B. EXPERIMENTAL PROJECT

THE EFFECT OF SIX SUMMER GRAIN LEGUMES GROWN WITH DIFFERENT DURATIONS OF IRRIGATION ON THE SUBSEQUENT NITROGEN UP-TAKE AND YIELD OF COTTON THE FOLLOWING YEAR

ABSTRACT

The use grain legumes in rotation cropping is relatively new in Australia, particularly in irrigated farming systems. In 1986-87, six summer grain legumes; soybean, cowpea, mung bean, navy bean, adzuki bean and pigeon pea, were grown on a cracking grey clay soil under three durations of irrigation and four field slopes. Cotton was then grown on the plots under the same irrigation regimes the following season. The effect of residual nitrogen (N) and irrigation time on the cotton were evaluated.

As irrigation time extended from 4 to 16 and 32 hours, N up-take by the cotton decreased by 15 %. Lint yield decreased 11 % over the same irrigation time. Cotton grown after soybeans had the highest N up-take (60.1 kg N/ha) and after adzuki beans the lowest (46.7 kg N/ha), with the other species inbetween. In terms of apparent recovery of fertiliser (90 kg N/ha) applied before the legumes, the soybean treatment had the largest apparent N recovery rate (2.03) and the navy bean treatment the least (0.87). Therefore short irrigation times and a prior crop of soybeans offers the greatest potential for residual N benefit to cotton (about 40 kg N/ha). Of the other legume species, mung bean and cowpea offer the greatest potential for residual N benefit to cotton the following season.

INTRODUCTION

Grain legumes are increasingly being incorporated into crop rotations with non-legume crops. This increase is partly due to market forces making these crops a viable farm enterprise, but it is also due to the contribution of fixed nitrogen (N) to the soil N pool (Hamblin, 1987). Marcellos (1984) estimates that chickpea, lupin and faba beans contributed at least the equivalent of 50 kg N/ha to the following wheat crop. Doughton and Mackenzie (1984) report that a prior crop of mung beans increased sorghum yield by the equivelent fertiliser application of 68 kg N/ha. Myers and Wood (1987) estimate that soybeans and mung beans contributed the equivalent of 42 and 27 kg N/ha respectively to the following rice crop.

Irrigated cotton grown in north-western New South Wales requires large amounts of N fertiliser to give economic yields (Hearn, 1981; Constable and Rochester, 1988). This fertiliser cost can be considerable, as the desired N uptake by the crop is around 100 kg N/ha (Hearn, 1986). Therefore possible reduction of this cost by including grain legumes into a cotton-legume rotation would be desireable.

One of the problems with including legume crops into a cotton-legume rotation is the deleterious effect of waterlogging on legumes (Section 3.3.2). It is not clear quantitatively, how waterlogging affects the residual N left after the legume crops are harvested (Section 3.6). The grey clay soils on which furrow irrigated cotton is mostly grown are often waterlogged for several days following irrigation (Hodgson, 1982). Waterlogging occurs due to the fields being flat and the soils having a low saturated hydraulic conductivity. This results in slow surface and internal drainage (Hodgson and Chan, 1982). If the deleterious effects of waterlogging on legumes could be reduced by efficient irrigation systems, the potential benefit of an irrigated cotton-legume crop rotation system is considerable.

The effects of waterlogging on legumes will vary with the particular species (Smith, 1987). Hodgson *et al.* (1988) report the effects of different irrigation systems on six summer grain legumes species. To investigate the potential of these species in a cotton-legume rotation cotton was grown the subsequent year with no application of fertiliser. This enabled the comparison of the residual effect of these legumes on cotton, as influenced by different irrigation inundation times and field slopes. The results and implications of this experiment are reported below.

MATERIALS AND METHODS

The experimental site was located at the N.S.W. Depatment of Agriculture's Research Station at Narrabri (149°47' E, 30°13' S). The climate in the region is variable, with summer crop season rainfall ranging from 100 to 600 mm, and the average maximum and minimum screen temperatures of 33/19°C and 17/4°C for mid-summer and mid-winter, respectively. Temperatures can vary widely and often the summer maximum is above 40°C and winter minimum below 0°C. The monthly rainfall, maximum and minimum temperatures experienced during the growth of the cotton are shown in Table 1.

Table 1. Monthly rainfall, maximum and minimum temperatures experienced during the 1987-88 cotton season.

Month/Yr	9/87	10/87	11/87	12/87	1/88	2/88	3/88	4/88	5/88	6/88	7/88
Rainfall (mm)	3.0	50.6	33.0	73.2	90.4	97.0	21.7	183.8	35.2	47.8	64.0
Max Temp (°C)	28.3	25.1	29.1	32.8	33.3	29.9	29.9	23.3	21.4	17.9	17.5
Min Temp (°C)	12.4	11.1	15.4	18.2	19.8	16.4	15.4	13.9	9.8	5.4	6.0

The soil is a fine textured, uniform grey clay vertisol (60 % clay), seasonally cracking with smooth-faced peds and is classified as Ug 5.25, (Northecote, 1979). The physical properties and behaviour of this soil under furrow irrigation have been described by Chan and Hodgson (1981). Common organic carbon and total nitrogen levels in the top 30 cm of soil are 0.8 % and 0.065 % respectively. Soil pH ranges from 8.0 - 8.8 (1:5 H_2O).

Experiment rational

The experiment was made up of two components and this report is concerned with the second. The first component comprised of six grain legumes grown in the 1986/87 season under three different irrigation duration times and four field slopes. Their relative sensitivity to field irrigation times and slopes is reported by Hodgson *et al.* (1988). Cotton was then grown (as the second component) in 1987/88 after the grain legumes, to examine their residual nitrogen effect on cotton grown under the same irrigation time and field slope treatments as the legumes.

Experimental design and treatments

The experimental design was a split plot, split a second time all of which were replicated three times. This is shown diagrammatically in Figure 1. The main plot consisted of four slopes of 1:500, 1:1000, 1:1500 and 1:2000. Each main plot was split to give three irrigation durations of 4, 16 and 32 hours of pipe flow. These sub-plots were then split again by six summer grain-legume species. Each sub sub-plot or legume plot was 10 metres long by 6 metres (6 rows) wide. Irrigation was by pipes over a bank flowing into furrows one metre apart. Slopes, irrigation times and legumes were randomly arranged within each replicate and plot. The six grain legumes were soybean (*Glycine max* (L.) Merr., cv. Forrest), pigeon pea (*Cajanus cajan* (L.) Millsp., breeding line B15B), adzuki bean (*Vigna angularis* (Willd.) Ohwi and Ohashi, cv. Bloodwood), navy bean (*Phaseolus vulgaris* L., cv. Actolac), cowpea (*V. unguiculata* (L.) Walp., cv. Banjo) and mung bean (*V. radiata* L., cv. Berken).

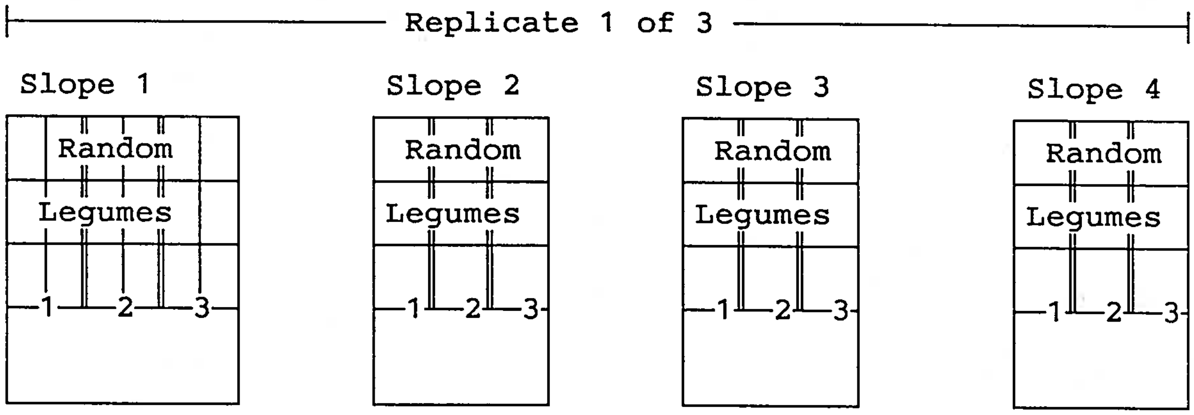

Figure 1. Experimental design

Slopes 1,2,3,4 refer to randomised slopes 1:500, 1:1000, 1:1500 and 1:2000.
Numbers 1,2,3 refer to randomised irrigation times of 4,16, and 32 hours.
Random legumes refer to the six legume treatments randomised within each irrigation treatment (demonstrated in slope 1).

