THE ROOT GROWTH OF IRRIGATED PERENNIAL PASTURES AND ITS EFFECT ON SOIL STRUCTURE

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Summary

A separate of coherent organic particles obtained from soil suspensions by flotation and filtration is termed macroorganic matter. Three-year-old irrigated perennial pastures were found to have added 10 tons per acre of oven-dry macroorganic matter to a sandy loam at Deniliquin. Over half of this material had been added to the top three inches of the soil.

For any one pasture, as the macroorganic matter content of the top three inches of soil increased, infiltration rate decreased. When comparison was made at common macroorganic matter and soil moisture contents, soils under co-dominant white clover-perennial grass pastures were found to have higher infiltration rates than soils under lucerne-dominant pastures.

The variability of the quantities measured is described.

I. INTRODUCTION

Flood irrigation deteriorates the structure of certain Riverina soils (Tisdall 1950; Sinicins 1950), but this effect may be opposed by the growth of pastures, which usually promotes crumb formation (Rostovzeva and Avaeva 1935; Ackerman and Meyers 1943; Ward 1949). Less is known about the differences in structure-building ability which may exist between pastures. Ward (1949) has shown that significant differences in aggregation, permeability, and apparent density of soil may develop between sites sown to monospecific stands of certain grasses and legumes within three years of sowing. In this experiment measurements were made of aggregation, infiltration rate, and apparent density under five three-year-old perennial pastures, and differences in root growth were related to the effects of these pastures on soil structure.

West (1934) measured the root distribution of lucerne, wheat, beans, rice, and citrus on Riverina soils, and used his data as a guide to water application. The root distribution of irrigated perennial pastures, measured in this experiment, is of limited use in estimation of the depth of wetting which should be achieved by irrigation.

II. SOIL AND PASTURE TYPES

Measurements were made in 1950 on a number of 0.01-acre plots of perennial pasture species, which had been sown in autumn 1947 on soil type B at Falkiner Memorial Field Station.† The profile of soil B is described in Table 1.

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† The trial was primarily designed to compare herbage yields.

The mean annual rainfall of 16 in. was supplemented between September and May by 12 to 14 irrigations each of 3 in. Superphosphate at 2 cwt per acre was applied by top-dressing in autumn and spring of each year. The area was grazed by sheep, the practice being to graze back rapidly to 2 in. from an average height of 8 in.

TABLE 1

PROFILE OF SOIL TYPE B

Horizon	Depth (in.)	Characteristics
A_1	0-9	Grey-brown sandy loam, with weak grade of granular structure
A_2	9-13	Bleached, compacted, sandy loam
B_1	13-25	Dark grey-brown clay, with moderate grade of medium blocky structure
B_2	25-30	Sandy clay with slight lime, becoming cemented in depth
B—C	30-60	Heavily cemented sandy clay loam

Each legume under test was grown with perennial ryegrass, and each grass with white clover. Three plots per treatment were randomly located within an area of 4 acres. Treatments chosen for study were:

(i) The following grasses associated with white clover: cocksfoot (Akaroa strain) (*Dactylis glomerata*), paspalum (*Paspalum dilatatum*), phalaris (*Phalaris tuberosa*), and perennial ryegrass (Clunes) (*Lolium perenne*).

TABLE 2

YIELD OF DRY MATTER, JUNE 1948-MARCH 1950

	Phalaris — White Clover	Paspalum — White Clover	Cocksfoot — White Clover	Ryegrass — White Clover	Lucerne* — Ryegrass
Dry matter (ton/acre)	5.0	5.6	5.4	6.3	7.8

* Lucerne dominant.

(ii) The following legumes associated with perennial ryegrass: lucerne (Hunter River) (*Medicago sativa*) and white clover (Irrigation) (*Trifolium repens*).

Total herbage yields over the two-year period preceding root sampling are shown in Table 2.

III. SAMPLING

Six infiltration sites were located by a grid on each plot. Veihmeyer tube cores of 1-in. diameter were taken for the determination of soil moisture and macroorganic matter concentration. Immediately before infiltration four cores were taken equidistant from one another and 2 ft from the rim of each infiltration ring, the cores being bulked for each of the depths 0-3 in., 3-9 in., and 9-18 in. Twenty cores for macroorganic matter determination were taken at random from a 22-ft-wide fallow strip adjacent to the experimental area. A Coile apparatus of 4-in. diameter was used for taking samples for the determination of apparent density and aggregation, six samples being taken per plot. Infiltrations were run, and Veihmeyer tube and Coile apparatus samples were taken between May 17 and May 22, 1950. Between July 24 and August 11, 1950, two soil prisms from each pasture were excavated and washed to expose contained roots.

