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EFFECT OF LUCERNE—WHEAT ROTATIONS ON THE YIELD AND QUALITY OF SUBSEQUENT WHEAT CROPS ON THE DARLING DOWNS, QUEENSLAND

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SUMMARY

In one experiment, on a soil of medium fertility, wheat grown after 3 years of grazed lucerne and grass sheep pasture was compared with wheat grown after 3 years of summer (grain sorghum) or winter (grazing oats) annual cropping.

In a second experiment, on a more fertile soil, an 8-year rotation of alternate wheat-grain sorghum was compared with a sequence of sorghum, wheat, oats, wheat grown after 4 years of lucerne used for the production of hay.

Wheat yields were increased by the growing of lucerne on the more fertile soil, which had good moisture-holding capacity. Lucerne did not increase wheat yield on the less fertile soil, probably through the failure of subsoil moisture to be replenished following the lucerne phase. Grain protein content was increased where wheat followed lucerne and this effect was most noticeable in the less fertile soil. Flour quality improved where wheat followed lucerne.

I. INTRODUCTION

The natural fertility of the dark brown and black basaltic soils of the Darling Downs of south-eastern Queensland is of a high level, and the soils have been able to support high yields of wheat and similar crops for several decades without the need for fertilizers. Continual cropping, and particularly long periods of intensive cultivation, have been associated with a decline in productivity.

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In other parts of the world, nitrogen fertilizer is commonly applied to wheat and fertilizer requirements have been thoroughly worked out for particular soil types. In the dryland farming area of eastern Washington, U.S.A., for example, it was found that approximately 3 lb of nitrogen per acre increased wheat yield by 1 bus/ac over the range where nitrogen was limiting yield (Leggett 1959).

In an area of old cultivation at Pampas, on the Darling Downs, wheat yields were increased by the preplanting use of urea (Littler 1961), and use of nitrogenous fertilizers has tended to become common practice on older areas of the Darling Downs in recent years.

It was evident in the late 1940's (Bell 1949) that wheat yields and grain quality were declining in the areas of older cultivation and that steps were needed to combat soil erosion and loss of fertility. In this connexion it was considered that investigations were warranted into the effects on soil fertility of crop rotation and the grazing of animals. A series of experiments was designed by the Regional Experiment Stations Branch of the Department of Agriculture and Stock (now Department of Primary Industries). In this paper, the crop rotation experiments at Hermitage Research Station on the south-eastern Darling Downs are summarized, and data on the effects on the yield and quality of wheat of crop rotation systems involving lucerne are presented.

II. MATERIALS AND METHODS

Soils.—The area used for the first experiment was a brown colluvial clay loam derived from basalt and sandstone. In the second experiment the soil was a dark brown clay derived from basalt. Profile differences between these soils were marked. The soil in the first experiment changed to a yellow clay at approximately 24 in., whereas the basalt-derived soil used for the second experiment was uniform in texture throughout the profile of the root zone but changed slightly in colour to a brown clay below 24 in. Moisture-holding capacity was distinctly higher in the basalt-derived soil.

Chemical analyses of these soils are shown below for the surface 12 in. These analyses disclose a lower phosphate status in the first soil. The difference in fertility shown by the analyses would be greater under field conditions because of the greater depth of the second soil.

Depth (in.)	Experiment No.	pH	Total N (%)	K + (m-equiv./100 g)	Available P_2O_5 (p.p.m.)
0–6	1	7·3	0·13	0·91	60
6–12	1	7·8	0·08	0·45	28
0–6	2	7·8	0·12	0·68	128
6–12	2	7·8	0·12	0·75	85

Treatments.—In experiment 1, conducted from 1956 to 1962, a number of rotation sequences were carried out on a replicated plot basis. The following treatments were succeeded after 4 years by three seasons of wheat:—

1. Lucerne + Rhodes grass.
2. Lucerne + green panic grass.
3. Annual grazing oats.
4. Lucerne, Rhodes grass, Phalaris tuberosa, Wimmera ryegrass.
5. Annual grain sorghum.

Throughout the first 4 years, treatments 1–4 were grazed by sheep.

Treatments were in plots of area 0·4 ac, and the trial was in the form of a 5 x 4 randomized block experiment.

