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EFFECTS OF POST-PLANTING APPLICATIONS OF NITROGENOUS FERTILIZERS ON GRAIN YIELD, GRAIN PROTEIN CONTENT AND MOTTLING OF WHEAT

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SUMMARY

The effects of post-planting applications of nitrogenous fertilizers on grain yields, grain protein content and mottling of wheat (cv. Mendos) were studied at nitrogen-deficient sites on the Darling Downs in south-eastern Queensland in 1966–1968. The efficiency with which wheat plants could utilize nitrogen applied either as a spray or as a solid top-dressing appeared to be largely dependent upon subsequent rainfall.

Urea sprays applied in dual applications at 4-5, 6-7 and 8-9 weeks after emergence in 1966 increased grain yield and protein content. These sprays (15, 30 and 45% urea applied at 112 litres/ha) also had a marked effect on the degree of mottling, but had only a slight effect on reducing the total percentage. However, in the dry season of 1967, neither urea sprayed at the same rates at 4, 7 and 10 weeks after emergence or equivalent rates of solid urea applied at planting had any effect.

In 1968, nitrogen application either at planting or post-planting (6 weeks after emergence) increased grain yield and protein content of wheat. Post-planting applications of urea (solid and spray), ammonium nitrate (solid and spray), ammonium sulphate (solid) and sodium nitrate (solid), applied at rates of 11, 22 and 45 kg nitrogen/ha, had a similar beneficial effect on yield, protein content and mottling of wheat as equivalent rates of urea applied at planting.

In those seasons in which wheat responded to nitrogenous fertilizer applications, an inverse relationship between grain protein content and mottling was found.

I. INTRODUCTION

Soil application of nitrogen at planting has been the standard practice in wheat-growing in Queensland.

Split applications of nitrogen, including one or more post-planting applications, are used throughout the world on a wide range of crops. Depending on crop requirements, nitrogen fertilizers may be applied after planting as either a top-dressing (solid) or a foliar spray.

Many workers have observed that post-planting nitrogen increased grain yield and protein content of wheat with increasing rate of nitrogen supplied (e.g. Reeves 1954; Littler 1963; Sadaphal and Das 1966). Similarly, many workers have found corresponding decreases in mottling.

The superiority of solution over solid post-planting application of urea on grain protein content of wheat was reported by Reeves (1954). In contrast, Hanley, Ridgman and Beveridge (1966) found that solid outyielded solution applications. The efficiency of any applied post-planting nitrogen has been suggested as being dependent on rainfall after its application (Littler 1963; Hanley, Ridgman and Beveridge 1966). Because of the unreliability of growing season rain on the Darling Downs, in south-eastern Queensland, the benefit of post-planting nitrogen might be considered to be questionable.

Amongst the nitrogen fertilizers, urea is very convenient for foliar application as it contains a high percentage of nitrogen (46%) and is readily soluble in water. Thus relatively large amounts of nitrogen can be applied. Urea solutions of high concentration have been used as foliar sprays with little or no injury; e.g. Chesnin and Shafer (1953) sprayed nearly saturated solutions of urea (80%) at rates up to 67 kg N/ha onto wheat with no apparent injury to the plants. Furthermore, urea can be applied in a weedicide or insecticide spraying programme (Thorne 1956).

This work was initiated to test the effectiveness of post-planting nitrogen applications to wheat, a topic which has received little research in the Darling Downs region.

II. MATERIALS AND METHODS

Experimental site data.—Site data for the three seasons are given in Table 1.

Treatments.—In 1966, urea sprays (15, 30 and 45%) in dual applications 1 week apart at 4 and 5, 6 and 7, and 8 and 9 weeks after emergence were applied at 112 litres/ha per application so as to supply total applications of 16, 31 and 45 kg N/ha.

In 1967, urea at rates equivalent to those in 1966 was sprayed at 4 weeks after emergence (tillering), 7 weeks (spikelet initiation) and 10 weeks (booting) at 225 litres/ha. The same rates of urea were soil-applied at planting through the combine.

