Biomass Yield and Flower Production in Sunn Hemp: Effect of Cutting the Main Stem

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ABSTRACT. A field experiment was conducted at the Tropical Research and Education Center, University of Florida, Homestead, to determine the effects on plant morphology, biomass yield, and flower production. of cutting the main stem of sunn hemp (*Crotalaria juncea*

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L.) plants at different heights. Seeds treated with cowpea (*Vigua unguicalata*)-type rhizobium were sown on 15 April 1999. The main stems were cut at 30, 60, and 90 cm above soil surface 100 days after seeding when the plants were about 1.5 m tall. Control plants were left uncut. Biomass that had been cut from plants was included in the total biomass yield. Seventy days following stem cutting, individual plants were evaluated for: plant height; main stem diameter; fresh and dry weights of roots, main stems, primary branches, secondary branches, leaves, open flowers, and unopened flowers. Leaf area and nutritional analyses of the plant parts were determined. Cutting the main stem at 30 and 60 cm above soil surface reduced total plant biomass, whereas cutting at 90 cm height increased biomass yield. Cutting at 30 cm produced the highest quality of biomass by increasing the leaf yield and reducing the weights of root and main stem both of which are low in N and high in C/N. Cutting the main stem at 90 cm produced the highest biomass yield, increased the number and weight of primary and secondary branches and, consequently, increased the number of flowers per plant. Nitrogen was highest in flowers and lowest in roots and main stems. Flowers were highest in K, P, Zn and Cu, whereas roots were highest in Fe content. We conclude that cutting the main stem at 30 cm height and allowing the plants to grow for an additional 70 d result in the highest quality biomass for use as green manure, windbreaks, and mulch. Cutting at 90 cm produced the largest biomass yield and increased flower production.

KEYWORDS. *Crotalaria juncea,* cover crops, plant mulches, tropical legumes, leaf area, nematode resistance, biomass production, flower production, macronutrients, micronutrients

INTRODUCTION

There is a great need for cover crop species that grow well in south Florida and in comparable environments for use as cover crops and green manures in vegetable production rotations. Sunn hemp *(Crotalaria juncea* L.*)* has been suggested as a potential candidate because the species has many important agronomic attributes (Lates and Mobbayad, 1983; Natl. Acad. Sci., 1975). These attributes include adaptation to tropical conditions (Rotar and Joy, 1983), rapid growth (Reeves, 1997), high biomass yield (Chang, 1975; Li et al., 1999; Zinati et al., 1999), adequate performance in calcareous soils with high pH, efficient nitrogen fixation (Magistad et al., 1939), resistance to root-knot (*Meloidogyne* spp.) nematodes (McSorley et al., 1994), and effectiveness in suppression of weeds (Li et al., 1999; Rotar and Joy, 1983). During the late 1950's, seeds were harvested from 1,075 ha in the U.S. and sufficient seed was produced to plant 14,000 ha (Markle et al., 1998). Currently, commercial seed production has been limited to Hawaii and centered around 'Tropic Sun'–a cultivar that was released in 1982 by the Soil Conservation Service and the Hawaii Institute of Tropical Agriculture and Hawaii Resources, University of Hawaii (U.S. Dept. Agr., 1983).

Recent renewal of interest in sunn hemp as a potential tropical cover crop to improve soil fertility created an imbalance between supply and demand, and often resulted in shortages of seed supplies and increased prices. Retail market value of seeds currently averages four dollars per kg. At recommended seeding rates of 40 to 65 kg ha^{-1} for cover crop production, seed cost becomes discouraging to growers (U.S. Dept. Agr., 1983). In addition, there have not been any significant breeding programs or germplasm collection to improve seed production potential or seed quality (Natl. Acad. Sci., 1975). Although sunn hemp seeds are not known to have any dormancy or hard seededness, and should germinate rapidly (Magistad et al., 1939), germination of commercially available seeds runs around 80%, and the seed population in the lot contains broken seeds and immature seeds that are easily distinguishable from mature seeds by their greenish seed coat. Any successful attempt to expand seed production areas in the U.S. to locations in addition to Hawaii to meet market demand at affordable prices, will expedite the use of sunn hemp as a cover crop. It is logical to attempt to produce seeds in tropical locations, such as south Florida, since sunn hemp has been successfully grown for centuries in the tropical countries of India, Indonesia, Rhodesia, Malaysia, Taiwan, China, and Thailand (Rotar and Joy, 1983).

Successful production of this annual summer legume depends on climate and cultural practices. If planted in the spring, the plants grow vigorously and produce 6 to 9 Mg ha^{-1} of dry biomass in ten to twelve weeks (Rotar and Joy, 1983; Yadvinder et al., 1992). At this stage, which corresponds to early flowering, biomass quality is high for green manure declines.

Branching height and formation of primary and secondary branches depend on plant density (Rotar and Joy, 1983). Low plant population densities give rise to more branching. Branching in many species may also be induced by cutting the main stem at a certain height–a practice often applied successfully to several other cover crops to induce more vegetative growth, but has never been applied to sunn hemp. In fact, cutting the main stem reduces apical dominance, increases the number and size of primary and secondary branches, and concomitantly induces more new leaves on the newly formed branches. This practice may likely induce more flowers since flowers on the sunn hemp plant appear in racemes only at the terminal 15 to 20 cm of secondary branches. Consequently, any cultural practice which increases number and size of secondary branches is likely to produce more flowers and, subsequently, more seeds per plant. This experiment was set forth to evaluate the validity of the hypothesis, namely, can more primary and secondary branches and ultimately, more flowers, be induced by cutting the main stem? If so, what cutting height produces the most flowers?

Hence, the objective of this study was to determine the effects of cutting the main stems of sunn hemp plants at different heights on the number and size of primary and secondary branches, and ultimately, on flower production in these plants.