Treatment 4 was intended originally to provide winter and summer grass components with lucerne. Phalaris and Wimmera ryegrass did not survive after the first year in sufficient quantity to materially affect the composition of this treatment, which became virtually a mixture of lucerne and Rhodes grass.

The area was ploughed late in 1959 and bare-fallowed until Spica wheat was planted approximately 6 months later, this being a short fallow. The area was cropped with wheat in the 1960, 1961 and 1962 seasons with a bare fallow of approximately 6 months between crops.

In experiment 2, the rotations used were (1) a 4-year phase of lucerne (harvested for hay) followed by grain sorghum, wheat, grazing oats and wheat; and (2) grain sorghum and wheat grown in alternate years. The first wheat harvests were made in 1955. The experiment was set out in 11 plots each of 0·2 ac, so arranged that in any season each phase of the rotations was represented by a single plot.

Yield and protein content.—In both experiments, wheat yield was measured and protein content and grain quality were determined. Protein was determined by the Kjeldahl method (N x 5·7). Moisture was determined by the electric oven (2g, 1 hr, 130°C) method. Physical measurements of flour were made by the Brabender Extensograph and Farinograph. In the baking test, improvers were used and the best loaf selected from three fermentation times.

III. RESULTS

(a) Yield

Experiment 1.—Wheat yields in experiment 1 (Table 1) were higher in both 1960 and 1962 after 4 years of grain sorghum than after 4 years of lucerne + Rhodes grass. In 1960, wheat yielded higher after annual cropping treatments (oats and grain sorghum) than after lucerne + Rhodes grass. The widest range of yields occurred in 1960. There were no significant differences between treatments in 1961. The lower yields in 1962 may be attributed to a late planting (July 30). The 1960 and 1961 plantings were made in early June.

TABLE 1

EXPERIMENT 1: EFFECT OF TREATMENT ON WHEAT YIELD

Treatments, 1956–1959	Yield (bus/ac)		
	1960	1961	1962
1. Lucerne + Rhodes grass ..	22·06	30·05	18·16
2. Lucerne + green panic ..	25·78	30·83	18·28
3. Annual grazing oats	32·99	27·34	20·14
4. Lucerne + Rhodes grass + winter grasses	27·01	30·44	18·50
5. Annual grain sorghum ..	32·99	28·70	22·59
Mean	28·17	29·47	19·53
Significance of differences ..	3,5$\gg$1	N.S.	5$\gg$1,2,4

Soil moisture measurements carried out during 1960, shortly after planting, indicated that moisture at 24–36 in. was at the lowest level in the plots which had been under lucerne + Rhodes grass (Table 2). No significant differences in soil moisture content were observed between lucerne + Rhodes grass and annually cropped areas at the end of the 1960 wheat season nor at time of planting of the 1961 crop.

TABLE 2

EXPERIMENT 1: EFFECT OF TREATMENT ON SOIL MOISTURE PERCENTAGE AT 24–36 in. DEPTH

Treatments, 1956–1959	1960		1961 Planting
	Planting	Harvest	
1. Lucerne/Rhodes grass ..	21·0	18·5	18·2
3. Annual grazing oats	24·6	20·0	19·6
5. Annual grain sorghum ..	25·4	19·8	20·2
Significance of differences ..	3,5$\gg$1	N.S.	N.S.

TABLE 3

EXPERIMENT 1: RAINFALL (IN.) IN GROWING PERIOD OF WHEAT

Month	1960	1961	1962
June	1·09	0·84	0·12
July	1·20	3·65	2·51
August	1·32	1·28	1·52
September	0·42	0·64	2·19
Total	4·03	6·41	6·34

Experiment 2.—In experiment 2, as each phase of the rotations was represented by one plot each year, there were three wheat plots for yield comparison annually; of these, one was a "control" plot from the grain sorghum-wheat rotation and the others followed either grain sorghum or oats in the lucerne-based rotation. These wheat plots may be referred to as long fallow or short fallow, depending on whether wheat followed grain sorghum with a fallow of approximately 14 months between the two crops, or wheat followed grazing oats with a fallow period of about 5 months.

In the lucerne-based rotations, long-fallow wheat outyielded short-fallow wheat in all but one of the 8 years of the experiment (Table 4). Long-fallow wheat after lucerne also outyielded long-fallow wheat in the control treatment. For mean yields taken over the 8-year period, long-fallow wheat after lucerne outyielded the other two treatments (1% level).

