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ROOT STUDIES ON A TROPICAL ULTISOL IN RELATION TO NITROGEN MANAGEMENT

Report of field work at IITA's high rainfall substation at Onne (Port Harcourt, Nigeria) in 1985

by

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and Greenland, 1960; Odu, 1977; Vitousek **et al.**, 1983).

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bush has been cleared yield levels decline rapidly during subsequent years of cropping.

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Although decomposition in tropical forests is fast compared with that in temperate regions, nutrient release is spread over a number of months at the start of the rainy season. Bernhard-Reversat (1972) showed that decay of fresh organic matter (forest litter) was approximately exponential, but coupled to an almost linear nutrient release, completed in about 5 months. Differences in decomposition rates of leaves of different tree species cannot be directly related to their C/N ratio, because apparently leaf surface structure (Bartholomew **et al.**, 1953) and secondary plant substances as tannins play a role as well. Madge (1965) found decomposition of **Alchornea** leaves to be slow. Diversity in the vegetation of a rain forest may contribute to a gradual nutrient release from decaying dead organic matter. Heterogeneity of dead organic matter input may have a seasonal, structural (leaves, fruits, twigs and branches) and chemical aspect. (Madge (1965) and Hopkins (1966) published data from Nigerian semideciduous forest on seasonal aspects of litterfall.

The rapid decomposition of soil organic matter in the cropping phase forms the major source of nutrition to the crops, but leads to exhaustion of soil organic matter at a greater speed than that at which it is build up in the fallow phase. The absence of a protective cover on the soil during considerable parts of the cropping phase leads to an increased mineralisation of soil organic matter which usually is not (completely) in phase with nutrient uptake by the crops. If the nutrient supply is (temporarily) in excess of crop demand, nutrients can easily be lost from the root zone by leaching.

When compared to the forest vegetation with its closed nutrient cycle, cropped land may experience losses from the nutrient balance, due to a number of factors:

* topsoil erosion,
* removal of nutrients in the crops harvested,
* high mineralisation rate which exceeds crop demands in the first year of cropping,
* absence of a continuous root system and uptake capacity by crops,
* lack of seasonal correspondence between mineralisation and uptake requirements of the crops, mineralisation can be too fast early in the rainy season and too slow later on (Swift **et al.** 1981; Anderson and Swift, 1983),
* lack of diversity in organic matter input through crop residues, giving sharp peaks in mineralisation (Woodmansee, 1984; Swift, 1984)

* probable decline of non-symbiotic N fixation as a consequence of reduced carbon supply to the soil.

Although the relative importance of each of these factors cannot yet be assessed, the mineralisation process and the way it is influenced by topsoil microclimate probably is a key-factor in the nutrient use efficiency of tropical farming systems. Research aimed at improving soil management practices has to take all these aspects into account, to reduce "leakage" from the system and to increase input. The problem can be tackled in different ways: synchronisation of supply and demand can be improved, storage or buffer capacity of the soil/root system can be increased chemically or physically by increasing the rooting depth.

Bartholomew (1977) reviewed evidence for the rapid losses of nitrogen from the soil organic matter pool in the first two years of cropping (100 - 700 kg N per ha per year) and the comparatively fast buildup of N in vegetation in the first two years of fallowing (200 - 350 kg per ha per year). Rather than considering all N losses to be permanent and all N gains to be fixed N, he suggests that N may be leached to the subsoil in the cropping phase and subsequently recovered by a deep-rooted fallow vegetation. Obviously the depth of leaching will depend on climate and soil type. Bartholomew quotes data showing that within the range of 500-1000 mm annual rainfall, 1 mm of rainfall roughly corresponds to 1 mm of downward movement for non-adsorbed nutrients. In regions of higher rainfall the downward movement increases in relative as well as absolute terms (about 4000 mm displacement at 1600 mm rainfall). Bartholomew could find hardly any data to corroborate or reject the assumed difference in rooting depth between crops and fallow vegetation.

Improving nitrogen management

To improve bush fallow systems, two options are 1) to maintain an alternation of crop and fallow phase and to improve the effectiveness of the fallow vegetation in building up soil organic matter, in improving soil structure and/or in suppressing weeds (whichever is the critical function of fallowing in the local situation) and 2) to integrate restorative functions of the fallow vegetation into the cropping period in a form of permanent farming.

In the past much effort has been directed at the first option, by searching for "planted fallow" or leguminous cover crops as alternative for natural bush regrowth, with rather variable results. Nye and Hutton (1957) found that a planted **Acioa** coppice gives a higher organic matter input than a natural bush fallow, although the amount of nutrients stored in the vegetation is slightly lower. In yield effect on oil palms intercropping a natural bush fallow vegetation proved to be as positive as a planted leguminous covercrop (**Pueraria**). Singh (1961) gave additional data for the same experiments, showing that two years of bushfallow or **Pennisetum** (elephant grass) may be sufficient to maintain maize yield levels in some cases. Elephant grass appears to be the most effective fallow replacement, especially in restoring soil structure. Jaiyebo and Moore (1964) showed that a natural bush fallow of **Acioa** and **Alchornea** is effective as a legume and much more than a natural grass cover in restoring soil fertility. In contrast, Sanchez **et al.** (1982) concluded that a leguminous cover crop (**Pueraria**) for 1-2 years has the same restorative effect on the soil as 25 years of forest fallow.

The option of improving fallow effectiveness has to be combined with efficient reclamation techniques at the start of the cropping period, as major losses of nitrogen occur during crop land reclamation by fire; nearly all N in the plant material is lost and, depending on the burning technique, a part of soil organic N as well (Andriesse and Koopmans, 1984; Stromgaard, 1984).

The second option, permanent farming techniques, has recently received most attention. Research on improved farming practices, e.g. at the International Institute of Tropical Agriculture in Nigeria (IITA, 1984a and b; Kang and Van der Heide, 1985) is currently directed to improved nitrogen management in permanent farming through:

a. Protecting the soil from erosion by maintaining a continuous cover of crops and/or mulch and reducing soil tillage operations; many of the techniques tested rely heavily on herbicides for weed control and/or killing cover crops. Effects of such practices on mineralisation rates have not been investigated in detail as yet but organic matter on top of the soil decomposes rather slowly, possibly in phase with crop demand. Soil compaction by machinery in mechanised farming, which creates an apparent need for more intensive soil tillage operations, remains an unsolved problem.

b. mixed cropping practices. A widely recognised criteria for the usefulness of mixed cropping is that the crops used should be complementary to each other (at least partially) in using environmental resources (light, water, nutrients). Under these conditions the "Relative Yield Total" (RYT) and the "Land Equivalence Ratio" (LER) can be above 1.0 (Willey, 1979; Steiner, 1982). Recently avoidance of risks has been quantified as well as a useful criterion (Vandermeer, 1984). In ecological terminology positive effects on total yield can be expected as far as there is "niche-separation" between the crops used. The main niche-aspects with respect to nitrogen use are: N fixation, season of main uptake activity, vertical root distribution and horizontal spread of the root system in relation to the crop spacing used. As a special case of mixed cropping, "weeds" can in certain cases be positive in preventing nutrients from leaching in periods of low uptake capacity of the crops and maintaining them in the nutrient cycle (Mishra and Ramakrishnan, 1984).

c. Introducing trees into mixed cropping systems to incorporate some of the favourable characteristics of the fallow vegetation into the cropping cycle. Deep-rooted trees, such as **Acacia albida** in arid regions (Charreau and Vidal, 1965; Freeman and Fricke, 1980), do not compete for nutrients and water with crops and may act as "nutrient pumps" recovering leached nutrients and soil weathering products from lower depths; through leaf fall or by deliberate use of lopped tree branches as mulch, the small annual yield of soil weathering processes can thus be added to the topsoil; recently "alley-cropping" has received much interest in the humid tropics (Kang **et al.**, 1981; Getahun **et al.**, 1982; Nair **et al.**, 1984; Kang **et al.**, 1985).

d. Increasing nitrogen input by including N-fixing plants in the crop rotation or in mixed cropping systems (Ossewaarde and Wellensiek, 1948; Whyte **et al.**, 1953; Agboola and Fayemi, 1972; Ayanaba and Dart, 1977; Nnadi **et al.**, 1981; Graham and Harris, 1982; Atkins, 1984). Symbiotic N fixation generally leads to acidification of the soil; e.g. Kowal and Tinker (1957) found soil pH to be lowered by a long period of **Pueraria** cover while it remained stable under weeds/bush cover. Deep-rooted leguminous trees may combine the advantages of nitrogen fixation with sufficient cation recirculation from deeper layers to maintain soil pH. Substantial bacterial N-fixation (about 100 kg N per ha per year) can take place in the rhizosphere of certain grasses, e.g. **Pennisetum** (elephant grass) (Ayanaba and Dart, 1977).

e. Mutually adjusting the rate of mineralisation and plant uptake requirements, by applying mulches of high C/N ratio in periods when mineralisation may be too fast otherwise and by establishing nitrogen demanding crops as soon as possible after the start of the rains (Prabhakaran Nair and Ghosh, 1984; van Faassen and Smilde, 1985). These possibilities have been little exploited sofar (Dommergues and Diem, 1982; Swift, 1984). The fact that multiple cropping systems will give a more heterogeneous input of organic matter to the soil resulting in a more even rate of mineralisation during the cropping season has been little studied as yet.

In all these research topics agricultural research sofar is mainly following rather than guiding local farming practices (Richards, 1985); e.g. alley-cropping techniques were developed on the basis of local farming practice, coppicing trees of the bush fallow vegetation rather than removing them before growing crops. There is scope for "learning from the forest" by analysing the ecological processes by which natural vegetations deal with the local environment, as well as "learning from the farmer". By integrating both types of knowledge we may hope to develop agricultural systems which can deal with the increased production levels required, at moderate levels of external inputs, using all available resources as efficiently as possible.

Rooting depth and nitrogen management

Efficient use of nitrogen under conditions of high rainfall and hence severe leaching depends on either adequate synchronisation of plant demand for nitrogen with the mineralisation rate or on the ability to develop deep root systems, able to recover leached nutrients from deeper soil layers. Figure 1.2 shows that there may be variation in the demand curve of the crop and in the mineralisation rate (e.g. due to differences in soil microclimate as affected by soil cover), but complete synchronisation is hardly possible. The larger the gap between supply and immediate demand, the deeper nutrients will leach into the soil and the deeper the plant root system will have to be to recover them. Quantification of this relationship depends on local climate and soil characteristics.

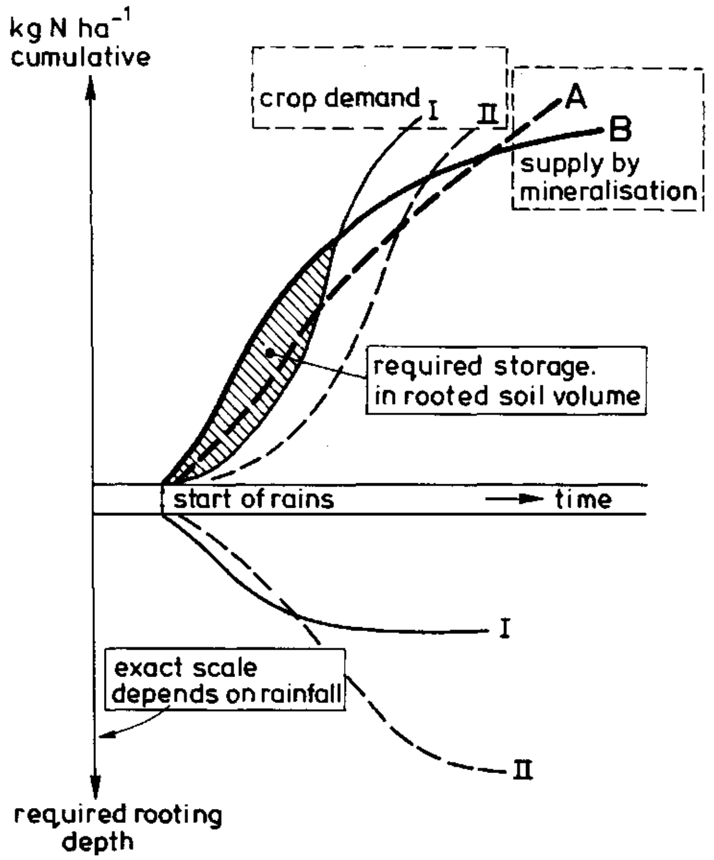


Figure 1.2. Schematic interaction between (lack of) synchronisation of supply of nutrients by mineralisation and crop demand for nitrogen, with the rooting depth required for full recovery of leached nitrogen.

At IITA's high rainfall station in Onne (Port Harcourt, S.E. Nigeria) the soil is a typical ultisol. Efficiency of nitrogen use, both of fertiliser and organic origin, as measured in lysimeters and with ^{15}N in the field, is low (Van der Heide **et al.**, 1985). The efficiency of fertiliser N use (apparent recovery rate) in the current trials is 30-40% (at a moderate N-input level of 90 kg N/ha). Physical and chemical aspects of leaching on this soil type have been described by Pleysier and Juo (1981) and Arora and Juo (1982) and have been incorporated with microbiological processes in a dynamic simulation model for nitrogen leaching by de Willigen (1985).

Figure 1.3 shows the result of some calculations with the model in which rooting depth was varied and possibilities for uptake by the crop were calculated. Clearly a deeper root system can take up a considerably larger share of the nitrogen which becomes available by mineralisation. Any measure to improve rooting depth under these conditions will be helpful in improving nitrogen use efficiency.

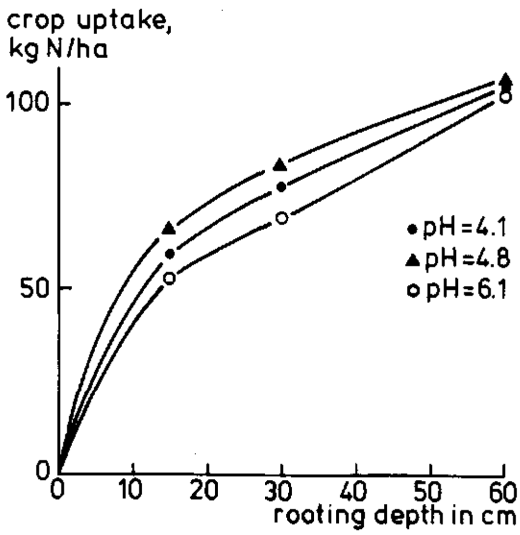


Figure 1.3. Results of a simulation model of nitrogen dynamics for soil and climatic conditions of Onne (S.E. Nigeria). Crop N uptake has been calculated for a fertiliser N dosis of 150 kg N per ha, given in three applications, for three soil pH levels and with varying rooting depth (De Willigen, 1985).

Factors affecting rooting depth

Highly leached tropical upland soils often have a low fertility and are characterised by a low base saturation, high levels of exchangeable Al and a low pH. Sanchez and Salinas (1981) reviewed low input technology for managing acid soils in the tropics. Two options are possible: to adapt the farming system by selecting acid-tolerant crops (and crop varieties), or to adapt the soil to standard farming conditions by applying (large amounts of) lime.

In large parts of the humid tropics acid soil conditions hinder the development of deep root systems and therefore lead to a low efficiency of N use. Liming is a well known procedure to improve root development in acid soil layers, although it has to be continued for a long time if deeper soil layers have to be improved without soil tillage (Arora and Juo, 1982). Effects of liming on nitrogen management may be of a mixed nature, however, as a beneficial effect of deeper root development will coincide with an increased risk of leaching. The risk of nitrogen losses due to leaching is increased by liming, because nitrate rather than ammonium becomes the dominant form of nitrogen, nitrification being stimulated at higher soil pH levels (De Willigen, 1985, figure 1.3). In large parts of the humid tropics lime is not locally available and transportation costs (considering the large amounts necessary) will limit the use of lime under these conditions. Selection of acid-tolerant cultivars and crop combinations seems to be the only obvious approach here. Information on root development under field conditions should be a first step.

The main limitation to root development on acid soils probably arises from the high availability of aluminium and manganese ions. Considerable variation in tolerance for aluminium and manganese exists between crops and cultivars of crops (Foy **et al.**, 1978). Tolerance of different crops to acid soils and to high Al levels is based on various physiological principles. These include fixation of Al ions in root cell walls, interactions with calcium and phosphate uptake and a local change of pH around the root. Rhizosphere pH depends on the balance between anions and cations taken up by the roots. The main variable component of this balance is nitrogen, leading to a rhizosphere pH which is either higher (in the case of predominant nitrate uptake) or lower than bulk soil pH (in case of predominant ammonium uptake) (Riley and Barber, 1971; Nye, 1981). Fleming (1983) showed Al tolerance of wheat cultivars to be based on preferential nitrate uptake from ammonium/nitrate mixtures. Boubele (1984), studying Al tolerance of agroforestry trees (**Leucaena**, **Gliricidia**, **Sesbania** and **Calliandra**), found the slow-growing **Calliandra** to be least affected by Al in culture solution, probably because of its ability to maintain adequate Ca levels in the shoot (**Sesbania** was the least tolerant in this comparison). Generally leguminous crops with functioning symbiotic N fixation will acidify their root environment (van Beusichem, 1984). Some **Leguminosae**, such as **Lupinus**, form "proteoid", thickened roots in which proton excretion is concentrated, which is helpful in phosphorus uptake from neutral soils (Gardner **et al.**, 1982). Rhizosphere acidification raises the question whether it is possible at all to combine efficient N fixation and Al tolerance in the long run.

Leguminous crops differ markedly in their tolerance to acid soil conditions (and/or high levels of available aluminium) and some progress in selecting tolerant varieties has been made. **Stylosanthes humilis** is known to be a tolerant crop (Pinkerton and Simpson, 1983), able to exploit acidic soil layers under conditions of low P supply. **Leucaena** is considered to be not very tolerant to acid soil conditions (Sanchez and Salinas, 1981), although recently some new genotypes with improved tolerance have become available.

Apart from soil acidity, root development may be influenced by soil structure and the availability of pores left by other roots and/or by soil organisms (e.g. Kowal and Kassam (1978) mentioned termites as important organisms for root development in Nigerian savanna soils). Little is known of such effects in a context of shifting cultivation. It may well be possible that relatively deep root development under a fallow vegetation permits relatively deep crop root development in the first years of cropping, with a subsequent decline when the structure of the soil deteriorates. Such effects would contribute to the decline of crop yields generally ascribed to decreasing chemical soil fertility. Information on root development of shrubs and trees of the fallow vegetation is relevant in this respect (Nye and Greenland, 1960)

Purpose of present research

Knowledge of the root system of all crops in the farming system can be helpful in improving nutrient use efficiency. Major aspects are:

* depth of root penetration,
* horizontal spread of the roots, timely establishment of complete exploitation of topsoil, in relation to planting scheme,
* compatibility of crops in intercropping,
* nodulation of leguminous crops,
* mycorrhiza formation (mainly in relation to P-uptake efficiency).

This report will cover field observations on root development at Onne in 1985. A new experiment was laid out to study root development of leguminous cover crops, as influenced by liming. In three existing experiments observations on root development were made: upland rice with and without NPK fertilisation, maize/cassava intercropping and an alley cropping experiment. Two semi-quantitative techniques for root observation were chosen (Schuurman and Goedewaagen, 1972 and Böhm, 1979):

A. Pinboard technique: this gives an overall view of root distribution, root branching of a single plant, allows determination of root dry weight and root/shoot ratios and allows separation of a root system intermingled with that of neighbouring plants.

B. Root mapping technique: this allows a detailed description of root distribution. Maps can be made in a vertical plane to study distribution of roots in relation to the soil profile and in a horizontal plane to study whether or not a soil layer is homogeneously exploited by roots.

For all crops studied some preliminary observations were made on mycorrhizal infection of roots.

root at 40 cm depth (compare plate IV.d); B. roots growing in a horizontal ant channel.

ing to prevent shading of crops (Swennen, 1984). The often rather shallow root systems of leguminous crops make them more suitable for intercropping with perennial tree crops, though not as a complete replacement of the bush fallow in terms of restoration of soil fertility. Morel and

2. ROOT PENETRATION INTO THE SOIL AT ONNE

20

Rain(R)
mm/day
20

22

Quantin stated that sown **Pueraria** stands, characterised by shallow stolons, a dense root mat in the top 5 cm and very few deep roots are replaced by grasses in natural succession after about 5 years. The effect of **Pueraria** and **Stylosanthes** on the regeneration of soil structure is restricted to the top-soil, the relatively deep-rooted **Cajanus indicus** is the best leguminous crop in this respect (their data relate to the 1500 mm rainfall zone). Nye and Hutton (1958) found a comparatively low root mass of **Pueraria** stands in the top 25 cm of the profile compared to bush fallow or elephant grass in the rain forest zone of Nigeria.

Tropical Leguminosae commonly used by farmers, such as **Centrosema pubescens**, **Stylosanthes gracilis**, **Calopogonium mucunoides**, **Pueraria phaseoloides** and **Vigna sinensis** are capable of nodulation and nitrogen fixation under normal conditions (Adeboyejo, 1976). **Centrosema pubescens** is known to produce good growth and fix appreciable quantities of nitrogen in the absence of fertiliser. Otisi (1979) studied nodulation of **Centrosema** and **Psophocarpus** in a pot experiment, using soil from IITA's high rainfall substation at Onne. **Centrosema** gave a poor nodulation, regardless of inoculation. **Psophocarpus** showed a reasonable degree of nodulation, which was not improved by inoculation. **Psophocarpus** belongs to the cowpea cross-inoculant group.

Liming in small amounts is known to improve root development in acid soils (Arora and Juo, 1982). Kang (1970) found that liming improved nodulation of cowpea and corrected N deficiency in an acid soil from Onne. Large responses to liming were observed with rates between 0.25 and 1 t $CaCO_3$ per ha, which have little effect on soil pH but may temporarily reduce Al-levels in the soil. Murphy **et al.** (1984) found that concentrations in soil solution of over 25 micromolar aluminium delayed the appearance of nodules, reduced the percentage of plants which nodulated and decreased the number and dry weight of nodules produced by **Centrosema pubescens**, **Macroptilium lathyroides** and **Stylosanthes guianensis.** **Rhizobium** seems to be more sensitive to Al toxicity than the host plant. Horst (1984) developed a screening test for Al tolerance of cowpea varieties based on germination in soil containing 2.2 meq Al per 100 g soil by comparing germination with plant performance in a long-term pot experiment, using a soil from Onne. In both the short- and the long-term experiment the same genotypes were classified as most tolerant and most sensitive. The period of crop establishment apparently is a critical stage for leguminous crops under these conditions and small amounts of lime may help to overcome problems in the initial stages.

The present study concentrated on root development and nodulation of acid-tolerant leguminous cover crops, as affected by liming (750 kg $Ca(OH)_2$ per ha equivalent to 1 t $CaCO_3$ per ha). Rooting depth was studied as well as root dry weight, which is a measure of input of organic matter into the soil.

3.2. Methods

Plots with leguminous cover crops for root observations were sown at IITA's high rainfall substation at Onne (Port Harcourt), S.E. Nigeria. The experimental site was laid out on a part of the farm which was mechanically cleared of forest and tree stumps more than 10 years ago and has been under mechanised farming since then. Before the cover crops experiment was started the area was covered with a natural grass fallow, cut regularly. Some properties of the soil before the experiment was started are shown in table 3.1. Lime was broadcast on 27 April, 3 days before planting.

Six species of leguminous (cover) crops were used: **Centrosema macrocarpum** (CIAT no 5062, lot 82.234, Quilichao), **Desmodium ovalifolium** (CIAT 3784, lot 82.228), **Pueraria phaseoloides** and **Psophocarpus palustris** (both from seeds supplied by Dr. B T Kang (IITA)), **Mucuna utilis** and **Vigna unguiculata** (from seeds available in Onne). For each species four plots were used (0 and 750 kg $Ca(OH)_2$ per ha, equivalent to 1 t $CaCO_3$ per ha, in duplicate) in a randomized block design with plots of 6 x 5 m^2 (total experimental area 28 x 46 m^2).

Three seeds were planted per cluster (hill); the seedlings were later thinned to one. Seeds were planted between 30 April and 2 May, at a planting distance of 30 x 20 cm. Weeding was done in plots with crops that are slow in their establishment: once for **Centrosema** and **Pueraria,** twice for **Psophocarpus** and three times for **Desmodium.** During the investigation the cowpea (**Vigna**) plot was sprayed weekly with Gameline 20 for insect control. Light interception was measured weekly with a light meter (BBC Goerz Metrawatt M 1507.3717.k52), whereby light intensity at five positions in each plot was compared with the immediately following measurement outside the plot.

TABLE 3.1. Soil properties of the field used for cover crop experiment at Onne.

Soil depth (cm)	pH (H_2O)	Org.Mat. (%)	Sand (%)	Silt (%)	Clay (%)	Texture	Bulk density g/cm^3 (n = 4) average ± s.d.
0- 5	4.5	1.78	83	13	4	loamy sand	1.40 + 0.14
5-15	4.5	1.31	83	13	4	loamy sand	1.50 + 0.08
15-25	4.5	0.98	77	12	11	sandy loam	1.48 + 0.05
25-40	4.5	0.73	73	10	17	sandy loam	1.40 + 0.08

Soil Depth (cm)	Total N (%)	P-Bray (ppm)	NH_4OAc-Ca	Exch. cations (me/100 g)				Total acid. (me/100 g)	CEC (me/100 g)
				Mg	Mn	K	Na		
0-5	0.111	78.75	1.03	0.46	-	0.17	0.21	1.642	3.53
5-15	0.071	54.05	0.64	0.21	-	-	0.19	1.798	2.90
15-25	0.061	47.70	0.74	0.05	-	-	0.16	2.007	3.10
25-40	0.082	46.80	0.56	-	-	-	0.24	2.048	2.99

Four times - 2, 5, 8 and 14 weeks after emergence - samples of the root system were taken with a pinboard (Schuurman and Goedewaagen, 1972) of 40 x 60 x 12 cm, each sample containing 2 plants (60 = 2 x 30). After washing away the soil a photograph was taken of the root system. The sample was subsequently cut in 10-cm layers and subdivided according to distance to the plant (0-5 cm and 5-15 cm, see figure 3.1).

For each subsample root dry weight and nodule dry weight was recorded after cleaning the roots. At the same dates above-ground biomass was sampled from three 1-m strips of plants in each plot. Samples of plant tops were dried at 65 °C, weighed and mixed for N analysis.

A composite soil sample (for the four layers as in table 3.1) was collected on the same dates as the root examinations and analysed at IITA (Ibadan) for pH, CEC, exchangeable Al, Ca, K and Mg.

On the last date of root sampling some fine roots of each species were collected and stored in alcohol for mycorrhiza analysis at the Institute for Soil Fertility; staining techniques were used for roots and the proportion of infected roots was determined as described by Giovanetti and Mosse (1980).

Additional observations were made on a 2-year old **Pueraria** field on the same part of the experimental station.

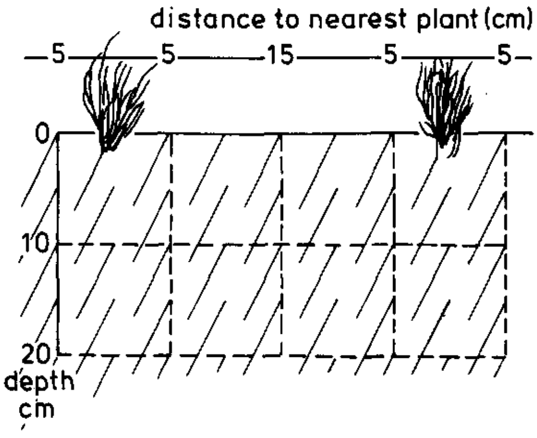


Figure 3.1. Schematic representation of a pinboard sample and its division in subsamples. Average root density in a layer is obtained by a 1:2 weighting of average root density in the "5-5" and "5-15" subsamples. The combination of plant density and pinboard size allow for an efficient sampling of the "unit soil area" (Van Noordwijk **et al.**, 1985).

3.3. Results

Soil analysis

Soil analysis during the experiment (figure 3.2) showed that liming had no effect on exchangeable Mg, K, Mn and Na concentration. Total acidity, exchangeable Al concentration and CEC decreased while soil pH and Ca concentration in the top layer increased, although variation among samples is large. Effects on Ca and pH did not appear until 5-8 weeks after liming, but a decrease of Al in the topsoil was already evident after 2 weeks. If all $Ca(OH)_2$ would have dissolved and had been found in the soil analysis of the top 10 cm an increase of about 1.4 me Ca per 100 g could be expected [750 kg $Ca(OH)_2$ per ha = 2×10^7 me Ca per ha; 1 ha x 10 cm = 10^9 cm^3 = 1.4×10^9 g (assuming a bulk density of 1.4); hence 750 kg $Ca(OH_2)$ per ha = 2×10^7 me Ca per ha = 2 /1.4 = 1.4 me Ca per 100 g]. The observed increase is only about 0.4 me Ca per 100 g.

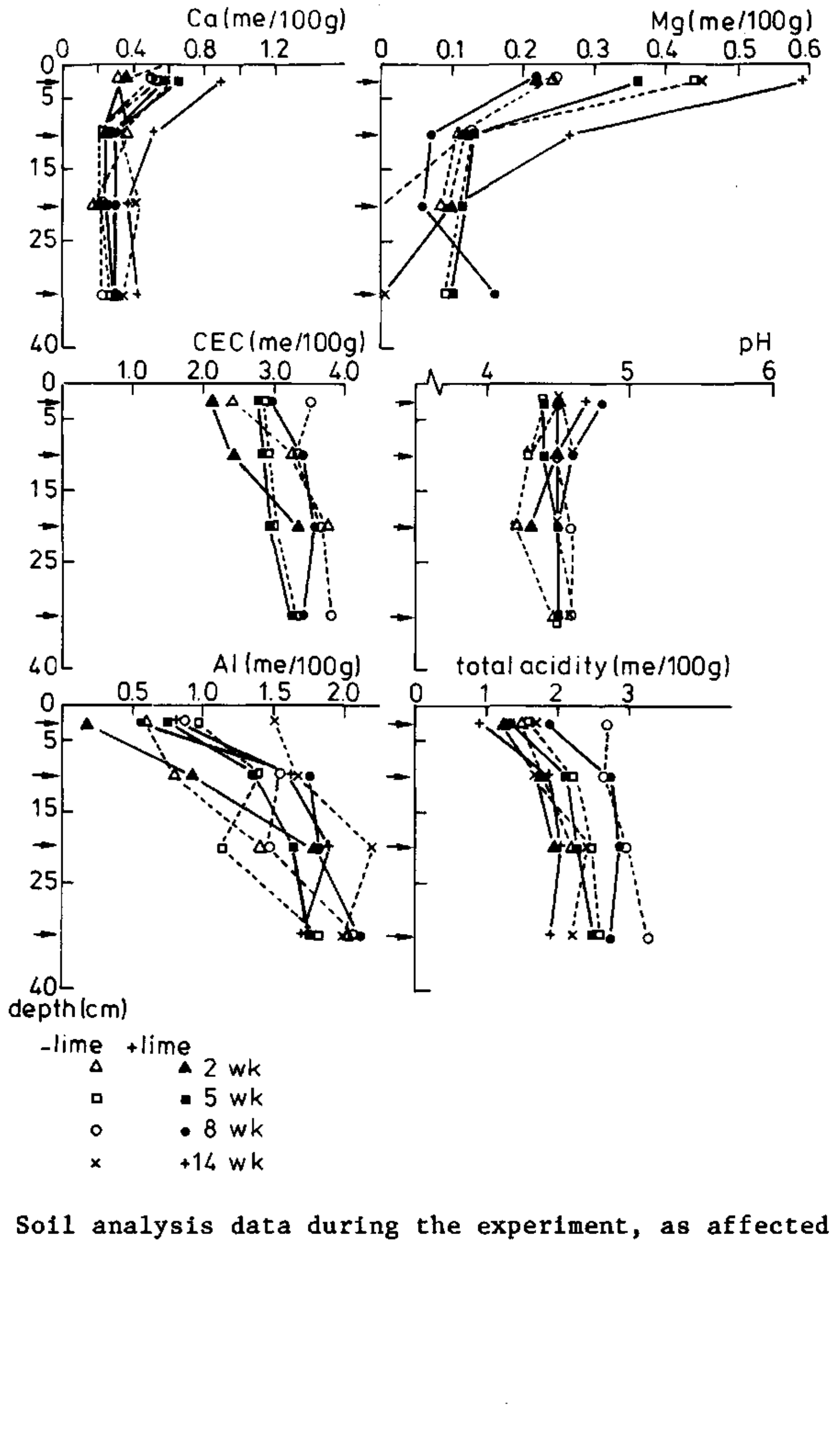


Figure 3.2. Soil analysis data during the experiment, as affected by liming.