In 1968, four solid nitrogen sources (urea, ammonium nitrate, ammonium sulphate and sodium nitrate) were top-dressed onto wheat at rates equivalent to 11, 22 and 45 kg N/ha. Urea and ammonium nitrate were sprayed at similar rates at 112 litres/ha. All of these fertilizer applications were carried out at tillering (6 weeks after emergence). As well as the tillering applications, urea was applied through the combine at planting at rates equivalent to 11, 22, 45, 67, and 90 kg N/ha.

All of the foliar fertilizer applications in the three seasons were applied through a boom spray with a wetting agent (25 ml/100 litres) added to the fertilizer solution.

Measurements.—Harvesting was carried out with a commercial header modified slightly for experimental purposes. Subsamples of grain were taken at maturity for protein determination. Grain protein content was calculated from Kjeldahl nitrogen analyses using the conversion factor of 5·7. All protein contents were expressed on a standard basis of 13·5% moisture.

Mottling assessments were made on the grain samples from all treatments. In 1966 the incidence of mottling was assessed into three categories (on an individual grain basis):

(*a*) Severely mottled, with more than 50% of the total area of the grain (normally vitreous) showing opaque patches.

(*b*) Slightly mottled, with less than 50% of the grain appearing mottled.

(*c*) Non-mottled.

In 1968 wheat grains were assessed into mottled and non-mottled grain categories.

TABLE 1

EXPERIMENTAL SITE DATA

——	1966	1967	1968
A. *Site*			
Location	Oakey	Brookstead	Mt. Tyson
Period of cultivation (years)	More than 40	8	More than 40
Soil type	Oakey Ck. Alluvial (variant of Black Earth)†	Cecilvale*	Valley Waco (variant of Black Earth)†
Cropping history and yield obtained (tonnes/ha)	1963 Wheat 1·4 1964 Wheat 1·4 1965 Wheat 1·4 History of mottling	1962 Wheat 2·4 1963 Barley 2·7 1964 Barley 2·7 1965 Barley 1·9 1966–67 Sorghum 3·6	1964–5 Sorghum grazed‡ 1965 Barley grazed ‡ 1965–6 Panicum 2·3 1966–7 Panicum 0·8 1967 Barley 2·5‡
Soil N test (kg NO_3—N/ha 60 cm)	*n.d.*	23	63
B. *Planting*			
Date	June 7	July 26	June 11
Rate (kg/ha)	56	63	50
Depth of soil moisture (cm)	*n.d.*	75	90
Plot size (ha)	0·06	0·03	0·02
Applied P (kg/ha) ..	12	21	14
C. *Season*			
Total rainfall (mm) ..	307	168	185
D. *Harvest*			
Date	November 13	November 24	November 15
Plot size (ha)	0·02	0·015	0·01
E. *Design*			
Randomized block ..	10 × 2	13 × 3	24 × 3

* Thompson and Beckmann (1960)

† Variants of Black Earth (Thompson—personal communication 1969)

‡ 36 kg N/ha applied.

n.d. Not determined because trial was located in the co-operator's commercial crop after planting.

Growing season rainfall.—Rainfall during the growing season is shown in Figure 1.