TABLE 4

EXPERIMENT 2: EFFECT OF TREATMENTS ON WHEAT YIELDS, 1955–1962 (BUS/AC)

Rotation	1955	1956	1957	1958	1959	1960	1961	1962	Mean
1. *Control.* Long-fallow wheat after sorghum	28·2	16·6	25·9	18·9	23·7	40·6	29·0	28·2	26·4
2. *Lucerne rotation.* Long-fallow wheat after sorghum ..	32·6	28·8	28·0	23·6	32·2	45·0	36·9	38·9	33·3
3. *Lucerne rotation.* Short-fallow wheat after oats	28·4	23·1	23·1	20·7	24·1	40·2	36·9	29·7	28·3

Significance of differences 2≫1,3

TABLE 5

EXPERIMENT 1: EFFECT OF TREATMENT ON PERCENTAGE AND YIELD OF PROTEIN

Treatments, 1956–1959	Wheat Protein (% at 13·5% moisture)			Wheat Protein (lb/ac)		
	1960	1961	1962	1960	1961	1962
1. Lucerne + Rhodes grass	15·0	12·4	13·8	198	223	151
2. Lucerne + green panic	14·7	12·7	13·6	228	234	149
3. Annual grazing oats ..	12·2	9·9	10·9	242	163	131
4. Lucerne + Rhodes grass + winter grasses ..	14·6	12·3	13·4	234	225	149
5. Annual grain sorghum	12·4	10·5	11·2	244	182	151
Significance of differences	1,2,4≫3,5	1,2,4≫3,5	1,2,4≫3,5	N.S.	1,2,4≫3,5	N.S.

In experiment 2, in most seasons grain protein percentage was higher when wheat was grown in a lucerne-based rotation than in rotation with grain sorghum (Table 6).

TABLE 6

Experiment 2: Effect of Treatment on Wheat Grain Protein Percentage at 13·5% Moisture, 1955–1962

Treatments, 1955–1962	1955	1956	1957	1958	1959	1960	1961	Means
1. *Control.* Long-fallow wheat after sorghum	10·1	13·5	13·9	14·1	12·8	13·2	12·4	12·9
2. *Lucerne rotation.* Long-fallow wheat after sorghum	12·7	14·4	12·8	13·8	13·0	14·2	13·3	13·5
3. *Lucerne rotation.* Short-fallow wheat after oats	12·0	14·3	13·7	14·2	13·5	13·7	12·9	13·5