Shoot growth

Figure 3.3 shows the time course of the light interception by the individual crops. **Mucuna** and **Vigna** had a quick start and took about 4 weeks to reach 50% light interception, but they started to senesce after 13 weeks. **Centrosema**, **Pueraria** and **Psophocarpus** had a slow start and took 7, 10 and 13 weeks, respectively, to reach 50% light interception, but did not show any senescence during the experiment. **Desmodium** was even slower than **Psophocarpus** and had not yet reached 50% light interception after 13 weeks.

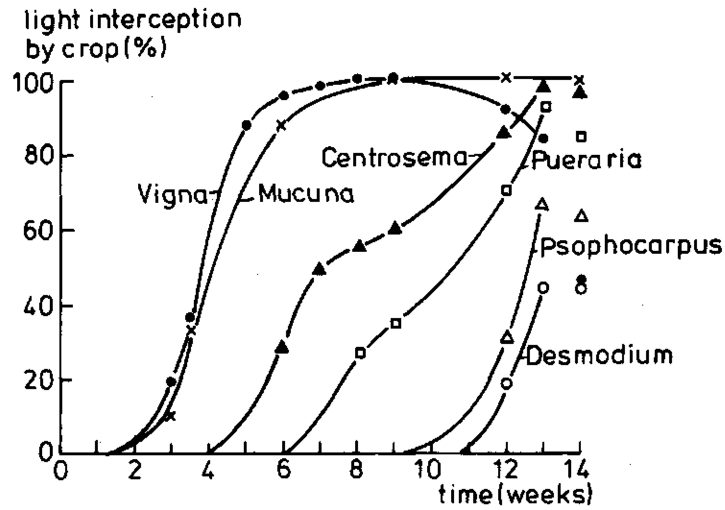


Figure 3.3. Light interception by six cover crops (average for with and without lime) as measured with a light meter comparing light intensities inside and outside plots.

The differences among the species in above-ground production as reflected in dry matter yields at 5, 8 and 14 weeks after emergence are shown in figure 3.4. Liming had no significant effects on plant growth except for **Vigna** at 8 weeks (positive) and **Mucuna** at 14 weeks (negative). For dry matter production the six crops can be ranked in the decreasing order: **Mucuna**, **Vigna**, **Centrosema**, **Pueraria**, **Psophocarpus** and **Desmodium**.

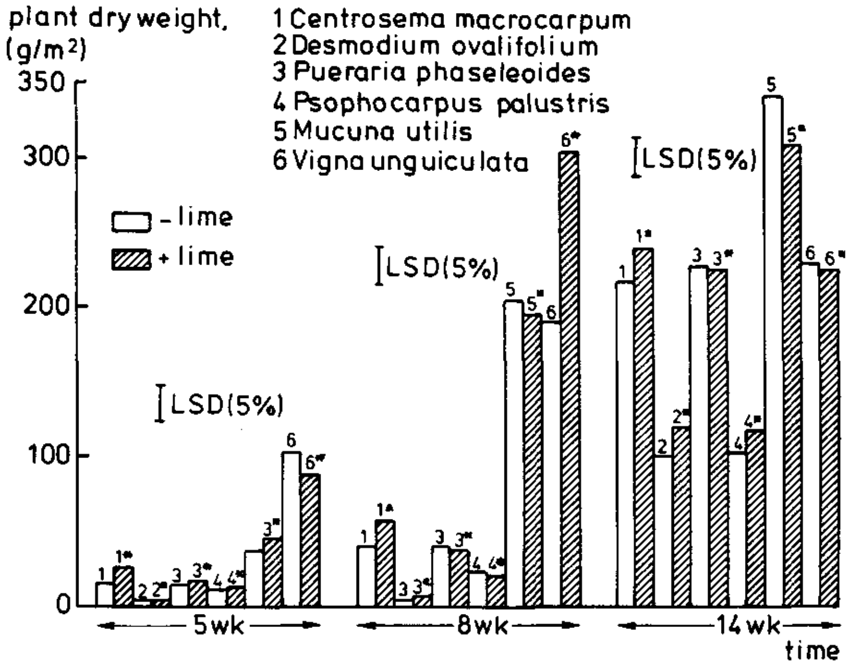


Figure 3.4. Above-ground dry matter production by six cover crops as affected by liming.

Nitrogen uptake

Table 3.2 gives data on total nitrogen concentration of above-ground biomass of the six species (for **Desmodium** no sample was collected on the first two dates because of insufficient plant growth).

Liming slightly increased the nitrogen concentration of all crops. Nitrogen concentration decreased with time in all crops. Liming considerably increased the Ca concentration of all crops and had a positive effect on K and P concentration as well.

Figure 3.5 shows the nitrogen uptake in above-ground biomass for the six species as it developed in time. **Mucuna** and **Vigna** showed the fastest growth and uptake and grew at an average N concentration of about 3.5%. After 8 weeks the N concentration of the cowpea (**Vigna**) crop started to decrease when most of its N had been redistributed internally to the seeds. N uptake by **Mucuna** proceeded at a low rate after 8 weeks. The other crops were considerably slower in their N uptake and grew at N concentrations of 2-3%; after 14 weeks they were still in the initial part of a sigmoid uptake pattern.

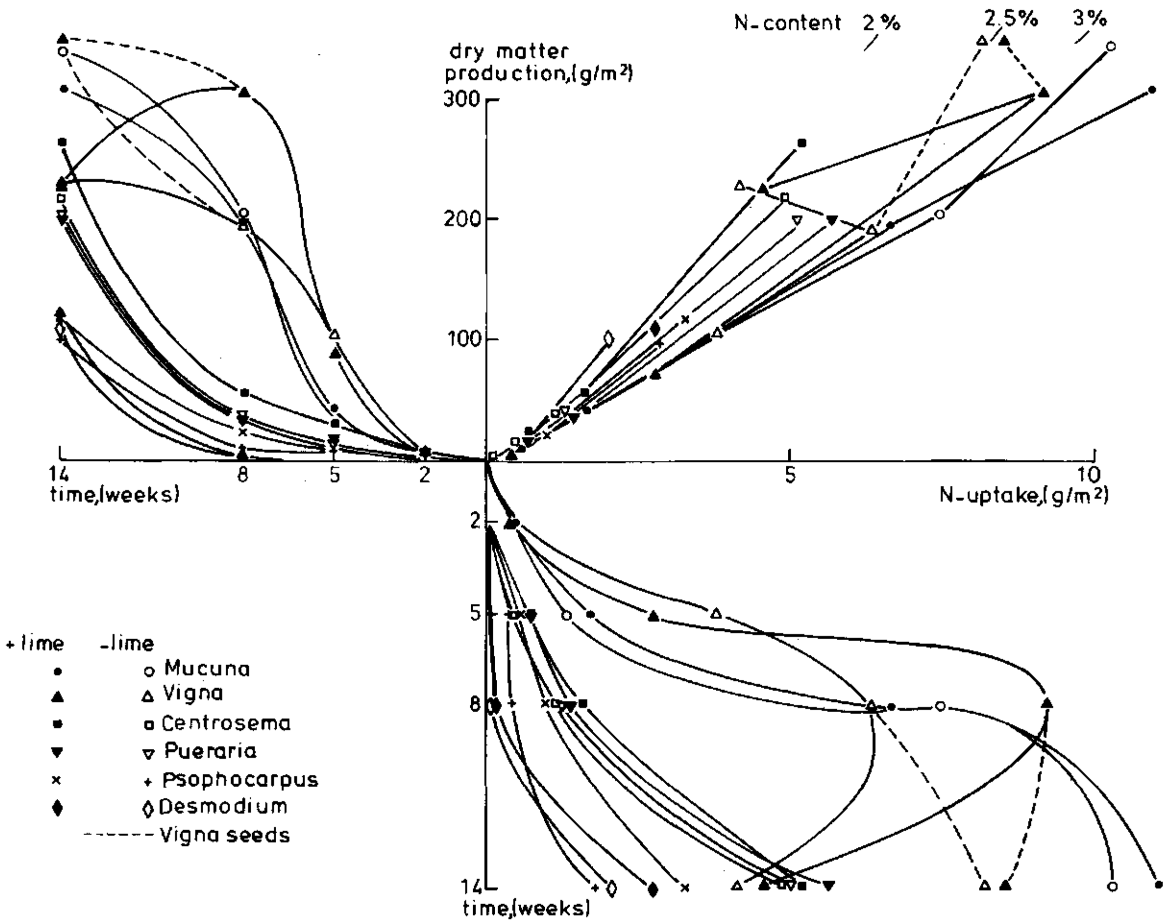


Figure 3.5. Nitrogen uptake and dry matter production (above-ground) by six cover crops.

TABLE 3.2. A. Total nitrogen concentration of shoots (% N) for limed (1) and unlimed (0) treatments at four harvest periods. Data given are average values for duplicate samples. B. Total P, K and Ca concentration (% of dry matter) 14 weeks after sowing.

Species	Treatment							
	0	1	0	1	0	1	0	1
	A. N concentration							
	2 weeks		**5 weeks**		**8 weeks**		**14 weeks**	
Mucuna	4.6	4.9	3.6	3.9	3.6	3.4	3.0	3.5
Vigna vegetative	5.4	5.5	3.6	3.6	3.4	3.0	1.8	2.0
pods	.	.	.	.	.	.	3.2	3.0
Centrosema	4.3	4.8	2.8	2.6	2.8	2.7	2.2	1.9
Pueraria	4.7	4.6	3.5	4.4	3.2	3.5	2.5	2.8
Psophocarpus	5.0	5.1	4.1	4.2	4.1	4.7	2.8	2.8
Desmodium	.	.	.	.	3.1	3.1	2.0	2.3
	B. P concentration (%)		**K concentration (%)**		**Ca concentration (%)**			
Mucuna	0.23	0.23	1.23	1.22	0.21	0.29		
Vigna vegetative	0.22	0.27	1.00	1.27	0.21	0.30		
pods	0.22	0.29	0.43	0.64	0.02	0.02		
Centrosema	0.23	0.28	0.82	1.30	0.33	0.46		
Pueraria	0.24	0.27	0.95	1.05	0.21	0.34		
Psophocarpus	0.26	0.28	0.92	1.25	0.21	0.37		
Desmodium	0.16	0.20	0.79	1.04	0.19	0.23		

Root observations

The root system of the six crops at final harvest is shown in plate II and III and figure 3.6. Details of the distribution of root dry weight over the profile are given in figure 3.7. Data on nodulation and mycorrhiza are given in figures 3.8. and 3.9. Table 3.3 summarizes the data as regards the effects of liming.

Although the root system of the six crops had the same overall shape with a vertical taproot and abundant branch roots in the topsoil, there were some marked differences in root development. **Centrosema** roots penetrated to 70 cm depth while the other species did not grow beyond 50 cm. All species formed abundant branch roots in the top 10 cm of the soil, but the proportion of total root dry weight found in the top 10 cm of the profile varied from 85% for **Mucuna** to 57% for **Centrosema** and **Desmodium** (unlimed treatments). In some cases a typical thickening of part of the roots was observed which resembles "proteoid roots" as described by Gardner **et al.**, 1982 (figure 3.6). Such roots were seen in **Mucuna** (+lime, 2 weeks, 5-10 cm depth), **Pueraria** (+lime, 8 weeks, 10-15 cm depth) and **Psophocarpus** (-lime, 2 weeks, 5-10 cm depth).

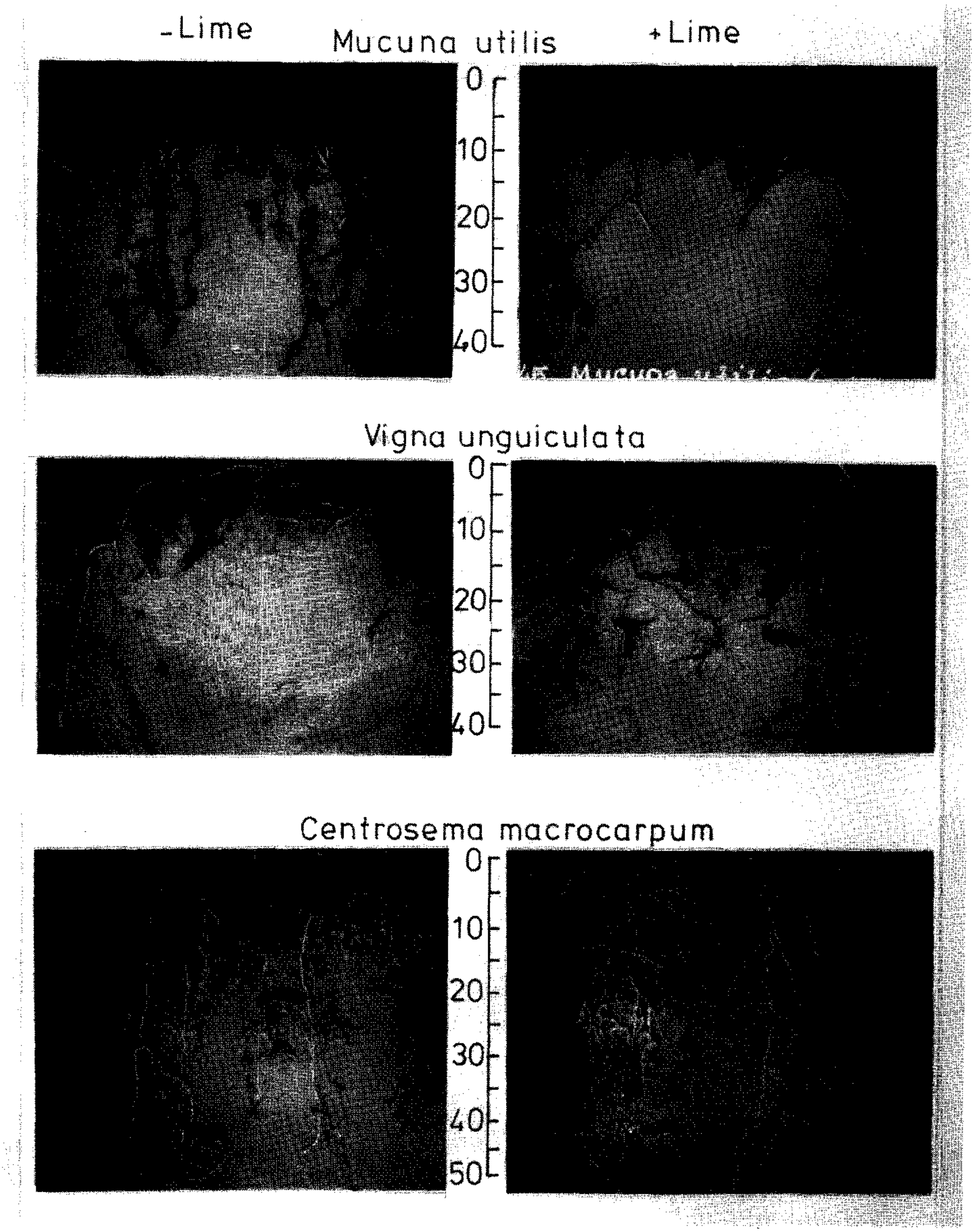


Plate II. Root system of cover crops (**Mucuna utilis, Vigna ungaiculata, Centrosema macrocarpum**) washed from pinboard sample at final harvest for the six species as affected by liming.

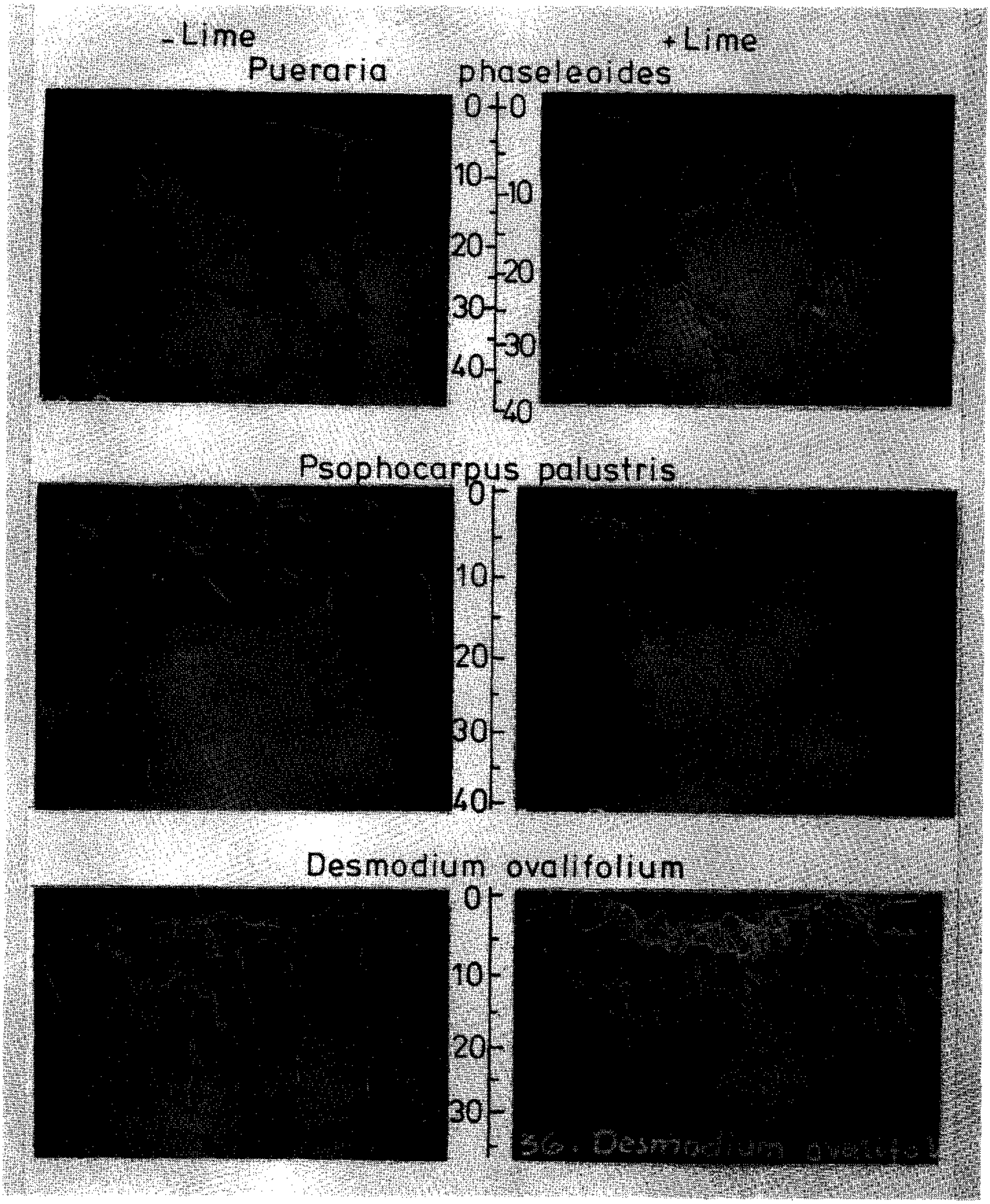


Plate III. Root system of cover crops (**Pueraria phaseleoides, Psophocarpus palustris, Desmodium ovatifolium**) washed from pinboard sample at final harvest for the six species as affected by liming.

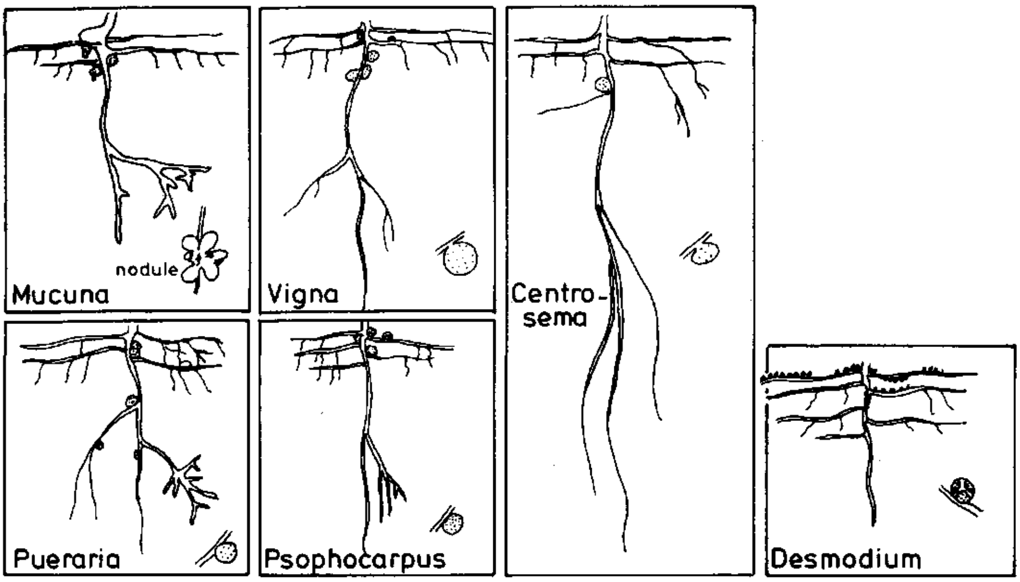
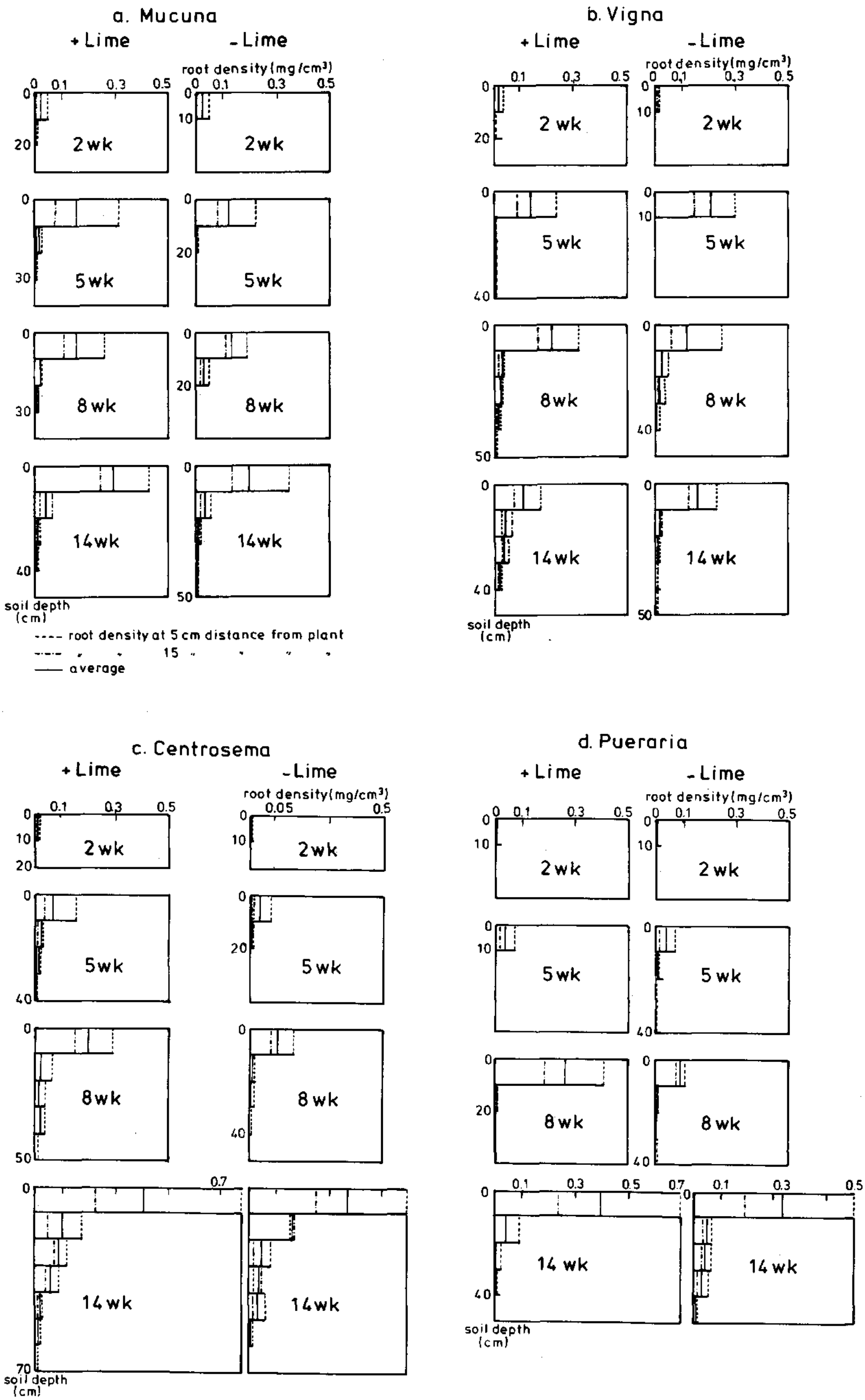


Figure 3.6. Diagram of root distribution of the six species, also showing the shape and position of the nodules.


a. Mucuna
+Lime
-Lime
root density (mg/cm³)
0 0.1 0.3 0.5
2wk
5wk
8wk
14wk
soil depth (cm)
---- root density at 5 cm distance from plant
-·-·- " " 15 " " " "
—— average
b. Vigna
+Lime
-Lime
root density (mg/cm³)
0.1 0.3 0.5
2 wk
5 wk
8 wk
14 wk
soil depth (cm)
c. Centrosema
+Lime
-Lime
root density (mg/cm³)
0.1 0.3 0.5
0.05 0.5
0.7
2 wk
5 wk
8 wk
14 wk
soil depth (cm)
d. Pueraria
+Lime
-Lime
root density (mg/cm³)
0 0.1 0.3 0.5 0.7
2 wk
5 wk
8 wk
14 wk
soil depth (cm)

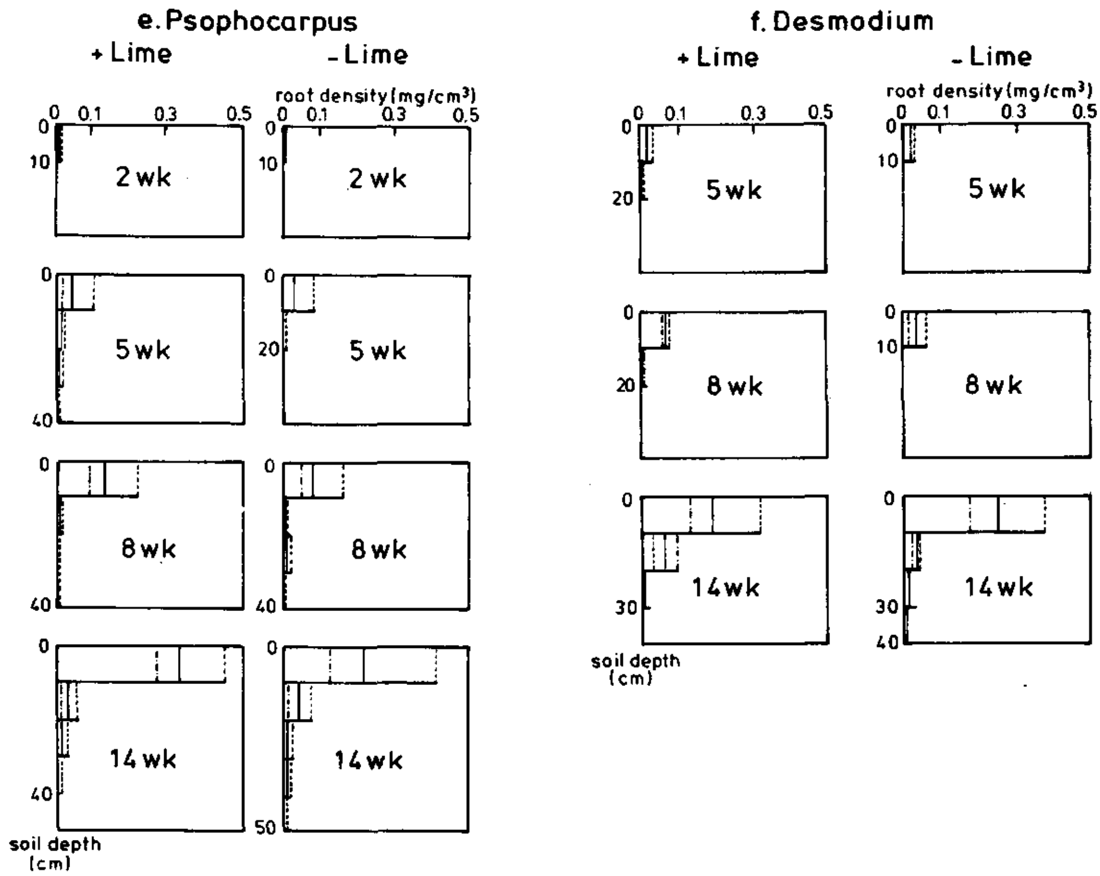


Figure 3.7. Distribution of root dry weight of cover crops. For each layer root dry weight at 0-5 and at 5-15 cm from the nearest plant is shown as well as the average for the layer.

For all species the highest root weight density (mg/cm^3) occurred in the top layer at 0-5 cm from the plant. Root weight density in the top layer at 5-15 cm from the plant. The difference between the two sample positions was smaller in the subsoil than in the topsoil (figure 3.7).

Nodulation was restricted to the topsoil, except for **Pueraria** which formed nodules even at 40 cm depth. Nodule morphology (figure 3.7) varies from irregular, cylindrical for **Mucuna** to globular for the other species, with **Vigna** and **Pueraria** forming the largest nodules and **Desmodium** by far the smallest. Nodule shape conformed to the descriptions given by Corby **et al.** (1983). **Pueraria** and **Psophocarpus** had by far the highest nodule dry weight. A rough impression of nodule efficiency can be obtained by observing the colour of nodules under a dissecting microscope after cutting them. N fixation by **Rhizobium** is only possible under anaerobic conditions and the red-coloured "leghemoglobin" is responsible for

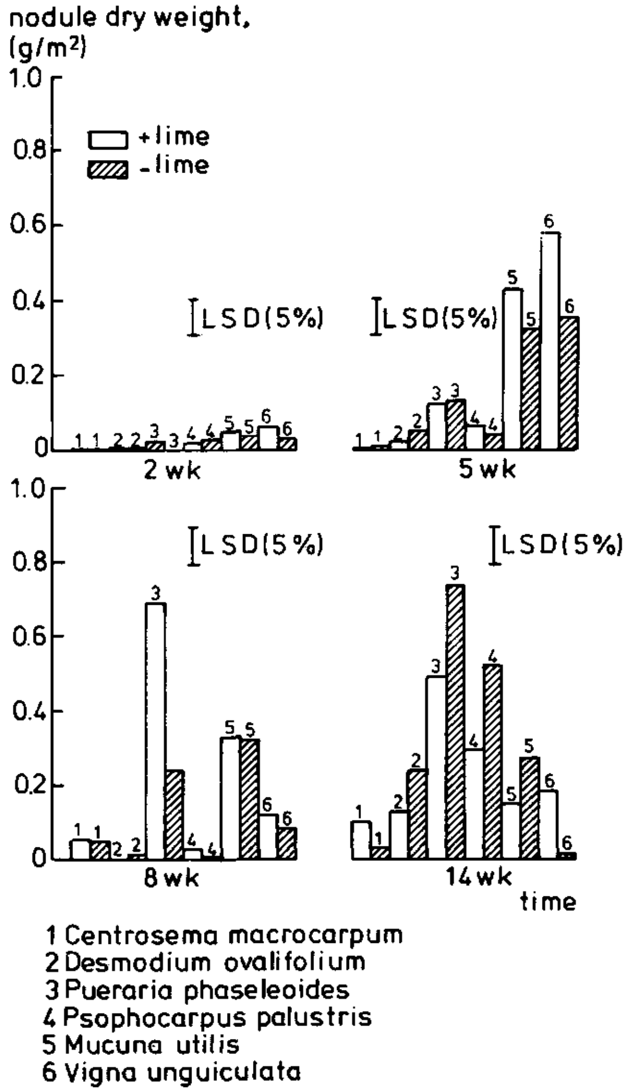


Figure 3.8. Dry weight of nodules for the six species as affected by liming.

maintaining anaerobic conditions inside a nodule. Nodules which are not red can be considered as "non-effective". The percentage "non-effective" nodules varied among the cover crops and generally decreased during the season. In **Vigna** and especially **Mucuna** it increased again at the time of the last two observations (nodules had turned brown and rotten at the time of the last observation). Nodules of **Centrosema** were "non-effective" in the first two observations and only gradually improved (still about 40% "non-effective" after 14 weeks). In **Pueraria** "non-effective" nodules were seen mainly in the first observation; in **Psophocarpus** about 60% of the nodules remained "non-effective" after 8 weeks. **Desmodium** had the lowest percentage "non-effective" nodules (10-20%).

There was little difference between mycorrhiza infection of the roots in the topsoil and the subsoil (figure 3.9).

