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Full Length Research Paper

Watermelon production on stored rainwater in Sahelian sandy soils

D. Fatondji, D. Pasternak and L. Woltering*

ICRISAT Niamey, P.O. Box 12404, Niamey Niger

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Watermelon [*Citrullus lanatus* (Thumb) Matsun and Nakai] is an important cash crop in West Africa where it is cultivated under rainfed conditions. The objective of this work was to identify best cultural practices for production of watermelons in the Sahel on stored rainwater in acid sandy soils. The experiments were carried out at the ICRISAT Sadore research center in Niger during two consecutive dry seasons, 2003 - 2004 and 2004 - 2005. Three soil management treatments were applied: micro-catchments (also called half -moons), planting pits (also called zaï) and sowing on flat land. Each of these three treatments came with and without a soil amendment comprising of 500 g of manure mixed with 24 g of a complete (NPK) fertilizer (15-15-15) individually applied to each planting hill. Two watermelon cultivars were tested: 'Malali' and 'Kaolack'. In each of the two years the experiments were sown on the 1st and on the 21st of September. Fruit and biomass yield, fruit Total Soluble Solids (TSS), days to fruiting and harvesting were determined. Soil fertility, root development and other physiological parameters were monitored to explain some of the differences between treatments. Soil amendments increased marketable yields from 1.3 to 3.5 tons ha^{-1} on average. Marketable yields at the first planting date were double the yields of the second planting date (3.2 vs. 1.6 tons ha^{-1}). Yield differences were due to changes in fruit number not in fruit weight. Deep placement of soil amendments resulted in significant root development in deeper soil layers. Highest watermelon yields were achieved when sowing the *Malali* cultivar in amended planting pits on September 1st giving a yield of 8.2 tons ha^{-1}.

Key words: *Citrullus lanatus*, Malali, Kaolack, Zaï, planting pits, half moons, stored water, root development, Sahel.

INTRODUCTION

Watermelons [*Citrullus lanatus* (Thumb) Matsun and Nakai] belong to the Curcubitacea family. It originates in the dry regions of southern Africa. It is produced all over the world particularly in the semi arid regions (Wehner et al., 2001).

Watermelons are produced under irrigation or on stored rainwater (Maynard, 2001). Under irrigation fruit yield can be as high as 72.0 tons ha^{-1} (Simonne et al., 2005) whereas when grown on stored rainwater yields can be as low as 3.0 tons ha^{-1} (Pala et al., 2000).

Watermelons are becoming a very important source of income for small scale farmers of the semi arid tropics of West Africa. In the Kaolack region of Senegal (about 600 mm y^{-1} of rainfall) watermelon cultivation has replaced millet production in many places because of its higher income per hectare (Diatta, personal communication). Watermelon is composed of about 90% water and 8% carbohydrates. It is rich in pro-vitamin A (beta caroten) and in licopen, a very effective anti oxidant. It is also high in Potassium (120 mg/100g dry weight) and fibers and low in Sodium (National Research Council, 2008). The Segou area of Mali (rainfall about 600 mm y^{-1}) is also a well-known semi-arid watermelon producing region.

In 2002, a preliminary study aiming at the identification of constraints for watermelon production during and following the rainy season was conducted at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) experimental station at Sadore, situated in the Sahelian region of Africa. Watermelons were planted in June, July, August and September. The June and July plantings produced a large biomass but fruit yield was very low due to heavy insect attack and lack of female flowers. Yields from August and September plantings were reasonable and insect attack was much less signifi-

*Corresponding author: E-mail: L.Woltering@cgiar.org.

cant. It was also noted that plants had a very small canopy with the exception of an area where there was a destroyed termite mound. This indicated that watermelons are highly sensitive to the low fertility of the Sahelian soil. These observations have led to the design of the trials reported in this paper where planting time, varieties and soil fertility effects were investigated. The objective of the experiment was to identify best practices for production of watermelons on stored rainwater.

MATERIALS AND METHODS

The experiment was conducted at ICRISAT Sadore research station in Niger (13°15'N, 2°17'E). The soil is classified as a sandy silicious isohyperthemic Psammentic Paleustalf (West et al., 1984). 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 acid to strongly acid, pH ranging from 4.5 to 5.2. Aluminum comprises a high percentage of the exchangeable cations (47%) stimulating Aluminum toxicity in many crops. Average annual rainfall is 560 mm that normally falls between June and September.

