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ROOT GROWTH IN AN INTERCROP OF PEARL MILLET/GROUNDNUT

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ABSTRACT

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The growth of monocropped and intercropped pearl millet and groundnut was studied during the 1978 rainy season in India. Washed cores of soil and a trench profile technique were used to measure the root length and spatial distribution of roots. These measurements were then analysed to assess wnether intercropping changed the size of the root system and whether intermingling of roots from the two crop species occurred.

Monocropped millet produced a longer root length per unit ground area than monocropped groundnut (3500 m m^{-2} compared with 2500 m m^{-2}) and also rooted deeper (90 cm compared with 70 cm). The distribution of root length also differed for the two monocrops while the intercrop appeared intermediate both in total length and in its distribution. Observations made in trenches confirmed the greater length of the millet root system compared with the groundnut and indicated that roots in adjacent rows of millet and groundnut in the intercrop were mixing mid-way through the growing season. This suggests that root interaction between crops may occur during intercropping; it is unlikely, however, that this was a major factor contributing to the increased yields measured in this experiment.

Criteria for assessing yield advantages in intercropping are discussed briefly. Two different assessments showed that intercropping resulted in additional root growth, and during the later stages of growth produced 10—15% more root length as compared to the monocrop.

INTRODUCTION

In a review of the productivity of mixtures, Trenbath (1974) concluded that only a minority of binary mixtures resulted in increased yields and that the margin of yield increase was usually statistically insignificant and very sensitive to environmental conditions. However, more recent results have shown consistent advantages of mixed cropping as compared to monocropping (Baker, 1978; Rao and Willey, 1980) and a number of reasons have been sug-

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gested for these apparent increases of yield. Willey (1979) discusses many of the possible explanations, but the chief factor for which there is any experimental evidence appears to be the improved use of growth resources particularly light, water and nutrients.

Although the principles involved in the competition between root systems for water and nutrients are less thoroughly formulated than those involving competition for light by shoots, the concept of "nutrient mobility" together with a knowledge of the nature of the root system provides a framework for progress (Bray, 1954). However, roots in mixed cropping have rarely been studied largely because of their inaccessibility and because appropriate techniques to examine them are lacking.

Washing roots out from soil cores (Welbank and Williams, 1968) has been widely used to study growth in monocrops, but it is very time-consuming. Moreover, although a quantitative measure of root growth is obtained, it requires considerable replication to obtain spatial distributions and in mixed communities it is impossible to separate roots of different species. Radioisotopes have been proposed as a means of examining spatial relationships in neighbouring plants (Litav and Harper, 1967; Baldwin and Tinker, 1972) but these are difficult to use on a routine basis in field investigations. Böhm (1976) proposed a technique for examining root systems based on washing away a thin layer of soil from a smoothed soil profile and estimating the length of roots visible at the profile face. Although the estimates did not compare well quantitatively with washed cores of soil this modified "trench-profile" method was used successfully to investigate the root growth of soybeans at different spacings (Böhm, 1977).

The study presented here was part of an experiment undertaken by the Cropping Systems Section at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to measure the growth and resource use of intercropped pearl millet (*Pennisetum typhoides*) and groundnut (*Arachis hypogaea*). The agronomic results of the experiment and an analysis of resource use (light, water and nutrients) have already been published (Reddy and Willey, 1981). A future paper will examine the efficiency with which light energy is converted to dry matter (Marshall, 1982). The purpose of the work reported in this paper was two-fold. Firstly, to measure the length of roots and their distribution in the soil profile to determine whether intercropping changed the size of the root system; and secondly, to measure the spatial distribution of roots with depth and distance between plant rows to determine whether intermingling of different root systems occurred in intercropping.

MATERIALS AND METHODS

Site and season

The experimental site was a 0.4 ha area of field RA 10 at ICRISAT on a medium-deep alfisol with a sandy—clay—loam topsoil over-lying a clay subsoil

(Singh and Krantz, 1976). Measurements were made during the rainy season of 1978 which was characterised by above average rainfall of 932 mm (average 760 mm) distributed throughout growth. This meant that the soil within the depth of rooting was close to field capacity for most of the growing period; details of the weather during the experiment are given by Reddy and Willey (1981).