MATERIALS AND METHODS

The experiment was conducted between 15 April and 5 October, 1999 on the farm of the University of Florida Tropical Research and Education Center, Homestead, Florida. The soil is Krome very gravelly loamy (loamy-skeletal, carbonatic, hyperthermic Lithic Undorthents), pH 7.5 and consists of about 33% soil and 67% pebbles (> 2 mm). 'Tropic Sun' sunn hemp seed was obtained from commercial sources. Seed inoculated with cowpea-type rhizobium was sown on 15 April, 1999 at 5.5 kg ha^{-1} following conventional tillage (moldboard plowing, disking, and leveling) practices for use as green manure or seed production (Mansoer et al., 1997, Rotar and Joy, 1983; U.S. Dept. Agr., 1983). Seeds were planted on flat ground in double rows with 78 cm between double rows within the bed, 95 cm between one double row and the next, and 9 cm between plants within the row. This resulted in a plant density of about 113,300 plants ha^{-1}. No fertilizer was applied to the crop.

The experimental design was completely randomized with cutting height of the main stem as the main treatment. There were four treatments each replicated three times: Uncut main stem (control), and stems cut at 30, 60 and 90 cm above ground. Each replication consisted of one double-row 6 m long (about 350 plants). Plants were cut by hand on 8 August at which time they were about 100 d old and about 150 cm high. On 5 October, 1999, after an additional 70 d of growth following stem cutting, when plants were in full bloom, they were pulled from the soil and evaluated. Dry biomass of the cut portion was determined by separating the stem (including main stem and any primary branches) from the leaves and drying at 75°C for one week. Total biomass yield included the biomass of the portion cut at 100 d plus the biomass of the whole plant at the time the plants were harvested.

Plant Measurements

Nine individual plants were randomly sampled for each treatment (three from each replicate) by pulling from the soil with their roots and transferring to the laboratory. Plant height and stem diameter at ground level were recorded. Each plant was then separated into root, main stem, primary branches, secondary branches, total leaves (all leaves of all ages from main stem, primary and secondary branches combined), open flowers, and unopened flowers (before anthesis). Fresh and dry weights of these tissues were determined as stated earlier. The number of primary branches, secondary branches, and open flowers per plant was recorded in order to assess the effect of cutting the plants at different heights of the main stem on these plant parts and, ultimately, on total vegetative and flower biomass.

Nutritional Analysis

Analysis of plant parts for macro and micronutrients was carried out on representative sub-samples of roots, main stems, primary branches, secondary branches, aggregate leaves (representing senescing leaves from the main stem and fully expanded leaves from primary and secondary branches in almost equal dry weight proportions), open flowers, and unopened flowers. Three sub-samples, one from each replicate, were used for analyses of each plant part. Tissues were dried in a forced-air oven at 70°C for 7 days, ground, passed through 0.6 mm sieve, and extracted (except for N and C) following the standard procedure for determining elements in plant tissue (Hanlon et al., 1994). The elements in the extracts were determined using Inductively Coupled Argon Plasma Spectroscopy (ICAPS; Model 61E Thermo Jarrell Ash Inc., Franklin, MA). Sub-samples of finely ground plant material were analyzed for total N and C using a Carol Erba NA 1500 C and N Analyzer, Valencia, CA.

Leaf Area Measurements

Leaf area was determined on senescing leaves taken from main stems and on fully expanded leaves from primary and secondary branches. Four leaf samples from each of these tissues, each consisting of 15 leaves, were used per replication. Leaf area was measured with a Leaf Area Meter, Model CI-201, CID Inc., Moscow, Idaho. Fresh and dry weights were then determined in order to establish area and weight differences among leaves located on the main stem, primary branches, and secondary branches.

Data analysis

Analysis of variance and separation of means were performed using Duncan's Multiple Range Test at < 0.01 and < 0.05 probability levels of the Statistical Analysis System (SAS Institute, 1985).

RESULTS

Cutting the main stems of one hundred-day old sunn hemp plants at 30, 60, and 90 cm above the soil surface induced a number of major morphological changes in comparison to uncut (control) plants. Cutting the main stem significantly reduced plant height at maturity, increased stem diameter at 60 and 90 cm cutting heights, and increased the number of flowers per plant (Table 1). The greatest response to stem cutting was exhibited by the 90 cm cutting height treatment, progressively diminishing with response as the cutting height was lowered.

Morphological changes induced by cutting the main stem were also coupled with significant changes in weight of all measured plant parts. Fresh and dry weights of roots increased significantly only in plants cut at height of 90 cm but not at 30 and 60 cm (Figure 1A).

Main stems responded negatively to cutting (Figure 1B), and the greatest reduction in stem weight was noted in the 30 cm followed by the 60 cm treatment. At 90 cm cutting height, stem weight was not reduced compared to uncut plants.

The greatest response to cutting the main stem was exhibited by highly significant (< 0.01) increases in number (Figure 2) and weight of primary (Figure 3A) and secondary (Figure 3B) branches. The number of both primary and secondary branches significantly increased in the 90 cm cutting treatment. Fresh and dry weight increases in primary branches were significant and linear with cutting height, with the highest weight increase in primary branches in plants cut at 90 cm followed by plants cut at 60 cm. Weight of primary branches in the 30 cm cut treatment did not differ from the control.

