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CHARACTERIZATION OF VELVETBEAN (*MUCUNA PRURIENS*) LINES FOR COVER CROP USE

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Abstract. **The phenology, morphology and biomass production of nine velvetbean (*Mucuna pruriens* var. *utilis*) lines were evaluated at Homestead, Fla. The time from seeding to first floral buds ranged from 69-135 days, to first blooms 89-153 days, and to first pods 103-160 days. The nine lines initiated blooming in a certain order, which could be described either by calendar days or degree-days. Five lines had an indeterminate flowering habit, while four were determinate. Lines 2, 5 and 7 produced the most biomass and line 8 the least. The petiole constitutes 14% to 28% of total leaf weight. Leaf weight at bloom accounted for 62% of above-ground plant weight in indeterminate lines, and 70 to 81% in determinate lines. The period from first bloom to first pods spanned 10 weeks. Differences in velvetbean growth habits may be used to stagger planting dates of vegetables. Growers may implement a strategy of "one time planting" of several velvetbean lines of various maturation rates each on a fraction of their acreage. Two weeks in advance of each vegetable planting, the appropriate velvetbean line would be soil-incorporated, and this process would be repeated at appropriate intervals allowing staggered vegetable planting over ten weeks.**

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Florida accounts for almost all of the U.S. winter production of tomato (*Lycopersicon esculentum* Mill.), bell pepper (*Capsicum annuum* L.), snap bean (*Phaseolus vulgaris* L.), and sweet corn (*Zea mays* L.) (Hansen et al., 1999). One component of a sustainable south Florida production system is the implementation of summer cover crops such as sunn hemp (*Crotalaria juncea* L.), *Dolichus lablab* L., cowpea (*Vigna unguiculata* [L.] Walp.), and velvetbean (*Mucuna pruriens* var. *utilis* (Wall. ex Wright) Baker ex Burck) (Abdul-Baki et al., 2005). The number of leguminous cover crop species well suited for use in tropical and subtropical environments is quite limited, and each has certain limitations when used without rotation. Thus, in developing sustainable cropping systems there is a need to identify additional well-suited cover crop species so that they can be rotated within the cropping system. It is necessary to understand the growth patterns and morphological traits of various lines of each cover crop species in order to make use of the full potential of each line with respect to a given production system.

Velvetbean is a vigorous annual legume which possesses many desirable agronomic attributes. As a ground cover it reduces erosion, fixes N (Harrison et al., 2004), suppresses weeds (Baijkya et al., 2005), reduces populations of certain plant-parasitic nematodes (Vargas-Ayala and Rodríguez-Kábana, 2001), assimilates and sequesters left over nutrients and increases crop yields (Abdul-Baki et al., 2005). In south Florida velvetbean can be grown in the rainy summer months in rotation with vegetable crops grown in the dry winter months.

Use of velvetbean in rotation with vegetables may be considered as a component of best management practices (BMPs). The goal of this research was to elucidate the growth habits, morphology and phenological characteristics of nine velvetbean lines in order to utilize them effectively in various cropping systems.

Materials and Methods

Nine velvetbean lines were field evaluated during 2003, 2004 and 2005 at the Tropical Research and Education Center (TREC), Homestead, Fla. (Table 1). In 2003 and 2004,

Table 1. Characteristics of velvetbean (*Mucuna pruriens*) lines tested.

Line	Plant Introduction Number	Other ID	Origin	Seed color	Source
1	494877 01 SD	ZFA 3577	Zambia	Ivory	R. Pitman[z]
2	337098 01 SD		Brazil	Black	R. Pitman
4	365414 01 SD	Osccola	Mozambique	Brown mottling on light tan background	R. Pitman
5	365415 01 SD	Verde Radio	Mozambique	Brown mottling on olive background	R. Pitman
6	365573 01 SD		Brazil	Black	R. Pitman
7	383272 01 SD	African Yellow	U.S.A.	Yellowish-green	R. Pitman
8	'Florida Bush'		U.S.A.	Lime	K.L. Buhr[y]
9	Georgia V-1021-AC		U.S.A.	Brown mottling on tan background	S. Phatak[x]
'GA Bush'	'GA Bush' V-1001-AC-PB		U.S.A.	Brown mottling on tan background	S. Phatak