Crops and management

The treatments were laid out in four randomized blocks.

Pearl millet (cv. 'BK 560') and groundnut (cv. 'Robut 33-1') were sown in rows running almost north/south, 30 cm apart, on 25 June 1978. The intercrop consisted of one row millet and three rows groundnut with the same inter-row and within-row spacings as the monocrops. Millet was thinned to 15 cm apart (22.2 plants per m^2) but the groundnut population was slightly lower than intended because of uneven establishment. Nevertheless, mean within row spacings of 14.3 cm (23.3 plants per m^2) and 14.0 cm (23.8 plants per m^2) were obtained in monocrop and intercrop groundnuts respectively.

Superphosphate fertilizer was applied as a basal dressing of 20 kg P_2O_5/ha before sowing followed by 30 kg P_2O_5/ha on 7 July while nitrogen fertilizer was given only to the millet in two equal dressings on 7 and 20 July at a rate equivalent to 80 kg N/ha for the monocrop and 20 kg N/ha for the intercrop. Because of the intercrop row arrangement, the N available per row of millet was the same in both monocrop and intercrop. The gentle southwards slope of the field together with heavy rainfall caused waterlogging during the early growth of the groundnuts at the southern end of the plots. To partially remedy the poor growth, an application of 9 kg N and 23 kg P_2O_5/ha was made to the groundnuts (monocropped and intercropped) in this area on 28 July.

Measurements of root growth

At 7—10 day intervals, cores of soil were extracted from areas where shoots had recently been removed for measurements of growth. A powered core-sampler mounted on a Landrover was used to obtain undisturbed cores of soil, 6.8 cm in diameter, to a maximum depth of 90 cm. Two cores were taken from each of the monocrops (from on and between the rows) while in the intercrop, five cores taken from on and between row positions were sampled along a transect running from the millet row to the central groundnut row. The cores were cut into 10 cm increments to a depth of 50 cm and then from 50 to 70 cm and from 70 to 90 cm.

Roots in the cores were washed out with water over a 0.5 mm aperture sieve and separated from other organic debris by spreading on a piece of blotting paper on a tension table. On draining the table, the pale brown "live" roots could be discerned and were picked into glass vials using forceps. Root length (L, cm) was estimated by counting intersections (N) with a 1-cm grid (Tennant,

1975) when:

$$L = \frac{1}{4}\pi N$$

Using this technique, it was impossible to distinguish roots of the groundnut and millet in the intercrop cores, and a mixture of the two crops had to be accepted. These measurements allowed the calculation of the total root length for each crop and of the distribution of root length with depth in the soil profile.

Spatial distributions of roots across plant rows were measured in trenches spanning four rows of the monocrops and six rows of the intercrop, dug to a depth of 50—60 cm at the northern end of the block of treatments. The southerly faces were covered with sheets of polythene to prevent evaporation and the trenches were roofed with pieces of asbestos to exclude rain. On each occasion of measurement, the plants closest to the south face of a trench were removed and the trench advanced up the row by at least 15 cm to within 2—3 cm of the base of a plant. The new south face was made as smooth as possible with a trowel and then sprayed with water from a crop-sprayer for 5—10 min which left the cut roots exposed. After washing, a wooden frame with a wire grid of 2 cm squares was placed against the face and the number of root ends in each square was counted and noted. In the monocrops, only one measurement was made but in the intercrop, the grid was moved to cover the complete cropping pattern (usually just over 120 cm). In some cases it was possible to distinguish the roots of the two different crops in the intercrop and notes were made of the degree of sideways growth and interpenetration. Unfortunately, soil below 40 cm contained a high clay content and it was difficult to expose the roots; measurements were therefore confined to 0—40 cm.