The field experiments were conducted in 2003 - 2004 and in 2004 - 2005 "dry seasons". In each year there were two planting dates; September 1st and September 21st. The following treatments were applied:

Land management: techniques comprised of sowing on flat ground, in planting pits and in micro-catchments or half-moons (Reij et al., 1996). Planting pits are called Zaï pits when amended with manure and are an indigenous technology developed by farmers of the Sahel to overcome problems of soil water infiltration and low fertility (Fatondji et al., 2006). Planting pits were 20 cm deep and 20 cm wide. The half-moon had a width and a length of 1.5 m. In 2003 the planting pits and half-moons were prepared during the first week of July whereas in 2004 these were prepared during the first week of August.

Soil amendment: comprised of adding to each planting hill 24 g of a complete fertilizer (15-15-15) containing 15% N, 6.5% P and 12.4% K giving a total of 60 kg ha^{-1} of 15-15-15. In addition 500 g of composted cow manure was added to each planting hill giving a total of 1.25 tons ha^{-1} of compost. The soil amendment treatment was compared with a zero amendment control. In the flat and the half-moon treatments soil amendments (compost and fertilizers) were applied to the surface and incorporated into the top 5 cm of the soil. Soil amendments were added to the bottom of the planting pit. During the rainy season prior to planting, the compost was covered (by erosion) with a 10 cm layer of sand.

Two open pollinated watermelon cultivars: were compared; "Malali" from Hazera company in Israel and "Kaolack" a cultivar from Senegal purchased from the Agrimex Company in Niger.

Planting dates: Superimposed on the above there were, in each of the two experimental years, two planting dates: September 1st and September 21st.

The 2004 trials were carried out in the same field as in 2003 trial using the same experimental layout.

The experimental design was a randomized complete block (RCBD) in four replications. Treatment combinations were Land management x Soil amendment x Cultivar x Planting dates (3 x 2 x 2 x 2).

In each planting date there were 48 plots. Plot size was 100 m^2. Field size for each planting date including borders was 6,000 m^2. Watermelons were planted at a spacing of 2 x 2 m with 3 seeds per hole. When plants reached the two-true-leaves stage seedlings were thinned to one plant per hole.

Yield (marketable and non-marketable), number of fruits, leaves and stem dry weight, days to first fruit and harvest, TSS, soil chemical parameters (Total N and P-Bray) and root length were analyzed using the GenStat® release 9.1 (Lawes Agricultural trust 2006). Soil fertility was determined three times (2nd of August, 8th of November 2003 and 17th of January 2004) during the two years trial but only the results of the January 2004 sampling will be presented. Samples were taken from each soil management and amendment treatment in three replications. Samples were taken from the following depths: 0-10, 10-20 and 20-40 cm. Available P was determined using the Bray N° 1 method (Bray and Kurtz, 1945); total nitrogen was determined using the Kjeldahl method (Bremner and Mulvaney, 1982). To determine watermelon root length density samples were collected in mid-January 2004 in all treatments and replications to a depth of 200 cm at 20 cm intervals using the destructive method described in Manske (1997). Samples were collected with a metal frame measuring 20 x 20 x 10 cm from 0 – 20 cm. Below this depth, aluminum tube of 7.5 cm diameter as per the principle of the Viehmeyer tube (Viehmeyer, 1929) was used with the difference that in the present case, the soil was sandy and aluminum tube was sufficient to take the samples from deeper layers. The roots were washed, and root length was determined by the grid counting method (Newman 1966). The grid size of 2 x 2 cm was used for the coarse roots and 1 x 1 cm for the fine roots. The coarse roots were counted on a sub-sample of 2 g taken from the main sample. In the case of the fine roots, if the fresh weight of the total sample was more than 1 g, a sub-sample of 1 g was taken for the count. The samples were cut into small pieces of 1 cm and spread in the dish with a small amount of water. Specific root length was calculated from the counts.

Days to first fruit and dates to first harvest were determined in all treatments. Leaf and shoots biomass were determined at the end of the trial for each treatment in each of the two years.

To prevent soil moisture depletion by weeds the field was weeded throughout the rainy season (June-September). Firewood ash, a traditional insecticide, was sprinkled on the young plants once a week for the first four weeks after germination. Thereafter there was no need for applications of pesticides or fungicides.

First harvest took place about 100 days from sowing. In 2003 there were three harvest events for each of the two planting dates and in 2004 there were four.

At each harvest occasion fruit were separated into spoiled and marketable fruit. Fruit in each of the two categories were counted and weighed separately. The main reason for fruit spoilage was fruit cracking. In the last harvest all unripe fruit (spoiled and none spoiled) were counted, weighed and categorized as spoiled fruit.

