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Effect of pasture on subsequent wheat crops on a black earth soil of the Darling Downs. II. Organic C, nitrogen and pH changes

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Summary

During the 11 year period 1958 to 1968, continuous cropping to wheat was compared with a rotation involving 3 or 4 years of lucerne-prairie grass pasture followed by wheat, on a Darling Downs black earth.

Soil chemical measurements made at various times showed that 2 to 4 years of lucerne based pasture increased organic carbon, total N, mineralisable-N, while pH decreased. Soil total N build-up maximised after 2 years of pasture while the residual effect of 3 or 4 years pasture produced significantly higher nitrate-N levels in soil for up to 7 years, and was related to wheat yield and quality improvements.

INTRODUCTION

In southern Australia wheat is frequently grown in rotation with legume based pastures, with the common result that wheat quality and yield are improved, such improvement generally being attributed to soil nitrogen build-up (Donald 1965).

Available data, however, relate mainly to clover or medic based pastures on soils of poorer natural fertility than Darling Downs black earths. To quantify the effect of a lucerne-prairie grass pasture on subsequent wheat production on the Darling Downs, Littler (1984) carried out an 11 year rotation trial on a Waco black earth at Jondaryan.

The extent of the pasture effect on wheat yield and quality has been described by Littler (1984). This paper examines the soil chemical changes which resulted from experimental treatments and relates them to crop performance.

MATERIALS AND METHODS

Design

Details of the randomised block trial of nine treatments x four replications are given by Littler (1984). The key to treatments for each of the trial's 11 years duration is given in Table 1.

Soil sampling

Composite samples (five 5 cm diameter cores in 10 cm increments to 60 cm) of all plots of the trial were taken in February 1958, May 1963 and April 1966 for total N and organic carbon measurements, while pH was also measured on the 1966 samples.

Mineralizable-N measurements were carried out on composite samples (5 cm cores in 15 cm increments to 60 cm) taken in June 1967. Each year from 1960 to 1968 wheat plots were samples (5 cm cores in 10 cm increments to 60 cm) and analysed for nitrate-N just before crop planting. In 1960-66, composites from replicate treatments were bulked before nitrate-N analysis, but in 1967-68 replicate plots were analysed separately. For each sampling, soils were air dried and ground immediately after sampling. Soils from 1958 were stored until analysed in 1963.

Table 1. Key to treatments

Treatment number	Year										
	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968
1	W	W	W	W	P	P	P	P	W	W	W
2	P	W	W	W	W	P	P	P	P	W	W
3	P	P	W	W	W	W	P	P	P	P	W
4	P	P	P	W	W	W	W	W	W	W	W
5	P	P	P	P	W	W	W	W	W	W	W
6	W	P	P	P	P	W	W	W	W	W	W
7	W	W	P	P	P	P	W	W	W	W	W
8	W	W	W	P	P	P	P	W	W	W	W
9	W	W	W	W	W	W	W	W	W	W	W

W=Wheat; P=Pasture

Analytical methods

Soil samples were analysed for total nitrogen by macro-Kjeldahl procedure, without prior reduction to include nitrate (Bremner 1960); for organic carbon by the Walkley and Black (1934) procedure; for mineralisable-N using the waterlogged incubation procedure of Waring and Bremner (1964); and for pH using a 1:2.5 soil/water suspension. Soil nitrate was extracted (1:5) with 1 N KCl and analysed before 1966 by the micro-diffusion method of Bremner and Shaw (1956), and from 1966 by the steam distillation procedure of Bremner and Keeney (1966).

RESULTS AND DISCUSSION

Since the trial site had been cropped continuously for 22 years before treatments were imposed, the effect of variable numbers of wheat (W) crops preceding the pasture (P) phase would be minimal. Thus, the apparent confounding effect of variable years of W preceding P can be ignored, and the history before the P phase in all treatments can be regarded as long term continuous cropping.

Changes in total N

Changes in total N for surface (0 to 10 cm) soil following various cropping histories are shown in Table 2. No significant difference between treatments could be detected at depths below 10 cm.

The pertinent feature of the build-up and decline pattern is the rapid nitrogen accretion during the pasture phase and its slow decline with subsequent cropping. Based on a 2 year change of 0.0247% N (mean of treatments 6, 7 and 8 minus treatment 9) and a measured bulk density of 0.95 for 0 to 10 cm soil, 2 years of pasture added 235 kg/ha N with no further accumulation in the third and fourth years.

