EFFECT OF TIME AND RATE OF APPLICATION OF UREA TO WHEAT

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SUMMARY

A series of field trials involving the use of urea was carried out on a 70-year-old cultivation in the Pampas district of the Darling Downs in south-eastern Queensland.

It was shown that the use of urea resulted in a higher level of soil nitrate, improved grain yields, improved grain protein, and to a lesser extent improved baking quality. Furthermore, the number of mottled grains was reduced with increasing rates of application of urea.

An inverse correlation between protein content and grain mottling was shown to exist. Residual effects of the urea application were demonstrated in succeeding years. The economic aspect of this use of nitrogen fertilizer was investigated.

I. INTRODUCTION

The Darling Downs area of south-eastern Queensland is well suited to grain production and grain crops have been grown on the eastern portion from about 1890. Since that time, continuous monoculture has largely been carried on and there is evidence of a decline in both yield and protein content of wheat.

W. T. Kelso (unpublished Departmental data) has shown that grain of poor bread-making quality is produced in the Pampas district, where wheat has been grown for many years. In these older cultivations, soil nitrogen is low and available phosphate high. Observation trials laid down in 1954 using nitrogenous fertilizer showed increases in yield and grain protein. The series of trials with urea as a source of nitrogen, reported here, were initiated in 1956 and continued for four consecutive seasons.

II. EXPERIMENTAL SITES

The experimental sites were located on a 70-year-old cultivation in the Pampas district, where the growing of fodder crops for dairy production in the early years changed to continuous grain production. The soil is a dark grey-brown heavy clay of medium structure belonging to the Anchorfield association within the Australian black earths (Thompson and Beckmann 1960). The area has an even surface sloping gently towards the south; there is little visual evidence of gilgai formation. The analysis of the soil of the experimental area is shown in Table 1.

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TABLE 1

CHEMICAL ANALYSIS OF SOIL OF THE EXPERIMENTAL AREA

Depth (in.)	0–4	4–8	8–12	24	36
pH	7·8	7·9	7·7	8·1	8·4
Average P_2O_5 (p.p.m)	1155	1200	1170	1250	1600
Total N (%)	·068	·062	·060	·046	·040
Replaceable K^+ (m-equiv. %) ..	1·16	1·02	·82	·76	·68

III. EXPERIMENTAL METHODS

The experiment comprised three original trials (1956, 1957 and 1958 seasons), and four residual trials comprising trials of residual effects of the 1956 applications in 1957 and 1958 and of the 1957 and 1958 applications in 1958 and 1959 respectively.

Land preparation was carried out in the usual way and sowing took place in June or July, depending on planting rains. The variety Festival was used throughout the experiment because of its excellent agronomic features, its heavy demands on the soil and its popularity on the Darling Downs. Planting was carried out with a standard cultivator-drill (combine).

The experiment was laid down as a 16 x 4 randomized block in two tiers. Treatments were 4 rates of urea (0, ½, 1, and 2 cwt/ac) and 4 stages of growth (sowing, tillering, shotblade and flowering). Plot size excluding buffer areas was 1/20 ac.

Soil samples for assessment of available nitrogen were taken from the three primary or original trials in co-operation with the Department's Agricultural Chemical Laboratory. Five treatments (0 (control), and 2-cwt rates at the four growth stages) were sampled at five different times (sowing, tillering, shotblade, flowering, and 4 weeks after flowering), at five depths (0–4 in., 4–8 in., 8–12 in., 24 in., and 36 in.). Initial samples were taken prior to application of urea. Each sample was a composite of three random subsamples. Sampling was carried out using a 4-in. Jarrett auger.

Urea was applied broadcast at sowing, and was sprayed at the three other growth stages. A "Marino" power spray was used for spray applications, using a 2-nozzle lance at 250 p.s.i. Buffer areas were so designed as to permit the passage of the utility truck transporting the spray equipment between the plots without damage to the harvested area of the plots.

Harvesting was carried out with a commercial header, precautions being taken to ensure as accurate yield and quality sampling as possible. From each of the original trials, 64 samples for grain protein determination and 16 samples for baking quality assessments were taken. From the residual trials, 64 samples for grain protein and 6 samples for baking quality were taken, the baking quality samples being from the control, 1 cwt at sowing and four 2-cwt treatments.

Counts were made of the number of tillers and the number and length of heads.

The treatments were as follows:—

No.	Treatment	No.	Treatment
1.	No urea at sowing	9.	1 cwt urea at sowing
2.	No urea at tillering	10.	1 cwt urea at tillering
3.	No urea at shotblade	11.	1 cwt urea at shotblade
4.	No urea at flowering	12.	1 cwt urea at flowering
5.	$\frac{1}{2}$ cwt urea at sowing	13.	2 cwt urea at sowing
6.	$\frac{1}{2}$ cwt urea at tillering	14.	2 cwt urea at tillering
7.	$\frac{1}{2}$ cwt urea at shotblade	15.	2 cwt urea at shotblade
8.	$\frac{1}{2}$ cwt urea at flowering	16.	2 cwt urea at flowering

Baking quality determinations were made by the Agricultural Chemical Laboratory Branch of the Department.

Nitrogen was determined by the Kjeldahl procedure and protein calculated using the factor N x 5·7. All percentages were calculated on the common basis of 13·5 per cent. moisture. All samples for baking quality were milled on the Buhler mill. The flour was then tested on the Farinograph to a consistency of 500 Brabender units and Extensograph recordings at 45, 90 and 135-min were made.

The baking results were obtained from the best of three fermentation procedures, using malt flour and a commercial improver containing potassium bromate.

IV. RESULTS

(a) General Observations

Application of urea gave differences in plant colour, maturity, yield, grain mottling, protein content and baking quality.

In the original trials, colour differences were noted following urea application at either sowing or tillering. The earliest differentiation in colour was five weeks after the sowing application in 1956. In the residual trials, the 1 cwt and 2 cwt treatments in most instances were readily distinguished from the other plots by their darker shade of green.

Observations made during 1956 revealed differences in maturity of more than one week between the higher nitrogen treatments and the more forward control plots. These observations, as shown hereunder, were made at the "dough" stage of development, but with the ripening of the grain this gap was narrowed.

Item	Treatment							
	1	5	9	13	6	10	14	15
Straw colour ..	y	y.g	y.g	g.	y.g	y.g	g.	g.
Stage	h.d.	l.s.d.	l.s.d.	s.d.	l.s.d.	l.s.d.	s.d.	s.d.

g., green; y.g., yellow green; y., yellow; s.d., soft dough; l.s.d., late soft dough; h.d., hard dough.

No height differences were observed between the various treatments. General observations did not reveal any apparent treatment differences in ear length. Observations made on the original trials revealed that scorching of foliage was restricted to the 2-cwt applications of urea. The tips of leaves and also the heads following the application at flowering were scorched. However, plants recovered and damage did not appear to be serious.

(b) Effect on Grain Yields

Grain yields for the three original trials are expressed graphically in Figure 1.

