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Effect of depth and method of primary tillage on fallow soil water and nitrate changes and wheat grain yield

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Summary

An experiment was conducted on an alluvial soil at Biloela Research Station from 1970 to 1975 to determine the effect of two depths (10 to 15 cm and 20 to 30 cm) and two methods (disc and chisel) of primary tillage on changes in soil water and nitrate-nitrogen over the fallow period and on subsequent wheat grain yield.

There were no significant ($P<0.05$) treatment differences in available soil water levels to a depth of 1.4 m at the beginning and end of the fallow period in any year. Deep (20 to 30 cm) disc primary tillage resulted in a greater increase in soil nitrate-nitrogen levels in the 0 to 40 cm layer over the fallow period than shallow (10 to 15 cm) disc or chisel primary tillage or deep (20 to 30 cm) chisel primary tillage in three of the four years of the experiment. Significant ($P<0.05$) increases in grain yield were obtained with deep disc primary tillage in two of the three years in which higher soil nitrate-nitrogen status occurred at planting in this treatment. The occurrence of a yield response to the higher soil nitrate-nitrogen levels in the 0 to 40 cm layer following deep disc primary tillage appeared to depend on seasonal conditions during crop growth. Grain protein content was generally similar for all treatments in any one year.

INTRODUCTION

Farmers cropping the alluvial soils of the Callide Valley in central Queensland have observed that deep primary tillage, particularly with a disc plough, may result in higher grain yield of the subsequent wheat crop than shallower primary tillage.

In reviewing previous tillage research on alluvial soil at Biloela Research Station in the Callide Valley, Thomas and Hazard (1974) found that deep disc or chisel tillage had generally given no yield response in a number of crops, although there were indications in some experiments that deep chisel tillage had resulted in better water penetration into the soil. Other Australian and overseas research on cultivation and fallowing practices has shown that generally only small, if any, increases in crop yield occur as a result of deep tillage (Khan 1963; Sims 1977). In field experiments where increases in grain yield of wheat have been reported to deeper tillage, they have been generally related to improved soil water or nitrate-nitrogen status of the soil, as a result of better weed control or greater degree of stubble incorporation with deeper tillage (Fenster, Domingo and Burnside 1969; Bond, Power and Willis 1971; Tucker, Cox and Eck 1971).

A further experiment was conducted at Biloela Research Station from 1970 to 1975 to determine the effect of depth and method of primary tillage on soil water and nitrate-nitrogen changes over the fallow period and on subsequent wheat grain yields.

MATERIALS AND METHODS

The experiment was located at the Queensland Department of Primary Industries' Biloela Research Station (latitude 24°22′S, longitude 150°31′E) in the Callide Valley district of central Queensland. The experimental area (Q6 border) had been under pasture for a number of years before being planted to oats in 1969 and 1970. Soil type was a deep alluvial clay loam, Dd 1.13 to Gn 3.43 (Northcote 1971). Table 1 gives the pH, available phosphorus and total nitrogen characteristics of the soil profile at the beginning of the experiment in December 1970. Soil pH was measured on a 1:2.5 soil:water suspension. Available phosphorus was extracted in 0.01 N sulphuric acid (Kerr and von Stieglitz 1938) and determined by an auto-analyser modification of the method of John (1970). Total nitrogen from Kjeldahl digests of soils was determined using an automated isocyanurate procedure similar to that of Crooke and Simpson (1971).

Table 1. pH, available phosphorus and total nitrogen characteristics of the soil profile, December 1970

Depth (cm)	pH	Available phosphorus (ppm)	Total nitrogen (%)
0- 20	6.8	254	0.12
20- 40	6.7	210	0.08
40- 60	7.0	210	0.06
60- 80	7.3	257	0.06
80-100	7.9	261	0.05
100-120	8.2	268	0.04
120-140	8.2	234	0.04

Experimental design was a randomised block of six replicates.

The four primary tillage treatments were as follows:

1. shallow disc tillage (10 to 15 cm);
2. deep disc tillage (20 to 30 cm);
3. shallow chisel tillage (10 to 15 cm);
4. deep chisel tillage (20 to 30 cm).

Plot size was 24×12 m.

