiment was carried out at the ICRISAT Sadore Research Center in Niger during the 2006 rainy season. Five long duration varieties (Malgorou, Batchoudine, Sanioba, Yabo Maiwa and Somno Damari) as forage crops were compared at two planting densities (10,000 and 20,000 hills/ha). Dry matter yield and forage quality was assessed at the boot, anthesis and at the soft dough stages. The higher planting density gave in this year higher dry matter (and grain) yield than the lower density. The dough stage was the most suitable stage for harvest because dry matter was at its highest. However, organic matter digestibility and crude protein are higher at the boot stage compared with the dough stage. The Malgorou variety gave the highest dry matter yield at the dough stage (8.57 tons/ha at the high planting density). The high forage productivity of this variety was attributed to the longer growing period of time before anthesis and the bigger number of tillers. The results of this study demonstrated that long duration varieties of pearl millet can become an important source of forage in the Sahel under rainfed conditions.

Key words: Forage millet, varieties, planting density, harvest stage, dry matter yield, Sahel.

INTRODUCTION

Feed scarcity is the major constraint for livestock production in the Sahel (Glatzle, 1992). In this region, animals graze in natural rangelands for about 6 months of the year and live from crop residues for the remaining six months (Williams et al., 1997). Animal fattening is an important economic practice in the Sahel. Fattening of sheep before the Islamic festival Eid al Kabir (commonly known as Tabaski) is mostly conducted by resource poor farmers (Hiernaux and Ayatunde, 2004). Resource rich entrepreneurs carry out mainly cattle fattening for local market and for regional exports. In the towns and cities of the Sahel, many households raise livestock in their backyards. These animals are fed from purchased fodder. Forage trade is one of the most important economic activities in many Sahelian cities. The main sources of rough fodder in the Sahel are: bush straw, sorghum straw, groundnut haulms and cowpeas hay. Pearl millet (*Pennisetum glaucum* [L.] R. Br.) is the main grain crop of the Sahel. This species is tolerant to drought, heat and to the nutrients-leached acid sandy soils of this region (Andrew and Kumar, 1992). Potentially, pearl millet has one of the highest rates of growth among the tropical cereals (Craufurd and Bidinger, 1989). In trials in Alabama, dry matter yield of rain-fed pearl millet was around 7.0 t/ha, significantly higher than that of Sudax, a common high yielding forage crop in Southern USA. Pearl millet fodder is comparable in quality or even superior to fodder from other grasses. For example, De Leeuw and Schihorn (1978) demonstrated that heifers grazing pearl millet gained more weight than heifers grazing Rhodes grass (*Chloris gayana*). Likewise,

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Stobbs (1975) found that feeding forage millet to milking cows resulted in higher milk yield as compared with feeding forage sorghum (*Sorghum bicolor*).

The high growth rate of pearl millet combined with its high adaptability to the Sahelian climate and soils makes it a most promising candidate of rain-fed forage in the Sahel. Forage millet is commonly grown in many countries of the world but not in West Africa where grain varieties dominate the landscape (Andrew and Kumar, 1992) because local farmers put higher emphasis on grain than on forage production. For this reason very little research has been conducted on millet forage production in the Sudano Sahel under rainfed conditions. Makeri and Ugherughe (1992) is an exemption. These workers compared the productivity and some quality parameters of 20 pearl millet varieties in northern Nigeria. Dry matter production ranged between 7.2 to 9.92 tons ha^{-1}, but there were no differences in crude protein content among the 20 varieties. Since so little has been done on rainfed forage millet in the Sahel there was a need to identify best sowing density and best harvest time for maximum forage yield under rainfed conditions. Alhassan and Nwasike (1987) working in northern Nigeria found that forage yield was highest at seed set as compared with earlier stages but this was inversely related to forage quality. According to literature the important traits of forage millet varieties are:

1. Dwarfness: Dwarf varieties of pearl millet should make better quality forage than tall varieties because the dwarf varieties have a higher leaf/stem ratio (Johnson et al., 1968). However total biomass production is lower.
2. Long duration: Burton et al. (1986) demonstrated that late maturing varieties of millet produce higher dry matter yield and are leafier than early maturing varieties. Late maturing varieties contain higher crude protein concentration and are more digestible than early varieties.
3. Regeneration following harvests: Most forage millet varieties are harvested a few times during the season. Burger and Hittle (1967) found that highest yields are achieved with three harvests per growing season. However in our preliminary studies, multiple cuttings actually reduced dry matter yield (unpublished).

