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BIOMASS AND NITROGEN TRAITS OF SUMMER PIGEON PEAS AND WINTER WHEAT GROWN FOR THREE ROTATIONS IN CONTAINERS

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ABSTRACT

Pigeon pea [*Cajanus cajan* (L.) Millsp.] cultivars, 'Georgia-1' and 'ICPL-87', were grown without inoculation and with *Bradyrhizobium* inoculation (multistrain, TAL 1127, or TAL 1132) to evaluate legume dry weight (DW) and nitrogen (N) content, soil mineral N, and subsequent wheat (*Triticum aestivum* L.) productivity. Pigeon peas were grown during summer and 'TAM 101' wheat was grown during winter, along with summer fallow controls fertilized with 0, 45, and 90 kg N ha^{-1}, in 36-cm diam. 20-L pots from 1992 to 1995. Representative pigeon peas were harvested in the fall and remaining plants were incorporated into the soil. Wheat was planted and soil cores were collected at 35 to 48 d after pigeon pea harvest. Wheat was harvested the following spring. Factors affecting DW and N content of both

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crops included length of growing season, environmental variation, and contribution of residual N. Among pigeon pea cultivars, Georgia-1 occasionally demonstrated higher DW and N content compared with ICPL-87. Estimation of N provided by pigeon pea to the last wheat crop in the third sequence of yearly rotations was 30 kg N ha^{-1}. Pigeon pea treatments demonstrating highest DW, N content, and contribution to soil N generally produced winter wheat with higher yield and N content compared with other treatments. While yield and N content of winter wheat fertilized at 90 kg N ha^{-1} either decreased or stayed the same from 1993 to 1995, these same measurements in wheat following pigeon peas demonstrated a 3- to 4-fold increase over the same time period and warrant further research in field rotation systems of the southern Great Plains.

INTRODUCTION

Pigeon pea [*Cajanus cajan* (L.) Millsp.] can persist during hot and dry periods (1) such as those encountered after winter wheat (*Triticum aestivum* L.) harvest in the southern Great Plains. Therefore, pigeon pea has been promoted as a crop that can provide additional grain (2) and forage (3) during summer months in stress prone environments. Pigeon pea can also help minimize soil erosion, suppress weed proliferation during summer months (4), and fix atmospheric N_2 for use by subsequent crops (5). However, the full potential for seasonal forage production, N-fixation, and subsequent benefit to winter wheat in the southern Great Plains is unknown.

In India, pigeon pea has been reported to fix 58 to 88 kg N ha^{-1} in sole crop systems (6) and may provide 30 to 50 kg N ha^{-1} of residual N in crop rotations with maize [*Zea mays* (L.)] (7), sorghum [*Sorghum bicolor* (L.) Moench], or wheat (5). It is not known whether similar N returns are possible in cropping systems of the U.S. southern Great Plains.

In other parts of the world, research has shown that the use of specific cultivars and *(Brady)Rhizobium* strains may optimize yield (8,9) and N_2-fixation (10,11) of pigeon pea. One of the first steps in evaluating the benefits of pigeon pea, therefore, is to determine whether or not similar variation exists in the performance of cultivars and inoculum strains fit for this region. In this investigation, pigeon peas were grown in the summer, followed by winter wheat, to simulate a pigeon pea–wheat cropping system in Oklahoma. Cultivar and inoculum strain combinations were evaluated to determine the effect(s) of environment (as influenced by year to year variation), cultivar, *Bradyrhizobium* strain, and interactions thereof, on biomass components and N content of pigeon pea, as well as available soil mineral N after harvest. Biomass and N accumulation of winter wheat were measured to assess potential benefits of a pigeon pea rotation.

MATERIALS AND METHODS

Experiments were conducted from 1992 to 1995 outside at the University of Central Oklahoma in Edmond, Oklahoma. Pigeon peas were grown during summer and harvested in late summer or early fall of 1992, 1993, and 1994. Winter wheat was planted following pigeon peas and harvested in spring of 1993, 1994, and 1995. All plants were grown in 36-cm diam. clay pots with free drainage. The pots contained about 20 L of a 1:1 mixture of potting soil [Fafard Soil Mix No. 2, Fafard Soil Company, Quebec, Canada (12)] and Dale silt loam (fine-silty, mixed, thermic Pachic Haplustoll) with a pH of 6.6. About 3 L of the same soil mix was added to each pot after wheat harvest to compensate for losses from samples of soil and legume roots taken during the previous year.