Primary tillage treatments were carried out in November or December each year following harvest of the preceding crop. Shallow disc tillage was performed with a one-way, 14 disc plough with disc diameter of 55 cm. A reversible, three disc plough with disc diameter of 70 cm was used for the deep disc tillage treatment. Shallow chisel tillage was carried out with a nine tine chisel plough with tines spaced at 30 cm intervals and fitted with cultivating sweeps. The deep chisel tillage treatments were first cultivated in the same manner as the shallow chisel tillage treatments to obtain weed control. The cultivating sweeps were then removed and the chisel points used for the deep chisel tillage operation. Subsequent cultivations over the fallow period were carried out as required for weed control, generally at the same time and with the same implement (disc or tine) in all treatments.

At the end of each fallow period, the plots were planted to wheat (cv. Timgalen). Planting time ranged from mid May to late June. The wheat was harvested in October or November using a small-plot autoheader with 1.8 m width of cut. The area harvested from each plot for grain yield determinations was 22×1.8 m.

Tillage treatments commenced in the 1970-71 season and were repeated in the same plots each year until and including 1974-75, with the exception of the 1973-74 season. In this season, the tillage treatments in December 1973 were interrupted by wet weather and flooding of the experimental area, which prevented all treatments being completed at the same time. A prolonged period of wet weather prevented further cultivation until early March 1974, when it was considered to be too late to complete the tillage treatments.

The site received uniform cultivation for the remainder of the fallow. The site was planted to wheat in late May 1974 but data from the 1973-74 season have not been included in the results because all the primary tillage treatments were not imposed. Further details of cultural operations are shown in Table 2.

Table 2. Details of cultural operations and rainfall (mm)

Season	1970-71	1971-72	1972-73	1974-75
Harvest date of preceding wheat crop (beginning of fallow)	1 Nov 70	27 Oct 71	19 Oct 72	7 Nov 74
Date of primary tillage	3 Dec 70	25 Nov 71	16 Nov 72	13 Dec 74
Number of secondary tillage operations				
disc	2	1	1	0
tine	3	3	4	4
Planting date (end of fallow)	16 Jun 71	17 May 72	17 Jun 73	26 Jun 75
Rainfall during fallow (mm)	711	535	423	575
Rainfall during crop (mm)	199	83	248	303

Average rainfall, 1924 to 1973, for fallow period (November to May) 537 mm

Average rainfall, 1924 to 1973, for cropping period (June to October) 167 mm

Soil water content was determined gravimetrically from two or four cores per plot to a depth of 1.4 m in 20 cm increments at the beginning and end of each fallow period in either all six or only three replicates of each treatment. Bulk density data were also obtained to a depth of 1.4 m in 20 cm increments to enable soil water data to be expressed in volumetric terms. Soil water data from the driest profile recorded were used to enable plant available soil water levels to a depth of 1.4 m to be determined.

Soil nitrate-nitrogen was determined for the 0 to 40 cm layer at the beginning and end of each fallow period from bulked samples of four or six cores per plot. Nitrate was extracted in water at a soil:water ratio of 1:5 and determined by a selective ion electrode method (Bremner, Bundy and Agarwal 1968).

Grain nitrogen was determined by a Kjeldahl procedure on samples taken from each plot at harvest in 1971-72, 1972-73 and 1974-75. Grain protein content was then calculated (grain protein %=grain nitrogen %×6.25).

RESULTS

Rainfall over the fallow and crop periods in each year of the experiment is given in Table 2, together with long term mean rainfall data for these periods. Rainfall over the fallow period was average or above in 1970-71, 1971-72 and 1974-75 and below average in 1972-73. Rainfall during crop growth was above average in 1970-71, 1972-73 and 1974-75 and below average in 1971-72.

There were no significant ($P<0.05$) treatment differences in available soil water at the beginning and end of the fallow period in any of the four years (Table 3). However, available soil water levels were higher in shallow disc tillage than other treatments at the beginning of the fallow in 1970-71, lower in deep disc tillage than other treatments at the end of the fallow in 1972-73 and lower in the chisel tillage than disc tillage treatments at both the beginning and end of the fallow in 1974-75.