IV. Techniques

Living and partly decomposed underground plant parts were separated by centrifuging suspensions of soil in sodium chloride solution of density 1.2 g/cc, and filtering the supernatant. The residue was washed on the filter with water to remove excess sodium chloride, and subsequently oven-dried at 55°C and weighed. The separate was termed macroorganic matter. Control determinations were made on soil kept fallow during the experiment, and the control values were subtracted from treatment means.

Root growth habit was assessed by tracing the course of main roots on a trench face, and by washing out roots from soil prisms 8 in. wide by 3 in. thick by 18 in. deep. The prisms were collected in open boxes with wire mesh bottoms. The boxed prisms were soaked in a dilute sodium chloride solution for four days between each of a series of washings with a fine spray. Position of the main roots was noted during washing. Some loss of minor roots could not be prevented. After washed root systems had been floated out in a shallow tank, the roots of the associated grass or legume were removed from those of the species under examination. The separated root system of each species was floated and stored in 3 per cent. formalin solution, until photographed against a background 3-in. grid.

The depth of water which infiltrated into the soil during 10-minute intervals to 60 minutes was measured using an unbuffered 12-in. ring supplied with water at a constant head. Ground surface was not disturbed before the rings were inserted, the depth of insertion being 3 in. Total infiltration values were corrected to a common antecedent soil moisture by a regression method (Tisdall 1951). Probe depth was measured at the centre of each ring 24 hours after infiltration, with a $\frac{5}{8}$-in. diameter steel probe.

Water-stable aggregation > 1 mm was determined by wet sieving after flood wetting and soaking for 16 hours. Per cent. aggregation was calculated from the expression:

$$\text{Per cent. aggregation} = 100(Ra - Rb)/(M - Rb)\%,$$

where Ra is the dry weight of residue obtained after soaking and wet sieving, *Rb* is the dry weight of residue obtained after complete dispersion and wet sieving, and

M is the sample dry weight.

V. Results

(*a*) *Root Growth Habit*

All species showed a marked reduction in root concentration at the compacted A_2 horizon and at the cemented B_2 horizon. Few roots of white clover, ryegrass, or cocksfoot penetrated deeper than 25 in., and few roots of paspalum or phalaris penetrated deeper than 30 in. Most of the lucerne tap-roots penetrated to between 3 and 4 ft, and a few reached 7 ft. Some roots were deflected laterally by the cemented B_2 horizon. Roots of the different species varied in their ability to penetrate the blocky macro-aggregates of the B horizon. Perennial ryegrass, cocksfoot, and white clover roots tended to be restricted to the cleavage faces, but the coarse roots of phalaris and paspalum penetrated through the mass of the aggregates.

Two types of root were present in the root system of each grass: main roots of wide diameter arising from the tiller bases and penetrating more or less vertically, and fibrous lateral roots of lesser diameter which obliquely ramified through the soil. The contrast between the morphology of main and lateral roots was most pronounced in phalaris, in which the main roots were 0.1 to 0.2 in. in diameter. The cortex of these roots easily stripped away from the stele, and the wood bundles were large. Most young main roots were visibly hairy. The main roots of paspalum had a smaller diameter, but higher tensile strength than the main roots of phalaris. The contrast between main and lateral roots was less marked in ryegrass and cocksfoot, in which the roots were closely branched. Average diameter of ryegrass roots was less than that of phalaris or paspalum, but greater than that of cocksfoot. The ryegrass root system formed a dense, hair-like mass in the A_1 horizon, below which the root concentration sharply declined. Cocksfoot had a finely ramifying root system with laterals of narrower diameter than those of any other species examined.

White clover stolons and adventitious roots had built up an A_0 horizon from 1 to 2 in. in depth. Most clover roots penetrated the soil vertically from the runner nodes. Small rounded nodules of about 0.1-in. diameter were distributed evenly over the root system in the A_2 horizon. Nodules occurred more sparsely on roots growing in cleavages of the B horizon, and were flattened in the plane of the cleavage. The lucerne root system was distinguished by its tap root habit. Lateral roots were sparsely developed compared with the grasses. Few nodules were found, but individual nodules were large, ranging up to 0.7 in. in length.