This differs from the nitrogen build-up pattern evident under most clover and medic based pastures in southern Australia in that, in this experiment, nitrogen accretion has rapidly reached an asymptote.

Mullaly, McPherson, Mann and Rooney (1967) found total N accretion was 0.0047% per year in 0 to 15 cm soil under barrel medic on a grey soil of heavy texture at Longerenong, Victoria, and was linear over the 8 year period of the experiment. They obtained similar linear rates of nitrogen accretion under sub-clover at Dookie and Rutherglen. Russell (1960) found that total N build-up on a solonetzic soil at Kybybolite had still not reached an asymptote after 39 years of sub-clover. Only Meagher and Rooney

(1966) showed that, for a barrel medic pasture on Wimmera grey soil, most nitrogen accretion over a 4 year period occurred in the first 2 years and this was attributed to better seasonal conditions in those years.

Table 2. % N, % C, pH and C/N ratio in 0 to 10 cm soil following various pasture histories

March 1963 sampling showing the build-up phase

History	% N	% C	C/N ratio
(9) 5W (control)	0.125*a*	1.18*a*	9.44
(1)4W1P	0.139*b*	1.25*ab*	8.99
(8) 3W2P	0.153*bc*	1.32*bc*	8.62
(7) 2W3P	0.147*bc*	1.32*bc*	8.98
(6) 1W4P	0.149*bc*	1.37*c*	9.19
l.s.d. $P<0.05$	0.014	0.11	n.s.
$P<0.01$	0.019	0.15	

May 1966 sampling showing the decline phase

History	% N	% C	C/N ratio	pH
(1) 4W4P	0.157*a*	1.33*a*	8.46*a*	8.07*a*
(8) 3W4P1W	0.150*ab*	1.38*a*	9.25*b*	8.22*b*
(7) 2W4P2W	0.144*bc*	1.33*a*	9.31*b*	8.21*b*
(6) 1W4P3W	0.148*bc*	1.37*a*	9.31*b*	8.21*b*
(5) 4P4W	0.144*bc*	1.35*a*	9.37*b*	8.20*b*
(4) 3P5W	0.141*c*	1.31*a*	9.35*b*	8.23*b*
(9) 8W (control)	0.124*d*	1.16*b*	9.32*b*	8.31*c*
l.s.d. $P<0.05$	0.008	0.08	0.61	0.08
$P<0.01$	0.010	0.10	0.86	0.11

Initial 0 to 10 cm sample taken in 1958 showed % N=0.132, % C=1.22.

An explanation for the difference from southern experiences is not readily apparent.

The Waco soil under study did have a much higher total N level initially than the southern comparisons (0.13% N compared to 0.09% at Longerenong, 0.08% at Dookie, 0.05% at Rutherglen and 0.06% at Kybybolite), and the soil did have a high apparent mineralisation capacity (Treatment 3, Table 3). Since legumes fix less nitrogen when grown under a high nitrate-N regime (Pate and Dart 1961), it is possible that, after 2 years of pasture when the prairie grass had phased out, nitrate production from mineralisation was sufficient to restrict further N fixation.

It is also possible that the initial rapid build-up of total N in the surface was partly due to uptake of nitrate-N leached beyond 60 cm during previous cropping (Waring and Teakle 1960), and that, given a longer pasture phase, a long term linear increase trend may have emerged after the initial rapid increase.

In the run-down phase of the rotation, continuous cropping to wheat following 3 or 4 years of pasture produced a linear decline in soil total N of 0.0027% N per year:

$\%N=0.1540-0.0027$ (years of wheat); $R^2=0.50^{**}$, $n=24$

Based on these figures 8 years of continuous wheat would be needed to reduce the soil total N to the original 1958 level of 0.132%.

While information on nitrogen build-up under various pastures is well documented there is a dearth of published data on long term decline in soil nitrogen during cropping. However, the decline rate in this black earth is considerably slower than that measured by Penman (1951) at Rutherglen, Victoria. Data from Table 5 of Penman's paper show a linear decline rate of 0.0064% N per year in 0 to 15 cm soil over a cropping period of 6 years following a 14 year clover ley.

