GRAIN SORGHUM - HIGH YIELD, SATISFACTORY PROTEIN CONTENT OR BOTH?

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ABSTRACT

Negative correlations have been found to exist between yield and grain protein concentration in grain sorghum, and the problem of low protein levels appears to be associated particularly with high-yielding hybrid cultivars.

Solution culture experiments with the hybrid Texas 610 showed that the effects of nitrogen deficiency on grain yield are are greatest when the deficiency occurs early in the growing season, the magnitude of the effect ranking: pre-head initiation > initiation to anthesis > post-anthesis. By contrast large and consistent effects of nitrogen deficiency on grain protein concentration were observed only when the deficiency was imposed between anthesis and maturity.

In the field, nitrogen supply was shown to have large effects on both yield 0.8 to 9.2 tonnes/ha and on grain protein concentrations (6.6 to 18.9%), low yields being associated with exhaustion of plant available nitrogen during the early part of the season, and low protein concentrations with nitrogen shortage during the latter part of the season.

It is concluded that the desired objectives of high yield and satisfactory grain protein concentrations can be achieved if care is taken to ensure that adequate nitrogen is available to the crop throughout the growing season up to and including the grain filling stage.

INTRODUCTION

It has often been observed that high yielding cereal cultivars tend to produce grain of lower protein content than lower yielding cultivars and in recent years plant breeders appear to have been paying increasing attention to grain protein levels while at the same time seeking to increase yields (c.f. Frey 1973). However progress in this area is to some extent limited by a lack of detailed information concerning the contributions to the problem of genotype and various environmental factors including the supply of plant available nitrogen.

In the case of grain sorghum, data of Miller **et al.** (1964) Malm (1968) and Worker and Ruckman (1968) show significant negative correlations between grain yield and grain protein content. Frequently high-yielding hybrid cultivars have been found to produce grain of a lower protein content than that of their parents (Kambal and Webster, 1966) or of open-pollinated commercial cultivars (Littler, 1967; Mackenzie **et al.,** 1970). However the same cultivar may produce grain of widely differing protein content under different cultural or seasonal conditions. Thus in one study involving two planting dates in each of six seasons, the protein content of grain from the hybrid Texas 610 (RS 610) varied from 8.8% to 19.7% (Worker and Ruckman 1968). Hence the problem of low grain protein levels in high-yielding cultivars does not appear to be simply one of inability to accumulate adequate amounts of protein nitrogen in the grain.

In Australia, grain sorghum is by far the most important summer grain crop both in terms of area sown and amount of grain produced. Since the 1950's when hybrid cultivars were developed in the U.S.A., there has been a marked trend in Australia towards increased use of these high-yielding cultivars, and concern over the maintenance of satisfactory grain protein levels has been coupled with this trend.

More than half of Australia's grain sorghum is grown in Queensland, and for several years research workers at the University of Queensland have been actively engaged in sorghum research. This paper outlines the results obtained in a series of experiments on the effects of nitrogen supply on yield and grain protein concentration in Texas 610, a well-known high-yeilding hybrid found in a number of studies to produce grain of variable and often low protein content (Millar **et al.,** 1964; Littler, 1967; Worker and Ruckman, 1968; Mackenzie **et al.,** 1970).

METHODS

Glasshouse Solution Culture Experiments

Plants were grown for varying lengths of time up to grain maturity in plastic-lined steel drums holding approximately 21 litres of nutrient solution. Control of plant nitrogen status was maintained throughout by the method of programmed nutrient addition (Asher and Cowie, 1970) in which frequent small additions of nitrogen are made to the nutrient solutions, the size and frequency of these additions being calculated to permit unrestricted growth (control plants) or to reduce growth rates by some predetermined percentage (nitrogen stressed plants).