The effect of cutting the main stem on weight of secondary branches was noticed only in the 90 cm cutting treatment (Figure 3B). Cutting at 30 and 60 cm had no significant effect on weight of secondary branches. Weight in-

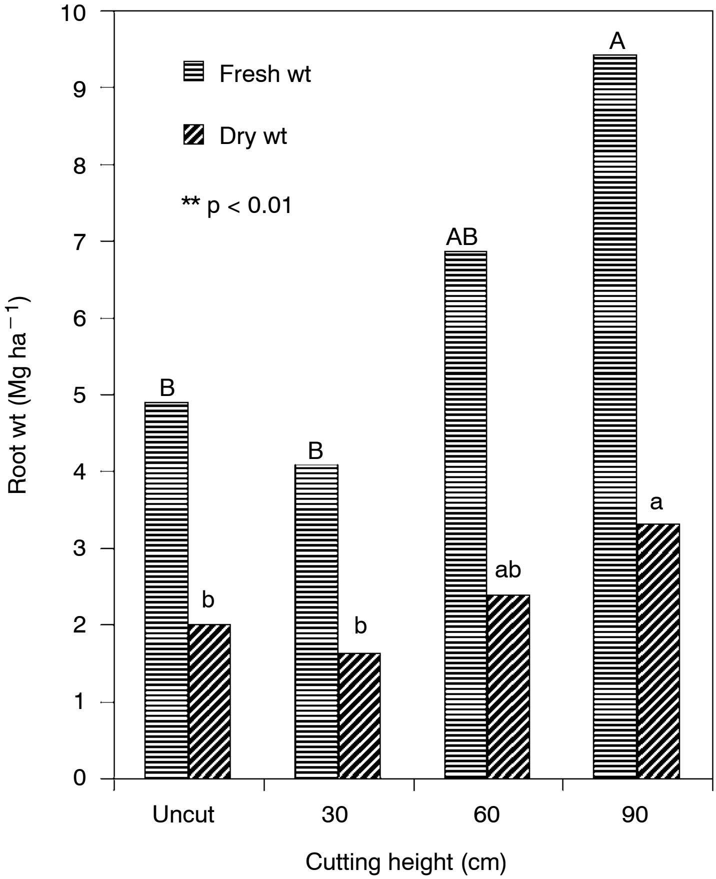
TABLE 1. Effect of cutting the main stem of 100 day-old sunn hemp plants on height, stem diameter and number of open flowers per plant seventy days after cutting.

Cutting height (cm)	Plant height (cm)	Stem diameter (mm)	Open flowers No./plant
Uncut	327 a[z]	23 b	24 b
30	225 c	21 b	45 ab
60	255 b	26 ab	68 ab
90	258 b	31 a	86 a

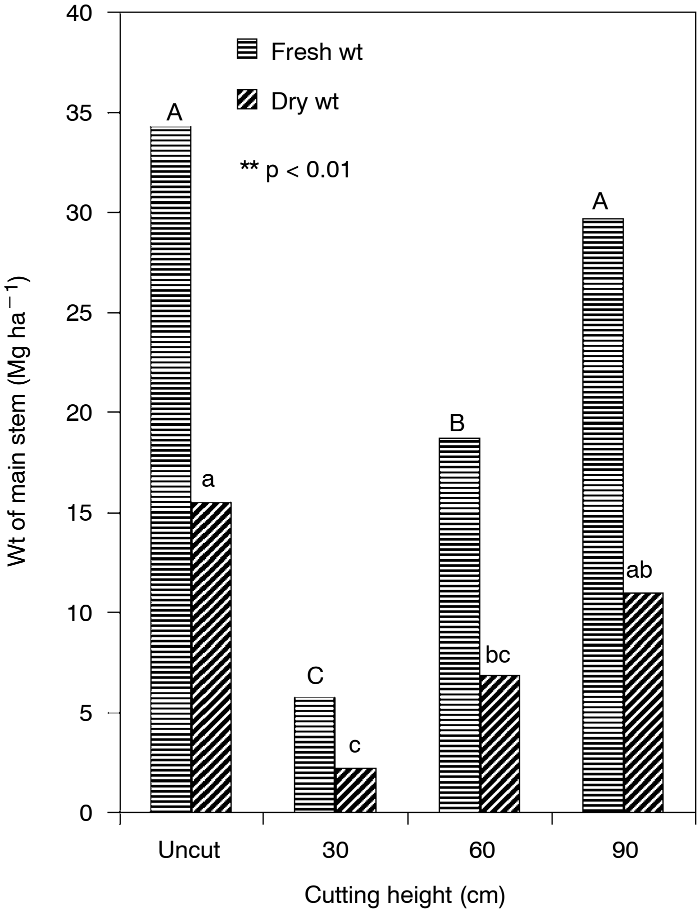
[z] Values in same column followed by the same letter are not significantly different at 5% level by Duncan's multiple range test.

FIGURE 1. Fresh and dry weights of roots (1A) and main stems (1B) of sunn hemp plants as affected by cutting the main stems at 30, 60, and 90 cm above soil surface.

1A



1B



creases in primary and secondary branches in response to cutting the main stem were identical to increases in number of branches induced by cutting (Figures 2, 3A, 3B). A highly significant increase ($p < 0.01$) in number of primary and secondary branches over the control was noticed in the 90 cm cutting treatment.

Data on the effect of cutting the main stem on leaf weight per plant showed that cutting the plants at 30 cm height slightly (but not significantly) increased fresh and dry weights in comparison to the control (Figure 4).

Cutting the main stem at 60 cm height resulted in fresh and dry leaf weights similar to the control, whereas cutting the stem at 90 cm significantly

FIGURE 2. Number of primary and secondary branches for sunn hemp plant as affected by cutting the main stem at 30, 60, and 90 cm above soil surface.