The above analysis led to the design of an experiment aiming at the: (i) identification of pearl millet varieties, planting densities and best harvest timing to give maximum forage production at reasonable feed quality and (ii) identification of physiological traits responsible for high forage yield in pearl millet.

MATERIALS AND METHODS

Study site

The experiment was conducted at the Sadoré Research Station of ICRISAT in Niger. Sadoré is situated at latitude 13° 15′N and longitude 2° 18′E, 40 km southeast from Niamey, the capital of Niger. The climate is characterized by a rainy season that occurs between June and September, and a dry season that prevail during the rest of the year. The mean annual rainfall at Sadoré is 560 mm (Sivakumar, 1987). The average temperature is 29°C (West et al., 1984). The soil is classified as a sandy silicious isohyperthemic Psammentic Paleustalf. It belongs to the Labucheri type, characterized by a high sand content, low native fertility with low organic matter and low cation exchange capacity that limits nutrient storage and water holding ability. These soils are generally very strongly acidic to strongly acidic (pH 4.5 - 5.0), with aluminum comprising of a high percentage (47%) of the exchangeable cations (West et al., 1984).

Experimental layout and determinations

The experiment was set up in a split plot design with five replications included two factors. Pearl millet varieties (Malgorou, coming from the Dosso region of Niger, Batchoudine and Saniobo originating in the Aïr Mountains-Niger, Yabo Maiwa from central Mali and Somno Damari coming from a village at the vicinity of the ICRISAT experimental station) were arranged in the main plots and two planting densities 1 m × 1 m (10,000 hills/ha) and 1 m × 0.5 m (20,000 hills/ha) were assigned in the subplots. Main plot size was 18 m × 18 m (324 m^2) and the sub plot size was 18 m × 8 m (144 m^2). The area of the experimental field was 1,336 m^2. The experiment was planted in a field that lay fallow during a period of 5 years prior to sowing. A complete fertilizer (15-15-15) containing 15% N, 6.5% P and 12.4% K was broadcasted prior to planting at a rate of 150 kg/ha and incorporated with a disc.

Millet was sown in hills on July 14th, 2006. Two weeks after planting, plants were thinned and 2 plants per hill were left till harvest. There were two weeding events. The plants were harvesting at three events: 50% boot stage, 50% anthesis and at 50% dough stage. Time for 50% boot, 50% anthesis and 50% dough stage was determined for each variety. The number of tillers per plant was counted on the third harvest occasion. In each of the three harvest occasions 45 hills/plot were harvested at the high density treatment and 24 hills/plot were harvested at the low density treatment. Plants were separated into leaves, stems and heads and fresh weight was determined.

Plant parts were dried for 48 hours in a forced ventilation oven at 70°C and dry weight was determined. In addition to the three main harvest events plants were sampled every ten days from germination until the wax stage for leaf area and dry weight determinations. Samples were taken only from the low density treatment. Six hills per plot were harvested. Leaf area was determined using a L1 3100 Area meter. Plants were dried and dry weight was also determined. These data were used to calculate the leaf area index (LAI) and the relative growth rates (RGR) of the five varieties (Hunt, 1990).

Forage quality analysis

Composite samples were taken from sampled plant parts at each harvest event and were analyzed for feed value. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) and lignin were analyzed according the procedures of Van Soest et al. (1985). Cellulose was calculated as the differences of ADF − lignin. Organic matter digestibility (OMD) was determined by the *in vitro* gas production technique calibrated with standards obtained *in vivo* (Menke et al., 1979). Nitrogen was determined with the Kjeldahl method (Bremner and Mulvaney, 1982) and crude protein content was determined by multiplying the N content by 6.25.