The root growth habit of each species is illustrated in Plate 1.

(*b*) *Addition of Macroorganic Matter to the Soil*

The concentration by weight of macroorganic matter present in the fallowed control strip decreased from 0.25 per cent. at 0-3 in. through 0.17 per cent. at 3-9 in. to 0.11 per cent. at 9-18 in. depth. Table 3 shows the additional concentration of macroorganic matter found at each depth under the five pasture treatments.

TABLE 3

ADDED MACROORGANIC MATTER UNDER FIVE PASTURE TREATMENTS

Depth (in.)	Added Macroorganic Matter (dry wt. % of oven-dry soil)					Difference for Significance at	
	Phalaris — White Clover	Paspalum — White Clover	Cocksfoot — White Clover	Ryegrass — White Clover	Lucerne — Ryegrass	$P = 0.05$	$P = 0.2$
0-3	1.55	1.86	1.24	1.88	0.92	0.58	0.36
3-9	0.25	0.37	0.16	0.25	0.30	N.S.	0.10
9-18	0.14	0.13	0.04	0.07	0.07	N.S.	0.04

White clover-perennial grass pastures added substantially more macroorganic matter to the top 3 in. of soil than did the lucerne-dominant pasture, the difference probably resulting from higher concentration of tiller bases, rhizomes, and lateral roots under the clover-grass associations. Within the clover-grass group, ryegrass and paspalum pastures each added more macroorganic matter to the top 3 in. than did the cocksfoot pasture. Pastures containing phalaris or paspalum, each of which is a deeply rooting grass, tended to add most macroorganic matter to the 9-18 in. depth. From half to three-quarters of the macroorganic matter added to the 0-18 in. soil depth occurred in the top 3 in.

(*c*) *Effects of Pastures on Soil Structure*

(i) *Water-stable Aggregation.*—Determinations were made on 0-3 in. samples from three pastures, samples from the two remaining pastures having been spoiled. Water-stable aggregation tended to be higher under cocksfoot-clover than under ryegrass-clover or lucerne-dominant pastures. Results are given in Table 4.

TABLE 4

WATER-STABLE AGGREGATION > 1 MM. ON 0-3 IN. SAMPLES

	Cocksfoot — White Clover	Ryegrass — White Clover	Lucerne — Ryegrass	Difference for Significance at $P = 0.05$	$P = 0.2$
Water-stable aggregation (%)	10.2	6.6	6.0	N.S.	2.5

Aggregation may be favoured by the intensely ramifying system of fine roots possessed by cocksfoot.

(ii) *Apparent Density*.—Apparent density of the 0-3 in. soil depth did not differ between treatments, and showed no relationship with weight of added macroorganic matter. It follows that roots occupied existing pore space, although pore size distribution may have been altered by their growth.

(iii) *Infiltration Rate*.—For any one pasture, as macroorganic matter concentration in the 0-3 in. depth increased, infiltration rate decreased, the correlation being significant at $P = 0.05$ within a macroorganic matter concentration range of 0.6 to 2.2 per cent.

$$I_{60} = a - 1.45R,$$

where I_{60} is the infiltration rate in in. water per 60 min, and

R is the weight of macroorganic matter added by the pastures per cent. of soil at 0-3 in. depth.

The relationship may be due to plant material occupying a greater part of soil pore space at higher macroorganic matter weights. Infiltration values computed at a common concentration of added macroorganic matter of 1.5 per cent. in the 0-3 in. depth are given in Table 5.

TABLE 5

INFILTRATION RATE AT A COMMON CONCENTRATION OF ADDED MACROORGANIC MATTER OF 1.5 PER CENT. AT 0-3 IN.

	Phalaris — White Clover	Paspalum — White Clover	Cocksfoot — White Clover	Ryegrass — White Clover	Lucerne — Rye-grass	Difference for Significance at $P = 0.05$
Infiltration rate (in./60 min)	1.9	2.3	1.6	1.8	0.7	0.7

Infiltration rate differences between pastures at common macroorganic matter and soil moisture contents are most likely to be caused by differences in root quality or in ground cover. The higher infiltration value for the paspalum than for the cocksfoot pasture may result from the coarser, deeper growth habit of the paspalum. The lucerne-dominant pasture exposed a higher proportion of bare ground than the co-dominant grass-clover pastures, and structural deterioration of the exposed surfaces may have been the cause of its lower infiltration value.