Table 3. Mineralizable-N in soil samples before planting wheat in June 1967

Treatment		Mineralizable-N as ppm NH_4-N			
Number	Rotation history to sampling	0-15 cm	15-30 cm	30-45 cm	45-60 cm
3	2P 4W 3P	65.8	23.0	20.7	20.4
2*	1P 4W 4P	47.6	23.8	23.0	22.6
1	4W 4P 1W	42.3	22.3	20.2	16.8
8	3W 4P 2W	44.0	21.5	26.4	22.0
7	2W 4P 3W	42.4	19.2	22.3	22.2
6	1W 4P 4W	43.2	24.3	25.7	24.5
5	4P 5W	38.3	24.8	20.3	21.4
4	3P 6W	33.5	22.3	26.1	23.6
9	9W	34.4	19.2	19.9	19.1
	l.s.d. $P<0.05$	6.2			
	$P<0.01$	8.4	n.s.	n.s.	n.s.

*Pasture broken up for 9 months

Changes in organic carbon and C/N ratio

Organic carbon followed a linear regression increase trend over the 4 years of pasture, increasing at the rate of 0.04% C/yr for 0 to 10 cm soil. No differences were detected below 10 cm. As with total N, the rate of decline in organic matter was more gradual (0.015% C/yr) than the build-up rate, and after 5 years of cropping, old pasture plots still contained significantly ($P<0.05$) more organic matter than continuous wheat plots.

No significant differences in C/N ratio were obtained in the 1963 sampling although in 1966 a tendency towards narrower C/N ratios was noted on soil still under pasture (Table 2). Rixon (1966) at Deniliquin also found that C/N ratios decreased slightly as total nitrogen built up under pasture.

Changes in pH

Pasture produced a small but significant ($P<0.05$) decrease in pH (0.1 to 0.2 units) in 0 to 10 cm soil (Table 2). On cropping to wheat, pH again increased from 8.1 to 8.2, and after five crops was still slightly but significantly ($P<0.05$) lower than the continuous wheat treatment of pH 8.3.

Changes in mineralisable-N

Table 3 shows the effect of cultural history on nitrogen mineralisation capacity of the soil as measured by the waterlogged incubation technique of Waring and Bremner (1964). Significant differences were again apparent only in the surface. While mineralisation potential of subsoil as measured by this technique is high (possibly due to drying and grinding soils before carrying out the test) no significant differences between treatments are apparent in subsoil. Thus, we attribute differences found in subsoil nitrate to differences in nitrate production in the surface layer.

A marked decrease in mineralisation capacity of 0 to 15 cm soil occured during the first fallow after breaking up the pasture. A comparison of Treatment 3 (still under pasture) and Treatment 2 (9 months fallow after 4 years pasture) shows that mineralisation capacity decreased by 28% during the first 9 months and then took 5 years to decrease a further 14%. After five wheat crops no significant difference from continuous wheat could be detected even though there was a real difference in both total N and nitrate-N.

Changes in nitrate-N

Nitrate-N was measured in all wheat plots before planting wheat for the years 1960-68 (Table 4). Each year the highest soil nitrate level was obtained in the treatment broken up from pasture in the previous September in preparation for the first wheat crop. This flush of nitrate production during the first fallow after pasture coincided with the sharp drop in mineralisation capacity of the soil mentioned previously (Table 3).

Intensive soil sampling for nitrate-N in 1967 and 1968 showed that soil nitrate production on previous pasture plots decreased at a level of approximately 11 ppm NO_3-N (0 to 60 cm soil) between the fourth and sixth wheat crops. Nitrate-N before planting the seventh crop after pasture was, however, still significantly ($P<0.05$) greater than that from continuous wheat.

