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A WET EXCAVATION METHOD FOR ROOT/SHOOT STUDIES OF PEARL MILLET ON THE SANDY SOILS OF THE SAHEL

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SUMMARY

Root/shoot relations of two cultivars of pearl millet (*Pennisetum glaucum*) were studied on a sandy soil at Sadore in Niger using a wet excavation method. For the first 10 days after emergence (DAE), the length of the seminal root showed an exponential growth rate while plant height increased more or less linearly. The maximum rooting depth for millet was 168 cm and the maximum number of root axes and primary laterals, 172 per plant. Root length continued to increase up to 75 DAE, the maximum length exceeding 5000 cm per plant. The proportion of total day matter accumulated in the roots decreased from 30% in the early stages to less than 20% by maturity. The wet excavation method is a promising technique for the rapid removal of intact root systems of pearl millet from the sandy soils of the Sahel.

Estudios sobre raíz/brotes de mijo perlado

RESUMEN

Se estudiaron las relaciones entre raíz/brotes de dos variedades de mijo perlado (*Pennisetum glaucum*) en suelo arenoso en Sadore, Níger, utilizando un método de excavación húmeda. Durante los primeros 10 días a partir de la emergencia, la longitud de la raíz seminal presentó un índice de crecimiento exponencial, mientras que la altura de la planta aumentó más o menos en forma lineal. La profundidad máxima de raíz para el mijo fue de 168 cm, mientras que la máxima cantidad de ejes de raíz y laterales primarios fue de 172 por planta. La longitud de raíz siguió aumentando hasta los 75 días a partir de la emergencia, con una longitud máxima superior a los 5.000 cm por planta. La proporción de materia seca total acumulada en las raíces pasó de un 30% en la etapas tempranas, a menos de un 20% en la madurez. El método de excavación en húmedo constituye una técnica prometedora para la rápida e intacta extracción de sistemas de raíces de mijo perlado en los suelos arenosos del Sahel.

INTRODUCTION

Despite the widespread recognition of the importance of the role of root systems, studies on the root/shoot relations of pearl millet are limited (Soman and Mahalakshmi, 1992), though some aspects have been studied in India (Kanitkar, 1944; Gregory and Squire, 1979) and forage millet has been studied in Australia (Begg, 1965; Begg *et al.*, 1964; Wetselaar and Norman, 1960).

From studies in controlled glasshouses, Gregory (1986) showed that the length of individual root axes of millet increased exponentially with time for the first 20 days after sowing (DAS) and that the relationship between root length and leaf area was linear. In studies of the root growth of pearl millet grown sole and in intercropping systems with groundnut, Vorasoot (1983) found that the root density of sole millet in the surface 10 cm was greater than that of sole groundnut early in the season.

Investigations of the root systems of pearl millet in West Africa have been limited and have dealt with mature root systems rather than with growth throughout the growing season. They have mainly been conducted in pans (Vidal, 1963) or in hydroponic systems (Siband, 1979). Azam-Ali *et al.* (1984) studied the root growth of pearl millet to a depth of 140 cm on a sandy soil in Niger during the post-rainy season. Their limited data indicated a rapid expansion of the root system between 17 and 31 DAS, and a maximum rooting depth of 140 cm at 31 DAS. In a water balance study in Niger, Payne *et al.* (1990) found that the maximum depth of root penetration of millet was 150 cm.

The present study used an adaptation of the classical wet excavation method, using water under pressure to remove soil particles from whole root systems, to study the root/shoot relations of millet on sandy soils.

MATERIALS AND METHODS

The experiment was conducted during the 1991 rainy season at Sadore in Niger (13° 15′N, 2° 17′E). The soils are classified as sandy, siliceous, isohyperthermic Psammentic Paleustalfs with 91% sand, 5% silt and 4% clay in the A horizon, a bulk density of about 1.65 mg m^{-3} (West *et al.*, 1984), a pH of 4.9 (in 1:1 soil:water suspension), a cation exchange capacity of 1.3 cmol kg^{-1}, a base saturation of 41.9%, an organic carbon content of 0.2% and an available phosphorus content (Bray-P1) of 3 ppm.

The experiment was sown in a randomized block design with four replications. A basal dressing of 45 kg ha^{-1} of P_2O_5, as single superphosphate, was applied before sowing. Two millet cultivars, CIVT and Sadore Local, were planted in pockets spaced 80 cm apart on ridges formed 75 cm apart on 5 May 1991, following 12.1 mm of rainfall on 28 April and 18.6 mm on 4 May. Emergence had occurred by 8 May and the plant stand was excellent. Calcium ammonium nitrate was applied at 21 and 45 days after planting to supply a total of 45 kg ha^{-1} of nitrogen.