RESULTS AND DISCUSSION

Root length

Fig. 1 shows the total length of roots produced by the crops. The length of millet roots increased until about anthesis and thereafter decreased slightly — a pattern of growth observed previously in millet (Gregory and Squire, 1979) and also in other cereals crops (Welbank and Williams, 1968; Gregory et al., 1978). For groundnut, the length of root continued to increase until close to the final harvest, but was always less than that of millet. The pattern of growth of roots in the intercrop appeared as a mixture of the two monocrops with root length in the later stages of growth being intermediate between the two monocrops. The distributions of root length with depth in the soil (Fig. 2) were also different for the different crops. In summary, the millet generally rooted slightly deeper than the groundnut (90 cm compared to 70 cm) and the groundnuts had a higher proportion of their root length in the

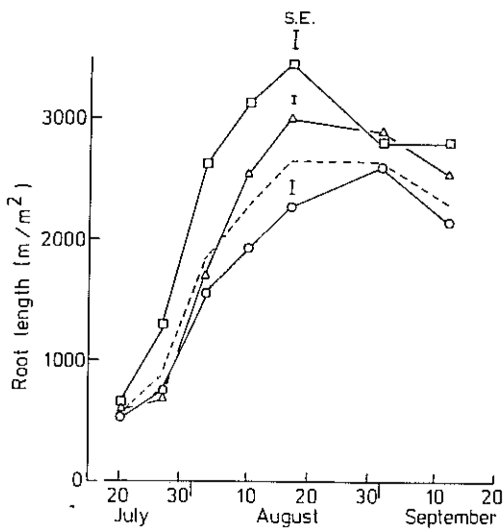


Fig. 1. Changes in total root length with time for monocrop groundnut (○), monocrop millet (□) and the intercrop (△). The standard errors (S.E.) are for the values on 17 August.