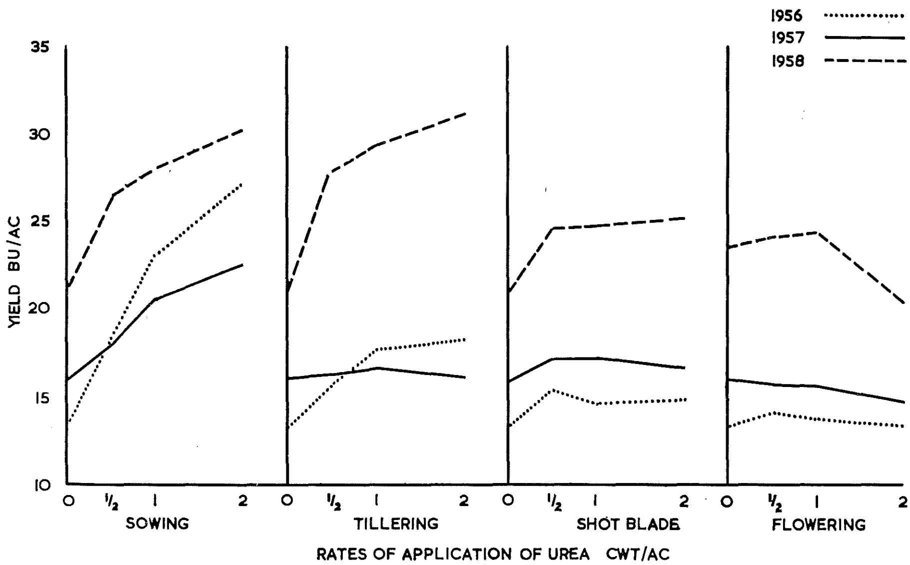

Fig. 1.—Effect of urea application on grain yields in original trials.

In the 1956 season, the greatest increases in yield resulted from applications of urea at sowing. The 2 cwt per acre rate, for instance, doubled the grain yield (13·6–27·2 bus/ac). All "sowing" applications were highly significant at the 1 per cent. level. This also applies to the 1 and 2 cwt rates applied at tillering. Applications at the shotblade and flowering stages had no significant effect on yield.

In the 1957 season, highly significant ($P < \cdot 01$) yield increases resulted from applications at sowing only—16·0 to 22·6 bus/ac. The lack of response to later applications is ascribed to lower soil moisture reserves. At planting time in 1956 the soil moisture was at field capacity, whereas at planting time in 1957 the soil moisture level was considerably lower due to failure of the usual summer rains. The rainfall during the growing period of the crops was 4·81 in. in 1956 and 3·25 in. in 1957. In both years the period July to October was virtually rainless.

In the 1958 season, all applications made at sowing, tillering and shotblade gave highly significant ($P < \cdot 01$) yield increases, the biggest increase resulting from the application of 2 cwt at tillering—21·1 to 31·1 bus/ac. Although more rain fell in the growing period (7·48 in.) than in the corresponding period in the previous two years, the plots, especially those receiving 2 cwt at sowing, suffered from moisture stress. This was due to lower soil moisture reserves at planting.

In general, then, it is evident that the greatest increases in yield resulted from applications of urea at sowing. Although the 2-cwt application at tillering in 1958 gave the highest yield (31·1 bus/ac), a similar application at sowing produced 30·1 bus. This slight reduction in yield was undoubtedly due to the higher water consumption of the rapidly growing "sowing" plots.

As the stage of growth advanced, the effect of urea applications on grain yield decreased. It would appear, however, that seasonal conditions, mainly rainfall, have a modifying effect on this generalization and significant increases in yield can occur from applications at the shotblade stage, as happened in 1958.

Results of the residual trials are presented graphically in Figure 2.

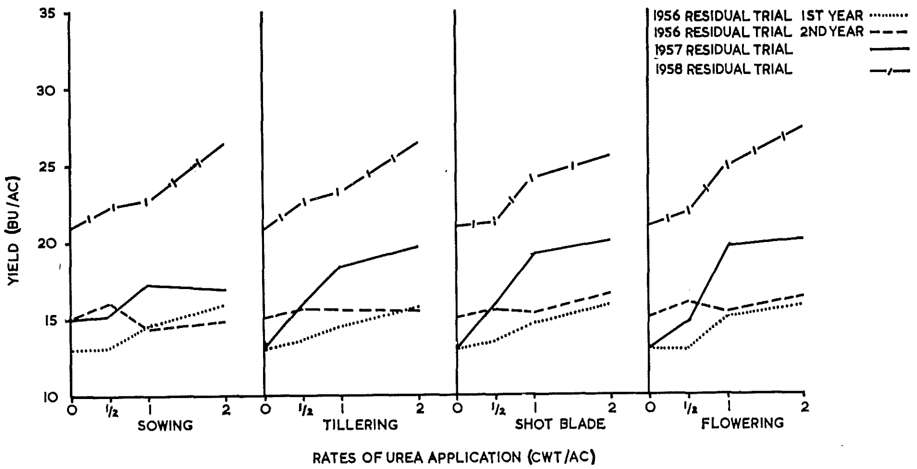

Fig. 2.—Effect of urea application on grain yields in residual trials.

CORRECTIONS

Vol. 20, page 327: In Fig. 2, the value for yield at nil level of application at sowing is 13·04, not 15·00 as shown.

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In the first residual trial, on the site of the 1956 trial, all 1 cwt treatments, except at tillering, gave significant ($P < 0 \cdot 05$) increases in grain. All 2-cwt treatments gave increases significant at the 1 per cent. level.

In the second residual trial of the 1956 original planting, the only plot showing significantly ($P < 0 \cdot 05$) increased grain yields over the control was that which received 2 cwt at the shotblade stage. It would appear that urea applied at rates below 2 cwt/ac under the conditions of the experiment is either used up or dissipated after one succeeding crop.

In the residual trial of the 1957 original, all plots that had received applications of urea showed highly significant ($P < 0 \cdot 01$) increases in grain yield.

In the residual trial of the 1958 original there was no significant increase in plots receiving ½ cwt. All 1 cwt and 2 cwt treatments gave highly significant ($P < 0 \cdot 01$) increases in grain yield except the 1-cwt treatment at sowing ($P < 0 \cdot 05$).

As anticipated, the time of the original application had no significance *per se* in the residual trials, as all original applications were virtually applications at sowing to the succeeding crop. The effect of time of application was evident in the extent of the yield increase, and the plots which gave little or no grain yield increase in the original trial (mainly applications at shotblade and flowering) showed the greatest residual effects. For example, in the residual trials of the 1957 and 1958 applications, the grain yields for the plots originally treated with 2 cwt at flowering were 19·2 and 27·8 bus, compared with controls yielding 13·0 and 21·0 bus respectively, while for the plots originally receiving 2 cwt at sowing, the comparable grain yields for the 1957 and 1958 residual trials were 13·0–16·7 and 21·0–26·5 bus respectively. This trend is, however, not observed in the yields obtained in the 1956 residual trial.

Another point of interest is that in the 1958 residual of the 1957 trial, significant increases in grain yields were obtained also in plots receiving originally ½ cwt. It seems that the conditions of low soil moisture and low rainfall during the 1957 growing season prevented the effective utilization of the applied nitrogen by that season's crop.

Tiller counts on random samples gave the following means for tillers per plant:

Treatment	1956	1957	1958
1	4·0	3·7	3·0
13	6·6	4·7	4·0

In the 1958 original trial and the 1958 residual trial of the 1957 original, correlation coefficients for head count and yield were +0·947 and +0·956 respectively.

(c) Effect on Grain Protein

The data on grain protein in the three original trials are presented graphically in Figure 3. In all of the trials there is a highly significant ($P < \cdot 01$) increase in grain protein content as a result of applying urea at all rates used at all growth stages, except in the 1957 trial, where the $\frac{1}{2}$–cwt treatment at shotblade gave only a significant ($P < 0 \cdot 05$) increase. In 1956 and 1957, the increase was of a similar magnitude—from about 9·5 to about 12·3 per cent., an increase of about 29 per cent. In 1958, the increase was from 10·3 to 15·1 per cent., an increase of about 47 per cent. No satisfactory explanation can be advanced for this considerably greater increase in grain protein in the 1958 season.