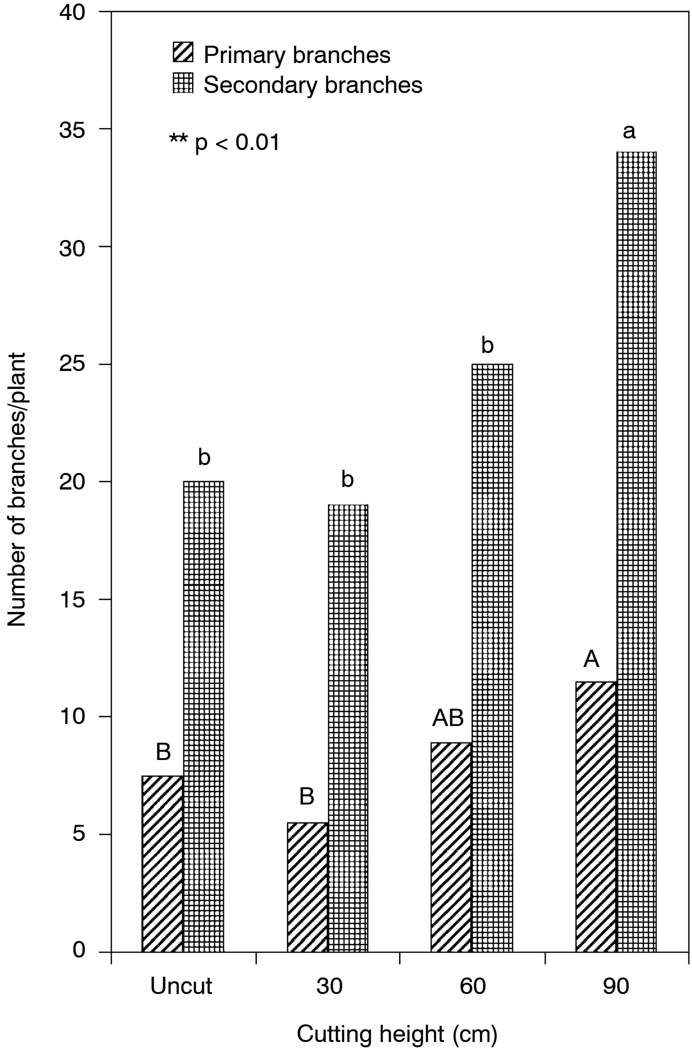
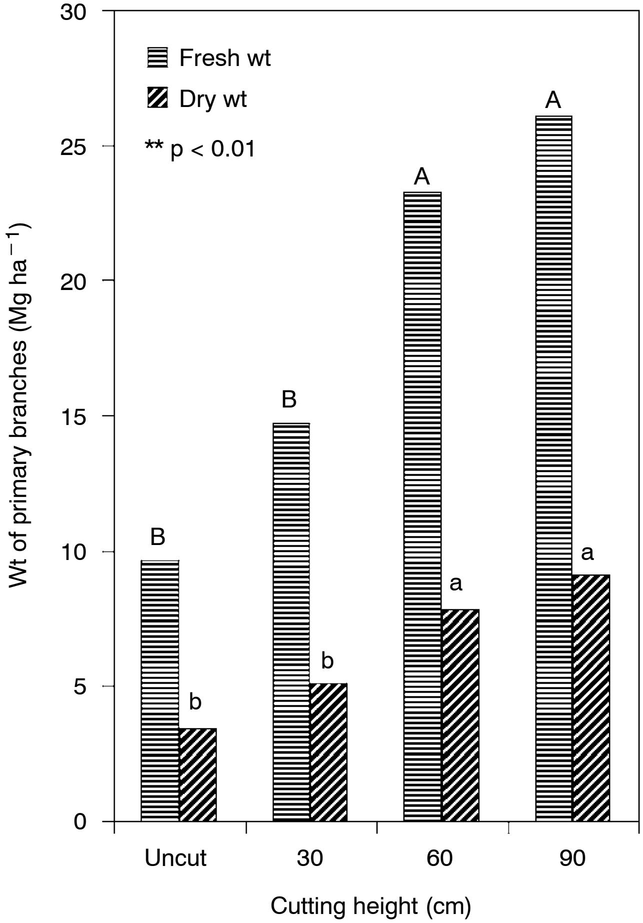
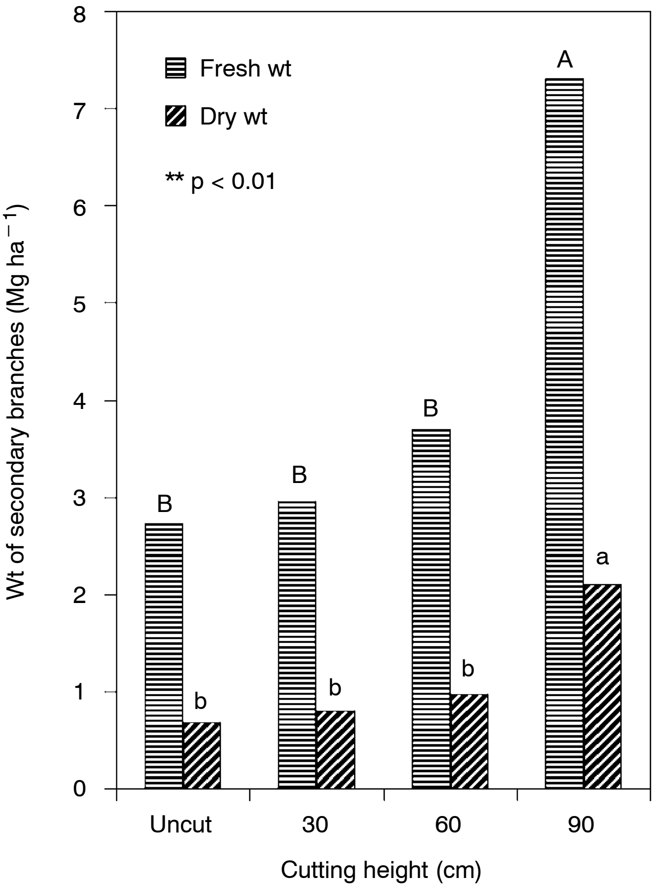


FIGURE 3. Fresh and dry weights of primary (3A) and secondary (3B) branches of sunn hemp plants as affected by cutting the main stem at 30, 60, and 90 cm above soil surface.