Total Soluble Solids (TSS) of fruit flesh was measured with an Automatic Compensation Refractometer model ATC-1E (manufactured by ATAGO CO. LTD; http://nttl-net.ne.jp/atago/index.html) and was expressed as percentage of fresh fruit weight.

RESULTS AND DISCUSSION

Climate conditions

Total annual rainfall in 2003 was 562 mm and in 2004 it was 507 mm slightly below the average for Sadore. In both years a significant amount of rain (110 – 112 mm)

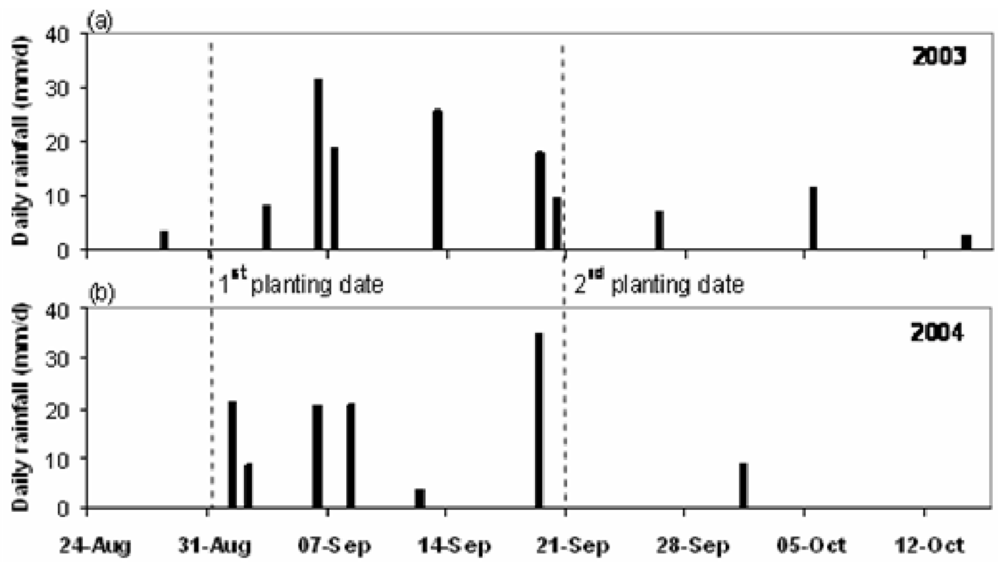

Figure 1. Daily rainfall at ICRISAT Sadore research station after first and second planting in 2003 (a) and 2004 (b)

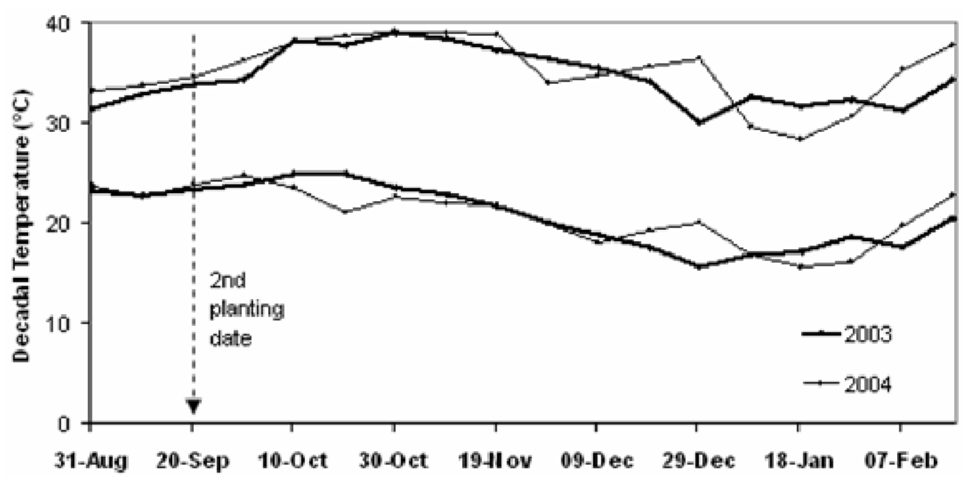

Figure 2. Decadal maximum and minimum temperatures (°C) during 2003 - 2004 and 2004 - 2005

fell during the first three weeks after the first sowing. In both years showers fell at a frequency of 5 - 6 days (Figure 1) that probably ensured good germination and field establishment. There were however significant differences in the amount of rain and in rain distribution following the second sowing. In 2003 there were three showers after the second sowing spaced over a period of 19 days with a total amount of 22 mm, whereas in 2004 there was only one single 9mm-shower after the second sowing (Figure 1).