Crop agronomy

The six grain legumes were sown into moist soil on 13 Dec. 1986. Nitrogen fertiliser had been previously applied as anhydrous ammonia at 90 kg N/ha on the 12 July 1986. All seed was inoculated with the recommended strain of *Rhizobium* and a single row was sown per ridge. Plant dry matter and nitrogen uptake in the shoots were measured 37 and 54 days after planting for all species. Similar measurements were taken 103 days after planting for the slower maturing soybean and pigeon pea. Grain was harvested in the order cowpea (17 March 1987), mung bean (18 March), adzuki bean (1 April), navy bean (7 April), soybean (15 April) and pigeon pea (20 May). The crop cultural practices and methods of measurement have been previously reported by Hodgson *et al.* (1988).

After the harvest of the legumes the same plots were re-formed in prepartation for the following cotton (*Gossypium hirsutum*) crop. Legume residues were not incorporated, but were allowed to break down on the soil surface. Treflan (R) was applied on 16 Sept. 1987 when the beds were reformed. Cotton (cv. Siokra) was planted at 18 seeds per metre on the one-meter spaced beds on the 12 Oct. 1987. The crop was sown and then irrigated the following day. Emergence occured around the 27 Oct. 1987. Irrigation treatments were not imposed for the irrigation directly after sowing, but were imposed during four subsequent irrigations on 27 Dec 1987; 16 Jan. 1988; 4 Feb. 1988 and 27 Feb. 1988 respectively. Sampling of the crop occured on the mid two rows and central six metre lengths. Cultural practices of weed cultivation and pest control were carried out as deemed necessary using current commercial methods.

Plant measurements

Petiole nitrate, which gives an indication of the N transport in the plant, was measured at day 0 (four hours before irrigation) and 4 and 8 days after the first irrigation. This was done by collecting petioles of the youngest mature leaf, drying to a constant weight at 70°C, and then grinding to a powder. A sample of 0.1 g was extracted with distilled water for one hour, and the nitrate concentration of the extracted solution was measured spectrophotometrically.

The youngest mature leaf (YML), (of twenty five plants), which gives an indication of the N status of the plant, was collected on day 4 after the first irrigation started. The nitrogen content of the dried and ground leaf sample was then measured by infra-red spectroscopy on a Neotech (R) infra-red protein analyser calibrated to total nitrogen.

Nitrogen uptake in the shoots of the cotton was estimated at two times. The first estimate was 11 days after the first irrigation (or 88 days post-planting) taken from the 1:1500 slope. One metre cuts of plants at soil surface level were made in the middle of the second row of each treatment. Samples were dried to a constant weight at 80°C, weighed, and finely ground. Subsamples were then measured for nitrogen concentration by the Neotec (R) infra-red protein analyser and N uptake calculated as kg N uptake per ha.

The second estimate of N uptake was taken at 133 days post planting (22 Feb. 1988) at peak leaf area index (LAI). This measurement has been shown to be well correlated to lint yield; plants do not take up much more N, instead leaf N is translocated and utilized (Constable and Rochester, 1988). To decreased sample variability, cuts of two metres were made from the middle of the third row of each treatment. Fresh weight was measured and a subsample of approximately 1/3 of the plants were taken. From these plants, bolls and stalks were separated, washed and oven dried at 80°C to a constant weight. Lint was then removed and weighed. The N content of the non-lint component (stalks and residues of bolls) was determined as before. The N content of the lint was determined by semi-micro Kjeldahl digestion and measured on the auto-analyser. From this dry-matter cut the following measurements were obtained: boll number/m^2, boll weight/m^2, plant dry-matter/m^2, plant number/m^2, lint/m^2, plant N %/m^2 and N uptake/m^2.

The apparent recoverys of the N fertiliser applied before the legume crops were calculated in order to estimate the efficiency of utilization of applied N fertiliser. The amount of N removed in the legume seed in 1987 and by the cotton in 1988 was divided by the amount of N fertiliser applied.

The crop was defoliated when 60 % of the bolls were open. The middle two rows of each treatment was mechanically harvested and cotton yield from each row was measured in the field. Subsamples of 100 g from each row were taken to be ginned by a 20 saw Continental gin. From this, ginning-out percentage and final lint yield were calculated.

Analysis of variance for each parameter was carried out using the Genstat statistical package (Alvey *et al.* 1982). Means were compared to using Duncan's multiple range test. Transformations of the data were only necessary for the petiole nitrate analysis to normalize the residuals.

RESULTS

1. Treatments Effect

The treatment effects on the measured parameters are shown in Table 2. As can be seen the slope main effect is not significant for any of the measured parameters. The main treatment effects of interest are irrigation time and the previous legume species. The specific treatment differences for the measured parametres will be discussed under irrigation time effect and species effect.

Table 2. Levels of significant differences for each treatment and measured parameter.

Treatment	Measured parameter													
	Yield				133 Day Cut (peak LAI)			88 Day cut (11 DAI)			Petiole N DAI			YML 4 DAI
	Seed cott	Seed	Lint	G %	Dm	Nup	% N	Dm	Nup	% N	0	4	8	% N
Slope (S)	ns	ns	ns	ns	ns	ns	ns	nm	nm	nm	nm	nm	nm	nm
Irr. Time (I)	-	ns	*	ns	*	*	ns	ns	*	*	*	ns	*	*
S * I	ns	ns	ns	-	ns	ns	ns	nm	ns	nm	nm	nm	nm	nm
Leg. sp. (L)	*	**	*	-	***	**	ns	ns	ns	ns	ns	*	ns	ns
S * L	ns	ns	ns	ns	ns	ns	ns	nm	nm	nm	nm	nm	nm	nm
T * L	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	*	ns
S * T * L	ns	ns	ns	-	-	ns	ns	nm	nm	nm	nm	nm	nm	nm

* : significant different at $p<0.05$
\- : significant different at $p<0.10$
ns : not significant different at $p<0.10$
nm : not measured
G %: gin percentage = lint/raw cotton
Dm : dry-matter of shoots
Nup: nitrogen up-take in shoots
% N: nitrogen concentration
YML: youngest mature leaf
DAI: days after first irrigation

2. Irrigation Time Effect

The overall effect of irrigation time was first evident in the petiole nitrate measurement one half a day before the first irrigation (Figure 2). This effect of irrigation time is that of availability of N resulting from the previous year's irrigation time. From petiole measurements four and eight days after the first irrigation (DAI), it can be seen that the availability of N varies with species and irrigation time (Figure 3 and 4). Therefore, nitrate transport to the leaves in cotton will vary with irrigation time, depending on the preceeding legume species.

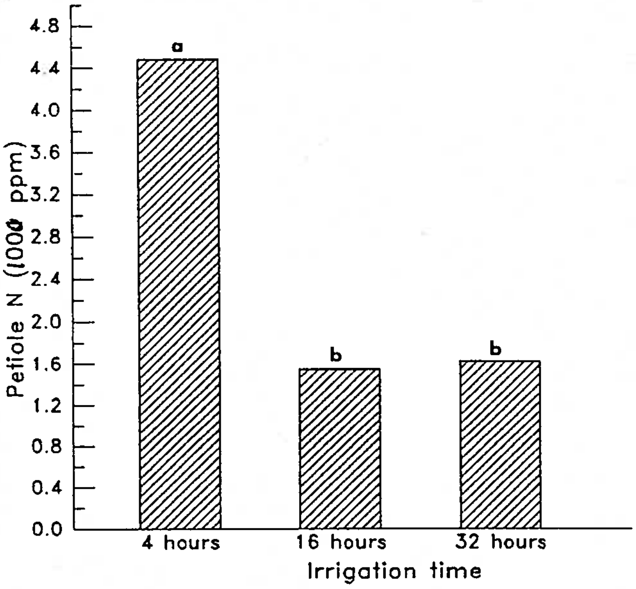

Figure 2^a. Cotton petiole nitrate levels at three times of irrigation, half a day before the first irrigation.