An early-maturing pigeon pea cultivar, 'ICPL-87,' and a mid-maturing pigeon pea cultivar, 'Georgia-1,' were obtained from the International Crop Research Institute for Semi-Arid Tropics at Patancheru, India, and the Horticulture Department at the University of Georgia, Tifton, GA, respectively. 'TAM 101' winter wheat was obtained from a local seed distributor in El Reno, OK.

Two distinct strains of pigeon pea *Bradyrhizobium*, TAL 1127 (IHP 38) and TAL 1132 (IHP 195), recommended by the Nitrogen Fixation by Tropical Agricultural Legumes Project, University of Hawaii, Paia, HI, were used. In addition, a commercial multistrain inoculum (Nitragen; LiphaTech, Inc., Milwaukee, WI) and a control treatment without inoculum were used. Seed was inoculated by mixing peat inoculum (10 mg seed^{-1}; 10^9 cells g^{-1} peat) with legume seeds coated with molasses. Seeds treated with only molasses served as controls.

A total of eight treatment combinations, consisting of two cultivars and four inoculum treatments of each cultivar, were evaluated for the summer legume part of this experiment. Three additional pots per replicate were used as fallow treatments of the winter wheat part of the experiment and received 0, 45, or 90 kg N ha^{-1} as urea each year about 4 wk after planting the wheat. All pots were arranged in a randomized complete block design with four replications.

Exactly 10 inoculated or uninoculated pigeon pea seeds were planted per legume pot on 30 July 1992, 11 July 1993, and 16 June 1994. Soil was fertilized each year with 40 kg P ha^{-1} as treble superphosphate. Plants were watered at least every 2 d throughout the growing season. Temperature and rainfall records were obtained from an Oklahoma Climatological Station

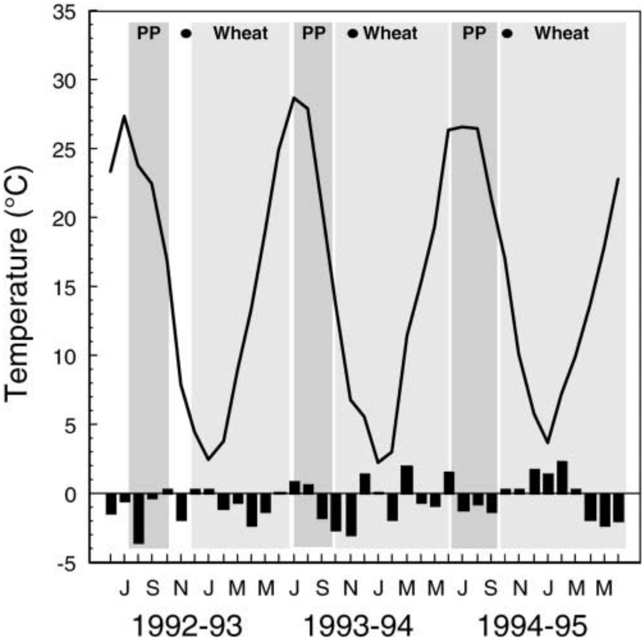

Figure 1. Average monthly temperatures (solid line) and departures from the normal (vertical solid bars) for the Oklahoma City weather station located 37 km from the experimental site. Vertical shaded bars represent growth duration of the pigeon pea (PP) and winter wheat (Wheat) crop rotations, and filled circles indicate sampling dates for soil cores.

located 37 km away (Fig. 1). Seedlings were thinned to five plants per pot within 2 wk of emergence. One pigeon pea plant (roots and shoots) was removed on three successive dates, the last of which was used to collect data for this investigation. Because year-to-year variation affected time of planting and harvest, the ages of pigeon peas used for analyses were 84 (22 October 1992), 88 (7 October 1993), and 98 (22 September 1994) d after planting (DAP). Whole plants were removed by excavating roots and soil in a 10-cm core centered on the stem to the complete depth of the pot. Leaves, stems, and pods were separated from shoots and dried for 96 h at 40°C to obtain dry weight (DW) and to prepare tissues for N determinations.