Mean maximum and minimum growing season temperatures in both years were very similar (Figure 2) and probably could not account for yield differences between the years. The more favorable temperatures following the first sowing are probably another advantage of the early sowing date. Watermelons were able to develop, produce flowers and yield at daily maximum temperatures of 35 - 40°C showing that this is a highly heat tolerant species.

Yield and yield components

Land management, amendment, cultivars and sowing dates, significantly affected total and marketable fruit yield, fruit number and individual fruit weight (except for marketable fruit weight), but there were no significant differences between the years. There were significant interactions between land management and amend-

Table 1. Effect of land management, soil amendments, cultivar and planting date on watermelons yield and yield components over the two experimental years.

	Marketable			Total		
	Fruit yield (kg ha^{-1})	Fruit number (no. ha^{-1})	Mean fruit weight (kg)	Fruit yield (kg ha^{-1})	Fruit number (no. ha^{-1})	Mean fruit weight (kg)
Land management						
Flat	1,940	933	1.96	3,102	2,695	1.11
Planting pit	3,221	1,181	2.31	4,539	2,808	1.53
Half-moon	2,161	863	2.26	3,256	2,283	1.37
LSD (0.05)	457	139	0.27	515	278	0.15
Amendment						
Control	1,340	643	1.84	2,430	2,222	1.06
Compost + NPK	3,541	1,342	2.52	4,834	2,969	1.62
LSD (0.05)	373	113	0.22	421	227	0.12
Cultivar						
Kaolack	1,960	798	2.00	2,937	2,329	1.22
Malali	2,922	1,186	2.36	4,328	2,861	1.46
LSD (0.05)	373	113	0.22	421	227	0.12
Planting date						
1st	3,291	1,273	2.32	4,490	2,953	1.46
2nd	1,591	711	2.03	2,775	2,238	1.22
LSD (0.05)	373	113	0.22	421	227	0.12
CV (%)	54	40	35	41	31	32

ment years and planting dates, amendment and planting date and cultivar and planting date.

Tables 1 - 5 give the watermelon yield and yield components as affected by the experimental treatments and analyze the four cases where interactions between treatments were significant.

As can be seen from Table 1 total and marketable fruit yield in the planting pits treatment was significantly higher than in the flat or in the half-moon treatment but there were no significant differences in fruit yield between the flat and half-moon treatments. The marketable fruit relative to the total fruit harvest was higher for the planting pit treatment.

Soil amendments had the biggest effect on watermelon yields as compared with other treatments. This is an indicator that low soil fertility is the major limiting factor for watermelon production in the acid, nutrient depleted Sahelian soil. Addition of nutrients almost doubled the percentage of marketable fruit indicating that low soil fertility has a significant negative effect on fruit quality. Fruit splitting was the main reason for fruit spoilage.

Malali marketable fruit yield was 50% higher than Kaolack. There was not much difference in individual fruit weight between the two varieties (2.36 kg for Malali vs. 2.00 kg for Kaolack). Marketable watermelon yield at the first planting date was double the yield of the second planting date. Percentage of spoiled fruit was higher in the second as compared with the first planting date indicating again that bad growing conditions such as nutrient and water deficiencies negatively affected fruit quality of watermelons.

Early planting resulted in significantly higher marketable and total yield than late planting in both 2003 and 2004 (Table 2). However, in 2004 the difference in yield between early and late planting was much greater than in 2003. In 2003 there were three showers following late planting giving a total of 22 mm, but in 2004 there was only one 9 mm shower after the second sowing (Figure 1). Thus in 2003 second sowing plants had better conditions for germination and establishment than in 2004. The variability in rain amount and rain distribution at the second half of September seen in Figure 1 and previously emphasized by Sivakumar (1991) makes the second planting date (late September) a risky date for planting watermelons in the Sahel of Niger.

In both 2003 and 2004 late sowing resulted in signifycant reduction in fruit number but fruit weight was not affected.

Marketable yield of Malali was significantly higher than that of Kaolack only in the first planting date. In other words, late planting reduces yield of Malali relatively more than of the Kaolack cultivar in comparison with early planting (Table 3). Yield differences between the two varieties resulted from changes in fruit number, not in fruit weight.

Improving soil fertility resulted in significantly higher

Table 2. Effect of year and planting date on marketable and total watermelon harvest indicators averaged over land management, cultivar and soil amendments applied.