(*d*) *Variability*

The variability data given in Table 6 refer to values for 0.01-acre pasture plots randomly located over an area of apparently uniform sandy loam soil. Plot means for aggregation and infiltration were highly variable.

Apparent density and probe depth had relatively low inter-plot variation, but differed in that intra-plot variation was very small for apparent density, but very high for probe depth. Macroorganic matter weights were moderately variable within and between plots.

TABLE 6

VARIABILITY OF SOIL STRUCTURAL PROPERTIES AND ROOT WEIGHTS

Measure	Coefficient of Variation of Replicates Freed from Sampling Error	Factor by which Coefficient of Variation is Increased for k Samples/Plot	Replicates showing 20% Difference between Means as Significant at $P = 0.05$ for 6 Samples/Plot
Water-stable aggregation > 1 mm at 0-3 in. (%)	17.3	$\sqrt{1 + 2.86/k}$	15
Infiltration (corrected for soil moisture) (in./60 min)	17.3	$\sqrt{1 + 6.62/k}$	15
Probe depth after infiltration (in.)	3.5	$\sqrt{1 + 48.6/k}$	2
Apparent density at 0-3 in. (g/c.c.)	8.0	$\sqrt{1 + 0.03/k}$	2
Macroorganic matter at 0-3 in. (dry wt. % of soil)	15.4	$\sqrt{1 + 4.35/k}$	9
Macroorganic matter at 0-18 in. (dry wt. % of soil)	13.1	$\sqrt{1 + 3.65/k}$	6

VI. DISCUSSION

The quantity of macroorganic matter added to the soil by pastures in this experiment was high compared with the amounts of underground plant material reported by workers in other countries. The difference may be attributed partly to the method of separation and partly to differences in productivity. Underground plant parts and the products of their partial decomposition have usually been separated by wet denudation and collection on sieves. The separate has been variously termed "underground yields" (Shively and Weaver 1939), "roots and other plant residues" (Saharina 1940), "root fibre" (Stevenson and White 1941), and "underground plant materials" (Troughton 1951). Collection on sieves allows the loss of fine roots and portion of the partially decomposed material. The flotation and filtration procedure used in this experiment separates coherent organic matter particles of diameter > 2 μ, the term *macroorganic matter* being introduced to describe this fraction. Intact roots may be hand-separated from the residue on the filter, if their mass is specifically required. Root growth may provide almost all the macroorganic matter added to the lower parts of the profile, but in the top few inches, rhizomes, tiller bases, and dung and plant debris trampled in by stock will be important additional sources.

The macroorganic matter concentrations found correspond to a mean addition of the order of 10 tons of oven-dry material per acre to a depth of 18 in. Troughton (1951), using a denudation method with sieves of 0.01 in. minimum aperture, found from 5 to 9 tons of air-dry underground plant material per acre to a depth of 24 in. under perennial pastures growing at Aberystwyth on a clay soil. Goedewaagen and Schuurman (1950), using 0.03 in. aperture sieves, found 3.5 tons of air-dry roots and rhizomes per acre to a depth of 8 in. under three-year-old grassland on a sandy soil.