The development of the seminal root and its relation to plant height was studied for the first 10 days after emergence (DAE) by sampling whole plants with intact root systems at daily intervals. Five plants were sampled from each plot; plant height was measured from the base of the stem to the tip of the top leaf and the root length of the seminal root was measured with a ruler.

From 20 DAE until harvest, the wet excavation method was used to extract roots at 7–10 day intervals. Care was taken to select pockets with normally developed plants. A trench measuring approximately 1.0 m long and 0.8 m wide was dug around the selected pocket. To allow collection of water and mud at the bottom of the trench, the trench was always kept 30–40 cm deeper than the deepest root and thus increased in depth during the season, reaching a maximum depth of 250 cm. Care was taken that no laterally growing roots were destroyed while the trench was being dug. Water for washing the soil from the roots was provided from a mobile 6000 l tank, parked adjacent to the plot at approximately 75 cm above the ground level; this supplied a stream of gravity-fed water at a pressure ranging from 12 to 25 KPa.

Washing of the soil was always started at the top and continued steadily downwards. Initial experience showed that the caving in of the trench walls could be avoided by preventing overhangs and by retaining a broad base at the bottom of the trench until a large proportion of the soil at the top had been washed away. Generally it took about three to four hours to wash the root system free of soil and extract the whole root system from one trench.

On removal of the root system, the tops and roots were separated. The root samples were placed in flat dishes filled with water and separated with the aid of tweezers. The terminology used here in describing root production is similar to that used by Gregory (1983): each cylinder of root tissue developed from the seed or stem is called an axis, roots produced from the axis are called primary laterals and those produced from the primary laterals are called secondary laterals. In this study the number of roots is the sum of the number of root axes and primary laterals.

Root length of each individual root axis and each primary lateral was measured directly with a ruler. No attempt was made to measure the length of the secondary and tertiary laterals as this would have taken too much time. The different plant components, comprising leaves, stems, heads and roots, were then dried in a forced-draft oven at 60°C for 24–48 hours and their dry weights recorded. Final yields were obtained from an area of 25 m^2.

RESULTS

Daily rainfall distribution during the 1991 rainy season is shown in Fig. 1. The total rainfall of 603 mm was uniformly distributed throughout the season, favouring millet growth.

There were no significant differences between the varieties in the root parameters measured, hence the pooled data of the two varieties are used in discussing the results. The increase in plant height was more or less linear for the first 10 DAE (Fig. 2) but root growth rate was exponential. Subsequently, rooting depths increased with time (Fig. 3a). The total number of root axes and primary laterals continued to increase up to 75 DAE (Fig. 3b). Root length showed an increase up to 80 DAE (Fig. 3c), with a maximum length of about 5000 cm.

Up to 38 DAE, over 30% of the total dry matter accumulated was in the roots, but this proportion had decreased to 20% by 45 DAE, while the stems continued to accumulate dry matter (Table 1). At the time of final sampling, 15% of the dry weight accumulated was in the roots for cv. CIVT and 18% for cv. Sadore Local. There was no difference between the cultivars in final grain yield, but the straw yield of Sadore Local was significantly greater than that of cv. CIVT (Table 2).

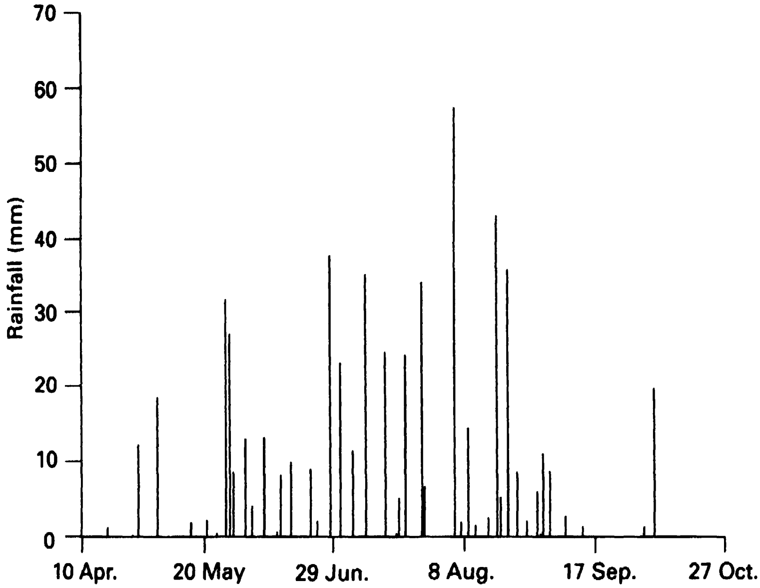

Fig. 1. Rainfall distribution during the 1991 rainy season at Sadore, Niger.

