EFFECTS OF LAND SMOOTHING ON GILGAIED BRIGALOW SOILS ON CERTAIN SOIL PROPERTIES AND PLANT GROWTH

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ABSTRACT

With the intensification of cultivation in brigalow lands smoothing operations on gilgaied soils are becoming more common. Data for virgin gilgaied clay soils suggest that smoothing will expose material which is more acid, more saline and with lower organic matter and available P contents.

Analysis of areas with different histories of smoothing at Meandarra confirmed these changes for pH, soil N and available P. Although surface salinity and exchangeable Na levels were increased by smoothing in some of the samples taken for pot experiments the evidence from profile samples was not conclusive.

Pot experiments with legumes showed marked plant yield responses to P on soils from exposed areas, plus responses to lime and Mo. No significant response to S or to trace elements other than Mo was observed.

A field experiment on a smoothed area at Meandarra showed significant response by oats to superphosphate on exposed areas. Although undersown temperate legumes established well, yields were low and were significantly higher on filled-in areas than on exposed areas.

Application of phosphorus and molybdenum and establishment of legumes is desirable to increase N and organic matter levels in the exposed subsoils.

The applicability of the results at Meandarra to other areas of gilgaied clay soils is discussed.

INTRODUCTION

Isbell (1962) estimated that of 5 million *hectares* of soil groups supporting a brigalow (*Acacia harpophylla*) dominant vegetation in Eastern Australia more than 50 per cent had significant microrelief. Vertical intervals may be as much as 150 cm and are commonly 60-90 cm. Gilgais with these vertical intervals may also have frequencies of 50-75 per hectare. Some parameters of this microrelief have been calculated by Russell and Moore (1972).

Although microrelief has advantages for pasture growth in the concentration of water in the depressions in low rainfall years, and in the prevention of runoff in high rainfall years, the microrelief limits intensive land use. The limitations are most pronounced with conventional cultivating, sowing and harvesting equipment used for cereals or coarse grain culture. There are also limitations in operations such as the control of brigalow regrowth and in the establishment of improved pastures. Another limitation is in the permanent species that can grow in this environment. Thus depressions may contain water for many months and some perennial species cannot survive. On the other hand, higher parts of the microrelief are quite arid in dry periods due both to runoff into depressions and to higher evaporation rates due to greater exposure and air movement.

With the intensification of agriculture in these areas large scale land planes have been developed for smoothing gilgais. Smoothing involves removal of topsoil from the higher parts of the microrelief and its deposition in the lower parts exposing areas of subsoil material.

Some observations and experiments on the effects of smoothing on soil properties and on plant growth in the greenhouse and field have been carried out. The results are discussed in this paper.

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METHODS

Soil Sampling

Experiments were carried out at Meandarra in S. Queensland on soils mapped by Isbell (1957) as deep gilgaied clays. Three areas in close proximity with different histories of smoothing were available. In one area the brigalow forest had been ring-barked and the trees removed but no soil cultivation had been carried out. This was classed as a virgin soil. In an adjacent area in addition to tree removal some smoothing operations had been carried out and the area was cultivated from time to time. This was classed as partially smoothed. A part of this area had more intensive smoothing operations carried out to further reduce microrelief. This was classed as smoothed. Microrelief at each area was measured with a dumpy level and staff. Two random soil profiles were sampled from the upper part of the microrelief in each area in December 1966.

Paired soils were also taken for pot experiments by sampling exposed subsoils on smoothed areas and adjacent unsmoothed surface soils. The soils for experiment 1 were sampled in April 1967 and for experiment 2 in June 1971.

Chemical analyses were carried out on both sets of samples. pH was determined by the paste method and on a 1 : 5 soil-water suspension. Available P was determined using an acid extraction (0.01N H_2SO_4, 1 : 200 soil solution ratio) and a bicarbonate extraction (0.5M $NaHCO_3$ buffered to pH 8.5, 1 : 100 soil solution ratio). Conductivity of the saturation extract was determined by the method of Richards (1954), chloride colorimetrically on a 1 : 5 soil-water suspension, exchangeable cations using 1N $NH_4.CH_2COOH$ at pH 7.0, nitrogen by the Kjeldahl method.

