SARE Project LS93-053

Reprinted from *Agronomy Journal*
Vol. 87, No. 4

Yield and Yield Components of Spring-Sown White Lupin in the Southeastern USA

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ABSTRACT

Management studies must be conducted to realize the full potential of white lupin (*Lupinus albus* L.) as a grain crop for the southeastern USA. This experiment examined planting date, row spacing, and seeding rate effects on grain and biomass yield of spring-sown white lupin. In 1991 and 1992, field studies were conducted in northern Alabama on a Wynnville fine sandy loam (fine-loamy, siliceous, thermic Glossic Fragiudult), in central Alabama on a Hiwassee sandy loam (clayey, kaolinitic, thermic Typic Kanhapludult), and in southern Alabama on a Lucedale fine sandy loam (fine-loamy, siliceous, thermic Rhodic Paleudult). Treatments included three planting dates, three row spacings (17.5, 35, and 70 cm), three seeding rates (17.5, 35, and 52.5 seeds m^{-1}), and two cultivars (Primorsky and Ultra). Prevailing weather allowed only one planting date in northern Alabama in 1991 and 1992. In the second year of the study, only one and two plantings were successful in central and southern Alabama, respectively. Grain yields averaged 551 kg ha^{-1} in 1991 and 604 kg ha^{-1} in 1992. Grain and biomass yield was always highest in northern Alabama. Planting date affected grain and biomass yield the most in central and southern Alabama in 1991. Decreased row spacing increased grain yields as much as 10 kg ha^{-1} per unit decrease in spacing. Grain yields increased as much as 19 kg ha^{-1} for every unit increase in seeding rate. Principal component analysis of yield components created factors branch, seed mass, and mainstem, which accounted for 57, 23, and 14% of the original variance, respectively. Factors branch and mainstem were highly correlated ($r > 0.75$) with grain and biomass yield. Seed mass and mainstem were highly correlated with harvest index ($r > 0.65$). For the southeastern USA, high yields in spring-sown white lupin will require (i) early seeding, (ii) narrow row spacing, and (iii) high seeding rates.

ALABAMA AND THE SOUTHEASTERN USA have a climate that allows two cropping seasons per year. The choice of traditional winter crops is limited to wheat (*Triticum aestivum* L.), oat (*Avena sativa* L.), and rye (*Secale cereale* L.) as forages and wheat as a grain crop. Hectarage of winter wheat for grain has declined steadily due to decreasing profitability. White lupin has potential to fill this void (Reeves et al., 1991).

Based on vernalization requirements, lupin cultivars can be classified as spring, intermediate (semiwinter), or winter types. Spring types have lower vernalization requirements and lower cold tolerance, and they flower earlier than winter and intermediate types. Management studies have not been conducted with spring types in the southeastern USA and similar climates.

Putnam et al. (1993) found lower yields in spring-sown white lupin in Minnesota for extremely early planting dates compared with later plantings. Early planting dates of spring types in the United Kingdom produced lower yields per-plant and overall yield than later planting dates, due to the reduction in plant height and branches and the early maturity promoted by vernalization (Bradley, 1982). In a 3-yr study at two locations in Wisconsin, however, the earliest planting dates provided the highest yields (Oplinger and Martinka, 1991). Early spring planting may be needed in the Southeast to avoid high temperatures and late-season disease and insect pressure.

Narrower row spacing reduced weed pressure with the cultivar Ultra in Minnesota and increased grain yield of spring-sown white lupin in Wisconsin and Minnesota (Oplinger and Martinka, 1991; Putnam et al., 1992). Narrower row spacings may be necessary in the Southeast as well, to reduce weed competition through early canopy closure.

If lower seeding rates can be used without a significant decrease in grain yield, the cost of white lupin production will be reduced; however, higher seeding rates may result in more uniform and earlier-maturing seeds and pods, due to the concentration of seed production on the mainstem (Clapham and Elbert-May, 1989). Mainstem seeds also tend to have a higher and more uniform seed mass than seeds from branches (Herbert, 1977; Clapham and Elbert-May, 1989). Higher seeding rates reduced pods per plant and seeds per pod on branches, but produced higher seed yields in spring plantings of the cultivar Ultra in New Zealand (Herbert, 1977, 1979). Mainstem contributions to total plant yield have generally exceeded 45% (Herbert, 1977).