Year	Planting date	Marketable			Total		
		Fruit yield (kg ha^{-1})	Fruit number (no. ha^{-1})	Mean fruit weight (kg)	Fruit yield (kg ha^{-1})	Fruit number (no. ha^{-1})	Mean fruit weight (kg)
2003	1st	3,045	1,317	2.1	3,818	2,715	1.36
	2nd	2,022	960	1.98	3,086	2,479	1.23
2004	1st	3,537	1,229	2.55	5,162	3,192	1.56
	2nd	1,159	463	2.08	2,463	1,996	1.21
	LSD (0.05)	602	168	NS	718	360	NS

Table 3. Effect of cultivar and planting date on marketable and total watermelon harvest indicators averaged over land management, year and soil amendments applied.

Cultivar	Planting date	Marketable			Total		
		Fruit yield (kg ha^{-1})	Fruit number (no. ha^{-1})	Mean fruit weight (kg)	Fruit yield (kg ha^{-1})	Fruit number (no. ha^{-1})	Mean fruit weight (kg)
Kaolack	1st	2,563	985	2.22	3,573	2,610	1.33
	2nd	1,357	610	1.77	2,300	2,048	1.1
Malali	1st	4,019	1,560	2.43	5,407	3,296	1.58
	2nd	1,825	813	2.29	3,249	2,427	1.34
	LSD (0.05)	527	160	NS	595	NS	NS

Table 4. Effect of land management and soil amendment on marketable and total watermelon harvest indicators averaged over cultivar, planting date and year.

Land man.	Amendment	Marketable			Total		
		Fruit yield (kg ha^{-1})	Fruit number (no. ha^{-1})	Mean fruit weight (kg)	Fruit yield (kg ha^{-1})	Fruit number (no. ha^{-1})	Mean fruit weight (kg)
Flat	Control	1,319	713	1.73	2,416	2,416	0.96
	Compost + NPK	2,561	1,153	2.18	3,789	2,975	1.27
Planting pit	Control	1,423	644	1.81	2,552	2,241	1.1
	Compost + NPK	5,019	1,719	2.82	6,526	3,375	1.97
Half-moon	Control	1,278	572	1.97	2,323	2,009	1.12
	Compost + NPK	3,044	1,153	2.56	4,189	2,556	1.63
	LSD (0.05)	646	196	NS	729	NS	0.211

marketable yields in the three soil management treatments (Table 4). The effect of improved nutrition was more pronounced in the planting pit treatment than in the other two treatments. There was no significant difference in marketable yield between the flat and the half-moon soil management treatments. Adding soil amendments led to a decrease of 10 - 25% in number of spoiled fruit, contributing to increased marketable yields. Improving soil fertility (amendments) increased marketable yield in the second planting date more than in the first (Table 5). This shows that improved soil fertility can help watermelons overcome to some extent the effects of water deficiency that were apparent for the second planting date.

In summary, highest watermelon marketable yields (8.2 tons ha^{-1}) were obtained when seeds were sown at the beginning of September, in planting pits with 500 g compost and 24 g of 15-15-15 using the Malali cultivar (Figure 3).

Fruit quality

Improved soil fertility had no significant effect on Total Soluble Solids (TSS) of the Malali cultivar but it significantly increased the TSS of the Kaolack cultivar (Table 6). Other works confirm the fact that watermelon TSS is

Table 5. Effect of soil amendment and planting date on marketable and total watermelon yields and yield components averaged over land management, cultivar and year.

Amendment	Planting date	Marketable			Total		
		Fruit yield (kg ha^{-1})	Fruit number (no. ha^{-1})	Mean fruit weight (kg)	Fruit yield (kg ha^{-1})	Fruit number (no. ha^{-1})	Mean fruit weight (kg)
Control	1st	1,847	840	1.96	2,903	2,454	1.14
	2nd	834	446	1.71	1,958	1,990	0.97
Compost + NPK	1st	4,735	1,706	2.69	6,078	3,452	1.77
	2nd	2,347	977	2.35	3,591	2,485	1.48
LSD (0.05)		527	160	NS	595	321	NS