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seeds of each line were planted in late May in a Krome gravelly loam soil (loamy-skeletal, carbonatic hyperthermic lithic Udorthents). A 20-cm (8 inch) band of 6-6-12 N-P-K fertilizer was applied prior to planting at 56 kg N per ha (50 lb / ac). Seeds were treated with a cowpea-type Rhizobium at planting time. Plot size was 9.1 × 2.4 m (30 × 8 ft). Within row spacing was 30 cm (1 ft) for lines 1 thru 7 and 20 cm (8 inch) for lines 8 and 9. Spacing between rows was 60 cm (2 ft). Rainfall was supplemented with overhead irrigation. In 2003, leaf and petiole weights and leaf areas from 10 leaves, total plant weight and vine weight from five plants, velvetbean coverage outside of plots, weight of 200 seeds, seed protein and above-ground biomass from one 4.18 m^2 (45 ft^2) per line were determined. Phenological observations were made weekly until pods had become fully mature. The numbers of calendar days for each line to reach each major phenological event and the number of degree-days required for initiation of flowering were recorded. The latter was suggested to be more reliable because it allows direct comparison between cultivars which have different phenological and developmental patterns (Russelle et al., 1984). Therefore, temperatures in degrees Celsius at 60 cm (2 ft) above the soil recorded every 15 minutes used to calculate the degree-days until the appearance of the first blooms in each line. Developmental zero was assumed to be 5°C (41°F). In 2004 above-ground biomass samples were collected from one 4.18 m^2 (45 ft^2) per line approximately 3-months after planting. All plant materials were dried at 70°C (158°F) for 5 d, weighed and ground.

In 2005 a field experiment was conducted at TREC on a Krome gravelly loam soil and at Pine Island Farms (PIF), South Miami, Fla. on Opalocka - Rock Outcrop Complex soil (sandy, siliceous, hyperthermic lithic Udorthents). 'Georgia Bush' was seeded at 56 $kg \cdot ha^{-1}$ (50 lb / ac) in four replicated plots at both sites. Seeds were planted in early June and above-ground biomass was collected, dried and weighed as before. Phenological observations were made at weekly intervals until pods had become fully mature. The occurrence of Hurricanes Katrina and Wilma may have affected biomass data and seed yields reported here. N content of dry seeds was determined.

Dry seeds were ground in a Wiley mill, passed through a 60-mesh sieve and analyzed for C and N content using a Leco CHN 600 Analyzer. The samples were combusted at 960°C (1,760°F). Carbon was analyzed by infra-red and N by thermal conductivity, and the latter values were used to estimate protein content as explained by Campbell (1992).

Replicated data are expressed as means. Differences between lines and locations were determined by analysis of variance, and means were compared with Tukey's adjustment for multiple comparisons ($P < 0.05$) using SAS 9.1 (SAS, Cary, N.C.).

Results

The velvetbean lines varied greatly in their phenology, morphology and biomass production. Lines 5 and 7 produced the largest leaves based upon dry weight and leaf area and line 8 the smallest (Table 2). Petiole weight as percent of total leaf weight ranged from 13.9% in line 1 to 28% in line 9. At the time of single leaf collection, line 9 was the most mature with the lowest leaf moisture.

Above-ground dry weight of line nine plants was lighter than that of all other lines (Table 2). The next lightest plants were from line 4, and the weight was significantly different from line 1, which produced the heaviest plants. The dry weight attained by vines depended on the flowering habit of the lines. Determinate lines 4, 8 and 9 had the lowest vine weights (Table 2). Line 9 and 'Georgia Bush' are vineless. There was no statistically significant difference in vine weights among the indeterminate lines. The ground coverage outside the plot was greatest for line 5, which did not differ statistically from line 7 (Table 2). The indeterminate lines, 1 and 2, had coverage similar to the determinate lines 4 and 8. Line 9, a forerunner of 'Georgia Bush', was the poorest at covering area beyond its seeding area.