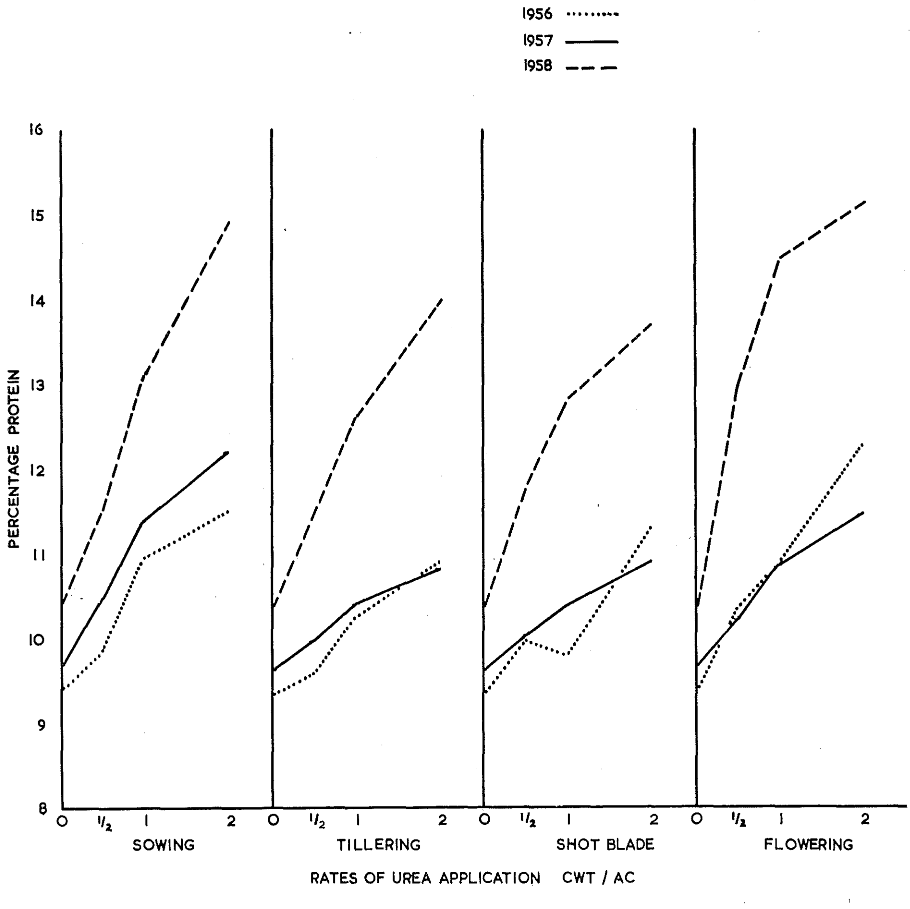

Fig. 3.—Effect of urea application on grain protein in original trials.

In the 1956 and 1958 seasons, the greatest increase in grain protein resulted from application of 2 cwt at the flowering stage, while in the 1957 season the greatest increase resulted from the application of 2 cwt at sowing.

This result is, however, not so divergent as it appears, because there is a difference of only 0·2 per cent. in the grain protein content of the sowing and flowering plots. As stated previously, 1957 was a very dry year.

The general effect, then, was that applications of urea at the flowering stage produced the greatest increases in grain protein content. The applications at tillering and shotblade did not produce increases in grain protein of the order of those produced by applications at sowing and flowering, the difference being significant at the 5 per cent. level in 1956 and 1958 and at the 1 per cent. level in 1957. The physiology of the wheat plant does not seem to offer an explanation of this phenomen, as it is stated in the literature (e.g. Olsen and Rhoades 1953) that much of the nitrogen required by the wheat plant is taken up prior to the heading stage. This suggests that nitrogen uptake at tillering and shotblade should be good. Loss of nitrogen in the form of ammonia gas, resulting from surface applications of urea, may be a contributing factor (Kresge and Satchell 1960; Ernest and Massey 1960; and Volk 1959).

Data from the residual trials are presented graphically in Figure 4.

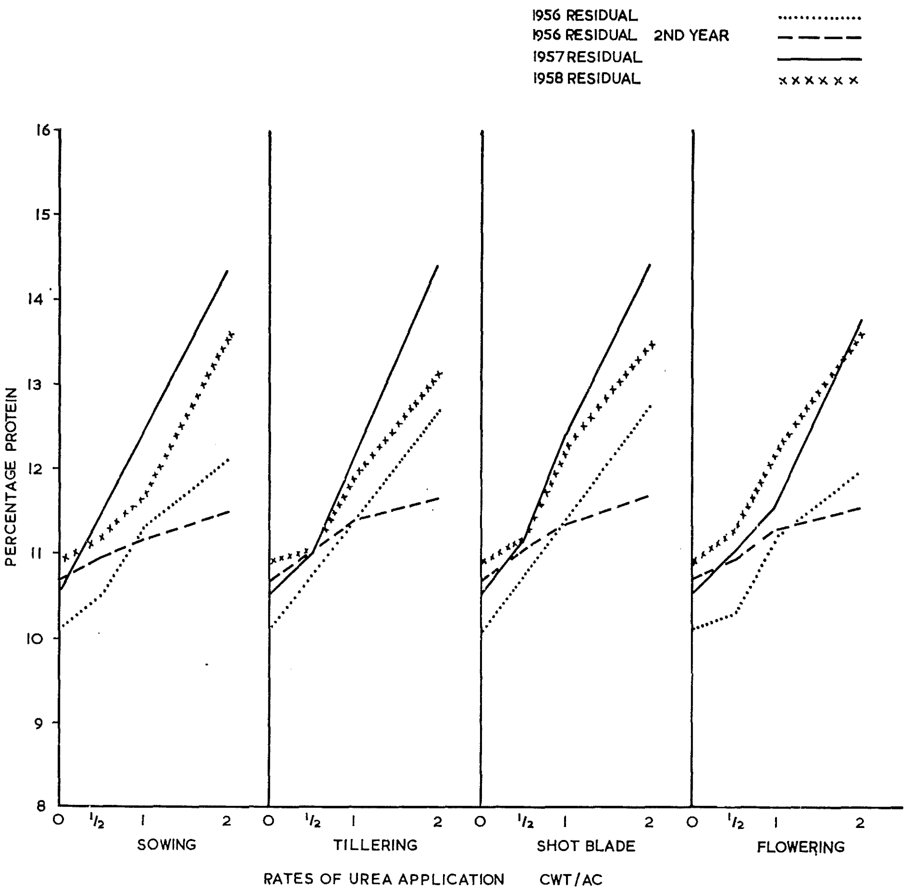

Fig. 4.—Effect of urea application on grain protein in residual trials.

In the 1957 residual of the 1956 trial, the data are incomplete inasmuch as the ½–cwt and 1–cwt treatments at tillering and shotblade were not sampled. While no statistical significance can be attached to the figures obtained, it is of interest to note that the highest grain protein content occurred in the 2–cwt plots at tillering and shotblade. In the original trials, these plots showed lower grain protein content than the comparable plots receiving applications of urea at sowing and flowering.

In the second residual trial (1958) of the 1956 original, all plots were sampled and a significant ($P < 0{\cdot}05$) increase in grain protein content resulted from all applications of 1 cwt and 2 cwt.

In the residual trial of the 1957 original, significant ($P < 0{\cdot}05$) increases in grain protein content occurred in all plots receiving applications of urea except those receiving ½ cwt at tillering and flowering. All 1–cwt and 2–cwt treatments gave highly significant ($P < 0{\cdot}01$) increases in grain protein content.

In the residual trial of the 1958 original all the 1–cwt and 2–cwt treatments gave highly significant ($P < 0{\cdot}01$) increases over the control plots.

The percentage increases are of interest. For the residual trials they are respectively 27, 9 (second year), 37 and 25, compared with 31, 27 and 47 for the original trials.

Whereas highest increases in grain protein content in the original trials occurred in the plots receiving applications at sowing and flowering, this was not manifest in the residual trials.