After harvest, existing pods were removed from the remaining two plants and above ground vegetative growth was chopped and incorporated into the top 10 cm of soil. Approximately 50 wheat seeds were then planted into each pot on 12 December 1992, 12 October 1993, and 1 October 1994. All pots were watered to ensure hydration of seeds and incorporation of fertilizer in appropriate treatments. All treatments were thinned to 25 wheat seedlings per pot after germination.

Two soil cores (2.5-cm diam., 30-cm deep) were collected from each pot within 4 wk after wheat planting, which was at 39, 48, and 35 d after harvesting pigeon peas in 1992, 1993, and 1994, respectively. Wheat plants were thereafter watered as needed until harvest at 210 (4 July 1993), 229 (7 June 1994), and 255 (22 June 1995) DAP. Wheat plants were cut at 5.0 cm above soil surface and the stubble was incorporated into the soil with a hand trowel to a depth of 10 cm before planting legume seed.

Dried plant parts, ground to pass through a 1-mm screen of an Udy Cyclone Mill (Udy, Ft. Collins, CO), and composite soil core samples from each pot were used for N analyses. Total N concentration of plant tissue was determined by combustion analysis using a CHN-1000 analyzer (LECO Co., St. Joseph, MO). Soil samples were frozen immediately at −15°C and within 3 wk analyzed for mineral N after thawing at 23°C and extracting the thawed samples within 2 h using 2 *M* KCl. Micro-Kjeldahl steam distillation was used to determine NH_4^+-N and NO_3^--N (13).

Analyses of variance (ANOVA) were used to determine differences in traits as affected by year, cultivar, inoculum, and interactions thereof, as well as fallow treatments. Statistical analyses were conducted separately for pigeon pea and wheat data because the wheat experiment included analyses of additional treatments following a summer fallow period. In both cases, SAS PROC GLM (14) was used to process data sets containing missing values. When year effects were significant, the effects of treatments on traits were evaluated for each year. Least significant differences were evaluated at the 0.05 level of probability.

RESULTS

Pigeon pea DW components and N content were significantly affected by year (Table 1). Cultivar significantly affected stem and total DW as well as stem N content, and the year × cultivar interaction reflected significant variation in stem DW and N. Inoculum and inoculum interaction effects for all biomass and N content traits were not significant. Because ANOVAs revealed significant variation in DW and N contents of several plant parts as affected by year and cultivar, tables were constructed to evaluate differences between cultivars for each year.

Pigeon pea plants were harvested at 84, 88, and 98 DAP in 1992, 1993, and 1994, respectively. Dry weight components increased each year (Table 2); the increase from 1992 to 1993 was 2.7-fold and from 1993 to 1994, the increase was 2.9-fold. The contribution of leaf DW to total shoot DW was 47% in 1992, but as total shoot DW increased in 1993 and 1994, the contribution of leaf DW to total shoot DW decreased to about 40%. Pod DW was determined for both cultivars in 1994 but not in 1992 or 1993 because few, if any, pods were formed on the first two legume crops. In 1994, pod DW was not significantly different between

Table 1. Significance of Mean Squares for Shoot Biomass Dry Weight and N Content of Plant Parts of ‘Georgia-1’ and ‘ICPL-87’ Pigeon Pea Cultivars Using Different *Bradyrhizobium* Strains

		Biomass Dry Weight (g plant^{-1})				N Content (mg plant^{-1})			
Source	df	Leaf	Stem	Pod	Total	Leaf	Stem	Pod	Total
Year (Y)	2	**	**	—	**	**	**	—	**
Replicate	3	NS	NS	—	NS	NS	NS	—	NS
Error a	6								
Cultivar (C)	1	NS	**	NS	*	NS	**	NS	NS
Y × C	2	NS	**	—	NS	NS	**	—	NS
Error b	9								
Inoculum (I)	3	NS	NS	NS	NS	NS	NS	NS	NS
C × I	3	NS	NS	NS	NS	NS	NS	NS	NS
Y × I	6	NS	NS	—	NS	NS	NS	—	NS
Y × C × I	6	NS	NS	—	NS	NS	NS	—	NS
Residual	54								

NS, *, ** Not significant and significant at the 0.05 and 0.01 probability levels, respectively.

