THE ROLE
of
THE ROOTS OF SOME GRASS AND CLOVER SPECIES
in the
IMPROVEMENT
of the
SOIL STRUCTURE
of a
TOKOMARU SILT LOAM.

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SECTION I.

INTRODUCTION.

It has long been realised that grassland has a beneficial effect on the fertility of soil. This is not only the case with the natural grasslands of the world which are found in areas of limited precipitation and cold winters, and which have provided a rich harvest of grain products for many years after their initial ploughing. It is also so in those other agricultural areas where forest was the natural cover, and where it has now been found necessary to alternate the exhaustive periods of crop growing with restorative periods in pastures.

The improvement in soil fertility due to the growth of the grass-clover-herb mixtures is partially due to the build up of nitrogen through both free-living and symbiotic nitrogen fixing organisms (78). It can also be the result of the supplemental feeding of the grazing animals. But some of the value of the pasture rest period has been shown to be due to the more suitable arrangement of the soil particles following this period in pasture. These primary particles are normally gathered together into aggregates or clods or crumbs, and the size distribution and the stability of these determines the soil structure. Davies (11) goes so far as to say that the chief fertility effect of the grass/legume ley is per medium of soil structure. Common observations together with measured improvements in crumb structure in many recent experiments (50, 58, 75, 39, 44) have demonstrated these changes in the soil. Other investigations (3, 56, 53) have shown the beneficial effect of this improved structure on the crops subsequently grown.

On the other hand in some of the world's main grain growing regions, although the yields remain payable, excessive cropping without any restorative periods has reduced the structural condition of the soil to a stage where in some parts soil erosion has become so serious that remedial measures are difficult to apply. The "Dust Bowl" of the United States is a case in point, and it seems likely that some of the world's desert areas have been extended as a result of similar circumstances.

Little, however, is known of the relative value of grasses and legumes in the maintenance of good soil structure, nor have many of the grass species been evaluated in terms of their structure building ability. Russian (26) and English (39) workers differ in their conclusions as to how long the restoration of structure by grassland takes, the former contending it is complete in two to three years, the latter considering that it is still far from completed after 25 years. No indication is available as to what happens under New Zealand conditions, although with our present proportion of arable land to pasture, and with the short time that any one paddock is under the plough, the problem is not of major importance in our agricultural areas. However, it is probable that with increasing population we shall have to increase arable crop production to an extent not yet known in New Zealand. When that happens knowledge of the value of grasses and clovers in structure restoration will be imperative, as it is now on many of the intensively cropped soils of the world.

This experiment was designed to investigate some of the unanswered problems outlined by Davies (11) in 1949, in particular:-

"1. What is the role of grasses, legumes and herbs in relation to soil structure?

2. Is a quickly decomposing root system such as is found in the ryegrass/white clover ley better adapted to soil up-building than a slowly decomposing turf?

3. Have the tufted grasses as ryegrass, cocksfoot and timothy any advantage or disadvantage in relation to soil conditions over the rhizome-forming grasses?"

As no suitable plots of single species were available on soil of low structural stability, it was decided to sow down such plots and follow the changes in structure and in root growth during a period of about two years. To gain further information about the effect of the sub-aerial parts of the grasses and clovers, a subsidiary pot experiment was designed to give some information on the rate of breakdown of grass and clover roots in the soil and to measure what effect this had on the stability of the aggregates in that soil.

The paucity of information on methods of measuring soil structure in New Zealand meant that careful consideration had to be given to techniques used elsewhere. Consequently, much of the early work in the investigation consisted in developing a satisfactory technique for the prevailing conditions. Because of the importance of being able to obtain repeatable results in line with field conditions, the work leading up to the method finally adopted is fully reported in Section III.

SECTION II

REVIEW OF LITERATURE.

A. Soil Structure

As already mentioned, the development of soil structure is largely due to the formation of stable aggregates of primary particles. Baver (12) in 1948 considered that this cementation was caused by the soil colloidal material which is composed of at least three distinct groups:

(i) Clay particles;

(ii) Inorganic colloids such as oxides of iron and alumina;

(iii) Organic colloids.