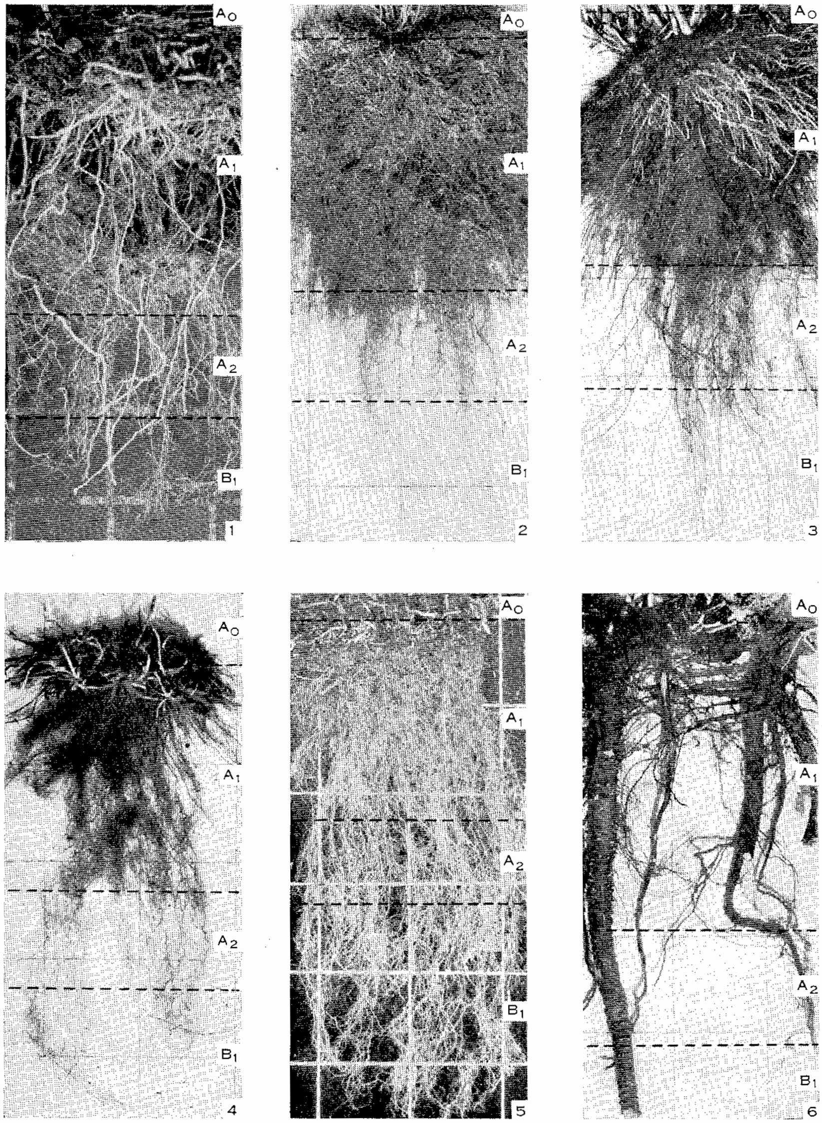
A rapid decrease in concentration of added material with depth has been reported by numerous workers, and it also occurred under the conditions of this experiment. The top 3 in. of soil contained from half to three-quarters of the macroorganic matter added to the 0-18 in. depth.

A comparison of the effects of the various pastures on soil structure showed that differences in quality of the added materials were as important as the quantities added. Pastures were shown to differ in their effects on infiltration rate even at a common concentration of added macroorganic matter. Iovenko (1939) concluded that irrigated ryegrass ley increased the porosity and granulation of the 0-8 in. depth of a chestnut loam more than did lucerne, which tended to produce a lumpy structure, and he attributed the difference to the greater ramification of grass roots in the top soil. In this experiment the low rate of infiltration into lucerne-dominant pasture, compared with the grass-clover pastures at a common soil macroorganic matter concentration, may result chiefly from structural breakdown of bare surfaces exposed between lucerne rows.

The decrease in infiltration rate, which accompanied increase in macroorganic matter content of the 0-3 in. depth of soil, is tentatively attributed to pore blockage by plant roots. In this depth roots occupied more than 10 per cent. of pore space, and their development under irrigation conditions failed to increase pore space. Conditions favouring root decay might ultimately lead to increase in infiltration rates and reversal in the infiltration rate ranking of replicates, because of macropore continuity provided along old root channels.

To prevent loss of water by deep percolation, irrigations should wet the soil to a depth not exceeding that occupied by the root system. Subjective assessments of depth of occupation may be used as a proximate guide to the desirable depth of wetting, providing that, previous to the assessment, lack of water in depth has not itself limited root penetration. Since many lucerne roots had penetrated to four feet depth on soil type B, it is unlikely that lack of water in depth limited the penetration of shallower rooted species. Wetting soil type B to field capacity to a depth exceeding 2.0 ft where clover-ryegrass or clover-cocksfoot pastures are

EFFECT OF ROOT GROWTH ON SOIL STRUCTURE



The root systems of pasture species denuded from soil prisms 8 in. by 18 in. by 3 in., and separated by hand from the root system of the associated legume or grass. Background grid = 3 in. by 3 in. 1, phalaris; 2, ryegrass; 3, paspalum; 4, cocksfoot; 5, white clover; 6, lucerne.

grown, or to a depth exceeding 2.5 ft where clover-paspalum or clover-phalaris pastures are grown, is likely to lead to loss of water by deep percolation, since very few roots of the pastures concerned penetrate beyond those depths.

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