Pot Experiments

Two pot experiments were carried out comparing plant growth on soil from exposed subsoils with virgin soils. Properties of the soils used are shown in Table 1.

Experiment 1 was a 4×2^4 factorial. Four levels of P as $NaH_2PO_4.2H_2O$ at 0, 0.215, 0.430 and 0.860 g per pot were applied. The two-level treatments were Mo, S, lime and soil treatments (virgin, exposed). Mo was applied as $Na_2MoO_4.2H_2O$ at 0 and 0.002 g per pot, S as Na_2SO_4 at 0 and 0.436 g per pot and $CaCO_3$ at the rate of 0 and 4.6 g per pot. The soil treatment compared soil sampled (0-15 cm) from a puff where topsoil had been removed and a virgin soil. The experiment was sown to inoculated *Medicago sativa* (cv. Hunter River) on 24/4/67. Four harvests were made in 1967 on 15/6, 26/7, 1/9 and 3/10. Plant analyses for N and P were made.

Experiment 2 was a $2 \times 4 \times 2^4$ factorial. Soils from two locations were sampled (0-15 cm) comparing virgin and exposed soils. Treatments were similar to experiment 1 except that a combined treatment of Cu, Zn, B and Mn replaced the S treatment. Cu was applied as $CuSO_4.5H_2O$, Zn as $ZnSO_4.7H_2O$ and B as $Na_2B_4O_7.10H_2O$, all at 0.002 g/pot. Mn was applied as $MnSO_4.H_2O$ at 0.004 g/pot. The experiment was sown to inoculated *Medicago truncatula* (principally the Cyprus cultivar) on 6/8/71. The plants were harvested on 15/10/71. Following harvesting of the *M. truncatula* the soil was tilled, allowed to lie fallow and inoculated *Macoptilum atropurpureum* (cv. Siratro) was sown on 3/11/71. The plants were harvested on 7/1/72 and 8/3/72.

Field Experiment

An area of four hectares of gilgaied clay soil at Meandarra was partially smoothed by deep ploughing, bulldozing the upper parts of the microrelief into the lower parts and then smoothing the area with a grader. Approximately two hectares was sown to oats (*A. sativa* cv. Bentland) in mid-June 1971. The area was divided into six sub-plots; five were undersown with legume species and one was

TABLE 1

Properties of soils used in pot experiments.

Pot Experiment No.	Location	Soil Treatment	pH Paste	pH 1:5 soil water	Available P (ppm P) Acid Extraction	Available P (ppm P) Bicarbonate Extraction	Salinity Conductivity mmhos/cm at 25°C.	Chloride ppm	Exchangeable Cations (me/100 g) Ca	Mg	K	Na
1*		Virgin	5.4	5.9	15.0	8.5	6.0	670	14.15	10.43	0.75	2.44
		Exposed Subsoil	5.0	5.4	13.5	8.0	12.6	950	8.06	10.57	0.60	2.78
2	A	Virgin	4.5	4.7	7.0	5.5	10.0	1060	9.61	11.23	0.64	2.52
		Exposed Subsoil	4.6	5.0	9.5	6.5	9.4	850	10.26	11.80	0.55	2.57
	B	Virgin	6.2	6.3	15.5	8.5	8.6	580	16.48	8.17	0.86	1.39
		Exposed Subsoil	5.0	5.3	6.0	4.0	12.9	1300	10.00	11.23	0.28	3.83

* Soils for experiment 1 sampled from Sect. 13 Burtagal and for experiment 2 from Sect. 9 Burtagal, Meandarra.