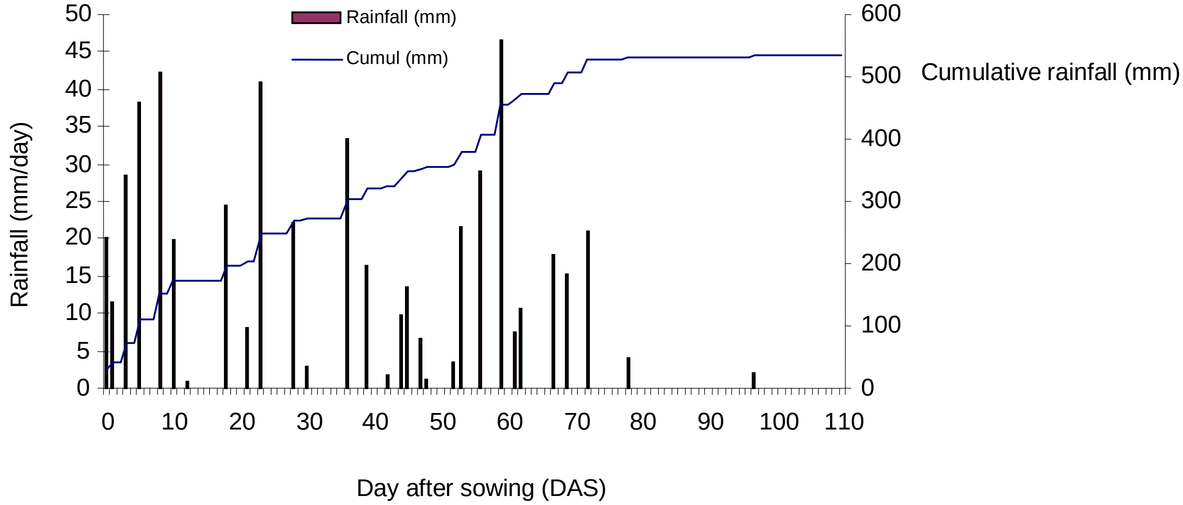

Figure 1. Rainfall distribution (mm) during 2006 rainy season at ICRISAT-Sahelian Center, Sadoré Niger.

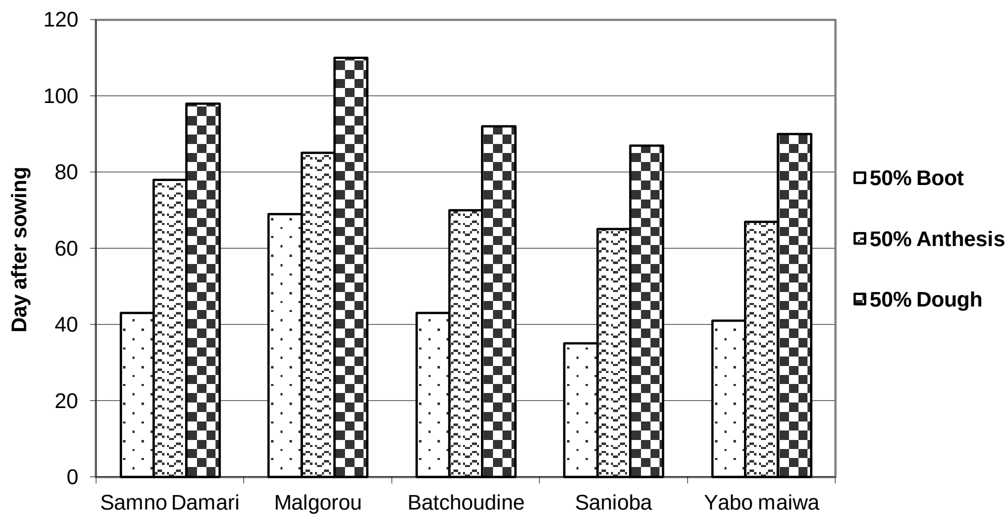

Figure 2. Number of days for 50% boot, flowering and dough stages for the five varieties.

Statistical analysis

Data collected were subjected to analysis of variance using the GenStat® 9th (Lawes Agricultural Trust, 2007). Least significant difference at 5% level of significance was used for means separation.

RESULTS AND DISCUSSION

Rainfall distribution

The total rain recorded in 2006 was similar to the average for the region with a very good distribution during the period July to October (Figure 1). This factor together with the long fallow period that proceeded planting were probably responsible for the high dry matter and grain yield obtained in this year. This good rainfall distribution increased soil moisture content which increased the solubility and availability of soil nutrients, all of which in turn increased nutrient absorption, thereby resulting in high dry matter production.

Phenological stages

The number of days for boot, anthesis and dough stages for the five varieties is given in Figure 2. The variety Malgorou reached the boot stage 20 days, anthesis 15 days and dough stages 15 days later than then of the other four varieties.