(d) Effect on Mottling Incidence

Samples comprising 200 wheat grains were taken at random from the 2–lb samples collected for grain protein analysis from each of the 64 plots in all trials and the incidence of mottling was noted in two categories: (1) "mottled", with otherwise vitreous grain showing opaque areas up to 50 per cent. of the total area, and (2) "badly mottled", with more than 50 per cent. of the grain appearing mottled.

It is evident from Figure 5 that application of urea at any stage of growth reduces the percentage of "mottled" grain. The aberrant value at tillering in 1956 is undoubtedly due to sampling or visual errors. It is also evident that generally speaking, incidence of "mottling" decreases with increasing rate of application of urea, and that this reduction is greater when applications are made at sowing or flowering. The data suggest that "mottling" could be eliminated by higher application of urea and this possibility is being examined.

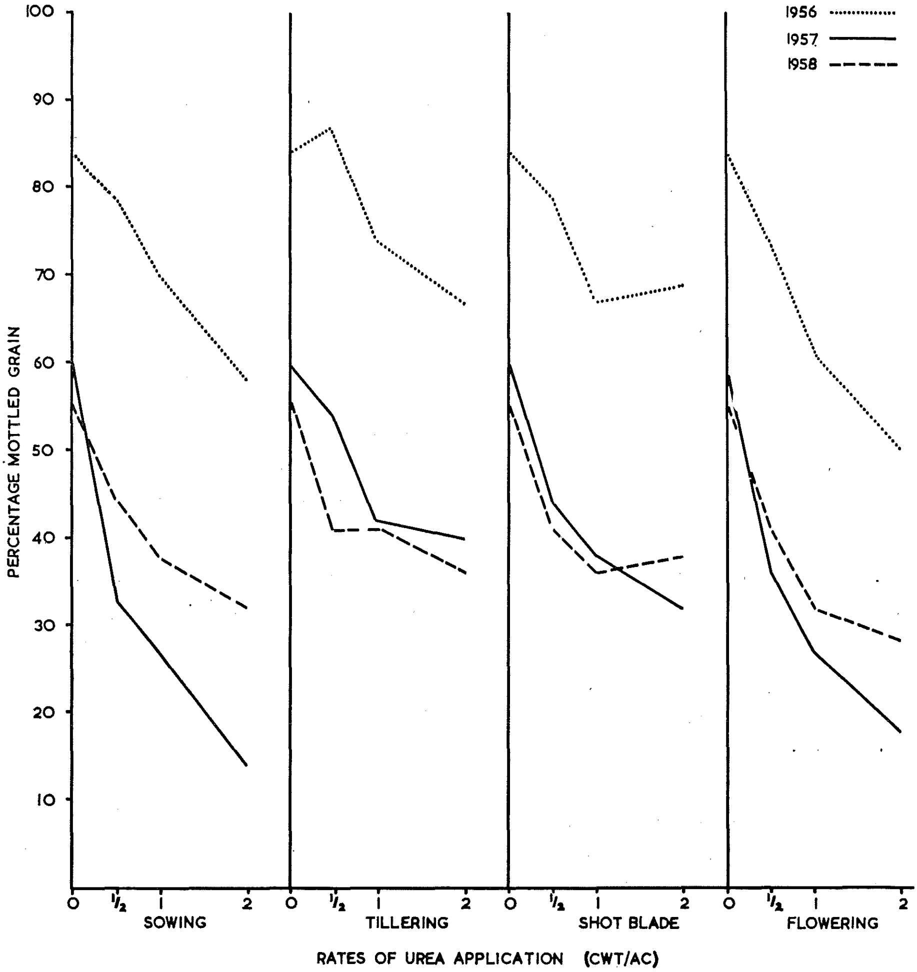

Fig. 5.—Effect of urea application on incidence of mottling.

The effects of applications, of urea on the percentage of "badly mottled" grain are presented graphically in Figure 6. The percentage of "badly mottled" grain decreases with increasing amount of applied urea. The information from these trials indicates that the formation of "badly mottled" grain can be prevented by application of urea at any stage of growth at the rate of 2 cwt/ac.

The inverse relationship in the results of grain protein (Figure 3) and percentage of "mottled" grain (Figure 5) is obvious. The high negative correlation between grain protein content and percentage of "mottled" grain is shown by the correlation coefficients for the 1956, 1957 and 1958 trials ($P < 0 \cdot 01$). These are —0·948, —0·964 and —0·998 respectively.

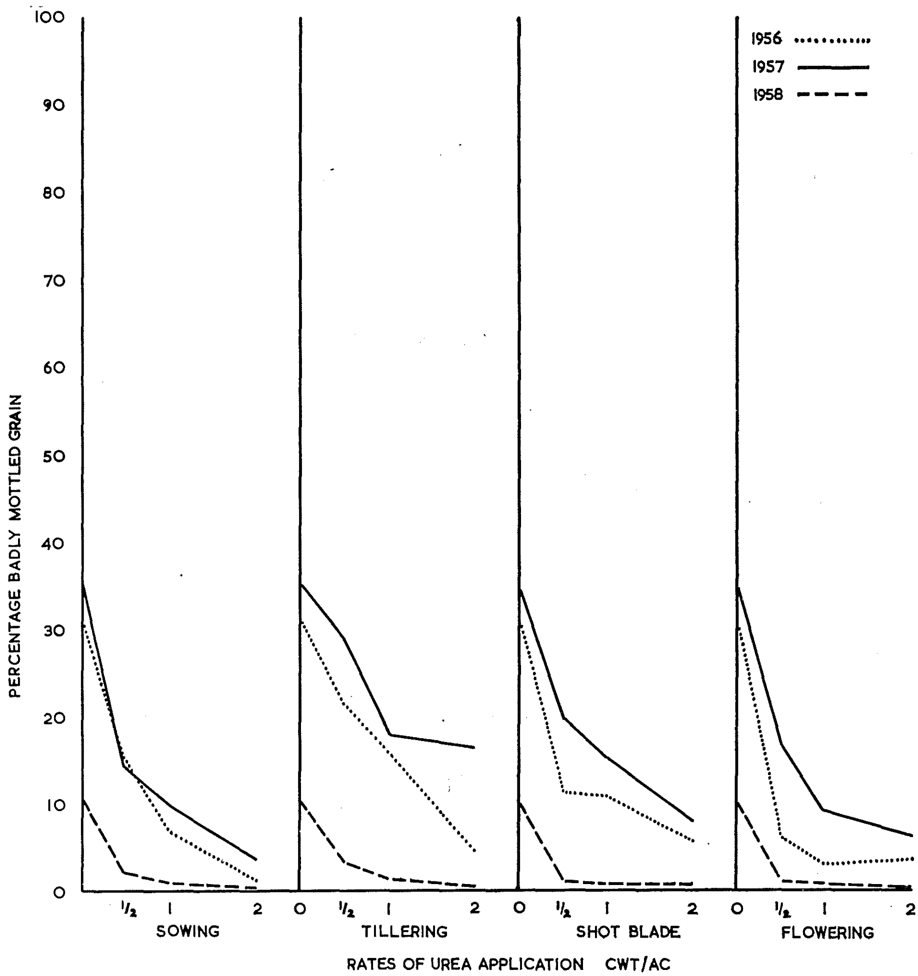

Fig. 6.—Effect of urea application on incidence of bad mottling.

(e) Effect on Baking Quality

Figures 7–9 show results of baking and physical quality tests on flour from grain harvested from various treatments.

(i) *Original Trials*.—For all treatments (time and rate) the 1958 trial was superior both in protein content and in baking quality to the two preceding trials, which differed little from one another. Time of application had little effect on quality.