There was little difference in the amount of biomass produced by each line between years, and the relative order of biomass production among the lines was the same in both years (Table 2). Lines 2, 5 and 7 produced the most biomass while line

Table 2. Leaf and petiole weights, leaf area and moisture, seed weight and biomass production by various velvetbean (*Mucuna pruriens*) lines at Homestead, Florida[z].

Line number	Dry wt. leaf blade (g)[y]	Dry wt. petiole (g)[y]	Total leaf weight (g)[y]	Leaf area (cm^3)[y]	Leaf moisture (%)	Dry wt. whole plant (g)[x]	Dry wt. vines (g)[x]	Coverage (cm)[w]	Biomass 2003 (Mt ha^{-1})[v]	Biomass 2004 (Mt ha^{-1})[v]
1	0.87	0.14	1.01	255.3	75.8	672 a[u]	255 a	191 cd	6.1	5.9
2	0.84	0.19	1.03	278.9	80.3	583 ab	233 a	132 c	7.9	7.6
4	0.82	0.20	1.02	237.3	75.9	176 b	65 b	197 cd	7.2	6.9
5	0.97	0.23	1.20	317.8	71.8	478 ab	162 ab	366 a	7.9	7.6
6	0.82	0.19	1.01	215.3	76.4	368 ab	134 ab	249 b	6.3	6.0
7	1.02	0.22	1.24	304.9	75.2	365 ab	124 ab	332 ab	8.1	7.7
8	0.60	0.13	0.73	216.4	72.4	254 ab	79 b	216 c	3.6	3.5
9	0.81	0.28	1.09	223.5	67.0	62 c	12 c	156 d	6.0	5.8
9 late planting	0.81	0.25	1.06	235.6	Na[t]	Na[t]	Na[t]	Na[t]	2.1	2.8
'GA Bush'	1.12 [t]	0.50[t]	1.62[t]	287 [t]	75.0[t]	191[t]	65[t]	91[t]	6.9 [t]	6.9

[z]Based upon observations made in 2003; [y]Average of 10 leaves;
[x]Average of five plants;
[w]Distance that the plants covered beyond the western edge of the plot.
[v]From a 4.18 m^2 area; these biomass values do not represent the full potential of the lines because the plants were not terminated in the optimum stage of development;
[u]Means followed by the same letter are not significantly different according to Tukey's adjustment for multiple comparisons ($P < 0.05$);
[t]Data not available.
[s]Data obtained from 'Georgia Bush' grown in 2006 at the Tropical Research and Education Center.

8 produced the least. During both years a late planting of line 9 substantially decreased total biomass production. There were no weeds in the plots of the three highest biomass-producing lines (data not shown). Weeds (>0.4 Mt ha^{-1}) (>356 lb / ac) at biomass harvest were present in the plots of lines 8 and 9.

The velvetbean lines varied in phenology and flowering habit (Table 3). The numbers of calendar days to reach first bloom from shortest to longest were as follows: Line 9, line 8, line 4, 'Georgia Bush', line 1, line 7, line 2, line 5 and line 6. This order is essentially identical to the order using degree-days (Table 3). Hence the calendar-day method appears to be adequate for characterizing development, and is more practical than the degree-day method.

Of the determinate lines 'Georgia Bush' took the longest to mature. In 2003, the number of calendar days from first to last bloom for the determinate lines was less than 30 days. In "GA Bush' the time from first to last bloom was only 7 d in 2003, but in 2005 this period was 38 d at TREC and 43 d at PIF (Table 4). All of the indeterminate lines took over 100 d to form the first floral buds; and they varied greatly in the number of days from first to last bloom. The blooming period in the indeterminate lines lasted as follows: line 5 (96 d), lines 1 and 7 (both 71 d), line 6 (57 d) and line 2 (49 d).

The phenology of line 9 was manipulated by delaying the planting date by 45 d as shown in Table 3. Phenology was also influenced by year and location (Tables 3 and 4). In 2005, 'Georgia Bush' matured slightly more rapidly than in 2003 (Table 4). The numbers of days to first floral buds and to first blooms were less at PIF than at TREC, but, conversely, the number of days from first to last bloom was 5 d greater at the former than at the latter site.