The properties of clay make it a very important factor in aggregate formation, but the importance of colloidal iron has not been evaluated sufficiently to date. However, these two effects will not be discussed in detail as the role of plant roots in aggregate formation is unlikely to be operative in this direction. There is no doubt that the effects of organic colloids in developing stable aggregates are widespread. The findings of Martin (47, 48) McHenry and Russell (43) and Elson and Lutz (15) are typical of those of many others who have found that the quantity and quality of organic matter additions to soils have had pronounced effects on their structural changes. It is also known now that organic substances other than colloids can act as binding agents in the formation of water stable soil granules. (21, 41, 65, 88, 36). These consist of cells of micro-organisms and their secretory products such as mucus, slime or gum produced during growth (85). Other materials such as polysaccharides, synthesized by certain soil micro-organisms are known to improve the aggregating propensities of soils. Martin and Waksman (46) found that the more readily the organic matter decomposed, the greater was the effect on aggregation. In the case of decomposition by fungi, the extensive mycelial growth caused a mechanical binding of the soil particles in addition to aggregation from synthesized organic compounds.

Many investigators have found that a high state of aggregation may be produced by the addition of various organic materials to the soil. These substances are metabolites and are being built up and broken down continuously by biological means (62). The speed of decomposition depends largely on the same factors that determine the nutrition of the plant. So that the maintenance of good structure is therefore dependent on a continuous supply of organic matter or on the presence of aggregating substances capable of withstanding rapid breakdown by biological or other means. These latter are not normally present naturally but have been synthesized artificially, the one best known in New Zealand being Krilium (23).

Increased stability of soil aggregates formed from worm casts has been reported by Dutt (14), Hopp (25), Swaby (88) and Bakhtin and Polsky (1). The reasons for this have not been worked out but are thought to be due to mucilages produced either by the worm or by bacteria in its gut (69). Worm casts on pasture were found to be more stable than those from arable land indicating that the composition of the organic matter in the diet of the worms was different in each case. However, the effect of the worms was small compared with the effect of a 3 year ley. Watkin (95) found no definite trends in size distribution of soil aggregates in samples taken from plots having big differences in worm populations.

Nikolsky (55), among many others, considers that in a pasture, the improvement in soil structure is at least partially due to the return of organic matter both from ungrazed aerial parts and from the roots to the soil. As Baver (4) states, there is no satisfactory explanation as yet of the nature of the beneficial root effects. Nikolsky suggests that the root hairs serve to bind mechanical elements together and that the humus produced by the enhanced biological activity of the rhizosphere cements the more finely divided particles.

He postulates the formation at this stage of a water-stable mass and its simultaneous breakdown into granules by the action of root pressure and temperature changes. Sekera and Brunner (79) maintain that the smaller aggregates are composed of particles bound by colloidal cements, and that the larger aggregates are held together by living matter such as root hairs and fungal mycelia. Russell (69) agrees that the larger clusters are probably held together by roots, but is not sure whether the smaller granules are the result of direct action of the living material such as root hairs and micro-organisms or of biproducts of their life and death. Jacks (26) states that the most active part of a grass crop in aggregate formation is the root system which is not only the source of much of the humus which cements the soil particles into aggregates, but also has a mechanical effect in breaking up the clods and preventing them from coalescing. Keen's (34) conclusions in 1949 were similar. He says "In part, structure is mechanically caused by the roots pushing the soil particles into closer contact. In general, grasses would be expected to be more efficient in this respect than legumes because their total root length is much greater. Some form of cementing material, organic or inorganic or both, is involved in the water stability of the crumbs formed. Among agents that are responsible for this are the decomposition products of dead roots, the shedding of root caps in growth, siliceous compounds from root decay, lignification of roots into resistant compounds, and exudation from the living roots."