Values with the same letter are not significantly different (5 % lsd).

[a] Levels of petiole nitrate were only significant once a $\log_e$ transformation was carried out to normalize the residuals. For ease of comparison levels presented here are the exponent of the tranformed means, hence will vary from the raw means. The lsd is that for the transformed means.

Whereas an interaction between irrigation time and legume species was found for petiole nitrate after the first irrigation, no such interaction was found in any of the later measurement of N % or N up-take. Figure 5 shows that nitrogen contents of the youngest mature leaf (YML) and shoots 4 and 11 DAI respectively was only significant for time of irrigation. It can be seen that extending the irrigation time from 4 to 16 hours caused a decrease in the N % of 11.2 % and 8.8 % for the YML and shoots respectively.

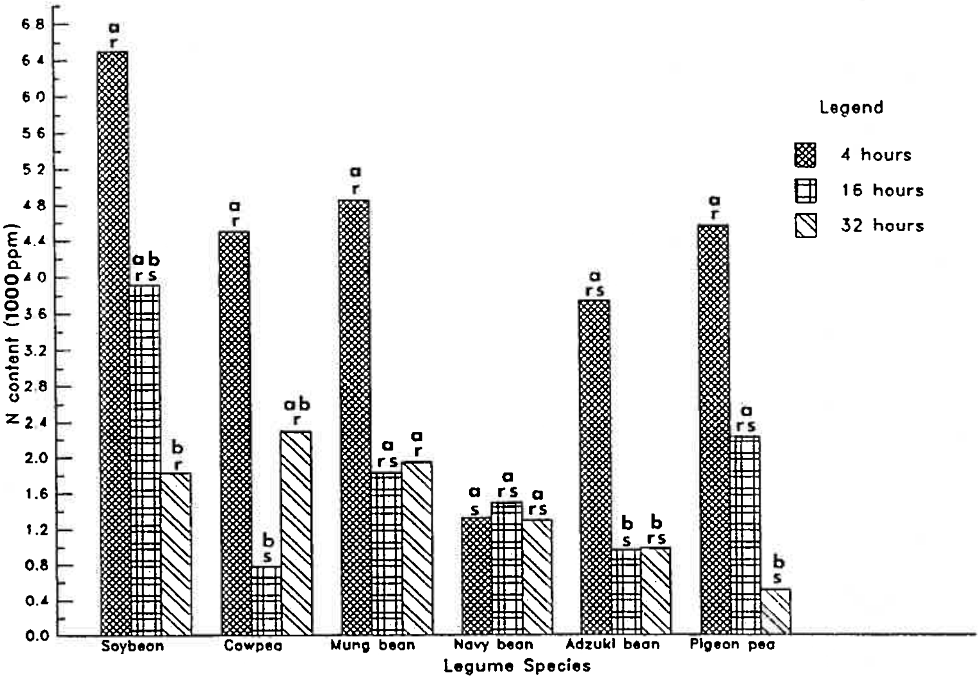

Figure 3.[a] Cotton petiole nitrate levels as affected by three times of irrigation and six previous legume species four days after irrigation started.

Levels with the same letter a,b, or c are not significantly different (5 % lsd) within species between irrigation times.

Levels with the same letter r,s, or t, are not significantly different (5 % lsd) within irrigation time between species.

[a] Levels of petiole nitrate were only significant once a $\log_e$ transformation was carried out to normalize the residuals. For ease of comparison levels presented here are the exponent of the tranformed means, hence will vary from the raw means. The lsd is that for the transformed means.

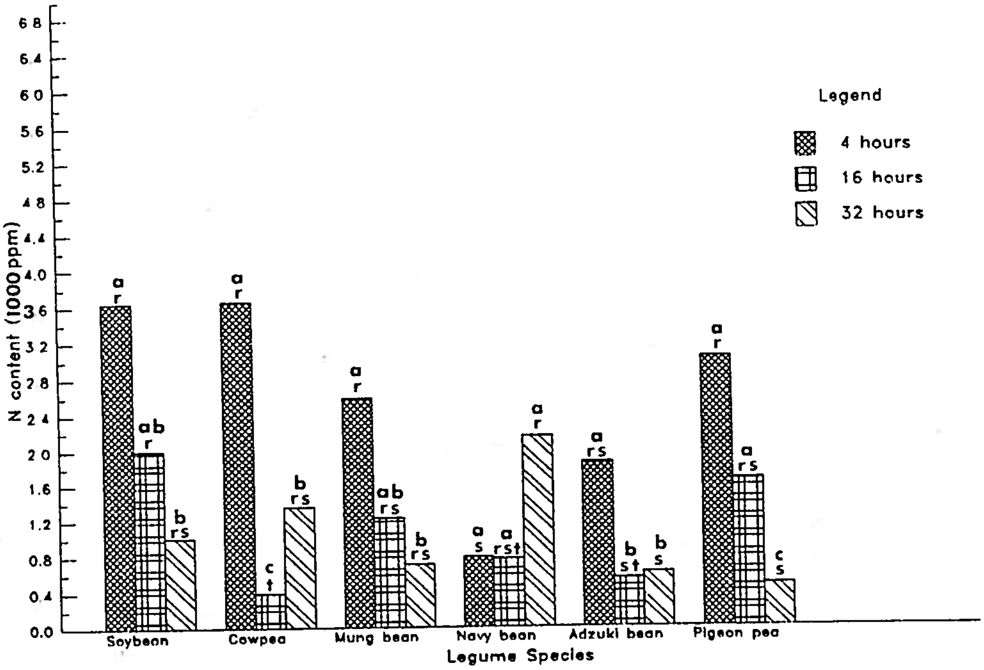

Figure 4.[a] Cotton petiole nitrate levels as affected by three times of irrigation and six previous legume species eight days after irrigation started.

Levels with the same letter a,b, or c are not significantly different (5 % lsd) within species between irrigation times.

Levels with the same letter r,s, or t are not significantly different (5 % lsd) within irrigation time between species.

[a] Levels of petiole nitrate were only significant once a $\log_e$ transformation was carried out to normalize the residuals. For ease of comparison levels presented here are the exponent of the tranformed means, hence will vary from the raw means. The lsd is that for the transformed means.

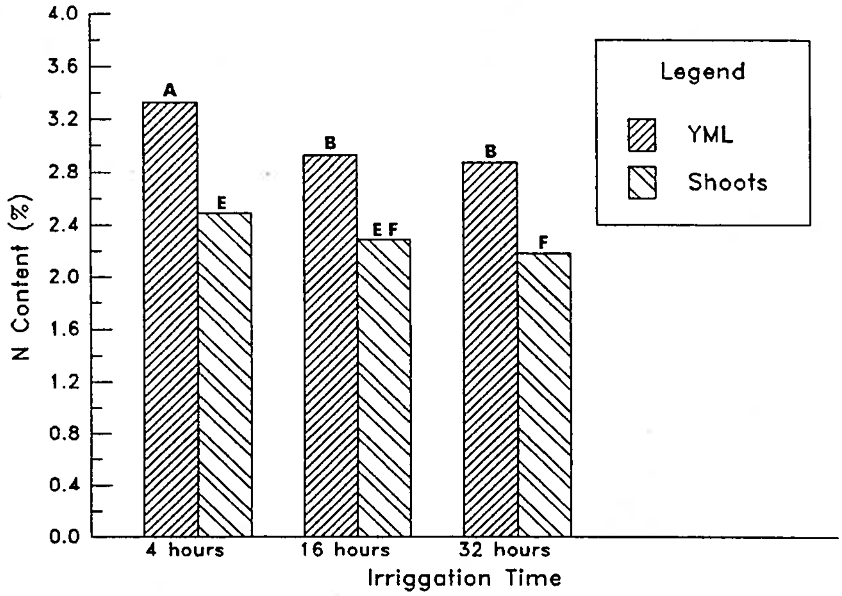

Figure 5. Nitrogen content of the YML (4 DAI) and shoots (11 DAI) of cotton as affected by three irrigation times.