Table 2. Biomass Dry Weights of 'Georgia-1' and 'ICPL-87' Pigeon Pea Cultivars Harvested at 84, 88, and 98 d After Planting in 1992, 1993, and 1994, Respectively

Cultivar	Leaf ($g\,plant^{-1}$)	Stem ($g\,plant^{-1}$)	Pod ($g\,plant^{-1}$)	Total ($g\,plant^{-1}$)
1992[a]				
Georgia-1	2.26	2.52	—	4.78
ICPL-87	2.19	2.42	—	4.61
Mean	2.22	2.47	—	4.69
LSD (0.05)	NS	NS	—	NS
1993				
Georgia-1	5.71	7.85	—	13.6
ICPL-87	4.59	6.77	—	11.4
Mean	5.15	7.31	—	12.5
LSD(0.05)	NS	NS	—	NS
1994				
Georgia-1	14.9	23.5	3.40	41.8
ICPL-87	12.8	15.9	1.96	30.7
Mean	13.9	19.7	2.73	36.3
LSD(0.05)	NS	6.7	NS	NS
All years combined				
Georgia-1	7.62	11.3	—	18.9
ICPL-87	6.53	8.36	—	14.8
Mean	7.08	9.83	—	16.9
LSD(0.05)	NS	1.89	—	3.5

NS Not significant at the 0.05 probability level.

[a] Least significant differences across years are 2.57, 2.91, and 6.17 for leaf, stem, and total shoot dry weight, respectively.

pigeon pea cultivars and contributed 7.2% of the total shoot DW. Dry weight values were always numerically greater for Georgia-1 compared with ICPL-87, but cultivar differences in dry weight were seldom significant. Georgia-1 stem DW was greater than that of ICPL-87 in 1994 and averaged across years. Total DW of Georgia-1 was also greater than ICPL-87 when averaged across years.

Nitrogen content of plant parts increased each year (Table 3), 3.2-fold from 1992 to 1993 and 2.5-fold from 1993 to 1994. Leaf N content was greater than stem N content because leaf N concentration (26.7 to 33.8 $mg\,g^{-1}$; data not shown) was more than stem N concentration (6.6 to 13.6 $mg\,g^{-1}$; data not shown) throughout the experiment. Even though the N concentrations of pods (26.4 to 27.5 $mg\,g^{-1}$; data not shown) in 1994 was equal or slightly less than that of leaves, the amount of N contributed by pods was less than that of leaves or stems

Table 3. Amount of N in 'Georgia-1' and 'ICPL-87' Pigeon Pea Cultivars Harvested at 84, 88, and 98 d After Planting in 1992, 1993, and 1994, Respectively

Cultivar	Leaf (mg plant^{-1})	Stem (mg plant^{-1})	Pod (mg plant^{-1})	Total (mg plant^{-1})
1992[a]				
Georgia-1	62.7	25.6	—	88.3
ICPL-87	58.4	23.0	—	81.4
Mean	60.6	24.3	—	84.9
LSD(0.05)	NS	NS	—	NS
1993				
Georgia-1	184	109	—	293
ICPL-87	155	90.7	—	246
Mean	170	99.7	—	270
LSD(0.05)	NS	NS	—	NS
1994				
Georgia-1	467	163	95.0	725
ICPL-87	432	106	53.1	591
Mean	449	134	75.6	659
LSD(0.05)	NS	NS	NS	NS
All years combined				
Georgia-1	238	99.1	—	369
ICPL-87	215	73.2	—	306
Mean	227	86.2	—	338
LSD(0.05)	NS	19.4	—	NS

NS Not significant at the 0.05 probability level.

[a] Least significant differences across years are 87.1, 45.5, and 142 for leaf, stem, and total shoot N, respectively.

because of low pod weights (Table 2). The amounts of N in Georgia-1 plant parts were always numerically greater than that of ICPL-87, but were significant only in stems when averaged across years.

Year, treatment, and the year × treatment interaction effects were significant for soil mineral N as well as winter wheat yield and N content (Table 4). Most of the year-to-year differences for these traits could be attributed to differences between summer legume and summer fallow rotations. In 1992, soil mineral N was unaffected by treatment and averaged only 3.88 mg kg^{-1} (Table 5). As in 1992, differences in soil mineral N among the summer fallow treatments were not significant in 1993 and 1994. The concentration of soil mineral N in the fallow treatments, however, was less than some of the pigeon pea treatments, particularly those that were inoculated with TAL 1127 and TAL 1132 *Bradyrhizobium* strains.