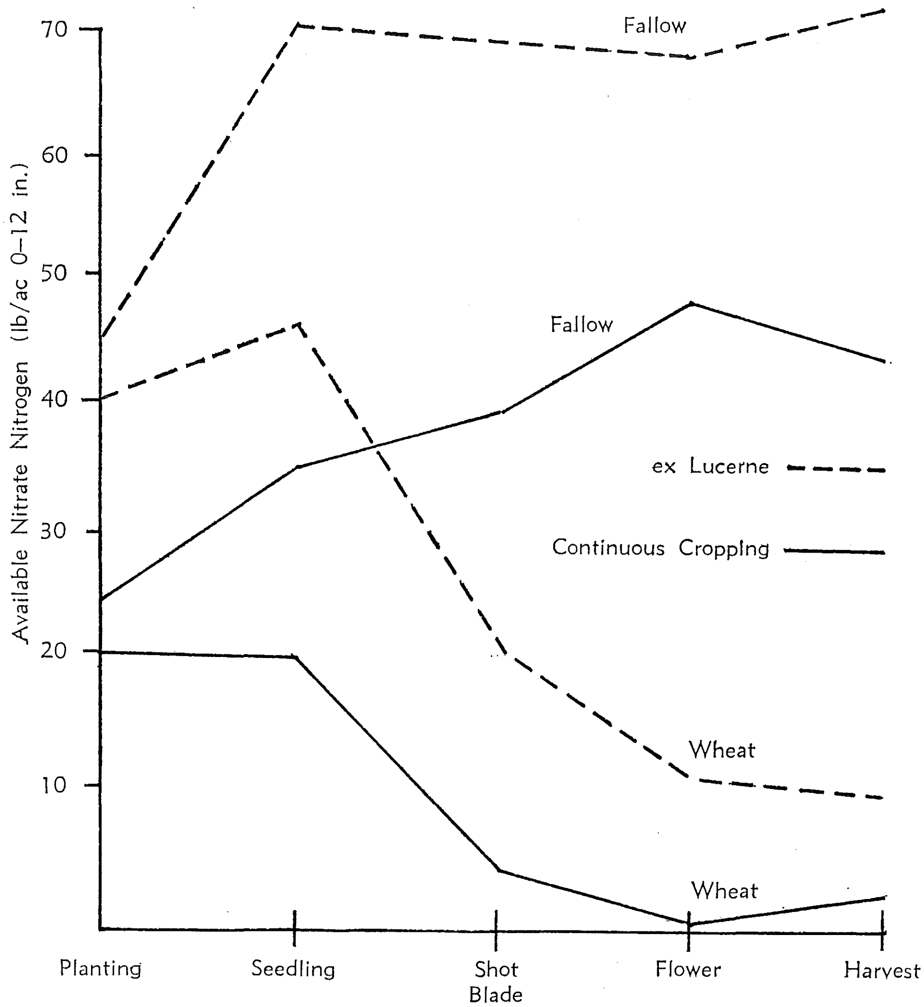

Fig. 1.—Changes in available soil nitrate nitrogen under wheat and fallow in experiment 2

In this experiment also, soil nitrate nitrogen determinations confirmed that higher rates of nitrification were a feature of the plots previously under lucerne, in comparison with the continuously cropped plots. In Figure 1, fluctuations in available nitrogen in the top 12 in. of soil during a fallow period and under wheat are shown for the 1955 season.

(b) **Wheat Quality**

For each of the 3 years of wheat harvests in experiment 1, grain protein percentage was significantly higher following lucerne + Rhodes grass (Table 5). Significantly different yields of protein per acre were obtained only in 1961, when yield of protein in lucerne-based treatments exceeded that of the other treatments. In 1960 and 1962 the lack of differences in yield of protein was probably a reflection of a negative relationship between grain yield and percentage content of protein that appeared to exist in each of these two years.

(c) **Flour Quality**

In experiment 1, where wheat followed legume-based treatments, flour quality was good. Strong to very strong, overstable flour was produced. In contrast, where wheat followed oats or grain sorghum cropping, flour quality was fair. Medium strong flour with fair extensibility was produced.

In experiment 2, flour quality from long-fallow wheat in the lucerne-based rotation was good, the flour being extensible, well balanced and very strong. Flours from treatments involving short-fallow wheat in the lucerne-based rotation and continuous sorghum-wheat were inferior in quality to flour from long-fallow wheat but comparable with one another.

(d) **Moisture Utilization by Wheat**

Moisture utilization by a succession of wheat crops in experiment 2 is shown in Table 7. The stored moisture used from the top 5 ft of soil was calculated by subtracting the amount of available moisture present at harvest from the amount present at planting and the value obtained added to the effective rainfall during the growing season to give the total usage of moisture. This figure was used to derive an estimate of the number of bushels of grain produced per inch of utilized moisture.

TABLE 7

EXPERIMENT 2: MOISTURE UTILIZATION (IN.) BY WHEAT

Year	1957		1958		1959	
Rotation	Continuous Cropping	Lucerne Rotation	Continuous Cropping	Lucerne Rotation	Continuous Cropping	Lucerne Rotation
Available moisture at planting, 0–60″	7·71	8·35	5·73	4·78	8·87	8·25
Available moisture at harvest, 0–60″	1·27	1·46	1·89	1·80	7·54	7·02
Available moisture used, 0–60″ ..	6·44	6·89	3·84	2·98	1·33	1·23
Effective rainfall estimate (in.) ..	3·83	3·83	8·55	8·55	13·36	13·36
Total moisture used (in.)* ..	10·27	10·72	12·39	11·53	14·69	14·59
Yield of grain (bus/ac)	25·9	28·0	18·7	20·7	23·7	32·2
Bushels of grain per inch of moisture	2·5	2·6	1·5	1·8	1·6	2·2

* Total usage = depletion of planting moisture + effective rainfall.

In each of the years 1957, 1958 and 1959 a wheat plot from the continuous cropping rotation was compared with a wheat plot from the lucerne-based rotation.

