EFFECTS OF WATER, NITROGEN, AND COMPETITION
ON GROWTH, YIELD AND YIELD COMPONENTS
OF FIELD-GROWN TEPARY BEAN

by

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DEDICATION

I dedicate this work to a special friend, Gary Nabhan, whose energy and sensitivity gave strength to an otherwise dormant dream and whose unyielding enthusiasm for the tepary bean may well be its savior.

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ABSTRACT

Tepary bean (Phaseolus acutifolius A. Gray) was grown in Tucson, Arizona during the summer rainy seasons of 1987 and 1988. Effects of water and nitrogen on growth, yield and yield components were evaluated in 1987. In 1988, effects of water and intercrop competition with Sonoran panicgrass (Panicum sonorum Beal) were evaluated.

Total shoot biomass, seed yields and pod yields were significantly reduced by lack of applied water in both 1987 and 1988. Seeds pod⁻¹ were unaffected by lack of applied water in both 1987 and 1988 while mean seed weight was significantly reduced for rainfed treatments relative to irrigated treatments in 1987 but not in 1988. In 1987, addition of nitrogen had no significant effect on total shoot biomass, seed yield or yield components. In 1988, intercrop competition significantly reduced total shoot biomass, seed and pod yields of tepary bean. Seeds pod⁻¹ and mean seed weight were not affected by competition.

INTRODUCTION

Environmental limitations, especially high temperatures and lack of water, pose challenges to crop production around the world. Approximately one-third of all potentially arable lands worldwide are characterized by an insufficient water supply, and crop yields on most of the remaining lands are frequently reduced by drought (Kramer, 1980). Kramer (1980) suggests that losses in crop yield due to water deficits exceed losses due to all other causes combined.

Tepary bean (Phaseolus acutifolius A. Gray) is a heat- and drought-tolerant legume long cultivated by the indigenous peoples of the southwestern United States and northwestern Mexico (Nabhan and Felger, 1978). It is a summer annual crop, planted after the onset of the summer rainy season when daily maximal temperatures consistently exceed 37 C. Although tepary beans were traditionally planted when soils were saturated from summer rains, high temperatures and quickly drying soil profiles necessitated the ability to grow and yield under extreme environmental conditions.

Recent research has mainly focused on the mechanisms by which tepary bean copes with high temperatures and drought conditions (Parsons and Howe, 1984; Markhart, 1985) as well as on the potential transfer of heat- and drought-tolerant traits to common bean, P. vulgaris (Thomas et al., 1983).

The primary objective of this study was to determine the effects of water deficits, under high temperature conditions, on growth, yield

and yield components of tepary bean. In 1987, the secondary objective was to examine the effects of nitrogen and its possible interaction with water deficits on growth, yield and yield components of tepary bean. In 1988, the secondary objective was to examine the effects of intercrop competition on growth, yield and yield components of tepary bean, since legume-cereal mixtures are a commonly used cropping system in many developing countries and are gaining acceptance in more industrialized nations (Francis, 1986).

LITERATURE REVIEW

Although tepary bean has long been considered a drought-tolerant legume, evidence supporting this claim consists mainly of its continued but limited cultivation in the extremely hot and dry southwestern U.S. Its potential as a crop for water limited agricultural regions was noted by both Freeman (1918) and Hendry (1918) in the early part of this century. Yield trials from the early 1900's show variable seed yield of tepary bean under both dry-farmed (400-2000 kg acre⁻¹) and irrigated (1200-4600 kg acre⁻¹) conditions (Nabhan and Felger, 1978). More recently, Rodriguez Perez (1987) reports some yield and forage data for yellow and white tepary beans in field trials on Tenerife Island. Average seed yields for tepary beans were approximately 1000 kg ha⁻¹ and 250 kg ha⁻¹ for irrigated and non-irrigated conditions, respectively. Unfortunately, the irrigated and non-irrigated treatments were performed during different growing seasons as separate experiments (irrigated, planted 9 August, 1982 and non-irrigated, planted 26 April, 1983) so

that direct comparisons of seed yield are limited since temperature and rainfall patterns for the different seasons and years likely played an important role in the response of tepary bean.