3A

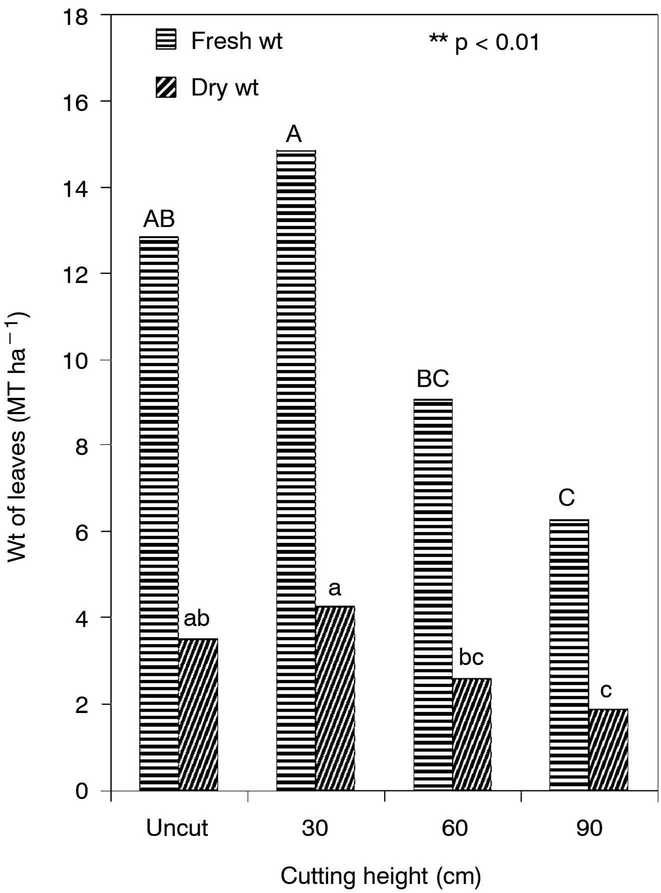


3B



reduced leaf weight per plant. As noted previously, cutting the main stem induced the formation and growth of many primary and secondary branches (Figures 2, 3A and 3B). Fully expanded leaves on these newly formed branches were younger and consequently smaller in size, weight, and surface area than leaves on the main stems (Table 2). Although no attempt was made to separate leaves on the basis of age, we noticed that these young leaves on primary and secondary branches comprised a higher percentage (both by number and weight) of the total leaves per cut plant than in the uncut control. Furthermore, the fully mature green leaves on primary and secondary branches were photosynthetically more active than those on the main stem as

FIGURE 4. Fresh and dry weights of leaves of sunn hemp plants as affected by cutting the main stem at 30, 60, and 90 cm above soil surface.



reflected by their significantly higher N content. They probably provided most of the synthates to the pods as new pods were formed.

Cutting the main stem at all heights increased the weight of open flowers per plant though only cutting at 90 cm height significantly increased their weight over the control (Figure 5A). Similar results were obtained on unopened flowers (Figure 5B), i.e., only cutting the stem at 90 cm height significantly increased their weight over those of unopened flowers in the other three treatments.

TABLE 2. Fresh weight, dry weight, and leaf area of sunn hemp leaves taken from main stem, primary and secondary branches of uncut control plants.

Leaf position on plant	Weight/15 leaves		Area/15 leaves
	Fresh wt. (g)	Dry wt. (g)	(cm^2)
Main stem	6.7 a[z]	1.8 a	386.0 a
Primary branches	4.2 b	1.3 b	226.7 b
Secondary branches	2.4 c	0.7 c	113.7 c

[z] Means in the same column with same letter are not significantly different at 5% level by Duncan's multiple range test.

Distribution of Biomass Among Plant Parts

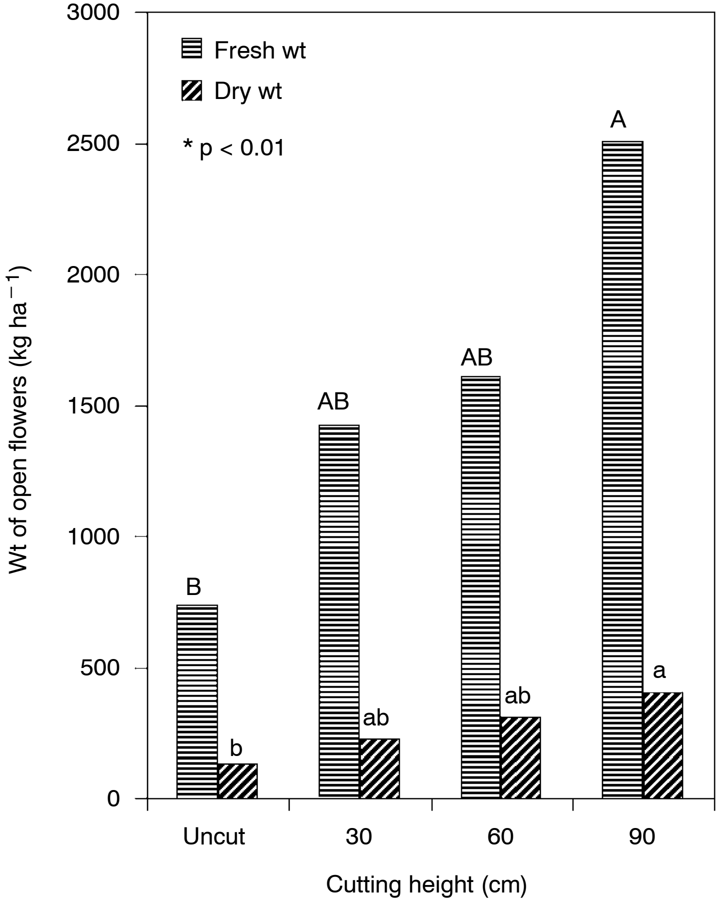
Table 3 sums total dry biomass of each plant tissue as affected by cutting height of the main stem. Total dry biomass of each tissue was obtained by adding the dry biomass of the cut portion (i.e., the part of the plant that was removed when the main stem was cut at 30, 60 and 90 cm) to the dry biomass of the various plant parts at termination time. Weights of primary and secondary branches were combined with the main stem in Table 3 to present data more clearly. Our biomass yields are comparable to those reported by Li et al. (1999) on sunn hemp though the age of their plants was less. They reported a somewhat greater total biomass.