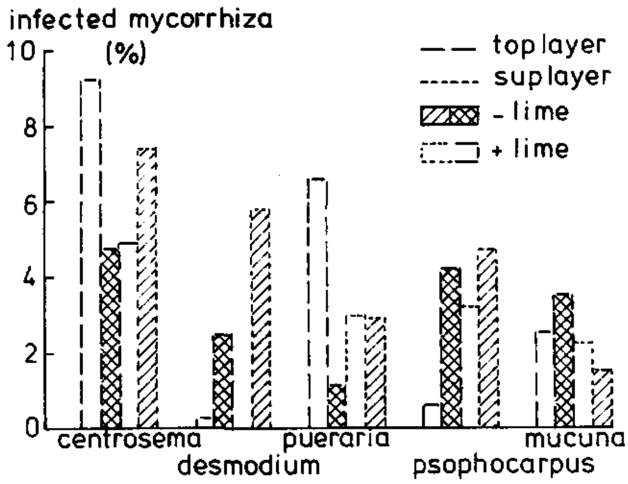


Figure 3.9. Percentage infection with Vesicular-Arbuscular Mycorrhiza (V.A.M.) of fine roots of the six species at final harvest; "top-layer" refers to 0-15 cm, "sub-layer" to 15-40 cm.

Liming did not have dramatic effects on root growth, but there was a general tendency for root densities in the topsoil to increase while rooting depth was decreased. Total root dry weight was increased by liming in the fast-growing species **Mucuna** and **Vigna** as well as in the slower growing **Psophocarpus**; it was unaffected for **Centrosema** and **Pueraria** and decreased for **Desmodium** (table 3.3). Liming had a positive effect on the maximum nodule dry weight in the fast-growing species **Mucuna**, **Vigna** and **Centrosema** and a negative effect in the three slower growing species. Liming seems to have a clearly negative effect on V.A.M. in **Desmodium**, a weakly negative one in **Psophocarpus** and no or a weakly positive effect in the others.

TABLE 3.3. Effects of liming on root parameters (0 = unlimed, 1 = limed).

Species	Treatment									
	max. dry weight (g/m^2)		max. root depth (cm)		% root weight in top 10 cm		max. nodule dry weight (g/m^2)		max. V.A.M. % infection	
	0	1	0	1	0	1	0	1	0	1
Mucuna	24.1	33.0	50	40	84	86	4.5	6.0	3.5	2.5
Vigna	22.3	31.6	50	40	78	54	4.9	8.0	-	6.3
Centrosema	56.6	55.5	70	70	58	60	0.5	1.4	7.4	9.2
Pueraria	45.8	44.3	50	40	73	88	10.3	6.8	2.9	6.6
Psophocarpus	28.3	37.3	50	50	77	86	7.2	4.0	4.7	3.2
Desmodium	29.4	21.8	40	30	57	76	3.4	1.8	5.8	0.3

Root/shoot ratio

Figure 3.10 compares above-ground and below-ground biomass production for the six species. In the initial stages all species conformed to a root:shoot ratio of 1:4, but later **Vigna** and **Mucuna** hardly formed more roots while shoot dry weight increased, leading to root:shoot ratios of about 1:12, while the other species maintained a root:shoot ratio of 1:4 or even increased to 1:2. Maximum root dry weight (**Centrosema**, **Pueraria** and **Psophocarpus**) did not coincide with maximum shoot production (**Mucuna**, **Vigna** and **Centrosema**).

Observations on a 2-year old Pueraria field

Some additional observations were made in a 2-year old **Pueraria** field at the start of the rainy season. Plate IV shows root systems as washed from pinboard samples. Table 3.4 gives some data. **Pueraria** forms many stolons (creeping stems just above the ground) which form a dense mat. Individual plants can no longer be recognised. N concentration and root: shoot ratio are similar to the values for the 14-weeks old plants in the experiment.

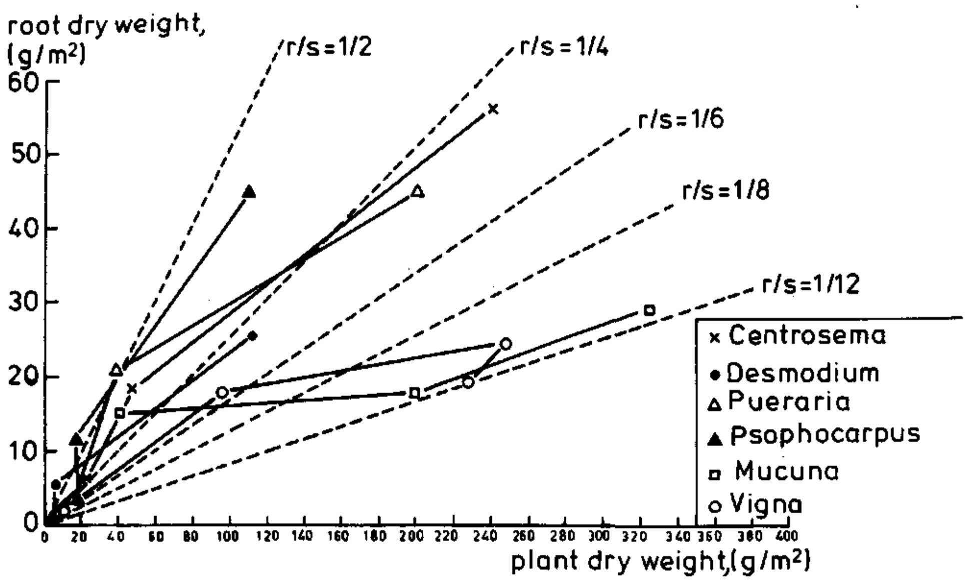


Figure 3.10. Relation between root and shoot growth for cover crops (average for lime and no lime).

TABLE 3.4. Quantitative data on the **Pueraria** samples shown in Plate IV. Shoot dry weight was determined for three samples from 0.6 m^2.

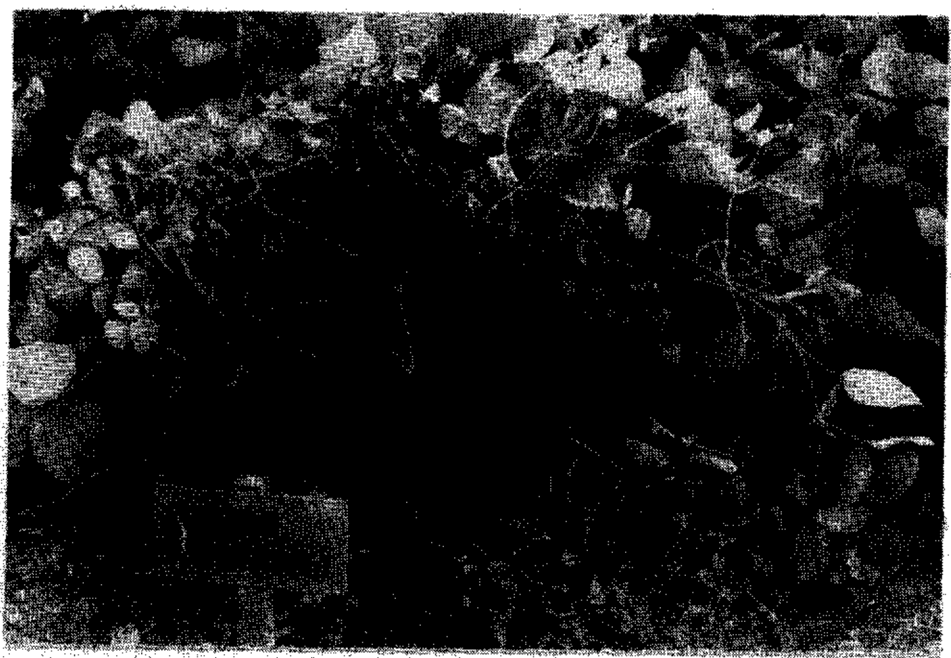
	Plant dry weight (g/m2)	N concentration (%)	Mycorrhizal infection (%)
shoot(n=3)	190	2.52 + 0.08	
stolon	189		
root 0 - 10	48		5.2
10 - 20	20		
20 - 30	5.7		
30 - 40	6.1		
40 - 50	2.9		
50 - 60	1.0		
total 0 - 60	83		
root:shoot ratio	0.21		

3.4. Discussion

The six species used in this experiment showed obvious differences in life cycle, rapidity of covering the soil, necessity of weeding and depth of root development, which may affect their suitability as a cover crop. Two species (**Mucuna** and **Vigna**) exhibited fast growth, coupled with early senescence, a low root:shoot ratio and a relatively high N concentration. These crops may benefit from the flush in mineralisation at the start of the rains through rapid uptake; they may be suitable as a short-term cover crop, releasing nitrogen from decaying organic matter in the second part of the growth season. Their root development and consequently chances of recovering leached nutrients are not impressive. The other crops have a slow start and grow at a higher root:shoot ratio (investing a larger proportion of their dry matter production in the root system). These plants may prove valuable in the long run when they have a deep root system (**Centrosema**) or good nodulation (**Pueraria**). The **Psophocarpus** and **Desmodium** varieties tested are unsuitable under these conditions because of their slow establishment. **Pueraria** and to a lesser extent **Psophocarpus** are not suitable for intercropping (except with trees) due to their winding stems, which on the other hand make them well suited for suppressing weeds when used in a planted fallow system.

Liming had no dramatic effect on plant growth. Above-ground production was not significantly affected, although Ca and K concentration increased considerably and N and P concentration slightly. The increase in N concentration as well as a reduction of nodulation in the slow starting species **Pueraria** and **Psophocarpus** may be attributed to (locally) increased N mineralisation by local effects on soil pH around lime particles. Such local effects on pH may be more important than effects on bulk soil pH. For the faster growing species **Vigna** and **Mucuna** (which take up considerably more N in the first period), the effect of lime on nodulation is positive. Liming influences root distribution by decreasing maximum root

Plate IV. Root distribution under a 2-year old **Pueraria** stand; A. and B. show two replicate samples, A. with and B. without a thick layer of stolons; C. shows details of nodules up to 20 cm depth; D. gives a detail of **Pueraria** roots in an old palm root channel; E. pictures a demonstration plot of **Pueraria** in Ibadan at IITA's main campus, showing a mat of stolons and decaying leaf litter with little connection with the soil (the same effect is even more obvious in **Desmodium** plots).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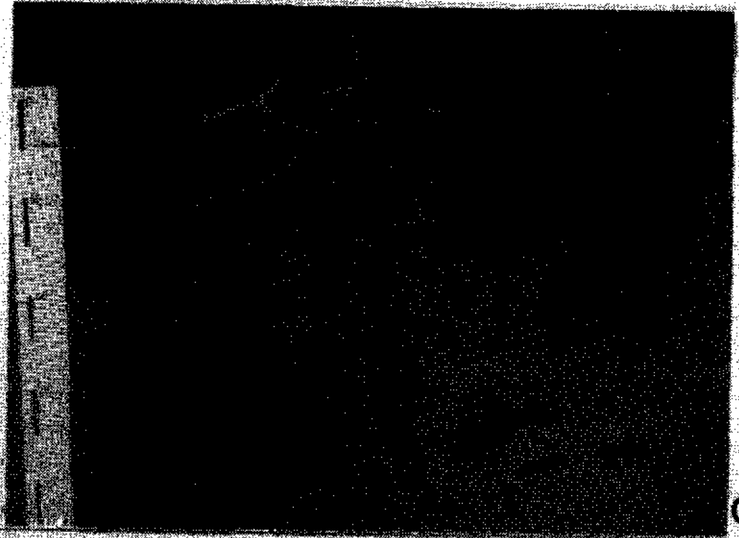
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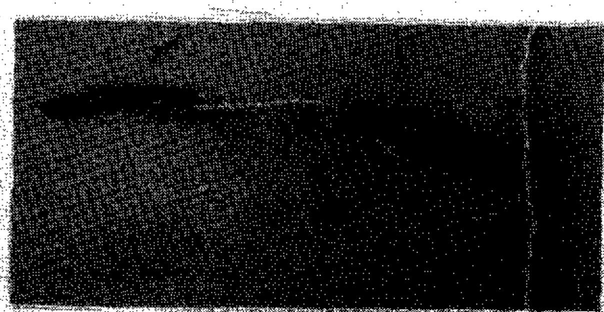
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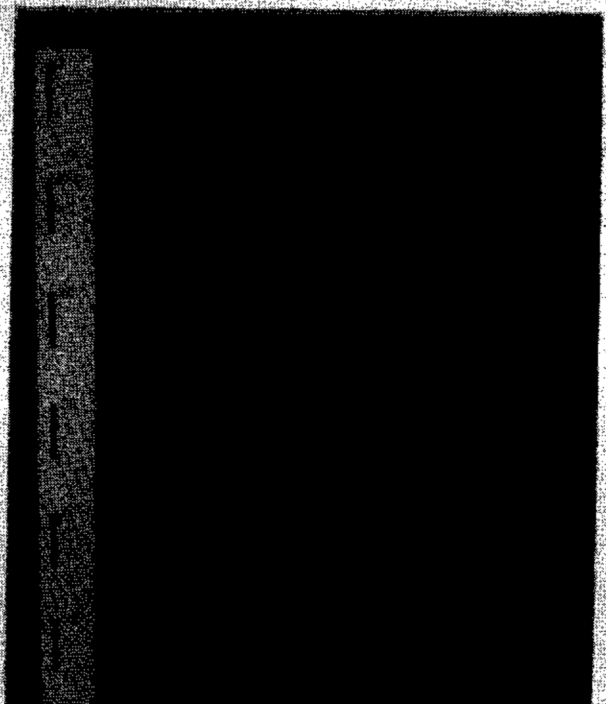
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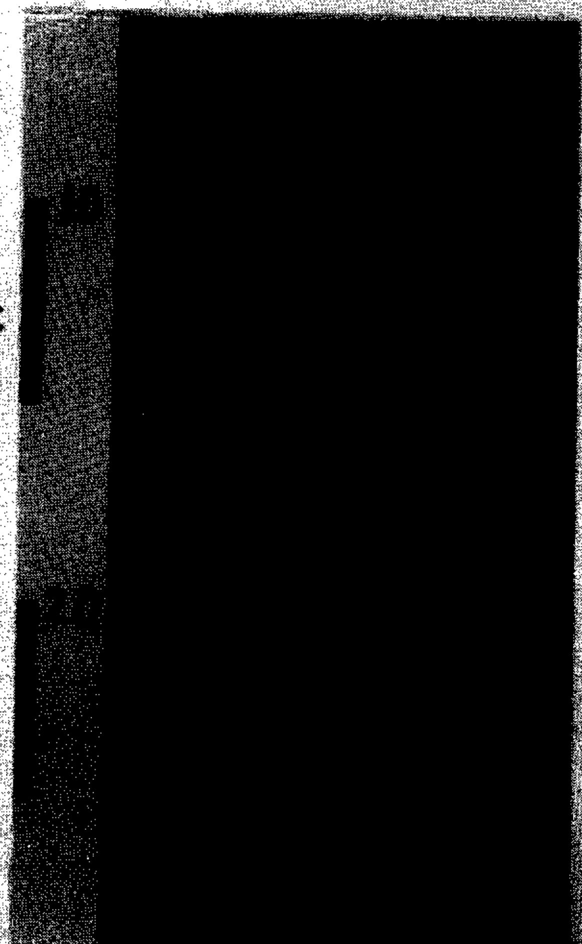

c

depth and increasing the proportion of total root weight present in the topsoil. The overall effect of lime on the efficiency of nitrogen utilization probably depends on the crop and the degreee of synchronisation between crop demand and soil supply. Lime application can increase local mineralisation, but this is only useful in periods of high crop demand. As lime can be applied at any time, its time of application can be chosen such that N mineralisation takes place in the right period.

There were considerable differences in nodulation among the species considered when planted without inoculation. Nodulation in **Centrosema** was poor; this plant might benefit from inoculation, but pot experiments by Otisi (1979) showed that inoculation of the soil with **Rhizobium** did not improve nodulation (at least not for the **Rhizobium** strain tested). Nodulation starts slowly in **Pueraria** and **Phophocarpus** at first accompanied by yellowing of the leaves, so these plants might benefit in their initial stages of growth from inoculation. Desmodium has a low nodule dry weight, but the large number of small nodules all seem to be "effective". Mycorrhizal infection levels are low, but due to the rather high soil P levels, P nutrition is not a problem and mycorrhiza is not strictly necessary under the conditions of Onne.

4. UPLAND RICE

4.1. Introduction

Upland rice (**Oryza sativa** L.) is widely grown in the humid tropics. Richards (1985) discussed the large number of varieties traditionally used in Sierra Leone and S.W. Nigeria, adapted to a variety of growing conditions. The root system of rice grown under upland conditions differs considerably from the root system under wet (sawah) conditions. The roots of upland rice can penetrate quite deeply into the soil. According to Nicou and Chopart (1979) the root system of upland rice is intermediate (in rooting depth and root dry weight in the topsoil) between maize and **Sorghum** on the one hand and **Pennisetum** (millet) on the other, on sandy and sandy clay loams in Senegal. According to Westphal **et al.** (1985) the root system of traditional upland rice varieties, adapted to low soil fertility (especially nitrogen) extends deeper into the soil than that of "modern" cultivars.

Observations on roots of upland rice reported here, were made in experimental plots where leaching of water and nutrients was studied under field conditions, with and without NPK fertilisation. Nutrient use efficiency generally depends on the fertility level of the soil. Fertilisation can modify both the supply of nutrients in the soil and the capacity for uptake by the crop by influencing root development. At higher fertility levels root development may be better in absolute terms - although root:shoot ratio will be lower - than under poor soil conditons, due to a generally better plant growth. The general pattern of this response for annual crops has been described by Schuurman (1983), as shown in figure 4.1.

Figure 4.1 can explain the contrasting reports in the literature on effects of fertilisation on root development: positive, neutral and negative effects can be expected, depending on the original fertility level of the soil. Although the graph has been derived from pot experiments under temperate climatic conditions, the overall shape is probably valid under tropical conditions as well as it is based on elementary principles of the functional equilibrium between root and shoot growth (Brouwer, 1984). Only a few quantitative studies under tropical conditions are available in the literature. Ligthart (1981) found a positive effect of NPK fertilisation (30 kg N per ha, 25 kg P_2O_5/ha, 30 kg K_2O/ha) on root mass of maize on six soils, and a negative effect on one soil in S.E. Kenya (Kaloleni area); positive effects on root development were greatest in the topsoil, with a slight improvement of deep root development. Nutrient use efficiency under conditions of high leaching can be expected to decrease sharply when fertilisation exceeds the level for maximum root growth. It can be expected that nutrient use efficiency is highest at sub-maximum shoot growth.

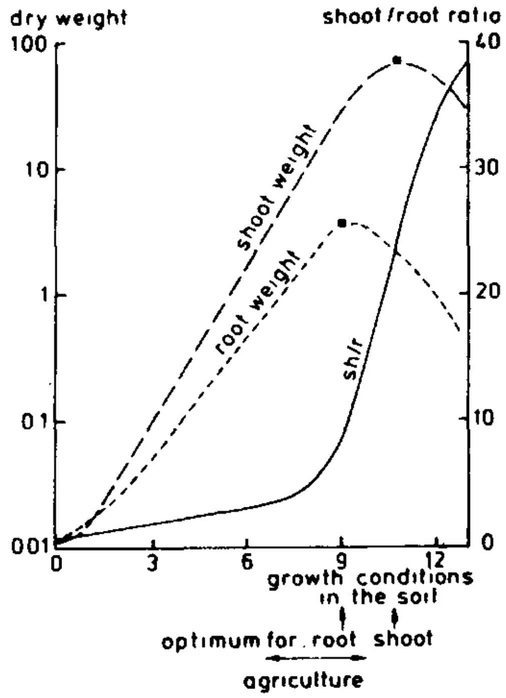


Figure 4.1. General reponse of annual (cereal) plants on increasing supply of water and nutrients. The optimum for root growth is reached at a lower soil fertility level than that for shoot growth. Shoot:root ratio increases gradually up to the optimum for root growth and rises sharply beyond this point.

4.2. Methods

Root observations were made in plots of upland rice (table 4.1) where soil moisture content and the composition of the soil solution were monitored by M. Weber (Landwirtschaftliche Forschungsanstalt Büntehof, Kali und Salz AG, FRG). Rice (variety ITA 307) was sown on 27 March 1985 at a plant spacing of 30 x 15 cm. Amounts of 90 kg NPK (15:15:15) and 100 kg $MgSO_4$ per ha were applied in two splits (3 weeks and 6 weeks after sowing, respectively). Soil solution probes and tensiometers were installed in the crop fields (in fertilised and unfertilised part) at 10 cm depth intervals for monitoring water and nutrient distribution in the soil (data not yet available).

TABLE 4.1. Some soil characteristics of the upland rice plot.

Depth (cm)	pH (H_2O)	pH (KCl)	bulk density (g/cm^3)
0 - 15	4.6	3.6	1.37 + 0.03 (n = 4)
15 - 25	4.6	3.65	1.52 + 0.01 (n = 3)

Duplicate root samples were taken in fertilised and unfertilised plots using a pinboard of 40x60x12 cm at 3, 5, 9 and 14 weeks after sowing. Each pinboard sample contained two plant rows. After washing and photographing under standard conditions each sample was cut into subsamples per 10 cm depth and according to distance to the plant (compare figure 3.1). For every subsample root length was measured using the line-intercept method of Newman (Böhm, 1979) and dry weight was subsequently determined. Plant samples from the pinboard were dried and analysed for N and P.

4.3. Results

Shoot growth, N and P uptake

Figure 4.2 shows dry matter production and N and P uptake for fertilised and unfertilised rice. Five weeks after emergence (two weeks after the first fertiliser application) no difference between fertilised and unfertilised plots could be seen. After five weeks clear differences in growth were observed. Nitrogen uptake occurred mainly in the period between week 5 and week 9. After week 9 no net uptake of N occurred (in fact N was lost from the crop) and N concentration (as % of dry matter) decreased considerably. Unfertilised plots showed the same pattern as fertilised plots, although at a lower level. Phosphate uptake was linear with time from week 5 to week 14. Between week 9 and week 14 P concentration (as % of dry matter) increased.

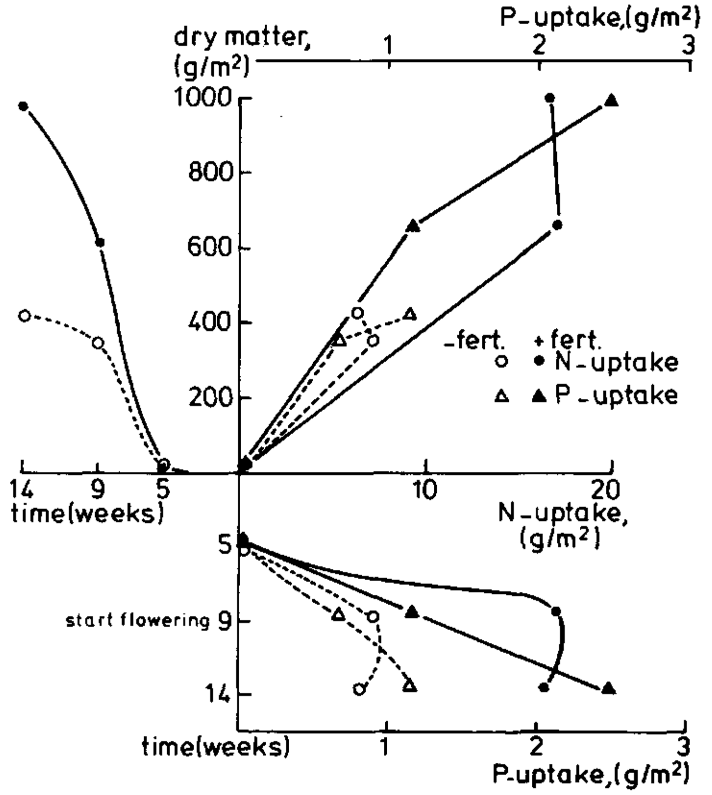


Figure 4.2. Time course of dry matter production and N and P uptake in fertilised and unfertilised upland rice.

Root observations

The root systems as obtained by pinboard sampling are shown in plate V and figure 4.3. Distribution of root dry weight is shown in figure 4.4. and root length in figure 4.5. At 5 weeks after emergence (2 weeks after the first NPK split application) the root system on the unfertilised plots was slightly better developed. At 9 weeks the root system in the fertilised plots was more dense in the topsoil and extended deeper into the soil than the roots in the unfertilized plots. Between week 9 and week 14 root development on both plots continued. On the fertilised plots roots extended beyond a depth of 70 cm, on the unfertilised plots they reached 40 cm. A duplicate pinboard sample confirmed the deep rooting behaviour of the fertilised plants. Root length densities in the top 10 cm of soil reached values of 5 cm/cm^3, the difference between the two subsample positions ("5-5" and "5-15" cm from the plant) decreased with time. Specific root length (cm/mg) generally increased with depth (figure 4.6.).

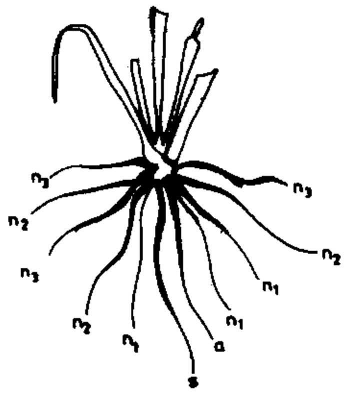
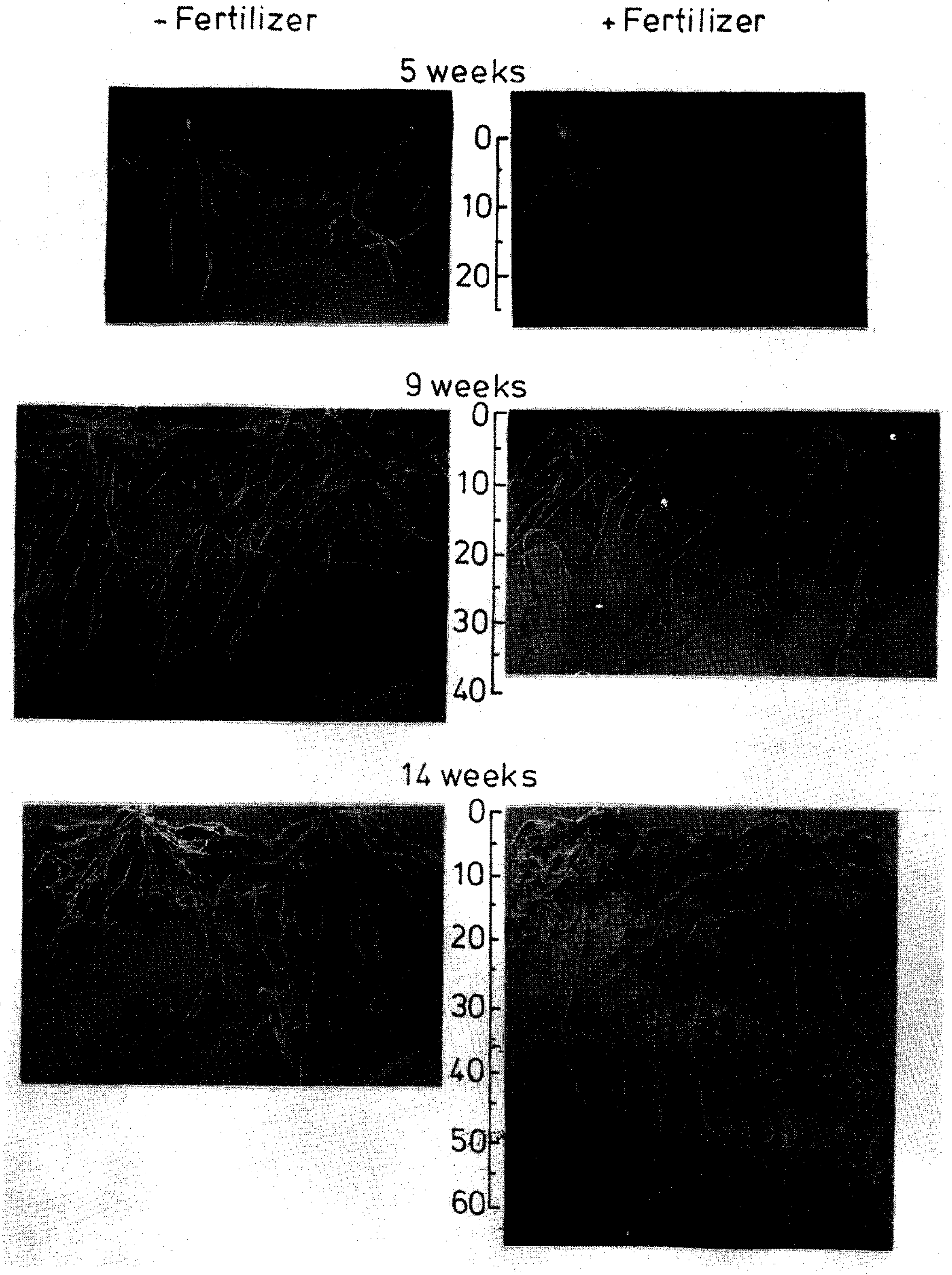


Figure 4.3. Diagram of rice root development: s = seminal root system, a = adventitious root, n1, n2, n3 = nodal roots of 1st, 2nd and 3rd whorl.

Plate V. Root systems of upland rice on pinboards.



- Fertilizer
+ Fertilizer
5 weeks
9 weeks
14 weeks
0
10
20
30
40
50
60

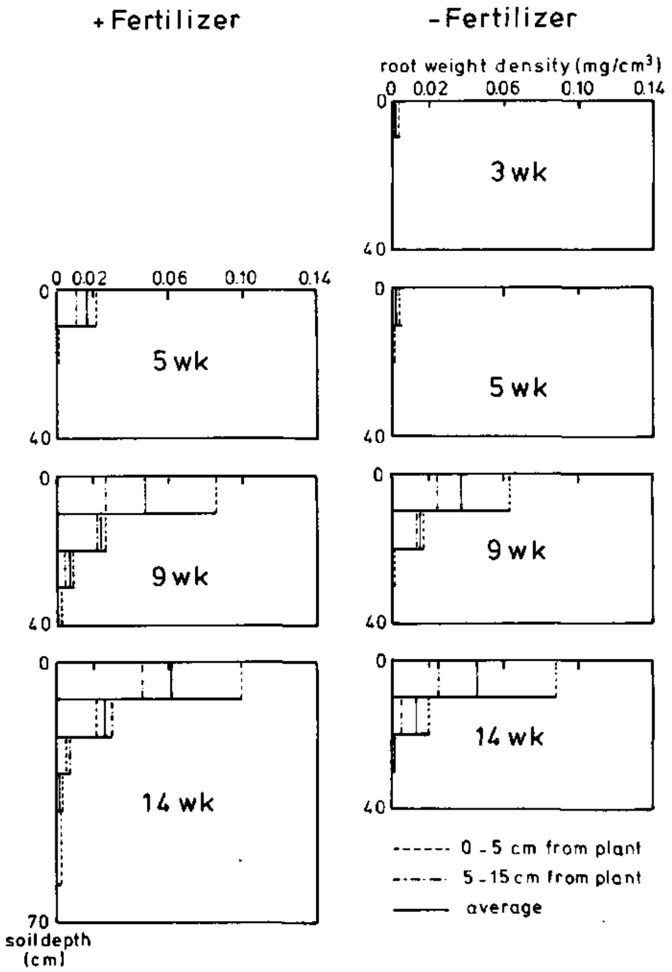


Figure 4.4. Distribution of root dry weight in upland rice.

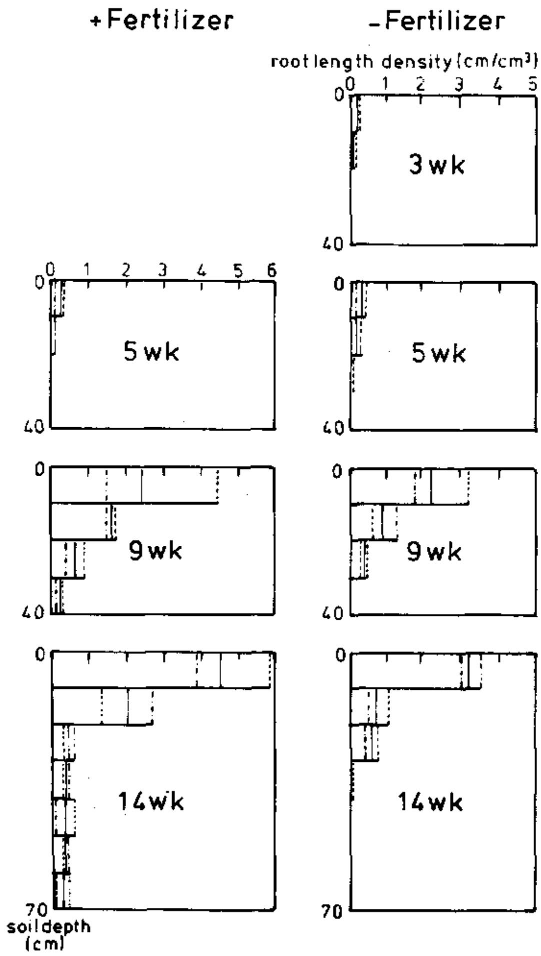


Figure 4.5. Distribution of root length in upland rice.