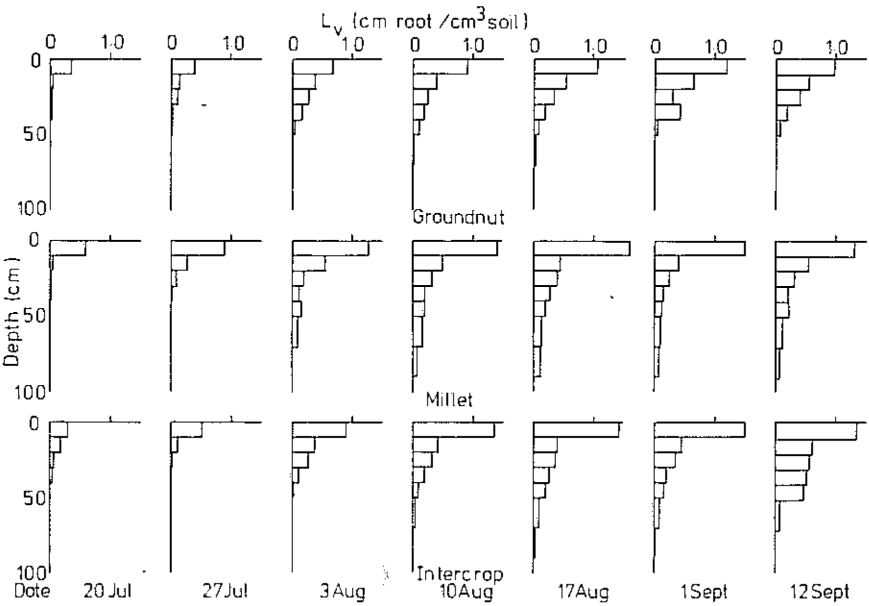
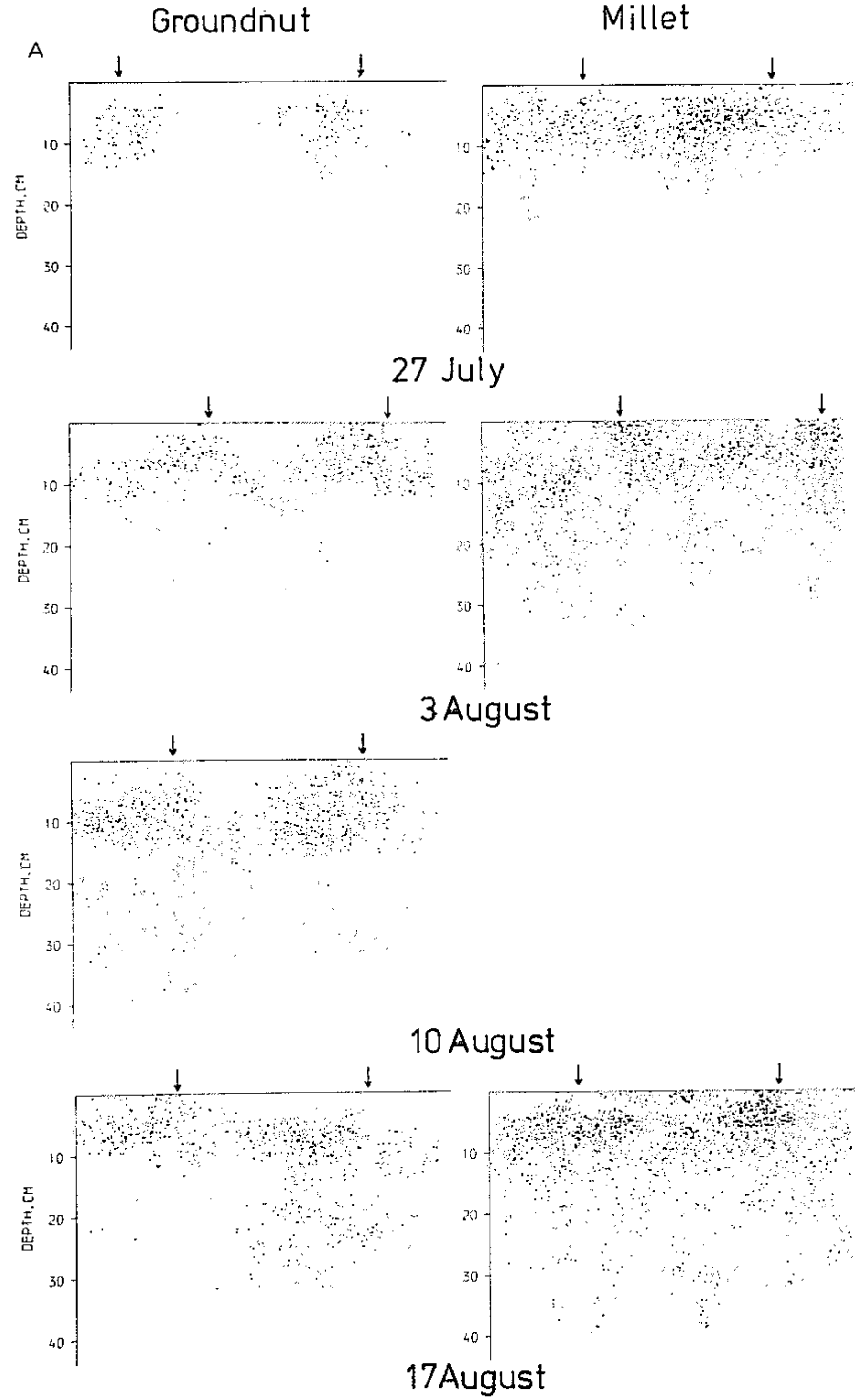


Fig. 2. Distribution of root length in the soil profile at different times determined from washed soil cores.

top 30 cm of soil (80% compared with 70% for millet). However, millet always had a greater rooting density than groundnut in the 0—10 cm soil layer. The distribution of roots in the intercrop was intermediate between the two monocrops.