Table 4. ppm nitrate-N 0 to 60 cm, sampled before planting wheat each year*

Sampled 1 Jul 60			Sampled 12 Jul 61			Sampled 11 Apr 62		
Treatment		ppm NO_3-N 0 to 60 cm	Treatment		ppm NO_3-N 0 to 60 cm	Treatment		ppm NO_3-N 0 to 60 cm
Number	History		Number	History		Number	History	
2	1P1W	16.0	2	1P2W	13.1	3	2P2W	17.5
3	2P	32.8	3	2P1W	26.1	4	3P1W	21.0
9	2W	12.3	4	3P	43.4	5	4P	42.0
			9	3W	13.1	9	4W	9.0
Sampled 25 Jun 63			Sampled 8 Jul 61			Sampled 3 Sep 65		
3	2P3W	15.5	4	3P3W	11.2	4	3P4W	9.9
4	3P2W	20.1	5	4P2W	9.8	5	4P3W	12.4
5	4P1W	21.3	6	1W4P1W	15.3	6	1W4P2W	10.1
6	1W4P	30.9	7	2W4P	20.4	7	2W4P1W	13.2
9	5W	14.3	9	6W	8.9	8	3W4P	19.5
						9	7W	9.0
Sampled 4 Jul 66			Sampled 5 Jun 67			Sampled 28 May 68		
4	3P5W	17.6	4	3P6W	11.6	4	3P7W	10.0
5	4P4W	15.4	5	4P5W	10.4	5	4P6W	13.7
6	1W4P3W	16.6	6	1W4P4W	11.4	6	1W4P5W	11.7
7	2W4P2W	18.4	7	2W4P3W	10.6	7	2W4P4W	9.7
8	3W4P1W	24.1	8	3W4P2W	14.7	8	3W4P3W	13.9
1	4W4P	37.7	1	4W4P1W	23.1	1	4W4P2W	18.2
9	8W	11.0	2	1P4W4P	35.8	2	1P4W4P1W	29.0
			9	9W	7.3	3	2P4W4P	36.3
						9	10W	7.3
			l.s.d. $P<0.05=3.0$			l.s.d. $P<0.05=3.4$		
			$P<0.01=4.1$			$P<0.01=4.6$		

Treatments ending in P are pasture plots broken up and fallowed from September of the previous year.
*Values stated are weighted mean values for 0 to 60 cm calculated from separate analyses on 10 cm profile increments. In the years 1960-66, sample from replicate plots were composited before analysis. Conversion to kgN/ha is ppm×6 (mean B.D. 0 to 60 cm=1.0)

Watson (1963) in Western Australia, found that the benefit conferred on cereal cropping by subterranean pastures decreased appreciably after the first wheat crop and suggested a shortening of the rotation to 1 year of wheat following 2 years of pasture. Rixon (1971) showed at Deniliquin, NSW, that the greater rate of mineralisation of nitrogen after perennial white clover pasture than after annual pastures was sustained for four wheat crops, and suggested a lengthening of the wheat rotation. Measurements of pre-planting soil nitrate presented here show that the improved nitrate-N status produced by 3 or 4 years of lucerne-prairie grass pasture (which reverted to lucerne after 18 months) is sustained for up to seven wheat crops.

