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MANAGING PASTURES FOR BETTER SOILS:

STABILISING SOILS WITH PASTURE

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Abstract: Pastures are seen as a vital component in the sustainability of agricultural production on many hardsetting soils in NSW. Without pastures there is often a general decline in the physical fertility or soil structure of a soil. The total cost of this to agricultural production has been estimated to be as much as $144 million per year in the Murray -Darling Basin. Good soil physical fertility is necessary for plants to obtain adequate amounts of water, air and space for root growth, to maximise productivity. Pastures enhance soil physical fertility by providing protection for the soil surface, adding organic matter to the soil and developing networks of macropores in the soil. Results from trials and experiments are presented to support these statements. Consideration of the evidence suggests that to do nothing about low soil physical fertility will lead to losses in yield through; loss of useable rainfall as runoff, poor seedbed conditions especially crusting, poor aeration and low trafficability hampering farming and grazing operations. As well, low physical fertility can lead to increased erosion, threatening the long term sustainability of agricultural production.

INTRODUCTION

Soil structure decline is a major problem in the cropping areas of New South Wales. A recent survey by the Soil Conservation Service (SCS, 1989) showed that 28% of the soils in central New South Wales are affected by soil structural decline. Another estimate is that up to $144 million in lost production can be attributed to soil structural decline each year (Murray-Darling Basin Environmental Resource Study). Similarly, in southern subtropical Queensland, it is estimated that 1.2 million hectares of a total cropping area of 1.5 million hectares are affected by soil fertility decline, physical and chemical, with a consequent reduction in crop yield and grain quality valued at an output loss of $324 m/yr (Dalal *et al.*, 1991).

The focus of this paper is how pasture growth can improve the physical status of soil, increase productivity and enhance sustainability of agricultural production.

THE IMPORTANCE OF STRUCTURE AND PHYSICAL FERTILITY OF SOIL

Soil structure refers to the physical fertility of the soil. One thing lacking in a lot of discussion on soil structure is a clear understanding of what is meant by the term *soil structure*. A suitable definition is "the arrangement of air space and solid soil particles within a soil". A typical piece of rock has no air space and is solid with bulk density of 2.65 g/cm3. A typical agricultural soil has about 48% air space when dry and a bulk density of 1.40 g/cm3. When wet, some of that air space will be filled with water.

Air or pore spaces in a soil are necessary for plant growth. The pore space performs the following functions:

- Transport of water from the surface into the soil
- Transport of oxygen into the soil and of carbon dioxide from the soil
- Provides protection for newly sown seed, providing a moist environment for germination and emergence
- Provides space for the newly germinated seedling allowing it to emerge with a minimum of resistance and stress
- Provides space for the growth of roots
- Holds water so that it is available to plant roots.

EFFECTS OF OVER-CULTIVATION ON SOIL STRUCTURE

Over-cultivation is a major cause of soil structural decline. It has the following effects:

1. Severs organic bonds and causes oxidation or loss of organic matter. Lighter textured soils (*eg.* red-brown earths) are particularly dependent on organic matter for structural stability;
2. Pulverises aggregates, breaking them into ultimate particles;
3. Destroys or cuts off from the surface all the large pores in the soil which may have been formed by plant roots or soil animals such as worms;
4. The loose condition formed by the cultivation in structurally degraded soil is very unstable because of low aggregate stability and after the first rains the soil is quickly packed down to a dense mass with a thick crust; and,
5. Cultivation implements smear and compact in moist

conditions, forming thin layers of very low permeability, high bulk density and high soil strength.

Grazing may also cause soil structural decline by stock compaction, particularly in wet soils. However, the extent of soil structural decline attributed to this cause is not as well documented (Packer, 1988).

THE MAINTENANCE AND BUILD UP OF SOIL STRUCTURE BY PASTURE

Plant growth can have a large effect on soil structural properties by the following processes;

- Providing protection at the soil surface from raindrop impact and stock trampling.
- Adding organic material to the soil.
- Developing networks of macropores in the soil.

Surface Protection

The growth of the above ground parts of plants protects the soil surface from raindrop impact preventing the destruction of soil structure and crust formation. It is generally considered that 70% cover is required to protect the soil surface from raindrop impact to prevent crusting and minimise erosion (Lang and McCaffrey, 1984).

Aggregate/Macropore Stability

Root growth improves aggregate and macropore stability to wetting and raindrop impact. It does this by growing through the soil, leaking organic substances into the soil and sloughing off cells. All these provide food for bacteria, fungi, earthworms and other small animal fauna.