Groundnut
Millet
A
DEPTH, CM
10
20
30
40
27 July
3 August
10 August
17August

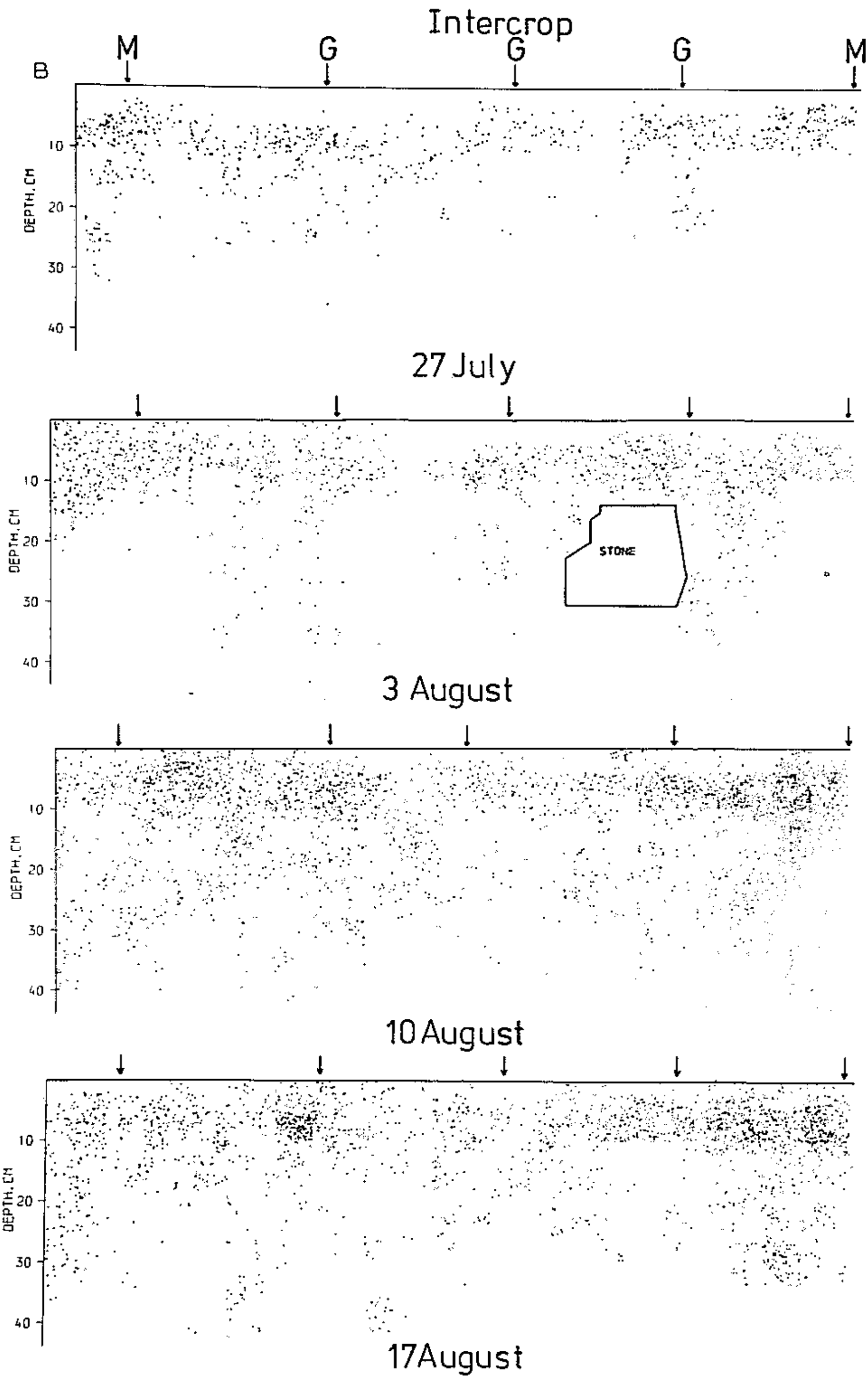


Fig. 3. Root distributions of monocropped and intercropped groundnut and millet determined using the trench-profile technique. The position of plants is indicated by arrows.

Root numbers

Table I shows the mean number of root ends per unit area of trench face for each crop. The root systems appeared to reach their maximum size at about 10 August slightly before the maximum observed using the washed soil cores. Moreover, the millet root system appears initially almost five times, and later twice, as large as the groundnut root system; the core measurements gave a difference of less than 2 throughout.