Pod number was the most important component for high grain yield of spring-type white lupin (Withers, 1984). Furthermore, pod number is suitable for comparing the effects of management on yield of a single cultivar evaluated in different environments, but is not a good parameter for comparing cultivars (Withers, 1984). Duthion and Pigeaire (1986) indicated that pod and seed number are more important than individual seed mass in determining grain yield.

Our objectives were to determine planting date, row spacing, and seeding rate effects on yield and yield components of two spring-sown white lupin cultivars.

MATERIALS AND METHODS

Field studies were conducted during the spring of 1991 and 1992 at locations in northern, central, and southern Alabama (Table 1). Seed was planted with a modified grain drill in a randomized complete block design with three replicates and a split-split plot restriction on randomization. Main plots were three planting dates corresponding to the average last −4.4, −2.2, and 0°C freeze at each location in 1991 (Table 1). In 1992, planting dates were the average last −8.8, −6.7, and −4.4°C freeze for northern Alabama and the average last −6.7, −4.4, and −2.2°C freeze for central and southern Alabama. Planting dates were earlier in 1992 to allow more time for pod development on the branches. Subplots were three row spacings (17.5, 35, and 70 cm) and sub-subplots were factorial combinations of two cultivars (Primorsky and Ultra) and three seeding rates (17.5, 35, and 52.5 seeds m^{-1}). Each sub-subplot consisted of three rows 6.1 m long, spaced at 90 cm.

Primorsky and Ultra sweet white lupin seed was treated with Captan 50 WP [*N*-trichloromethylthio-4-cyclohexene-1,2-dicarboximide] fungicide at 2.5 mL L^{-1} solution (9 L 100 kg^{-1} seed) before planting. *Rhizobium lupini* (LiphaTech, Milwaukee, WI)

Dep. of Agronomy and Soils, 202 Funchess Hall, Auburn Univ., Auburn University, AL 36849-5412. Research supported in part by Hatch funds allocated to Alabama Agric. Exp. Stn. Project no. ALA-03-005 and by funds from the Wheat and Feed Grain Committee of the Alabama Farmers Federation. Received 25 Feb. 1994. *Corresponding author. (Email: evsanten@ag.auburn.edu).

Published in Agron. J. 87:493–497 (1995).

was mixed with the seed at planting. Metolachlor [2-chloro-*N*-(2-ethyl-6-methyphenyl)-*N*-(2-methoxy-1-methylethyl) acetamide] and linuron [*N'*-(3,4-dichlorophenyl)-*N*-methoxy-*N*-methylurea] were applied at 1.12 kg a.i. ha^{-1} as preemergence herbicides. Supplemental P and K fertilizer was applied according to soil test recommendations for soybean [*Glycine max* (L.) Merr.] at each location. Insecticides and fungicides were applied as needed throughout the season.

The center 4.6 m of the middle row (4.15 m^2) of each sub-subplot was hand-harvested and weighed to determine total above-ground dry matter production, referred to henceforth as biomass yield. Ten plants were then randomly sampled to determine grain yield components. Remaining plants were counted and threshed for net seed yield determination.

Due to the loss of several planting dates each year, several overlapping ANOVAs were performed. Row spacing and seeding rate effects were analyzed by linear regression, treating each year–location–planting date as a separate environment. The 11 environments consisted of four early, four intermediate, and three late planting dates.

We considered 10 grain yield components for white lupin: mainstem pod mass, mainstem pod number, branch pod mass, branch pod number, mainstem seed mass, mainstem seed number, branch seed mass, branch seed number, 1000-seed mass for mainstem, 1000-seed mass for branches. Relating all 10 to each other and to biomass yield, grain yield, and harvest index would have resulted in 78 correlation coefficients to be interpreted. Furthermore, some of these correlations would not be independent of each other (e.g., 1000-seed mass for mainstem and branches were correlated at $r = 0.80$). Rather than being an impediment to the analysis, the covariance structure present among yield components can be actively employed in data interpretation. We used principal component analysis based on year × location × planting date means to reduce the dimensionality of the 10 grain yield components, applying the Varimax method of transformation (Mulaik, 1972). The criterion for the number of factors to be extracted was the 75% rule: all factors combined should extract at least 75% of the variability originally present among the 10 yield components.