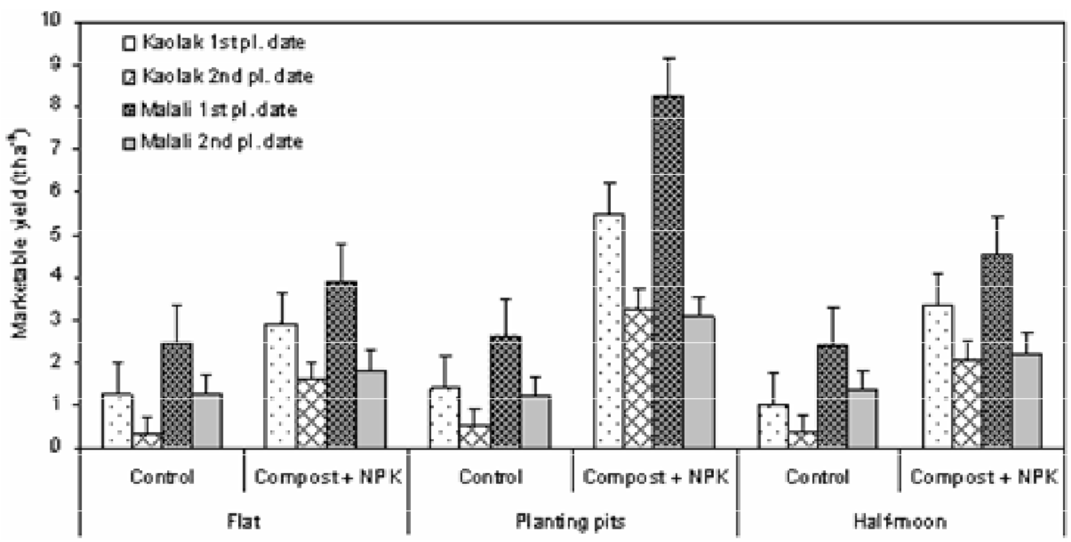

Figure 3. Effect of land management and soil amendments on marketable yields of two watermelon cultivars planted on the 1st and on the 21st of September. (Values are average of two experimental years. – pl. date = planting date).

Table 6. Effect of amendment and variety on TSS averaged over two years.

Amendment	Cultivar	TSS (%)
Control	Kaolack	7.49
	Malali	7.48
Compost + NPK	Kaolack	9.01
	Malali	7.93
LSD (0.05)		0.73

not affected by treatments such as irrigation or fertilization (Hegde, 1988). Kaolack had a higher percentage of spoiled fruit than Malali (Tables 1 and 3). Fruit cracking was the main reason for fruit spoilage. Malali has a thicker and harder rind than Kaolack and this might have been the reason for less cracking in the Malali cultivar (Sugiyama et al., 1999)

Physiological aspects

Leaves plus stems dry weight (averaged over 2 years) in the various treatments is given in Table 7. As expected, plants receiving amendments were bigger than plants with no amendments, a symptom of the low fertility status of the soil. The shoot dry weight of Malali was signify-cantly higher than that of Kaolack.

The effect of land management, soil amendment, cultivar and planting date on days to first fruit and on days to first harvest is presented in Table 8.

Soil management without amendments had no effect on these two parameters. Soil amendments reduced the time to first harvest by almost 20 days as compared with no amendments. Kaolack produced fruit earlier and matured earlier than Malali. Late planting increased the time to first harvest as compared with early planting.

Data from tables 7 and 8 can explain the superiority of the cultivar Malali over Kaolack. Fruits started to develop

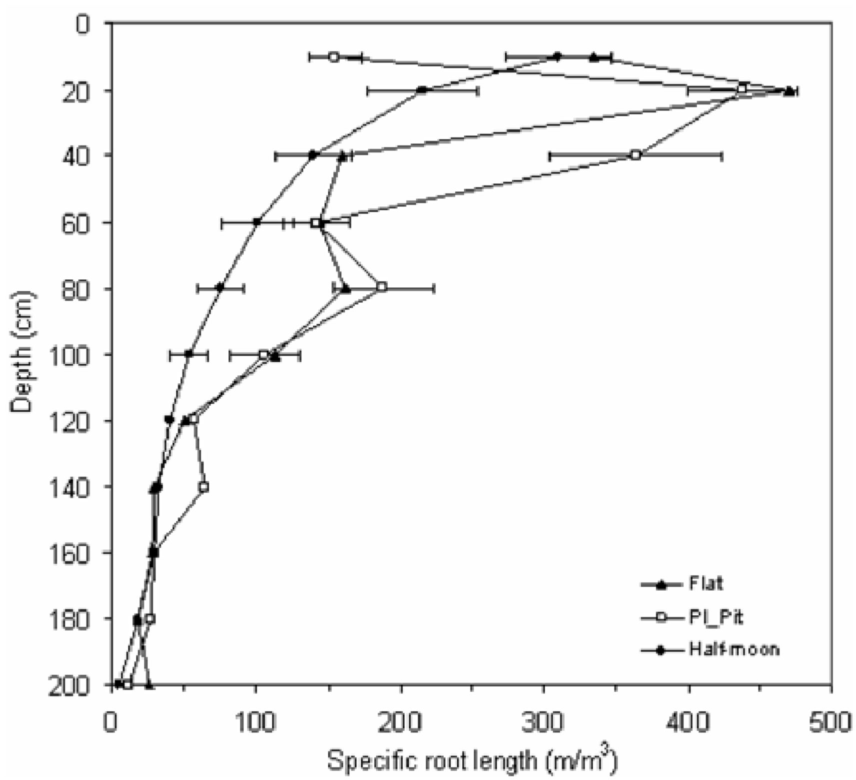

Figure 4. Specific root length in the Flat, Planting pit (Pl_Pit) and Half-moon treatment down to a depth of 2 meters at the end of the 2004/2005 season. Values are average of the plus and minus amendment treatments.