Baver (4) recalls that the earliest explanation of the effect of a grass sod was based on the pressure exerted by the growing roots, which effects a separation of the particles adjacent to the root and the pressing together of these units into aggregates. The penetration of sufficient root hairs or roots throughout a clod causes the formation of granules. One of the more recent suggestions is that granulation is accomplished by changes in moisture in the vicinity of the root system as a result of water uptake by the plant. This produces localized dehydration which brings about shrinkage and the formation of surfaces of fracture. It seems plausible to conclude that hypothetical materials produced during root growth and decay stabilize any aggregates that are formed. M.B. Russell (75) describes the effects of sod-crops in very similar words.

Bradfield (quoted by Jacks (26)) believes that the distribution of humus in the soil is more important than its quantity. He considers that grass roots provide the ideal distribution. Normal applications of farmyard manure are too localised, while tillage operations tend to give too high a degree of dispersion.

A perennial grass crop is generally considered to be superior to any other plant cover in the development of aggregation, but the effect of legumes is considerable and has been compared with that of grasses under a number of conditions. Several Russian investigators have been quoted by Jacks (26). Pavlov found that the percentage of water stable aggregates under old irrigated meadow was far superior to that in soils which had carried clover and lucerne for up to six years. Savvinov and Varobieva found no advantage for crested wheat grass over lucerne on steppe soils in Russia. Iovenko considers that legumes produce a "cloddy" structure throughout the entire root-inhabiting layer. Grasses, especially ryegrass produce a well-developed medium to fine granular structure, restricted however to the top 12-15 inches.

Shaw (80) at Ohio on Paulding clay found that continuous bluegrass produced a higher state of aggregation than continuous lucerne and this is confirmed by similar experiments at Iowa by Wilson and Browning (103) on Marshall silt loam. Both Gëltser (20) and Tysganov (91) record poor structure forming capacity in lucerne and other legumes compared with grasses.

In Uganda, Martin's (50) investigations indicate that the root systems of legumes are not so valuable in crumb formation as are those of grasses.

On the other hand, Ward (94), also at Iowa, recorded that "legumes (lotus corniculatus and three lespedeza species) were superior in three growing seasons to the prairie grasses on the Weller silt loam on a basis of their increases in aggregation". He considered that the degree of change manifested by a legume or grass was related to soil type.

The effect of individual grass and clover species used separately and together has been investigated by a number of workers. The majority of these have reported on results from the cropping areas of Russia and the United States. Tysganov (91) found that rapidly growing brome grass was an excellent structure former even in its first year. Agropyron tenerum had its maximum effect in its second year and A. cristatum (crested wheat grass) in its third year. Stevenson and White (86) in comparing the effects of crested wheat grass, brome grass and slender wheat grass found they increased the size of soil aggregates in that order. They concluded that the older and tougher root fibres were more efficient structure formers than the slender, easily decomposed roots. Pavlychenko (61) placed these three grasses in the same sequence, but there was no appreciable effect at depths exceeding four inches. Brome grass produced the greatest amount of underground material in the first two years, but at the end of four years, underground material from crested wheat grass exceeded that of brome grass and still more that of slender wheat grass. He suggested the soil-binding equivalent, i.e. the product of the length in centimetres of the roots per cubic centimetre of soil and their tensile strength in grams, as a measure of the value of a grass in structure improvement. These three grasses were placed in the same order for soil-binding equivalents. He considered, however, that the depth of root penetration and the length of time that the land had remained in sod were important additional factors. McHenry and Newell (44) found no difference in percentage of water stable aggregates on Butler silty clay loam soil on which brome grass and crested wheat grass had been growing for 7 years. Significant differences in structure development between native pasture species in North America have been obtained by McHenry and Newell (44), Pavlychenko (61) and Ward (94) but there is considerable disagreement between them in the placing of the species, depending on the soil type, the depth of sampling and the length of time since the land was sown down.

