QUEENSLAND DEPARTMENT OF PRIMARY INDUSTRIES
DIVISION OF PLANT INDUSTRY BULLETIN No. 521

YIELD AND ECONOMIC RESPONSE TO NITROGEN AND PHOSPHORUS FERTILIZERS ON A LOW-PHOSPHORUS SOIL OF THE DARLING DOWNS, QUEENSLAND

By D. E. HIBBERD, B.Agr.Sc., M. J. WHITEHOUSE, B.Sc., and O. W. DUNCAN, M.Agr.Sc.

SUMMARY

While maximum wheat yields appear to be obtained with rates of up to 3·6 cwt superphosphate and 2 cwt urea per acre (37 lb P and 103 lb N respectively) on the Mywybilla series of Darling Downs black earths, economical rates were 1 cwt superphosphate and ½ cwt urea per acre (11 lb P and 26 lb N respectively). It is recommended that both fertilizers be applied for fertility maintenance.

Highly significant responses in grain protein occurred but these were not sufficient to raise the grain quality status on the Australian price structure.

Increased stubble may be expected with the use of fertilizer.

I. INTRODUCTION

The Mywybilla series of the Darling Downs black earths presents a low level of available phosphorus (10-20 p.p.m. acid extractable P) and at the same time shows evidence of available nitrogen shortage. This soil has formed in clay alluvium of mixed origin, derived mostly from the Condamine River system. The soil has been described by Beckmann and Thompson (1960).

Average wheat yield for the area is approximately 30 bus/ac and grain protein is low. Varying degrees of mottling are experienced. Growers in the area commonly obtain spasmodic responses to nitrogenous and phosphatic fertilizers.

Increases in yield and protein level of wheat with nitrogen usage on the Darling Downs on some soils low in available nitrogen have been well established by Bisset and Andrew (1953), Littler (1963) and Wood and Fox (1965). Martin and Cox (1956) have shown that mineral nitrogen fractions vary seasonally.

Most of the work by these authors was done on soils of satisfactory phosphorus status. An estimation of superphosphate requirements for phosphorus-deficient soils has been derived by Colwell and Esdaile (1966) for wheat-growing soils of northern New South Wales. The heavier soils of the Mywybilla area, however, have not been studied for requirement of either element. Possible N x P interactions have not been reported.

A series of trials conducted from 1963 to 1966 was designed to determine the nature and reliability of responses in wheat yield and protein content of grain to different rates of superphosphate and urea applications.

II. METHODS AND MATERIALS

A standard trial design was used for each of the 4 years of the project. This was a 5 x 5 factorial in lattice design, combining 5 levels of standard 9·6% superphosphate (0, ½, 1, 2 and 5 cwt/ac) with 5 levels of urea (0, ½, ¾, 1 and 2 cwt/ac). There were two replications.

Trials were located at Norwin on soil representative of the Mywybilla type with a cultivation age of 16 years under cereal production. All operations of fertilizer spreading, planting and harvesting were carried out with standard farm machinery. Urea was applied 2-3 weeks before planting to avoid toxic effects on seed germination (Littler 1964, 1965). Superphosphate was drilled with the seed and planting in all 4 years was made at the rate of 1 bus/ac.

Spica was used in seasons 1963 to 1965, and Gamut in 1966 due to stem rust incidence in the former variety. Fertilizer was applied to a plot of 24 rows each 156 ft long. The outside two rows were mown prior to harvest, giving a harvested datum area of 1/25 ac. A 16 ft buffer zone was left between blocks with 18 in. laterally between plots.

Extractable soil phosphorus (0-4 in. depth) by the N/100 H_2SO_4 extraction method of Kerr and von Stieglitz (1938) and the M/2 $NaHCO_3$ method of Colwell (1963) are shown in Table 1. Nitrate nitrogen is also shown as the weighted mean of nitrate N (p.p.m.) for 0-2 ft depth.