Two major experiments were conducted to determine effects on the distribution of dry matter and nitrogen, and on grain yield and grain protein concentration, of either continuous nitrogen stress or nitrogen stress imposed during particular stages of growth. In the former experiment there were 3 nitrogen treatments (control, moderate stress and severe stress), 9 harvests, and 6 replications. In the latter experiment nitrogen stress was imposed separately or in all combinations at each of 3 physiological growth stages (planting to head initiation, head initiation to anthesis, anthesis to maturity) to give a total of 8 nitrogen treatments, 6 harvests and 4 replications. In addition, separate experiments were conducted to establish the time course of accumulation of dry matter and nitrogen in the grain, and to study effects of surgical removal of flowers on grain weight and protein content (not reported here).

Field Experiment

Conclusions from the glasshouse experiments were tested in a large field experiment (40 nitrogen treatments) at Gatton in south-eastern Queensland. The site chosen was low in available nitrogen (4-5 ppm No^3 in top 20cm) but generally well supplied with other nutrients. However, as a precautionary measure a basal fertilizer mixture containing potassium, phosphorus, sulphur and zinc was applied to all plots.

A split-plot design was used with 4 replications. The treatments supplied nitrogen at 0, 34, 112 or 336 kg N/ha at planting (main plots) followed by no further nitrogen or sidedressings of 34, 112, or 336 kg N/ha at the "boot" stage, anthesis or two weeks after anthesis (sub plots). Commercial planting equipment was used to sow the plots and apply the initial dressing of fertilizer. Sidedressings were made by hand and watered in with sprinkler irrigation on the day of application. Urea was used throughout as the nitrogen source.

The soil was sampled down to 90 cm on 8 occasions during the growing season and analysed for total mineral nitrogen.

RESULTS AND DISCUSSION

Seasonal Pattern of Nitrogen Uptake

There is considerable confusion in the literature concerning the relative amounts of nitrogen taken up by cereals at various stages of growth, some studies suggesting that most of the nitrogen is absorbed early in the growing season, while others suggest continuing uptake throughout the season with substantial uptake occuring between anthesis and grain maturity.

In the solution culture experiments of the present study, Texas 610 sorghum plants with a nonlimiting nitrogen supply throughout the entire growth period absorbed from 46% (Figure 1) to 61% of their total nitrogen after anthesis. For plants transferred from a deficient to a non-limiting nitrogen supply at anthesis, uptake between anthesis and maturity was found to be as high as 80% of the total. In the field, nitrogen applications at anthesis or two weeks later, in the present study, produced substantial changes in leaf colour and grain nitrogen content, while recent work of Roy and Wright (1974) on the hybrid CSH-I showed an almost linear increase in plant nitrogen and phosphorus up to maturity. Hence it is concluded that under both glasshouse and field conditions the grain sorghum root system retains its ability to absorb substantial amounts of nitrogen for most if not all of the growing season. It would appear, therefore, that absence of significant nitrogen uptake during the latter part of the growing season observed in some studies, is more likely to be related to a lack of plant available nitrogen in the rooting zone at that time than to any inbuilt tendency for the plant to absorb most of its nitrogen early in the season (c.f. Table 2, this paper).

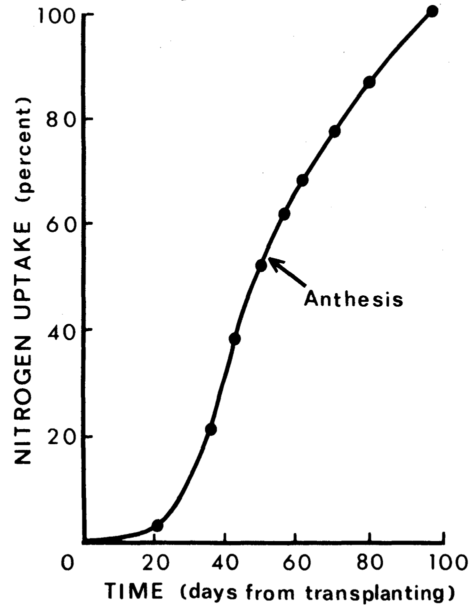

Figure 1: Time course of nitrogen uptake in Texas 610 grain sorghum plants grown in solution culture with a non-limiting nitrogen supply (100% = g N/plant; experimental points are means of 6 reps).