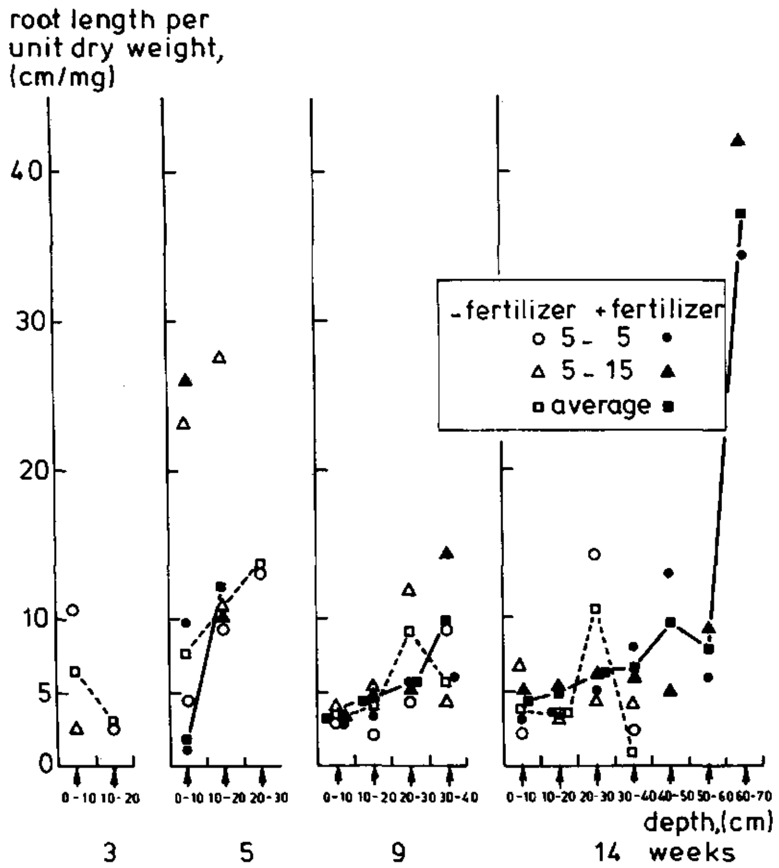


Figure 4.6. Specific root length (root length per unit dry weight, cm/mg) in upland rice.

Root:shoot ratio

Figure 4.7 shows the relation between root and shoot growth with time. Root:shoot ratio decreased continuously over the season up to a value of 1:7 for unfertilised plots and to almost 1:10 for fertilised plots. When we compare these data with figure 4.1, it is likely that the fertilised plots show the maximum root development that can be expected under these conditions.

4.4. Discussion

The rooting depth observed here was beyond all expectations, especially on the fertilised plots. The direct effect on root growth of the first split application of NPK, as observed after 5 weeks, was negative. It took longer before all topsoil was exploited by the roots in the fertilised as compared to unfertilised plots and considerable nutrient losses may have occurred in this period. After 9 weeks the root systems on fertilised and unfertilised plots were similar and in the last period root development was greatest in the fertilised plots. The rooting depth of 70 cm reached can, however, not be very significant for N uptake as the total N content decreased in this period (i.e. N losses from the plant exceed uptake). A more detailed discussion will be possible when the results of the soil solution analysis will be available. The present data on above-ground dry matter production are not very reliable as they are based on samples from small areas.

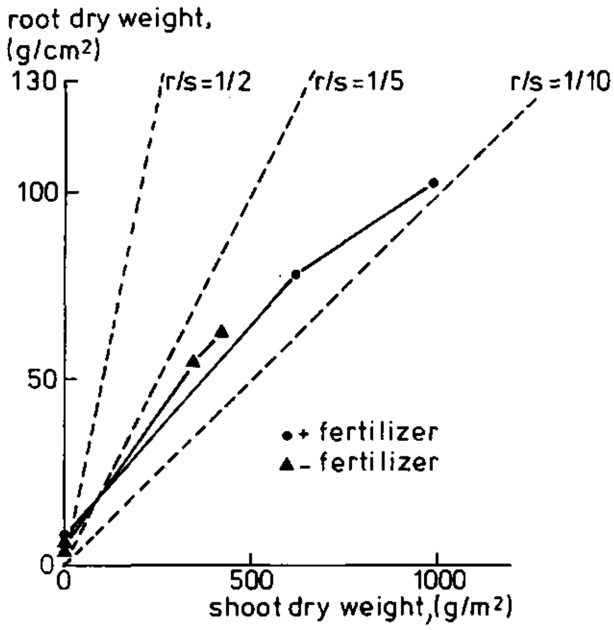


Figure 4.7. Relation between root and shoot growth of upland rice.

5. MAIZE/CASSAVA INTERCROPPING

5.1. Introduction

Roots and intercropping

Intercropping as practised by farmers in the tropics for centuries is an intensive production system, as it may increase land productivity through an efficient utilisation of space, soil moisture and nutrients, solar radiation and other environmental growth factors. Advantages to the farmer include: high and relatively stable yields, a better distribution of labour and production over the growing season, reduced adverse effects of pests and diseases and often a better protection of the soil from erosion. The main disadvantage is the limited possibility of using farm machines. Research aimed at improving intercropping systems by introducing new techniques has been slow (Richards, 1985) because of the complicated nature of intercropping, in which positive effects on one component often are accompanied by negative effects on others. The basic concept in an analysis of intercropping is that of reducing competition, "niche-specialisation" or complementarity of crops, as it can be studied in "replacement series" (De Wit, 1960).

The principles involved in the competition between root systems for water and nutrients are less thoroughly formulated than those involved in competition for light by shoots. Combinations of crops on the same field may give a better utilization of soil resources if (and in so far as) the root systems of the component crops are complementary in space and/or time, i.e. the root systems differ in soil layers exploited and/or in the period of highest uptake requirement. Root research of the component crops in a monoculture as well as in mixtures may help to understand competition for soil resources by the crops and help to develop planting techniques for the purpose of reducing competition and increasing the combined nutrient use efficiency.

Lal and Maurya (1982) studied the root system of important crops of the humid tropics in deep boxes filled with a sandy topsoil (figure 5.1). Root development of most crops under these favourable conditions was deep, with some interesting differences in root pattern among crops.

Maize showed the characteristic combination of a deep seminal root system with nodal roots extending horizontally before growing almost vertically into the soil. Cassava roots tended to concentrate in the topsoil, extending horizontally over considerable distances, although deeper soil layers were adequately rooted as well. The root distribution of yam was homogeneous throughout the box. Sweet potato and cowpea had most of their roots concentrated near the plant. As the authors remarked, root distribution in the field may differ considerably from the pattern found under their experimental conditions, depending on the soil profile. Adequate descriptions of root growth in the field are very scarce, however.

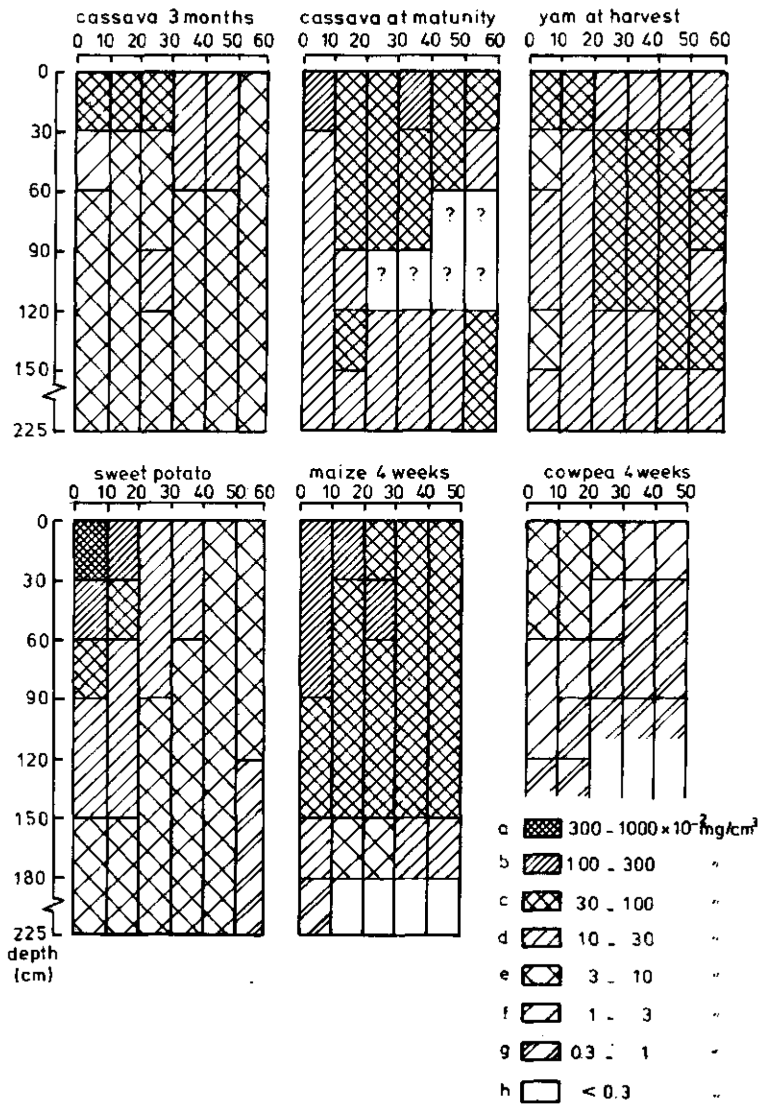


Figure 5.1. Root distribution in a box filled with topsoil (data from Lal and Maurya, 1982).

A considerable effort has been made recently in the semi-arid tropics to describe root development in grain/legume intercropping (pearl millet/ groundnut; Gregory and Reddy, 1982; Vorasoot, 1983). They showed that in combination with a relative yield total of more than 1.0 for above-ground production (1.1-1.3), the "relative root total" also exceeded 1.0 (1.0-1.2). Shoot:root ratios and nutrient uptake per unit root length appeared to be unaffected by intercropping. Lal and Maurya (1982) demonstrated the existence of a "relative root total" in excess of 1.0 in a cowpea/maize mixture.

Research on cassava/maize intercropping at Onne (van der Heide **et al.**, 1985) showed that cassava did not reduce maize yield when the two were intercropped, but cassava yields in intercropping were lower than in monoculture, especially when N fertilisation increased maize growth. Shading is obviously important but other microclimatic aspects can be relevant as well. The high humidity of the air inside closed crop canopies can give problems in maize (fungus diseases, germination of seeds inside the cobs). Local farming practice around Onne is to use a plant spacing which reduces such problems, by planting maize in small clusters in-between cassava, rather than as individual plants in rows which one would expect to be the best way to fully intercept all light. Planting maize in small clusters reduces adverse effects of rainstorms on young plants early in the season and results in a more open crop canopy reducing disease problems (the effect probably depends on the scale of the plots and the presence of "wind breaks"). A negative aspect of such a planting scheme might be, however, that the soil is exploited less efficiently by roots than by a regularly spaced crop. We decided to make regular root observations in an experiment in which nitrogen fertilisation was tested in three planting patterns as shown in figure 5.2.

5.2. Methods

Root observations were made in an experiment of the on-going N management project (experiment 3), in which the N reponse in different plant spacings is tested in a randomized block design with 3 replicates (two N levels: 0 and 60 kg N/ha, three maize spacings as shown in figure 5.2 and two cassava spacings: 1 and 2 m). Root observations were made in one of the replicates, gradually destroying half of the plot by digging soil pits, at a cassava spacing of 1 m.

The field was in the second year after manually clearing the secondary forest when the bulk density of top soil was still low (1.20 + 0.03 g per cm^3 (n = 4) as measured in rings of 5870 cm^3). All plots received basal treatments of 40 kg single superphosphate, 80 kg K as muriate of potash, 20 kg Mg as magnesium sulphate and 2 kg Zn as zinc sulphate per ha. These fertilizers were applied one day before planting (19 April). Urea as N source was applied in the relevant plots in two split applications of 30 kg N per ha each, 4 and 8 weeks after planting (17 May and 14 June).

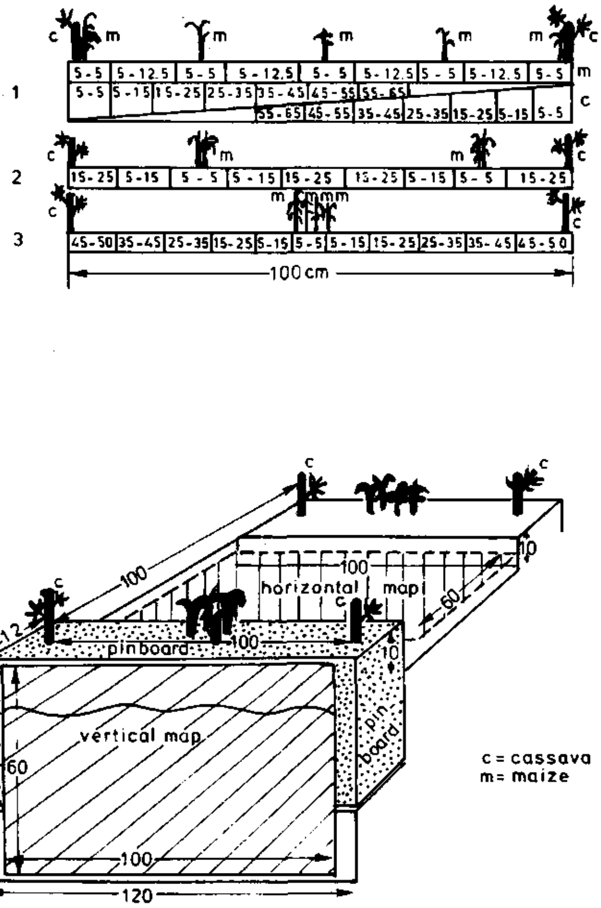


Figure 5.2. Schematic presentation of plant spacing and the position of pinboard sample and root maps.

Four maize seeds were planted per cluster for 1 m maize spacing, two seeds for the 0.5 m spacing and one for the 0.25 m spacing. Roots were sampled with a combined pinboard of 40 x 120 x 12 cm at 2, 5, 8 and 14 weeks after planting. After the sample was washed and photographed, it was cut per 10 cm depth and subdivided according to the distance to the plant, as shown in figure 5.2. For each subsample root dry weight and root length were recorded. Before a pinboard sample was taken a vertical root map was made of the soil profile (almost in the plant row) to a depth of 50 cm. After the pinboard sample was taken a horizontal map was made at 5-10 cm depth from about 15 to 65 cm from the plant row. Roots on the maps were counted on a 5 x 5 cm grid. From the final harvest some roots were collected for counting mycorrhizal infection as before. Above-ground production on each occasion was measured from an area of 2-4 m^2; samples were analysed for N concentration.

5.3. Results

Shoot growth and N uptake

Figures 5.3 and 5.4 show the time course of dry matter production and N uptake by maize and cassava. As the data are based on samples of only 2 m^2 interpretation is complicated by a large sample variation. In maize N uptake occurred in two periods, 2-5 and 8-14 weeks, with little uptake in-between. On the unfertilised plots initial uptake of mineralised soil N was fair (up to a total crop N content of about 10 kg N per ha after 5 weeks), but after 5 weeks uptake stagnated. After 14 weeks, the sampled plants from treatments 0.2 and 0.3 were rather exceptional in that they had no cobs (other plants in the plot had) and that the plot from which the 0.1 sample was taken, was exceptionally good (final yield of this plot was 50% above the average for the 3 replicates). The plant sampled from the 0.1 plot grew next to an old **Anthonata** stump in the plot, which may have allowed for a deep root development (although this was not included in the pinboard sample). Except for this last plot, the unfertilised maize started at an N concentration of approx. 2% and later decreased to approx. 1%. The fertilised plants at first also contained about 2% N. After 5 weeks they had taken up about 10 kg N per ha more than the unfertilised plants (from an N application of 30 kg N per ha). Between week 5 and week 8 hardly any nitrogen was taken up and the N concentration decreased to about 1%, apparently without effects on dry matter production rate which proceeded at about 75 kg DM per ha per day. The second split application of fertiliser N after week 8 (30 kg N per ha) resulted in a return of the internal N concentration to 2-2.5%. Total N uptake between week 5 and 8 was appr. 35 kg N per ha.

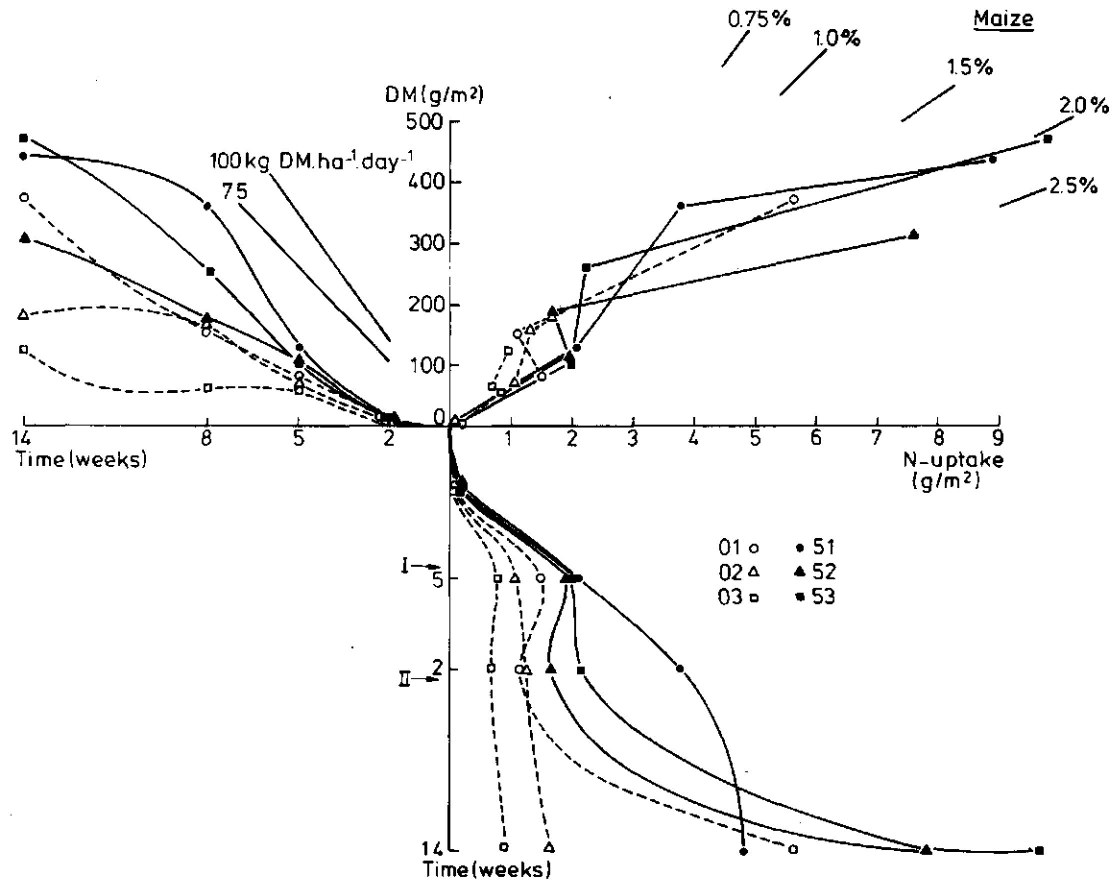


Figure 5.3. Above-ground dry matter production and N uptake by the maize component of the intercropping experiment.

The growth rate of cassava was much lower than that of maize in these first 14 weeks and was only approx. 15 kg DM per ha per day. The N concentration in the shoots was high at first (about 5%) but decreased later to 1.5-2%. N uptake occured in two periods, just as in the maize. Uptake between week 5 and 8 was very small. Fertilisation had little effect on N uptake. Total N content of the cassava crop after 14 weeks was about 20 kg N per ha.

Root growth

The general shape of the root systems of maize and cassava is shown in plates VI and VII. The maize roots were mainly restricted to the top 10 cm layer, while the cassava roots went deeper and extended well below those of the maize plants. A problem in sampling cassava roots with a pinboard is that roots are formed in certain sectors but not in others, giving either large or small amounts of roots in a pinboard, but never "average" values. Figure 5.5 suggests that planting scheme .1 gave a better utilisation of the soil, although maize roots in scheme .3 extended horizontally far enough to reach the cassava plants.

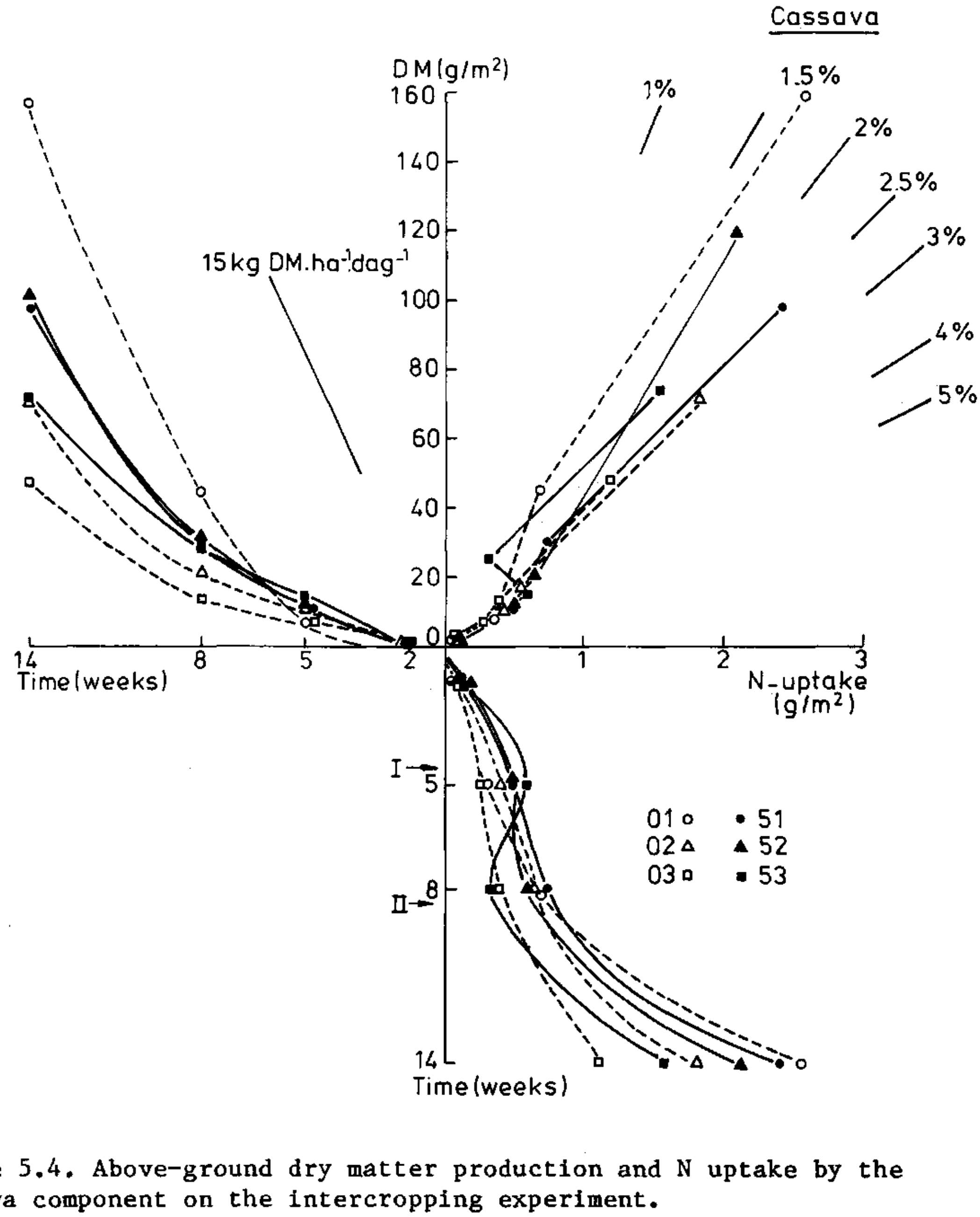
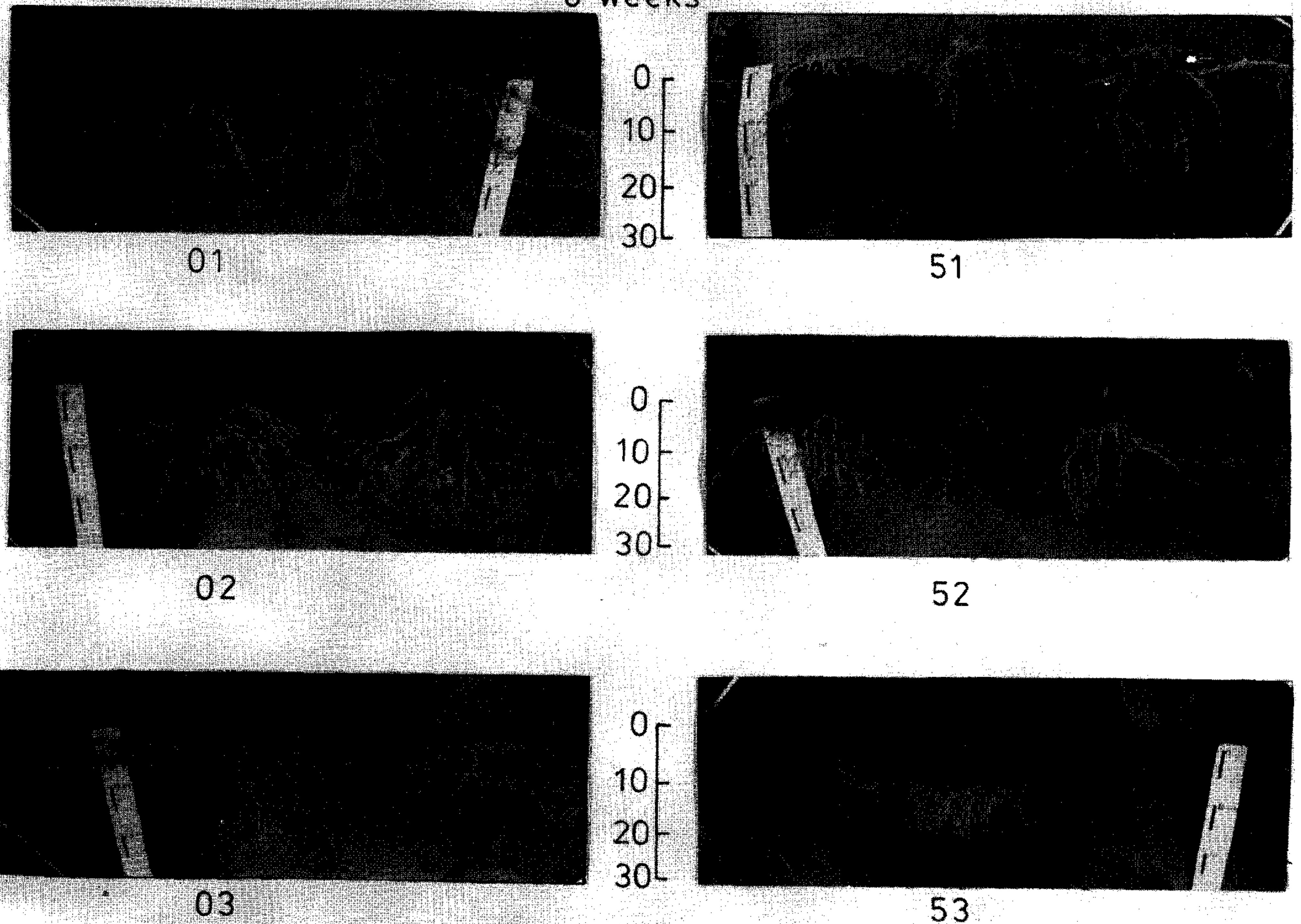


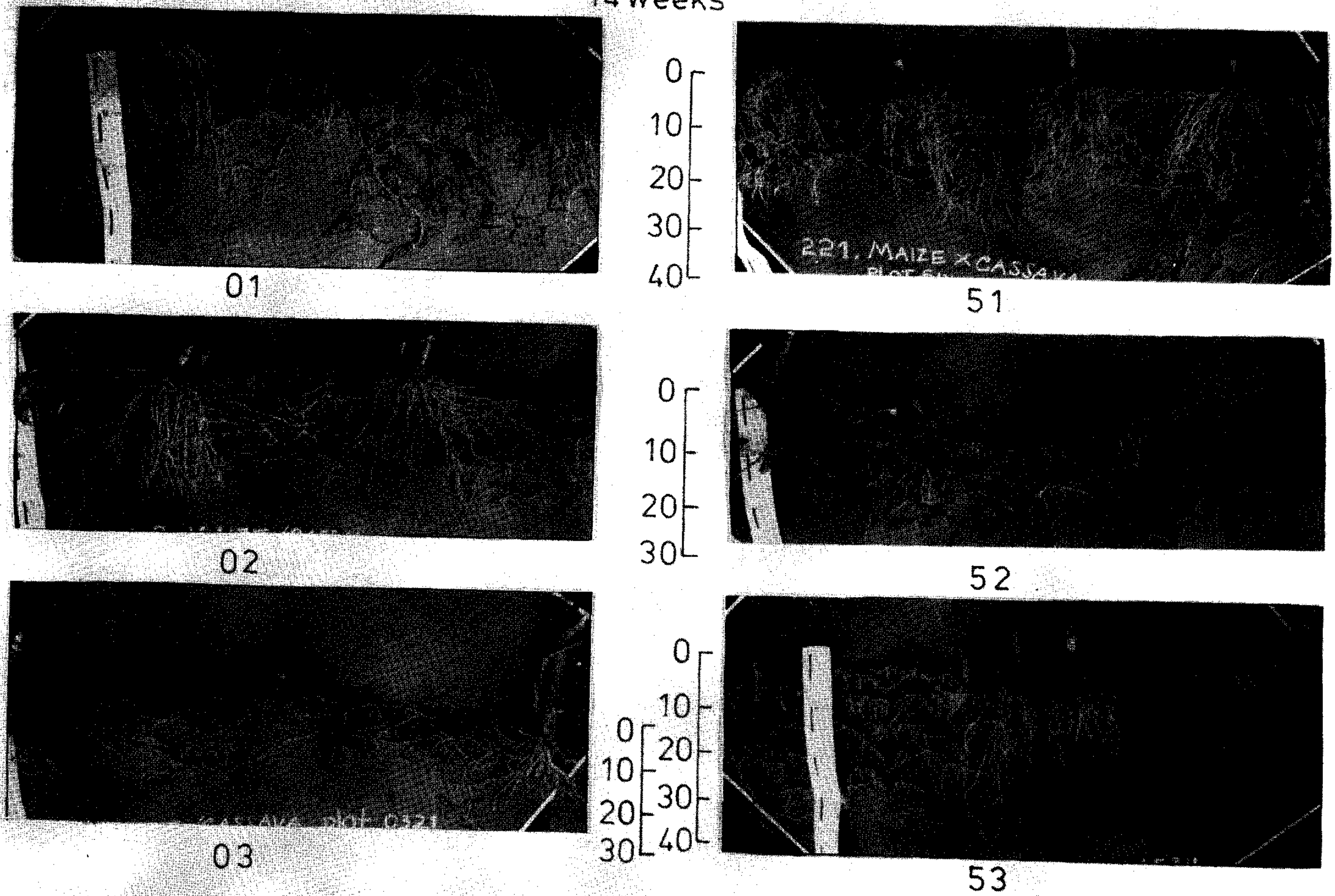
Figure 5.4. Above-ground dry matter production and N uptake by the cassava component on the intercropping experiment.

Plate VI and VII. Photographs of root systems of the intercropping experiment washed from pinboards.

8 weeks



14 weeks



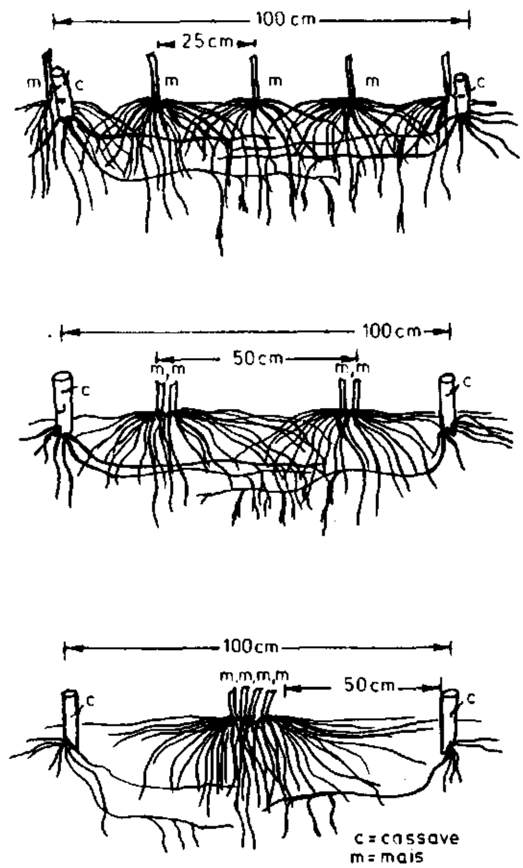


Figure 5.5. Schematic shape of the root system of maize and cassava for the three planting schemes.