Table 4. Significance of Mean Squares for Soil Total Mineral N ($NH_4^+ + NO_3^-$) Measured Within 4 Weeks After Planting Winter Wheat and Shoot Dry Weight and N Content of Plant Parts of Winter Wheat at Harvest Following Summer Pigeon Pea or Fallow Treatments

			Biomass Dry Weight			N Content		
Source	df	Soil Total Mineral N	Stem ($g\,pot^{-1}$)	Head ($g\,pot^{-1}$)	Total ($g\,pot^{-1}$)	Stem ($mg\,pot^{-1}$)	Head ($mg\,pot^{-1}$)	Total ($mg\,pot^{-1}$)
Year (Y)	2	*	**	**	**	**	**	**
Replicate	3	NS	NS	NS	NS	NS	NS	NS
Error a	6							
Treatment (T)	10	**	**	**	**	**	**	**
Y*T	20	**	**	**	**	**	**	**
Residual	88							

NS, *, ** Not significant at the 0.05 probability level and significant at the 0.05, and 0.01 probability level., respectively.

Table 5. Soil Total Mineral N ($NH_4^+ + NO_3^-$) Measured Within 4 Weeks After Planting Winter Wheat and Before Additions of Fertilizer N to Fallow Treatments (Shoot Residues of Legumes Were Incorporated in the Top 10 cm of Soil 39, 48, and 35 d Before Collecting Soil Samples in 1992, 1993, and 1994, Respectively)

	Soil Total Mineral N [mg($NH_4^+ + NO_3^-$)-N kg^{-1}]		
Treatment	1992	1993	1994
Wheat after Georgia-1			
Control	3.58	5.33	12.3
Multistrain	2.92	5.11	14.6
TAL 1127	3.90	7.43	21.3
TAL 1132	4.17	7.69	18.4
Wheat after ICPL-87			
Control	4.16	5.10	14.2
Multistrain	4.41	4.54	16.9
TAL 1127	4.20	7.05	12.3
TAL 1132	4.63	6.93	16.5
Wheat after fallow			
0 kg N ha^{-1}	3.76	2.80	9.93
45 kg N ha^{-1}	3.80	3.97	10.5
90 kg N ha^{-1}	3.18	4.87	8.44
LSD (0.05)	NS	2.81	4.96

After the first year, biomass and N content traits of the legume–wheat rotation were usually greater than even the fallow treatment fertilized with 90 kg N ha^{-1} (Tables 6 and 7). Productivity differences between legume and fallow rotations were greatest for the third cycle. Shoot biomass and N content of wheat grown after legumes increased 3.4-fold from 1993 to 1995. In contrast, from 1993 to 1995 shoot biomass decreased 2.9-fold and shoot N content decreased 1.7-fold in fallow-wheat rotation treatments. For the first cycle of rotations in 1993, total shoot biomass of wheat grown after summer fallow and fertilized with 90 kg N ha^{-1} was greater than all other treatments except Georgia-1 inoculated with TAL 1127 and TAL 1132 (Table 6). Differences in total shoot N accumulation among treatments, however, were not significant the first year (Table 7). In 1994 and 1995, differences in biomass and N content traits of wheat among the legume-inoculum treatment combinations were almost always not significant, but biomass and N content traits of wheat plants grown after legumes were almost always greater than those of the summer fallow treatments. During the last of the three cycles (1995), wheat plants of the 0 kg N ha^{-1} fallow treatment emerged but within the first 6 wk they were chlorotic and stunted and eventually died following a series of hard freezes that occurred 8 wk after

Table 6. Biomass Dry Weight of 'TAM 101' Winter Wheat After Summer Pigeon Pea or Fallow Treatments and Harvested at 210, 229, and 255 d After Planting in 1993, 1994, and 1995, Respectively