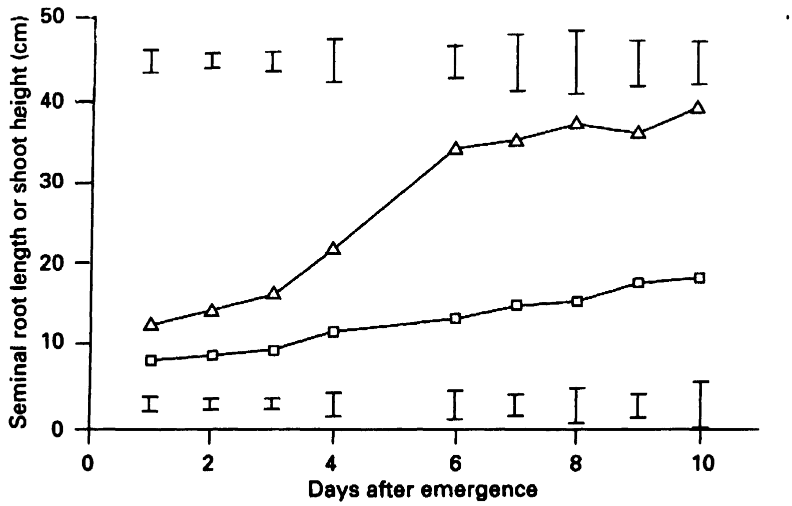

Fig. 2. Changes in plant height (□—□) and seminal root length (△—△) in the first 10 days after emergence (data pooled from two cultivars), 1991 rainy season.

DISCUSSION

Our results show that the wet excavation method is a useful technique for the rapid removal of intact root systems of millet from sandy soils, the texture of which permits easy washing and removal of roots with little damage. Unlike the framed