Figure 5.6 quantifies root length distribution for maize and cassava. Details of distribution with regard to distance to the nearest plant are given in appendix 1 for every layer. Details of root weight distribution are given in appendix 2 and 3. Figure 5.6 shows that maize root growth almost stopped after 8 weeks; in the period between 8 and 14 weeks there was hardly any net root growth, while roots are gradually becoming brown and started to decay (especially on the fertilised plots). Specific root length (figure 5.7) decreased with time from appr. 8 to ca 2.5 cm per mg. In every soil layer the value first increased when the roots became more branched, but later decreased again when the fine roots started to decay. Fertilisation had no consistent effect on specific root length, but increased root length density in the topsoil from 1-4 cm per cm^3 to 2-6 cm per cm^3.

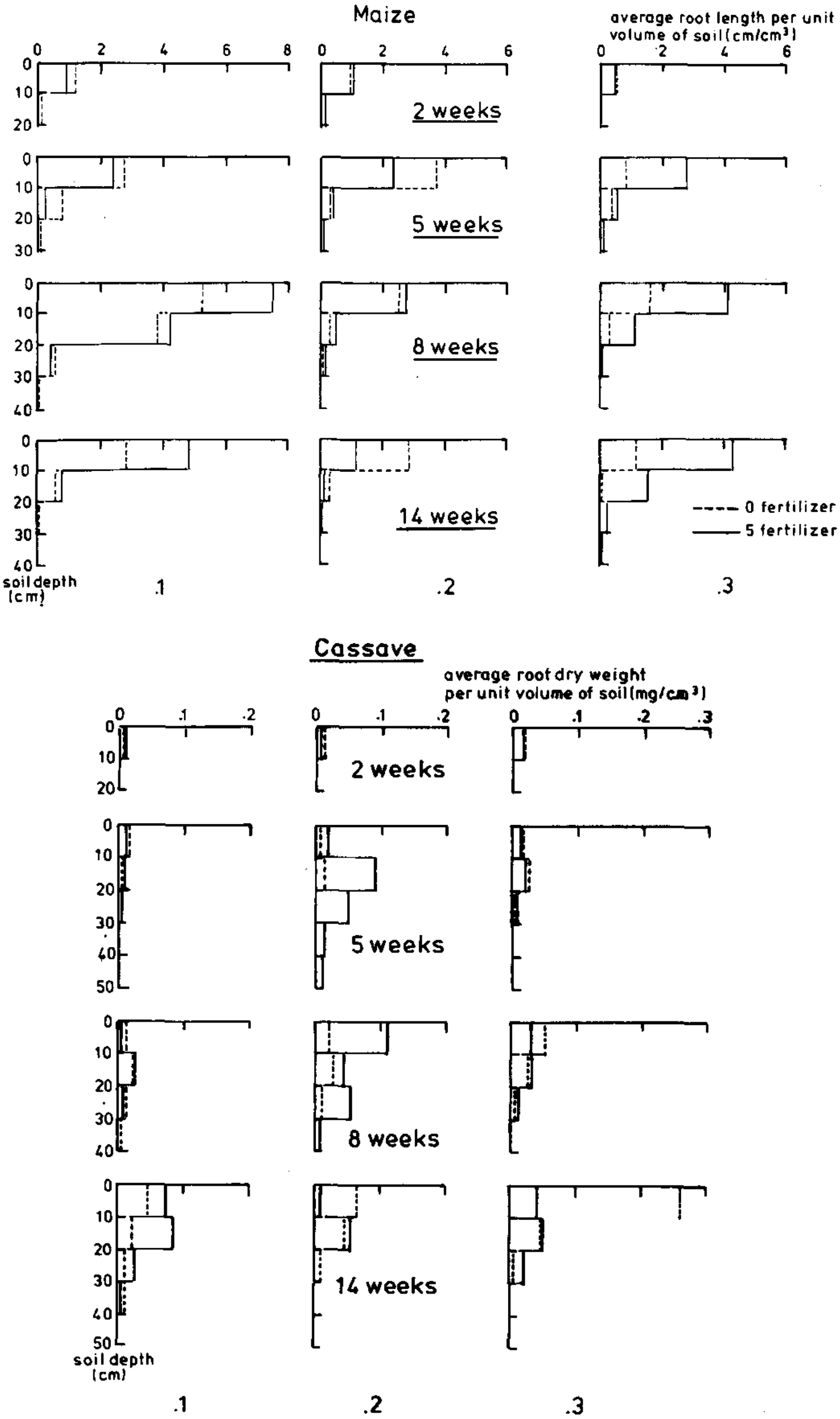


Figure 5.6. Root length density (averaged over postions near and in between plants) of maize as it develops in time in fertilised and unfertilised plots.

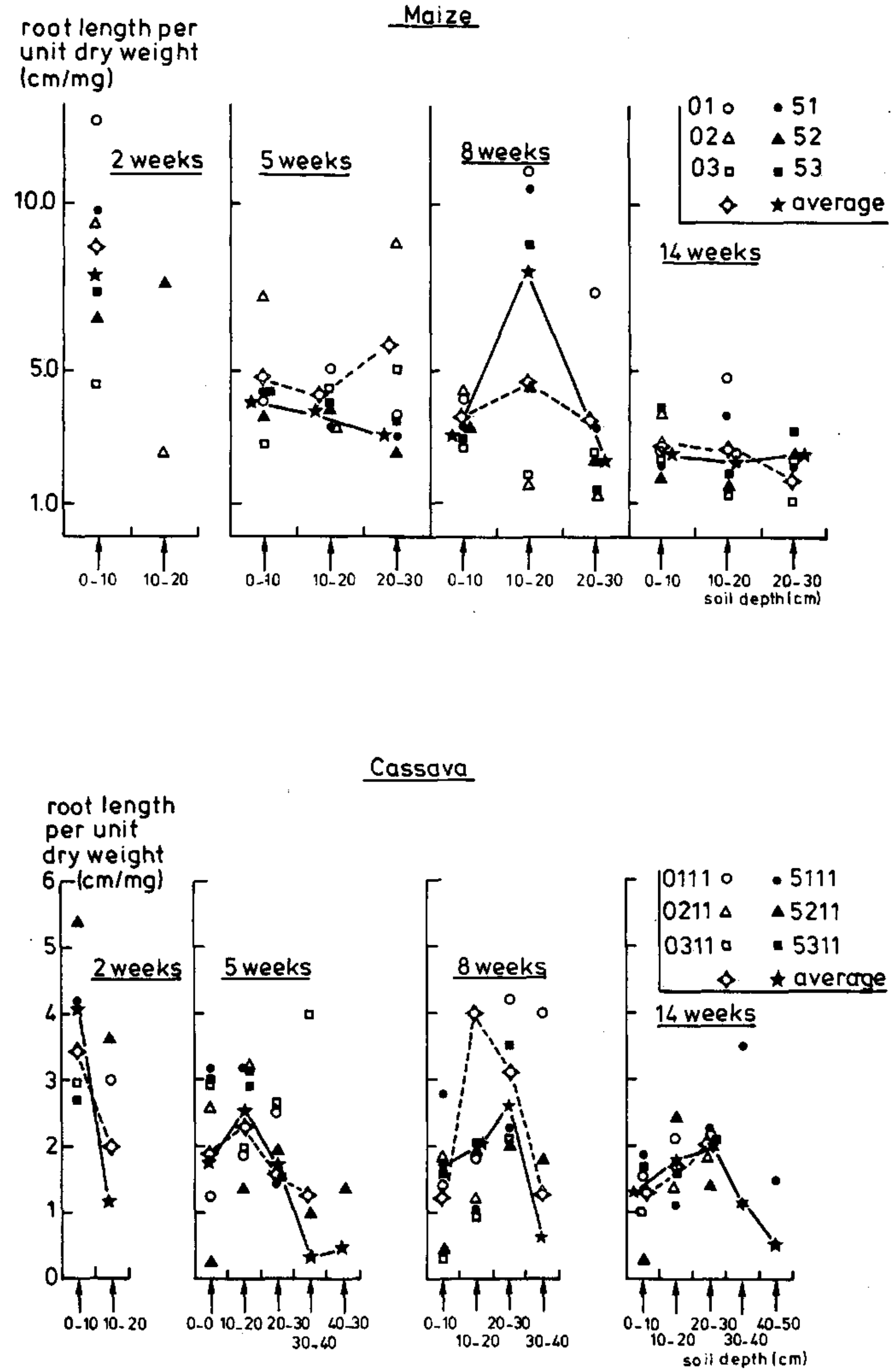


Figure 5.7. Specific root length (root length per unit dry weight) of maize (A) and cassava (B) for different soil layers.

In both fertilised and unfertilised plots there was little difference in root length density between positions near and in between plants for planting scheme 1, while there was a large difference for scheme 3 and an intermediate effect in scheme 2 (appendix 1). For cassava, root length density in the topsoil continued to increase over the 14-week period. Root length density after 14 weeks was still lower than that of maize by a factor 10 (figure 5.6.B), but root density was more constant over the top 30-cm layer, with some roots extending to 40 cm depth. In all soil layers root density decreased with distance from the plant. At 45-55 cm from the plant cassava root length density was about half the average for the whole soil layer. Fertilisation had no consistent effects on root distribution, total root length or specific root length in cassava. Specific root length decreased over the season from circa 3.5 to appr. 1.5 cm per mg.

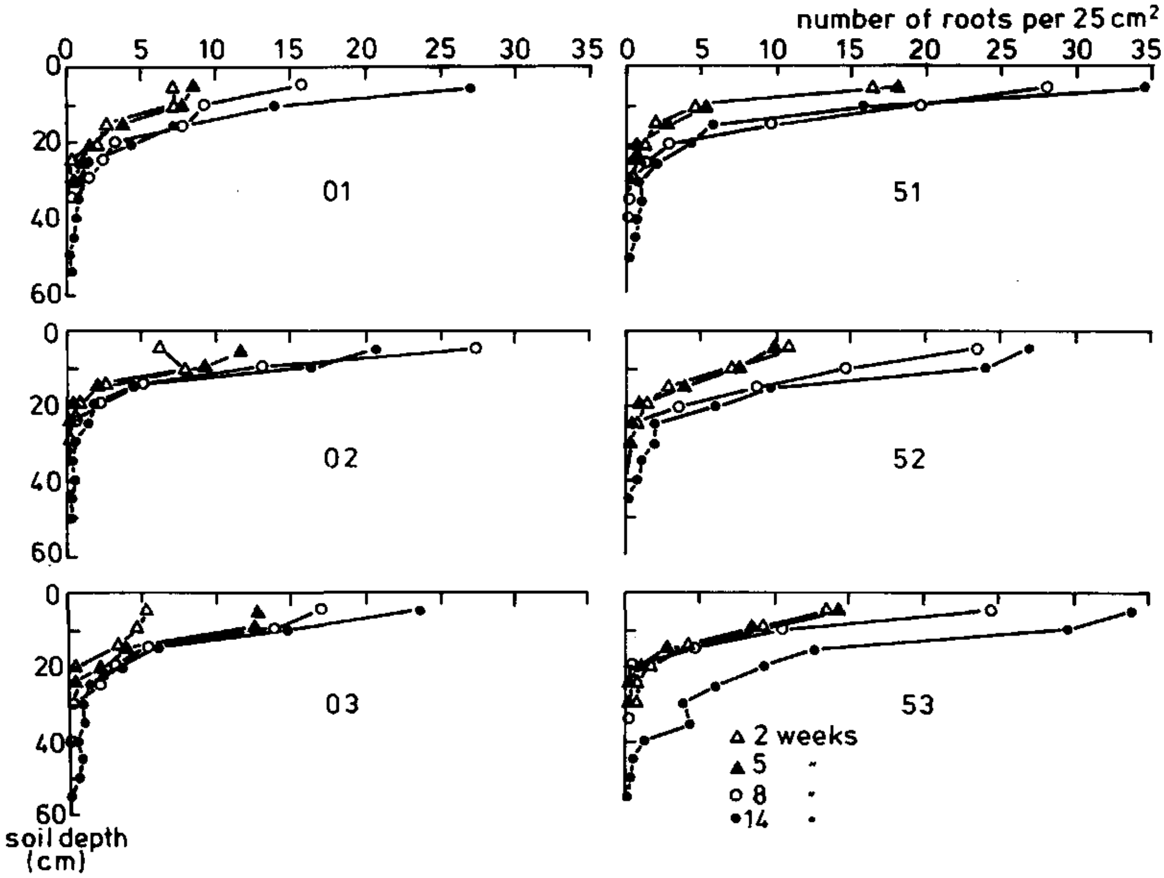


Figure 5.8. Average root density system seen on vertical root maps (number of roots seen per 5 x 5 cm^2).

Results for the vertical root maps are shown in figures 5.8 and 5.9. Total root density on these maps increased steadily with time at all depths. Overall root density on the maps was higher in the fertilised plots. The general pattern confirms the data for maize in figure 5.6.A, as maize had by far the highest root length density.

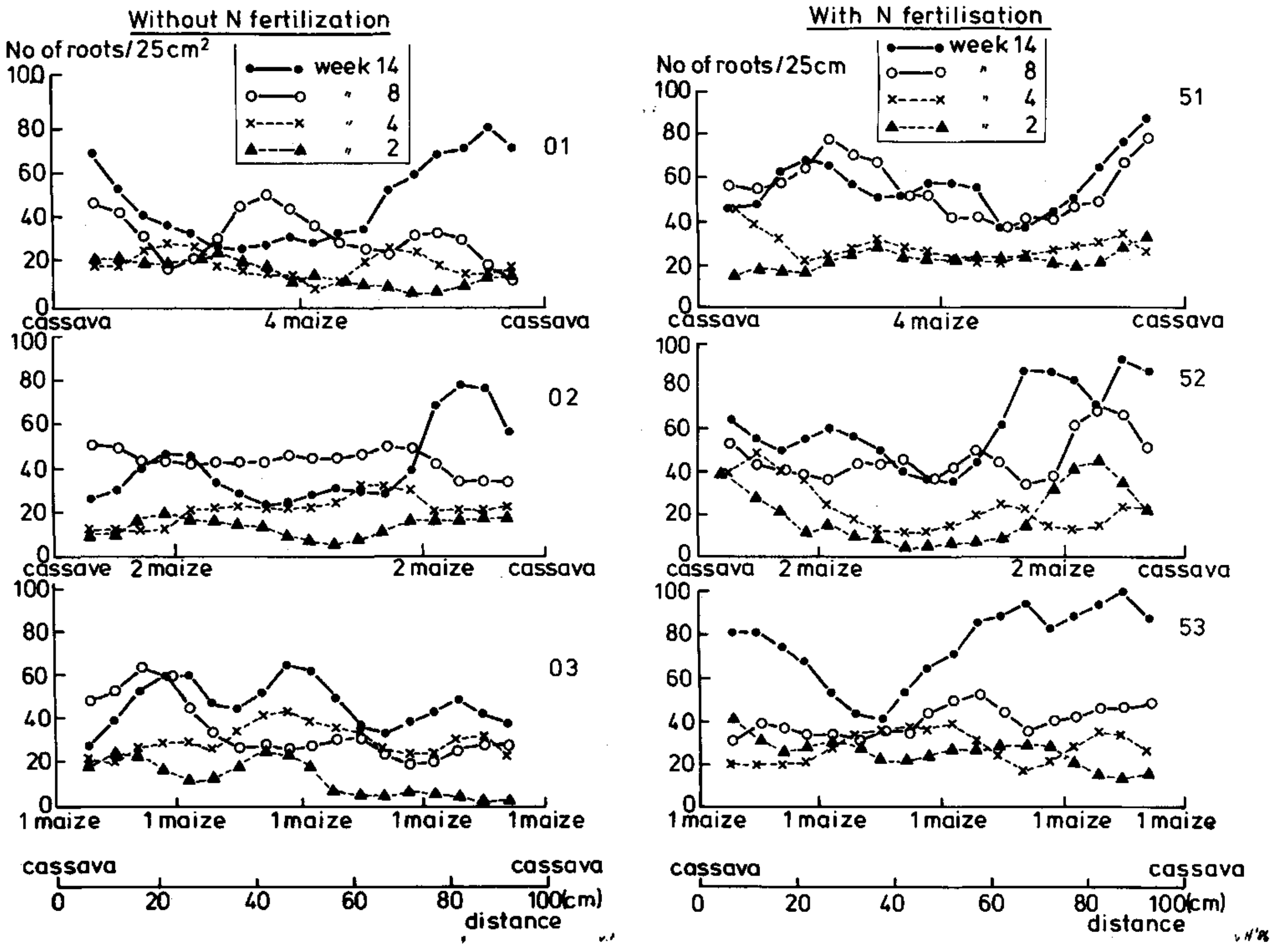
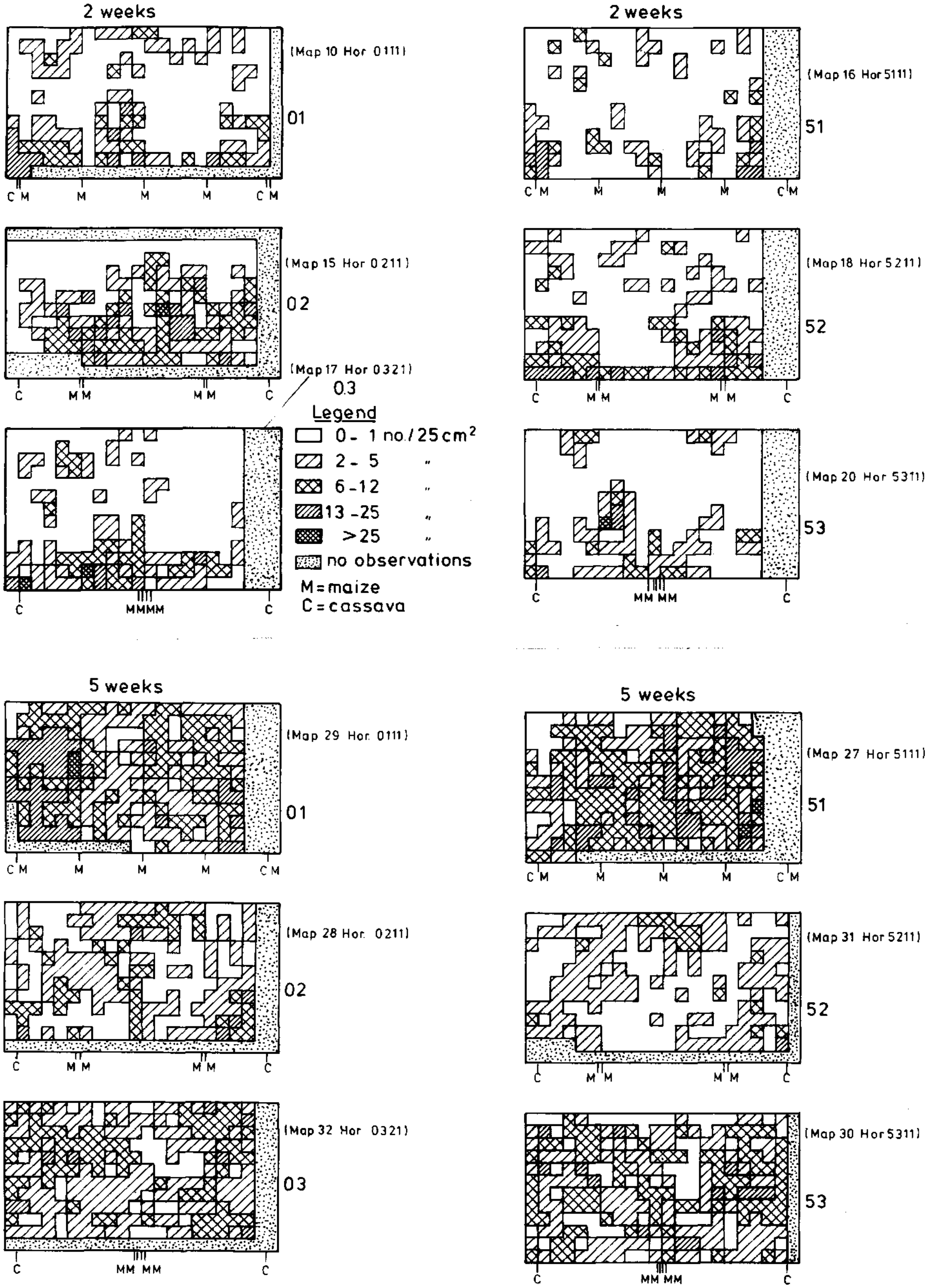


Figure 5.9. Distribution of roots in top soil (0-20 cm) on vertical root maps, according to distance to the plants.

Results for the horizontal root maps are shown in figure 5.10 and 5.11. After 2 weeks more than 50% (average 64%) of the space in between plant rows still was not covered by roots (0 or 1 root per 25 cm^2).


2 weeks
(Map 10 Hor 0111)
01
C M
M
M
M
C M
(Map 15 Hor 0211)
02
C
M M
M M
C
(Map 17 Hor 0321)
03
C
MMMM
C
Legend
0 - 1 no./25cm²
2 - 5 "
6 - 12 "
13 - 25 "
>25 "
no observations
M = maize
C = cassava
2 weeks
(Map 16 Hor 5111)
51
C M
M
M
M
C M
(Map 18 Hor 5211)
52
C
M M
M M
C
(Map 20 Hor 5311)
53
C
MM MM
C
5 weeks
(Map 29 Hor 0111)
01
C M
M
M
M
C M
(Map 28 Hor 0211)
02
C
M M
M M
C
(Map 32 Hor 0321)
03
C
MM MM
C
5 weeks
(Map 27 Hor 5111)
51
C M
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53
C
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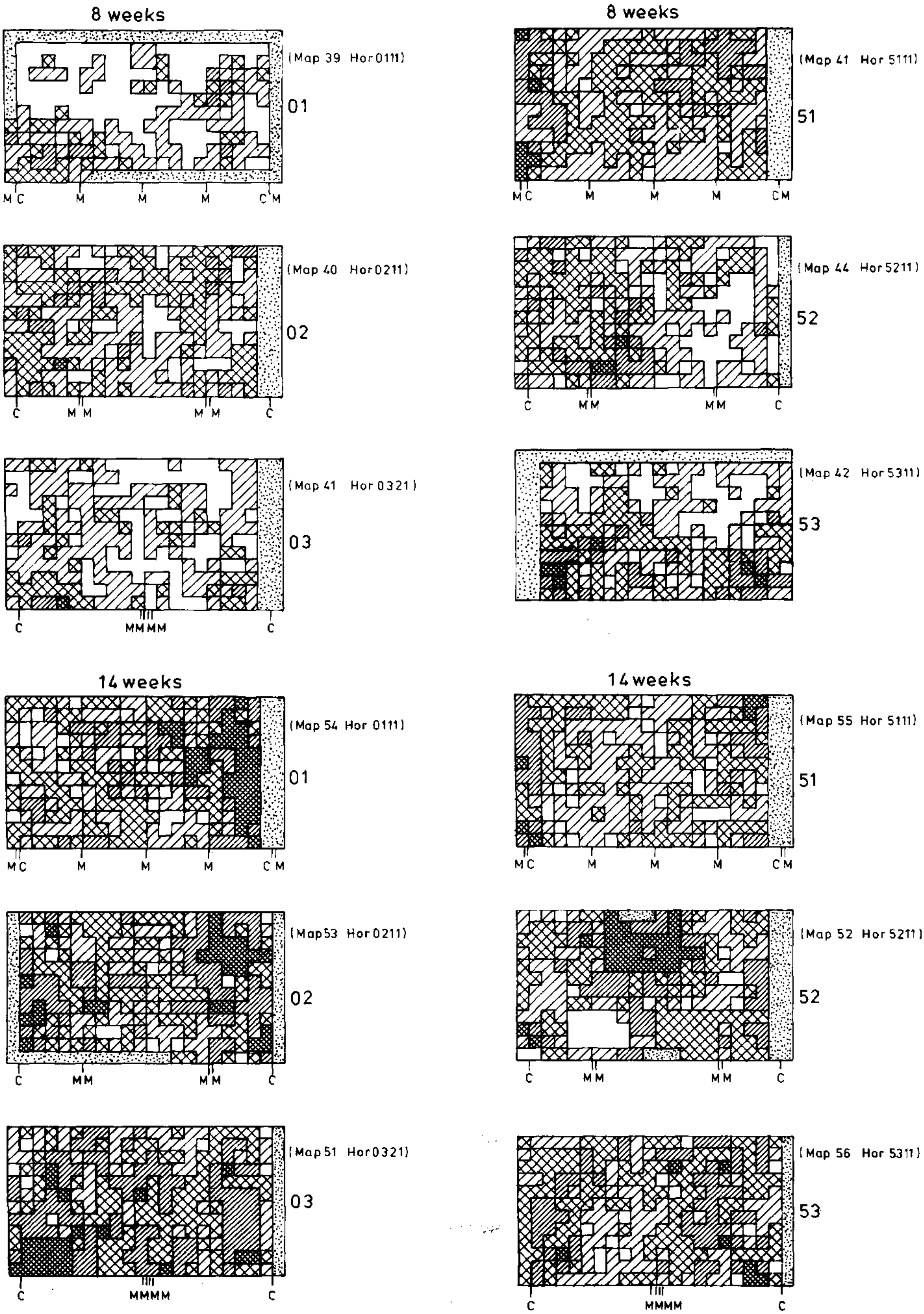

Figure 5.10. Distribution of roots on horizontal maps at 5 - 10 cm depth.

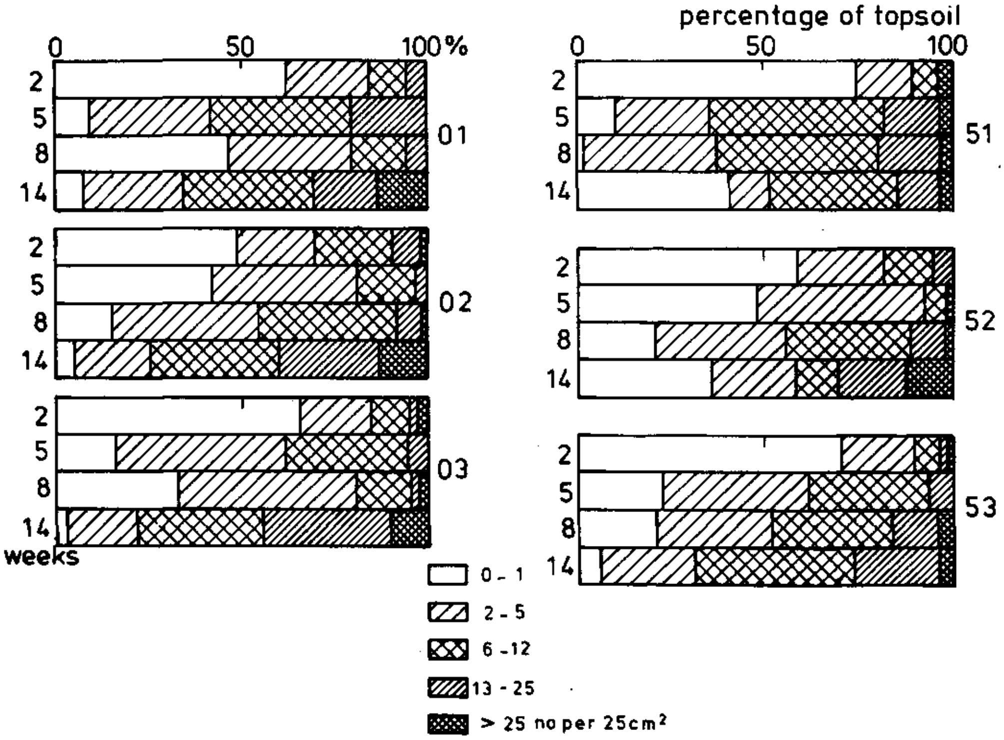

Figure 5.11. Frequency distribution of root density on horizontal root maps.

After 5 weeks on the average 25% of the area still had not been reached by roots. The results were rather variable, possibly because there can be a sharp decrease of root density in the range of depths in which the map was made (5-10 cm depth). In the last observation no fixed criterion was used whether or not to include decaying maize roots. No consistent effects of planting pattern or fertilisation emerges, although especially after 5 weeks the .1 planting scheme gave the most even distribution of roots.

Figure 5.12 shows cassava root distribution at harvest time, at the end of the dry season, planted in the previous year. Compared to the observations in maize/cassava after 14 weeks, the root density in the topsoil was lower, while root density in the subsoil was slightly higher (roots penetrate below 60 cm, especially in old tree root channels, compare plate I). Apparently cassava root density in the topsoil gradually increased after the maize harvest, while root development in the subsoil continued slowly. N fertilisation had little effect on cassava root distribution (deep root development was slightly better in the fertilised plots). Horizontal distribution of roots in both topsoil and subsoil was fairly homogeneous.

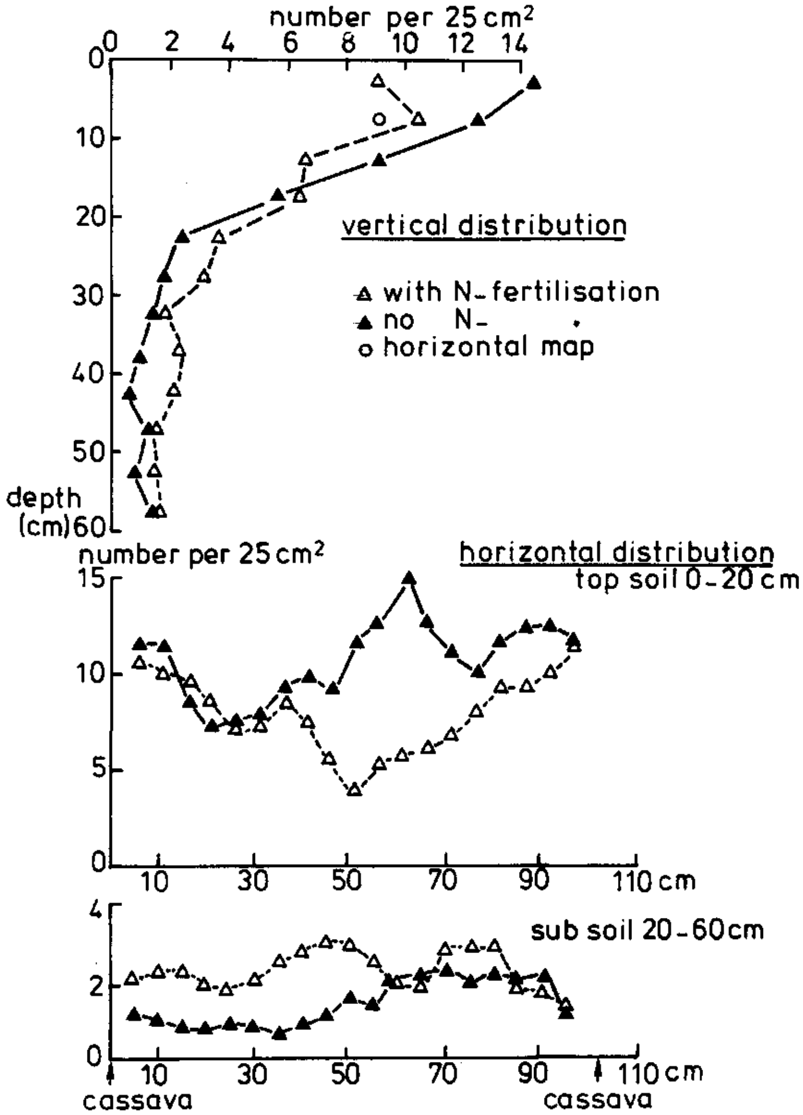

Figure 5.12. Results of vertical root map for one year old cassava.

Mycorrhizal infection

Mycorrhizal infection (table 5.1) of both maize and cassava was high compared to the results for cover crops. N fertilisation had a negative effect on mycorrhizal infection in the topsoil, but a positive effect in the subsoil.

TABLE 5.1. Mycorrhizal infection (% of root length) 14 weeks after planting.

Depth	Maize		Cassava	
	0N	60N	0N	60N
0-15 cm	42.7	3.9	31.8	33.9
15-30 cm	19.2	32.1	53.3	32.9

5.4. Discussion

The root distribution of maize and cassava appears to be complementary in both space and time, which makes positive results in intercropping understandable. Cassava roots extend somewhat deeper into the soil and develop later in the season, giving the maize the opportunity to exploit the topsoil and the mineralisation flush at the beginning of the rains. The root density of cassava in the topsoil remained low until after the harvest time of the maize. This pattern may explain the relatively high recovery of fertiliser N in cassava found in fertilisation experiments (Van der Heide **et al.**, 1985).