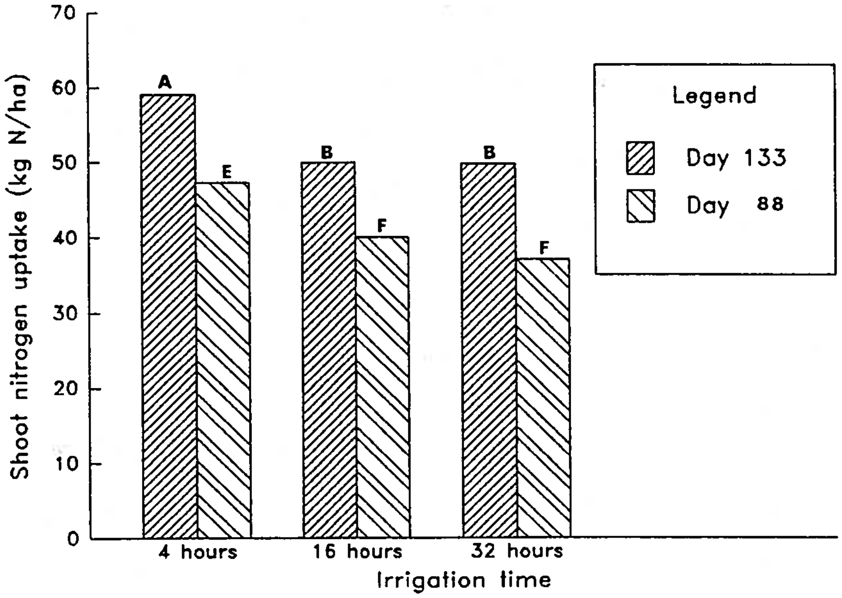

Figure 6. Nitrogen up-take by cotton shoots 88 (11 DAI) and 133 days post plant as affected by three irrigation times

(Figures 5 and 6) Measurement levels between irrigation time with the same letter are not significantly different (5 % lsd).

Figure 6 shows the effect of irrigation time on the amount of N taken up in the shoots for days 88 (11 DAI) and 133 post planting. The reduction in N taken up between the 4 and the 16 hour irrigation treatments is in the order of 15 %. Harvested lint follows the same pattern but the reduction is only about 11 % (Figure 7). Irrigation effects on seed cotton and gin out-turn were only significant at the 10 % level (data no shown).

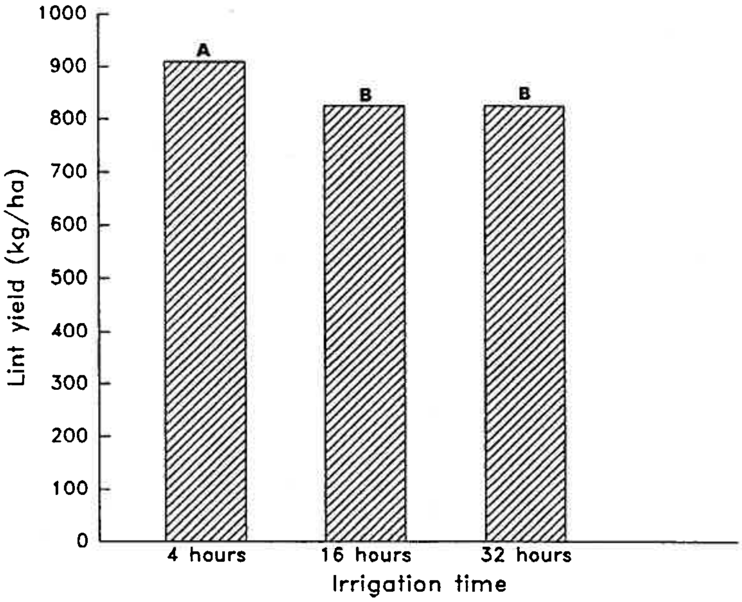

Figure 7. Lint yield of cotton as affected by three irrigation times.

Measurement levels between irrigation time with the same letter are not significantly different (5 % lsd).

3. Species Effect

Prior legume species produced a significant difference in shoot dry-matter 133 days after planting. The soybean treatment had the highest dry-matter produced and adzuki bean the least with the other species treatment intermediate (Figure 8).

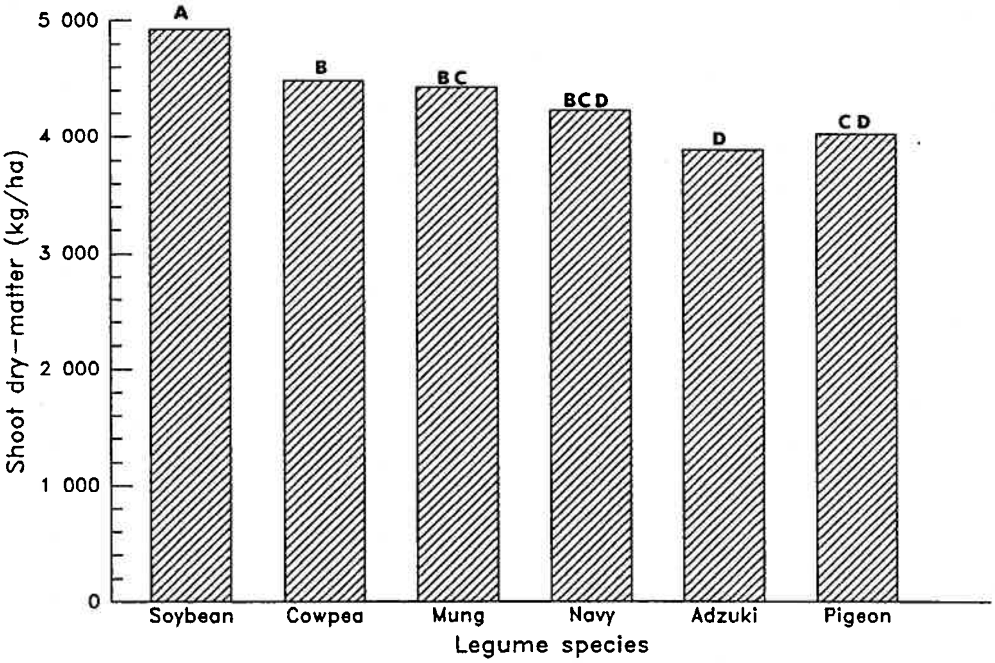

Figure 8. Cotton shoot dry-matter production 133 days after planting as affected by the legume species grown the prior year.

Values with the same letter are not significantly different at $p<0.05$ by Duncans Multiple Rannge test.

Similar to the dry-matter production 133 days after planting the previous legume species produced a significant difference in N up-take by cotton shoots and lint (Figure 9). The soybean treatment had the greatest up-take. Compared to soybean the up-take for the other species were: cowpea (88.6%), mung bean (91.6%), navy bean (88.8%), adzuki bean

(77.8%) and pigeon pea (82.2%). As the N concentration (as a percentage) of the cotton in the species treatments was not significant, the differences in the N up-take is largely a function of the dry-matter produced.