Soil nitrate-nitrogen levels (Table 4) did not differ significantly ($P<0.05$) between treatments at the beginning of the fallow in 1971-72, 1972-73 or 1974-75. In 1970-71, soil nitrate-nitrogen status was slightly higher in the deep chisel tillage treatment than other treatments at both the beginning and end of the fallow period, but the increase over the fallow was similar for all treatments. The increases in soil nitrate-nitrogen status over the fallow period and levels at the end of the fallow were higher in deep disc tillage than other treatments in 1971-72, 1972-73 and 1974-75, the differences being significant ($P<0.05$) in 1971-72 and 1972-73.

Grain yield results are given in Table 5. Deep disc primary tillage resulted in significant ($P<0.05$) increases in grain yield over the other three treatments in 1971-72 and 1974-75, but no other significant ($P<0.05$) yield differences occurred in these or the other two seasons. Mean grain yields declined from 1970-71 to 1974-75. Lower yields in 1974-75 can be attributed to the effects of weather damage to grain and lodging of the crop as a result of rain at maturity.

Table 3. Available soil water (mm) to a depth of 1.4m at the beginning and end of the fallow period

	Available soil water (mm)							
Season	1970-71		1971-72		1972-73		1974-75	
Sampling time*	A	B	A	B	A	B	A	B
Treatment								
1. Shallow disc tillage	168	302	113	257	85	248	232	260
2. Deep disc tillage	140	306	120	257	84	227	244	265
3. Shallow chisel tillage	137	300	117	260	84	235	213	238
4. Deep chisel tillage	142	297	123	263	82	241	206	243
Mean	147	301	118	259	84	238	224	252
l.s.d. ($P<0.05$)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

*A=beginning of the fallow period (post-harvest).
B=end of the fallow period (pre-planting).

Table 4. Soil nitrate-nitrogen (ppm) to a depth of 40 cm at the beginning and end of the fallow period

	Soil nitrate-nitrogen (ppm), 0 to 40 cm							
Season	1970-71		1971-72		1972-73		1974-75	
Sampling time*	A	B	A	B	A	B	A	B
Treatment								
1. Shallow disc tillage	10	11	10	14	7	18	4	15
2. Deep disc tillage	8	10	8	20	8	23	3	18
3. Shallow chisel tillage	10	12	8	16	6	16	3	15
4. Deep chisel tillage	13	14	9	13	7	18	3	15
Mean	10	12	9	16	7	19	3	16
l.s.d. ($P<0.05$)	n.a.	n.a.	n.s.	2	n.s.	4	n.s.	n.s.

*A=beginning of the fallow period (post-harvest).
B=end of the fallow period (pre-planting).
n.a.=data not statistically analysed.

Table 5. Wheat grain yield (kg/ha)

	Grain yield (kg/ha)			
Season	1970-71	1971-72	1972-73	1974-75
Treatment				
1. Shallow disc tillage	2834	2608	2479	1958
2. Deep disc tillage	2832	2844	2442	2303
3. Shallow chisel tillage	2792	2565	2579	2043
4. Deep chisel tillage	2902	2622	2477	2060
Mean	2840	2660	2494	2091
l.s.d. ($P<0.05$)	n.s.	200	n.s.	223

Grain protein content (Table 6) was significantly ($P<0.05$) lower in shallow chisel tillage than the other three treatments in 1971-72, but no significant ($P<0.05$) treatment differences occurred in 1972-73 or 1974-75. However, grain protein levels were slightly higher in deep disc tillage than other treatments in all years.

Table 6. Grain protein content (%)

Season	Grain protein content (%)		
	1971-72	1972-73	1974-75
Treatment			
1. Shallow disc tillage	15.7	14.7	11.0
2. Deep disc tillage	16.1	15.1	11.7
3. Shallow chisel tillage	14.4	14.5	11.1
4. Deep chisel tillage	15.7	14.4	11.2
Mean	15.5	14.7	11.3
l.s.d. ($P<0.05$)	1.2	n.s.	n.s.

