A 20 year comparison of four agricultural systems for their sustainability in the northern wheat belt

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Summary. An experiment on two adjoining soil types was commenced in 1966 to compare three pasture legume/cereal rotations, a grain legume/cereal rotation, and a long fallow/cereal rotation with continuous cereal growing. Lucerne leys of 2.5 to 5.5 years had significant beneficial effects lasting for at least nine years of subsequent wheat crops and four years of subsequent sorghum. Lucerne raised total soil nitrogen on both soil types, but it raised soil organic carbon (C) only in the black earth. In 1989, nitrogen and C were both higher than the original levels in the black earth but not in the red clay, following lucerne leys lasting a total of 7.5 years. Generally cereal yields after a grain legume, such as cowpeas, have been similar to yields after long fallow.

Introduction

The nitrogen and organic components of sustainability of cereal production in southern Australia have been achieved traditionally by crop rotation with leguminous pastures, particularly subterranean clover. Clover has not been used to any extent in the northern wheat belt, to which perennial lucerne is more suited because of the frequency of summer rainfall. Evidence of the value of lucerne for sustaining cereal productivity was anecdotal only at the time an experiment was commenced on two adjoining soil types in 1966 near Tamworth. This paper describes some of the results of this experiment (5) which is now in its 26th year.

Methods

The overall aim of this rotation experiment was to compare three pasture legume/cereal rotations, a grain legume/cereal rotation, and a long fallow/cereal sequence for sustaining cereal production. The experiment was designed as a 6x6 Latin Square, and it was placed on a black earth and a red clay in adjoining paddocks. The experiment has been in two phases: the first (1966-79) comparing three durations of lucerne and a cowpea/wheat rotation (1) and the second (1979-87) comparing different methods of establishing and managing lucerne and a faba bean or cowpea/cereal rotation (3). Each phase consisted of a treatment and an evaluation period so that all the treatment effects were tested under the same climatic conditions. For evaluating treatment effects (cereal productivity), the first phase used wheat (1970 or 1973-79) and the second grain sorghum (1983-87).

Because results for the three pasture legume rotations were similar only one of these treatments is reported. In the first phase, long fallowing, which was included as a control treatment, extended for the full duration of the lucerne treatments, and thereafter wheat was grown continuously until 1979 and then in alternate years. The double-cropped cowpea/wheat rotation in phase 1 was generally unsuccessful so results are not presented. In phase 2, faba beans or cowpeas were grown in alternate years with wheat or sorghum. Periods of pasture and uncultivated fallows have been grazed (sheep); crop stubble was burnt and cultivated up to 1980, and since then has been conserved and uncultivated (1980-83) or cultivated (1983-present) for three months prior to sowing.

Plant sampling for nitrogen analysis has been carried out at flowering and/or maturity of all pastures and crops. Soil sampling to depths up to 200 cm has been carried out at least annually throughout the experiment. Soils have been analysed for organic carbon and total and mineral nitrogen.

Results and discussion

The mean annual rainfall for the past 31 years at this site has been 690 mm, but rainfall has fluctuated widely during the experiment with resultant large variations in cereal production (Tables 1 and 2). Rainfall has had a dominant effect on crop yields, and it has had an indirect influence through its effects on lucerne yield and associated nitrogen fixation and leaching and denitrification of mineral nitrogen especially during the fallow. Rainfall was very low (>150 mm below average) in 1967, 1972, 1974, 1980, 1982 and 1986, and was very high (>150 mm above average) in 1973, 1976 and 1984.

Table 1. Wheat grain yields (t/ha) from 1970-79 following 3.5 years of lucerne, five years of long fallow, or continuous wheat.