	1993			1994			1995		
Treatment	Stem (g pot^{-1})	Head (g pot^{-1})	Total (g pot^{-1})	Stem (g pot^{-1})	Head (g pot^{-1})	Total (g pot^{-1})	Stem (g pot^{-1})	Head (g pot^{-1})	Total (g pot^{-1})
Wheat after Georgia-1									
Control	1.44	3.57	5.01	3.03	6.97	10.0	8.70	10.7	19.4
Multistrain	1.82	4.48	6.30	3.75	7.96	11.7	9.56	11.2	20.8
TAL 1127	2.52	5.98	8.50	3.90	8.78	12.7	8.61	9.41	18.0
TAL 1132	2.39	6.16	8.55	3.76	8.05	11.8	11.1	12.1	23.2
Wheat after ICPL-87									
Control	1.23	3.08	4.31	3.12	7.22	10.4	8.85	11.1	20.0
Multistrain	1.58	3.57	5.15	3.95	9.34	13.3	8.93	10.1	19.0
TAL 1127	1.95	4.48	6.43	3.81	8.37	12.2	8.31	12.0	20.3
TAL 1132	1.32	2.81	4.13	3.11	6.90	10.0	9.94	11.3	21.2
Wheat after fallow									
0 kg N ha^{-1}	2.47	3.59	6.06	2.39	3.93	6.32	0.00	0.00	0.00
45 kg N ha^{-1}	2.76	3.42	6.18	2.76	4.60	7.36	1.83	1.97	3.80
90 kg N ha^{-1}	4.89	5.43	10.3	3.17	4.53	7.70	2.10	1.73	3.83
LSD (0.05)	NS	NS	NS	NS	3.51	2.57	2.41	3.25	5.29

Table 7. N Content of ‘TAM 101’ Winter Wheat After Summer Pigeon Pea or Fallow Treatments and Harvested at 210, 229, and 255 d After Planting in 1993, 1994, and 1995, Respectively

	1993			1994			1995 (mg pot^{-1})		
Treatment	Stem (mg pot^{-1})	Head (mg pot^{-1})	Total (mg pot^{-1})	Stem (mg pot^{-1})	Head (mg pot^{-1})	Total (mg pot^{-1})	Stem (mg pot^{-1})	Head (mg pot^{-1})	Total (mg pot^{-1})
Wheat after Georgia-1									
Control	5.27	58.5	63.8	18.3	129	147	67.4	221	288
Multistrain	5.32	59.5	64.8	17.7	135	153	66.4	236	302
TAL 1127	8.19	81.0	89.2	17.3	124	141	68.9	198	267
TAL 1132	8.36	85.8	94.2	17.9	131	149	84.8	251	335
Wheat after ICPL-87									
Control	4.74	47.2	51.9	15.0	118	133	64.3	224	288
Multistrain	4.96	51.4	56.4	17.3	154	171	66.1	210	276
TAL 1127	7.00	60.7	67.7	15.3	134	149	67.4	277	344
TAL 1132	4.84	43.4	48.2	15.9	116	132	76.8	241	318
Wheat after fallow									
0 kg N ha^{-1}	12.6	53.1	65.7	10.9	62.3	73.2	0.00	0.00	0.00
45 kg N ha^{-1}	12.5	42.5	55.0	11.3	70.6	81.9	20.2	44.2	64.4
90 kg N ha^{-1}	21.5	67.0	88.5	16.6	70.3	86.9	19.9	37.0	56.9
LSD (0.05)	NS	NS	NS	NS	42.5	46.0	17.8	65.0	73.4

planting. During this cycle, wheat after fallow that was fertilized with 45 or 90 kg N ha^{-1} survived but showed signs of N stress and was less tolerant of the cold weather than wheat grown after the legumes. Within each year, treatment effects on biomass and N content of wheat stem and head parts followed the same trends as the total shoot biomass and N traits.

DISCUSSION

Pigeon pea productivity failed to respond to inoculation. Both shoot biomass and N content of uninoculated plants were equivalent to those inoculated with a multistrain mixture or TAL1127 and TAL 1132 pigeon pea specific *Bradyrhizobium.* These results are consistent with a nearly complete lack of significant inoculum effects on nodule number, mass, and nitrogenase activity throughout growth as was previously reported (15).

Productivity and N accumulation of both cultivars increased ($P \leq 0.05$) each year. The yearly increases were partially the consequence of differences in growing degree days (GDD) among years. Duration of crop growth increased from 84 to 88 to 98 d between 1992 and 1994, and the corresponding GDD increased from 748 to 1098 to1280. Accumulated GDD in 1992 was 15% less than normal, while in 1993 and 1994, accumulated GDD was no more than 4% less than normal and is reflected by average monthly temperature deviations from normals during the pigeon pea growth intervals (Figure 1). Averaged over all years, total biomass of Georgia-1 pigeon pea was 27% greater than ICPL-87, primarily due to the greater stem biomass of Georgia-1 (Table 2). It is generally accepted in this study and others (16) that the yield and nitrogen fixing capacity of pigeon pea are affected by climate, length of season, and duration of the cultivar (10,17).