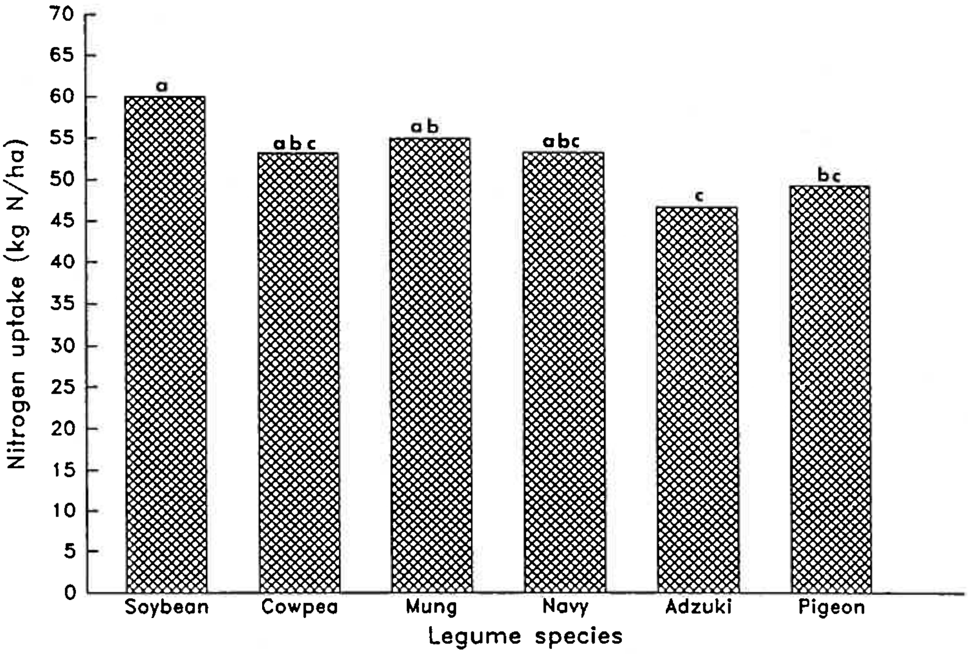

Figure 9. Total nitrogen up-take by cotton 133 days after planting as affected by the legume species grown the prior year.

Values with the same letter are not significantly different at $p < 0.05$ by Duncans Multiple Rannge test.

Significant differences were also found in the harvested cotton due to the previous legume species. Seed cotton is made up of seed, lint and trash. As Figure 10 shows, seed cotton, seed and lint differed significantly at least at $p < 0.05$ between the legume species treatment. However, gin-outurn which is a measure of the proportion of lint ginned from the seed cotton did not show the same level of significance (it was significant at $p < 0.10$) between the legume species treatments. Hence the not all species treatments gave the same proportion of lint from the seed cotton.

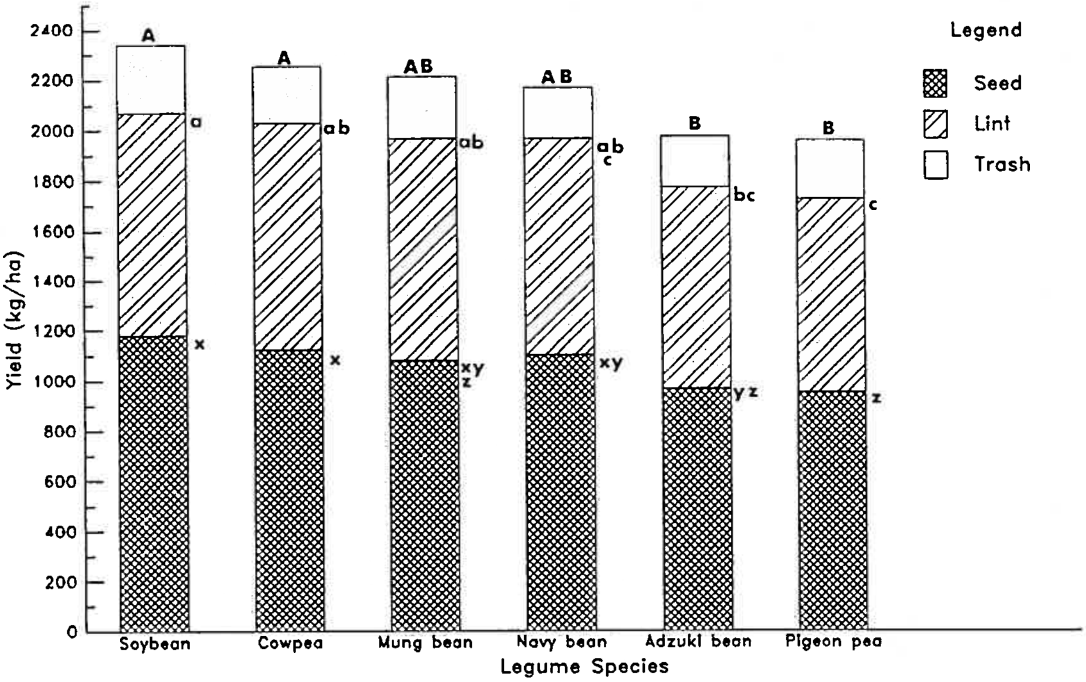

Figure 10. Harvested seed cotton made up of seed, lint and trash as affected by the legume species grown the prior year.

Values with the same letter are not significantly different at $p<0.05$ by Duncans Multiple Rannge test. Letters A,B,C refer to total seed cotton; a,b,c, refer to lint; and x,y,z refer to seed.

4. Nitrogen Up-take and Cotton Yield

Figure 11 shows the regression of cotton yield components against the N up-take of 133 days. Eighteen means from the irrigation time by legume species treatment were used for the regression lines. As the data came from three irrigation times, each regression line was initially tested for homogeneity of three lines. In each yield component keeping three lines did not significantly improve the residual sum of squares, hence lines were pooled to give the one regression line for each component. Regression equations are:

Seed cotton = 980.6 + 22.1(N up-take) R^2=71.0 %

Seed = 524.8 + 10.23(N up-take) R^2=51.3 %

Lint = 399 + 8.78(N up-take) R^2=66.7 %

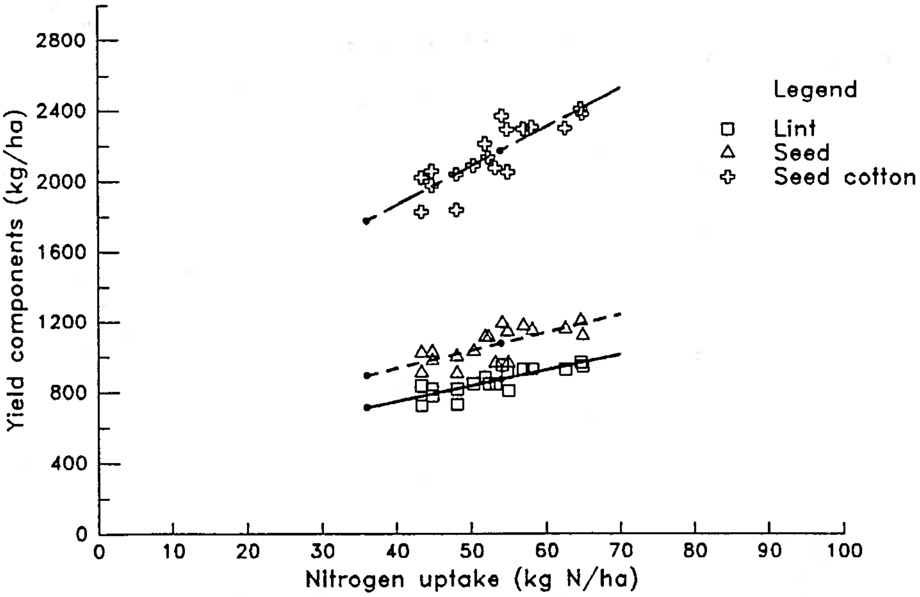

Figure 11. Regression of cotton yield components, seed cotton, seed and lint on nitrogen up-take at day 133.

5. Nitrogen Up-take and Removal by Legumes

Measurement of the N up-take by the six legume species was carried out at certain periods. Unfortunately no measurements were made in the 1987 season at peak nitrogen accumulation (generally just before leaf fall prior harvest) for most species, except perhaps soybeans which were harvested one week after N up-take was determined. The N up-take and N removed in the grain for each species are given in Appendices 1 to 3. Salient points from the data are listed in Table 3, which shows the apparent N usage over the two years that legumes species and cotton grew. The apparent N recovery assumes that all of the N fertiliser will be available for up-take and removal by the legumes. Hence no account is made for inherent soil N that may be mineralised, or fertiliser that may be immobilised. Despite the unreliability of the assumptions these values allow the comparison of the residual N benefit to the cotton from each legume species.