TABLE 2

Analyses of soil from the upper parts of the microrelief at three stages of land smoothing (Mean of two samples)

Soil Treatment	Mean Micro-relief Height Difference cm	Depth Sampled cm	pH (paste)	Total N Percent	Available P (ppm P) Acid Extraction	Available P (ppm P) Bicarbonate Extraction	Conductivity mmhos/cm at 25°C	Exchangeable Na (me/100 g)
Virgin	64.3	0-15	4.89	0.146	18.0	13.2	4.67	1.32
		15-30	4.34	0.103	10.0	9.5	4.77	2.73
		30-60	4.21	0.076	6.7	7.0	6.80	4.04
		60-90	3.95	0.060	6.0	4.5	9.56	4.26
Cultivated Partially Smoothed	38.2	0-15	4.46	0.100	11.7	9.5	6.37	1.82
		15-30	4.06	0.084	8.5	8.0	4.87	2.57
		30-60	3.85	0.061	6.5	4.0	5.32	3.90
		60-90	3.93	0.059	5.7	4.2	7.96	4.41
Cultivated Smoothed	10.2	0-15	4.57	0.089	6.2	6.0	3.38	1.52
		15-30	4.48	0.083	5.0	6.2	2.48	1.91
		30-60	4.12	0.064	3.2	4.2	3.28	2.75
		60-90	3.93	0.052	2.5	3.0	4.88	3.55
Least Significant Difference P = 0.05			0.040	0.027	5.2	2.6	2.15	0.40

left as a control. The five legume species were *Medicago truncatula* (cv. Cyprus), *M. truncatula* (cv. Jemalong), *M. scutellata* (cv. Snail), *M. littoralis* (cv. Harbinger) and *M. sativa* (cv. Hunter River). Seeding rate for the oats was 16.8 kg/ha, for *M. sativa* 11.2 kg/ha and for the remaining legumes 22.4 kg/ha. The legume sub-plots were split with 4 fertilizer treatments 0, 250 kg superphosphate, 250 kg superphosphate containing 0.1 kg Mo as molybdenum trioxide, 250 kg superphosphate containing 0.08 kg Mo, 2.25 kg Cu as copper sulphate and 2.0 kg Zn as zinc sulphate per hectare.

Stratified sampling of oats and legumes was carried out on September 1971, and 30 quadrats at random were harvested on each sub-sub plot, 15 on the exposed areas and 15 on the filled-in areas. Chemical analyses for N, P and Cl were carried out on the oats. Multi-element analyses using an emission spectrometer (Johnson & Simons 1972) were carried out on the legumes.

RESULTS

Soil Properties

Soil properties and microrelief levels from three sites at different stages of land smoothing are shown in Table 2. Available P levels with both extractants were significantly lower on the surface horizon of the smoothed soils than on virgin soils and significant differences between smoothed and partially smoothed surface soils were also evident. Soil N levels of the partially smoothed and smoothed soil were significantly lower than the virgin surface soil. The virgin surface soils were already quite acid, with a pH of 4.89. After smoothing, the exposed subsoils showed values of 0.4 units lower.

No significant differences between conductivity levels of the surface soil were observed due to treatment. There was some indication of increased exchangeable Na levels in the surface horizon of treated soils but only the partially smoothed soil was significantly higher than the control.

Of the three sets of paired soils used in the pot experiments two showed decreases of pH, available P and exchangeable Ca and K and increases in conductivity, chloride and exchangeable Na due to smoothing. However soil A in its virgin state was acid (pH 4.5) and saline. The exposed soil taken adjacent to this was very similar in soil properties.