TABLE 1

EXTRACTABLE SOIL PHOSPHORUS AND NITRATE NITROGEN IN SOIL

—	Mean	Range
N/100 H_2SO_4 (p.p.m. P at 0–4 in.)	12·6	9·5–16·8
M/2 $NaHCO_3$ (p.p.m. P at 0–4 in.) ..	13·3	9·4–15·9
Nitrate nitrogen (p.p.m. at 0–2 ft)	5·1	4·2–5·8

III. RESULTS AND DISCUSSION

Plant reaction to applied fertilizers was apparent in increased growth and colour about 3 weeks after emergence and these were maintained through to maturity. Plots with any level of applied urea were very much greener than controls. Superphosphate appeared to induce paler leaf colours on plots when applied alone, though growth was markedly increased.

At harvest, increased dry-matter yields were obtained, giving response patterns similar to grain yield responses with the applied fertilizers. Dry-matter yields and stubble yields (dry matter less grain yield) are presented in Tables 2 and 3. Stubble yields follow the same response pattern, showing that concurrent responses in grain yield and plant vegetative parts were obtained as a result of applied fertilizers.

TABLE 2

SUPERPHOSPHATE APPLICATION: DRY-MATTER YIELD OF THE WHOLE PLANT AT MATURITY AND DRY-MATTER YIELD OF STUBBLE (4-YEAR MEANS)

—	Level of Applied Superphosphate (cwt/ac)					Necessary Difference		S.E.
	0	½	1	2	5	5%	1%	
Whole plants at maturity (lb/ac)	5,435	5,773	6,248	6,406	6,737	399	529	141
Stubble (lb/ac)	3,432	3,648	3,985	4,090	4,367	344	457	122

TABLE 3

UREA APPLICATION: DRY-MATTER YIELD OF THE WHOLE PLANT AT MATURITY AND DRY-MATTER YIELD OF STUBBLE (4-YEAR MEANS)

—	Level of Applied Urea (cwt/ac)					Necessary Difference		S.E.
	0	½	¾	1	2	5%	1%	
Whole plants at maturity (lb/ac)	5,196	6,211	6,484	6,244	6,463	399	529	141
Stubble (lb/ac)	3,269	3,989	4,196	3,937	4,130	344	457	122

Data for grain yield and protein presented in Tables 4 and 5 are the means of 4 years' trial results from 1963 to 1966 inclusive. All years were significantly different ($P<0\cdot01$) for all data, so the mean trends are true over a variety of seasonal conditions. Standard errors are comparatively low, showing trends to be fairly reliable.

TABLE 4

SUPERPHOSPHATE APPLICATION: GRAIN YIELD AND GRAIN PROTEIN (4-YEAR MEANS)

—	Level of Applied Superphosphate (cwt/ac)					Necessary Difference		S.E.
	0	½	1	2	5	5%	1%	
Grain yield (bus/ac)	33·3	35·0	37·8	38·7	39·5	1·83	2·43	0·65
Grain protein (%) ..	11·0	10·70	10·72	10·70	10·58	0·33	0·44	0·117

TABLE 5

UREA APPLICATION: GRAIN YIELD AND GRAIN PROTEIN (4–YEAR MEANS)

—	Level of Applied Urea (cwt/ac)					Necessary Difference		S.E.
	0	½	¾	1	2	5%	1%	
Grain yield (bus/ac)	31·7	37·0	38·2	38·5	38·9	1·83	2·43	0·65
Grain protein (%) ..	9·54	10·36	10·86	11·08	11·85	0·33	0·44	0·117

Mean responses to superphosphate and urea over the trial period showed no overall significant interaction effect. These data were therefore considered separately. Grain yields for all fertilizer combinations are shown in Table 6.

TABLE 6

MEAN GRAIN YIELDS (bus/ac) OF 4 YEARS' WHEAT FERTILIZER TRIALS AT ALL COMBINATIONS OF FERTILIZER RATES

Rate of Urea (cwt/ac)	Rate of Superphosphate (cwt/ac)				
	0	½	1	2	5
0	30·58	28·37	31·88	33·61	33·68
½	33·69	35·03	38·05	38·08	39·99
¾	33·48	36·26	39·27	41·60	40·46
1	34·25	37·21	39·31	40·29	41·49
2	34·54	38·21	40·30	39·74	41·55

S.E. 1·45. Necessary differences for significance: 5%, 4·09; 1%, 5·43.