Table 3. Apparent nitrogen usage by the legume species and cotton

	Treatment Species					
	Soybean	Cowpea	Mung	Navy	Adzuki	Pigeon
Days to harvest after measured N up-take 6/2/87 (7/4/87)	68 (8)[a]	39	40	60	54	83 (43)
N up-take (kg N/ha) 6/2/87 (7/4/87)	60 (161)	62.9	59.6	25.1	33.2	35.3 (86.9)
N removed in seed of legumes 1987 (kg N/ha) **A**	122.4	51.1	53.5	25.3	32.1	44.9
N up-take in the 1988 cotton (kg N/ha) **B**	60.1	53.1	55.0	53.3	46.7	49.3
Total N removed from 1987-88 (kg N/ha) **A+B=C**	182.5	104.2	108.5	78.6	78.8	94.2
Apparent N recovery[b] (90 kg N/ha) relative total removed **C/90**	2.03	1.16	1.21	0.87	0.88	1.05
Apparent N recovery[b] (90 kg N/ha) relative cotton up-take **B/90**	0.67	0.59	0.61	0.59	0.56	0.52

[a] Values in brackets were taken at dates in brackets

[b] Apparent N recovery is a measure of the utilisation efficiency of the 90 kg N/ha fertiliser applied on the 12 July 1987. These values were obtained by dividing the total N removed in 1987-88 and N removed in just by the cotton in 1988.

DISCUSSION

The main treatment effects which determined the amount of lint harvested are irrigation time and legume species (Table 2). Each of these treatments had an effect on the amount of N taken up by the cotton. Irrigated cotton requires large amounts of N, consequently the production of lint is largely a function of the amount of N taken up by the plant (Hearn, 1981; Constable and Rochester, 1988). The discussion of the results will concentrate on the treatment effects on N uptake.

Irrigation Time Effect

Irrigation time and recovery from waterlogging

The importance of oxygen to the growth of cotton roots was demonstrated by Huck (1970), who showed that the growth of cotton roots decreased when oxygen concentration of the soil atmosphere around the roots was less than 10 %. If all the oxygen was removed from the zone around the roots, root growth stopped within 2 to 3 minutes. Periods of 3 hours or longer of complete anaerobiosis resulted in death of 100 % of the primary root tips. Irrigation of cotton results in the depletion of soil air with soil oxygen being consumed within a few hours of inundation by microbial respiration (Ponnamperuma, 1984).

Past experiments have shown that growth and yield of cotton is correlated with recovery of air filled porosity

(AFP) within the top 0-20 cm of the soil after irrigation. The suggested critical value of AFP for plant growth is 10 % but it ranges from 8 to 15 % according to soil texture and structure (Wesseling, 1974 cited in Hodgson and MacLeod, 1988). Hodgson (1982) working on a similar soil to that used in the present experiment showed that recovery of AFP to 10 % in the 0-10 cm depth, when averaged over three irrigations was 1.09, 1.93 and 2.34 days for 4, 16 and 32 hour irrigation times respectively. Similarly, recovery in the 10-20 cm depth was 1.37, 2.26 and 2.38 days for the above durations of irrigation. Similar values for 0-20 cm were obtained for 4 and 16 hours of irrigation by Hodgson and Chan (1982). Irrigation time thus reduces growth through its effect on the time taken for the soil to regain an AFP which will allow plant roots access to oxygen needed for cellular respiration.

Irrigation time and nitrogen uptake

The duration of irrigation is considered to have affected the amount of N taken up by the cotton in two ways. Firstly, it could be due to an indirect effect through the amount of residual N left by the legumes under the three different times of irrigation (4, 16 and 32 hours) the previous year. As discussed in section 3.3.2, waterlogging is known to decrease N fixation. Hodgson *et al.* (1988) report that growth of all six legume species was reduced with increased times of irrigation (see Appendices 1, 2, and 3). Therefore it is likely that the amount of residual N derived from the legume crop was also reduced with increased irrigation time.

Secondly, waterlogging could directly affect N uptake either by causing a rapid depletion in the availability of nitrate N to the plant through denitrification under anaerobic conditions, or through the plant itself being unable to take up the nitrate (Kozlowski and Pallardy, 1984). Reduced N uptake within the plant is due to decreased soil oxygen levels causing stomatal closure, which then decreases transpiration. As N is transported in the phloem, N uptake decreases as transpiration decreases (Sojka and Stolzy 1980; Kozlowski and Pallardy, 1984)

Petiole nitrate can be used as a measure of the amount of N moving into the plant (Burhan and Babikir, 1968). The petiole nitrate levels of the cotton taken just before the first irrigation (Figure 2) demonstrate the indirect effect of irrigation time. It can be seen that there is a significant reduction in available residual N as irrigation time extends from 4 to 16 and 32 hours. This is considered a residual N effect as at this time neither the cotton plants nor the soil has undergone different durations of irrigation. Nitrate concentration in the petioles of the youngest mature leaf are greatest from late vegetative to early bloom phase of plant growth (MacKenzie *et al.*, 1963; Burhan and Babikir, 1968). Suggested critical nitrate levels at this time are 19,000 ppm (Constable, 1987). Therefore the cotton in this experiment is very deficient in N (Figures 2, 3 and 4).

The reduced N concentration through increased irrigation time in the youngest mature leaf (YML) and shoots (Figure 5), will have been influenced by both residual N and the first irrigation. The main effect is likely to be that of residual

N, although increased irrigation times in the first irrigation will have reduced the N concentration of the YML and shoots, as cotton uptake of N is greatest during this point of plant growth (Burhan and Babikir, 1968). Unfortunately, the experimental design did not allow the differentiation between the effects of residual N and the first irrigation. The dominate effect of residual N is probably true as well for the amount of N taken up on day 88 (Figure 6), as the effects of increased waterlogging have not always be evident until after the second irrigation (Hodgson, 1982). However, the total N uptake at day 133 will have been influenced by irrigation time affecting both legume residual N and N uptake by the cotton this season. As predicted by the petiole nitrate levels (Figure 2), increased waterlogging decreasesd N uptake (Figure 6).

Irrigation time and lint yield

Lint production was affected in the same way as was N uptake, the main factor affecting cotton growth (Figure 7). Nitrogen uptake at day 133 was reduced by 15 % through extending the irrigation time from 4 to 16 an 32 hours; lint was decreased by 11 % over the same irrigation times. These results are similar to those reported by Hodgson and Chan (1982) who found lint yield decreased by 8 % when irrigation time was extended from 4 to 16 hours. Similarly Hodgson (1982) upon increasing the irrigation time from 4 to 16 and 32 hours, found lint to be decreased by 11 and 18 % respectively. Lack of difference between the 16 and 32 hours (compared to Hodgson 1982), may be due to the low soil N levels of the present experiment having the main effect on yield compared to this seasons irrigation.

Species effect

Species effect and nitrogen uptake

This experiment shows that there are significant differences between the effect of summer grain legume species on cotton in the subsequent year (Figures 8, 9 and 10). The results indicate that; in terms of how well the cotton grew and yielded after the legume crops, there is little difference between soybean, cowpea, mung bean and navy bean. The least growth by the cotton was consistantly after adzuki bean and pigeon pea. These results however, do not take into account the source of the N that was taken up by the cotton.

The N available to the cotton in this experiment could have come from any combination of three sources: the inherent soil N pool, the fertiliser applied at 90 kg N/ha before the legume species were sown, and the symbiotic N fixed by *Rhizobia* in association with the legumes and present in the residual dry-matter. Unfortunately measurements were not taken during this experiment that would have allowed the separation N contributed to the cotton from these sources.