TABLE 3

Yield and chemical composition of lucerne from pot experiment 1. *Values are means over the whole experiment.*

Treatment	Rate g/pot	Lucerne Yield g/pot	Plant Chemical Composition N %	Plant Chemical Composition P %
Virgin		11.09	3.26	0.18
Exposed		9.52	3.29	0.22
		***	N.S.†	***
Lime	0.0	9.50	3.20	0.22
(as $CaCO_3$)	4.6	11.11	3.35	0.19
		***	N.S.	***
Molybdenum	0.0	9.90	3.15	0.21
(as $Na_2MoO_4.2H_2O$)	0.002	10.71	3.40	0.20
		**	*	N.S.
Phosphorus	0.0	5.57	2.72	0.12
(as $NaH_2PO_4.2H_2O$)	0.215	10.05	3.33	0.17
	0.430	12.33	3.49	0.22
	0.860	13.26	3.56	0.30
		***	***	***

† N.S. not significant
* Significant at P = 0.05
** „ at P = 0.01
*** „ at P = 0.001

Pot Experiments

In experiment 1 with lucerne there were significant main effects on plant yield due to smoothing and to application of P, lime and Mo (Table 3). No yield response to S was found.

Two significant first order interactions are of interest (Table 4). The exposed soils showed yield responses to lime whereas the virgin soils did not. Both exposed and virgin soils responded to P but the virgin soil gave higher yields at the highest P levels.

TABLE 4

First order interactions between virgin and exposed soils and treatments in pot experiments 1 and 2 in relation to plant yields.

Pot Experiment No.	Species	Treatment	Plant Yield g/pot Soil Treatment: Virgin	Exposed	Least Significant Difference P = 0.05
1	*M. sativa*	— lime	11.14	7.86	0.97
		+ lime	11.04	11.17	
1	*M. sativa*	P level (g/pot)			
		0.0	5.23	5.91	1.94
		0.215	11.15	8.96	
		0.430	13.23	11.42	
		0.860	14.74	11.78	
2	*M. truncatula*	Soil A	1.02	0.99	0.17
		Soil B	2.36	0.91	
	M. truncatula	— lime	1.72	0.83	0.17
		+ lime	1.66	1.07	
2	*P. atropurpureus*	Soil A	6.47	10.11	1.04
		Soil B	17.24	6.36	
	P. atropurpureus	— lime	10.88	6.20	1.04
		+ lime	12.84	10.26	

There was a significant second order interaction between soil treatment, lime and Mo (Table 5). Part of the response to lime on the exposed soil could be obtained through the use of Mo.

TABLE 5

Second order interaction between virgin and exposed soil, lime and molybdenum on yield of lucerne (g/pot) from pot experiment 1.

Soil Treatment	Nutrient Treatment: — lime, — Mo	— lime, + Mo	+ lime, — Mo	+ lime, + Mo
Virgin	10.97	11.39	10.69	11.40
Exposed	6.82	8.91	11.11	11.23
L.S.D. (P = 0.05) = 1.94				

Application of both Mo and P significantly increased the N content of lucerne (Table 3). Application of P also significantly increased lucerne P level. On the other hand lime reduced plant P level and the P level of plants from exposed soils was slightly higher than from virgin soils.

In experiment 2 the main effects of treatment on the yield of *M. truncatula* and *M. atropurpureum* are shown in Table 6. There were significant decreases in the yield of both species due to smoothing and significant increases with P were obtained. *M. truncatula,* in particular, made very little growth on soil from exposed areas in the absence of applied P.

TABLE 6

Plant dry matter yields from pot Experiment 2. Values are means over the whole experiment

Treatment	Rate g/pot	Yield g/pot	
		Medicago truncatula	*Macrotilium atropurpureum*
Soil A		1.01	8.29
B		1.64	11.80
		***	***
Virgin		1.69	11.86
Exposed		0.95	8.23
		***	***
Lime	0.0	1.27	8.54
(as $CaCO_3$)	4.6	1.37	11.55
		N.S.	***
Phosphorus	0.0	0.50	7.56
(as $NaH_2PO_4.2H_2O$)	0.215	1.00	10.22
	0.430	1.44	11.29
	1.290	2.34	11.10
		***	***

An overall significant response to lime was obtained with *M. atropurpureum* (Table 6) and on the exposed soil with *M. truncatula* (Table 4). No significant yield effects were observed with Mo or with the trace elements Cu, Zn, B and Mn. The results in experiment 2 were greatly influenced by the interaction between the two soils and the effect of smoothing on plant yield (Table 4). With *M. truncatula* yields from the exposed and virgin soil A were similar but exposure greatly reduced yields from Soil B. On the other hand whilst yield of *M. atropurpureum* was greatly reduced by exposure in the case of soil B, yields from exposed soil A were actually higher than the virgin soil.