Preceding treatment	1970	71	73	74	75	76	77	78	79
BLACK EARTH									
Lucerne	1.51	3.22*	2.70	1.59*	2.18*	3.07*	1.20*	2.13	2.29*
Fallow	3.09	3.05	2.75	0.95	1.79	1.75	0.88	1.80	1.83
Cont. wheat	2.04	1.90		0.58	1.14	1.21	0.61	1.92	1.63
RED CLAY									
Lucerne			1.99*	1.49*	2.18*	0.78	1.03*	2.38*	1.99*
Fallow			2.12	1.00	1.56	0.63	0.77	2.00	1.55
Cont. wheat	2.26	1.08	1.68	0.53	1.08	0.62	0.56	1.92	1.32

* Positive lucerne effect significant (P<0.05)

Lucerne yields were noticeably depressed during the second phase of the experiment due to drought in 1980 and 1982, and this was most severe on the red clay (3). The results have shown that both soil types are equally productive with good soil moisture, but under drier conditions the black earth is more productive. The red clay is also more prone to nitrate leaching (and probably denitrification) under very wet conditions, and this caused very low wheat yields in 1976 on this soil (1).

Effects of lucerne on cereal yields and protein content

Lucerne leys lasting for 2.5 or more years had significant beneficial effects on subsequent wheat productivity for the whole period of measurement (Table 1) - that is, nine years on the black earth and seven years on the red clay (1). Similar large positive effects occurred in four years of subsequent sorghum cropping, especially on the black earth (Table 2). Lucerne also raised the grain protein concentration in the following crops of wheat (Table 3) and sorghum, but in the second phase on the red clay the protein effect was significant only in the first sorghum crop (Table 2). The beneficial effects on sorghum were generally much smaller on the red clay because of the very low lucerne yields preceding this crop (3).

Table 2. Sorghum grain yields (t/ha) and protein (%) from 1983-87 following lucerne, grain legume, long fallow, or continuous wheat.

Soil	Preceding Treatment	Grain Yields 1984	85	86	87	Protein 1984	85	86	87
BLACK EARTH	Lucerne	7.39*	1.09*	2.54*	5.01*	6.9*	11.2*	7.6*	7.9*
	G. legume	3.77		2.74*		4.7		6.4*	
	Fallow	3.99		2.94*		4.7		7.3*	
	Cont. wheat	3.87	0.39	1.36	3.01	4.7	10.2	5.3	6.7
RED CLAY	Lucerne	6.87*	0.47	1.59	2.37	7.1*	10.4	6.9	7.4
	G. legume	4.50		1.83		5.0		8.4*	
	Fallow	4.95		1.69		5.3		8.8*	
	Cont. wheat	4.31	0.37	1.17	2.01	4.8	11.0	6.5	6.7

* Treatment effects significant (P<0.05).

Table 3. Wheat grain protein (%) from 1970-79 following lucerne, long fallow, or continuous wheat.

Preceding treatment	1970	71	73	74	75	76	77	78	79
BLACK EARTH									
Lucerne	14.8*	15.8*	14.3*	16.7*	11.6*	10.9*	10.2*	10.6	7.9
Fallow	12.7*	13.6*	13.3*	16.3*	9.9	9.4			
Cont. wheat	10.1	10.8	12.6	14.8	9.4	8.6	9.5	10.4	7.2
RED CLAY									
Lucerne			16.2*	17.0*	10.7*	10.3*	11.4	10.9	7.7
Fallow			14.9*	15.3*	9.9*	9.7			
Cont. wheat			13.8	13.2	8.6	9.4	11.0	10.6	7.1

* Treatment effects significant (P<0.05).

The only adverse effect of lucerne on productivity was its dehydration of the soil which occurred to a depth of 200 cm after only 12 months of lucerne growth (5). To maximise the beneficial effects of lucerne the rainfall between lucerne and the first cereal crop must be sufficient to re-hydrate the soil. This did not occur on the black earth in 1970 when cereal yields after lucerne were very depressed (Table 1). On the other hand 18 months of fallow after lucerne on the red clay allowed the beneficial effect of lucerne to be manifested in 1973.