Expressed as percent of total plant biomass, root biomass was less than that of other parts (7.8% of total plant biomass) and increased with cutting height of the main stem to a maximum of 10.6% in the 90 cm cutting height treatment. Stem biomass (primary and secondary branches included) comprised 59.1% of total plant biomass in the 30 cm cutting height treatment about 72% of the 60 cm cutting height treatment, and about 77% in both the control and the 90 cm cutting height treatments. Stem biomass, in relation to total plant biomass, appeared high due to terminating the plants about two months past the optimum stage for plowing under as green manure. At this stage, the plants had already developed hard and thick stems. Similar results were reported by Mansoer et al. (1997) who showed an increase in stem/leaf ratio as plants advanced in age beyond the third week.

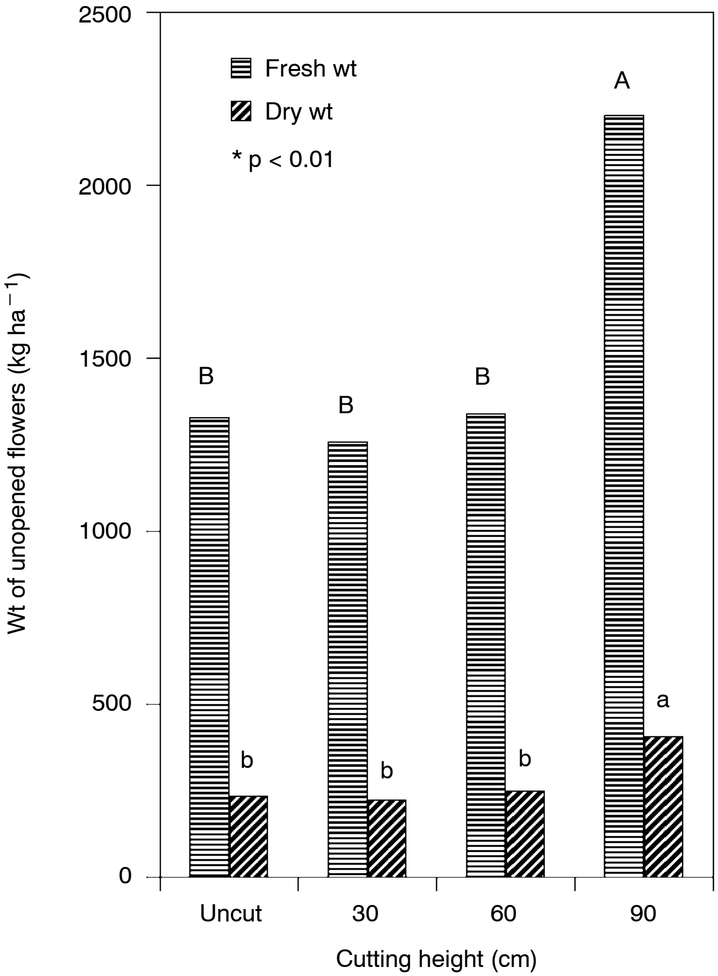
Total leaf biomass per plant ranged from a low of 10% in the 90 cm cutting height treatment to a high of 30.1% of total plant biomass in the 30 cm cutting height treatment. Total flower biomass (open plus unopened) increased progressively from a low of 1.2% in the control to a high of 2.6% in plants cut at 90 cm height.

FIGURE 5. Fresh weights of open (5A) and unopened (5B) flowers of sunn hemp plants as affected by cutting the main stem at 30, 60, and 90 cm above soil surface.

5A



5B



Nitrogen and C Contents of Plants

Nitrogen content varied dramatically from one plant part to another, whereas C content exhibited a low magnitude of change (Table 4). Percent N on a whole plant basis also changed with plant age and cutting height. Therefore, data in Table 4 on N and C contents, and on C/N ratios represent

TABLE 3. Sunn hemp plant parts as dry biomass and as percentages of plant total dry weight as affected by cutting height.

Cutting height (cm)	Cutting No.	Root	Stem[z]	Leaves	Flowers[y]	Total
		Mg ha^{-1}				
Uncut	First	n.a.[x]	0	0	0	0
	Final	2.0	19.7	3.5	0.3	25.5
	Total	2.0 (7.8)[w]	19.7 (77.2)	3.5 (13.7)	0.3 (1.2)	25.5 (100)
30	First	n.a.	2.9	1.4	n.a.	4.3
	Final	1.6	8.1	4.2	0.4	14.3
	Total	1.6 (8.6)	11 (59.1)	5.6 (30.1)	0.4 (2.2)	18.6 (100)
60	First	n.a.	2.3	1.3	n.a.	3.6
	Final	2.4	15.6	2.6	0.6	21.2
	Total	2.4 (9.7)	17.9 (72.2)	3.9 (15.7)	0.6 (2.4)	24.8 (100)
90	First	n.a.	1.7	1.2	n.a.	2.9
	Final	3.3	22.2	1.9	0.8	28.2
	Total	3.3 (10.6)	23.9 (76.8)	3.1 (10)	0.8 (2.6)	31.1 (100)

[z] Values include dry weights of main stem, primary, and secondary branches.
[y] Values include dry weights of open and unopened flowers.
[x] An undetermined value.
[w] Values in parentheses represent dry weights of plant parts as % of total plant weight.