Growth parameters

The number of tillers per plant for the five varieties at the two planting densities at the dough stage is given in Table 2. There were no significant differences in the number of tillers/plant between planting density treatments. However, varieties had significant effect on number of tillers per plant ($P<0.05$).The varieties Malgorou and Batchoudine had significantly higher number of tillers as compared with the other three varieties.

The leaf area index of the five varieties (low density only) during the first 91 days after sowing is given in Figure 3. The analysis of variance showed significant difference between the varieties ($P<0.05$) as indicated in Figure 3. While LAI of the other four varieties peaked at 71 days after sowing, the LAI of Malgorou continued to increase for an additional 10 days resulting in a significantly higher LAI for this variety during days 80-100 after sowing. Moreover, the relative growth rate (Figure 4) was similar for all 5 varieties during the first three months after sowing, indicating that there were no differences in the potential productivity among the five varieties ($P<0.05$).

Dry matter production

Effect of varieties and planting densities as well as their interactions at three growth phases on total dry matter production is given in Table 1. Dry matter yield was significantly affected by varietal differences ($P<0.05$). The Malgorou variety produced at both the anthesis and dough stages significantly higher dry matter than the other four varieties. A dry matter yield of 8.57 tons/ha obtained by the Malgorou variety at the dough stage was higher than recorded yields of rain fed forage millet with multiple cuttings (Craufurd and Bidinger 1989) and similar to forage yields obtained under high fertilization regimes (Reddy et al., 2003). It is comparable to dry matter yield from four cuttings in a higher rainfall area in north Nigeria (Makeri and Ugherughe (1992). Analysis of variance showed that planting densities had significantly affected dry matter yield ($P<0.05$).

The mean separation presented in Table 2 showed that the dense (0.5×1.0 m) planting spacing gave significantly higher dry matter yield than the sparse (1m × 1m) sowing at all three growth stages. Rajala (2006) demonstrated that high density (20,000 hills/ha) sowing is advantageous only under good rain distribution (short dry spells) as was evidenced in the 2006 rainy season (Figure 1). The increment of dry matter yield with high planting density was due to the high number of plant/m^2 which compensates the lowest number of tiller/ plant recorded with high planting density. Similar finding was recorded by Ali (2010). On the other hand, the interaction of varieties and planting densities had no significant effect on dry matter yield ($P>0.05$).

Leaf /stem ratio for the five varieties at three growth stages is given in Table 1. Leaf/stem ratio was significantly affected by cutting stages ($P<0.05$). In general and as expected, the leaf/stem ratio was highest during boot but with no statistical differences between varieties and planting densities. At anthesis, the leaf/stem ratio was about half the ratio at boot. The leaf/stem ratio for the varieties Sanioba and Somno Damari increased at the dough stage as compared with anthesis.

Grain yields

The data presented in Table 3 showed that grain yields were significantly affected by the varietal differences and planting densities ($P<0.05$). Highest grain yield was obtained with Somno Damari (2.19 tons/ha) at the high sowing density treatment. Malgorou had the lowest grain yield but the highest total dry matter yield compared to the others varieties. Apparently, this variety "invests' more dry matter into the shoot than into grains, which makes it a good candidate for dual purpose (grains and forage) millet. Means separation showed that with the increase in plant density, grain yields increase significantly (Table 4). This increment of grain with high plant density can be related to high number of plant/m^2. Similar finding was reported by Al-Suhaibani (2011).

Forage quality

Effect of varieties and planting densities presented in Table 5 showed that except cellulose content, all parameters of forage quality observed in this study (crude protein, *in vitro* digestibility and lignin contents) were significantly affected by the varietal differences. Planting densities had no statistical differences on *in vitro* digestibility, lignin and cellulose contents. However, planting densities had significantly affected crude protein content ($P<0.05$). Protein content at boot stage was the highest, diminishing with plant age (Table 6). At both the boot and at the anthesis stages, the low planting density plants had higher protein content than the high-density forage.

Furthermore, the means separation presented in Table 6 showed that crude protein of Malgorou was significantly lower than that of other varieties where the highest crude protein content was obtained with Samno Damari variety. The ODMD of the millet forage is similar to that of quality sorghum stover (Agyemang et al., 1998). Also, the highest *in vitro* digestibility occurred during the boot stage and the lowest during anthesis. At the dough stage, the Malgorou variety had the highest ODMD (600 $g.kg^{-1}$) of all five varieties. Lignin content of the five varieties was highest at anthesis, where it ranged between 9.3 to 12.1% compared to others cutting stages.