Effects of Nitrogen Supply on Yield

Nitrogen stress during any of the three stages in to which the growth period was divided caused significant reductions in grain number and grain yield (Table 1), the

TABLE 1: Effects of nitrogen stress at different stages of growth on the number and total weight of grains per head in Texas 610 grain sorghum (values are means of 4 reps).

Nitrogen Supply Regime	No. Grains per Head *	Wt. of Grain per Head (g)
Continuously High (Control)	2485	62.3
High - High - Low**	2220	56.2
High - Low - High	2061	50.3
High - Low - Low	1738	44.4
Low - High - High	1550	37.1
Low - High - Low	1260	31.1
Low - Low - High	1021	26.2
Continuously Low	896	22.5

* All treatment differences significant at P = 0.05 by Duncan's Multiple Range Test.

** Nitrogen supply during planting to head initiation, head initiation to anthesis, and anthesis to grain maturity respectively.

magnitude of the effect being greatest if stress was applied prior to head initiation, and smallest if applied after anthesis. Effects of nitrogen stress on single grain weight were small and with one exception non-significant, a point of difference with wheat in which significant effects of nitrogen supply on grain weight have been demonstrated (Langer and Liew, 1973).

Further and more detailed studies will be needed to elucidate fully the mechanisms by which grain numbers are reduced under nitrogen stress. However nitrogen stress in the period before head initiation altered the panicle structure reducing the number of primary branches by nearly 25%, the number of secondary branches by 45% and the number of florets visible at head emergence by nearly 37%.

Nitrogen stress between head initiation and anthesis had no effect on the number of primary branches in the inflorescence but significantly reduced the number of secondary branches, the effect being largest on plants which had also been subject to nitrogen stress prior to head initiation. Nitrogen stress during this period also caused some of the florets which had been initiated to abort, reducing the number of live florets at head emergence by from approximately 16% to 30%.

Reductions in grain number and grain yield due to nitrogen stress after anthesis were smaller than those due to nitrogen stress at earlier stages of growth, varying from approximately 10 to 19%.

Nitrogen stress prior to anthesis caused substantial reductions in the amounts of viable pollen produced per flower (up to 60% reduction) and per head (up to 84% reduction). However, in the glasshouse with high and low nitrogen plants growing in close proximity, no effects on flower set were evident. Further research would be needed to establish whether or not there are circumstances in which nitrogen deficiency might influence yields via effects on pollen production.

In the field, with nitrogen applications of 112 kg N/ha or less, little mineral nitrogen remained in the soil by anthesis, and grain yields were reduced severely by nitrogen deficiency (Table 2). This yield limitation could be removed completely by increasing the rate of nitrogen application at planting (at 336 kg N/ha yields were unaffected by further applications of N during the growing season) or partially by applying additional nitrogen at the "boot" stage or anthesis. Applications at the "boot" stage were more effective in this regard than those at anthesis. Thus, with 112 kg N/ha at planting, an additional 112 kg N/ha at the boot stage raised the yield to approximately 93% of the maximum, whereas an equivalent application at anthesis raised the yield to just under 73% of the maximum. Applications two weeks after anthesis were generally too late to produce significant yield effects.

TABLE 2: Effects of nitrogen applied at planting on grain yield and the concentrations of total mineral nitrogen in the top 30 cm of the profile 11 days after planting and at anthesis (All values are means of 4 reps).