Field Experiment

There was a significant yield response of oats to applied P in the field experiment on a smoothed area (Table 7). This occurred on both the exposed and filled in areas but was proportionately greater in the exposed areas. There were no significant effects of Cu, Zn and Mo on oat yields. Application of P increased the plant levels of P and Cl. Chloride levels on oats from the filled in areas were higher than from the exposed areas.

TABLE 7

Yield and chemical composition of oats from the field experiment at Meandarra

	Yield kg/ha	Chemical Composition (percent) N	P	Cl
Exposed	1273	2.70	0.31	3.50
Filled in	2260	2.60	0.32	3.95
L.S.D. P = 0.05	136	N.S.	N.S.	0.22
Fertilizer Treatment				
Nil	1461	2.61	0.22	3.40
P	1981	2.71	0.34	3.89
P + Mo	1931	2.66	0.33	3.84
P + CuZnMo	1692	2.64	0.36	3.78
LSD P = 0.05	192	N.S.	0.06	0.32

TABLE 8

Yield and chemical composition of temperate legumes from the field experiment at Meandarra

	Treatment	Yield kg/ha	Percent N	Percent P	Percent K	Percent Ca	Percent Mg	Percent S	Parts per million Al	Parts per million Fe	Parts per million Mn	Parts per million Cu	Parts per million Zn	Parts per million Mo	Parts per million B
Microrelief	Exposed	76	3.41	0.27	1.78	0.73	0.54	0.29	1291	315	103	7.1	35	1.09	43.7
	Filled in	189	3.28	0.27	2.50	0.77	0.35	0.30	763	250	62	7.3	28	0.56	39.8
	LSD P = 0.05	51	N.S.	N.S.	0.29	N.S.	0.10	N.S.	N.S.	N.S.	23	N.S.	5	0.38	N.S.
Fertilizer	Nil	104	3.30	0.21	1.93	0.83	0.47	0.29	1396	379	78	7.5	30	1.03	46.0
	P	129	3.07	0.28	2.07	0.77	0.40	0.29	974	301	78	6.3	29	0.77	43.7
	P + Mo	171	3.70	0.29	2.18	0.71	0.49	0.31	1078	285	89	6.8	29	0.80	38.2
	P + CuZnMo	126	3.27	0.27	2.03	0.79	0.40	0.29	1494	322	84	7.8	39	1.12	43.3
	LSD P = 0.05	N.S.	0.41	0.02	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	6	N.S.	N.S.
Species	M. littoralis	126	3.52	0.29	2.05	0.80	0.53	0.31	1350	345	101	6.8	39	1.22	43.3
	M. truncatula (Cyprus)	216	3.12	0.27	1.75	0.68	0.57	0.28	1382	381	88	7.0	31	0.80	37.8
	M. truncatula (Jemalong)	186	3.22	0.26	2.00	0.73	0.34	0.28	1134	299	76	5.0	27	0.70	35.3
	M. scutellata	105	3.30	0.29	2.23	0.74	0.42	0.30	1063	264	73	8.3	31	0.77	46.5
	M. sativa	29	3.58	0.25	2.67	0.80	0.37	0.29	208	123	72	8.0	30	0.65	45.7

Yields of legumes were significantly lower on exposed than on filled in areas. Although yield response to both P and Mo were found with the legume these were not significant at the 5 percent level. Better water relations in the filled in areas may have contributed to the higher yields.

Data on the chemical composition of legumes (Table 8) showed that the K levels were significantly higher and that the Mg, Mn and Zn levels were significantly lower from filled in areas than from exposed areas. Applied P significantly increased the P level of legumes. Of the trace elements Cu, Zn and Mo, only Zn significantly increased plant levels but there were indications that Mo increased legume N level.