Very little other yield data exist for tepary bean, either field-grown or under controlled environmental conditions, although several studies have reported seed yields of tepary bean under saline field conditions (Goertz and Kobriger, 1986; Coons and Pratt, 1988).

Although there is a paucity of information regarding tepary bean yields, there is even less information regarding the effects of nitrogen or competition on tepary bean. Legumes often show little or no response to nitrogen fertilization (Ofori and Stern, 1986). Rodriguez Perez (1987) reported no significant difference between fertilized and unfertilized tepary bean forage yields but did not give any information concerning seed yields.

The use of tepary bean in an intercrop system has indeed been reported by Wells et al. (1986). An intercrop of tepary bean and common bean (Phaseolus vulgaris L.) was planted at Riverside, California on 29 July 1985 and irrigated during the first two weeks after planting. Results suggest that intercropping tepary bean and common bean under water limited conditions may not be advantageous, since intercrop yields were less than the mean of the two sole crop yields (Wells et al., 1986).

Tepary bean was and continues to be of interest to researchers, although there appears to have been a shifting of emphasis from

agronomic to physiological and most recently genetic engineering interests. Nevertheless, there remains much to be learned about the responses of tepary beans to environmental stresses and consequently the mechanisms of tolerance to stress that tepary bean exhibits that allow it to successfully yield under extreme environmental conditions.

MATERIALS AND METHODS

Field studies were conducted in 1987 and 1988 at the Campus Agricultural Center of the University of Arizona in Tucson on a Torrey fluvane soil with a high clay content. The same field was used both years. Tucson is located near the northern limits of the Sonoran Desert in the southwestern United States at an elevation of 787 m. Average annual precipitation is approximately 300 mm distributed bimodally during winter and summer months (Turner and Brown, 1982). Winter rains (November-January) may account for 10% to 40% of the annual precipitation, while 30% to 60% may come in the form of summer monsoons (July-September) (Turner and Brown, 1982). Mean monthly maximal temperatures during June through September normally range from 34 C to 39 C, with June and July representing the hottest months. Mean monthly minimal temperatures range from 17 C to 23 C, with higher minimal temperatures occurring during the months of July and August. Temperature and rainfall data for 1987 and 1988 were obtained from a permanent weather station located at the Campus Agricultural Center.

Tepary bean lines grown locally on the Gila River Indian Reservation, Sacaton, Arizona were used both years. The 1987 and 1988

tepary bean lines were obtained from different farmers on the Reservation. In 1987, a mixture of brown and white tepary beans was used since the amount of brown tepary beans was not sufficient to plant the entire field. In 1988, only brown tepary beans were used.

1987 Experiment

The experiment in 1987 was designed to evaluate the main and interactive effects of water and nitrogen on growth, yield and yield components of tepary bean. A split-plot design with three replications consisting of a water treatment (irrigated and rainfed) as the main plot factor and a nitrogen treatment (high and low) as the subplot factor was utilized. Plot sizes were 4 m wide x 12 m long with 100 cm row spacing. Harvest areas were 4 m² (2 m wide x 2 m long) from the two central rows. The field was hand-planted and furrow-irrigated on 26 June. Prior to planting, the entire field was fertilized with 35 kg ha⁻¹ P as superphosphate and 108 kg ha⁻¹ K as potash. Tepary bean was inoculated with Rhizobium (Phaseolus Special 3, Nitragin Corp., Milwaukee, WI.). High nitrogen plots were side-dressed with 80 kg ha⁻¹ N as ammonium nitrate 10 days after planting (DAP). All treatments were furrow-irrigated 10 DAP to ensure seedling establishment, after which the rainfed treatments received no additional irrigation. Plots were thinned 18 DAP to a plant density of 130,000 plants ha⁻¹. Irrigated treatments received irrigations 21, 45, 65 and 83 DAP. Weeds were controlled manually.