Table 7. Effect of land management, soil amendments, cultivar and planting date on dry weight of watermelons leaves and stems averaged over two years.

	Leaves and stems dry weight (kg ha^{-1})
Land management	
Flat	127
Planting pit	157
Half-moon	148
LSD (0.05)	21
Amendment	
Control	117
Compost + NPK	171
LSD (0.05)	17
Cultivar	
Kaolack	119
Malali	169
LSD (0.05)	17
Planting. date	
1st	162
2nd	126
LSD (0.05)	17
CV (%)	42

Table 8. Effect of amendment, cultivar and planting date on days to first fruit set and first harvest of watermelon during the 2004 - 2005 seasons

	Days to	
	First fruit	**First harvest**
Amendment		
Control	46	106
Compost +NPK	40	87
LSD (0.05)	1.4	4.8
Cultivar		
Kaolack	41	95
Malali	44	98
LSD (0.05)	1.4	4.8
Planting date		
1st	44	94
2nd	42	99
LSD (0.05)	1.4	4.8
CV (%)	8.2	12.3

earlier in Kaolack than in Malali. They probably became a strong sink for photosynthates resulting in cessation of shoots leaf area expansion. Malali on the other hand started to produce fruit later allowing the canopy to deve-

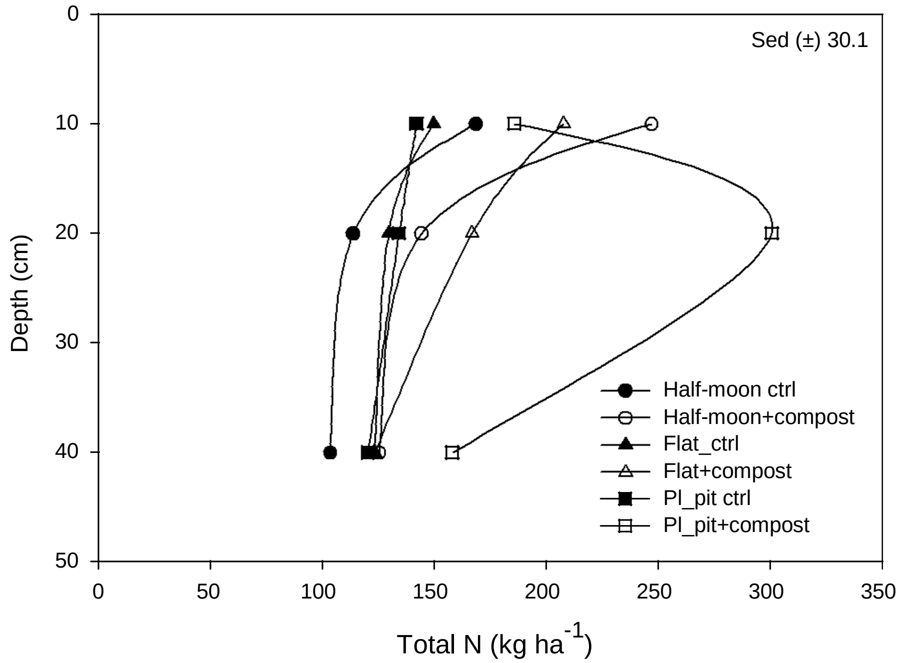

Figure 5. Total N content at harvest as affected by land and fertility management; Sadore January 2004 (Pl_Pit = planting pit; ctrl = control; compost = compost + NPK)

lop. The larger leaf area of Malali allowed the production of more fruit biomass as compared with Kaolack.

Specific root length by soil depth in three land management treatments is given in Figure 4. In the three land management treatments watermelon roots could be found at a depth of 200 cm. However it is doubtful whether the small volume of roots at this depth had a significant contribution to water exploitation by the plants.

Soil fertility induced root development. In the Flat and Half-moon treatments most soil fertility was concentrated in the upper 20 cm (Figures 5 and 6) and this is where the bulk of roots have developed. In the planting pit treatment both P and total N where higher at 40 cm depth (Figures 5 and 6) as compared with the other two land management treatments. This fact provides an explanation for the significantly higher specific root length at the depth of 40 cm in the planting pit treatment as compared with the other two land management treatments (Figure 4).