Table 1 shows that the amount of root material in the soil can be as high as 6 tonnes/ha under a long term actively growing grass stand.

The amount of roots tends to be less under a crop, being of the order of 1.5 t/ha. The length of root systems can give an indication of the amount of organic matter added to the soil by plant roots. Under long-term grass, the length of roots is of the order of 200 km/m^2 and under crop about 50 km/m^2. Of course the actual values in a paddock depend on the rainfall, the fertility of the soil, the depth and texture of the soil and the plant species. Figure 1 shows the effect of 3 years of grass pasture on aggregate stability, relative to adjacent native and cultivated situations, on North Star clay loam which is a hard setting soil.

Table 1: Quantity of roots found in the upper 10 cms of soil under different conditions (Adapted from Russell, 1961).

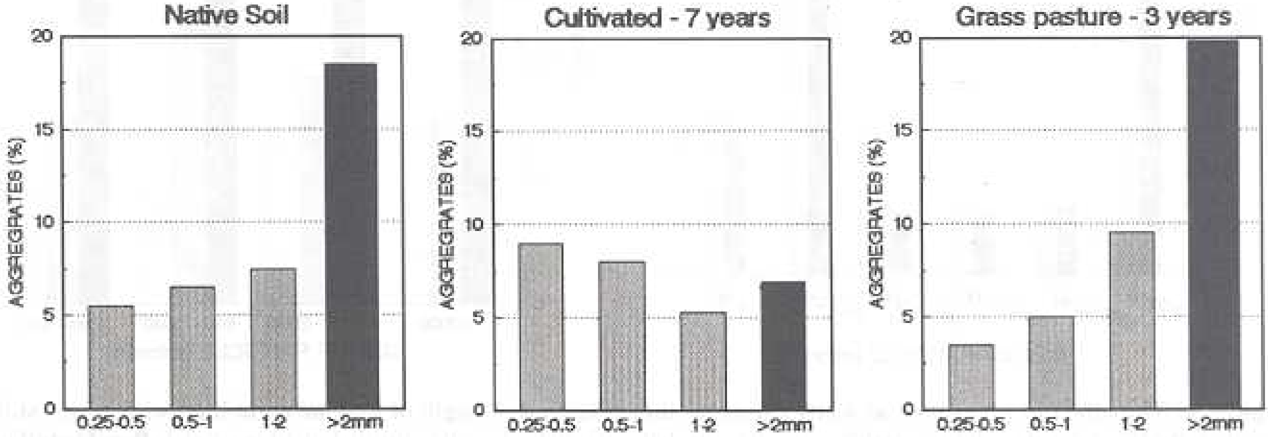
Root parameter	Long-term grass stand of crested wheat grass (*Agropyron cristatum*)	Wheat crop (*Triticum aestivum*)
Weight (t/ha)	6	1.5
Length (km/m^2)	200	50
Diameter (mm)	0.4 to 0.01	0.32 to 0.08

The size of roots is an important factor in predicting their effect on soil structure. Roots of grasses tend to be finer than those of the broadleaf plants (Figure 2).

Most grass roots tend to be less than 0.5 mm in size and smaller. This means they are very effective at binding soil particles together. Grasses are generally considered more effective for improving soil structure than broadleaf plants as shown by the comparison of the stabilising effects of rye grass and clover on soil structure (Figure 3). An explanation for this is the increased fungal hyphae length, associated with greater root activity of grasses (Figure 4).

Increased organic matter from roots enhances the activity of fungi, earthworms and other soil organisms. This activity increases the number and stability of macropores and soil aggregates by the following processes:

- Fine roots binding soil particles together
- Fungi, which feed on the root exudates, sloughed off root cells and dead roots binding the soil together
- Products from bacteria, fungi and roots (polysaccharides) binding soil particles together
- Earthworms ingesting soil and mixing it with organic matter to form worm casts which are stable to wetting
- The addition of organic substances to soil aggregates can make them water repellent, slowing down the rate of wetting and so making them more stable to wetting.


Native Soil

Cultivated - 7 years

Grass pasture - 3 years

Figure 1: The effect of landuse practices on aggregate stability at North Star on a hard setting clay loam. (Enright & Harte, unpublished).