RESULTS AND DISCUSSION

Grain and Biomass Yield

Local weather effects resulted in complete loss of certain planting dates (Table 1). In 1991 in northern Alabama, wet conditions permitted planting only at the second date (Fig. 1). A late spring drought eliminated grain production of the second and third planting dates at northern and central Alabama in 1992. At the southern Alabama location in 1992, soil crusting prevented emergence of the first date and rain interfered with planting of the second date. Therefore, only the last date produced grain.

The highest grain yield of 2872 kg ha^{-1} during this study was achieved in 1992 at the northern Alabama location. The specific treatment combination for this yield was the earliest planting date, narrowest row spacing, and highest seeding rate. Overall grain yield was low, however, averaging 551 and 604 kg ha^{-1} in 1991 and 1992, respectively. Northern Alabama had the highest overall grain and biomass yield, while southern Alabama usually had the lowest grain and biomass yield both years (Table 2). The probable cause for lower yields in southern Alabama was high temperatures during podset. Previous research with lupin in Australia has shown that higher temperatures terminate branch development and accelerate flower development and abortion (Nelson and Delane, 1991). The average daily temperature of 20°C was reached several weeks earlier in southern Alabama than in northern Alabama (Fig. 1). In 1991, central Alabama had lower grain and biomass yield than southern Alabama due to heavy disease pressure. Although no specific disease ratings were taken, *Pleiochaeta setosa* (Sacc.) S.J. Hughes and *Colletotrichum gloeosporioides* (Penz.) Penz. & Sacc. in Penz. were identified as the organisms associated with brownspot and anthracnose symptoms, respectively. A late-season drought significantly reduced grain and biomass yield at southern Alabama in 1992 (Fig. 1; Table 2).

Although some interactions were significant, they accounted for only a small portion of the total observed variance for grain and biomass yield in 1991 and 1992. Three and four-way interactions contributed <8% of the total variation, while two-way interactions contributed <14%. The significant cultivar × planting date interaction was primarily due to a magnitude effect; cultivar × planting date average grain yields differed as much as ninefold (Table 2). Similarly, row spacing × location (Fig. 2) and seeding rate × location (Fig. 3) means also varied greatly, thereby contributing to significant two-way interactions.

Of overriding importance were main effects. Planting date effects accounted for 25 to 53% of the variation for grain and biomass yield in central and southern Alabama in 1991. The earliest planting dates resulted in the highest grain and biomass yield (Table 2). In 1991, grain yield was reduced by ≈50% for Ultra when planted 4 wk later than the earliest date in southern Alabama. Grain yield was reduced by 63 to 87% for the third planting date in 1991 compared with the earliest planting. Similarly, the third planting in 1992 at the southern location resulted in grain yield reductions of up to 45% compared with the second planting date. Earlier dates had more time for vegetative and reproductive growth on the branches, which

Table 1. Locations, soil, latitudes, longitudes, and planting dates for Primorsky and Ultra white lupin, spring-sown at three dates in 1991 and 1992, at three seeding rates, and three row spacings in northern, central, and southern Alabama.

					Planting date					
					1991			1992		
Region	Location	Soil type	Latitude and longitude		1st	2nd	3rd	1st	2nd	3rd
North	Crossville	Wynnville fine sandy loam	34°17′ N	85°43 W	02 Mar.†	26 Mar.	06 Apr.†	07 Feb.	20 Feb.‡	02 Mar.‡
Central	Tallassee	Hiwassee sandy loam	32°42′ N	85°53 W	21 Feb.	10 Mar.	28 Mar.	19 Jan.	08 Feb.‡	21 Feb.‡
South	Monroeville	Lucedale fine sandy loam	31°35′ N	87°20 W	07 Feb.	25 Feb.	16 Mar.	22 Jan.†	07 Feb.	25 Feb.

† Excessive precipitation prevented planting at these dates.
‡ Drought destroyed grain production for these planting dates.