Fig. 3 shows the spatial distribution of the roots. The diagrams were obtained using a computer by filing the co-ordinates of each square in the grid used for measurements together with the corresponding number of roots counted. The roots were then allocated randomly by the computer to spaces within the individual squares of the grid; the maximum number of spaces (hence roots) for any 2 cm square of the grid was 25 (this was the maximum number ever counted).

TABLE I

The mean number of roots counted per cm^2 of trench face between 0 and 40 cm depth

	Date			
	27 July	3 August	10 August	17 August
Groundnut	0.07	0.21	0.33	0.29
Millet	0.35	0.70		0.73
Intercrop	0.14	0.24	0.51	0.45

On 27 July, the groundnut roots were visible as discrete groups confined around the individual plants and to the upper 20 cm of soil. By 3 August, the roots had elongated downwards to 30 cm and a few roots were evident in the mid-row positions. This proliferation of roots continued in the subsequent periods of measurement so that by 17 August, many roots were present at 20-30 cm depth and in the mid-row positions at 5—20 cm depth. The measurements show that most roots were restricted to the upper 15 cm and that mixing of root systems from adjacent plants was limited to a narrow band of soil.

Millet had a very different pattern of rooting and even on 27 July roots were visible in the mid-row positions at 10—15 cm depth. On 3 August roots were almost uniformly distributed in the top 15 cm between on-row and mid-row positions and roots had elongated to 35 cm. In contrast to the groundnut, roots were present in the upper 5 cm of soil. These different patterns of root growth probably arose because groundnut had a single tap-root which then produced laterals almost at right angles to it whereas millet produced a number of root axes which grew at varying angles from the plant. This means that a considerable degree of mixing of root systems in adjacent rows is possible in crops of millet.

The pattern of rooting produced by the intercrop was a combination of the two monocrop patterns. Initially, there were very few roots in the mid-row positions but this distribution changed rapidly so that by 17 August, millet and groundnut roots were mixing. On 3 August, a few roots were present between the millet and groundnut rows but there was only slight mixing. However, by 10 August, the millet roots had spread laterally to reach almost to the groundnut rows. The central groundnut row behaved like the monocrop groundnut, and little mixing of roots was seen between groundnut rows; no millet roots were seen between the groundnut rows.

Comparison of techniques

One advantage of the washed core technique for measuring root growth is that it provides a quantitative measurement of root length. The trench technique allows the spatial distribution of roots to be assessed in a much shorter time, but there are difficulties in relating the number of ends of roots intersecting a plane of unit surface area (N, number per cm^{-2}) to a root length per unit volume of soil (L_V, cm cm^{-3}). If all the roots are assumed to lie perpendicularly to the exposed face of the trench, then:

$$L_V = N \qquad (1)$$

but if roots are randomly distributed, then:

$$L_V = 2N \qquad (2)$$

(Melhuish and Lang, 1968). In most cases the relationship between L_V and N will probably lie somewhere between the two limits shown by eqs. (1) and (2).

Fig. 4 compares the trench and coring technique using the results from separate 10 cm layers in the top 40 cm of soil. For each crop there was a good relationship between the techniques and a small intercept showing that both provided an almost identical measure of root distribution. However, when the root systems were small, there were occasionally large differences between the methods. The slopes of the intercrop and groundnut relationships were the same ($L_V = 1.15N$ — intercept) and lay within the range expected from eqs. (1) and (2).