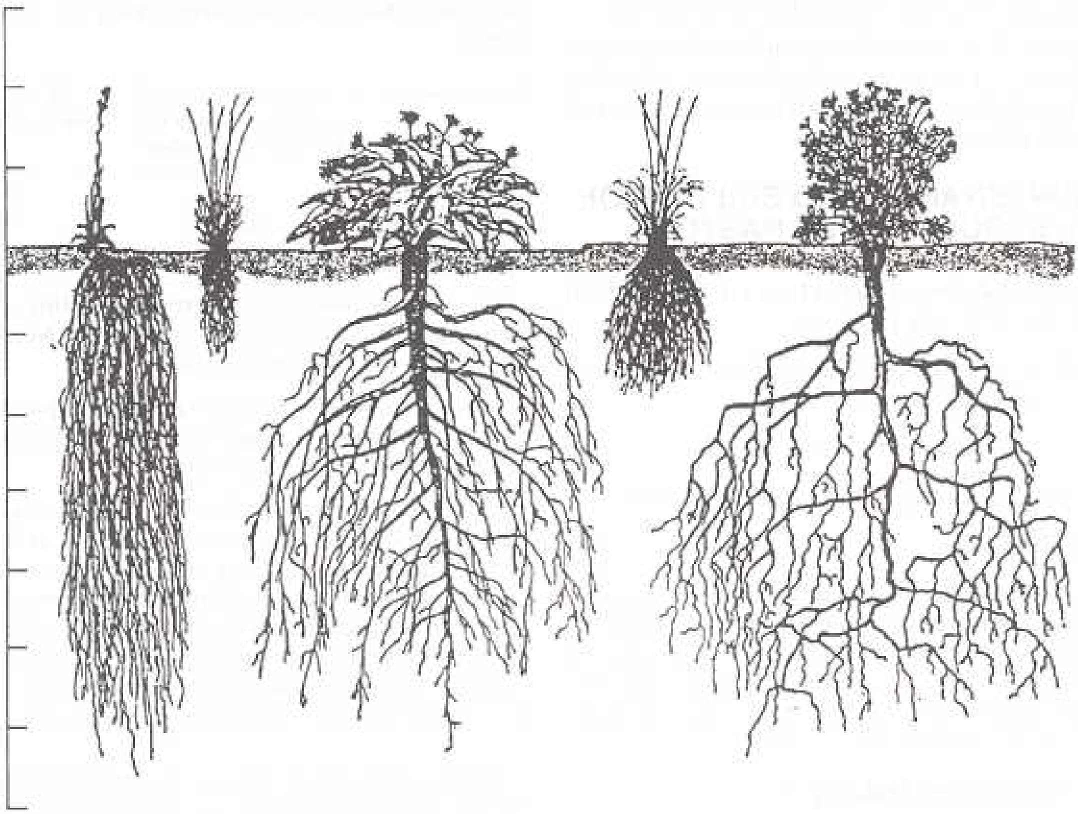


Figure 2: Bisect showing root and shoot habit of grass and broadleafed plants (adopted from Weaver and Clements, 1938).

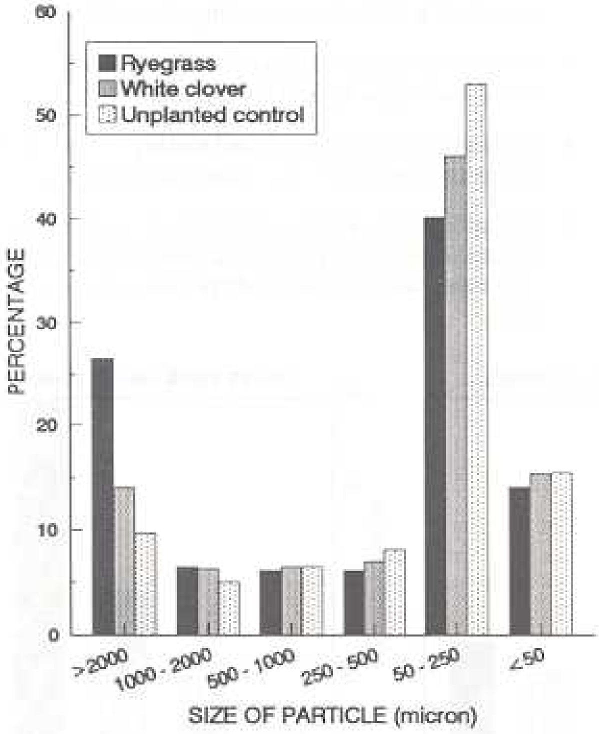


Figure 3.: The effect of ryegrass and white clover on the size distribution of water stable particles in soil (sampled at 14 weeks) (after Tisdall and Oades, 1979)