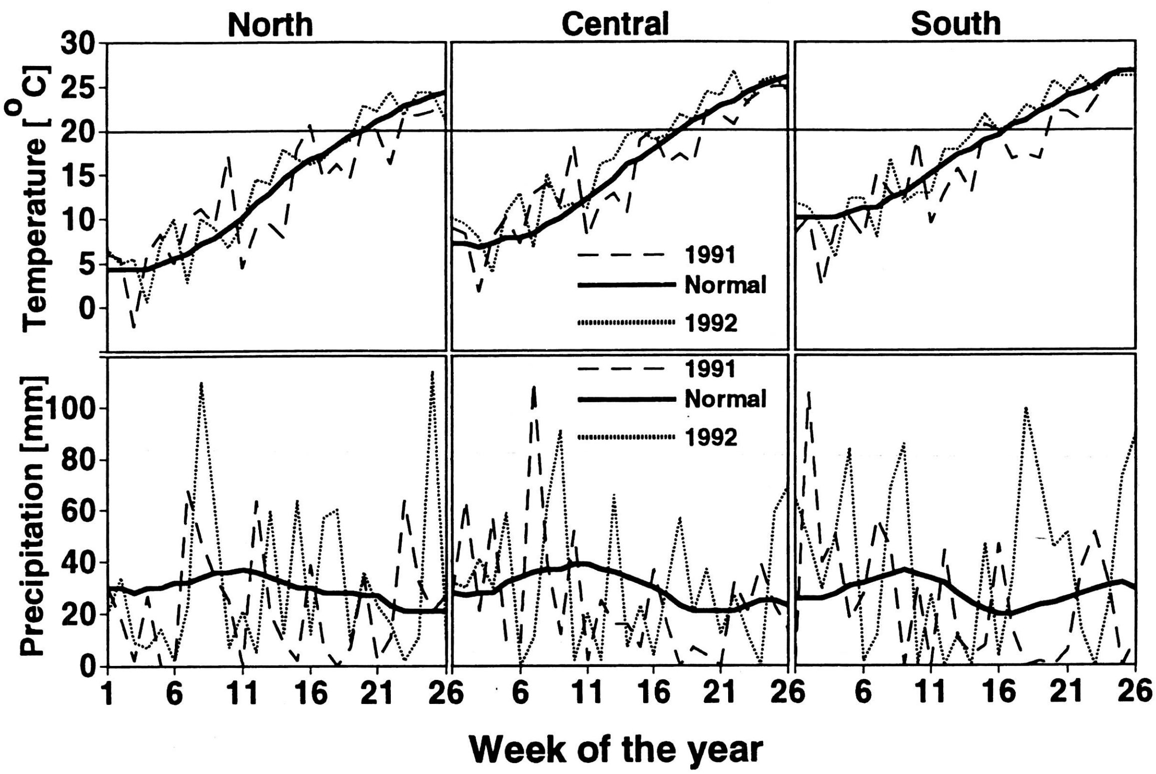

Fig. 1. Average weekly temperatures and total weekly precipitation in northern, central, and southern Alabama during the 1991 and 1992 crop years.

resulted in higher yields. Planting earlier than the first date in 1992 for each location may result in early flowering and increased risk of freeze damage during reproductive growth; however, delayed planting reduces the time for grain filling and pod formation. All planting date treatments terminated pod production within 1 wk of each other.

Eleven location × date × year combinations (Table 1) were available for the regression of grain yield on row spacing and seeding rate. The row spacing × seeding rate interaction was nonsignificant ($P > 0.20$). Row spacing effects were reduced with delayed planting (Table 3). Grain yield decreased as much as 10.2 kg ha^{-1} for every unit increase in row width. Row spacing is an important determinant of yield and results concur with previous studies in the northern USA (Oplinger and Martinka, 1991; Putnam et al., 1992). A 15- to 25-cm row spacing is recommended for spring-sown white lupin for the upper Midwest (Oplinger and Martinka, 1991). Narrow row spacings for the same plant population result in less intrarow competition and greater utilization of light and soil resources between rows. Full canopy closure was not achieved by the widest row spacings, which allowed weed growth and competition and provided poor utilization of incident radiation.

Similarly, seeding rate effects were significant at all planting dates (Table 3). Every one seed m^{-2} increase in seeding rate resulted in an average grain yield increase of 19.6, 17.1, and 5.0 kg ha^{-1} for the first, second, and third planting date, respectively. Increasing seeding rates did not necessarily change the relative contributions of branches vs.

Table 2. Effect of planting date on grain and biomass yield of Primorsky and Ultra white lupin spring-sown at three locations in Alabama in 1991 and 1992.