In the Half- moon treatment both P and total N were leached more than in the Flat treatment (Figures 5 and 6). This indicates that water- harvesting techniques in the sandy-nutrient deficient, low pH soils of the Sahel might negatively affect crop yields through leaching of essential nutrients. Deep placement of compost and fertilizers thus allows greater development of roots to a depth of 80 cm. This should result in a much higher exploitation of water stored in the soil as well as nutrients as compared with shallow placement of nutrients.

The results given in Figures 4 - 6 can explain the significantly higher yields of the combined Planting pit-amendment treatment over the combined Flat-amendment or the combined Half moon-amendment treatments shown in Table 4 (5.0, 3.0 and 2.6 tons ha^{-1} respectively).

These results might also explain the high performance of millet and sorghum planted in the Sahel in zaï pits (Fatondji et al., 2006).

Conclusions

This study has laid down a series of principles for production of watermelons on stored rainwater in the sandy acid soils of the Sahel.

Watermelons should be planted no later than the 1st of September towards the end of the rainy season. The amount of rain at the beginning of September can be substantial, supporting good germination and crop establishment.

Nutrition is the main limiting factor for watermelons production in the sandy acid soils of Niger. Soil enrichment with a combination of compost and fertilizers results in a significant increase in yield.

Nutrient placement is crucial. Deep placement (20 cm) results in greater root development in deeper soil layers that probably leads for better exploitation of stored rainwater and of plant nutrients. The application of compost and fertilizers in planting pits one to two months before sowing allows for some decomposition of the compost by soil termites (Hassan, 1996, Fatondji et al., 2006) and for leaching soluble nutrients to greater depth to support root development. The end result is much higher yield as compared with other methods of amendment placement. Spot application leads to savings of compost and fertilezers. Thus in these trials we used only 60 kg ha^{-1} of the

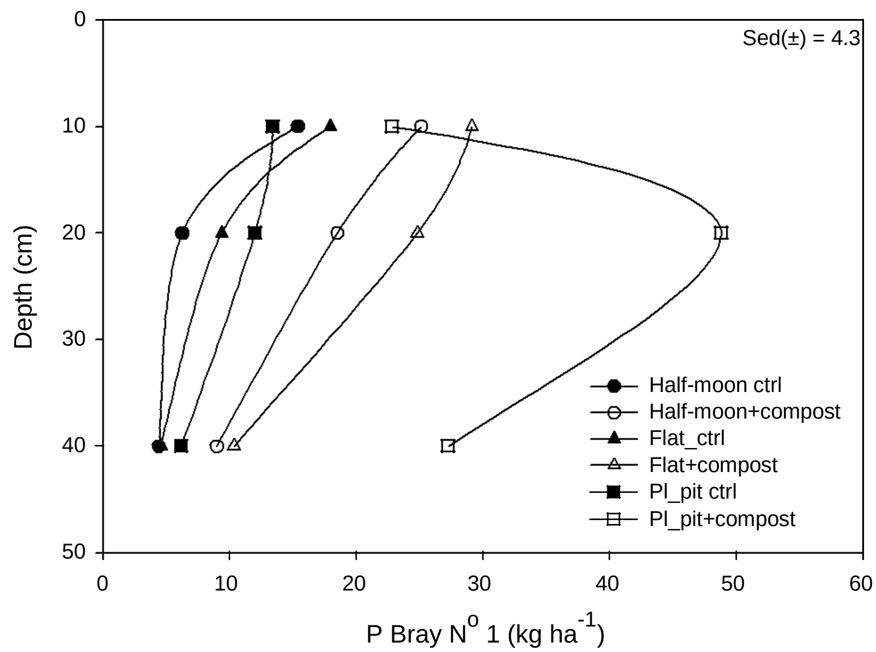

Figure 6. Soil Bray 1 P content at harvest as affected by land and fertility management; Sadore January 2004 (Pl_Pit = planting pit; ctrl = control; compost = compost + NPK).

complete fertilizer 15-15-15 and 1.25 tons ha^{-1} of composted cow manure.

Varieties react differently when produced on stored rainwater. The Malali cultivar produced at the early sowing season much higher yields than the Kaolack cultivar. However, this cultivar could not express its advantages when watermelons were planted later in the season. It seems that late maturing varieties like Malali can develop a larger leaf area than early maturing varieties that enables them to carry a heavier fruit load.

There is a need to look for varieties (and perhaps treatments) with less fruit spoilage. On the average only 40% of the fruit produced was suitable for marketing.

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