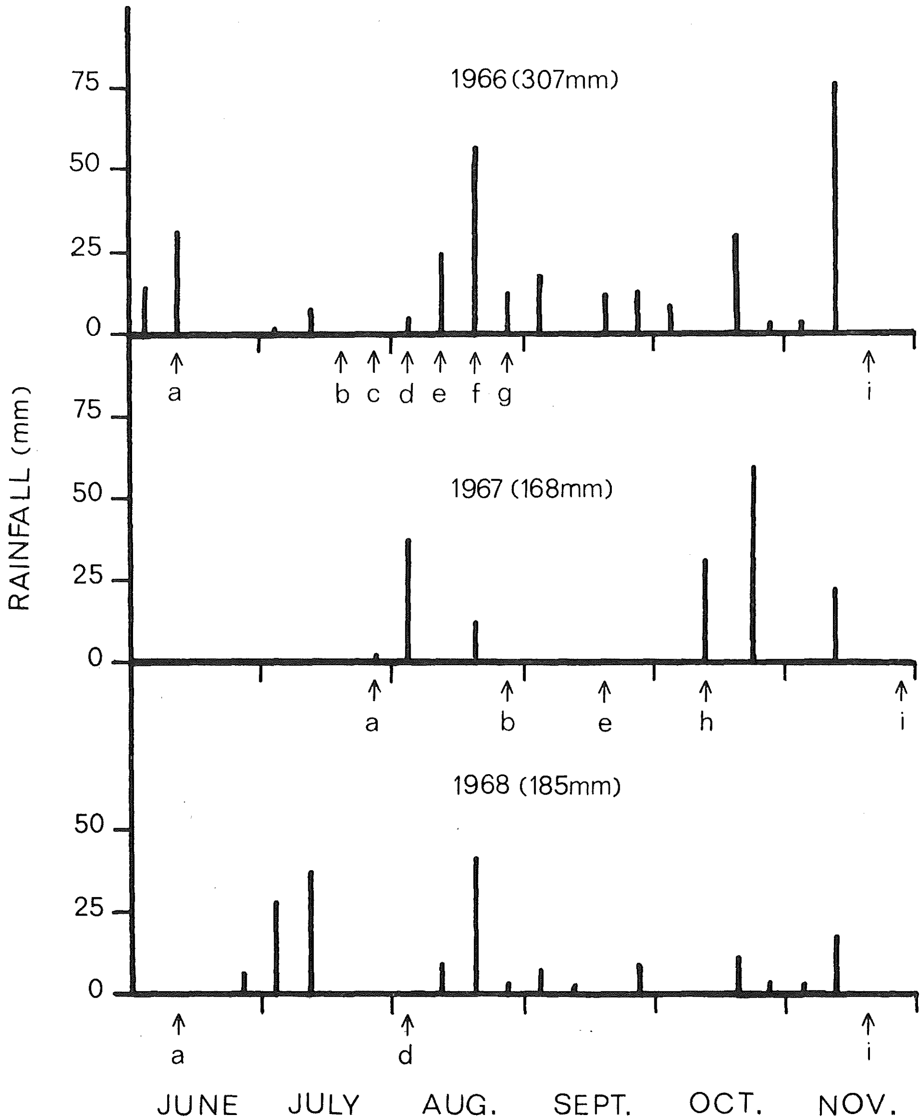

Fig. 1.—Growing season rainfall distribution patterns on a weekly total basis, a = planting; b = nitrogen application after emergence, 4 weeks; c = 5 weeks; d = 6 weeks; e = 7 weeks; f = 8 weeks; g = 9 weeks; h = 10 weeks; i = harvest.

III. RESULTS

(a) Foliar Application of Urea

Rate of application.—The effect of rate of application of urea sprays on yield is shown in Table 2.

TABLE 2

EFFECT OF RATE OF UREA SPRAYS

Rate applied (kg N/ha)	1966*				1967*		1968		
	Grain Yield (kg/ha)	% Protein	% Mottling		Grain Yield (kg/ha)	% Protein	Grain Yield (kg/ha)	% Protein	% Mottling
			Severe	Slight					
Control (0)	1849 a	9·6 a	92 a	6 a	930 a	13·7 a	2085 a	10·0 a	79 a
11 ..	..	..	..	..	..	..	2279 b	10·2 ab	66 b
16 ..	2244 b	10·2 a	78 a	16 a	1094 a	13·9 a	..	..	..
22 ..	..	..	..	..	..	..	2370 b	10·4 ab	49 c
31 ..	2524 c	10·5 ab	66 b	25 b	1002 a	14·1 a	..	..	..
45 ..	2789 d	10·8 b	53 c	31 b	1139 a	14·1 a	2546 c	10·9 b	42 d

No mottled grains observed in 1967.

Means of fertilized treatments followed by different letters are significantly different at $P = 0{\cdot}05$.

* Figures for all fertilized treatments in 1966 and 1967 are means of the three times of application.

In two out of three seasons plots receiving foliar application of urea outyielded unsprayed plots, there being significant increases with increasing rate of nitrogen applied. Urea sprays had a small positive but insignificant effect on protein content in 1966 and 1968, the 45 kg N/ha rate being most effective. No significant increases in yield or protein content were obtained in the driest season of 1967.