In the 1956 season, the five treatments sampled (1 cwt/ac at sowing; 1 cwt at flowering; 2 cwt at sowing; 2 cwt at tillering; 2 cwt at flowering) were better than the control in protein content, strength and baking quality. The best result, which was of mediocre standard, came from 2 cwt at flowering.

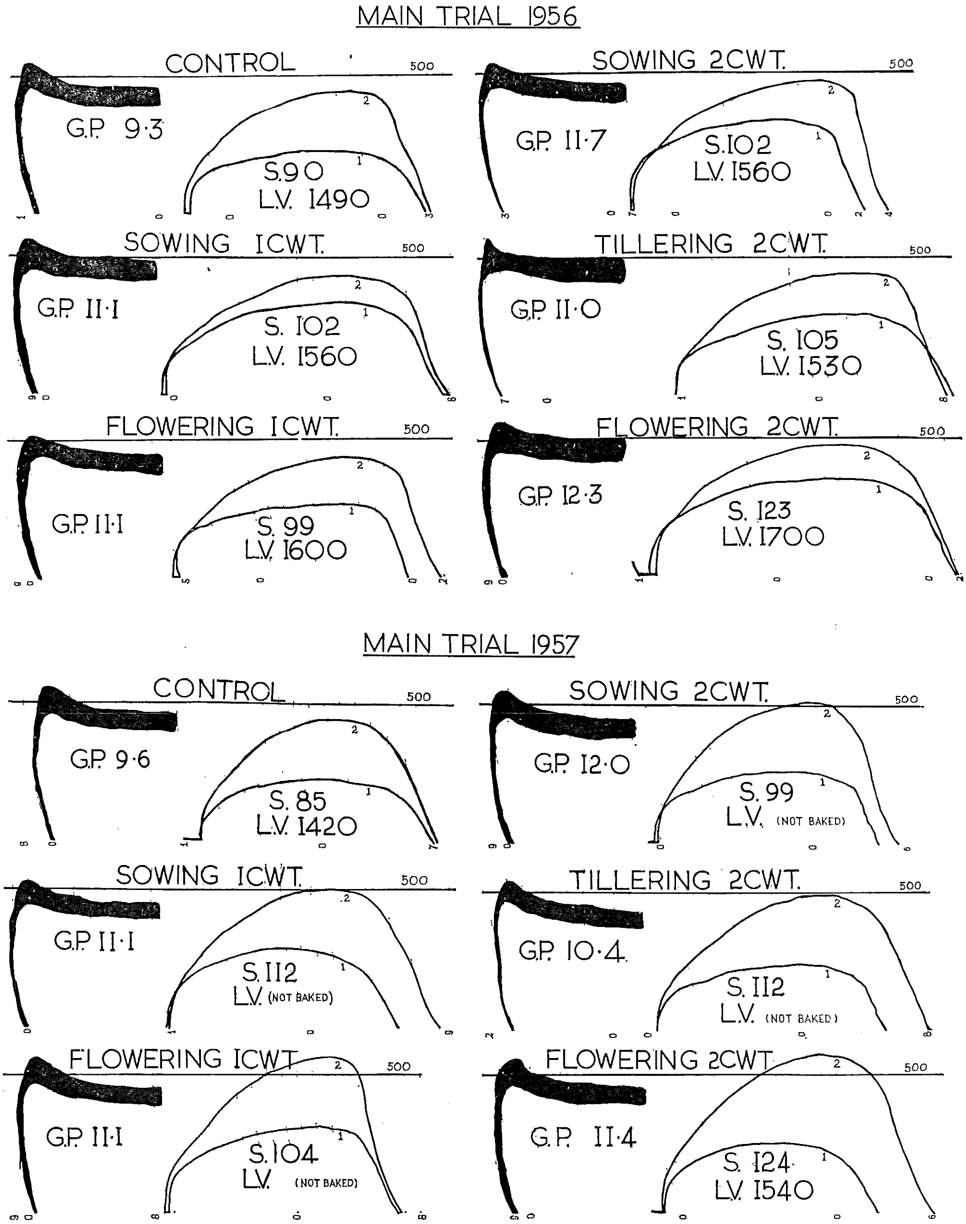

Fig. 7.—Baking and physical quality tests, main trial, 1956. S = Area under 135-minute graph, in square centimetres. L.V. = Loaf volume, in cubic centimetres. G.P. = Per cent. grain protein. 1 = 45 minutes. 2 = 135 minutes.

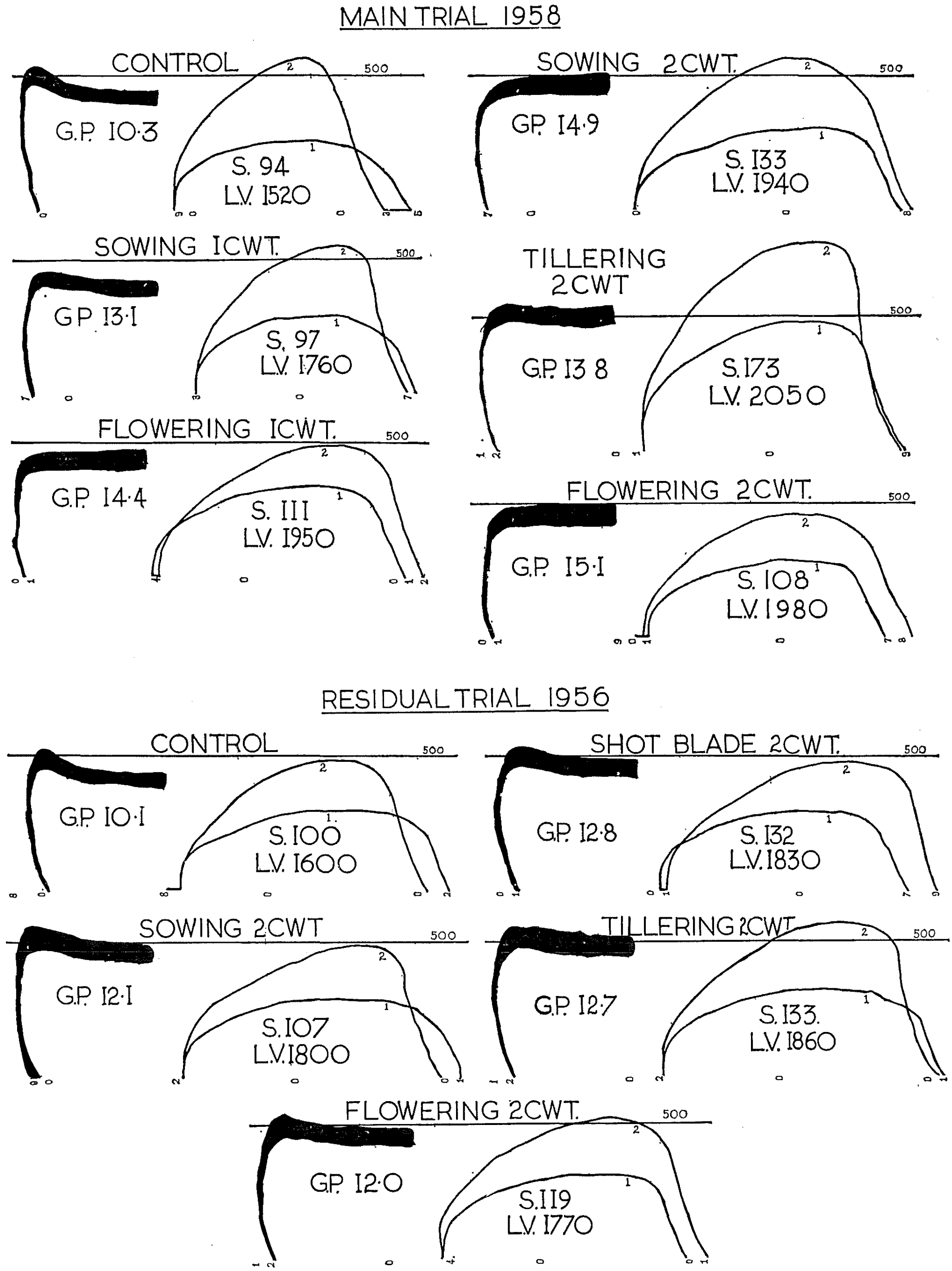

Fig. 8.—Baking and physical quality tests, main trial, 1958. (See Fig. 7 for description.)