Total shoot biomass harvests were performed 27, 53, 81 and 122 DAP, the final harvest consisting of a reproductive harvest prior to the vegetative harvest from the same area. Total shoot biomass harvesting was accomplished by cutting plant stems at the soil level within each harvest area. Plant material was oven dried at 80 C for 72 h and plant dry weight, seed yield and yield components (pod yield, seed number, and mean seed weight) were measured.

1988 Experiment

The experiment in 1988 was designed to evaluate the main and interactive effects of water and competition on growth, yield and yield components of tepary bean. Panicum sonorum Beal, Sonoran panicgrass, was used as an intercrop competitor. It is a heat- and drought-tolerant cereal indigenous to the Sonoran Desert. It is related to the Old World cereal Panicum miliaceum L., proso millet, which is also heat- and drought-tolerant.

The experimental design was a split-plot with three replications as in 1987. A water treatment (irrigated and rainfed) remained as the main plot factor while a competition treatment (sole crop and intercrop) became the subplot factor. Plot sizes were 8 m wide x 9 m long with 100 cm row spacing. Harvest areas were 4 m² (4 m wide x 1 m long) from the four central rows. The field was hand-planted and furrow-irrigated on 1 July. The entire field was fertilized with 90 kg ha⁻¹ N as ammonium sulfate and 40 kg ha⁻¹ P as superphosphate disced into the soil before planting. Nitrogen was added in order to minimize possible nitrogen

deficiencies in the panicgrass. Panicgrass was broadcast into individual rows of evenly spaced tepary bean to form an additive intercrop mixture. As in 1987, all plots received another irrigation 10 DAP to promote even establishment. Plots were thinned 18 DAP to 53,000 and 56,000 plants ha⁻¹ for tepary bean and panicgrass, respectively. Only two differential irrigation treatments occurred in 1988, 40 DAP and 64 DAP, since rainfall during the growing season was abundant.

Total shoot biomass harvests for tepary bean were performed 30, 59, 88 and 125 DAP. Tepary bean reproductive harvest occurred 125 DAP. Harvesting and measurements were conducted as described for 1987. Total shoot biomass and reproductive yield of panicgrass were not measured since our primary interests lay with the response of tepary bean.

Statistical Analysis

Results of a Chi-square approximation to a non-parametric Kruskal-Wallis test for homogeneity of variance (SAS, PROC NPAR1WAY) using within cell variances failed to indicate heteroscedasticity in both 1987 and 1988. Standard analysis of variance procedures were thus used to analyse the main effects of water and nitrogen as well as interactive effects for each harvest date in 1987. The same procedures were used in 1988 to determine main effects of water and competition as well as their interaction for each harvest date. Analysis of yield and yield components for 1987 and 1988 was accomplished with analysis of variance procedures.

RESULTS

Rainfall during the growing season differed greatly between the two years, while daily temperatures remained within the range of normal summer temperatures in both years. In 1987, total precipitation from June through October was only 59.9 mm, with June, July, August, September and October receiving 0.8, 4.3, 18.0, 19.0 and 17.8 mm, respectively (Fig. 1). In contrast, rainfall during the 1988 season (June-October) was 185.5 mm, a relatively normal summer in terms of rainfall. The months of July and August each received more rain than the entire 1987 season. Monthly precipitation in 1988 was 0.0, 60.2, 64.8, 2.8 and 57.7 mm for June, July, August, September and October, respectively (Fig. 2). Mean daily maximal temperatures for June, July, August, September and October were 37.9, 38.4, 36.5, 34.4, and 31.6 C, respectively, in 1987 (Fig. 1) and 37.7, 37.7, 36.4, 35.3 and 31.1 C, respectively, in 1988 (Fig. 2).