TABLE 4. Nitrogen, carbon and C/N ratio of sunn hemp plant parts at 170 days after seeding.

Plant part	N (%)	C (%)	C/N
Root	0.6 g[z]	44.3 cd	77.5 a
Main stem	0.6 g	45.8 a	75.0 a
Primary branches	1.0 f	45.7 ab	48. 8 b
Secondary branches	1.9 e	44.5 cd	23.1 c
Leaves from main stem	2.0 e	39.1 f	19.7 cd
Leaves from primary branches	3.2 d	41.9 e	13.1 cd
Leaves from secondary branches	4.0 c	42.5 e	10.7 d
Open flowers	4.7 b	44.7 bc	9.6 d
Unopened flowers	5.8 a	44.4 cd	7.6 d

[z] Means in the same column with same letter are not significantly different at 5% level by Duncan's multiple range test.

percentages of these two elements in parts of the plant at termination time (170 d old plants) and should not be viewed as representative yields of N and C per ha of sunn hemp biomass for plants that are typically plowed under when they are 10 to 12 weeks old. This is because the plants were left purposely about 70 d past the optimum age for use as green manure in order to evaluate the effect of cutting the main stem on flower production. Nonetheless, they provided an idea of the N and C content of sunn hemp plant parts at an advanced stage of plant growth irrespective of the cutting treatment. The cutting treatment changed the C to N balance by changing the percent weights of specific plant parts differently in relation to total plant biomass. Data in Table 4 show the analysis of plant parts at 170 d after seeding, which corresponds to the growth stage when about 50-60% of the flowers on the plants were open. Percent N in roots and stems was the lowest among plant parts (about 0.6%). Percent N in the stems which depended on plant maturity (age), attained 0.6% in main stems, increased up to 1% in primary branches, and reached a maximum of 1.9% in the tender secondary branches.

Leaf N was about 2% in the older, senescing leaves of the main stem. However, leaf N was 3.2% in fully expanded leaves of primary branches, and reached 4% in fully expanded leaves of secondary branches. Highest tissue N was found in unopened flowers (5.8%) followed by that in open flowers (4.7%), whereas leaves ranked third. The N content was lowest in the lowest extremities of the plant and increased to the highest content at the top of the plant. Our results on N content of different plant parts support those reported by Frankenberger and Abdelmagid (1985) who showed that N concentration in plants is higher in leaves than in stems and roots.

Percent C among sunn hemp plant parts did not differ much and, in most parts, ranged from 44 to 46% (Table 4). A notable exception is the low (39.1%) C content of senescing leaves from the main stem compared to all other measured tissues. Because percent C did not change much among plant parts compared to N, C/N ratios are lowest in tissues that are high in N and *vice versa*.

Other Macronutrients

Table 5 shows the contents of Ca, Mg, K and P as percentages of tissue dry weight of 170 d old sunn hemp plants. Highest percent Ca and Mg was in senescing leaves from the main stem followed by leaves from the primary branches. Calcium content was lowest in the main stem and primary branches. Roots, main stem, and primary branches were lowest in Mg. Flowers (open and unopened) had the highest content of K and P. Leaves from primary and secondary branches were lower in K, than the flowers, primary

TABLE 5. Macronutrient content in sunn hemp plant parts at 170 days after seeding.

Plant part	Ca	Mg	K	P
	%			
Root	1.1 d[z]	0.1 d	1.1 b	0.10 e
Main stem	0.2 f	0.2 d	0.7 c	0.08 e
Primary branches	0.5 ef	0.2 d	1.0 b	0.12 de
Secondary branches	0.9 de	0.3 c	1.2 b	0.21 c
Leaves from main stem	7.5 a	0.5 a	0.4 d	0.15 d
Leaves from primary branches	4.8 b	0.4 b	0.6 c	0.23 c
Leaves from secondary branches	4.2 c	0.3 c	0.5 cd	0.20 c
Open flowers	0.8 de	0.3 c	2.0 a	0.47 b
Unopened flowers	1.0 d	0.3 c	2.1 a	0.60 a

[z] Values in same column followed by same letter are not significantly different at 5% level by Duncan's multiple range test.

and secondary branches, and roots. Roots and main stems were lower in P than all other parts except primary branches.

Micronutrient Content

Tissue content of Zn, Cu, Mn, and Fe, expressed as mg/kg, differed significantly from one tissue to another (Table 6). Zinc content of main stem was lower than all other plant parts except roots and leaves from main stem. Copper content of flowers and leaves from secondary branches was higher than that of all other plant parts except leaves from primary branches. Manganese content of roots, main stem, and branches was lower than that of any of the leaves. Lowest Mn content was in the main stems and primary branches. Iron content in the roots was much higher than that in any other plant tissue. The next highest Fe content was in flowers and leaves from the main stem.

DISCUSSION

The morphological and biomass changes induced in sunn hemps plants by cutting the main stem at various heights above soil level are evaluated based on two utilization goals. The first goal relates to plowing the crop under as a green manure or leaving it on the soil surface as organic mulch. This goal is less relevant than the second because the plants were kept well beyond the age of 10 to 12 weeks recommended by many researchers for use as mulch or

TABLE 6. Micronutrient content in sunn hemp plant parts at 170 days after seeding.