Although average root density in the topsoil was high, considerable "gaps" without roots existed in the horizontal plane. It is possible that roots were present in the layer just above or just below the horizontal root map, but so far the gaps probably indicate that nitrogen mineralised in this volume of soil will not be intercepted and may leach to the subsoil. A root density of 2-5 per 25 cm^2 on the root map (roughly equivalent to a root length density of 0.16 - 0.4 cm per cm^3) can be just sufficient to take up all available nitrogen when it is present in the ammonium form (De Willigen, 1985).

The three planting schemes tested in this experiment showed some differences in rooting pattern, but less so than expected. Horizontal spread of maize roots from the cluster of plants in scheme .3 allowed exploitation of a large part of the topsoil, although somewhat later than in scheme .1.

Fertilisation increased root development in the topsoil, but had little effect on rooting depth. The time course of N uptake by the crop suggests that the second split application of N came just in time to prevent serious shortage of N in the crop. The factors involved in the good growth of unfertilised maize near old **Anthonata** stumps, deserve further study.

TABLE 5.2. Cassava and maize yields on experiment 3 (average for three replicate plots per treatment) in 1985 (Cassava planted in 1984, maize sown in 1985) (unpublished data kindly supplied by Ir. A.C.B.M. van der Kruijs).

	Cassava '84/'85 tuber freshweight, ton/ha		Maize '85 grain, kg/ha	
N-fertilisation (kg/ha):	0	60	0	60
cassava spacing 1 m				
maize 25 cm	29.5	30.2	643	1893
50 cm	32.8	31.9	546	1708
100 cm	32.2	28.2	540	1555
average	31.5	30.1	576	1719
cassava spacing 2 m				
maize 25 cm	24.0	25.1	542	1845
50 cm	28.6	29.2	771	1825
100 cm	24.9	25.7	648	1835
average	25.8	26.7	654	1835
cassava at 2 m / cassava at 1 m	0.78	0.84	1.14	1.07

Data of above-ground production in experiment 3 (table 5.2) show that neither the planting scheme nor N fertilisation had effect on cassava yields (1984 planting); halving plant density decreased cassava yields by 22% on unfertilised and 16% on fertilised plots. In 1985 N fertilisation was necessary to obtain reasonable maize yields in experiment 3. The planting scheme probably had some influence on maize yields for the 1 m spacing of cassava, but not for the 2 m spacing. Maize yields were 14 and 7% higher when cassava plant density was halved on unfertilised and fertilised plots respectively. The fact that the interference between maize and cassava decreases with N fertilisation suggests that competition for soil N rather than other factors such as competition for light is the main process on unfertilised plots (competition for light becoming more important both in absolute and in relative sense when fertiliser is applied and total production levels rise). Further discussion will be possible when yield and light interception data for the experiment as a whole will be available.

6. ALLEY CROPPING

6.1. Introduction

Root systems of alley cropping trees

Huck (1983) gave a summary of root distribution in relation to agroforestry and commented that little information is available on functional root parameters such as root length or root surface area. Nair **et al.** (1984) reviewed the suitability of a large number of tree species for agroforestry in different climatic zones, but gave little information on root development. Some data can be found in the work of Coster (1932, 1933a,b, c.) The opening sentence of one of his articles still seems to be valid: "Until thirty years ago research on the mutual influence of plants in a community (forest, arable land, meadows etc.) has mainly, if not exclusively, been directed at above-ground organs; mutual shading was studied especially. During the last ten years many researchers have become aware that below-ground organs are at least as important in this respect as above-ground organs." This statement can be compared to Howard's (1924) conclusion that "it is remarkable ... that no detailed information of the distribution of root activity during the year is available. Nevertheless it is clearly essential in the ecological studies of the future." Howard described root systems of several tropical (Indian) fruit trees, in a deeply weathered soil as consisting of both a deep tap root system and a superficial branch root systems.

Coster studied the suitability of large numbers of trees as green manures for integration into teak plantations. His first publication (1932) deals with the root system after six months of growth on a deep, homogeneous, red-brown volcanic soil. We may classify the root systems described by Coster into three groups: I. Deep penetration, few superficial branch roots, II. Deep penetration, many superficial branch roots and III. Shallow root systems with a large horizontal spread. Figure 6.1 shows two examples of each type. As can be seen from table 6.1, group I contains only relatively slow growing trees, with a root:shoot ratio of 2.5:1 to 1:2.5. Group II contains many faster growing trees, with a root:shoot ratio of 1:2 to 1:6. By far the deepest root penetration and

TABLE 6.1. Classification of tree species according to the shape of their root system after 6 months (based on data of Coster 1932, nomenclature and spelling of local names not modernised).

Family	No	Scientific name	Local name	1 shoot height m	2 shoot dry weight g	3 root: shoot (dry-weight)	4 main root length m	5 no. of branch roots > 1 m	6 branch :main root length	7 root system at later stage
Group I. Deep root system, few superficial roots, relatively slow growth										
Moraceaea	5	Artocarpus integra	Nangka	1.6	35	0.34	1.9	-	2.3	
Leguminosae	8	Albizzia lebbeck	Tekik	0.8	14	1.9	3.0	-	2.6	
	9	A. lebbeckioides	Kedinding	0.5	8.3	2.5	2.6	1	1.5	II
	12	Acacia leucophlaea	Pilang	0.8	11	0.70	1.9	1	2.6	
	17	Tamarindus indica	Asem	0.5	16	0.83	2.3	-	0.38	
	20	Bauhinia purpurea	Tajoeman	1.3	35	0.45	2.6	-	0.36	
	21	Cassia fistula	Trenggoeli	0.6	18	1.9	2.2	-	1.0	
	35	Dalbergia latifolia	Sonokling	0.5	17	1.1	2.3	-	3.1	I
	36	D. sissoo	Sono sissoo	1.4	36	0.47	3.5	-	0.54	
	37	Pterocarpus indica	Sono kembang	1.1	42	0.51	2.0	1	2.0	
Meliaceae	42	Swietenia humilis	-	0.3	31	0.39	2.1	-	1.1	
	46	S.macrophylla	Grootblad mahony	0.3	22	0.49	1.9	-	1.6	II
	46	Azaridachta indica	Mimba	0.8	25	0.55	1.8	-	1.7	
Euphorbiaceae	47	Hevea brasiliensis	Rubber	1.7	74	0.44	2.0	1	2.2	
Anacardiaceae	48	Gluta renghas	Rengas	1.2	42	0.43	2.1	-	2.2	
Sapindaceae	50	Schleichera oleosa	Kesambi	0.2	12	0.99	2.0	-	0.49	I
Group II. Deep root system, many superficial roots, relatively fast growth										
Leguminosae	6	Enterolobium saman	Regenboom	1.0	67	0.55	2.7	3	3.0	
	7	Albizzia falcata	Sengon laoet	2.2	450	0.27	2.4	9	8.2	II
	10	A. procera	Weroe	1.2	130	0.39	3.2	7	3.3	II
	11	Acacia villosa	-	2.0	120	0.25	1.8	8	7.3	I/II
	14	Leucaena glauca	Kemlandingan	0.9	56	0.54	2.4	4	3.1	I/II
	15	Adenanthera microsperma	Segawe	1.0	69	0.25	2.4	4	5.3	
	25	Cassia siamea	Djohar	0.8	240	0.27	3.4	6	4.8	II
	29	Indigofera galegoides	Marmojo	1.3	68	0.15	1.9	7	8.9	
	31	Tephrosia maxima	-	0.6	190	0.15	2.9	2	2.8	
	32	T. vogelii	-	1.2	500	0.22	2.9	8	5.6	
	33	Sesbania sesban	Djajanti	3.6	2400	0.18	4.4	15	6.7	
Meliaceae	45	Melia azadarach	Mindi	1.7	560	0.56	3.2	12	11	
Sterculiaceae	55	Melochia umbellata	Senoe	1.0	210	0.27	2.7	8	6.6	
	56	Guazuma ulmifolia	Djati londo	0.7	68	0.41	2.8	2	3.5	
	58	Kleinhovia hospita	Ketimono	0.8	56	0.54	2.6	7	4.5	
Lythraceae	61	Lagerstroemia speciosa	Woengoe	1.1	67	0.33	2.2	1	7.2	III
Myrtaceae	64	Eucalyptus alba	-	1.5	210	0.24	2.6	7	5.4	
Verbenaceae	69	Vitex pubescens	Laban	0.3	18	0.70	2.7	4	4.8	III
Group III. Shallow root system, many superficial roots, various growth rates										
Leguminosae	13	Acacia oraria	-	0.5	12	0.26	1.6	3	4.3	
	16	Adenanthera pavonina	Segawe sabrang	1.0	48	0.19	1.3	1	3.5	
	19	Bauhinia malabarica	Kendajahan	0.7	16	0.58	1.6	1	4.5	
	22	Cassia leschenaultiana	-	0.9	130	0.10	-	3	.	
	23	C. occidentalis	Senting	1.2	120	0.14	1.7	-	3.6	
	24	C. pumila	Entjeng 2	0.9	410	0.03	1.0	1	5.0	
	26	C. tora	Katepeng	0.4	32	0.15	1.2	2	5.6	
	27	Crotalaria anagyroides	-	1.7	490	0.24	1.0	8	6.9	
	30	Tephrosia candida	-	1.5	580	0.14	1.6	7	7.2	
	34	Aeschynomene americana	-	1.6	56	0.11	-	-	.	
	39	Flemingia strobilifera	Opo 2 kebo	0.9	200	0.21	1.7	6	8.1	
Anacardiaceae	49	Semecarpus heterophylla	Ingas tjelik	0.5	15	0.62	1.3	-	2.2	
Malvaceae	52	Thespesia lampas	Kemien	1.1	470	0.21	1.5	10	9.3	
Bombacaceae	53	Ceiba pentandra	Kapok	0.7	18	0.48	1.6	4	4.7	
	54	Ochroma lagopus	Balsa	0.8	110	0.40	1.3	11	18	
Bixaceae	59	Bixa orellana	Kasoemba keling	0.6	47	0.24	1.6	2	3.4	I
Flacourtiaceae	60	Homalium tomentosum	Delingsem	0.8	100	0.36	1.4	1	8.2	III
Myrtaceae	63	Tristania conferta	-	0.6	37	0.16	1.3	2	4.3	
Verbenaceae	66	Lantana camara	Temblekan	1.2	640	0.11	1.4	13	17	
	67	Tectona grandis	Djati	0.3	45	0.51	1.4	2	6.8	III
	68	T. hamiltoniana	-	0.5	12	0.37	1.5	-	2.8	

the highest shoot production was found is **Sesbania sesban.** Group III contains several shrubs and green manures, some with a considerable shoot production, with a low root:shoot ratio (1:2 to 1:30).

The most desirable root distribution for inclusion in mixed cropping, type I, seems to occur only in plants which establish themselves rather slowly. Figure 6.2 shows the relationship between length of the main root (which may serve as an indication of rooting depth), number of branch roots of more than 1 m in length (which is an indication of horizontal root extension in the topsoil) and shoot dry matter production for all individual trees described by Coster (1932). "Ideal" trees, open symbols in the upper right hand corner, apparently do not exist.

Later root development, as described by Coster (1933a), may be somewhat different: some trees of group I develop an extensive horizontal root system as well (**Albizzia lebbeckioides, Swietenia macrophylla**); some trees of group II can later be classified as belonging to group I, as the main, deep roots become the dominant aspect (**Leucaena** and to a lesser extent **Acacia villosa**); some trees of group II develop still more superficial roots (**Lagerstroemia, Vitex**) and one tree initially in group III forms a type I root system in later stages (**Bixa**). Early root development apparently cannot be considered indicative of that in later stages, although some correlation remains. According to Coster **Leucaena** is the most suitable tree for mixed cropping, due to its deep root development, especially at later stages. He considered **Gliricidia sepium** (not included in this study) to be a suitable tree as well. His observations were in agreement with a study of Keuchenius (1927) of trees used as shade trees in tea plantations. Data of Keuchenius have been summarised in figure 6.3.

For most tree species 50% of the root mass is found in the top 50 cm and 70% in the top 100 cm. For **Leucaena** this is 30 and 50%, respectively. Apart from a paper by Dijkman (1950) these trees seem not to have been studied after the second World War untill the 1970's, when interest in agroforestry was revived and new **Leucaena** varieties with a high growth rate and N-binding capacity were selected (National Research Council, 1984).

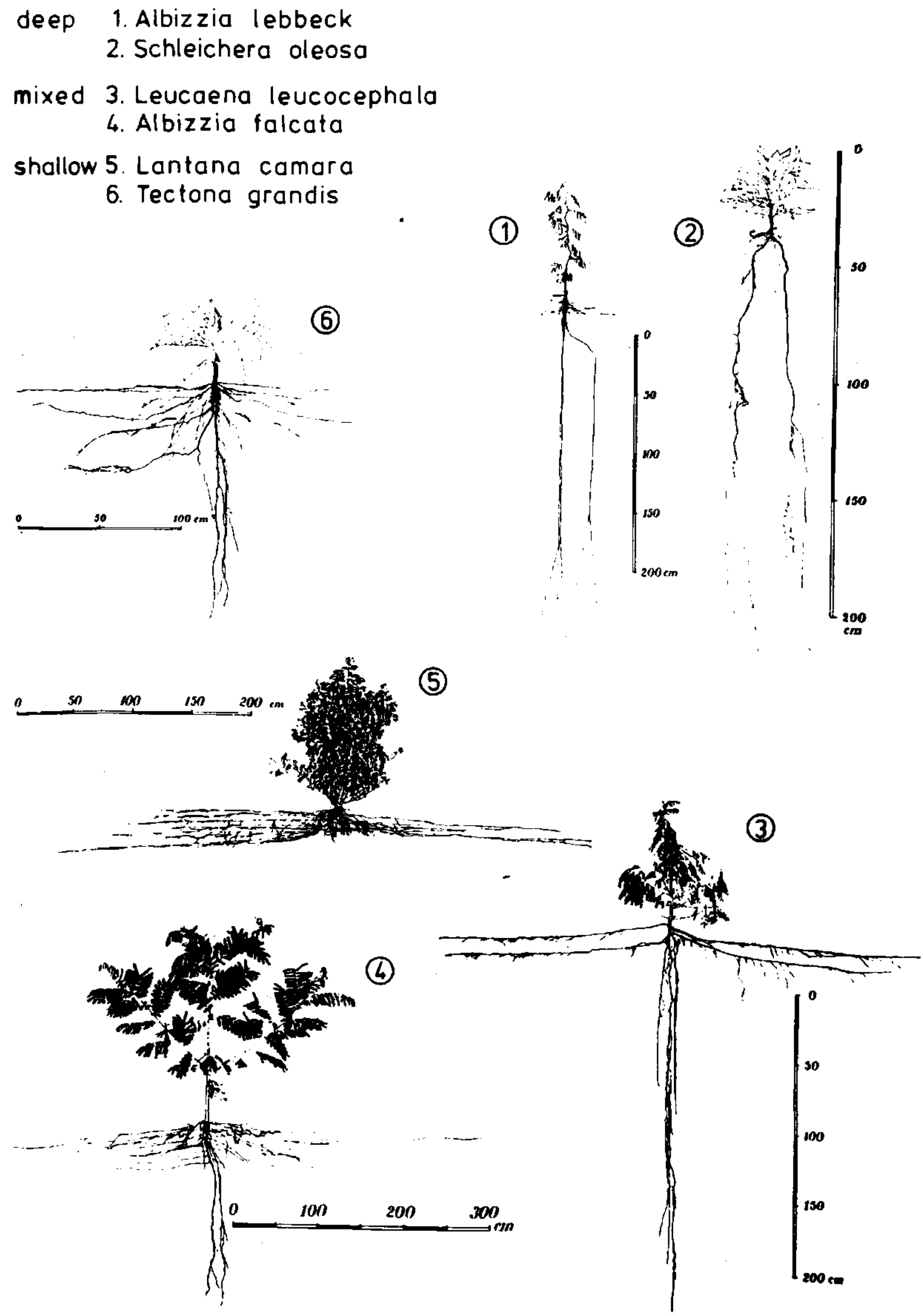

Figure 6.1. Exemples of tree root systems after 6 months by Coster (1932): group I. 1. **Albizzia lebbeck**, 2. **Schleichers oleosa**, Group II: 3. **Leucanea leucocephala**, 4. **Albizzia falcata**, Group III. 5. **Lantana camara**, 6. **Tectona grandis** (teak).

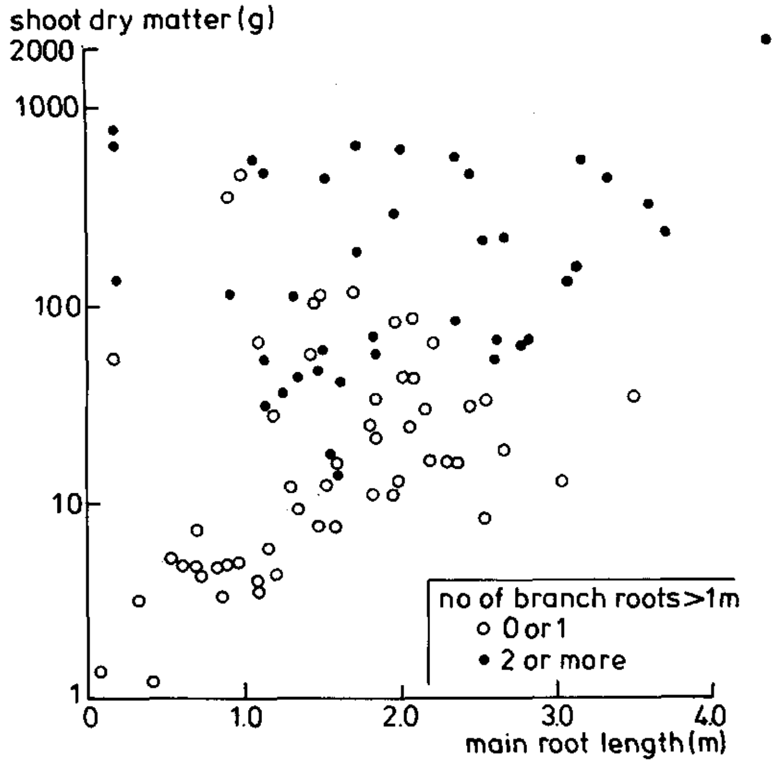

Figure 6.2. Relation between rooting depth, horizontal spread of roots and above-ground dry matter production of trees after 6 months by Coster (1932).

Agboola **et al.** (1982) have described how **Gliricidia sepium**, which had been introduced into Nigeria as a fence (hedge) species, was discovered by unknown Nigerian farmers as a suitable species to be included in mixed cropping, especially as a companion to yam, which can climb its stem. Agboola **et al.** commented that the leguminous **Gliricidia** improves soil fertility as well. Cole (1983) investigated root development of agroforestry trees at the IITA main station at Ibadan. His data are summarised in figure 6.4.

Leucaena and **Gliricidia** are deep-rooted, while **Acioa** and especially **Alchornea** have rather shallow root systems and extend horizontally well into the area reserved for growing arable crops. The fact that **Alchornea**, which is a common pioneer tree in secondary succession of bush fallows, has a very superficial root system seems to conform to a general pattern as can be derived from Kahn (1978) (figure 6.5).

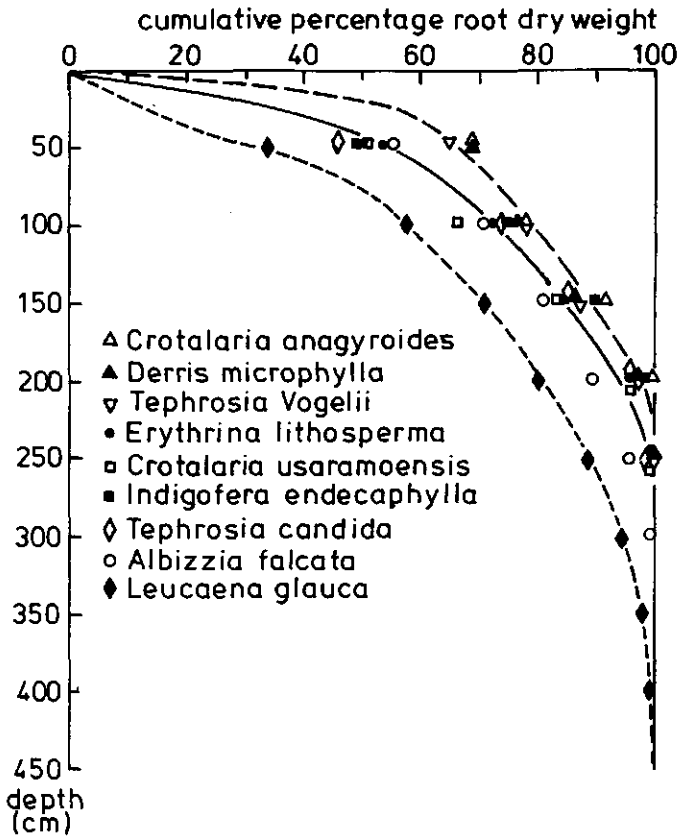

Figure 6.3. Root distribution of leguminous trees in tea plantations in Indonesia (data from Keuchenius, 1927).

This effect is also reflected in the overall distribution of tree roots under secondary forest (figure 6.6), although the root distribution apparently does not change after 5 years.

Kushwah **et al.** (1973) and Nelliat **et al.** (1974) discussed how knowledge of the shape of coconut palm root systems can be used for constructing planting schemes for agroforestry with little interference among crops. Root systems of oil palms are similar to those of coconut palms (Tan, 1979). Tinker and Ziboh (1959) described soil profiles of oil palm plantations in Southern Nigeria, mostly on acid sandy soils. Generally a heavy root mat is found in the top 5 cm with few roots penetrating below 40 cm, although in some profiles palm roots may be found at a depth of 150 cm.

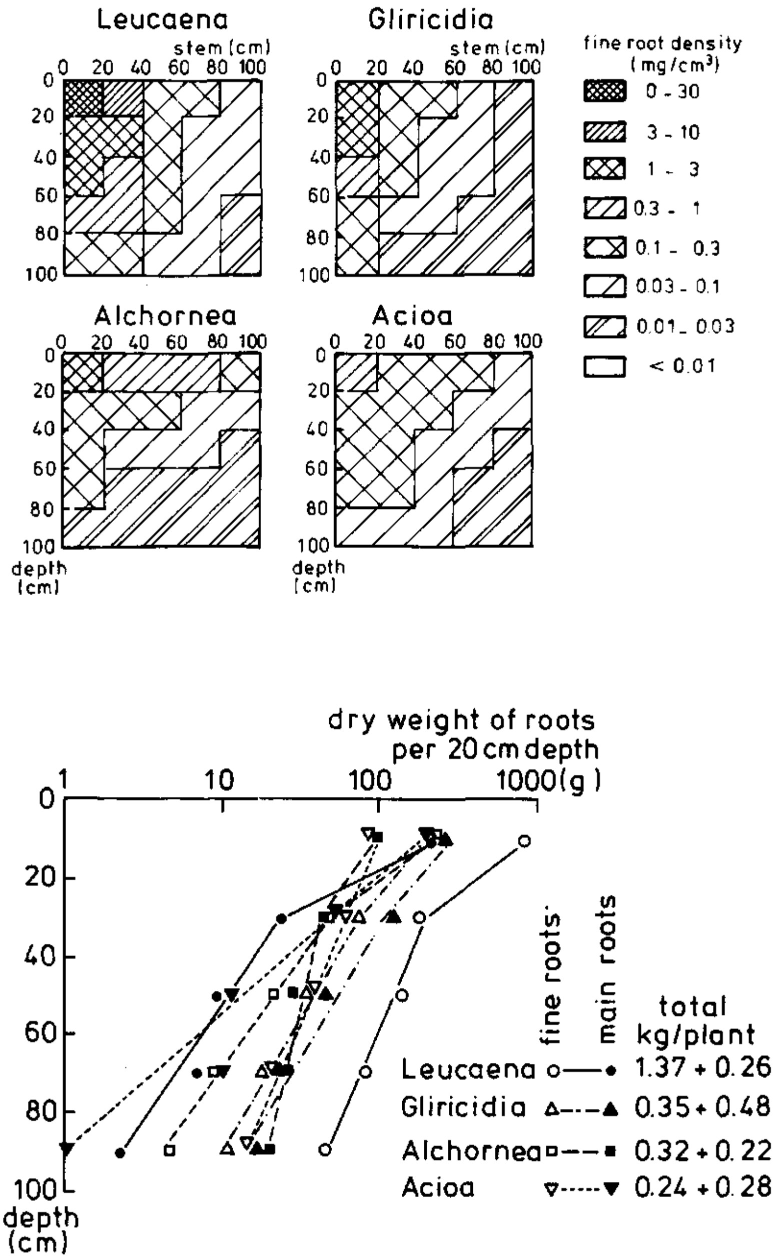

Figure 6.4. Root distribution of alley cropping trees (**Leucaena leucocephala, Gliricidia sepium, Alchornea cordifolia** and **Acioa barteri**) at Ibadan (data from Cole, 1983; calculation of total root dry weight assuming radial symmetry according to Van Noordwijk **et al.**, 1985).

Alley cropping at Onne

Following the successful development of alley cropping techniques on neutral alphisols at Ibadan (Kang **et al.**, 1985), similar experiments were started at Onne as well. As tree species four introduced species were tested (3 **Leguminosae: Leucaena leucocephala, Gliricidia sepium** and

Flemingia congesta an a well known forest plantation tree (related to teak, **Tectona**) **Gmelina arborea (verbenaceae)** and two local species (**Alchornea cordifolia (Euphorbiaceae)** and **Anthonata macrophulla (Caesalpinioideae- Leguminosae)**, which are dominant species in the bush fallow in SE Nigeria. Establishment of the tree rows proved to be difficult, especially for **Anthonata**, which is remarkable as it forms a major component of the surrounding bush, regrowing from many old stumps coppiced in the cropping period.

Knowledge of root growth of the tree, especially root depth and degree of interference with crop roots, was considered to be useful in evaluating the suitability of the various tree species.

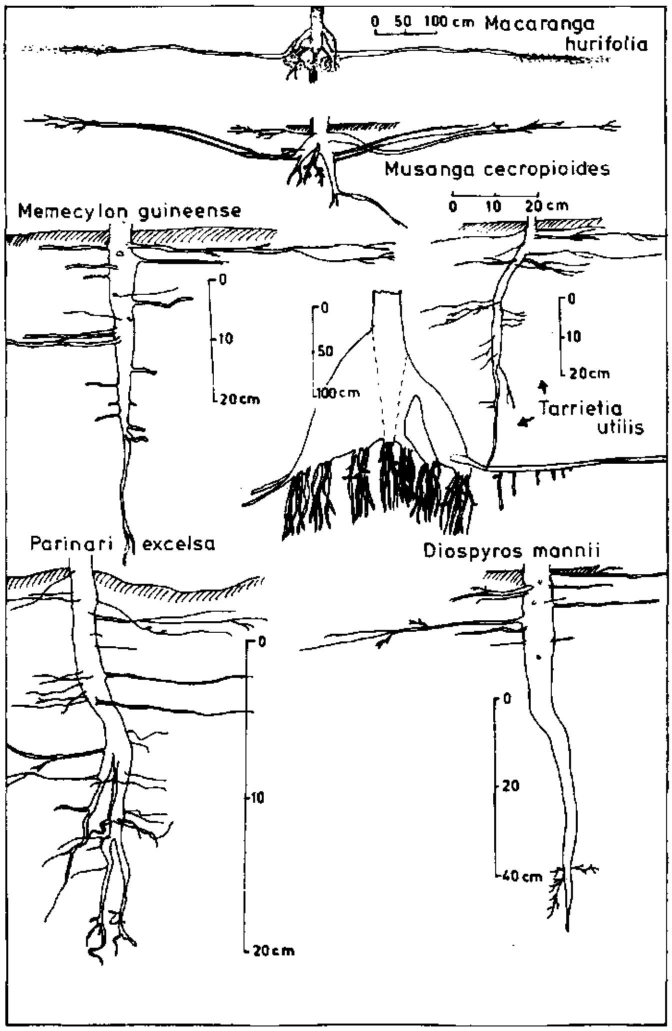

Figure 6.5. Root system of typical pioneer trees in secondary forest succession (**Macaranga, Musanga**) and trees of later successional stages (**Tarieta, Diospyros, Parinari, Memecylon**), according to Kahn (1978).

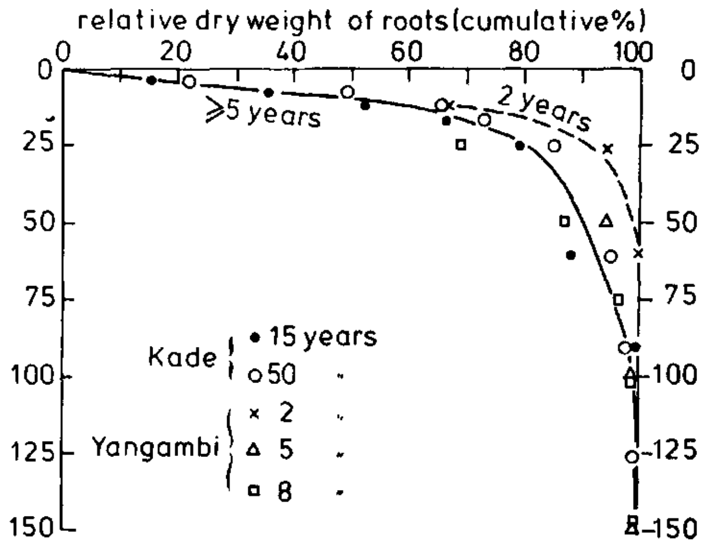

Figure 6.6. Root distribution of forest fallow vegetation under high rainfall conditions at Kade (Ghana) and Yangambi (Zaire) (data from Greenland and Kowal, 1960).

6.2. Methods

On two occasions, in April and June, vertical root maps were made in soil pits bordering the alley cropping experiment. Roots were mapped over a distance of 1 m (i.e. to the midpoint between two rows of trees (2 m apart). Samples were collected to observe mycorrhizal infection. As the remarkably slow establishment of **Anthonata** from seedlings might be related to poor establishment of **mycorrhiza**, to a number of seedlings grown in plastic bags some soil was added, collected near **Anthonata** trees that were growing well.

6.3. Results

Root maps of the alley cropping plots contained roots of trees, cassava and weeds. Only for the thicker roots identification was possible. Figure 6.7 shows the distribution of the main tree roots. **Alchornea** and **Gliricidia** hardly penetrated into the subsoil and extended its roots horizontally into the topsoil. **Anthonata** and **Flemingia** gave a slightly better penetration, but mainly extended horizontally. **Leucaena** and

Gmelina both covered the whole space of the root map; **Gmelina** roots could be found at 1 m depth at 1.5 m distance from the trunk. **Leucaena** showed both deep penetration and horizontal extension (Plate VIII). Figure 6.8 shows the total counts on the root maps. The **Leucaena**, **Gmelina** and **Flemingia** plots had the best root development both in topsoil and subsoil.