In keeping with low grain protein contents, high mottling percentages were recorded in 1966. Foliar application of urea decreased but did not completely alleviate mottling in 1966 and 1968. The percentage of severely mottled grain in 1966 was decreased by higher application rates of urea spray, the percentage of slightly mottled grain being increased simultaneously.

Time of application.—The time of application of urea sprays had no significant effect on grain yield (Table 3). Grain protein content was increased by the later urea sprays in 1966; i.e. sprays at 6–7 weeks or 8–9 weeks produced a significantly higher protein content than at 4–5 weeks. In keeping with its effect on grain protein content, later foliar application considerably reduced the incidence of severely mottled grain. However, there was a corresponding increase in the proportion of slightly mottled grain, with the result that the total percentage of mottled grain was only slightly decreased.

TABLE 3

EFFECT OF TIMING OF POST-PLANTING UREA SPRAYS

Time (weeks after emergence)	1966				1967	
	Grain Yield (kg/ha)	% Protein	% Moulting		Grain Yield (kg/ha)	% Protein
			Severe	Slight		
4–5	2527 a	10·0 a	82 a	14 a	980 a	13·8 a
6–7	2504 a	10·7 b	63 b	25 b	1117 a	14·2 a
8–9	2527 a	10·8 b	51 c	33 c	..	..
10	..	..	..	..	1101 a	14·2 a

No mottled grains observed in 1967.

Figures for all times of application are means of 16, 31 and 45 kg/N/ha rates.

Means of application times followed by different letters are significantly different at $P = 0{\cdot}05$.

(b) Planting Application of Urea

The effect of urea applied at planting is shown in Table 4. There was no significant effect on grain yield or protein content in 1967. In contrast, all but the lowest rate of urea significantly increased yield in 1968. Maximum grain yield was obtained with the 67 kg N/ha application rate, but yield responses with the 45, 67 and 90 kg N/ha rates were not significantly different.

TABLE 4

EFFECT OF UREA APPLIED AT PLANTING

Rate applied (kg N/ha)	1967		1968		
	Grain Yield (kg/ha)	% Protein	Grain Yield (kg/ha)	% Protein	% Mottling
0	930 a	13·7 a	2085 a	10·0 a	79 a
11	..	..	2176 a	10·1 a	68 b
16	1249 a	13·7 a	..	..	..
22	..	..	2498 b	10·5 a	44 c
31	1271 a	14·2 a	..	..	..
45	1081 a	14·3 a	2558 bc	11·5 b	25 d
67	..	..	2709 c	12·3 c	8 e
90	..	..	2649 bc	13·2 d	6 e

No mottled grains observed in 1967.

Figures followed by different letters are significantly different at $P = 0{\cdot}05$.

Urea applied at planting in 1968 significantly decreased mottling incidence. Rates of 45 kg N/ha and greater produced grain of significantly higher protein content than did the lower rates. Percentage of mottled grain was decreased with successive increments of applied nitrogen up to 67 kg N/ha to less than 10% mottling.

(c) Method of Nitrogen Application

Table 5 shows the effects of method of nitrogen application. Spray and solid post-planting applications of urea and ammonium nitrate significantly increased grain yield and protein content in 1968. Post-planting urea application (solid and spray) produced a similar yield of grain of only slightly lower protein content, as did urea applied at planting (solid).

TABLE 5

EFFECT OF SOLID AND SPRAY-APPLIED NITROGEN

Method of Application	Grain Yield (kg/ha)	% Protein	% Mottling
Urea			
Solid (at planting)	2410 a	10·7 a	46 a
Spray (at tillering)	2398 a	10·5 ab	52 b
Solid (at tillering)	2386 a	10·4 bc	54 b
Ammonium nitrate			
Spray (at tillering)	2373 a	10·7 a	60 a
Solid (at tillering)	2384 a	10·5 a	47 b
Control*	2085	10·0	79

Figures for all methods of application are means of 11, 22 and 45 kg N/ha rates.

Means of application methods followed by different letters are significantly different at $P = 0{\cdot}05$.

* Figures for all fertilized treatments are significantly different from control at $P = 0{\cdot}05$.