DISCUSSION

The lower levels of available P and total N and the increased acidity of surface soils from exposed areas following smoothing are in accord with expectations based on profile measurements of virgin soils. It might also be expected that soluble salts and exchangeable Na levels would increase but evidence for this was not conclusive. In the soil profiles examined there was little difference in soluble salts between profiles and only slight differences in exchangeable Na. Of the experimental pot soils sampled two out of the three smoothed soils showed increases in conductivity. All three smoothed soils showed increases in exchangeable Na but in two of these instances the increases were small. Soluble salts are mobile in the soil profile both horizontally and vertically. It is probable that movement occurs both in time and spatially in these soils and a more detailed study is necessary to explain salinity changes.

Smoothing operations on the gilgaied clay soils have undoubtedly accentuated P deficiency in legumes. Published evidence suggests that, in the virgin state, P is deficient on gilgaied soils in this area (Russell 1969; Russell, Moore and Coaldrake 1967). Removal of topsoil has significantly decreased available P levels at the surface. The field experiment showed a greater response of oats to superphosphate on exposed areas than on filled in areas. The pot experiments with *M. truncatula* showed that, on smoothed soils and on one of the virgin soils, growth in the absence of P was negligible. This effect was not as marked with *M. atropurpureum*.

Gilgaied clay soils at Meandarra are acid at the surface and smoothing operations increased surface acidity even further. The pot experiments showed significant yield effects of lime on lucerne and siratro and, on the exposed soils, with medic.

The application of lime to exposed subsoils in this environment is mainly of academic interest in view of the amounts required and cost of application, but the application of Mo is feasible. With lucerne, Mo had a significant effect on yield although this effect was not as great as that of lime. Whilst P and Mo gave the highest yield with legumes in the field experiment differences were not statistically significant.

In a greenhouse study of the nutrient status of clay soils of the brigalow region (Fergus 1962), nine out of ten soils showed significant responses to P and two out of ten to Mo. Analysis of total Mo levels in the soil at Meandarra indicates values of 4.0-5.0 ppm at the surface reducing to 2.0 ppm at depth.

In general, the effects of subsoil exposure in smoothed areas on plant growth will depend upon the depth trend of certain critical soil properties. Reeve, Isbell and Hubble (1963) analysed 22 deep gilgaied clay profiles from the brigalow region. Of these 8 had surface soils with pH values < 7.0 and 14 had surface soils > 7.0. However all subsoils were acid with values as low as pH 4.2-4.4 common. Total soluble salts increased in all cases with depth to levels of 0.5 percent but with some higher values. Organic matter and total P also declined with depth. Available P varied in the surface soil but even where surface levels were high it invariably declined to low values at depth.

Although the Meandarra soils represent the more acid types the depth trends of soil properties are similiar to those of gilgaied soils generally in this region. Thus, to some degree, the effects of subsoil exposure at Meandarra on plant growth may be anticipated on other gilgaied clay soils. One factor of importance in smoothing operations is the amount of topsoil which has to be removed to fill in the lower parts of the microrelief. This will depend on gilgai parameters and these parameters have been shown to be variable (Russell and Moore 1972). In areas with less pronounced microrelief the effects of subsoil exposure on plant growth may not be as extreme as those noted in this study.

These results suggest fertilizer should be applied to areas exposed by smoothing. Phosphorus is the most deficient element and small amounts of superphosphate (less than 100 kg/ha) have given worthwhile plant yield responses. Where legumes such as lucerne are to be grown an initial application of molybdenum should be made. Generally, exposed areas comprise less than 40 per cent of the smoothed area and fertilizer applications could be confined to the bare areas only. However the practical difficulties of doing this may outweigh the advantages of lesser fertilizer use. Also one of the reasons for smoothing is that the whole area can be treated for various cultural operations in the same way.

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