Very little work has been done to compare the effects of the temperate climate pasture species as soil aggregation improvers. McHenry and Newell (44) included Poa pratensis and Dactylis glomerata in their series but found no significant difference between them after seven years. Sarakhov (76) found that Italian ryegrass was relatively ineffective in the North Caucasian foothills in comparison with English ryegrass, brome grass and lucerne. Orchiston (59) found that on a silt loam in Canterbury, soils growing perennial and short rotation ryegrass were significantly higher in water stable aggregates than soil growing Italian ryegrass. In each case the grasses were sown with white clover and used for fodder conservation purposes. Williams (102) has found at Hurley that different grass species under field plot conditions have given statistically significant differences in the build up of water stable aggregates. These differences are related to the quantity of root material developed in the different swards.

B. Root Development and Deterioration.

Weinmann (100) in his recent review has indicated the importance of various environmental factors on the development of grass roots. The effects of nutrients and fertilizers differ with the other environmental conditions under which the various investigations have taken place, but in general can cause marked changes in the distribution and quantity of roots present. Soil texture also affects root development mainly by restricting growth in compacted sub-soil layers. Extremes of soil moisture inhibited root growth which was generally encouraged by "a relatively low water content so long as good growth was ensured." (97). Changes in root form and growth have been observed also as a result of temperature changes.

Weinmann records many examples of the effect of defoliation on root growth, and in practically all cases the more frequent cutting or grazing led to a decreased yield of roots. Individual species however, respond differently to such defoliation as illustrated in Table I adapted from Jacques (28).

TABLE I Comparative Yields of Air Dried Roots from Different Cutting Treatments.
(Calculated on basis of Certified Cocksfoot = 100)

Species	Cut Weekly	Cut two-Weekly.	Cut three-Weekly.	Uncut.
Certified Perennial Ryegrass	179	274	170	308
Uncertified Perennial Ryegrass	124	207	140	267
Certified Italian Ryegrass	120	306	164	306
Certified Cocksfoot	100	100	100	100
Totals calculated on basis: weekly cut = 100	100	236	355	825

Since Weinmann's review a number of investigations have confirmed and elaborated previous work on the effect of environment on root development. Typical of these is the report from Fox et al (18) on five Nebraska soils where both physical and chemical characteristics of those soils were found to be related to the distribution of grass roots.

Weaver and Zink (98) have commented on the dearth of information on the longevity of grass roots. A similar position exists in the case of legumes. Sprague (84) and Stuckey (87) found that with grasses of temperate climates between fifty and one hundred per cent of the root systems were replaced each year. Yen (108) observed marked deterioration of both clover and grass roots during the summer months. Sloughing of the cortex was used in the grasses as an indication of deterioration and occurred in up to 100% of the old roots. In the clovers the tap root showed signs of disintegration before the plants were a year old. There appears to be considerable variation among species in regard to root deterioration, while there is ample evidence that variations in environmental conditions such as soil moisture and rates of defoliation can affect the longevity of grass roots (5, 100). The roots of grasses and clovers in established pastures therefore can be expected to provide a continual and fairly regular supply of organic matter to the soil. In addition the root hairs of both grasses and clovers are a further source of supply of organic matter and almost certainly give a very intimate distribution of that organic matter throughout the soil. Although it has generally been considered that root hairs are transient, it has been noticed that they appear to be relatively longlined with many pasture species (12). However their survival can be no longer than the cortex of the roots.

In the establishment period of grasses, the plants are maintained by the seminal root system and a small contribution to the soil organic matter occurs when this system deteriorates within a few months of germination and establishment. No deterioration of the main root system of autumn sown pasture plants was found by Yen (108) until the early summer following sowing.

Variation in root form and yield between species growing under identical conditions has been demonstrated by Weaver (96) Jacques (31) and many other investigators. These differences are sufficiently great to produce a very big range of root patterns in the soil. To avoid variation from these factors in this investigation, care was taken to provide as identical environmental conditions as possible for each species. The plot area was small and compact, the site showed evenness in soil type, and defoliation was done with a mower, so that effects of stock through trampling, palatability, and dung and urine return were avoided.