Table 1. Total dry matter (kg/ha) and leaf/stem ratio of five pearl millet varieties planted at two planting densities harvested at three developmental stages.

Cutting stage	Variety	Planting density	Total dry matter (kg/ha)	Leaf/stem ratio (kg/kg)
Boot	Batchoudine	1 m × 0.5 m	1,388	0.68
		1 m × 1 m	1,124	0.65
	Malgorou	1 m × 0.5 m	2,462	0.81
		1 m × 1 m	1,614	0.92
	Sanioba	1 m × 0.5 m	2,044	0.82
		1 m × 1 m	1,401	0.86
	Somno Damari	1 m × 0.5 m	1,715	0.92
		1 m × 1 m	1,275	0.75
	Yabo Maiwa	1 m × 0.5 m	1,464	0.54
		1 m × 1 m	1,299	0.61
Anthesis	Batchoudine	1 m × 0.5 m	5,000	0.48
		1 m × 1 m	4,260	0.35
	Malgorou	1 m × 0.5 m	6,640	0.38
		1 m × 1 m	7,100	0.34
	Sanioba	1 m × 0.5 m	5,830	0.34
		1 m × 1 m	4,440	0.42
	Somno Damari	1 m × 0.5 m	5,360	0.41
		1 m × 1 m	3,150	0.46
	Yabo Maiwa	1 m × 0.5 m	5,210	0.41
		1 m × 1 m	4,220	0.40
Dough	Batchoudine	1 m × 0.5 m	6,627	0.45
		1 m × 1 m	5,038	0.50
	Malgorou	1 m × 0.5 m	8,574	0.38
		1 m × 1 m	6,277	0.49
	Sanioba	1 m × 0.5 m	6,068	0.55
		1 m × 1 m	4,777	0.59
	Somno Damari	1 m × 0.5 m	5,036	0.60
		1 m × 1 m	3,219	0.92
	Yabo Maiwa	1 m × 0.5 m	6,776	0.44
		1 m × 1 m	4,054	0.51
Probabilty (0.05)				
Varieties(V)			<0.001	0.256
Plant densities (PD)			<0.001	0.240
Cutting stages(CS)			<0.001	<0.001
V × PD			0.380	0.284
V × CS			<0.001	0.027
PD × CS			<0.001	0.264
V × PD × CS			0.016	0.144

Table 2. Means separation on total dry matter (kg/ha), leaf/stem ratio and Number of tillers/hill of five pearl millet varieties planted at different densities.

Data	Treatment	Total dry matter (kg/ha)	Leaf/stem ratio (kg/ha)	Number of tillers/hill
Means of varieties	Batchoudine	3,907[b]	0.52[a]	11.0[a]
	Malgorou	5,444[a]	0.55[a]	12.5[a]
	Sanioba	4,093[b]	0.60[a]	7.8[c]
	Somno Damari	3,293[c]	0.68[a]	9.6[b]
	Yabo Maiwa	3,838[b]	0.48[a]	9.9[b]
Means of plant densities	1 m × 0.5 m	4,680[a]	0.58[a]	9.7[a]
	1 m × 1 m	3,550[b]	0.65[a]	10.6[a]
Means of cutting stage	Boot	1,579[c]	0.88[a]	
	Anthesis	5,122[b]	0.42[c]	
	Dough	5,645[a]	0.58[b]	
LSD for:				
Varieties		579.4	0.23	1.74
Planting densities		234.5	0.12	1.30
Cutting stages		299.0	0.15	