DISCUSSION

Increases in soil water and nitrate-nitrogen levels over cultivated fallow, as occurred in this experiment, have been documented previously for wheat cropping in Queensland (Allen and George 1956; Waring, Fox and Teakle 1958; Waring and Teakle 1960). As has been found by other workers (Sims 1977), there were no marked differences in the effect of the primary tillage treatments on soil water accumulation over the fallow period or available soil water levels at the end of the fallow (Table 3). Trends which did occur in available soil water levels at the end of the fallow were not reflected in subsequent grain yields (Table 5). Rainfall over the fallow period was sufficient (Table 2) to result in relatively high levels of available soil water in the profile at the end of the fallow in all years (Table 3). Under these conditions, any effects of the tillage treatments on water penetration into the soil which may have occurred during the fallow would not be evident from the soil water data obtained. The average proportions of total rainfall received over the fallow period which were accumulated in the soil were 22%, 26%, 36% and 1% in 1970-71, 1971-72, 1972-73 and 1974-75 respectively (Tables 2 and 3). The first three values are similar to the higher values obtained on black earth wheatlands of the Darling Downs and are in the range of 20% to 35% which many other results have indicated (Waring, Fox and Teakle 1958). A combination of low soil water accumulation over the fallow period but high available soil water levels at planting resulted in very low efficiency of water accumulation over the fallow period in 1974-75. This effect was also recorded by Waring, Fox and Teakle (1958). Rainfall in excess of plant requirements in the months immediately preceding harvest of the 1974 wheat crop resulted in high soil water levels at the start of the 1974-75 fallow period, causing low infiltration and storage over the fallow.

Mineralisation and availability of soil nitrogen and the crop response to it are strongly influenced by seasonal conditions and the resulting soil water regime (Birch 1964; Storrier 1965; Craswell and Strong 1976; Strong and Cooper 1980). In 1970-71 the increases in soil nitrate-nitrogen levels in the 0 to 40 cm layer over the fallow and levels at the end of the fallow were lower than in subsequent years (Table 4), possibly as a result of the high rainfall over the fallow period (Table 2) which caused flooding of the experimental area and difficulties in controlling weed growth, and may have resulted in denitrification (Craswell and Strong 1976) and leaching of nitrate-nitrogen to lower depths of the soil profile.

There were no marked yield responses (Table 5) to the treatment differences in soil nitrate-nitrogen levels which occurred at planting in 1970-71. In 1971-72, 1972-73 and 1974-75, mean soil nitrate-nitrogen levels in the 0 to 40 cm layer at planting were relatively high in all treatments (Table 4). The greater increase in soil nitrate-nitrogen levels over the fallow period with deep disc tillage in these years may have been due to a combination of factors such as improved aeration and a greater degree of wetting and drying (Birch 1964) due to the soil being left in a very rough condition initially or the effects of better weed control and a greater degree of stubble incorporation (Fenster *et al.* 1969; Bond *et al.* 1971; Tucker *et al.* 1971) in the deep disc tillage treatment.

The higher levels of soil nitrate-nitrogen in the 0 to 40 cm layer at planting in the deep disc tillage treatment were associated with higher grain yields in 1971-72 and 1974-75 but not in 1972-73 (Table 5). Above average rainfall occurred during the early stages of crop growth in 1972-73 and some losses of nitrogen may have occurred from the 0 to 40 cm layer by leaching to lower depths of the soil profile, reducing any effect of the surface differences which were evident at planting. Soil nitrate-nitrogen levels below 40 cm were not measured so it is not possible to determine the effects of soil nitrate-nitrogen accumulation and use below 40 cm, the occurrence of which was demonstrated by Allen and George (1956) and Waring and Teakle (1960).

The higher soil nitrate-nitrogen levels in the 0 to 40 cm layer at planting with deep disc tillage were reflected only slightly in grain protein levels (Table 6) but were apparently adequate to prevent any reduction in grain protein content with the higher yields obtained in this treatment in 1971-72 and 1974-75.

Results from this experiment, therefore, indicate that deep (20 to 30 cm) disc primary tillage may result in a greater increase in soil nitrate-nitrogen levels over the fallow period in the 0 to 40 cm layer than shallow (10 to 15 cm) disc or chisel primary tillage and deep (20 to 30 cm) chisel primary tillage. However, the occurrence of a grain yield response in wheat to any such increase in soil nitrate-nitrogen levels at planting with deep disc primary tillage appears to depend on the seasonal conditions during crop growth.

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