At the end of each pigeon pea growth interval, the leaf and stem tissues of two plants (equivalent to 196,000 plants ha^{-1}) were returned to the soil to provide N for the following winter wheat. The average amount of N incorporated was about 17, 53, and 114 kg ha^{-1}, in 1992, 1993, and 1994, respectively. These amounts, particularly in 1992 and 1993, are less than one would anticipate for a field grown crop. Typically, ‘Georgia-2’ pigeon pea, a slightly earlier maturing cultivar than Georgia-1, when grown at our location produces leaf plus stem tissue with about 188 kg N ha^{-1} at 85 DAP and a density of 111,000 plants ha^{-1} (Rao, personal communication, 1999). Measurements of total soil mineral N at 5 to 7 wk after harvesting the legumes followed the same trend as yearly legume N content. Hence, total soil mineral N increased each year from 3.9 to 6.1 to 14.0 mg kg^{-1} between 1992 and 1994 (Table 5, average of legume treatments each year). Because the amount of N returned by the legumes in 1992 was negligible, the mineral N levels were similar for both summer legume and fallow treatments. As the incorporation of legume N increased in 1993 and 1994, mineralization of legume tissues often led to an increase in mineral N compared to fallow treatments (Table 5).

Recent studies (18) demonstrate that wheat yield can vary as a result of rotation with grain legumes having different N_2 fixing capacities. Incorporation of the first crop of summer legumes into the soil elicited neither a beneficial nor a harmful response for the growth and N accumulation of the following winter wheat crop. For the first wheat crop, nearly all pigeon pea and inoculum combinations gave wheat total biomass yields equivalent to fallow rotation fertilized with 45 kg N ha^{-1} (Table 5), while differences in wheat total N accumulation were not significant among legume and fallow treatment combinations (Table 6). A clear benefit of legumes to wheat, however, was evident for the last two cycles of the rotation. Both an increase in legume productivity (and N accumulation) and a decrease in wheat productivity in the fallow rotation account for the legume rotation benefits of wheat harvested in 1994 and 1995.

Inputs of N, whether derived from fertilizer or legumes, were always substantially greater than the N recovered by winter wheat. Conversion of mg N pot^{-1} accumulated by wheat following pigeon peas (Table 7) revealed averages of 6.6, 14, and 30 kg N ha^{-1} in 1993, 1994, and 1995, respectively, even though N added by legumes averaged 17, 53, and 114 kg N ha^{-1}. This same conversion for fertilizer N revealed only 8.7, 8.5, and 5.6 kg N ha^{-1} was accumulated by wheat following application of 90 kg N ha^{-1} in 1993, 1994, and 1995, respectively. Thus, the range of N derived from pigeon peas varied from 23 to 38% and only 6 to 10% for the fallow treatment fertilized with 90 kg N ha^{-1}. Mineralization of legume N over an extended period, in contrast to the soluble source of fertilizer N may account for greater apparent recovery of N added with the legume source.

CONCLUSIONS

Even though legume productivity was not favorably enhanced with the use of pigeon pea specific *Bradyrhizobium*, the Georgia-1 pigeon pea was more productive than ICPL-87 and in a few cases, wheat biomass among the legume treatments was affected by the choice of inoculum treatment. Substitution of pigeon pea for summer fallow and chemical N fertilizer enhanced the productivity of winter wheat, especially the last year of the rotation. The favorable response of wheat following pigeon peas warrants development of field research into summer legume and winter wheat rotations for the southern Great Plains.