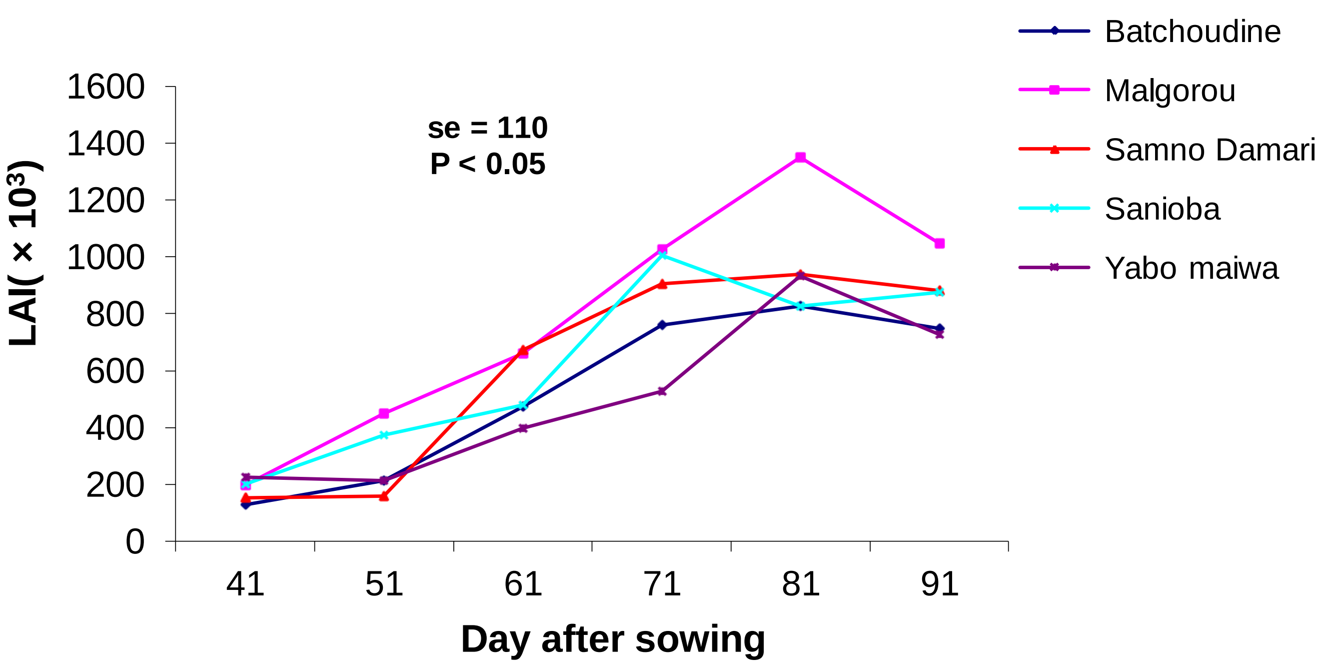

Figure 3. Leaf area index development of five pearl millet varieties during 91 days after sowing.

Conclusion

The experiment demonstrated that rainfed pearl millet can produce under about 500 mm annual rainfall high dry matter yields with reasonable forage quality, thus becoming a source of rainfed forage in semi-arid Sahel. Longer duration varieties are most suitable for forage production because the long period of growth before seeds set allows them to produce more dry matter than the shorter duration varieties. The Malgorou variety produced more dry matter than the other four varieties. The reasons for the significantly higher dry matter