In preliminary statistical evaluation of the response patterns, three response models were tested:

$$Y = Y_0 + ax + bx^2$$
$$Y = Y_0 + a\sqrt{x} + bx$$
$$Y = Y_0 + b \log x$$

where Y_0 is the estimated control yield,

Y is the calculated yield at a fertilizer value of x.

The relationship showing the correlation coefficients for grain yield and grain protein with applied fertilizers is shown in Table 7.

TABLE 7

COMPARISON OF REGRESSION MODELS TO DESCRIBE THE RELATIONSHIP BETWEEN GRAIN YIELDS OR GRAIN PROTEIN (Y) AND APPLIED FERTILIZERS (x)

Regression Model	"r" Value
Grain yield with applied superphosphate—	
(1) $Y = 33{\cdot}47 + 3{\cdot}94x - 0{\cdot}55x^2$	0·98
(2) $Y = 33{\cdot}04 + 5.03\sqrt{x} - 0{\cdot}93x$	0·96
(3) $Y = 36{\cdot}99 + 4{\cdot}21 \log x$	0·97
Grain yield with applied urea—	
(1) $Y = 31{\cdot}87 + 10{\cdot}98x - 3{\cdot}76x^2$	0·98
(2) $Y = 31{\cdot}54 + 10{\cdot}77\sqrt{x} - 3{\cdot}90x$	1·00
(3) $Y = 38{\cdot}32 + 2{\cdot}92 \log x$	0·74
Grain protein with applied urea—	
(1) $Y = 9{\cdot}53 + 2x - 0{\cdot}42x^2$	1·00
(2) $Y = 9{\cdot}56 + \sqrt{x} + 0{\cdot}45x$	0·95
(3) $Y = 11{\cdot}12 + 2{\cdot}42 \log x$	0·99

Based on "r" value the best fitting relationship between grain yield and applied superphosphate was given by

$$Y = 33{\cdot}47 + 3{\cdot}94x - 0{\cdot}55x^2.$$

This model best describes the yield change with fertilizer around the change-over point between response and non-response. Maximum yield, determined from $\frac{dy}{dx} = 0$, would be realized from 3·6 cwt superphosphate.

However, the most suitable relationship for estimation of maximum economic rate was given by

$$Y = 33{\cdot}04 + 5{\cdot}03\sqrt{x} - 0{\cdot}93x.$$

This is more suited to the trial data in the lower portion of the response curve. While "r" is high in equation 3, not all the data can be used as this relationship does not describe Y values where $x = 0$.

Maximum economic rate of approximately 1 cwt superphosphate per acre was found from the method used by Colwell (1967), where

$$\frac{\text{cost of 1 cwt super}}{\text{return of 1 bus of wheat}} = \frac{\$1.76}{\$1.22} = 1.44 = \frac{dy}{dx}.$$

Prices were based on bagged superphosphate at $27.20 per ton plus freight of $8.00 per ton. Return for a bushel of wheat to the grower in 1964–65 after levies were deducted was $1.22 for F.A.Q. standard.

Similarly, the response to urea followed the relationship

$$Y = 31{\cdot}54 + 10{\cdot}77\sqrt{x} - 3{\cdot}90x,$$

where maximum yield theoretically could be obtained from approximately 2 cwt per acre. The maximum economic rate, derived by substituting the cost of urea in $\frac{dy}{dx}$, was found to be 0·5 cwt urea per acre. Prices were based on urea at $85.20 per ton plus freight of $8.00 per ton.

Returns did not include deductions for machinery or labour.

Although there was no overall interaction, a positive interaction of the two fertilizers was shown in 2 of the 4 years. Possibly rainfall or poor distribution and effectiveness prevented interactions in all years. Rainfall is shown in Table 8. It may be worthwhile applying both fertilizers at the calculated maximum economic levels on this property. This may apply to the area as a regular practice from a point of view of fertility maintenance and wheat quality.