N Applied at Planting (kg/ha)	Total Mineral Nitrogen in Soil (ppm)						Grain Yield (tonnes/ha)*
	11 days after planting			Anthesis			
	0-10 cm	10-20 cm	20-30 cm	0-10 cm	10-20 cm	20-30 cm	
0	6	3	2	1	1	2	0.8
34	33	6	4	2	3	3	1.1
112	95	34	3	4	3	2	4.2
336	290	167	7	18	13	3	9.2

* All differences in grain yield significant at P = 0.05

Effects of Nitrogen Supply on Protein Content

In solution culture experiments nitrogen stress between anthesis and maturity caused large reductions in grain protein content regardless of nitrogen supply to the plant prior to anthesis, or of final grain yield (Table 3). The absence of marked effects of pre-flowering nitrogen nutrition on grain protein content is surprising when the apparently large contribution of previously absorbed nitrogen to grain nitrogen is considered (up to 85% in some treatments). However, it appears that when nitrogen stress occurs prior to anthesis, reductions in floret number may be sufficient to prevent large variations in the amount of plant nitrogen available per grain during the subsequent grain filling period.

TABLE 3: Effects of nitrogen stress at different stages of growth on grain protein concentrations in Texas 610 grain sorghum. (Corresponding grain yields in g/plant shown in parenthesis, all values are means of 4 reps.)

Nitrogen Supply Regime	Grain Protein (%)	
Continuously High	17.4 a*	(62.3)
High + Low - High**	17.6 a	(50.3)
Low - High - High	18.4 a	(37.1)
Low - Low - High	18.5 a	(26.2)
High - High - Low	8.1 b	(56.2)
High - Low - Low	7.6 c	(44.4)
Low - High - Low	8.5 b	(31.1)
Continuously Low	9.3 d	(22.5)

* Values followed by the same letter do not differ significantly at P = 0.05 by Duncan's Multiple Range Test.

** Nitrogen supply during the respective periods — planting to head initiation, head initiation to anthesis and anthesis to maturity.

In the field experiment, when nitrogen was applied at planting at rates of 112 kg N/ha or less, the resulting low levels of available nitrogen in the soil during grain filling were reflected in low grain protein concentrations (6.7% to 8.8%). However, protein concentrations were much higher when soil nitrogen levels during this period were raised by applying 336 kg N/ha at planting (11.3% protein) or applying additional nitrogen as sidedressings at the "boot" stage (12.6%), at anthesis (14.5%) or two weeks after anthesis (11.7%). Although sidedressings at anthesis were somewhat more effective in raising grain protein levels than those at the "boot" stage, the latter stage would probably be preferred in practice because of the greater affect on grain yields.

Table 4: Effects of nitrogen supplied at planting and at the "boot" stage on grain yield and protein content in Texas 610 grain sorghum grown at Gatton in south-eastern Queensland. (Values are means of 4 reps.)

Nitrogen Applied at Planting (kg/ha)	No further N Applied		34 kg N/ha Applied at "Boot" Stage	
	Yield (tonnes/ha)	Protein (%)	Yield (tonnes/ha)	Protein (%)
0	0.8 a	7.7 h	2.2 e	14.7 l
34	1.1 b	6.6 i	2.0 e	12.6 m
112	4.2 c	8.8 j	6.1 f	12.7 m
336	9.2 d	11.3 k	9.1 d	16.8 n

* Values followed by same letter do not differ significantly at P = 0.05 by Duncan's Multiple Range Test (grain yields a-f protein h-n).

Results of these experiments clearly demonstrate that both high yields and satisfactory protein concentrations can be obtained with an existing high-yielding commercial cultivar, provided careful attention is paid to the nitrogen nutrition of the crop throughout the entire growing season, up to and including the grain filling period. However, despite these results it may well be worth searching for cultivars which show superior efficiency in absorbing nitrogen or transferring it to the grain during grain filling. If this work is to be done effectively, it would seem essential to ensure that cultivars are selected under known and preferably controlled conditions of nitrogen supply with particular attention being paid to nitrogen supply during the grain filling period.

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