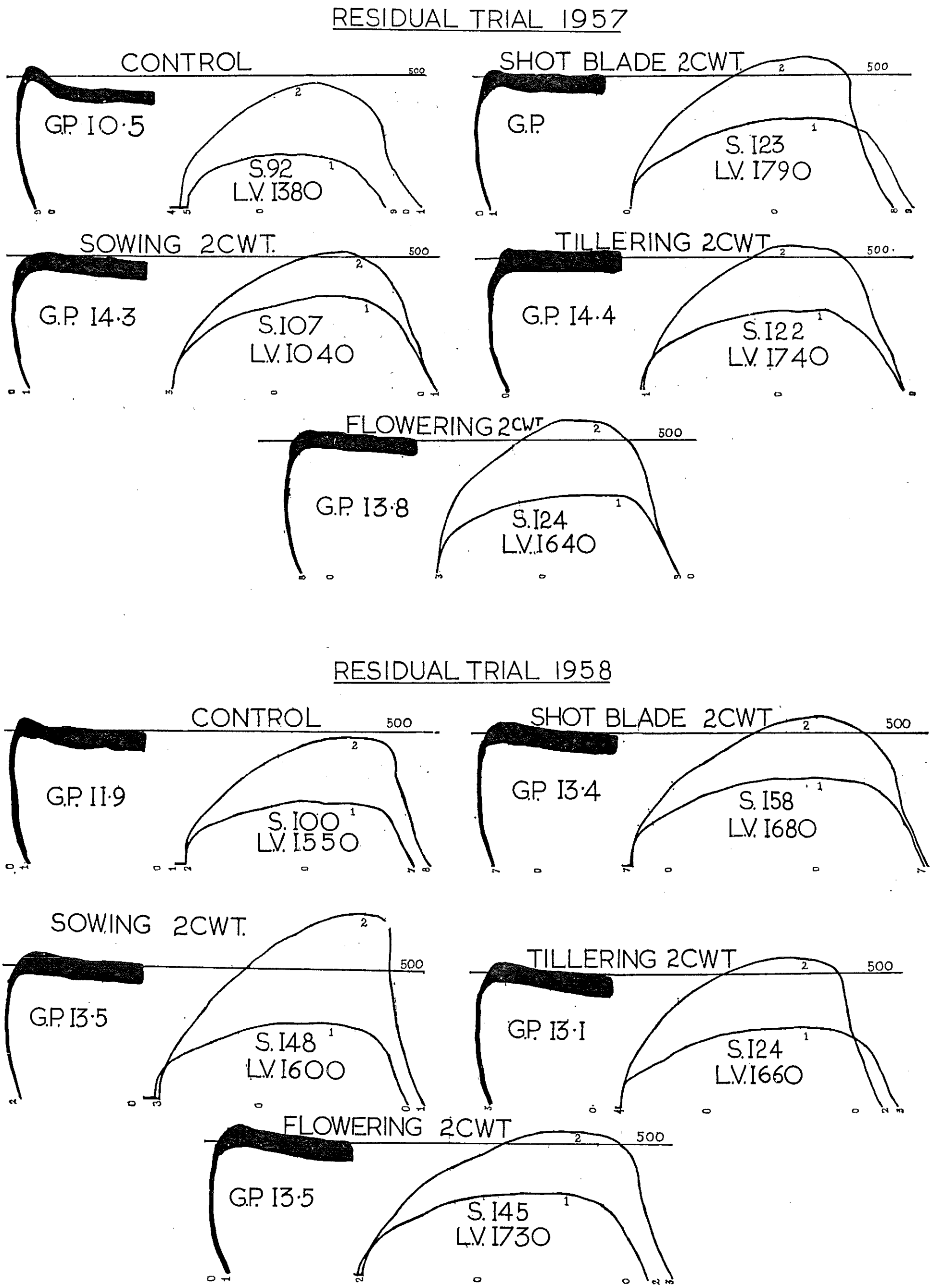

Fig. 9.—Baking and physical quality tests, residual trial, 1957. (See Fig. 7 for description.)

The 1957 season was the poorest of the three but as in 1956 the 2 cwt at flowering treatment gave the best results. In the 1958 season, quite good baking quality was achieved from 1 cwt at flowering, 2 cwt at sowing, 2 cwt at tillering and 2 cwt at flowering; 2 cwt at tillering produced the best quality. A mediocre sample came from 1 cwt at sowing and a poor sample from the control.

With one exception (the tillering treatments in 1958), time of application had little effect on quality. Thus, for the sake of brevity, only two stages have been chosen for comment, viz. sowing and flowering.

Effect of Urea at Sowing.—Moderate increases in protein content and strength due to urea application were noted in 1956. The baking quality showed only slight improvement.

In the 1957 season, the control gave 9·6 per cent. protein, 1 cwt/ac 11·1 per cent. and 2 cwt 12·0 per cent., with corresponding increases in strength which were not very marked. Baking quality for sowing treatments was not measured.

In the 1958 season, the protein content was raised from 10·3 (control) to 13·1 (1 cwt/ac) and 14·9 per cent. (2 cwt). The increase in strength was negligible at the 1-cwt level but very marked at the 2-cwt level. Baking quality showed an improvement at 1 cwt and still greater improvement at 2 cwt when the quality was good. The baking quality of the control was poor.

For the three seasons, the best quality was obtained from the 2-cwt/ac treatment in 1958; this was followed by the 1-cwt treatment of the same year.

Effect of Urea at Flowering.—The 1956 season was fairly favourable for treatments at flowering. Progressive protein increases resulted from control (9·3 per cent.) and 2 cwt/ac (12·3 per cent.) Strength increases followed a similar pattern. Baking quality was fair at the 2-cwt level and the best for these treatments.

In the 1957 season, protein content and strength increased from control to 1 cwt/ac and 2 cwt respectively.

The 1958 season produced very good results, with protein levels of 14·4 per cent. at 1 cwt/ac and 15·1 per cent at 2 cwt. Moderate increases in strength of the flour were obtained. Good baking quality was found at both levels of treatment.

Comparing the flowering treatments over the three seasons, the most favourable results were obtained in 1958 (2 cwt/ac and 1 cwt), followed by 1956 (2 cwt) and 1957 (2 cwt) in that order. A detailed examination of the 3 years' results showed that there was little to choose between the sowing and flowering treatments.

(ii) *Residual Trials*.—For the residual trials, quality was assessed for control and 2 cwt urea at each of the four application times.

In the residual trials of the 1956 and 1957 originals, the tillering and shotblade treatments, which were comparable, gave grain of better baking quality than applications at sowing and flowering. In the residual of the 1958 original, treatment at flowering was slightly superior in baking quality to the shotblade and tillering treatments, which were better than control and application at sowing.

(f) Soil Nitrate

Soil samples for nitrate nitrogen assessment were taken on five occasions from five treatments (control, and 2 cwt urea at sowing, tillering, shotblade and flowering) in the three original trials at depths of 0–4 in., 4–8 in., 8–12 in., 24 in. and 36 in. The data from these samplings are shown in Figures 10–12. Some additional samples taken at 0–6 in. are discussed later.