TABLE 8

MONTHLY RAINFALL (IN.) FROM MAY TO NOVEMBER FOR YEARS 1963–1966

Month	1963	1964	1965	1966
May	2·15	3·81	..	0·09
June	1·00	1·15	1·62	1·79
July	0·03	1·10	5·31	0·13
August	1·89	0·68	1·79	4·10
September	0·08	2·00	1·43	0·97
October	0·74	3·29	1·82	1·68
November	3·15	2·06	1·37	2·43
Total	9·04	14·09	13·34	11·19

Grain protein showed a sharp rise with the applications of urea given by the best fitting relationship

$$Y = 9 \cdot 53 + 2x - 0 \cdot 42x^2.$$

Total increase in protein percentages was 2·31% with 2 cwt urea per acre. Table 3 shows that the maximum economic rate for yield of 0·5 cwt urea per acre has increased protein percentage by 0·82% to the level of 10·36%. While this increase is large, it is not sufficient to bring it to the minimum protein level of 11·5% required for Prime Hard classification. Judged on protein F.A.Q. standard wheat only may be economically produced in the area.

All levels of superphosphate lowered the grain protein percentage highly significantly ($P<0 \cdot 01$) over controls but were not individually significantly different. This lowering was probably caused by the concurrent yield increases producing a dilution effect.

IV. ACKNOWLEDGEMENTS

The authors wish to thank Mr. B. Baartz, Norwin, for his co-operation and enthusiasm in the trials and for the use of his time, land and machinery. Laboratory analyses were carried out by Miss J. Counter.

REFERENCES

BECKMANN, G. G., and THOMPSON, C. H. (1960).—Soils and land use in the Kurrawa area, Darling Downs, Queensland. *Soils Ld Use Ser. C.S.I.R.O. Aust.* No. 37.

BISSET, W. J., and ANDREW, C. S. (1953).—The effect of nitrogen on the yield, nitrogen content, and baking quality of wheat grown in the Darling Downs, Queensland. *J. Aust. Inst. Agric. Sci.* 19:40-4.

COLWELL, J. D. (1963).—The estimation of the phosphorus fertilizer requirements of wheat in southern New South Wales by soil analysis. *Aust. J. Exp. Agric. Anim. Husb.* 3:190-7.

COLWELL, J. D. (1967).—The calibration of soil tests. Proceedings Soil and Plant Tissue Testing Symposium. *J. Aust. Inst. Agric. Sci.* 33:321-30.

COLWELL, J. D., and ESDAILE, R. J. (1966).—The application of production function analysis for the estimation of fertilizer requirements of wheat in northern New South Wales. *Aust. J. Exp. Agric. Anim. Husb.* 6:418-24.

KERR, H. W., and VON STIEGLITZ, C. R. (1938).—The laboratory determination of soil fertility. *Tech. Comm. Bur. Sug. Exp. Stns Qd* No. 9 of 1938.

LITTLER, J. W. (1963).—Effect of time and rate of application of urea to wheat. *Qd J. Agric. Sci.* 20:323-44.

LITTLER, J. W. (1964).—When using urea with cereal crops. *Qd Agric. J.* 90:168-70.

LITTLER, J. W. (1965).—Urea's use in agriculture. *Qd Agric. J.* 91:321-2.

MARTIN, A. E., and COX, J. E. (1956).—Nitrogen studies on black soils from the Darling Downs, Queensland. I. Seasonal variations in moisture and mineral nitrogen fractions. *Aust. J. Agric. Res.* 7:169-83.

WOOD, H. L., and FOX, W. E. (1965).—The interaction of nitrogen and water on yield, protein and mottling in wheat grown on black earth in Queensland. *Expl Agric.* 1:107-12.

(Received for publication December 27, 1968)

D. E. Hibberd is an officer of Agriculture Branch, Queensland Department of Primary Industries, Toowoomba, and M. J. Whitehouse is an officer of Agricultural Chemical Laboratory Branch, stationed at Queensland Wheat Research Institute, Toowoomba. O. W. Duncan (resigned) was formerly an officer of Agriculture Branch.