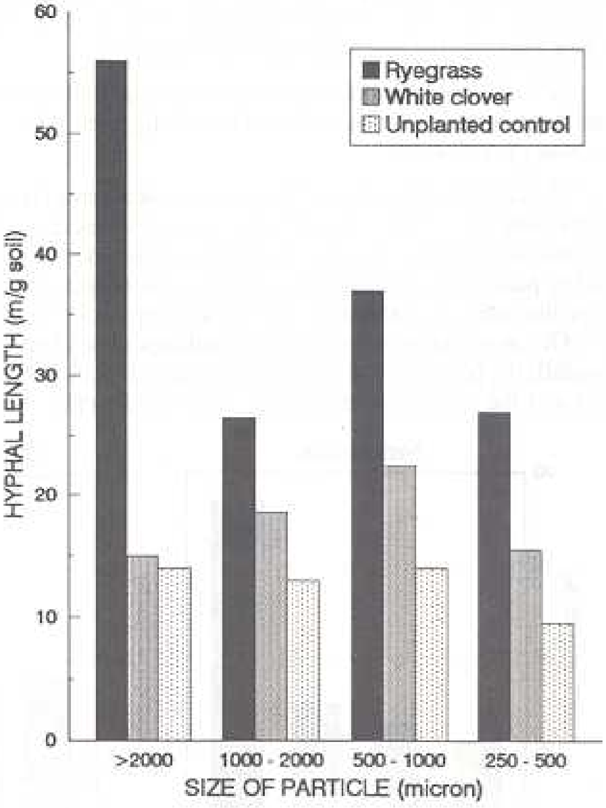


Figure 4: Length of hyphae combined with water stable particles in soil (sampled at 14 weeks) (after Tisdall and Oades, 1979)

Table 2: Typical values of soil structural properties of hardsetting soils in southern NSW for different management histories (Geeves *et al*., unpublished).

Soil parameter	Woodland	Long-Term Traditional Tillage	Long-Term Native Perennial Pasture	Heavily Grazed Pasture	Improve Pasture	Scalds
Organic Carbon %						
0-20 mm	6.17	0.92	6.42	1.05	3.30	-
20-50 mm	5.32	0.81	2.62	0.59	1.57	-
Water Stable Aggregrates (%)						
0-20 mm	57.5	28.7	63.1	29.7	66	-
20-50 mm	65.3	30.7	48.7	16.4	74	-
Infiltration (mm/hr)						
At the surface	160	18	146	20	61	2
Bulk density (g/cm^3)						
At 0-40 mm	0.91	1.5	1.18	1.59	1.32	-

The actual rate of growth of roots is determined by the growth of the above ground parts of the plant. If there is little growth above ground then there will be little root growth. Therefore an actively growing plant is necessary to maximise root growth in the soil and the addition of organic matter.

Development of Macropore Networks in Soil

As well as adding organic matter, roots can form networks of macropores in the soil by making room in the soil to grow. Thus roots can form a network of macropores in a soil which was previously dense and had no macropores (Figure 2). These can increase the infiltration and aeration of the soil and reduce the bulk density. Results showing this in the northern part of the state are shown in Figures 5 and 6. Results for the southern part of the state are shown in Tables 2 and 3.

The results from North Star show that higher infiltration and lower bulk density are associated with higher macroporosity in pasture soils (Figures 5 and 6). Results from southern NSW (Tables 2 and 3) show similar results, but it is clear that the two heavily grazed paddocks, the heavily grazed paddock in Table 2 and the oats paddock in Table 3, have soil structural properties closer to the long term traditional tillage treatment than the actively growing pastures. To explain this, it is necessary to consider the effect of grazing pressure on soil structure. Packer (1988), estimates the compactive pressure of sheep as 60 to 80 kPa, cattle as 160-190 kPa and tractors as 30-150 kPa. It has also been estimated that a sheep can cover 0.01 ha/day with their hooves. The potential for surface compaction from stock is a real problem and soil structural decline of the surface soil from this source may be much more widespread than previously recognised.

Table 3: Structurally Degraded Grazing Paddock.