1987 Experiment

Nitrogen had no significant effect on total shoot biomass at any of the four harvests (Fig. 3, Table 1), nor did it affect total reproductive yield or yield components of tepary bean (Tables 2,3). There was also no nitrogen x water interaction for total shoot biomass (Table 1), yield or yield components (Tables 2,3). In remaining discussions of the 1987 results, responses of irrigated and rainfed treatments have been averaged across nitrogen treatments.

Figure 1. Daily maximal temperatures (upper) and rainfall (lower) for 1987. Planting date was 26 June.

Figure 2. Daily maximal temperatures (upper) and rainfall (lower) for 1988. Planting date was 1 July.

Figure 3. Total shoot biomass of tepary bean in response to water and nitrogen treatments in 1987. Planting date was 26 June.

Table 1. Analysis of variance results for total shoot biomass of tepary bean in 1987.

Source	df	Harvest Date			
		27 DAP	53 DAP	81 DAP	122 DAP
Water (W)	1	*	ns	*	**
Block	2	*	ns	ns	ns
Error a	2	ns	ns	ns	ns
Nitrogen (N)	1	ns	ns	ns	ns
W x N	1	ns	ns	ns	ns
ns not significant					
* p < 0.05					
** p < 0.001					

Total shoot biomass was reduced in the rainfed treatments relative to irrigated treatments at the first, third and final harvests (Fig. 3, Table 1). At the final harvest, total shoot biomass of the rainfed treatments was only 25% of the irrigated treatments (Fig. 3). Rainfed treatments failed to increase in total shoot biomass after 53 DAP, in marked contrast to the gains observed for irrigated treatments (Fig. 3).

Yield and yield components of tepary bean were similarly affected by water. Total seed yield in the rainfed treatments was only 4% of that in the irrigated treatments (Tables 2,3). Pod yield and mean seed weight were reduced in the rainfed treatments, while seed number was unaffected (Tables 2,3).

1988 Experiment

Water had a significant effect on total shoot biomass of tepary bean at the third harvest and was on the margin of significance ($p=0.0522$) at the final harvest (Fig. 4, Table 4). Total shoot biomass continued to increase for all treatments until approximately 88 DAP. It then appeared to decrease in all treatments by the final harvest (Fig. 4). The slopes of the lines from 59 DAP to 88 DAP for the irrigated sole crop and intercrop tepary bean appear to be greater than the slopes for the respective rainfed treatments (Fig. 4), suggesting that water may have become limiting during this phase of growth.

Water had a similar effect on yield and yield components in 1988 as in 1987. For both sole crop and intercrop tepary bean, total seed yields under rainfed conditions were 31% of those under irrigated

Table 2. Yield and yield components of tepary bean in 1987 and 1988. Values are means of three replicates.

Year	Treatment	Seed yield (kg ha ⁻¹)	Pod yield (10 ⁶ pods ha ⁻¹)	Seed Number (seeds pod ⁻¹)	Seed Weight (g seed ⁻¹)
1987	Irrigated				
	High nitrogen	2136.75	4.89	3.38	0.130
	Low nitrogen	2470.09	5.54	3.40	0.131
	Rainfed				
1988	High nitrogen	100.94	0.24	3.36	0.100
	Low nitrogen	70.60	0.19	3.52	0.103
	Irrigated				
	Sole crop	1772.83	4.13	4.44	0.097
	Intercrop	1142.50	2.63	4.56	0.096
	Rainfed				
	Sole crop	557.58	1.38	4.60	0.092
	Intercrop	350.50	0.88	4.13	0.090

Table 3. Analysis of variance results for yield and yield components of tepary bean in 1987 and 1988.

Year	Source	df	Seed Yield (kg ha ⁻¹) (10 ⁶ pods ha ⁻¹)	Pod Yield (10 ⁶ pods ha ⁻¹)	Seed Number (seeds pod ⁻¹)	Seed Weight (g seed ⁻¹)
1987	Water (W)	1	**	**	ns	*
	Block	2	ns	ns	ns	ns
	Error a	2	ns	ns	ns	ns
	Nitrogen (N)	1	ns	ns	ns	ns
	W x N	1	ns	ns	ns	ns
1988	Water (W)	1	*	*	ns	ns
	Block	2	ns	ns	ns	ns
	Error a	2	ns	*	ns	ns
	Competition (C)	1	*	*	ns	ns
	W x C	1	ns	*	ns	ns

ns not significant

* p < 0.05

** p < 0.001

Figure 4. Total shoot biomass of tepary bean in response to water and competition treatments in 1988. Planting date was 1 July.