Differences in seed weights were used to establish seeding rates and spacing (Table 5). Line 9 produced the smallest seeds; hence it has the most seeds per kg. Lines 1, 7 and 8 had similar number of seeds required to achieve a seeding rate of 85 kg·ha^{-1} (76 lb / ac). Lines 2, 4, 5 and 6 were similar, and intermediate compared to the other lines, in number of seeds required per ha. Since line 9 is vineless, its seeds must be spaced close together to shade out weeds. Seed protein ranged from 25 to 29% of the mature seed weight (Table 5).

In 2005 'Georgia Bush' phenology, biomass and seed production were evaluated in two soil types (Table 4). These data were affected by Hurricanes Katrina and Wilma, which defoliated the vines. Biomass in 2005 was very low compared to previous years, and there was no difference in biomass production between the two sites. Significantly more seed was produced at TREC than at PIF.

Discussion

One of the most important morphological attributes of the velvetbean plant is the high proportion of leaf to total above-ground weight. Leaf weight to above-ground plant weight ratio in most indeterminate lines at the time of bloom was about 62%, whereas in the determinate lines it ranged up to 81%. In comparison, leaf to above-ground plant ratio in sunn hemp at the time of bloom is only 37% (Abdul-Baki et al., 2005), and the rest of the plant consists of a stem high in cellulose and low in N. The higher percent of leaf tissue in velvetbean compared to sunn hemp allows more immediate release of N for use by the subsequent crop.

Additionally, a valuable morphological attribute of velvetbean is its large petiole. Petioles in grapevine leaves normally have concentrations of nutrients about 3 times greater than in the leaf blade (Reuter and Robinson, 1986); and this is likely to be the case in velvetbean. Petiole extracts are also much more toxic to the root knot nematode than other plant parts (Zasada et al., 2006).

Table 3. Phenology of various velvetbean (*Mucuna pruriens*) lines at Homestead, Florida. All of the lines were seeded on June 2, 2003, and a 2nd seeding of Line 9 was made 45 days later on July 17, 2003. Degree-days using the Celsius scale were calculated on assumption that developmental zero is 5°C.

	Days from seeding to			Days from 1st to last blooms	Flowering Habit	Degree-Days to 1st bloom
	1st Floral buds	1st Blooms	1st Pods			
Line 1	118	138	145	71	Indeterminate	1847
Line 2	132	142	160	49	Indeterminate	1845
Line 4	83	103	111	15	Determinate	1390
Line 5	111	145	153	96	Indeterminate	1929
Line 6	135	153	160	57	Indeterminate	2026
Line 7	135	141	160	71	Indeterminate	1881
Line 8	89	97	111	29	Determinate	1311
Line 9	69	89	103	29	Determinate	1204
Line 9 late	43	60	68	15	Determinate	809
'GA Bush'	90	114	121	7	Determinate	1545

Table 4. Phenology, biomass production and seed weight of velvetbean (*Mucuna pruriens*) 'Georgia Bush' in 2005 at two locations in Florida.[z] Biomass and yield data were collected after the passage of Hurricane Wilma.

	Days from seeding to			Days from 1st to last blooms	Biomass (Mt ha^{-1})	Seed weight (g)[y]
Location	1st Floral buds	1st Blooms	1st Pods			
TREC[z]	84	108	115	38	0.43a[x]	882.5a
PIF[z]	72	79	108	43	0.48a	257.5b

[z]TREC is the Tropical Research and Education Center, Homestead, FL, soil type is Krome gravelly loam (loamy-skeletal, carbonatic hyperthermic lithic Udorthents); PIF is Pine Island Farm, South, Miami, FL, soil type is Opalocka - Rock Outcrop Complex (sandy, siliceous, hyperthermic lithic Udorthents).
[y]From a 4.18 m^2 area.
[x]Means followed by the same letter are not significantly different according to Tukey's adjustment for multiple comparisons (P < 0.05).