The relationship for millet was different from the other crops and the slope lay outside the expected range. Two explanations for the observed relationship are possible. The first is that because of differences in orientation of groundnut and millet roots, there is a genuine difference in the relationship between cut ends observed in a trench and L_V determined by cores. The second is that the L_V determined for millet is an underestimate of the true value: the roots of millet are finer than those of groundnut and it is possible that some may have been lost in the washing and cleaning process. However, the losses would have to be in the order of 40—50% of the measured total, and results on an adjacent experiment with millet also indicated rooting den-

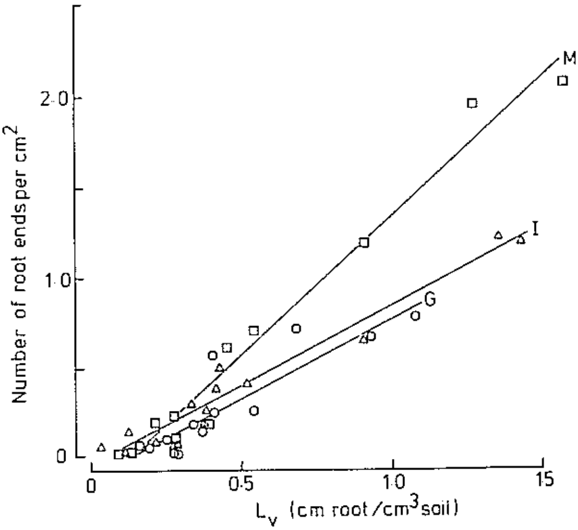


Fig. 4. Comparison of rooting densities determined by the trench-profile method with those determined from washed soil cores for monocropped groundnut (○, G), monocropped millet (□, M) and the intercrop (△, I). The linear regressions shown are:

G $y = 0.87x - 0.12$; $r = 0.88$,

M $y = 1.52x - 0.20$; $r = 0.99$,

I $y = 0.87x - 0.06$; $r = 0.97$.

sities similar to values in this experiment (M.B. Russell, personal communication, 1978).

Comparison of root growth in mono- and intercrops

There are several criteria available for assessing yield advantages in intercropping (Willey, 1979). When yields of the individual species grown as mono- and intercrops are available, then the use of a "Land Equivalent Ratio" (L.E.R.) is a suitable basis for comparison (Mead and Willey, 1980). This method of analysis serves to combine the yields of the components of the intercrop into a single index for expressing the yield advantage. However, when measuring roots, a combined measure of intercrop performance is already obtained because the two types of root are indistinguishable. The L.E.R. under these circumstances can only be calculated if some assumption about the ratio of root length to shoot dry weight is made. Reddy and Willey (1981) assumed that the ratio of root length to shoot dry weight was the same in both mono- and intercrops and their values of L.E.R. are shown in Table II: such an assumption is difficult to verify.

The present experiment was a simple replacement design with identical within and between row spacings for both mono- and intercrops. A convenient comparison of root growth can therefore be obtained by using the ratios in which the crops were sown so that K (the yield advantage of intercropping) is given by:

$$K = \frac{L_I}{0.75L_G + 0.25L_M}$$

where L is the length of root per unit area and subscripts I, M and G are intercrop, monocrop millet, and monocrop groundnut respectively.

Table II shows values of K calculated from results presented in Fig. 1 and Table I. Both the coring and trench methods show an increase of 10—15% in root length beneath the intercrop as compared to the monocrop. These values are consistent with the values of L.E.R. Whatever the method of comparison then, there was a greater root length associated with intercropping. However, this increased root growth was accompanied by increased shoot growth (Reddy and Willey, 1981 — L.E.R. = 1.28 at final harvest) and it is impossible to say whether the improved root growth was the cause of, or the result of, the improved shoot growth.

TABLE II

Comparison of indices for assessing root growth in mono- and intercrops and their changes during the season

Index	Date						
	20 July	27 July	3 Aug.	10 Aug.	17 Aug.	1 Sept.	12 Sept.
L.E.R. for total root length	1.08	1.04	1.00	1.18	1.18	1.15	1.10
K for total root length	1.09	0.76	0.93	1.14	1.13	1.09	1.10
K for root number	1.00	0.72	1.20	1.13			

The trench technique allowed the assessment of the spatial distributions of the two root systems and showed that roots of the two crop species of the intercrop were mixing at about 17 August. This result indicates that it is possible that root interaction between species may occur in intercropping although the timing of root mixing relative to the observed increase in shoot growth shows that this is unlikely to have been a major factor in the present experiment.

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