	Bulk density (g/cm3)		Hydraulic conductivity (mm/hr)	
Depth Tension	0-40mm	0-80 mm	10 mm	40 mm
Oats[A]	1.60	1.56	5.30	1.97
Pasture[B]	1.31	1.55	22.44	4.45
Significance (t-Test)	***	ns	**	***

[A] Oats paddock sown to oats in 8 consecutive years and grazed; [B] Pasture paddock grazed for 7 years, pasture growing strongly 30-40 cm; [C] Standard deviation, 8 replicates

Macropore networks may become critical in soil with compacted zones such as plough pans. Roots can grow through these when conditions are favourable in terms of aeration and soil strength, leaving macropores through which roots can grow in a much wider range of conditions than was previously possible. This may be one reason why plough pans may not be as restrictive to yield as was once thought.

Macropores only become available for air and water flow when roots die, desiccate and are broken down. It is possible for pasture to become root bound, where roots fill all the available macropores and cause low infiltration and aeration (Russell, 1966; Barley, 1953). In these circumstances a light tillage (say with lucerne points) may be beneficial but there is little information on the potential benefits of this.

Root growth can also improve soil porosity by increasing the activity of earthworms. McCredie and Parker (1991) showed steady state water infiltration rates could be increased by up to 24% by the pressure of earthworms.

IMPLICATIONS FOR SOIL MANAGEMENT

Increased aggregate stability and macroporosity gives significant advantages for soil management. These include:

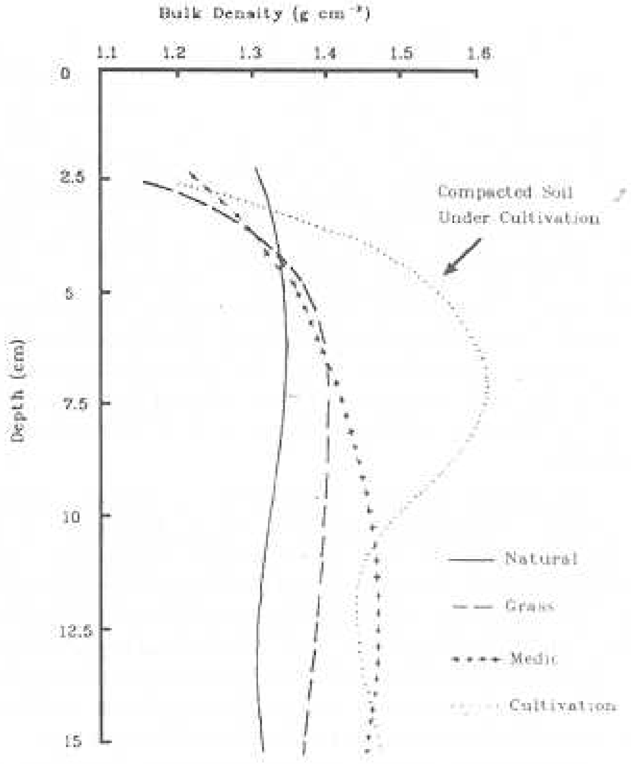


Figure 5: The effect of land management on soil bulk density at North Star

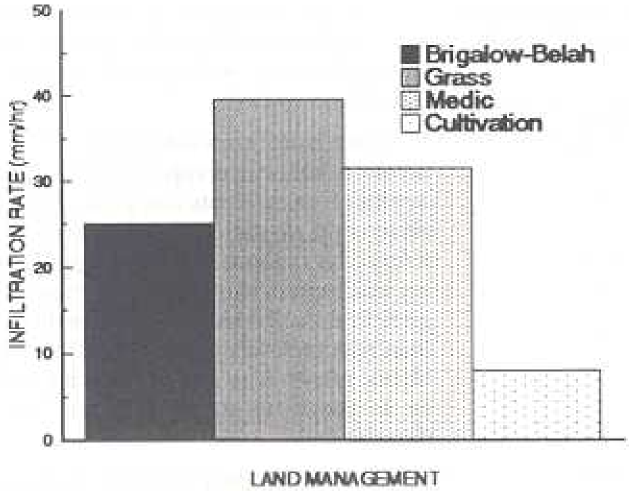


Figure 6: The effect of land management on water infiltration at North Star.

- Higher infiltration rates (see Tables 2 and 3; Figure 6))
- Better friability, making it easier to achieve a good seedbed with minimum cultivation
- Better trafficability associated with higher infiltration rates as water moves away from the soil surface more rapidly
- At those times when cultivation is considered necessary, say to incorporate lime, this operation can be carried out with minimum breakdown of the soil structural condition.