Table 4. Analysis of variance results for total shoot biomass of tepary bean in 1988.

Source	df	Harvest Date			
		30 DAP	59 DAP	88 DAP	125 DAP
Water (W)	1	ns	ns	*	ns
Block	2	ns	ns	ns	ns
Error a	2	ns	ns	ns	ns
Competition (C)	1	ns	*	*	*
W x C	1	ns	ns	ns	ns

ns not significant

* $p < 0.05$

** $p < 0.001$

conditions (Tables 2,3). Pod yields for rainfed sole crop and intercrop tepary bean were 33% of those for the respective irrigated treatments (Tables 2,3). Seed numbers and mean seed weights remained unaffected by irrigation treatment (Tables 2,3).

Intercrop competition from the panicgrass reduced the total shoot biomass of tepary bean in 1988 at the second, third and final harvests (Fig. 4, Table 4). Under irrigated conditions, total shoot biomass of intercrop tepary bean was 65% of that of sole crop tepary bean at the third harvest (88 DAP) (Fig. 4). For the same harvest, total shoot biomass of rainfed intercrop tepary bean was 61% of that of rainfed sole crop tepary bean.

The presence of an intercrop competitor also reduced yields. Under irrigated conditions, total seed yield of intercrop tepary bean was 64% of that of sole crop tepary bean (Tables 2,3). Under rainfed conditions, total seed yield of intercrop tepary bean was 63% of that of sole crop tepary bean (Tables 2,3). Pod yields under both rainfed and irrigated conditions were reduced by competition while seed numbers and mean seed weights remained unaffected (Tables 2,3). There was no significant water x competition interaction for total shoot biomass (Table 4), yield or yield components, except pod yield (Tables 2,3).

DISCUSSION

Growth responses to limited water resources vary with plant growth stage as well as with the duration and intensity of water deficits (Begg and Turner, 1976; Bradford and Hsiao, 1982). The sensitivity of various

physiological processes to water deficits varies, although there is general agreement that cell division and enlargement are among the first processes to be affected (Begg and Turner, 1976; Bradford and Hsiao; 1982). Reductions in cell growth translate directly into diminished leaf areas, in turn reducing total plant photosynthetic capacity and translocation of photosynthetic assimilates (Begg and Turner, 1976; Boyer, 1976).

Water deficits reduced growth and yield of tepary bean in both the 1987 and 1988 experiments. In 1987, total shoot biomass (at the final harvest) and seed yield of rainfed tepary bean were 75% and 96% lower, respectively, than those of irrigated tepary bean. In 1988, total shoot biomass (at the third harvest) of rainfed sole crop and intercrop tepary bean was 36% and 40% lower, respectively, than that of irrigated sole crop and intercrop tepary bean. Total seed yields of rainfed treatments were 69% lower than those of irrigated treatments for both sole crop and intercrop tepary bean.

The more frequent rainfall during the 1988 growing season likely contributed to the smaller total shoot biomass differences between rainfed and irrigated treatments in 1988 compared to 1987. Higher tepary bean plant densities in 1987 may also have contributed to larger differences in total shoot biomass between the irrigated and rainfed treatments for that year.

Reductions in reproductive yield depend on the duration, intensity and timing of water deficits, as well as the sensitivity to stress of

rapidly developing plant tissue (Begg and Turner, 1976). In the 1987 experiment, water became limiting early in the growing season and remained limiting through the reproductive stage and final harvest. Reproductive yield may have been reduced not only by drought during the reproductive stage but also by decreases in total leaf area as a result of prolonged water deficits during vegetative growth (Turk et al., 1980). In contrast, more abundant and frequent rainfall during the 1988 growing season may have provided relief from water deficits during critical stages of vegetative and reproductive ontogeny.