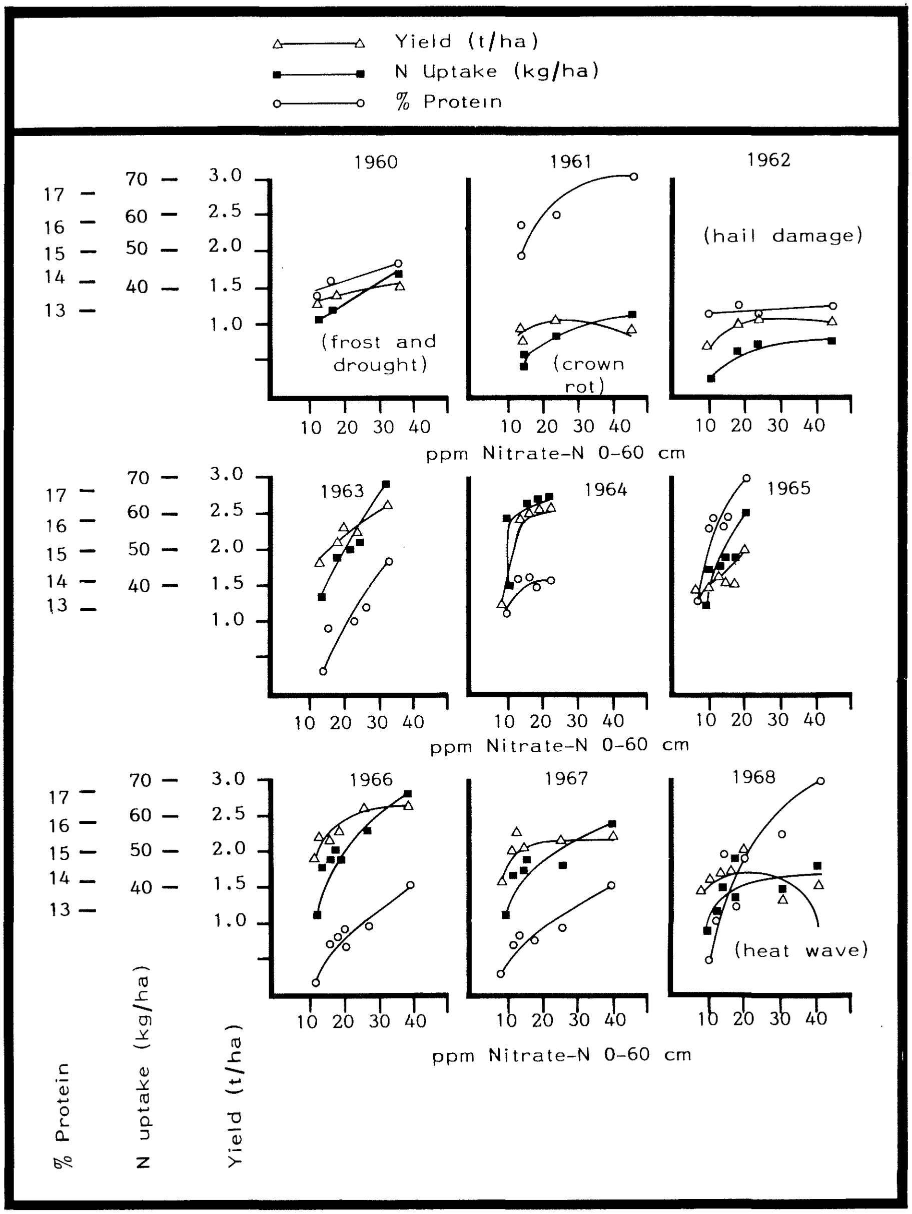

Figure 1. Relationship between soil nitrate-N and yield, % protein and N uptake. (curves free-hand)

Relationships between nitrate-N and yield, percentage protein and grain N uptake

As shown by the hand-fitted curves in Figure 1, there is usually a reasonable relationship between pre-planting nitrate-N (0 to 60 cm soil) and yield, percentage protein, or N uptake for any particular year. However, in different years these relationships can be linear, curvilinear or markedly exponential, and are obviously much influenced by seasonal conditions.

Over all years the general relationships between nitrate-N and the three plant variables are very diffuse (Table 5), although linear trends are significant for yield and N uptake when data from 1960 (frosted), 1961 (severe crown rot) and 1962 (hail damaged) are deleted.

Table 5. Linear regressions of yield, grain N uptake and grain % protein on soil nitrate-N 0 to 60 cm

Dependent variable *(y)*	Regression equation (x=ppm N03-N 0 to 60 cm)	R^2
Yield (t/ha)		
all years; n=51	y=1.782+0.0026 x	0.046 ns
1963-68; n=40	y=1.730+0.0181 x	0.170 **
Grain N uptake		
all years; n=51	y=39.1+0.238 x	0.034 ns
1963-68; n=40	y=37.4+0.621 x	0.307 **
Grain % protein		
all years; n=51	y=12.52+0.065 x	0.124 *
1963-68; n=40	y=12.44+0.061 x	0.092 ns

for n=51 $P<0.05$, R^2=.076 n=40 R^2=0.097
$P<0.01$, R^2=.130 R^2=0.162

Quadritic trends are non-significant for all relationships

Waring and Teakle (1960), on similar soils, attributed a lack of correlation between pre-planting mineral nitrogen on wheat yield to mineral nitrogen not being a limiting factor in yield production. In our study, mineral nitrogen was limiting since significant yield improvement in any 1 year was associated with higher nitrate-N levels.

CONCLUSION

The data presented have shown that a 3 or 4 year lucerne based pasture can produce measurable increases in the nitrogen fertility of a Darling Downs black earth, which can result in higher yields and quality of wheat for up to 7 years subsequently.

By inference from the total N build-up pattern (Table 2), a similar situation may occur after just 2 years of pasture.

Thus, if a lucerne-prairie grass pasture is to be used at all on the Darling Downs to build up soil nitrogen, an acceptable rotation could conceivably be 2 years of pasture in a 9 or 10 year rotation.

However, the soil investigated was not particularly low in total N (0.13%), and other Darling Downs black earths which have degenerated further may require a pasture phase longer than 2 years in 10 to maintain nitrogen fertility.

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