In order to determine which grain legume is best to grow in terms of residual N in a rotation with cotton, it is important to consider the source of the residual N. Residual

N from the legume crops will depend on how much mineral N is taken up from the soil, how much N is fixed and how much N is removed in the grain (Myers and Wood, 1987). To qualify the source of N for the cotton and thereby determine the best legume for a crop rotation, an N utilisation efficiency or apparent N recovery, for each legume treatment can be calculated. This recovery rate takes into account the N available to the legumes as N fertiliser, the N taken off in the legume seed and the N taken up by the subsequent cotton crop. This gives a relative standing for this experiment as to the value of each legume species as a N source. The recovery rate for each species treatment is calculated as the total N removed (ie. in the legume seed and taken up by the cotton) divided by the amount of N fertiliser applied (90 kg N/ha) before the legume crops were sown. The results of these calculations are shown in Table 3.

It is likely that the 90 kg N/ha fertiliser would have decreased N fixation in all species (see Section 3.1.1). As well, the legumes would have taken up some of the N fertiliser, hence it cannot be assumed that all the residual N has come from legume-*Rhizobium* symbiosis. As seen from Figures 9 and 10, cotton grown after navy bean had similar N uptake and lint yield as soybean, cowpea and mung bean. However, when the total N recovery rate in both legume seed and cotton shoots is considered (Table 3), only 0.87 or (87 %) of the 90 kg N/ha has been utilised. This is contrasted to soybeans which had a total N recovery rate 2.03. It is assumed that inherent soil N is the same for both treatments. Therefore, the value of soybean as an N source for cotton is much greater than navy bean.

This apparent N recovery rate while not defining the source of N for the cotton, does give the relative value of each legume as a N source. Therefore in terms of the apparent N recovery (or fertiliser efficiency) rate, the species decrease in the order; soybean > mung bean, cowpea > pigeon pea > adzuki bean and navy bean (Table 3). This is contrasted to the results stated above and shown in Figures 8, 9 and 10.

Soybeans consistently left more residual N than mung bean for rice grown on a grey clay in the Ord river scheme (Chapman and Myers, 1987). Soybean is reported to have fixed significantly more N than both cowpea and mung bean, which both fixed more than pigeon pea (Chapman and Munchow, 1985). However, the latter three species had higher residual N levels as soybean removed a large part of its N in the harvested seed. As the environmental stress of moisture deficit increased, the residual N left by mung bean and pigeon pea decreased to a level below that for soybean which was equal to that for cowpea. Giri and De (1980) reported that pearl millet was able to take up more N following cowpeas compared to mung beans or pigeon pea, with the latter two being very similar. Navy beans have been shown to have a lower N fixation capacity than soybeans and cowpeas (Piha and Munns, 1987). Navy beans are also reported to be unable to provide sufficient N for maximum yields; utilising added fertiliser N much more readily than fixing their own (Westermann *et al.* 1981).

The literature appears to support the results indicated by the apparent N recovery rates. Soybeans fix more N than most other species. Cowpea an mung bean are similar in the N utilisation, which is less than soybean. Pigeon pea while not fixing as much N as the above three species is superior to navy bean in terms of N fixation and apparent recovery of the N fertiliser. Adzuki bean is a relatively new crop hence little research has been carried out on it, though it seems similar to navy bean in its utilisation of N.

Crop nitrogen equivalents

In order to estimate how much N each legume contributed to the subsequent cotton crop, the contribution by inherent soil N to N uptake and recovery of fertiliser N have to be estimated, as these controls were not present in this experiment.

Estimates of N uptake for cotton following cotton without applied N fertiliser on soil very similar to this experiment lie between 32 to 68 kg N/ha (Constable and Hearn, 1981; Hearn, 1986). The value of 44.2 kg N/ha obtained by Hearn (1986) for cotton grown under similar conditions to this experiment will be used as the contribution by inherent soil N. Fertiliser recovery by cotton grown on this soil range from 30 to 45 % (Constable and Hearn, 1981; Hearn, 1986; Constable and Rochester, 1988). Hearn (1986) proposed that 40 % of nitrogen fertiliser was recovered by the cotton. As this is an average value, and it was obtained under similar field and climatic conditions this value will be used for the fertiliser recovery rate. Using the values obtained by Hearn (1986), estimates of fertiliser equivalents for the six grain legumes can be calculated (Table 4).

The N equivalent values for each legume (Table 4) show the relative difference between the species. Soybeans grown by Hearn (1986) were considered to have contributed 32.5 kg N/ha to the next cotton crop. The difference between the two crops may be due to the 90 kg N fertiliser/ha applied in this experiment. By applying the calculations and assumptions of fertiliser recovery to data from Giri and De (1980) cowpea and pigeon pea would have contributed 21.8 and 14.8 kg N/ha respectively. Mung beans grown before sorghum in southern Queensland were considered to have provided the equivalent of 68 kg N/ha (Doughton and MacKenzie, 1984). This high value may be due to a faster rate of mineralisation in those soils. Myers and Wood (1987) using Chapman and Myers (1987) data estimate soybeans and mung beans contributed the equivalent of 42 and 27 kg N/ha respectively to the following rice crop. In view of these reports, the fertiliser equivalent values obtained in this experiment are consistent with those found elsewhere. It must be remembered that direct comparisons are not feasible due to the assumptions involved concerning N recovery and inherent soil N. However, these values do give an indication of the relative merits of each species when 90 kg N/ha has been applied before the legume crops were planted.

Table 4. Estimated fertiliser nitrogen equivalents for the legume species

Legume	Soybean	Cowpea	Mung	Navy	Adzuki	Pigeon
N uptake by cotton after legumes **(A)** (kg N/ha)	60.1	53.1	55.0	53.3	46.7	49.3
Difference between N uptake after legumes and after cotton **(B)** **B** = **A** - 44.2 (kg N/ha)	15.9	8.9	10.8	9.1	2.5	5.1
Equivalent N fertiliser assuming a recovery efficiency of 40 % **(C)** **C** = **B** / 0.4	39.8	22.3	27.0	23.0	6.3	12.8

Species effect on petiole nitrate levels

As discussed above, petiole nitrate measurements give an indication of the amount of N moving into the plant. Comparison of Figures 3 and 4 shows that petiole nitrate levels were still decreasing eight days after the first irrigation.

Petiole nitrate levels show an interaction of species and time (Figures 3 and 4). This would suggest that waterlogging affects the availability of residual N from the legumes in different ways. The navy bean treatment shows the greatest difference in the availability of N over irrigation time compared to the other legumes. Where all the other species generally showed decreases in petiole nitrate with irrigation time, navy bean was not affected.

This result is thought to be somewhat anomalous due to the following reasons. The final N uptake for the navy bean treatment shows a large decrease in the amount of N taken up with increased waterlogging times (data not presented). Hence the apparent waterlogging effect on petiole N was not sustained for the duration of the season. If the result was related to the source of nitrate for the cotton, regardless of where the nitrate came from, the denitrifying effect of waterlogging would be the same (Ponnamperuma, 1984). The lack of difference in this irrigation may have resulted from the navy bean crop causing structural damage in the soil thus nullifying any irrigation time effect. This explantation is not considered likely for two reasons. First, any adverse effect should have carried over to the final N uptake measurements, yet they were not. Second, there are no other reports in the literature to suggest navy bean has this effect on soil. Therefore no explantation can be put forward at present for the lack of difference of petiole nitrate levels with irrigation time for navy bean.

Regression of lint on nitrogen uptake

Regression of lint on N uptake for experiments using N fertiliser have generally yielded an asymptote relationship in the form an Mitscherlich equation (Hearn, 1986; Constable and Rochester, 1988).

Lint yield = A (1 - $\mathrm{exp}^{B(Nup - C))}$

where A, B, and C are constants

Nup is nitrogen uptake by the cotton

This type of regression equation was applied to the data but the residuals failed to converge due to insufficient spread in the data. As can be seen from Figure 11, the data were best fitted by a linear model for the three parameters seed cotton, seed and lint. As predicted by the Mitscherlich equation there is a relatively linear increase in lint yield at lower levels of N uptake. Therefore, it is assumed that the range of N uptake found in this study is too low for yield to depart form a linear relationship with N uptake.