Table 5. Seed attributes of velvetbean (*Mucuna pruriens*) lines grown at Homestead, FL.[z]

Line number	Seed wt. (g)[y]	Number seeds kg^{-1}	Seeds required ha^{-1},[x]	Seed spacing (cm)[w]	Seed protein (%)[v]
1	189.0	1058	89,930	30	28.8
2	135.9	1472	125,120	22	26.2
4	154.3	1296	110,160	24	27.5
5	145.0	1379	117,215	23	27.5
6	144.1	1388	117,980	23	26.3
7	179.4	1115	94,775	28	25.8
8	181.7	1101	93,585	29	28.8
9	110.3	1814	154,190	18	25.1

[z]Data from observations made in 2003.
[y]Total weight of 200 seeds.
[x]Based upon a seeding rate of 85 $kg \cdot ha^{-1}$.
[w]Adjusted for 70% germination.
[v]Calculated as 6.25 × % N.

Biomass production reported here was significantly lower than reported previously (Abdul-Baki et al., 2005; Whitebread et al., 2004), because the plants were not terminated at optimal times. Biomass measurements of all lines on the same date did not accurately represent the relative performance of the lines due to differences in maturity. Therefore biomass should be measured at the time of terminating the cover crop and incorporating the cover crop into the soil. By that time the cover crop should have attained maximum biomass and high N content.

During the whole period of bud formation through seed development and maturation, demand for N and other nutrients by the reproductive tissue is high because of the need for synthesis and storage of proteins. During seed maturation and plant senescence, the available N diminishes in the leaves, and the quality of the plant as a cover crop is reduced. Furthermore, as the seeds reach a stage in their development that allows them to germinate, incorporating then into the soil will give them a chance to germinate and serve as weeds competing with the subsequent cash crop. Therefore, it is recommended that the velvetbean line be terminated and soil incorporated no later than two weeks after the first blooms.

Differences in growth habits of the tested lines offer a unique advantage to vegetable growers in south Florida. The common practice among large- and small-scale growers is to do more than one planting for each kind of vegetable crop per season and to stagger these plantings over several months. This practice allows them to provide the market with the quantities that can be consumed for a longer duration instead of over-saturating the market for a short duration. For example, in Miami-Dade County the fresh-market tomato planting season begins in late September to early October (for early yield) and ends in January (for late yield). Plantings are staggered at 2- to 3-week intervals to ensure steady and continuous supply. Differences among velvetbean lines to reach the optimal growth stage before termination offer an opportunity in this production system. Since the period between April and Sept. is an off-season for growing vegetables in south Florida the growers can implement a strategy of "one-time-planting" of velvetbean in fallow fields. In that "one-time-planting", they can seed short-, intermediate-, and long-growing season lines. The short growing season lines will mature early and will be ready to terminate and use as cover crops for early vegetable plantings whereas the late maturing lines will be terminated at a later date for late tomato planting dates. This strategy saves time by planting once instead of numerous times; planting is done at a time to make full use of the rainy summer season; and the cover crop protects the soil during the hurricane season.

From a pest management perspective, knowledge of velvetbean morphology, phenology and biomass production is also important. Zasada et al. (2006) found that velvetbean extracts suppress root-knot nematode development, and growth of the tomato and lettuce hypocotyls. For root-knot nematode, extracts from the above-ground portion of the plant are much more toxic than from the roots. Leaf blades, petioles, and vines have similar toxicities to the root-knot nematode. Therefore, from a nematode management perspective, lines which produce large amounts of biomass should be selected for maximum nematode suppression.

Velvetbean has been shown to suppress some weed species in tropical production systems (Baijukya et al., 2005). Competition for light and nutrients, as well as allelopathic compounds such as L-dopa (Fuji, 1999), play an important role in the ability of velvetbean to suppress weeds. Line 5 may be able to shade out weeds more effectively than the vineless lines by virtue of better ground cover; however this deficiency can be compensated by increasing the plant density of the vineless lines. The suppressive action on nematodes and weeds will be related to the amount of biomass produced.

Velvetbean, along with other cover crops, should be considered in the development of best management practices (BMPs) to protect water quality. The selection of an appropriate velvetbean line will also depend upon the length of time between cash crops, biomass production, N return and economics.

In summary the high proportion of leaf tissue rich in nutrients together with high biomass production and low susceptibility to pathogens should make the velvetbean plant a major component of sustainability of vegetable production in tropical and subtropical areas.

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