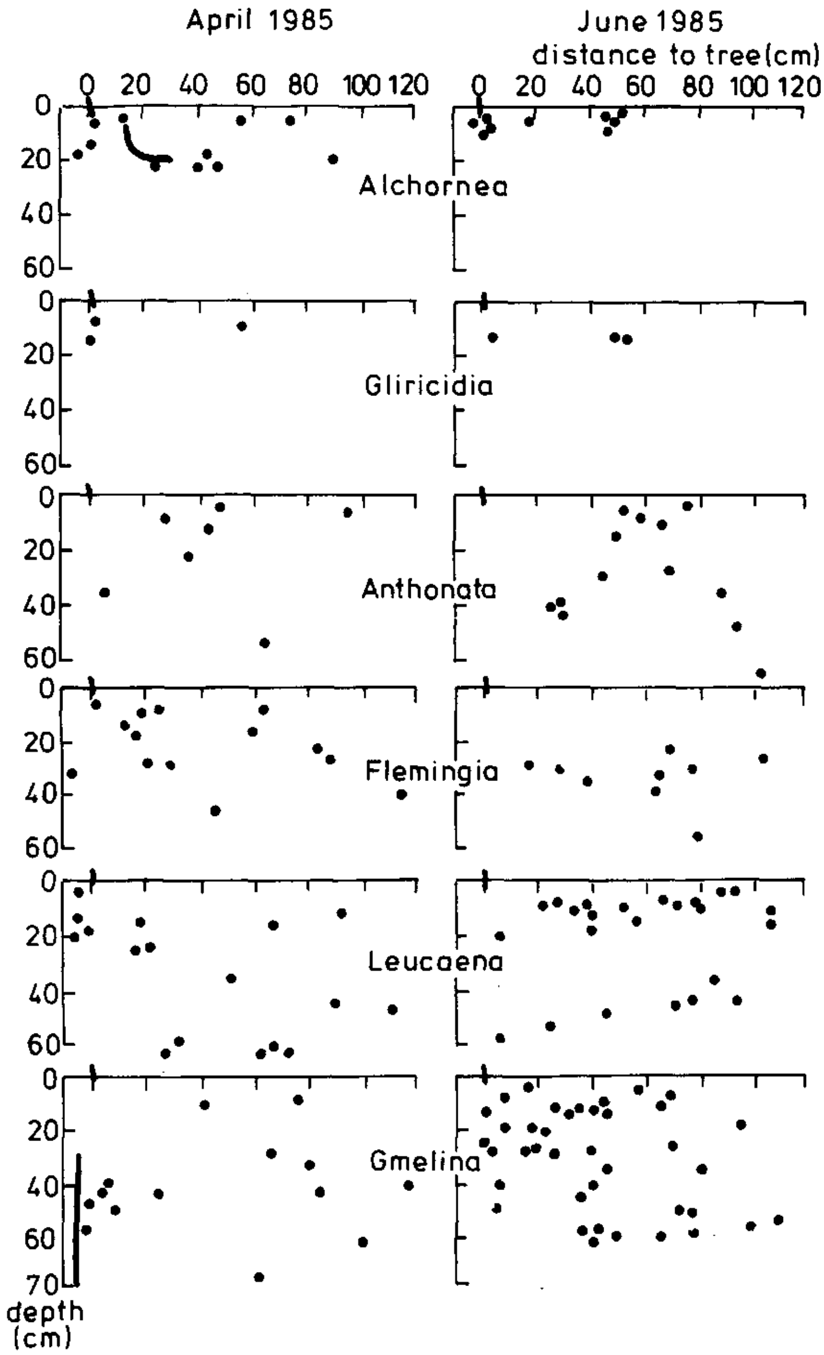

Figure 6.7. Distribution of woody roots on root maps of six alley cropping trees.

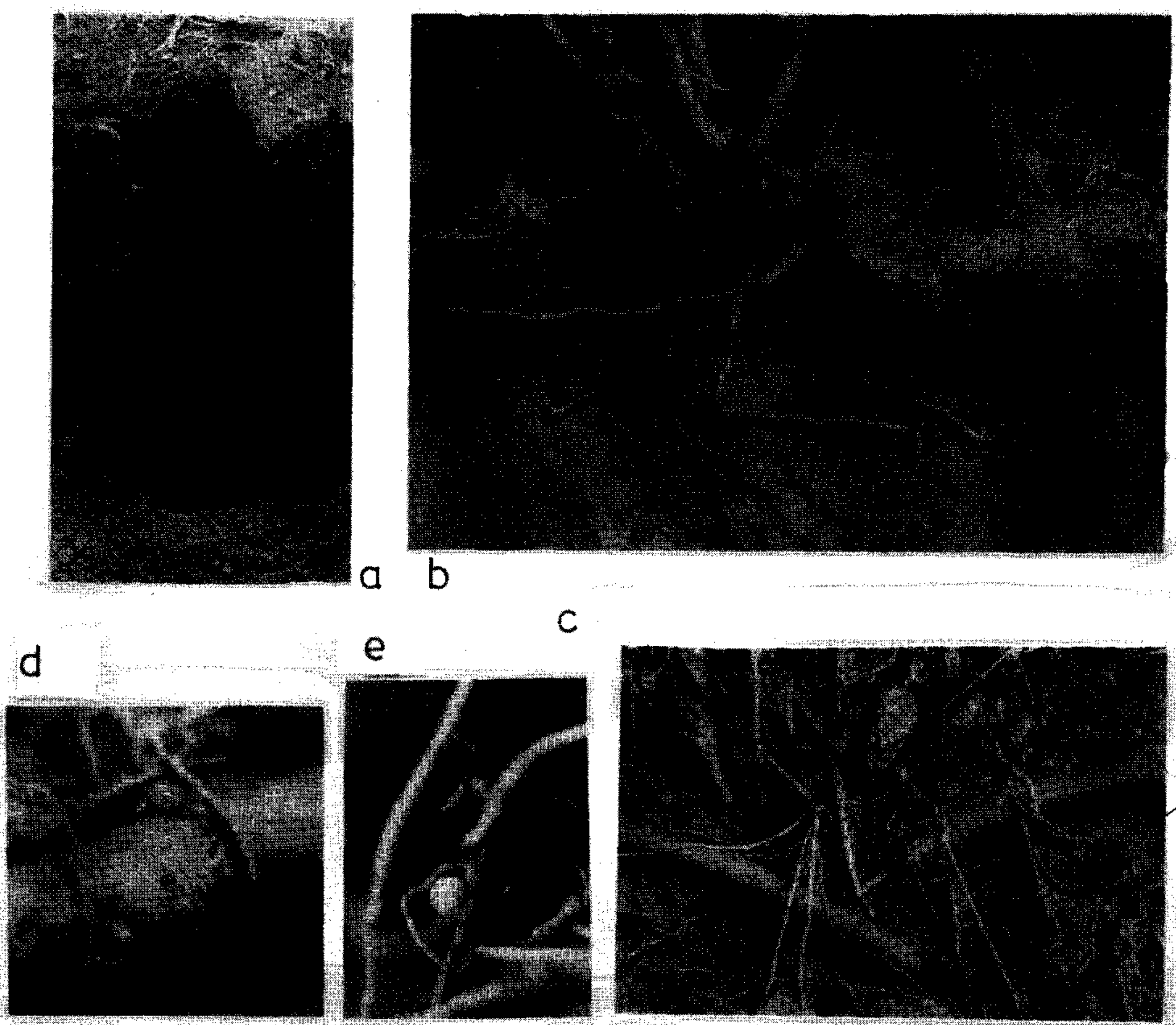

Plate VIII. Details of roots in alley cropping: A. Charcoaled old tree stump under ploughed layer in rice field, B. **Alchornea** roots restricted to the topsoil, C. **Leucaena**/cassava roots intermingled in the topsoil, D, E. detail of **Leucaena** nodule in direct contact with cassava tuber.

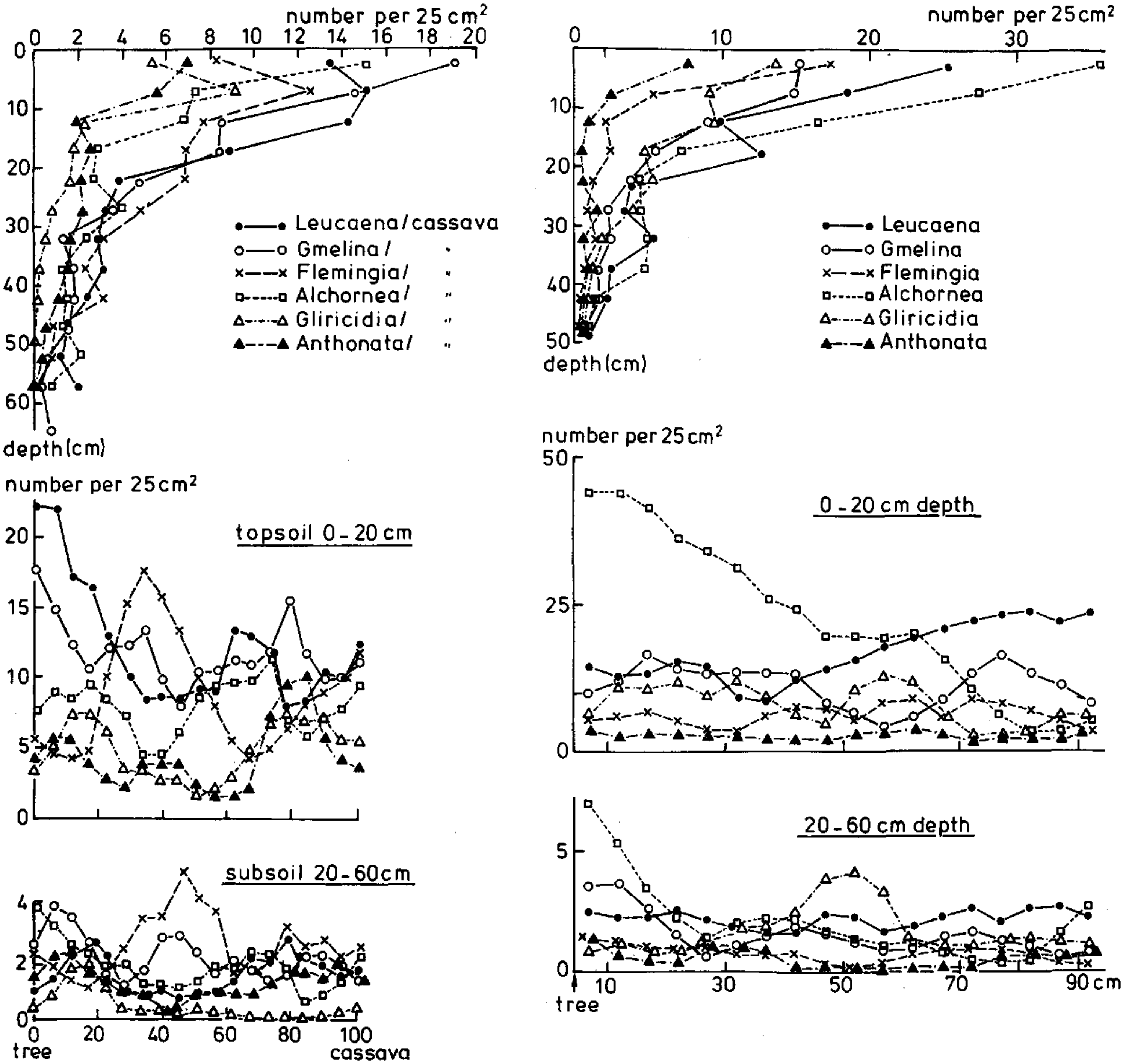

Figure 6.8. Distribution of fine roots in alley cropping plots: A. tree + cassava + grass roots in April, B. tree + grass roots in June.

Mycorrhizal infection was found to be low in the topsoil (2-5%) for all trees, except **Alchornea** (28%) and **Gliricidia** (13%). The small experiment on **Anthonata** seedlings gave negative results: the mycorrhiza infection level was quite high without adding "**Anthonata**" soil to the plastic bags. The treatment tested even seemed to have had a negative effect on mycorrhizal infection, without an effect on seedling growth. The slow establishment of **Anthonata** probably is not due to the absence of a suitable mycorrhizal symbiont.

TABLE 6.1. Mycorrhiza (% root length infected).

	April		June
Soil depth:	0-15	15-30	0-15
Anthonata	2.5	0.0	1.0
seedlings - infection			32.3
seedlings + infection			10.8
Alchornea	28.3		4.3
Gliricidia	12.5		25.0
Leucaena	3.5	3.3	2.6
Flemingia	1.6		2.3
Gmelina	3.8		0.0

6.4. Discussion

The six tree species observed showed marked differences in root distribution which probably affect their suitability for alley cropping. No tree species fits the ideal pattern of fast growth, deep root penetration and no roots in the topsoil between the crops. **Alchornea** and **Gliricidia** scarcely penetrate into the subsoil. **Anthonata** has a slow establishment phase but produces a reasonably deep root system later. **Flemingia** and **Leucaena** form roots both in the topsoil and in the subsoil. The deepest root development as well as the fastest growth above ground is found in **Gmelina**, but this tree also forms many roots in the topsoil and its shoot growth is rather wild and difficult to control.

Although the alley cropping trial was set up to get experience with local performance of the various tree species, not to make detailed, statistically reliable comparisons of yield levels, some indications may nevertheless be derived from the 1985 harvest of cassava (1984 planting) (figure 6.9). Cassava growth per surface area generally decxreased with decreasing distance between the alleys, except for the **Anthonata** plots which may serve as a control, as these trees did not grow well until the end of 1984. **Gmelina**, **Leucaena** and **Alchornea** gave the lowest cassava tuber yields. As cassava yield generally is insensitive to N supply (in Onne), negative effects of tree rows shading the crop probably are predominant in the case of cassava.

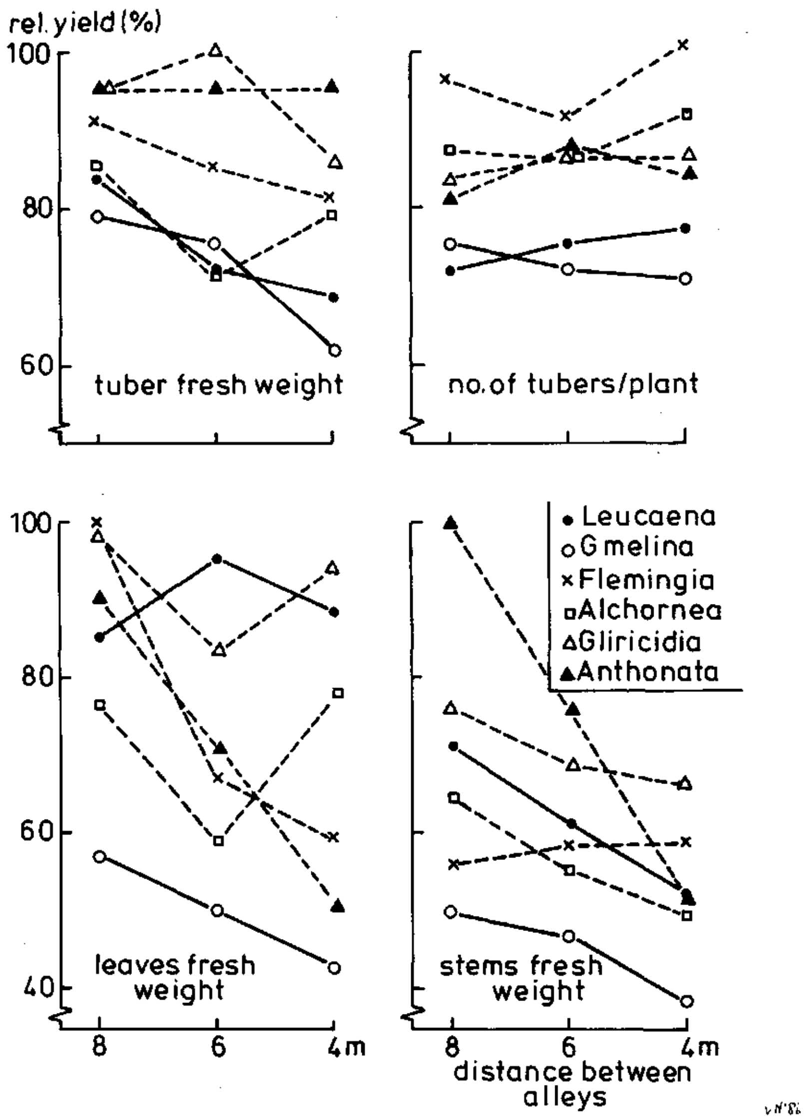

Figure 6.9. Relative yield of cassava (harvest April 1985) from alley-cropping trial, at 3 distances between the alleys.

Negative effects of tree rows are more pronounced on above-ground organs (leaves and stems) than on total tuber freshweight. The **Flemingia** plots yielded the highest number of tubers/plant, but gave an intermediate total tuber yield. Apparently the growth rhythm of the crops differs under the influence of accompanying trees (different times of shading or N flush from mineralisation of tree branches used as mulch ?).

One may wonder whether or not it is possible to find suitable tree species in the local vegetation which could be used for alley cropping. Such trees should not be sought in the pioneer stages of the forest (**Alchornea** type of root system), nor in the climax forest (slow establishment). Intermediate successional stages may contain the best available compromise between "ideal" root distribution and "ideal" fast establishment. **Anthonata** may serve as the example.

Alley cropping can be regarded as a linearly organised variant of the local **Anthonata**-coppice farming system (with the advantage of potential mechanisation). More research into the functioning of the latter under local farm conditions is important to learn the essential aspects to be included in alley cropping. Observations described here (chapter 2 and 5) of the presence of "old tree root channels" and their possible importance in the use of subsoil resources by the crop can be relevant in this respect. The local farming practice of planting certain crops near old **Anthonata** stumps should be evaluated.

7. GENERAL DISCUSSION

The observations on root distribution in the soil at Onne gave some surprising results. Conventional wisdom at the research station stated that no crop roots penetrate beyond 15 cm depth. Our observations showed that this statement is not true. A rooting depth of 50-100 cm was found for upland rice, **cassava**, **Centrosema**, **Gmelina** and **Leucaena**.

Root research in the initial phase of a research program can be helpful in selecting suitable crops for intercropping. Our observations indicate that **Alchornea** and **Desmodium** are not very suitable, while the maize/cassava mixture can be expected to have advantages over monocultures. For alley cropping trees it is too early to choose suitable species, as none of the tree species tested fulfills all requirements (fast growth, deep root development, no interference with crop roots).

Root research should be combined with observations on N uptake during the growing season to understand the dynamics of soil nitrogen under farming conditions. On the basis of N-uptake curves suitable timing for additional measures (fertilisation or possibly some manipulation of mineralisation rates) can be selected. Such measures can subsequently be tested on whether or not they increase nutrient use efficiency. The present research project, starting with the statistical evaluation of the interaction between various intercropping systems and fertiliser rates, may not be the most efficient way to improve local farming practices, unless it is combined with studies of relevant processes in soils and crops under local farming conditions as outlined here.

The present observations suggest that a need for additional research exists on details of the leaching process in the field, combined with root research (comparable to the upland rice experiment) and further studies of the role of old **Anthonata** stumps and old tree root channels in facilitating deep crop root development. The technique of horizontal root mapping in studies of intercropping may yield useful information (provided that some technical problems of variable depth of observation will be solved).

8. ACKNOWLEDGEMENTS

Thanks are due to the Netherlands Government and IITA for for granting a 9-months traineeship at Haren and at Ibadan/Onne, as part of the project "Nitrogen management in the humid tropics". Dr. B. T. Kang, Ir. Jan van der Heide and Ir. Ad van der Kruijs gave advice and supervision and helped organising all fieldwork. Mr. M. Weber allowed us to make root observations in his experimental plot. Mr. Emanuel Stephans proved to be a valuable assistant in the fieldwork, while Mr. Gerard Brouwer and Mr. Johan Floris gave assistance in Haren. Dr. Ir. Anton de Jager, Ir. Peter de Willigen and Ing. Marjolein Hanegraaf critically read the manuscript.

9. SUMMARY

In experimental fields aimed at improving nitrogen management in the humid tropics, root studies were made at IITA's high rainfall substation at Onne (S.E. Nigeria). Deep root development can be important for recovering leached nutrients including nitrogen, because (and in as far as) supply of nutrients though mineralisation and demand by the crop are not completely synchronised. Root development on acid soils can be restricted by toxic levels of Al. In Onne in several crops deep root development was observed in subsoil channels, formed by remains of tree roots. The soil in these channels was loose, but more acid than the surrounding subsoil. Soil compaction due to mechanised farming probably is as important in restricting root growth as soil acidity under these conditions.

Root observations were made in an experiment with six leguminous cover crops: **Centrosema macrocarpum, Desmodium ovalifolium, Pueraria phaseleoides, Psophocarpus palustris, Mucuna utilis** and **Vigna unguiculata.** A comparison was made between limed (1 ton per ha) and non-limed plots. Root systems were sampled with pinboards. The six crops differed in growth pattern and above-ground production as well as in root development. Although the basic shape of the root system was the same for all species, i.e. a vertical tap root and abundant branch roots in the topsoil, rooting depth varied from 70 cm in **Centrosema** to 40 cm in **Desmodium. Vigna** and **Mucuna** grew fast and aged quickly, coupled with a low root:shoot ratio and a relatively high N concentration. **Pueraria** established itself relatively slowly but showed the best nodulation. **Psophocarpus** and **Desmodium** are unsuitable under these conditions as they start too slowly and have to be weeded frequently. Liming had no dramatic effect on plant growth, but increased nodulation in the fast growing **Vigna** and **Mucuna.** Root distribution was influenced by liming in all species: maximum root depth decreased and root weight density in the topsoil increased. Mycorrhizal infection levels were low.

The root system of upland rice was studied in an experimental plot where leaching of water and nutrients is studied under field conditions, with and without NPK fertilisation. Five weeks after planting (two weeks after the first fertiliser application) fertilizer had a marked effect on dry matter production, but roots on the unfertilised plots were

slightly better developed. Later, roots on the fertilised plots extended to a depth of 70 cm, while on the unfertilised plot they only reached 40 cm depth. This root extension occurred after the main period of nitrogen and phosphorus uptake had passed. Root:shoot ratio decreased continuously over the season to a value of 1:7 for unfertilised and almost 1:10 for the fertilised plots.

Root observations were made in a maize/cassava intercropping experiment which is part of the on-going N management project (experiment 3), in which the N response in different plant spacings is compared with two levels of N fertilization (0 and 60 kg N per ha). Three maize spacings are used: plants in groups of 4 spaced 1 m apart, plants in groups of 2 spaced 50 cm apart or single plants at a spacing of 25 cm; cassava is planted at distances of 1 m. Root investigations were made with pinboards, vertical root maps and horizontal root maps in the topsoil. Maize roots were mainly restricted to the top 10 cm of the soil, while cassava roots went deeper and extended well below the maize plants, although at a much lower root length density. The maize spacing of 25 cm gave a slightly faster utilisation of the total topsoil volume. Fertilisation increased root development of maize, but had no effect on cassava. Nitrogen uptake by the maize occured in two peaks, immediately following the two fertiliser applications.

Some observations were made on the root development of six tree species which are being tested in an alley cropping experiment (**Anthonata macrophylla, Flemingia congesta, Gliricidia sepium, Leucaena leucocephala, Gmelina arborea, Alchornea cordifolia**). Vertical root maps were made, and the distribution of woody roots was recorded separately. **Gmelina, Leucaena** and **Flemingia** all showed a good penetration of the subsoil with their roots. **Alchornea** and **Gliricidia** roots were mainly restricted to the topsoil. Anthonata, which forms a major component of the local bush fallow agriculture, has a very slow establishment phase, but gives reasonable penetration of the subsoil.

10. SAMENVATTING

Onderzoek naar de beworteling van diverse gewassen werd uitgevoerd op proefvelden waar getracht wordt de stikstofhuishouding in de natte tropen te verbeteren op het sub-station van het IITA in Onne (Z.O. Nigeria). Diepe beworteling kan van belang zijn voor het opnemen van nutriënten (incl. stikstof) die uit de bovenlaag uitspoelen, aangezien (en voorzover) aanbod door mineralisatie en opnamebehoefte van het gewas niet volledig synchroon verlopen. Beworteling op zure gronden kan beperkt zijn door toxische Al-concentraties. In Onne bleken diverse gewassen diepe wortels te vormen in gangenstelsels in de ondergrond, gevormd door vroegere boomwortels. Grond in deze gangenstelsels was los, maar had een lagere pH dan de omringende ondergrond. Derhalve lijkt onder deze omstandigheden bodemverdichting door gemechaniseerde landbouw een zeker zo belangrijke factor die tot beperking van de beworteling kan leiden als de zuurgraad van de bodem.

Bewortelingsonderzoek werd uitgevoerd in een proef met zes vlinderbloemige groenbemesters: **Centrosema macrocarpum, Desmodium ovalifolium, Pueraria phaseoloides, Psophocarpus palustris, Mucuna utilis** en **Vigna unguiculata.** Bekalkte (1 ton per ha) en niet-bekalkte veldjes werden vergeleken. Wortelstelsels werden met naaldenplanken bemonsterd. De zes groenbemesters verschilden in groei-ritme en boven- zowel als ondergrondse produktie. Bij alle soorten had het wortelstelsel dezelfde grondvorm, een verticale penwortel en rijke zijwortelvorming in de bovengrond, maar de bewortelingsdiepte varieerde van 70 cm bij **Centrosema** tot 40 cm bij **Desmodium. Vigna** en **Mucuna** vertoonden een snelle groei, maar ook een snelle veroudering, bij een lage wortel/spruit-verhouding en relatief hoog N-gehalte. **Pueraria** vertoonde een langzame vestiging, maar vormde de meeste wortelknolletjes. **Psophocarpus** en **Desmodium** bleken ongeschikt voor deze omstandigheden, aangezien ze te traag aan de groei kwamen en vaak wieden derhalve noodzakelijk was. Bekalking had geen ingrijpende gevolgen voor de plantengroei, maar stimuleerde de wortelknolletjesvorming bij de snelgroeiende **Vigna** en **Mucuna.** De wortelverdeling werd bij alle gewassen beïnvloed door bekalking: de bewortelingsdiepte nam af en de bewortelingsintensiteit van de bovengrond nam toe. De wortels vertoonden weinig mycorrhiza.

De beworteling van "droge rijst" werd bestudeerd in een proefveld waar uitspoeling van water en nutriënten werd gevolgd onder veldomstandigheden, bij al of niet bemesten met NPK. Vijf weken na zaaien (twee weken na de eerste kunsmestgift) had de bemesting een duidelijk effect op de bovengrondse groei, maar op de onbemeste veldjes was de wortelontwikkeling iets beter. Later bleken op de bemeste veldjes de wortels tot een diepte van 70 cm door te dringen, terwijl op de onbemeste veldjes slechts 40 cm werd bereikt. Deze uitbreiding van de beworteling vond echter plaats na de periode van de voornaamste N- (en P-) opname. De wortel/spruit-verhouding daalde gedurende het gehele groeiseizoen tot een waarde van 1:7 op de onbemeste en bijna 1:10 op de bemeste veldjes.

De beworteling onder een mengteelt van mais en cassave werd onderzocht in een experiment van het lopende N-huishoudingsproject (experiment 3), waarin de stikstofreactie van diverse plantverbanden wordt onderzocht (bij 0 en 60 kg N/ha). Drie plantschema's voor mais worden vergeleken: planten in groepjes van 4, met 1 m tussenruimte, in groepjes van 2 met 50 cm tussenruimte en afzonderlijke planten met 25 cm tussenruimte; de cassave had steeds 1 m tussenruimte. Bewortelingsonderzoek werd uitgevoerd met naaldenplanken, verticale en horizontale "wortel-kaarten". De beworteling van de mais was in hoofdzaak beperkt tot de bovenste 10 cm van de grond, terwijl de cassave dieper wortelde en de gehele ruimte onder de mais opvulde, zij het met veel geringere bewortelingsintensiteit dan de mais vertoonde. Waar de mais om de 25 cm geplant werd, was de gehele bovengrond iets sneller beworteld dan bij de gegroepeerde mais het geval was. Bij bemesting met 60 kg N per ha nam de maisbeworteling toe, maar de cassavebeworteling bleef onveranderd. N-opname door de mais vond plaats in twee pieken, direct volgend op beide bemestingen.

Er werden ook enkele waarnemingen verricht aan de beworteling van zes boomsoorten die gebruikt worden voor "haag-teelt" (alley cropping) (**Anthonata macrophylla, Flemingia congesta, Gliricidia sepium, Leucaena leucocephala, Gmelina arborea** en **Alchornea cordifolia**). Er werden verticale wortelkaarten gemaakt en de verdeling van houtige wortels werd apart geregistreerd. **Gmelina, Leucaena** en **Flemingia** bleken alle drie goed in de ondergrond door te dringen met hun wortels, maar ook in de bovengrond, tussen de gewassen, wortels te vormen. **Alchornea** en **Gliricidia** bleken tot de bovengrond beperkt met hun wortels. **Anthonata**, een belangrijke component van het plaatselijke "stobben-braak" landbouwsysteem, blijkt zich slechts zeer langzaam te kunnen vestigen, maar wel goed met wortels in de

11. RINGKASAN

Penelitian ini diselenggarakan sehubungan dengan adanya perbaikan managemen Nitrogen di daerah humid tropis IITA-Onne sub stasiun yang bercurah hujan tinggi (Nigeria tenggara). Perkembangan akar yang dalam sangat penting artinya untuk mengatasi kehilangan nutrisi melalui pencucian seperti Nitrogen, dikarenakan tidak adanya sinkronisasi antara penambahan nutrisi melalui mineralisasi dan kebutuhan tanaman akan nutrisi. Perkembangan akar pada tanah asam sangat dibatasi oleh adanya kandungan Al yang terlalu tinggi. Di daerah Onne perkembangan akar yang dalam dari beberapa tanaman banyak dijumpai di dalam saluran akar pada lapisan bawah yang terbentuk dari sisa-sisa akar pohon tua. Struktur tanah di dalam saluran ini gembur, akan tetapi bereaksi lebih asam daripada tanah sekelilingnya. Pada situasi ini, pemadatan tanah yang disebabkan oleh mekanisasi pertanian juga merupakan faktor penting di dalam membatasi pertumbuhan akar seperti halnya kemasaman tanah.

Suatu penelitian akar dilakukan dengan mengunakan 6 macam tanaman kacang-kacangan penutup tanah yaitu, **Centrosema macrocarpum, Desmodium ovalifolium, Pueraria phaseoloides, Psophocarpus palustris, Mucuna utilis** dan **Vigna unguiculata.** Dalam percobaan ini membandingkan 2 perlakuan yaitu, pengapuran (1 ton/ha) dan tanpa pengapuran. Pengambilan contoh perakaran dilakukan dengan menggunakan metode pinboard. Ke enam tanaman menunjukan perbedaan dalam pola pertumbuhan dan produksi bagian tanaman di atas tanah, maupun dalam perkembangan akarnya. Walaupun demikian pola dasar dari sistim perakarannya adalah sama untuk semua species seperti "vertical tap root"nya dan percabangan akar yang banyak terdapat pada lapisan atas, sedangkan kedalaman perakaran yang berbeda adalah pada **Centrosema** sedalam 70 cm dan Desmodium sedalam 40 cm. **Vigna** dan **Mucuna** menunjukhan pertumbuhan yang cepat dan penurunan pertumbuhan yang cepat pula, ke duanya mempunyai nisbah akar: bagian tanaman di atas tanah (root: shoot ratio) yang rendah dan mempunyai konsentrasi Nitrogen yang relatif tinggi. **Pueraria** mempunyai tingkat pertumbuhan yang relatif lambat, tetapi nampaknya mempunyai bintil akar yang terbaik. **Psophocarpus** dan **Desmodium** tidak cocok tumbuh pada daerah ini, karena ke dua tanaman ini tumbuh sangat lambat sehingga sering kali harus dilakukan penyiangan. Pengapuran tidak mempunyai pengaruh yang kuat terhadap pertumbuhan tanaman, akan tetapi meningkatkan pembentukan bintil akar pada **Vigna** dan **Mucuna** yang memiliki tingkat pertumbuhan cepat. Distribusi akar dari semua species dipengaruhi oleh pengapuran yaitu, maksimum kedalaman akar menurun dan berat kering akar di lapisan atas meningkat. Adapun level infeksi dari mycorrhizae adalah rendah.

Penelitian sistim perakaran padi (upland rice) dilakukan pada plot percobaan pencucian air dan nutrisi pada kondisi lapang, dengan perlakuan pemupukan dan tanpa pemupukan NPK. Pada saat tanaman berumur 5 minggu (2 minggu setelah pemupukan pertama) pemupukan mempunyai pengaruh yang jelas terhadap produksi bahan kering, tetapi akar tanaman pada plot tanpa pemupukan menunjukkan perkembangan yang lebih baik. Namun pada akhirnya akar tanaman pada plot pemupukan berkembang sedalam 70 cm, sedang pada plot tanpa pemupukan hanya mencapai kedalaman 40 cm. Pengembangan akar ini terjadi setelah periode utama dari penyerapan nitrogen. Nisbah akar: bagian tanaman di atas tanah menurun secara teratur hingga mencapai nilai 1:7 untuk perlakuan tanpa pemupukan dan mendekati 1:10 untuk perlakuan pemupukan.

Penelitian sistimperakaran lainnya dilakukan pada plot percobaan jagung/ ketela pohon intercropping, yang mana merupakan bagian dari projek penelitian managemen nitrogen (percobaan 3) yaitu suatu percobaan mengenai respon N pada beberapa jarak tanam dengan perlakuan 2 level pemupukan (0 dan 60 kg N/ha). Tiga macam jarak tanam jagung yang digunakan adalah, 4 tanaman dalam 1 grup dengan jarak tanam 100 cm, 2 tanaman dalam 1 grup dengan jarak tanam 50 cm, dan 1 tanaman dalam 1 grup dengan jarak tanam 25 cm antara satu dan lainnya; ketela pohon ditanam dengan jarak tanam 100 cm. Metoda pengamatan akar yang digunakan adalah metoda pinboard, metoda pemetaan akar vertikal, dan pemetaan akar horisontal pada lapisan tanah atas. Akar-akar utama jagung terbatas 10 cm di lapisan atas, sedang akar ketela pohon tumbuh lebih dalam dan berkembang dengan baik di bawah akar tanaman jagung, walaupun panjang akarnya jauh lebih rendah. Akar jagung dengan jarak tanam 25 cm nampaknya dengan cepat menduduki seluruh lapisan atas. Pemupukan meningkatkan perkembangan akar jagung, akan tetapi tidak mempunyai pengaruh yang berarti terhadap ketela pohon. Uptake N oleh tanaman jagung terjadi dalam 2 titik puncak yang secara langsung mengikuti pola penambahan pupuk.