The optimum level of N uptake for 90 % maximum yield is about 100 kg N/ha (Hearn, 1986; Constable and Rochester, 1988). When this value is substituted into the lint regression equation (given in Figure 11)

$$\text{Lint} = 399 + 8.78(\text{N uptake})$$

it predicts a lint yield of 1277 kg/ha or 5.67 bales/ha. This predicted yield is similar to yields for this area. Therefore even though the regression equations came from a narrow range of predictors they adequately predict the yield in response to N uptake.

Lint appears the least responsive to N uptake compared to seed cotton and seed (Figures 10 and 11). Harvested seed cotton from plots with high N uptake may contain higher amounts of trash and heavier seed. This may be accounted for in two ways. Trash may have increased due to the increased plant growth, thus causing more vegetative material to be incorporated by the cotton harvester into the seed cotton. Secondly, seed may have increased due to cotton seed being high in protein. Consequently it will be a much larger N sink than the lint, hence the seed may increase in greater amounts relative to the lint for high N uptake plants.

Conclusions

The effect of increased irrigation time for both legume and cotton crops was to increase the duration of waterlogging experienced by these crops. This caused a decrease in the N uptake by the cotton and a reduction of harvested lint by 11 % when irrigation time was extended from 4 to 16 and 32 hours.

Soybeans had the highest apparent N fertiliser recovery ratio at 2.03. Mung bean and cowpea had similar recovery ratios followed by pigeon pea. Adzuki bean and navy bean had the least efficient N fertiliser recovery at 0.88 and 0.87 respectively. The calculated effective N fertiliser equivalents showed soybean contributed the most N to the subsequent cotton crop and adzuki bean the least (39.8 and 6.3 kg N/ha respectively).

It is concluded that cotton grown in rotation with soybeans using short irrigation times will receive the greatest residual N benefit. Of the other species, mung bean and cowpea offer the greatest potential for residual N. If N fertiliser is to be applied before the legume crop, navy bean must also be considered with mung bean and cowpea.

Therefore grain legumes can be grown successfully under irrigation and offer new opportunities to offset the rising cost of N fertiliser due to their ability to fix N. Future research should examine the amount of N fixed by the legumes under the same irrigation regimes. This would allow more accurate calculations of the N contribution of the legumes to the subsequent cotton crop. Hence any economic benefits from in terms of residual N could then be analysed.

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APPENDIX 1

Effect of field slope and duration of furrow irrigation on grain yield (at 12% moisture) of six legume crops.

Field slope	Durarion of irrigation (h)	Grain yield (kg/ha) of:						
		Soy-bean	Pigeon pea	Adzuki bean	Navy bean	Cow-pea	Mung-bean	Mean
1:500	4	2371	1431	794	703	1598	1597	1416
	16	2340	1377	756	655	1471	1708	1384
	32	2415	1122	638	187	1474	1503	1223
	Mean	2375	1310	730	515	1514	1602	1341
1:1000	4	2341	2033	1099	1180	1746	1792	1699
	16	2306	2052	1139	985	1840	1902	1704
	32	2526	2008	1134	748	1823	1760	1667
	Mean	2391	2031	1124	971	1803	1818	1690
1:1500	4	2285	1922	1003	1089	2008	1716	1670
	16	2625	2188	956	939	1912	1838	1743
	32	2571	2002	801	572	1750	1705	1567
	Mean	2494	2037	920	867	1890	1753	1660
1:2000	4	2320	2044	1115	821	1813	1782	1649
	16	2331	2301	998	794	1708	1974	1684
	32	2475	1836	859	597	1538	1584	1481
	Mean	2375	2060	991	737	1686	1780	1605
Mean	4	2329	1857	1003	948	1791	1722	1608
	16	2400	1979	962	843	1733	1856	1629
	32	2497	1742	858	526	1646	1838	1485
	Mean	2409	1860	941	772	1723	1738	1574

SE (Slope)	88.1
SE (Duration)	46.1
SE (Legume)	61.2
SE (S*D)	n.s.
SE (S*L)	142.3
SE (D*L)	107.2
SE (S*D*L)	n.s.

n.s.: not significant at $p < 0.05$

Source: Hodgson *et al.*, 1988

APPENDIX 2

Effect of field slope and duration of furrow irrigation on shoot nitrogen uptake of six legume crops on 6 February 1987.

Field slope	Durarion of irrigation (h)	Shoot nitrogen uptake (kg N/ha) of:						
		Soy-bean	Pigeon pea	Adzuki bean	Navy bean	Cow-pea	Mung-bean	Mean
1:500	4	51.9	26.2	26.8	24.3	65.4	39.5	39.0
	16	45.2	32.5	23.1	19.5	55.4	53.7	38.2
	32	38.6	24.4	30.1	9.1	47.7	55.1	34.2
	Mean	45.3	27.7	26.7	17.7	56.1	49.4	37.1
1:1000	4	74.6	39.8	30.3	45.7	60.3	72.3	53.8
	16	65.2	32.9	37.7	25.8	68.4	65.1	49.2
	32	70.4	33.6	32.7	25.3	66.3	64.1	48.7
	Mean	70.0	35.4	33.6	32.2	65.0	67.1	50.6
1:1500	4	71.4	42.2	39.6	20.9	66.4	83.7	54.1
	16	55.3	43.4	34.9	30.7	55.0	49.2	44.8
	32	64.2	32.5	30.4	25.4	58.6	59.3	45.1
	Mean	63.6	39.4	35.0	25.7	60.0	64.1	48.0
1:2000	4	66.1	45.5	40.6	33.0	67.0	52.1	50.7
	16	54.8	33.5	39.1	22.7	59.8	63.0	45.5
	32	62.3	36.9	33.4	18.3	72.6	57.7	46.9
	Mean	61.1	38.7	37.8	24.7	66.4	57.6	47.7
Mean	4	66.0	38.4	34.3	31.0	64.8	61.9	49.4
	16	55.1	35.6	33.7	24.7	59.7	57.7	44.4
	32	58.9	31.9	31.7	19.5	61.3	59.0	43.7
	Mean	60.0	35.3	33.2	25.1	61.9	59.6	45.8

LSD (Slope)	7.7
LSD (Duration)	2.4
LSD (Legume)	4.6
LSD (S*D)	n.s.
LSD (S*L)	n.s.
LSD (D*L)	n.s.
LSD (S*D*L)	n.s.

n.s.: not significant at $p < 0.05$

Source: Hodgson (unpublished data)

APPENDIX 3

Effect of field slope and duration of furrow irrigation on shoot nitrogen uptake of two legume crops on 7 April 1987.

Field slope	Durarion of irrigation (h)	Shoot nitrogen uptake (kg N/ha) of:		
		Soy-bean	Pigeon pea	Mean
1:500	4	160.5	74.5	117.5
	16	167.2	59.9	113.6
	32	154.2	49.6	101.9
	Mean	160.6	61.3	111.0
1:1000	4	167.9	106.3	137.1
	16	171.5	92.3	131.9
	32	143.1	76.1	109.6
	Mean	160.8	91.5	126.2
1:1500	4	150.6	83.3	116.9
	16	172.9	108.4	140.7
	32	147.9	82.9	115.4
	Mean	157.1	91.5	124.3
1:2000	4	143.5	114.4	128.9
	16	168.9	91.0	129.9
	32	183.6	104.7	144.1
	Mean	165.3	103.3	134.3
Mean	4	155.6	94.6	125.1
	16	170.1	87.9	129.0
	32	157.2	78.3	117.7
	Mean	161.0	86.9	124.0

LSD (Slope)	n.s.
LSD (Duration)	n.s.
LSD (Legume)	5.6
LSD (S*D)	n.s.
LSD (S*L)	n.s.
LSD (D*L)	n.s.
LSD (S*D*L)	n.s.

n.s.: not significant at $p < 0.05$

Source: Hodgson (unpublished data)