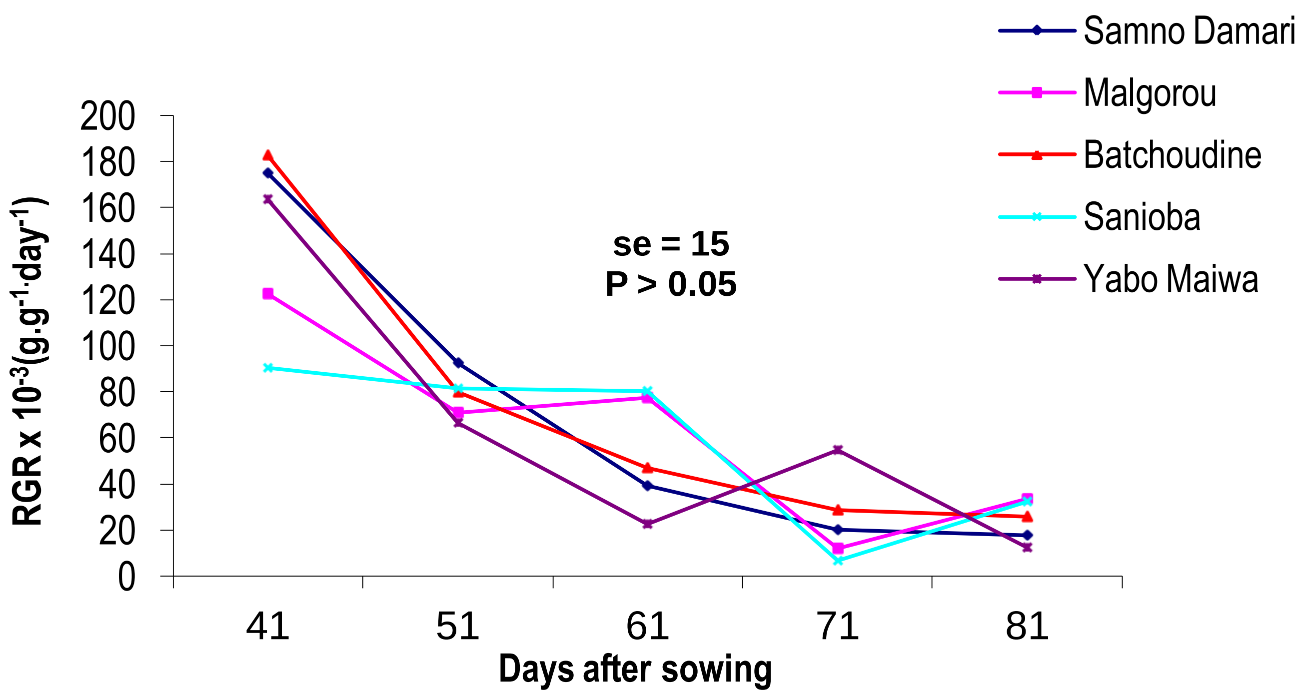

Figure 4. Relative Growth Rate of five pearl millet varieties during 81 days after sowing.

Table 3. Grain yield and yield components at grain harvesting.

Variety	Density	Grains (kg/ha)	Dry leaves (kg/ha)	Dry stem (kg/ha)
Batchoudine	1 m × 0.5 m	1,983	990	4,070
	1 m × 1 m	1,887	819	3,222
Malgorou	1 m × 0.5 m	1,490	1,752	4,895
	1 m × 1 m	1,170	1,238	3,688
Sanioba	1 m × 0.5 m	1,885	1,124	3,350
	1 m × 1 m	1,526	810	2,517
Samno Damari	1 m × 0.5 m	2,188	1,067	4,252
	1 m × 1 m	1,660	714	2,632
Yabo Maiwa	1 m × 0.5 m	1,632	1,048	3,529
	1 m × 1 m	1,269	724	2,825
Probability				
Variety		<0. 001	<0. 001	0.014
Planting Densities		<0. 001	<0. 001	<0. 001

production of Malgorou were a longer period before reaching boot stage, allowing more leaf and stem production and production of a higher number of tillers. Malgorou also had the highest dry matter content at grain harvest, making it a candidate for a dual purpose (grain/forage) variety for the Sahel.

In addition, with a seasonal rainfall of 540 mm and short dry spells, a density of 20,000 plants/ha gives higher dry matter and grain yield than a density of 10,000 plants/ha. With the exception of Somno Damari, the

Table 4. Means separation on Grain yield and yield components at grain harvesting.

Data	Treatments	Grains (kg/ha)	Dry leaves (kg/ha)	Dry stem (kg/ha)
Means of varieties	Batchoudine	1,935[a]	905[b]	3,646[ab]
	Malgorou	1,330[b]	1,495[a]	4,292[a]
	Sanioba	1,706[a]	967[b]	2,934[b]
	Somno Damari	1,924[a]	891[b]	3,442[b]
	Yabo Maiwa	1,451[b]	886[b]	3,177[b]
Means of plant densities	1 m × 0.5 m	1,832[a]	1,196[a]	4,019[a]
	1 m × 1 m	1,502[b]	861[b]	2,977[b]
LSD for:				
Varieties		263	186	743
Planting densities		149	113	350

Table 5. Quality parameters of five pearl millet varieties planted at two planting densities harvested at three developmental stages.