IV. DISCUSSION

Yield.—In experiment 1, 4 years' precropping with lucerne + Rhodes grass had no advantage over similar periods of precropping with grain sorghum and grazing oats so far as yields of subsequent wheat crops are concerned. This was possibly due to soil moisture reduction by the lucerne. This assumption is supported for the first wheat crop by the soil moisture levels taken at planting, which showed soil moisture to be significantly lower following lucerne + Rhodes grass than following annual crops. Subsoil moisture differences may have been less important in 1961 and 1962, as more rainfall was received during the growing season in these years (Table 3).

In experiment 2, yields were consistently and significantly higher for long-fallow wheat (i.e. wheat following grain sorghum) in rotations with a basal 4 years of lucerne than in a grain sorghum-wheat rotation, which is also a long-fallow for wheat. There was no consistent indication that short-fallow wheat in the lucerne-based rotations yielded better than long-fallow wheat in the grain sorghum-wheat rotation. This failure of short-fallow wheat in the lucerne-based rotations to show the same yield improvement shown by long-fallow wheat is probably due to a smaller accumulation of soil moisture and available nitrogen in the short fallow.

Protein content.—On the less fertile soil in experiment 1, a significant increase in grain protein content was apparent. As experiment 2 was only replicated in time, no statistical analysis was possible. However, the treatments involving lucerne produced wheat of a higher protein content than the control for all years except 1957 and 1958.

Soil nitrate.—Soil nitrate nitrogen measurements indicated a higher supply of available nitrogen in soil following lucerne. No attempt was made to evaluate the effect of any specific phase of the rotations studied but it was evident that the period under lucerne caused a marked response in the growth of succeeding crops.

Wheat growth.—On the less fertile soil type, wheat grown in the lucerne-cereal rotation was taller and better tillered than, and of superior colour and vigour to, wheat in an annual cropping cycle. On the more fertile soil, similar effects were noted in sorghum in the lucerne-cereal rotation in comparison with sorghum grown alternately with wheat.

Soil moisture.—Soil moisture was probably a limiting factor in the production of high wheat yields in the lucerne-cereal rotation. In experiment 1, depletion of subsoil moisture under lucerne was demonstrated. This moisture shortage was sufficient to affect wheat yield at least in the first crop after lucerne. It was frequently observed in experiment 2 that grain sorghum immediately following lucerne tended to exhaust soil moisture reserves and to "burn" at critical stages of development. This was accentuated by the high production of leaf which was a characteristic of sorghum growth after lucerne. Where the length of fallow after lucerne allowed the build-up of a satisfactory reserve of subsoil moisture, crops were able to respond to the better soil nitrogen status.

Moisture utilization data in Table 7 do not indicate different moisture usage by wheat in the two rotation treatments of experiment 2. They do provide a comparison of the effect of different seasonal rainfall conditions and moisture reserves at planting on wheat yield. In 1957 good subsoil moisture reserves counteracted the effect of poor seasonal rainfall, so reasonably good yields were obtained. In the following year yields were apparently reduced by poor subsoil reserves at planting despite higher seasonal rainfall than in 1957. Growing conditions during 1959 were favourable with regard to moisture; rainfall was adequate and well spaced. Under these conditions it would appear that higher soil nitrogen status of the old lucerne plot may have been responsible for the higher yield of this plot.

Moisture usage was greatest in the top 36 in. of soil. Between 1·5 and 2·5 bus of wheat per acre were produced for each inch of available moisture utilized.

Flour quality.—Flour quality investigations demonstrated that wheat following lucerne was generally capable of producing flour of better quality. The variety Spica, which was used in both experiments, is characterized by the ability to produce good quality flour under a range of soil conditions and this was probably responsible for the lack of marked differences in quality of wheat under the various rotations studied.

General.—On the more fertile soil, which had better moisture-holding capacity, lucerne had the effect of increasing the yield of subsequent wheat crops, but this did not occur on the less fertile soil, probably because of its lower water-holding capacity. Lucerne caused an increase in grain protein, particularly on the less fertile soil. Where wheat followed lucerne, flour quality was better in all cases.

These experiments indicated that yield, protein content and flour quality of subsequent wheat crops may be beneficially affected by crop rotation using lucerne under dryland farming conditions. In order to take advantage of these effects, careful planning of crop rotation management would be essential. In view of the dependence of dryland farming on the efficient utilization of rainfall, it is considered that a set rotation system would be impracticable in this region; any system adopted should possess flexibility in order to capitalize on deviations from expected rainfall patterns in relation to marketing opportunities.

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