Year	Location	Cultivar	Grain yield Date 1	Grain yield Date 2	Grain yield Date 3	Biomass yield Date 1	Biomass yield Date 2	Biomass yield Date 3
			kg ha^{-1}					
1991	North	Primorsky	†	579	†	†	2353	†
		Ultra	†	695	†	†	2606	†
	Central	Primorsky	685	534	256	2243	1782	1122
		Ultra	496	400	115	1861	1591	620
	South	Primorsky	855	840	214	2842	2366	1218
		Ultra	1020	526	128	3722	1620	1100
		LSD (0.10)	119	84	13	424	165	129
1992	North	Primorsky	1008	‡	‡	2295	‡	‡
		Ultra	762	‡	‡	1831	‡	‡
	Central	Primorsky	942	‡	‡	2079	‡	‡
		Ultra	505	‡	‡	1212	‡	‡
	South	Primorsky	†	256	172	†	812	588
		Ultra	†	244	134	†	695	480
		LSD (0.10)	156	167	78	334	370	252

† Excessive precipitation eliminated grain production for these dates.
‡ Drought destroyed grain production for these planting dates.

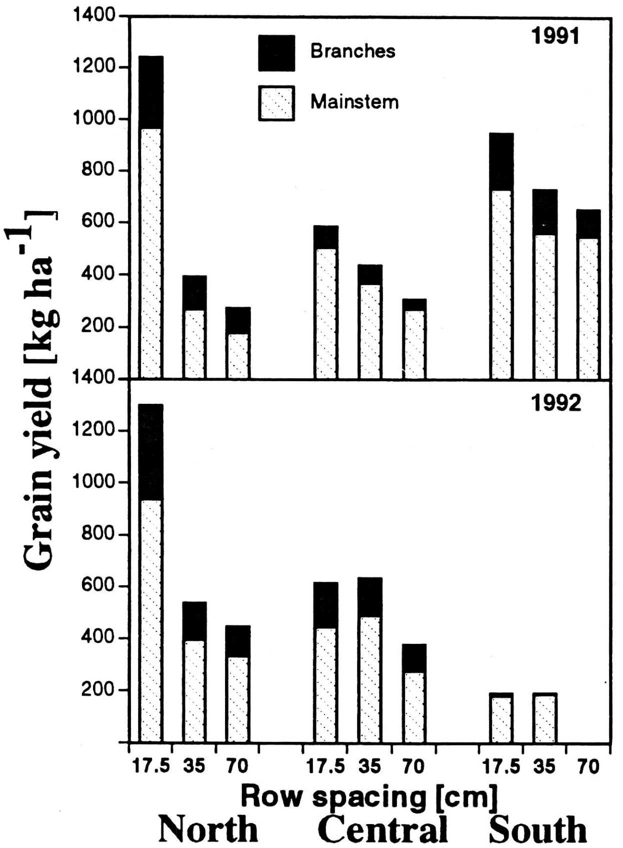

Fig. 2. Effect of row spacing on mainstem and branch grain yield of spring-sown white lupin. The 1991 data represent the second planting only for northern Alabama and all three planting dates for central and southern Alabama. The 1992 data are from the first planting date in northern and central Alabama and the second and third date for southern Alabama.

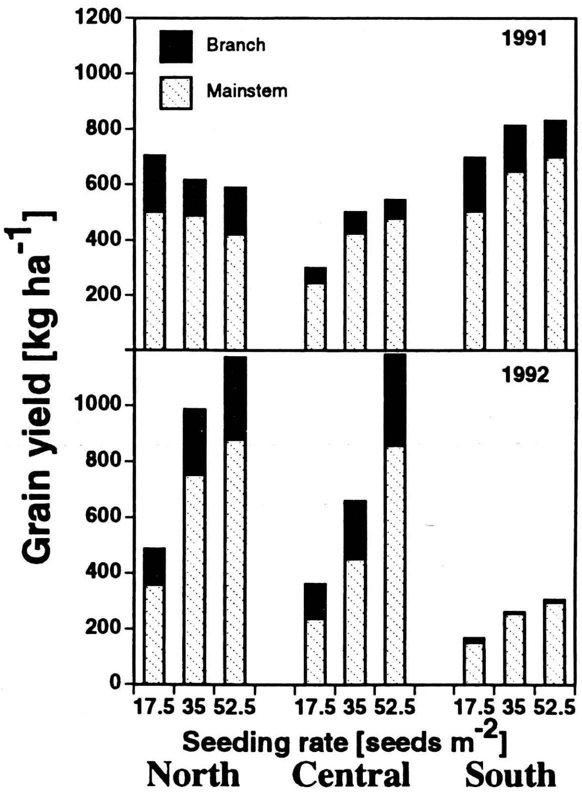

Fig. 3. Effect of seeding rate on mainstem and branch grain yield of spring-sown white lupin. The 1991 data represent the second planting only for northern Alabama and all three planting dates for central and southern Alabama. The 1992 data are from the first planting date in northern and central Alabama and the second and third date for southern Alabama.

mainstem (Fig. 3). Higher grain and biomass yields may be attainable by increasing seeding rates. However, seeding rates higher than those listed may not be economically justified: assuming an average seed mass of 200 mg, a seeding rate of 52.5 seeds m^{-1} translates to 105 kg ha^{-1}.