ECONOMIC IMPACT

Work currently underway by Dalal *et al.* (1991) in southern Queensland has produced comparative steady state budgets from a range of landuse options to estimate their relative profits. These options were based on fertiliser nitrogen, chickpea, annual medic, lucerne and mixed grass and legume pasture theoretically adopted on a farm with brigalow soil which is fertility depleted. The conclusions were that pasture leys would play a key role in ecologically and economically sustainable farming systems. There was no attempt to estimate separately the economic contributions made by restoration of soil chemical and physical fertility in these studies. In terms of the whole farm operation, it is not relevant in any case, to discuss one without the other. To be fully appreciated, one must use whole farm economic studies.

The economic ramifications of the 'do nothing' options are more easily presented given the scope of this paper. First approximations of costs of soil physical degradation in the Murray-Darling Basin have already been presented as high as $144 m per annum. It has also been shown that run off and soil loss in older cultivation soils are unacceptably high (Edwards, 1991). Soil is the medium for agricultural productivity and its annual loss for the same basin has been estimated to be costing as much as $5 million per year.

Exact figures on the economic impact of poor soil physical fertility on hard setting soils are difficult to obtain because the results are so seasonally dependent. Results are greatly affected by the particular seasonal conditions depending on the amount of rain falling in each intensity class, when and how much rain falls, the soil condition at sowing, the sowing time, the timing of hot windy days and so on. However, a few general statements can be made.

1. Reduced yields because of the loss of useable rainfall as runoff can be significant. In the north of the state, Murphy (1991) has estimated that for wheat yield losses of up to 300 kg/ha are possible in 50% of years when infiltration rates fall below 10 mm/hr. Equivalent figures for the centre of the state are 200-300 kg/ha and for the south 100 kg/ha. As a general rule, in years when water is limited, yield losses can be estimated at 10 kg/ha/mm of runoff or may be as high as 30 kg/ha/mm at critical times such at flowering or grainfill.
2. Poor physical condition of the soil can increase the cost of production requiring an increase in the number of cultivations necessary for seedbed preparation. Low surface and sub-surface infiltration may also lead to poor trafficability after rainfall hindering the timing of farming operations such as weed spraying and even sowing. The same poor trafficability may leave the surface soil susceptible to compaction damage by stock for a longer period than would be the case in a well structured soil.
3. Poor physical condition may make it difficult to implement cropping practices which are effective in erosion control. The use of direct drill/no till and reduced tillage may cause reduced yields in some poorly structured soils because of poor seedbed conditions.
4. Poor soil physical fertility can lead to increased erosion rates reducing the long term yield potential of soils. Aveyard and Charman (1991) have estimated that reductions in yield as consequence of erosion can be of the order of 0.5% per tonne of soil loss in hardsetting soils. Clearly, there is much circumstantial evidence that the "do nothing" option is not ecologically and economically acceptable.

IMPLICATIONS FOR MANAGEMENT

The results from this paper lead to the following conclusions about the management of pastures:

1. Active plant growth is essential for effective soil structure improvement. The amount of root growth is directly related to the amount of above ground plant growth. Heavy grazing is detrimental to the improvement of soil structure.
2. Protection of the soil surface to prevent the formation of surface crusts and erosion require at least a surface cover of 70% of plant material.
3. Grazing management should try to minimise the effect of stock compaction when soils are wet. This may require shifting stock from valuable pasture paddocks to other areas of the farm in wet conditions.
4. Grass species tend to have a greater effect on soil structural properties then broadleaf plants, including

legumes.

5. Root growth is a potential mechanism to overcome compacted layers in soil. Roots can grow through compacted layers in favourable conditions, forming macropores which subsequent roots can use to grow through in more adverse conditions.
6. Landusers need to keep a close eye on the structural condition of their soil so they can tell when a pasture phase will be necessary to improve their structure. One way to do this is to use visual assessment as outlined - leaflets such as 'Detecting Soil Structure Decline' (Murphy and Allworth, 1991) or "Soil Structure Assessment Kit' (McGuiness, 1991), or by keeping track of organic carbon levels and infiltration rates.

CONCLUSION

Sustainability of agricultural production on many soils, particularly the hardsetting soils of NSW and southern Queensland require a pasture phase in order to rejuvenate the structural status of the soil. Failure to do this can lead to increasing erosion and lower productivity because of erosion, difficulties with seedbed preparation, the formation of compacted zones and losses of useable rainfall as runoff.

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