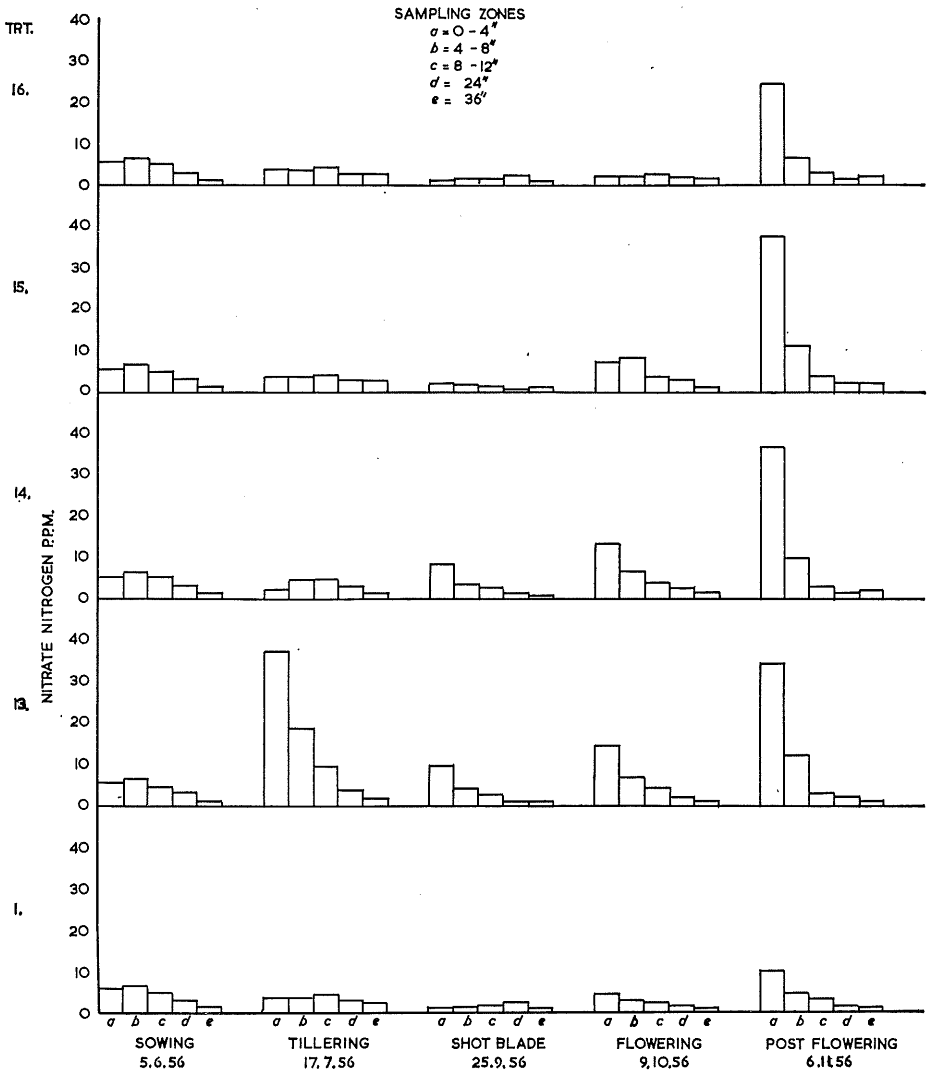

Fig. 10.—Soil nitrate content, main trial, 1956.

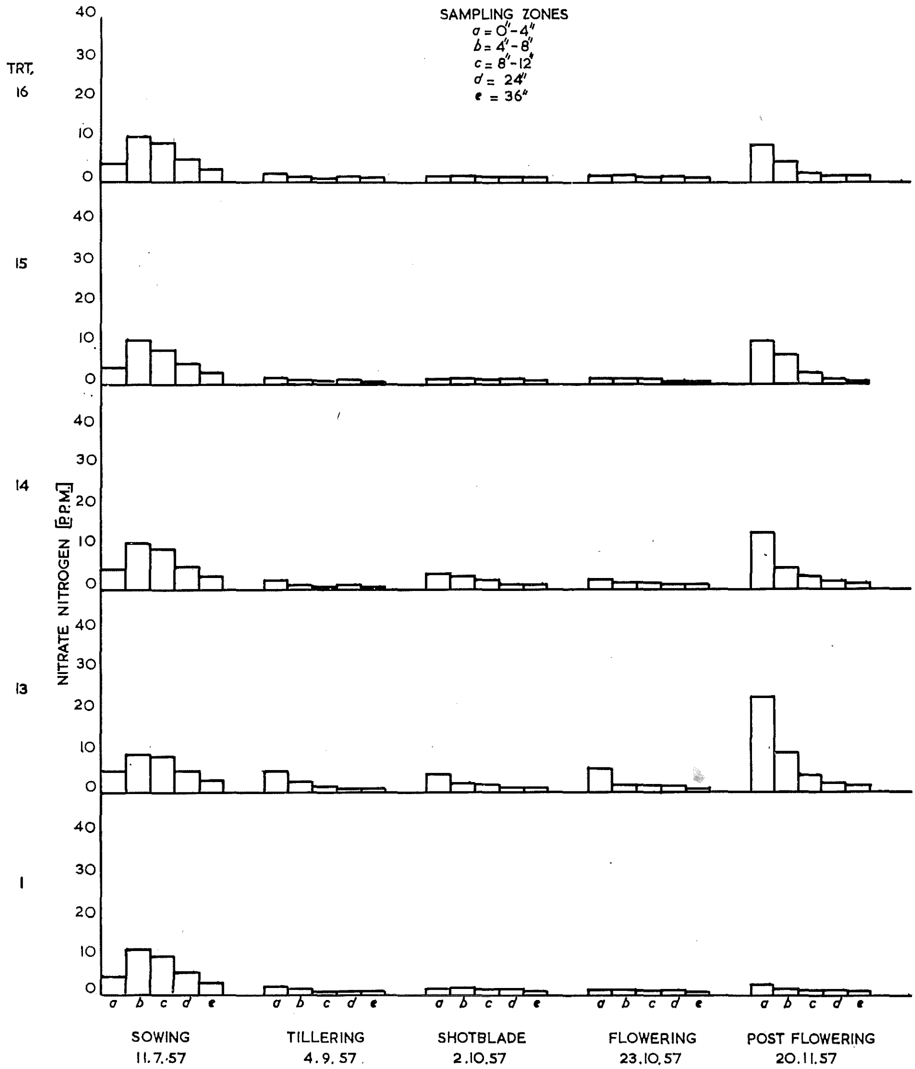

Fig. 11.—Soil nitrate content, main trial, 1957.

At sowing in each trial, the nitrate content of the soil was very low, the highest value being 11 p.p.m. at 4–8 in. in the 1957 season, and values in general not exceeding 6·0 p.p.m.

In the 1956 and 1958 seasons, the application of 2 cwt urea produced measurable increases in nitrate nitrogen in the 0–8 in. soil layer throughout the sampling period subsequent to application. In 1957, however, there was very little change in nitrate nitrogen content until the post-flowering period, due to the fact that no useful post-sowing rain was received until October 30.