Beberapa pengamatan akar dilakukan pada 6 species pohon yang sedang diteliti pada plot percobaan alley cropping (**Anthonata macrophylla, Flemingia congesta, Gliricidia sepium, Leucaena leucocephala, Gmelina**

arborea, Alchornea cordifolia). Pemetaan akar vertikal dan distribusi akar yang telah berkayu dilaporkan secara terpisah. **Gmelina, Leucaena** dan **Flemingia** semuanya menunjukkan penyebaran yang baik pada lapisan bawah. Alchornea dan Gliricidia terbatas pada lapisan atas. **Anthonata** yang merupakan komponen utama dari tanaman semak setempat, menunjukkan kelambatan dalam phase tertumbuhan, akan tetapi menunjukkan penetrasi akar yang cukup baik pada lapisan bawah.

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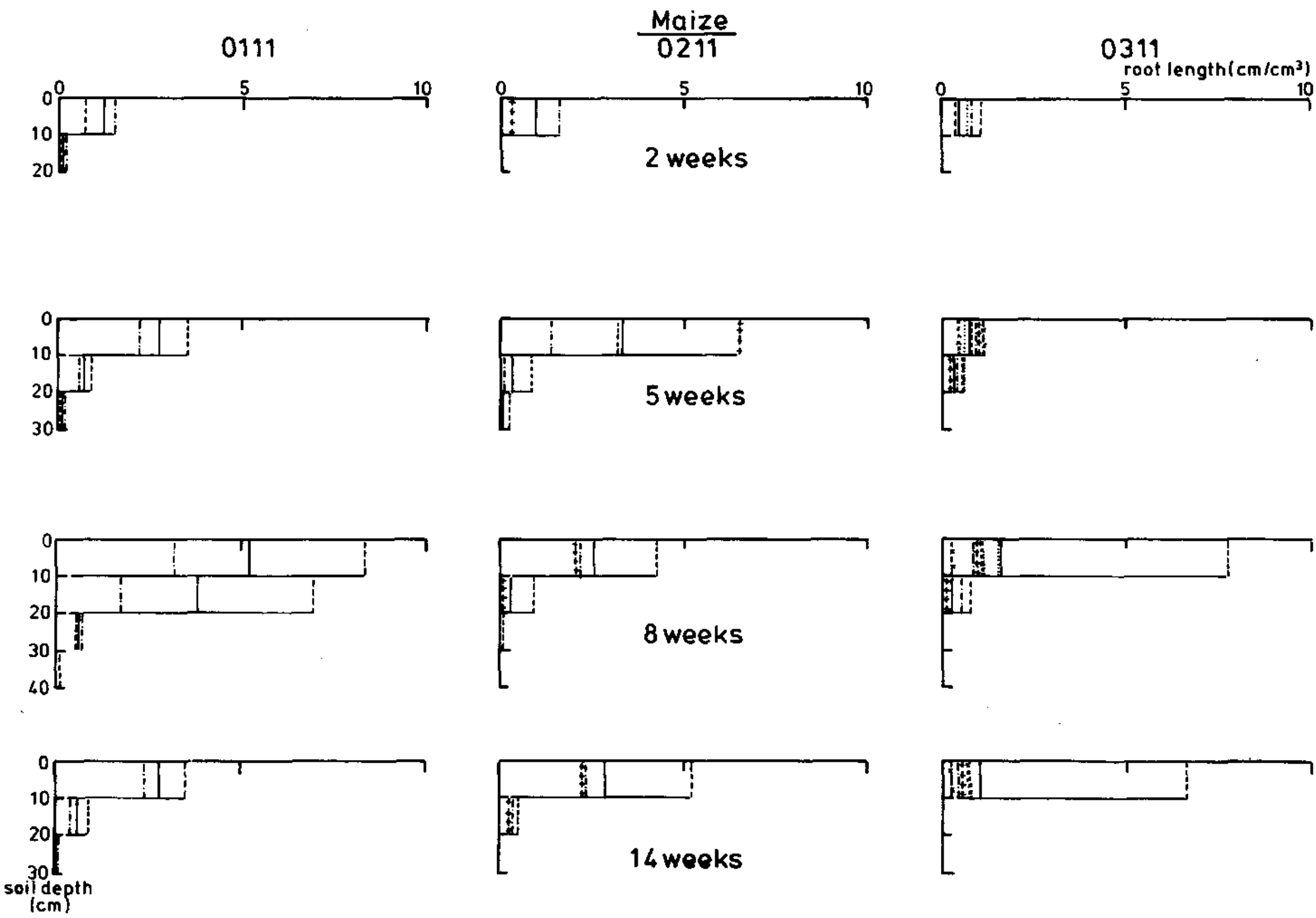
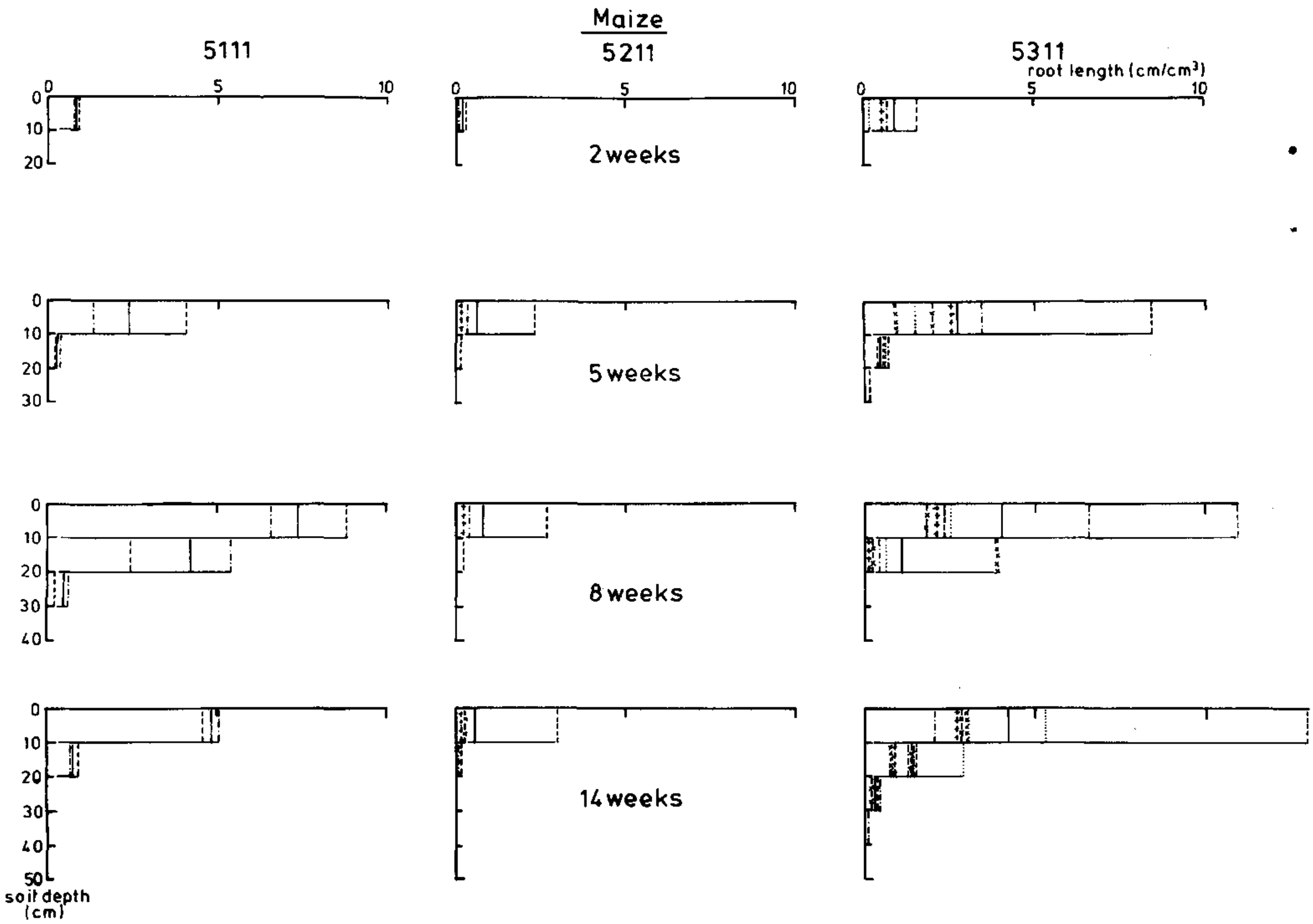
11. APPENDICES

APPENDIX I. Root length distribution of maize and cassava (legends see Appendix III).



APPENDIX I, continued.



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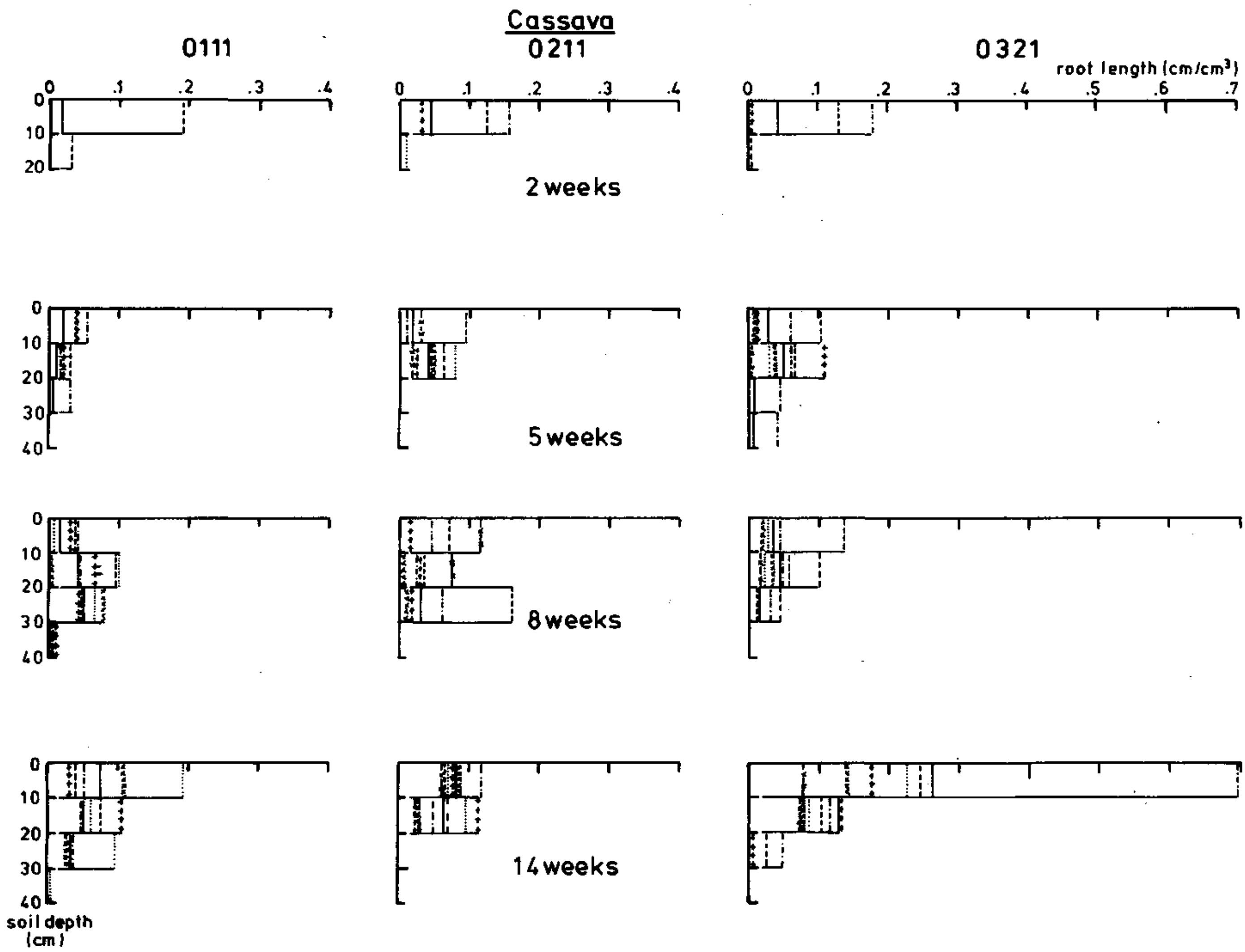

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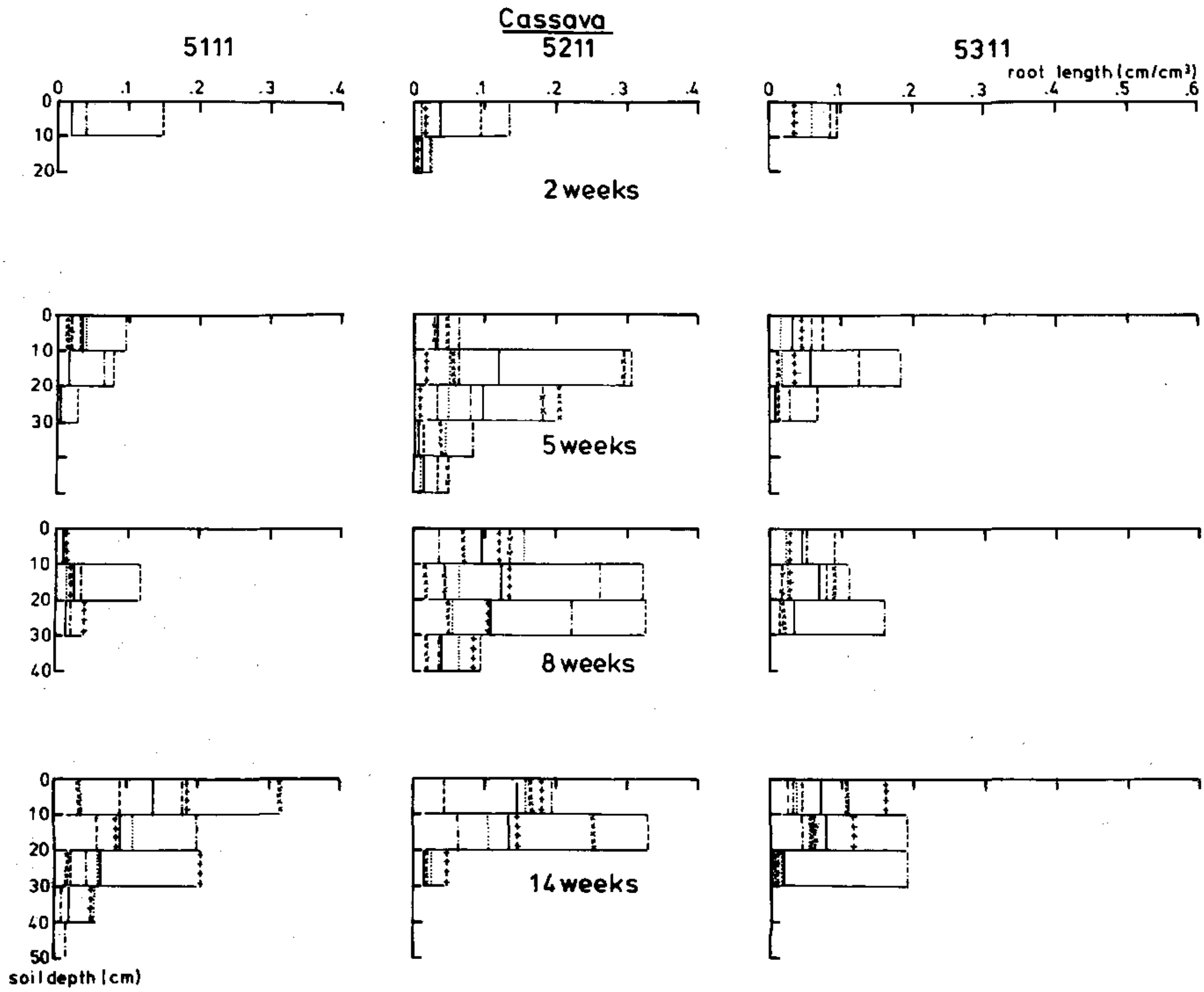
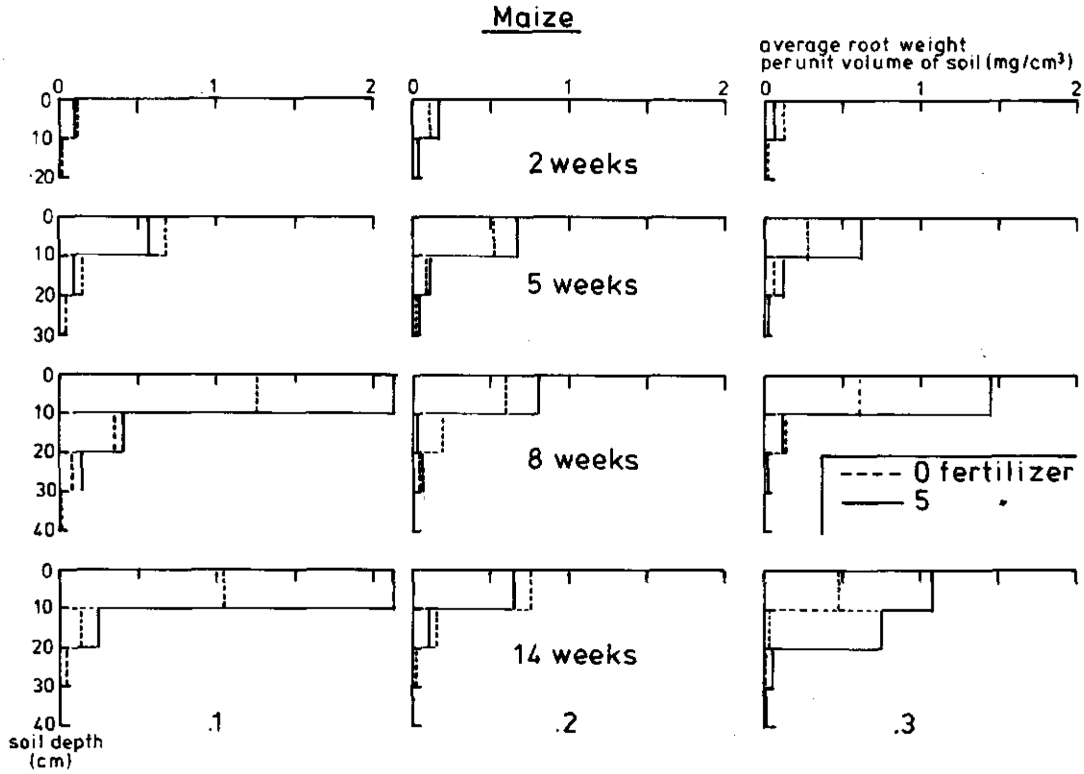
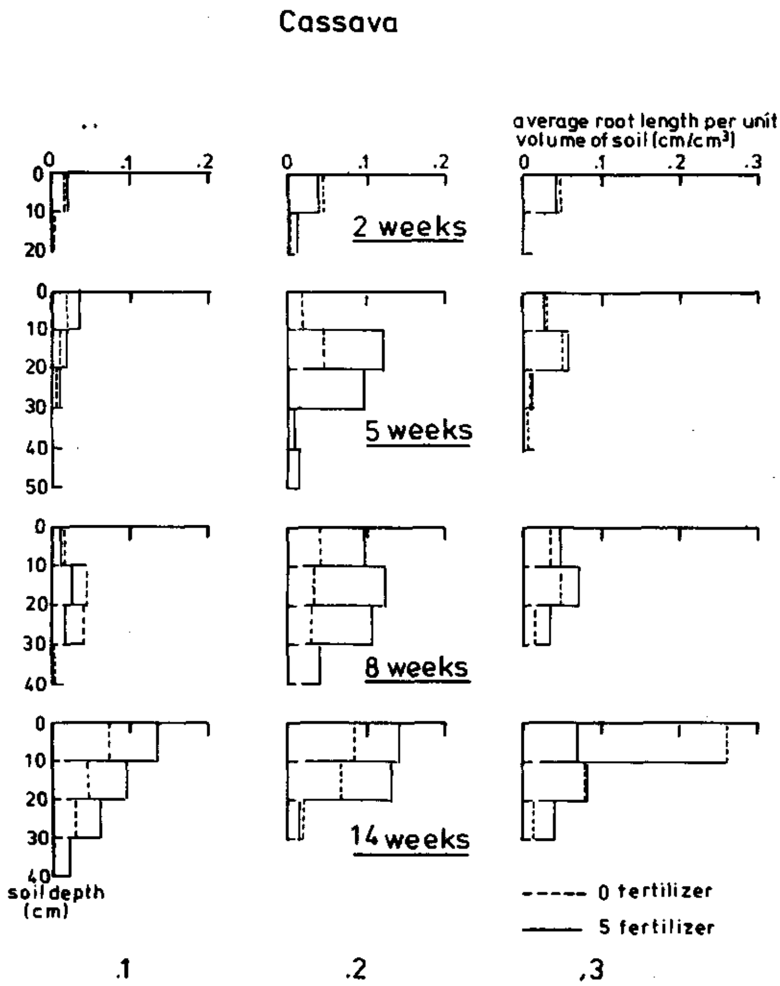
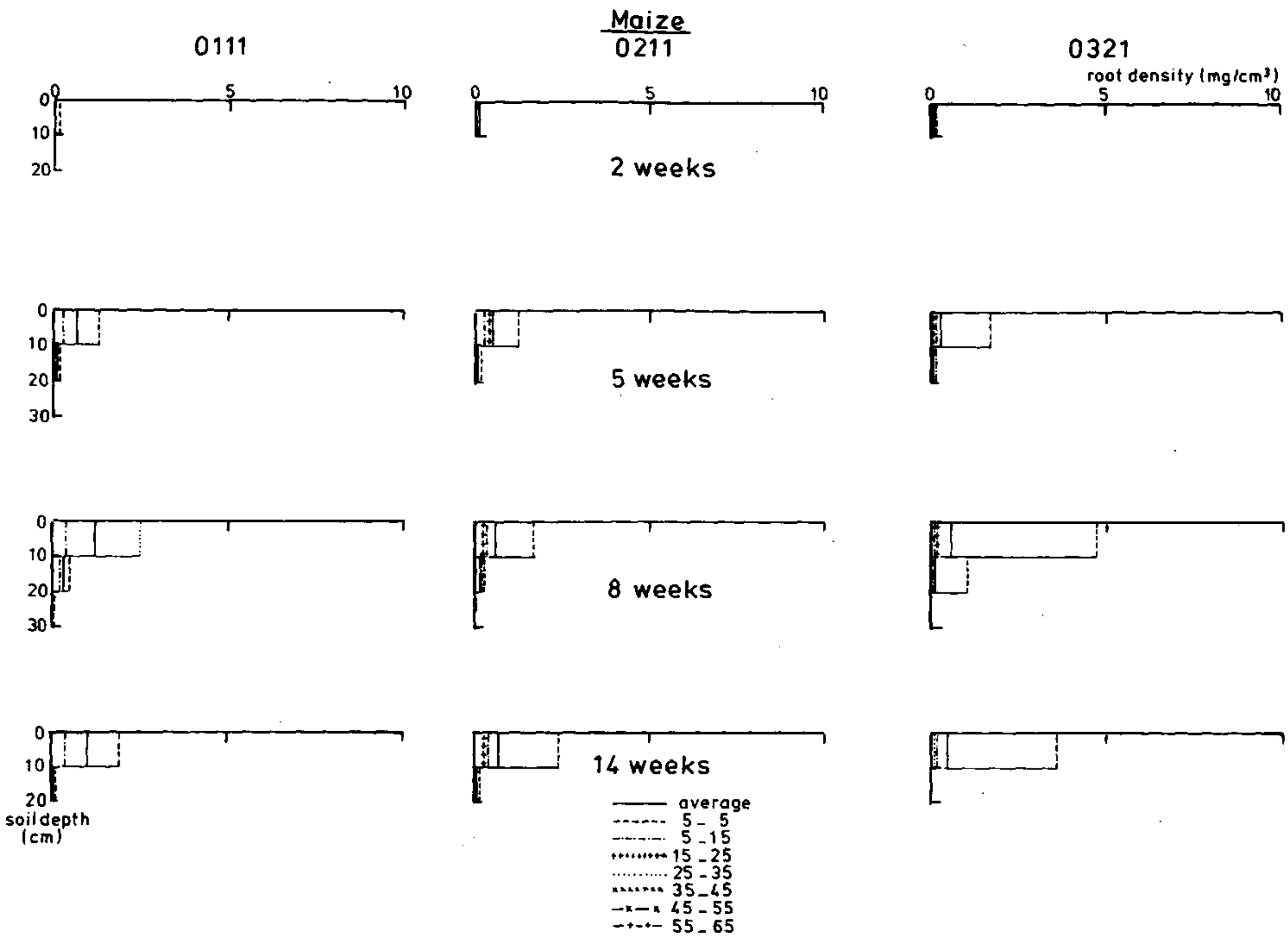


APPENDIX II. Root weights in maize/cassava intercropping.





APPENDIX III. Root weight distribution of maize and cassava.



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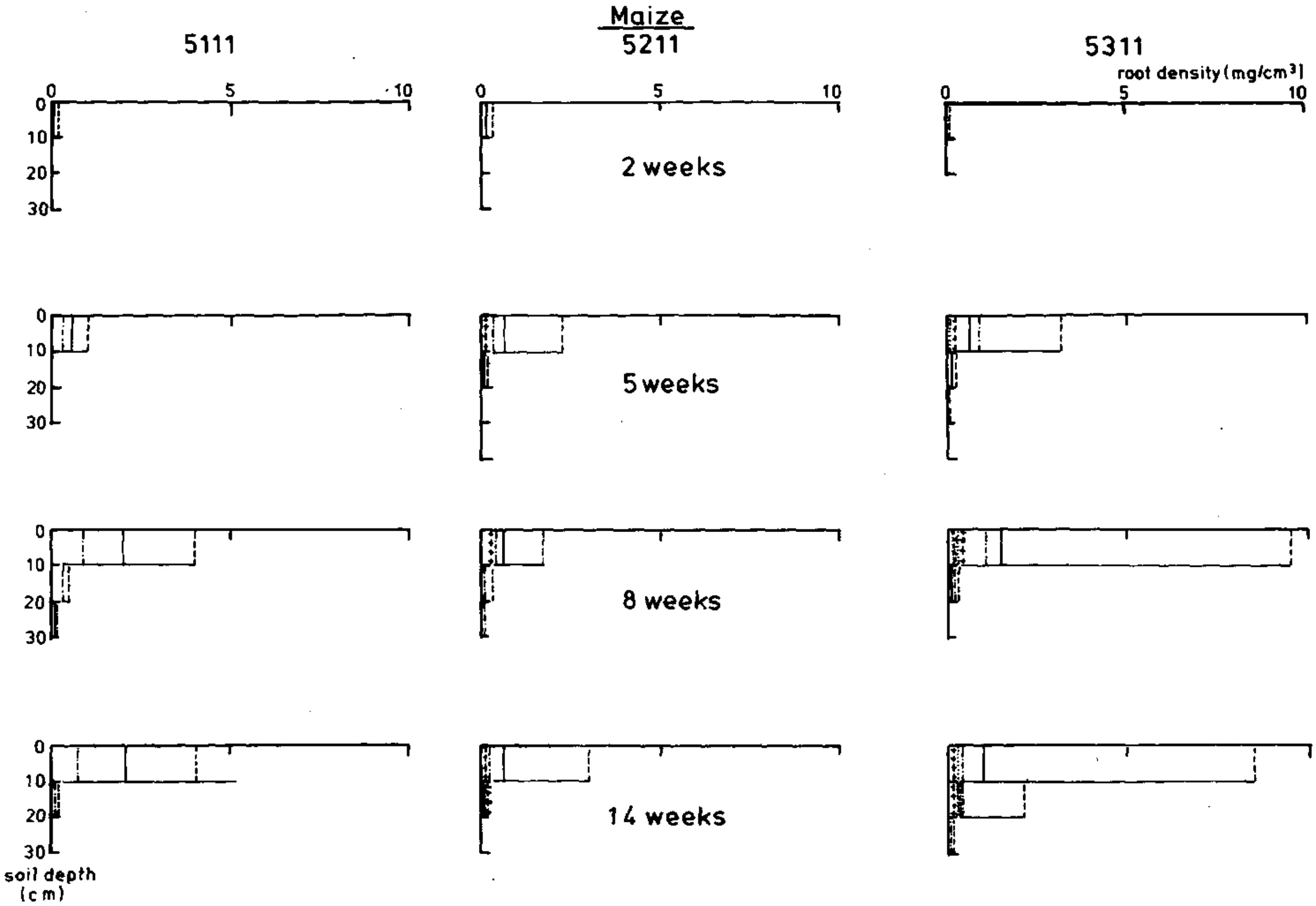

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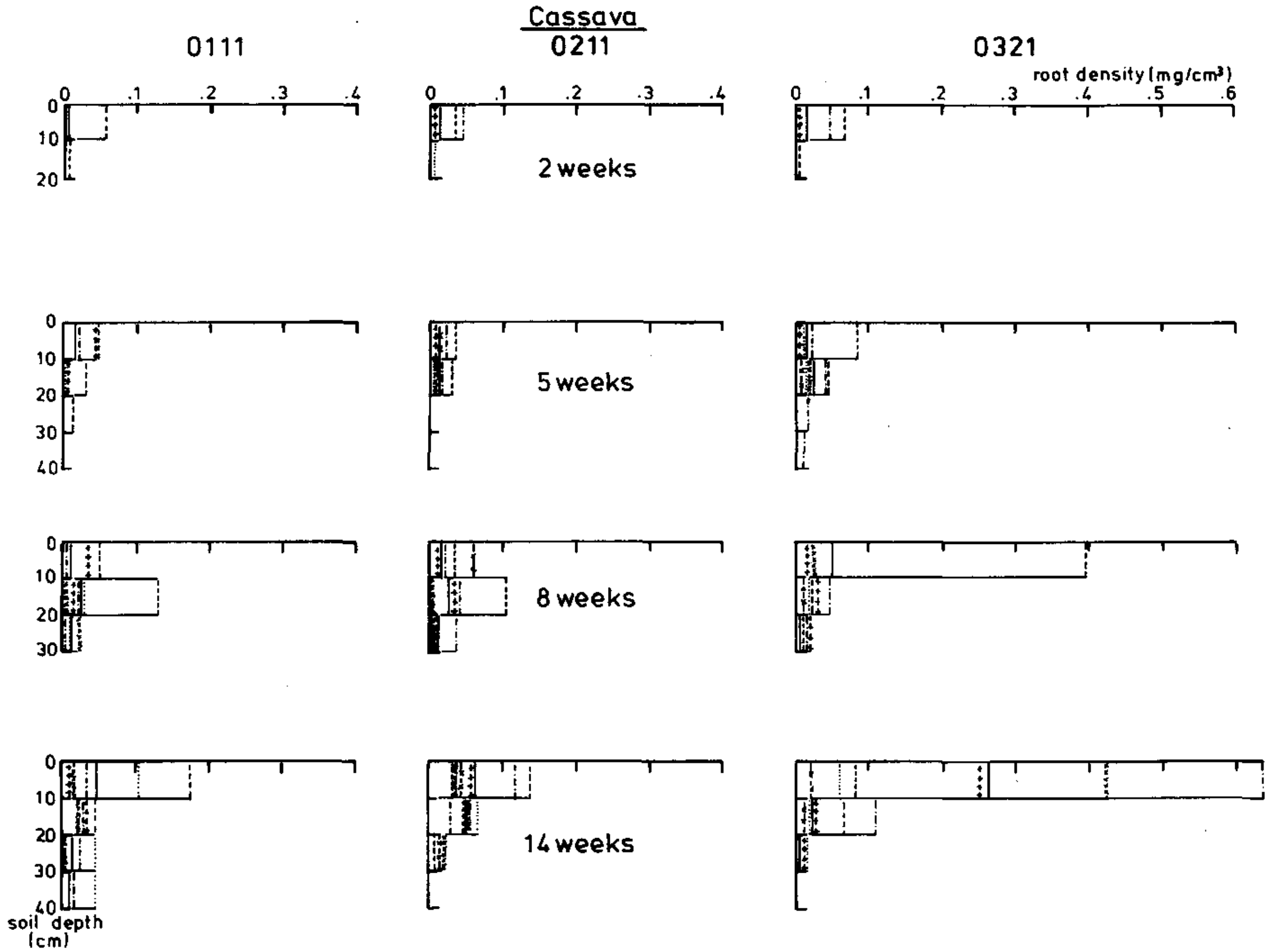

APPENDIX III, continued