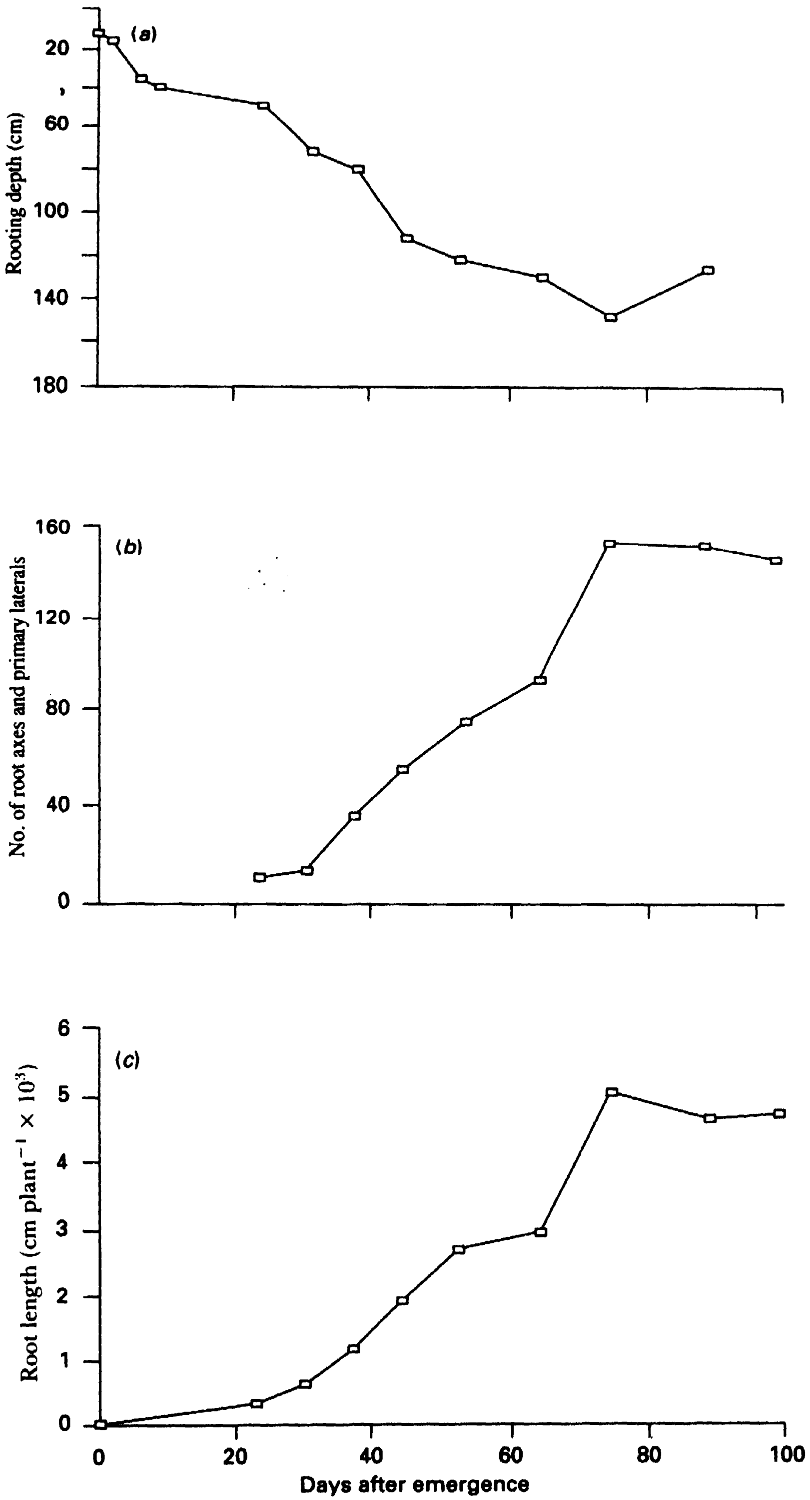

Fig. 3. Seasonal changes in (a) rooting depth, (b) total number of root axes and primary laterals and (c) total root length (data pooled from two cultivars), 1991 rainy season.

Table 1. *Dry weight (g m^{-2}) of plant components and root/shoot weight (%) of two millet cultivars (CIVT and Sadore Local, SL) from 24 to 108 days after emergence (DAE), 1991 rainy season*

	Roots		Leaves		Stems		Heads		Root/shoot	
DAE	CIVT	SL	CIVT	SL	CIVT	SL	CIVT	SL	CIVT	SL
24	1.2	0.7	1.5	1	1.5	1	—	—	40	35
31	3	2	4	2.2	5	2.8	—	—	33	40
38	22	11	25	12	44	14			31	42
45	50	24	123	42	131	57			20	24
54	43	55	91	85	102	120			22	27
65	71	82	183	174	235	220			17	21
87	95	140	157	290	325	376	147	99	15	18
98	119	114	121	202	493	311	205	109	15	18
108	—	105	—	135	—	246	—	210	—	18

Table 2. *Final grain and straw yields (t ha^{-1}), number of heads m^{-2} and 1000 grain weight (g) of cultivars CIVT and Sadore Local, 1991 rainy season*

	Final yield			
	Grain	Straw	No. of heads m^{-2}	1000 grain weight
CIVT	1.50	5.00	7.43	11.38
Sadore Local	1.33	8.21	5.95	10.43
SE	0.18	0.62	0.29	0.45

monolith method (Böhm *et al.*, 1977) which can also be used to remove intact root systems, the wet excavation method requires no special equipment apart from a large tanker with at least 1000 l of water. The flow of water was satisfactory for complete washing of the roots, but a large quantity of water had to be baled out of the trench at regular intervals during the experiment. The digging and subsequent filling of pits involved additional work. However, on the sandy soils of the Sahel this task is far easier than on heavier soils.

Our data show that millet exhibits characteristics that are most desirable in a drought-hardy cereal, namely exponential growth of seminal roots to a depth of 40 cm in the first ten days after emergence, accompanied by a significant accumulation of dry matter in the roots and the rapid production of deep root axes and primary laterals by the time the crop reaches anthesis at 50 DAE.

Gregory *et al.* (1978) reported that in winter wheat, root growth ceased at about anthesis. But in this study of millet, the total number of root axes and primary laterals continued to increase until 20 days after anthesis in both varieties. The millet in our study reached anthesis by the beginning of July. Less than 13 mm of rain fell in June, which may have caused the roots to grow deeper than usual to exploit water lower in the profile.

Gregory and Squire (1979) working with an unirrigated millet crop during the post-rainy season at Hyderabad in India reported that the proportion of dry matter in the roots remained unchanged at 15% from 40 DAS. Azam-Ali *et al.* (1984) found a value closer to 50%, but they felt that their samples may not have been representative. Our data (Table 1) show that the percentage of dry matter partitioned to roots continued to drop for 20–30 days beyond the stage of anthesis, probably because of changing sink strengths as the roots became less competitive as growth advanced (Tongoona *et al.*, 1984).

The dry weight of roots (110 g m^{-2}) reported in this study is much greater than that (63 g m^{-2}) reported by Gregory and Squire (1979). One reason for this difference could be that in our study whole plants were excavated and many of the root axes from the nodes above the soil surface were very thick and continued to grow deeply into the loose sandy soil.

The contribution of roots to soil organic matter can be substantial. On the basis of the mean value of 20% of total dry matter remaining in the roots at maturity obtained in our results, a millet crop producing 5 t ha^{-1} of total dry matter could leave 1000 kg ha^{-1} of organic matter in the soil. This is considerably greater than the figure of 350–450 kg ha^{-1} estimated by Chopart (1983).

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