Plant part	Zn	Cu	Mn	Fe
	mg kg^{-1}			
Root	11.3 cd[z]	9.2 bc	17.4 e	328.6 a
Main stem	7.14 d	3.6 d	10.8 e	28.2 f
Primary branches	14.0 bc	7.0 c	11.8 e	44.8 ef
Secondary branches	19.2 b	9.1 bc	17.9 e	42.0 ef
Leaves from main stem	2.9 bcd	7.2 bc	176.0 a	73.2 cd
Leaves from primary branches	16.8 bc	10.1 ab	127.8 b	67.5 de
Leaves from secondary branches	18.7 b	12.4 a	87.3 c	61.2 de
Open flowers	45.6 a	12.5 a	46.8 d	101.7 b
Unopened flowers	39.9 a	13.0 a	32.2 de	97.6 bc

[z] Values in same column followed by same letter are not significantly different at 5% level by Duncan's multiple range test.

green manure (Arceneaux et al., 1932; Mansoer et al., 1997; Rotar and Joy, 1983; U.S. Dept. Agr., 1983). The second utilization goal relates more to the main objective of that research and evaluates the induced changes with respect to impact of cutting height on flowering.

If the sunn hemp crop is intended for use as a cover crop to be cut and left on the surface or incorporated into the soil as green manure, then practices that produce highest yields of high quality biomass (low C/N ratio and decomposition within a reasonable period) are most desirable. These conditions are best attained by seeding at high rates (55-65 kg ha^{-1}) and terminating the crop 10-12 weeks from planting date. Our data suggest that of all the cutting height treatments, cutting the main stem at 30 cm height came closest to these requirements because it produced the highest leaf biomass (Figure 4), induced adequate amount of primary and secondary branches (Figures 2, 3A and 3B), and kept biomass of roots and main stems (which have a high C/N ratio) lower than those in the other treatments (Figure 1A and 1B). In addition, when sunn hemp plants are allowed to grow longer than 10-12 weeks from seeding they develop hard stems and roots, deposit high levels of cellulose (45-60%) in the main stem (Natl. Acad. Sci., 1975), and undergo a significant reduction in leaf/stem ratio (Mansoer et al., 1997).

If the crop is intended for seed production, treatments that induce additional flowering are most desirable. Since flowers in sunn hemp are formed in racemes only at terminal parts of secondary branches, treatments that increase the number and growth of secondary branches per plant are likely to produce the most flowers and, subsequently, the most seeds. The assumption for high seed production is that environmental conditions are favorable for flower fertilization and seed development. Our data provide evidence for the validity of this assumption by showing that cutting the main stem 90 cm above soil surface gave rise to the largest biomass yield (Table 3) and to the highest number of primary and secondary branches per plant (Figure 2). The same treatment that increased the number (Figure 2) and the weight (Figure 3A, B) of primary and secondary branches per plant also increased total biomass (Table 3) and the number of flowers per plant (Table 1; Figure 5A). The higher weight of unopened flowers in the same treatment over the other treatments including the control (Figure 5B), further supports the high potential of the 90 cm stem cutting treatment to produce flowers. It follows that this treatment met both objectives, namely, increasing biomass yield and flower production.

We had planned to pursue the experiment to seed harvest. However, the plants were badly damaged by Hurricane Irene on 15 October 1999. Nonetheless, we feel safe in inferring from the data that the treatment that produced the highest number of flowers per plant will most likely produce the highest yield of seed.

Sinclair et al. (1997) listed three major constraints that reduce biomass yield of forage crops during the winter months in south Florida. These constraints are: decreased incident solar radiation, limited rainfall, and low temperature. Both experimental (Kiniry et al., 1989) and theoretical (Sinclair and Horie, 1989) evidence indicate that the amount of crop biomass positively correlates approximately linearly with the amount of solar radiation intercepted by crop canopy. They defined this relationship as the radiation use efficiency (RUE, g mas per MJ solar radiation intercepted). It follows that the reduction of the gap between the actual yields and potential yiels should focus on (1) maximizing the fraction of incident solar radiation that is intercepted, and (2) increasing RUE.

Maximization of incident solar radiation in sunn hemp plants is attained by high plant densities. Both the germination of sunn hemp seeds and seedling growth are so rapid that weed growth is almost totally suppressed. In addition, the prolific and deep root system efficiently intercepts and sequesters nutrients into new biomass. This attribute reduces the need for fertilizer and consequently the leaching of nutrients into the groundwater. Furthermore, since RUE is closely linked to the N content of the leaves (Sinclair and Horie, 1989), and since the plant maintains a high N content (Table 4) and extensive foliage biomass (Table 3), it is likely that the sunn hemp plant maintains a high RUE. The efficiency of the canopy in intercepting incident radiation and the high RUE may explain the ability of the sunn hemp plant to produce high biomass yields in south Florida all year round even during the winter months.

The nutritional content of the sunn hemp plant reflects its ability to fix N and uptake macro- and micronutrients. Data on N and C in sunn hemp have been reported by others (Magistad et al., 1939; Mansoer et al., 1997; Rotar and Joy, 1983; U.S. Dept. Agr., 1983). Our data on N are within the range reported by these authors (120 B 300 kg ha^{-1} depending on termination age) although our plants were older at harvest. As for all other macro and micronutrients (Tables 5, 6), to our knowledge data on these elements in sunn hemp have not been published previously. The high content of Fe in the root tissue samples, compared to other tissues of the plant, may be partly due to root contamination by soil. Although the roots were washed several times, the possibility of contamination by soil cannot be ruled out.

We conclude that cutting the main stem at 30 cm above soil surface when plants are about 100 days old (1.5 m tall), produces high yield of quality biomass with a large amount of foliage and tender branches for use as organic mulch on the surface or for incorporation as green manure. On the other hand, with 150 cm tall plants that were planted in mid April, cutting the main stem at 90 cm height produces the largest biomass yield, induces more primary and secondary branches and subsequently yields the largest number of flowers per plant. Cutting main stems of 100-day old plants at 90 cm above soil surface appears to be a viable practice to maximize production of sunn hemp seeds economically in south Florida.

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