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REFERENCES

1. Saxena, N.P. Screening for Adaptation to Drought: Case Studies with Chickpea and Pigeonpea. *ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). Adaptation of Chickpea and Pigeonpea to Abiotic Stress*; Proceedings Consultants' Workshop, Dec 19–21, 1984, Patancheru, A.P.: India, 1987; 63–76.
2. Singh, L. Production Aspects of Pigeonpea and Future Prospects. *ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). Uses of Tropical Grain Legumes*; Proceedings Consultants Meeting, March 27–30, 1989, Patancheru, A.P.: India, 1991; 121–127.
3. Whiteman, P.C.; Norton, B.W. Alternative Uses for Pigeonpea. *ICRISAT (International Crops Research Institute for the Semi-Arid Tropics)*; Proceedings of International Workshop on Pigeonpeas, Dec 15–19, 1980, Patancheru, A.P.: India, 1981; Vol. 1, 365–377.
4. Nene, Y.L.; Sheila, V.K. Pigeonpea: Geography and Importance. In *The Pigeonpea*; Nene, Y.L., Hall, S.D., Sheila, V.K., Eds.; CAB International: Tucson, AZ, 1990; 1–14.
5. Kumar Rao, J.V.D.K. Pigeonpea: Nitrogen Fixation. In *The Pigeonpea*; Nene, Y.L., Hall, S.D., Sheila, V.K., Eds.; CAB International: Tucson, AZ, 1990; 233–256.
6. Kumar Rao, J.V.D.K.; Thompson, J.A.; Sastry, P.V.S.S.; Giller, K.E.; Day, J.M. Measurement of N_2-Fixation in Field-Grown Pigeonpea (*Cajanus cajan* (L.) Millsp.) Using ^{15}N-Labelled Fertilizer. Plant Soil **1987**, *101* (1), 107–113.
7. Kumar Rao, J.V.D.K.; Dart, P.J.; Sastry, P.V.S.S. Residual Effect of Pigeon Pea (*Cajanus cajan*) on Yield and Nitrogen Response of Maize. Expl. Agric. **1983**, *19* (2), 131–141.
8. Lopez, F.B.; Johansen, C.; Chauhan, Y.S. Limitations to Seed Yield in Short-Duration Pigeonpea Under Water Stress. Field Crops Res. **1994**, *36* (2), 95–102.
9. Chauhan, Y.S.; Johansen, C.; Saxena, K.B. Physiological Basis of Yield Variations in Short-Duration Pigeonpea Grown in Different Environments of the Semi-Arid Tropics. J. Agron. Crop Sci. **1995**, *174* (3), 163–171.
10. Quilt, P.; Dalal, R.C. Effect of Soil Mineral N Levels and Inoculation on Nodulation, Nitrogenase Activity, and Grain Yield of Pigeon Pea. Agron. J. **1979**, *71* (3), 450–452.

11. La Favre, J.S.; Focht, D.D. Comparison of N_2 Fixation and Yields in *Cajanus cajan* Between Hydrogenase-Positive and Hydrogenase-Negative Rhizobia by *in situ* Acetylene Reduction Assays and Direct ^{15}N Partitioning. Plant Physiol. **1983**, *72* (4), 971–977.
12. Reference to a Trade or Company Name Is for Specific Information Only and Does Not Imply Approval or Recommendation of the Company by the USDA or University of Central Oklahoma to the Exclusion of Others That may Be Suitable.
13. Bremner, J.M.; Keeney, D.R. Determination and Isotope-Ratio Analysis of Different Forms of Nitrogen in Soils. III. Exchangeable Ammonium, Nitrate, and Nitrite by Extraction–Distillation Methods. Soil Sci. Soc. Am. Proc. **1966**, *30*, 577–582.
14. SAS, *SAS User's Guide: Statistics*, 5th Ed.; SAS Institute: Cary, NC, 1985; 1290.
15. Bidlack, J.E.; Rao, S.C.; Demezas, D.H. Nodulation, Nitrogenase Activity, and Dry Weight of Chickpea and Pigeon Pea Cultivars Using Different Bradyrhizobium Strains. J. Plant Nutr. **2001**, *24* (3) in press.
16. Thompson, J.A.; Kumar Rao, J.D.V.K.; Dart, P.J. Measurement of Inoculation Response in Pigeonpea. *ICRISAT (International Crops Research Institute for the Semi-Arid Tropics)*; Proceedings of International Workshop on Pigeonpeas, Dec 15–19, 1980, Patancheru, A.P.: India, 1981; Vol. 1, 249–253.
17. Reddy, L.J. Pigeonpea: Morphology. In *The Pigeonpea*; Nene, Y.L., Hall, S.D., Sheila, V.K., Eds.; CAB International: Tucson, AZ, 1990; 47–87.
18. Badaruddin, M.; Meyer, D.W. Grain Legume Effects on Soil Nitrogen, Grain Yield, and Nitrogen Nutrition of Wheat. Crop Sci. **1994**, *34*, 1304–1309.