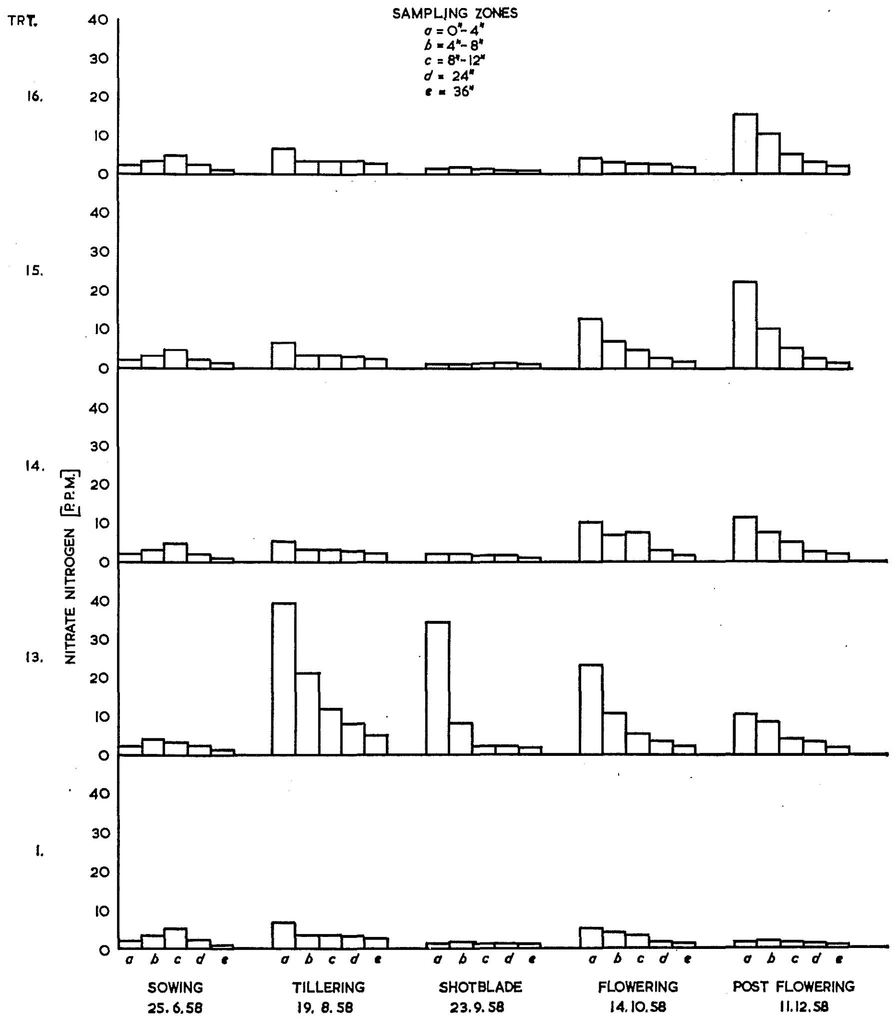

Fig. 12.—Soil nitrate content, main trial, 1958.

The post-flowering increase in nitrate nitrogen was particularly high in the 1956 season even from application of urea at sowing, rising to 35 p.p.m. in the top 4 in. of soil. In the lower root zone (24 in. and below) the concentration of nitrate nitrogen did not at any time exceed 5 p.p.m.

Samples taken at 0–6 in. permitted a direct comparison with samples taken at Rutherglen, in Victoria. Callaghan and Millington (1956) indicated that the amount of 50 lb of nitrate nitrogen per acre in the top 6 in. of soil at Rutherglen would be ample for a 40-bus crop of wheat. In the Pampas plots, only 8 lb nitrate nitrogen was present in the top 6 in. In the 1956 and 1958 seasons, the addition of 2 cwt urea at sowing raised the nitrate nitrogen content in the top 6 in. to about 40 lb at 42 (1956) and 55 (1958) days after application.

Plant samples taken at the flowering stage in 1958 from each of the four replications of Treatments 1 (control) and 13 (2 cwt at sowing) gave the following figures on chemical analysis (moisture-free):

—	Nitrogen (%)	P_2O_5 (%)	K (%)
Control ..	1·14	·447	1·59
2 cwt at sowing	1·64	·447	1·98

The nitrogen value for the control plots is low compared with other analyses.

(g) Economics

Some data on the economics of the use of urea were obtained. In determining a figure for additional income resulting from the use of urea, the yields from both the original trial and the succeeding residual trial were combined for each of the three seasons. In calculating additional gross income, an amount of 12s. 6d. per bus was employed. This represented the figure that a farmer could expect after paying certain expenses such as handling costs, insurance and other Wheat Board charges.

Costs (per acre) associated with increased production consisted of urea at £60 per ton, bags at 2s. 6d. each, bag sowing at 6d. per bag and cartage to the siding at 1s. 6d. per bag.

In Table 2, details of the most economical treatment in each of the three seasons are shown. Early application of urea at ½–1 cwt is indicated as being the most economical of the various treatments.

TABLE 2

FINANCIAL RETURNS FROM INCREASED YIELDS PER ACRE

—	1956	1957	1958
Most economical treatment	9 (1 cwt at sowing)	9 (1 cwt at sowing)	6 (½ cwt at tillering)
Yield, original trial (bus/ac)	23·05	20·57	27·86
Yield, residual trial (bus/ac)	14·55	17·09	22·58
Yield increase over untreated plots, original trial (bus/ac)	9·40	4·53	6·75
Yield increase over untreated plots, residual trial (bus/ac)	1·59	4·05	1·59
Total yield increase (bus/ac)	10·99	8·58	8·34
	£ s. d.	£ s. d.	£ s. d.
Additional income per acre	6 17 4	5 7 3	5 4 3
Additional costs per acre	3 18 0	3 13 6	2 3 6
Additional net income per acre	2 19 4	1 13 9	3 0 9

V. DISCUSSION

In a report on fertilizer experiments with wheat in Kansas, U.S.A., Smith (1954) showed that even in regions where farmers believed they could live on the "inexhaustible fertility" of their soils, the application of fertilizers was becoming more and more profitable.

The results obtained from the present trials indicate that there is a marked response, up to a doubling of yields, to the use of nitrogen fertilizer on older cultivations.

The need for adequate moisture for the breakdown to nitrate nitrogen of urea applied to the soil was clearly demonstrated by the soil nitrate investigations. In the dry season of 1957, when no worthwhile rain fell from July 2 until October, the increase in soil nitrate from the sowing applications of urea did not approach that in the two wetter seasons.

It was shown that where soil moisture was adequate the greatest responses in yield were obtained from the application at sowing time.

The 2-cwt rate of application gave the highest yield but more economical returns came from the $\frac{1}{2}$- and 1-cwt rates of application. In arriving at this conclusion, yields from the residual trials were taken into account.

Residual responses in yield were obtained in each year following the year of application of urea. It appears therefore that in the Pampas area, at least, there is a sufficient carry-over of nitrogen into the second season to effect an increase in yield. This supports the finding of Cuthbertson (1959) for oats in New South Wales.

The tiller counts recorded earlier among the general observations show that an increase in stand in treated over untreated plots could have been an important contributing factor in the higher yield from treated plots. The high positive correlation between head count and yield supports such a relationship.

The findings of the trials support the view that grain mottling is related to low soil fertility. Mottling was found in high proportions in the control plots in all the trials, and there was a marked reduction in treated plots. The improvement was greatest at the highest rate of urea application, particularly at the flowering stage. This fact, together with the trend to higher percentages of mottled grain at the intermediate stages of tillering and shotblade, is paralleled by the inverse relationship between mottling and protein content. Here again the greatest response stemmed from the highest rates of urea application, especially at the flowering stage. Finney (1951) reported increases in protein with increasing concentrations of urea spray.

The residual effect of the urea application was seen in regard to yield, grain mottling and protein content of the grain.

The variety Festival is a physically hard, overstable wheat. When this variety is grown in soils of good fertility, the protein content can rise to 17 per cent. from yields to over 40 bus per ac. Its baking quality in general is, however, not as good as that of most of the other varieties grown in Queensland. It will be observed that the protein content is not strongly correlated with normal strength and baking characteristics.

This series of experiments clearly demonstrated the achievement of marked increases in yield, protein content and to a lesser degree, baking quality as a result of the application of urea.

From the results obtained, the indications are that an extra financial return of from £2–£3 per acre may result from the use of urea.

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