The influence of these applications on mottling incidence parallels their effect on grain protein content. Both post-planting applications of urea were significantly less effective in alleviating mottling than was the planting application. There was no significant difference in effectiveness between the solid and the spray post-planting applications. Post-planting solid ammonium nitrate was more effective in alleviating mottling than was the foliar application of ammonium nitrate.

TABLE 6

EFFECT OF DIFFERENT FORMS OF NITROGEN FERTILIZER AT THREE RATES OF APPLICATION

Form of Nitrogen Fertilizer	Grain Yield (kg/ha)			% Protein		
	11	22	45	11	22	45
Urea	2219	2400	2576	10·1	10·4	11·1 a
Ammonium nitrate . .	2244	2400	2491	10·2	10·5	11·0 a
Ammonium sulphate . .	2267	2418	2498	10·1	10·4	10·8 a
Sodium nitrate	2309	2521	2588	10·3	10·7	12·1 b

Figures for all nitrogen forms are means of all methods of application.

Means of nitrogen forms followed by different letters are significantly different at $P = 0{\cdot}05$ (individual " t " tests used to compare various pairs of means).

(d) Form of Nitrogen Fertilizer

All nitrogen forms significantly increased grain yield, and there was no significant difference between these forms at any of the nitrogen rates applied (Table 6). With one exception (sodium nitrate at the 45 kg N/ha rate) all forms of nitrogen produced similar protein contents at all nitrogen rates. As found in the other field experiments, the severity of mottling was reduced as the protein content increased. Thus except for sodium nitrate at the 45 kg N/ha rate, all forms produced grain mottled to a similar degree at each nitrogen rate.

IV. DISCUSSION

Wheat yield enhancement by nitrogen fertilizers applied at or post-planting is due initially to the responsiveness of the site to fertilizer application and secondly to the amount and distribution of seasonal rainfall. Responsiveness of sites for this series of trials was indicated by cropping history in 1966 (low yields and mottling) and by soil test in 1967 and 1968. Unpublished data from the N x P trial programme at the Queensland Wheat Research Institute indicate that these soil nitrogen levels are in the nitrogen-deficient category.

The availability of a solid post-planting application of nitrogen is presumably strongly dependent on subsequent rainfall to assist its movement into the soil solution, from which it may be extracted by the crop. Foliar nitrogen spray is probably less dependent on rainfall because of the chance of direct foliar absorption of nitrogen. The relative importance of leaves and roots, under field conditions, as uptake sites for foliar-applied nitrogen is still open to question. Undoubtedly some nitrogen is taken up by the leaves but possibly the major portion that the plant utilizes is *via* the roots (Thorne 1956). Thus the efficiency of utilization of foliar nitrogen sprays by wheat is largely dependent on subsequent rainfall (Littler 1963; Hanley, Ridgman and Beveridge 1966), especially in the summer dominant rainfall regions of Queensland's cereal production.

The effectiveness of growing season rainfall on wheat response to applied nitrogen is evident in this series of trials. Grain yield increases were obtained in the seasons of higher rainfall in 1966 and 1968; the distribution of rainfall was also more even in these two seasons than in 1967 (Figure 1). In 1967 only 43·5 mm fell during the period from mid August to mid October, the period during which urea was sprayed onto the wheat crop at three growth stages. No rain fell after the 4 and 7-week foliar applications; however, 31 mm fell 2 days after the 10-week application. Thus the crop probably failed to respond to these applications (in yield and protein) because of the severe moisture stress it had suffered during this early growth period.

Post-planting application of nitrogen (solid and spray) in the early growth stages in two seasons proved to be just as suitable a method of applying nitrogen to wheat as application at planting, a commercially accepted method on the Darling Downs. Such post-planting applications could be a useful method of supplementing the crop's nitrogen supply when initial seasonal conditions cast doubt on the adequacy of the crop's nitrogen reserves. The longer these post-planting applications are delayed, the less will be their benefit to grain production and the greater will be their effect on protein content. Furthermore, nitrogen may be added to weedicide or insecticide solutions when these routine sprays are used during crop growth (Reeves 1954; Thorne 1956).

The form of nitrogen fertilizer used and the method of application are shown in this study to be of little importance. The use of sodium nitrate for top-dressing is not economical, since on the basis of nitrogen content, it is up to three times as expensive as the other forms of nitrogen fertilizer used.