Cutting stage	Variety	Planting density	Crude protein	*In vitro* OMD	Lignin	Cellulose
			(g/kg)			
Boot	Batchoudine	1 m × 0.5 m	139.2	604.4	80.8	387.5
		1 m × 1 m	161.8	621.4	73.6	322.4
	Malgorou	1 m × 0.5 m	130.0	625.2	74.9	369.4
		1 m × 1 m	143.2	616.0	78.3	370.1
	Sanioba	1 m × 0.5 m	154.6	640.8	60.6	411.3
		1 m × 1 m	152.7	621.8	78.2	377
	Somno Damari	1m × 0.5 m	143.2	633.5	76.4	379.3
		1 m × 1 m	168.4	614.9	73.9	389.7
	Yabo Maiwa	1 m × 0.5 m	120.8	620.7	69.7	400.9
		1 m × 1 m	149.1	624.8	79.0	413.1
Anthesis	Batchoudine	1 m × 0.5 m	74.6	559.4	97.7	469.6
		1 m × 1 m	82.3	501.9	105.4	459.2
	Malgorou	1 m × 0.5 m	67.9	506.6	92.7	440.9
		1 m × 1 m	70.0	510.0	99.3	440.6
	Sanioba	1 m × 0.5 m	80.0	490.5	94.9	452.2
		1 m × 1 m	85.2	487.7	100.9	454.0
	Somno Damari	1 m × 0.5 m	74.6	511.7	103.6	463.3
		1 m × 1 m	79.8	519.2	121.1	441.5
	Yabo Maiwa	1 m × 0.5 m	74.6	488.6	119.2	448.7
		1 m × 1 m	73.4	501.4	107.8	482.1
	Batchoudine	1 m × 0.5 m	54.3	576.0	75.8	409.2
		1 m × 1 m	50.3	582.5	89.8	396.2

Table 5. Contd.

Dough	Malgorou	1 m × 0.5 m	44.8	598.6	63.2	417.8
		1 m × 1 m	48.4	601.7	76.7	365.3
	Sanioba	1 m × 0.5 m	62.4	518.8	84.3	438.7
		1 m × 1 m	64.5	524.3	71.1	392.9
	Somno Damari	1 m × 0.5m	64.6	582.9	101.5	457.5
		1 m × 1 m	65.0	576.0	69.9	491.1
	Yabo Maiwa	1m × 0.5 m	64.7	550.5	95.3	417.7
		1 m × 1 m	64.2	526.3	86.9	415.1
Probabilty (0.05)						
Varieties(V)			0.032	0.012	0.020	0.122
Plant densities(PD)			0.030	0.593	0.015	0.308
Cutting stages(CS)			<.001	<0.001	<o.001	<o.001
V × PD			0.813	0.163	0.007	0.313
V × CS			0.052	0.208	0.310	0.573
PD × CS			0.354	0.383	0.859	0.881
V × PD × CS			0.758	0.470	0.125	0.697

Table 6. Means separation on forage quality parameters of five pearl millet varieties planted at different planting densities.

Data	Treatment	Crude protein (g/kg)	*In vitro* OMD (g/kg)	Lignin (g/kg)	Cellulose (g/kg)
Means of varieties	Batchoudine	93.8^{ab}	574.3^{a}	87.2^{ab}	407.6^{a}
	Malgorou	84.1^{b}	576.4^{a}	80.9^{b}	400.7^{a}
	Sanioba	99.9^{a}	547.3^{b}	81.7^{b}	421.1^{a}
	Somno Damari	99.3^{a}	573.1^{a}	91.1^{a}	437.1^{a}
	Yabo Maiwa	91.1^{ab}	552.1^{b}	92.9^{a}	429.6^{a}
Means of plant densities	1 m × 0.5 m	90.1^{b}	567.2^{a}	86.1^{a}	424.3^{a}
	1 m × 1 m	97.2^{a}	561.9^{a}	87.5^{a}	414.1^{a}
Means of cutting stages	Boot	146.3^{a}	622.4^{a}	74.5^{b}	382.1^{b}
	Anthesis	76.2^{b}	507.7^{c}	104.3^{a}	455.2^{a}
	Dough	58.3^{b}	563.8^{b}	81.6^{b}	420.2^{ab}
LSD for:					
Varieties		13.55	19.61	10.01	43.78
Plant densities		6.69	8.63	2.83	23.92
Cutting stages		28.68	29.03	7.53	46.10

dough stage seems to be the most suitable for harvesting because at this stage the dry matter yield of most varieties is at its highest. However, organic matter digestibility and crude protein are higher at the boot stage compared with the dough stage.

ACKNOWLEDGEMENTS

The authors gratefully appreciate the technical assistance of the staff of Systems and Crops Diversification Program and of the International Livestock Research Institute

(ILRI), at the International Crops Research Institute for semi-Arid Tropics (ICRISAT) Niamey, Niger.

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