The large fluctuations in yields of both the lucerne and non-lucerne rotations precluded the detection of trends in cereal productivity (Tables 1 and 2). In the last two years of the first phase of the experiment, wheat yields in the lucerne rotation on the red clay were similar to the first year (2.12 t/ha) but they were lower on the black earth (3.12 t/ha). Similarly, in the three most productive years of the lucerne rotation, wheat yields tended to increase (from 2.1 to 2.4 t/ha) on the red clay but decrease (from 3.3 to 2.3 t/ha) on the black earth. Furthermore the mean wheat yield (seven years) of the lucerne rotation on the red clay was 78% of that (nine years) on the black earth whereas the initial relative yield on the red clay was 68%. Hence it appears that the sustainability of wheat yields after lucerne was higher on the red clay than on the black earth even though lucerne productivity was lower on the former soil (1). This did not occur with sorghum, *as* the relative yield of the fourth sorghum crop after lucerne was 68% of the first crop on the black earth and only 35% on the red clay. This reflected the much lower lucerne yields on the red clay (9.0 t/ha) than on the black earth (16.5 t/ha) during the second phase (3).

Effects of lucerne on top soil nitrogen and organic carbon

Lucerne had a significant positive effect on C in the top 15 cm which lasted for the first three years of wheat cropping (2) and four years of sorghum cropping on the black earth (4). On the red clay, five years of lucerne were required to significantly increase C, and the duration of the effect in wheat was similar to the black earth but not significant in sorghum. The smaller and non significant effects of shorter periods of lucerne in the first phase of the experiment were caused by the extended fallowing (up to four years) which preceded these treatments.

Organic C was maintained at levels (1.13-1.29%) higher than the original (1.12%) throughout the 20 years of lucerne rotation in the black earth but it declined in the red clay from 1.26% to about 1.0% at the end of the second lucerne phase. It has increased since the beginning of sorghum cropping in 1983 to 1.07% in the red clay. Hence it may be concluded that the ability of lucerne to sustain organic fertility will depend on its productivity.

Lucerne had a larger and more sustained beneficial effect on total soil nitrogen than on C, and it lasted for the full nine years of wheat cropping and four years of sorghum cropping on the black earth (2,4). However after two years of lucerne in the second phase on the red clay, total nitrogen declined continuously (from 0.119-0.101%) for seven years, apparently because of the severe drought effect on lucerne.

Lucerne has sustained total soil nitrogen above the original level (0.116%) in the black earth (reaching a peak of 0.13% in 1983) for the entire period of the experiment except four years at the end of the first wheat-growing phase. Lucerne similarly sustained soil nitrogen above the original level (0.114%) for the first phase of the experiment in the red clay (2) but not during the second phase (4). Soil mineral nitrogen fluctuates widely through the year, but mid-year sampling indicated that lucerne had a similar positive effect to that on total nitrogen, but the sustainability was slightly shorter on the black earth and longer during sorghum on the red clay.

Effects of a grain legume rotation

The aim of this rotation was to grow cowpeas during the summer fallows of the first phase, and from 1979 to grow faba beans or cowpeas in a biennial rotation with wheat or sorghum. Only two cowpea crops were grown during four years of the first phase (1967-70) and two cowpea crops in rotation with sorghum during 1984-87. Faba beans were severely insect damaged in 1980 and were ploughed in, while cowpeas gave maximum yields of only 1.51 t/ha.

Generally cereal yields after a grain legume have been similar to yields after long fallow and in 1986 they were higher than after lucerne (Table 2). Soil organic C has been maintained at levels similar to continuous cereal growing in the black earth and intermediate between this treatment and the lucerne rotation in the red clay. The effect on total soil nitrogen has been similar to the effect on C in each soil type. Soil nitrate after six months of fallow following cowpeas has generally been lower than after 18 months of long fallow, but it was higher than after lucerne on the red clay in 1985 and 1987 (4).

Effects of long fallowing

Long-fallowing has generally maintained cereal productivity at levels intermediate between continuous cereal growing and the lucerne rotation. In the first cereal crop after the initial lucerne phase (Table 1), and in the third cereal crop after the second lucerne phase (Table 2) it outyielded the lucerne rotation. In the first wheat crop after sorghum it gave yields that were slightly greater than in the first year of the experiment.

In spite of its continuing beneficial effect on cereal productivity, long fallowing has caused the largest decline in C and total nitrogen. Nonetheless the accumulation of nitrate during long fallowing after sorghum in 1985 and 1987 (4) exceeded the nitrate levels in all other rotations. This suggests the possibility of biological nitrogen fixation by stubble-associated microorganisms in long fallows in recent years as this effect did not occur in earlier years when stubble was burnt or grazed (4).

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