Mottled grain is generally regarded as being a result of low nitrogen fertility. Rates below 67 kg N/ha of post-planting and planting applications of urea were insufficient to reduce mottling incidence to an acceptable level for prime hard classification of the grain (less than 10% mottled grain). As found by many other workers (e.g. Reeves 1954; Littler 1963; Sadaphal and Das 1966), percentage mottling showed an inverse relationship to grain protein content (Figure 2). Thus mottling incidence was reduced as grain protein content increased in response to added nitrogen fertilizer. Application rates in excess of 45 kg N/ha would appear necessary to reduce mottling to a level acceptable for prime hard classification when wheat is grown in nitrogen-deficient situations.

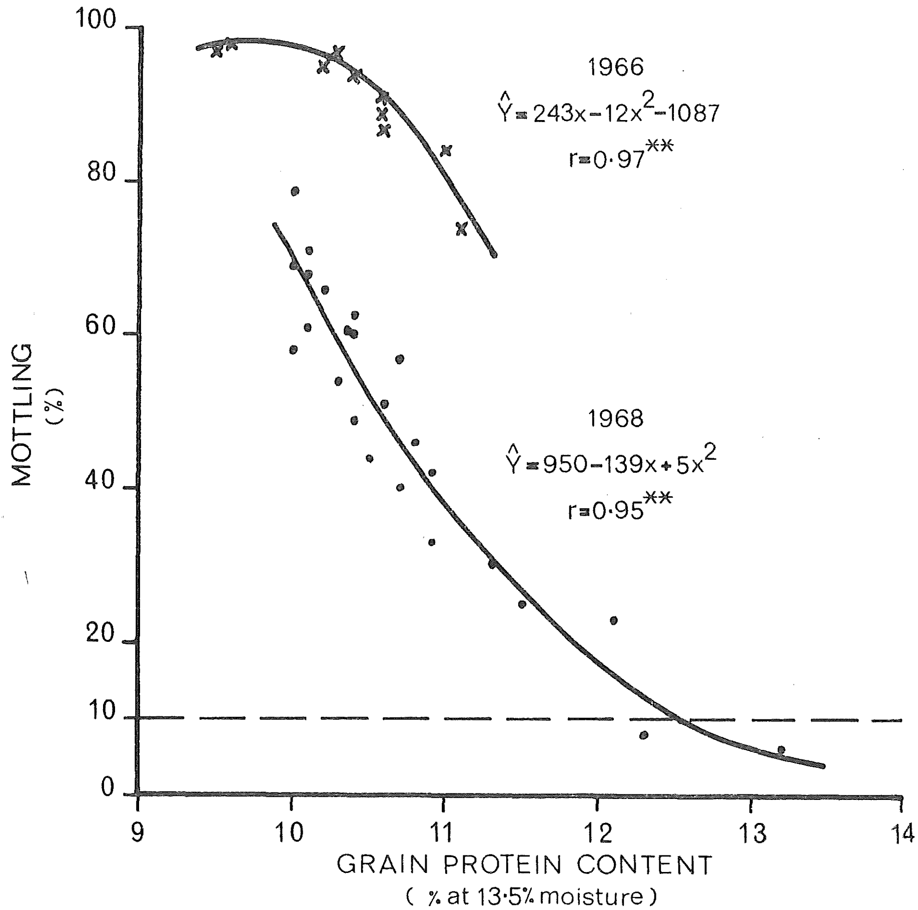

Fig. 2.—Mottling of wheat as related to grain protein content in two seasons. Each point is a mean of three replicates.

High concentrations of urea or ammonium nitrate (up to 45 kg N/ha in solution) showed no visible crop injury such as leaf burning. Chesnin and Shafer (1953) found that nearly saturated solutions of urea (80% w/v) applied at rates of up to 67 kg N/ha produced no apparent crop injury. Littler (1963) observed that the damage incurred by plants which were scorched by highly concentrated urea sprays (at rates of up to 115 kg N/ha) was only temporary.

Thus it seems probable that any apparent detrimental effect of foliar nitrogen sprays will be offset by the benefit of the added nitrogen resulting in a yield response similar to that achieved with a planting application.

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