Lloyd (1980) suggests that there are several sequential stages during a single reproductive season at which investments of resources to reproductive units may be made and that these stages represent temporal opportunities at which expenditures may be matched to available resources. The first stage at which control of maternal resources may occur is the number of flowers initiated and which reach anthesis. Water deficits experienced prior to or during anthesis could be expected to reduce final yields via reduced numbers of fruits set. Pod yields of tepary bean in the rainfed treatments were significantly lower than in the irrigated treatments in both 1987 and 1988.

Other mechanisms by which assimilates are allocated under resource limited conditions include restricting ovary development or seed size (Lloyd, 1980). Seed number of tepary bean was not reduced by water limitations in 1987 or 1988. Mean seed weight of tepary bean was significantly lower in the rainfed treatments in 1987 but not in 1988.

The differences in seed number and mean seed weight between years (Table 3) were likely due to differences between tepary bean lines used in the respective years.

Nitrogen had no effect on the total shoot biomass or reproductive yield of tepary bean in 1987. For legumes, added inorganic N, above a certain threshold level that often varies with species, may have little or no positive effect on plant dry matter yields (Ofori and Stern, 1986), and may actually decrease plant dry weight (Trang and Giddens, 1980). Wagmare and Singh (1984) suggest that other factors, such as soil fertility levels, plant densities, and environmental and plant physiological conditions, may be important in terms of the effect of nitrogen on plant yields.

Visual observation of root core samples taken from high and low nitrogen plots indicated that little or no nodulation occurred in 1987. High soil temperatures have been found to adversely affect establishment of Rhizobium spp. and could have been responsible for the lack of nodulation in 1987, although the concentration of applied inoculum or the Rhizobium strain may also have had an influence (Karanja and Wood, 1988).

Yield advantages in legume/cereal intercrops can theoretically be improved by minimizing competition between component crops for growth-limiting resources (Ofori and Stern, 1987). The intensity of competition between component crops, when arranged in defined rows, is determined by relative growth rates, duration of growth, and root

interactions (Ofori and Stern, 1987). The cereal component is generally the dominant component since cereals often exhibit higher growth rates, greater plant heights and more extensive root systems than legumes. Under intercropping, legume yields have consistently been shown to decline, suggesting that it is the legume component of intercrops that is competitively suppressed (Ofori and Stern, 1987).

The presence of Sonoran panicgrass as a competitor reduced growth and yield of intercrop tepary bean relative to sole crop tepary bean under both irrigated and rainfed conditions. Under irrigated conditions, total shoot biomass (at the third harvest) and seed yield of intercrop tepary bean were 35% and 36% lower, respectively, than those of sole crop tepary bean. Under rainfed conditions, total shoot biomass (at the third harvest) and seed yield of intercrop tepary bean were 39% and 37% lower, respectively, than those of sole crop tepary bean.

Competition for light may have been important in the tepary bean/panicgrass intercrop since panicgrass is an upright cereal that stands approximately 1 m tall at maturity, while tepary bean is a small bush that may be induced to vine under light limiting conditions. In an intercrop of groundnut/pearl millet, Marshall and Willey (1983) found that the amount of light intercepted by the intercrop groundnut was 27% less than the sole crop groundnut.

The competitive interactions of component crops under intercropping depend on plant densities (Natarajan and Willey, 1980), times to maturity (Willey, 1979) and row spatial arrangements (Rao and

Willey, 1983). Not only did the tepary bean and panicgrass mature at approximately the same time, but the panicgrass was "added" to the within-row density of the tepary bean sole crop, resulting in a total intercrop density over twice that of the sole crop. Thus, competition for resources was maximized in the tepary bean/panicgrass intercrop in relation to the tepary bean sole crop under both rainfed and irrigated conditions.

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