Grain Yield Components

Principal component analysis was very successful in reducing the dimensionality of grain yield components. Applying the rule of extracting at least 75% of the variance, three factors were identified. The first accounted for 57% of the variance and may be called branch. The highest weights (loads) for this factor related to total pod yield, grain yield, number of pods on the branches, and number of seeds on the branches. The second factor, seed mass, accounted for 23% of the variance and contained 1000-seed mass for mainstem and branches. The third factor, mainstem, extracted 14% of the variance. Grain yield components with high loads for this factor were number of pods and seeds on the mainstem, grain yield, and number of seeds per mainstem pod. The three factors combined extracted 94% of the total variance.

Based on the results of the principal component analysis, three new grain yield components were created, as follows. Each grain yield component was standardized to zero mean and unit variance by subtracting the mean and dividing by the sample standard deviation. The new components were then calculated as standardized grain yield components multiplied by their respective loads. Loads represent the coefficients of the linear combination of original variables defining a particular principal component. The new correlation matrix contained 15 entries, compared with the original 78 (Table 4). As expected, grain and biomass yield were highly correlated. Both branch and mainstem grain yield components were highly correlated with grain and biomass yield. For the most part, branches con-

Table 3. Intercept, regression coefficients for slope, probability, coefficient of determination, and number of observations for the regression of grain yield on row spacing and seeding rate for spring-type white lupin seeded at three locations in Alabama in 1991 and 1992.

Factor	Intercept	Slope†	Probability	R^2	n
Row spacing					
Date 1	1177.8	−10.2	≤0.01	0.50	12
Date 2	844.8	−5.3	≤0.04	0.48	9
Date 3	283.9	−2.4	≤0.01	0.86	9
Seeding rate					
Date 1	‡	19.6	≤0.01	0.87	12
Date 2	‡	17.1	≤0.01	0.93	9
Date 3	‡	5.0	≤0.01	0.96	9

† Regression coefficients among dates within regressions on row spacing and among dates within regressions on seeding rate are significantly different at $P \leq 0.05$.
‡ The intercept was forced through zero because there would be no yield at a seeding rate of zero.

Table 4. Phenotypic correlations among biomass yield, grain yield, harvest index, and three linear functions of yield components (branch, seed mass, mainstem) which were derived from principal component analysis for white lupin spring-sown at three locations in Alabama in 1991 and 1992.

	Biomass yield		Grain yield		Harvest Index		Branch		Seed mass	
	r†	*P*‡	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*
Biomass yield	1.00									
Grain yield	0.90	0.01								
Harvest index	0.34	0.12	0.69	0.01						
Branch	0.80	0.01	0.76	0.01	0.44	0.05				
Seed mass	−0.15	0.53	0.20	0.38	0.68	0.01	0.11	0.62		
Mainstem	0.76	0.01	0.82	0.01	0.66	0.01	0.59	0.01	0.10	0.67

† Pearson product moment correlations based on year × location × planting date means.
‡ Probability of $r > 0.00$ based on Fisher's r-to-z transformation.

tributed more to grain yield at narrower row-spacing than at wider row spacing (Fig. 2). Harvest index had a higher correlation with seed mass and mainstem components than with branch components (Table 4). Furthermore, increasing grain yields were more closely correlated with harvest index than biomass yield.

CONCLUSION

Planting date had the greatest effect on grain and biomass yield in central and southern Alabama in 1991. Early planting is essential to obtain high yield. The narrowest row spacing and highest seeding rate produced the highest grain and biomass yields. High yields require both narrow rows and high seeding rates. Although high yields may be obtained, problems with timely planting and soil crusting resulted in only a 61% success rate of stand establishment. Consistently high yields, therefore, may be difficult to attain.

ACKNOWLEDGMENTS

The authors thank Mr. J.O. Horton, Auburn University Department of Agronomy and Soils, and the personnel of the Alabama Agricultural Experiment Station for technical assistance in conducting these field experiments.

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