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Sorghum Accessions for Use as Cover Crops and Biofuel Feedstocks

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Abstract

Phenotypes of sorghum species (*Sorghum* sp.) have characteristics making them valuable summer annual cover crops and/or biofuel feedstocks for temperate climates. In field studies conducted at Urbana, IL, USA, fourteen USDA sorghum landrace accessions and three commercial sorghum accessions were evaluated for their growth habits and regrowth potential. In Canonical Discriminant Analysis (CDA) analysis, the first two canonical variates were significant and accounted for 86% of the among-accession variability. Unmown tiller number, regrowth tiller number, and regrowth biomass best discriminated between accessions in CDA and scattergrams. The accessions clustered into three subgroups. Three multi-stemmed accessions (two commercial varieties and one USDA accession) with an ability to regrow clustered away from the bulk of the USDA sorghums. Multi-stemmed accessions are useful for breeding improved summer annual cover crops that are tall, produce copious amounts of biomass, and rapidly regrow after defoliation; although propensity to lodging and poor germination of accessions will need attention. Additionally, landrace sorghum accessions in the USDA germplasm collection are useful for breeding cover crop and biofuel feedstocks, due to their great height and biomass production, although it will be necessary to select for improved regrowth potential. Crosses between USDA landraces and

the commercially available multi-stemmed accessions could lead to a sorghum cover crop and biofuel plant with great biomass and height and ability to regrow following defoliation.

Keywords: Sorghum, accessions, Canonical Discriminant Analysis, cover crops, biofuel

1. Introduction

1.1 Background

Sudangrass (*Sorghum sudanense* [Piper] Stapf.) rapidly closes canopy, reaches heights of 3m, produces up to 8 MT ha^{-1} shoot biomass, and immobilizes nutrients, making it more competitive than weeds (Ngouajio *et al.*, 2003; Snapp *et al*., 2005). Its terminal buds and basal and axillary tillers allow sudangrass to be repeatedly mown at 15 to 20 cm (Chamblee *et al*., 1995) and to re-grow following cutting (Bicksler *et al*., 2012; Muldoon, 1985). Most research on weed suppression has used a relatively few commercially available sorghum cultivars from the United States (Czarnota *et al.*, 2003; Nimbal *et al*., 1996). Moreover, sorghum species have the potential to be used as a biofuel through cellulosic ethanol conversion or as a powerplant feedstock (Hallam *et al*., 2001; Murray *et al*., 2008; Rooney *et al*., 2007), but research has also tended to focus on commercially available cultivars (Venuto and Kindiger, 2008; Zhao *et al*., 2009). The United States Department of Agriculture (USDA) maintains a sorghum germplasm repository with over 32,000 accessions from around the world (GRIN, 2013) with traits that could prove useful for weed suppressive cover crops or as biofuel feedstock.

1.2 Weed Suppression Potential

Weed suppression from sorghum cover crops may be improved by identifying cultivars or accessions with more competitive growth habits. Traits important for weed suppression by cover crops include: rapid biomass production, tall height, large surface area index, ability to regrow following defoliation to maintain interference against weed species, allelochemical production, and adaptation to local environmental conditions (Foley, 1999; Teasdale, 1998). Among these, increased height producing much biomass has been found to increase weed suppressive ability in cereal crops (Murphy *et al*., 2008; Foley, 1999). Cover crop light reduction originating from rapid growth rates, high shade tolerance, and competitive completion for light can effectively suppress weeds (Bicksler and Masiunas, 2009; Perry and Galatowitsch, 2006). Greenhouse research found that sudangrass regrowth after defoliation is important for suppressing Canada thistle, but tillering was not as important (Bicksler *et al*., 2012). The use of sorghum or sudangrass as a weed suppressing cover crop warrants further investigation. In other cereal cultivar studies, weed suppressive ability has varied considerably across cultivars (Hoad *et al*., 2008). Understanding the traits that make sorghum accessions have high weed suppressive ability would be beneficial for breeding or selecting improved weed-suppressive cover crops.

1.3 Allelopathy Potential

Besides their competitiveness, sorghum species can be allelopathic, inhibiting the growth of weeds. Sorgoleone (2-hydroxy-5-methoxy-3-[(*Z*,*Z*)-8’,11’,14’-pentadecatriene]-*p*-benzoquinone) and dhurrin (p-hydroxy-(S)-mandelonitrile-β-D-glucoside) are major hydrophobic components of sorghum (Czarnota *et al*., 2003; Dayan, 2006; Weston and Duke, 2003). Allelochemical production varies according to genotypes (Czarnota *et al*., 2003;

Nimbal *et al*., 1996). Sorghum shoots, as a surface mulch or a soil-incorporated residue, release phenolic compounds and cyanogenic glucosides, such as dhurrin, that can suppress weeds (Nielsen *et al*., 2008). Traditionally, farmers in many developing countries have used sorghum as a weed suppressing mulch and leaf extracts as a natural herbicide (Cheema, 2000; Cheema *et al*., 2004; Sène *et al*., 2000). Differences in suppression of indicator plants vary between sorghum genotypes and have been correlated with phenolic concentration (Alsaadawi *et al.*, 2007; Ben-Hammouda *et al*., 1995). It may be assumed that increasing sorghum biomass is a useful trait to suppress weeds both by its physical presence and potential allelopathic potential.

1.4 Biofuel Crop Potential

Sorghum also has potential as a warm-season annual biofuel crop (Saballos, 2008; Rooney *et al*., 2007, Murray *et al*., 2008, Stefaniak *et al*., 2012). Sorghum has high productivity, drought tolerance, and many accessions likely vary in traits useful for biofuel crops, such as high amounts of lignocellulose, sugar, and starch (Rooney *et al*., 2007). Also, many of the traits that make sorghum a useful cover crop (height, tillers, ability to undergo defoliation, and large biomass production) could also make sorghum a useful biofuel feedstock (Hallam *et al.*, 2001; Saballos, 2008; Venuto and Kindiger, 2008), if accessions could be isolated for specific traits and targeted for breeding. The ability of late-maturing sorghums to regrow after defoliation would be beneficial in a temperate biofuel usage where repeated defoliations could be made during the growing season (Venuto and Kindiger, 2008).

1.5 Using CDA to Assess Genetic Diversity

Assessing genetic diversity in sorghums (Teshome *et al*., 1997), hairy vetch (Yeater *et al*., 2004), and tall fescue (Vaylay and van Santen, 2002), has used Canonical Discriminant Analysis (CDA). CDA is an effective research tool because it can be paired with a nonhierarchical clustering procedure to group accessions into smaller subgroups that are most similar to each other (SAS Institute, 1999b; Yeater *et al.*, 2004). By joining CDA, clustering procedures, and graphical representations, accessions can be differentiated by phenotypic characteristics of importance for cover cropping and biofuel applications.

1.6 Purpose of the Study

The interest in sorghum as a temperate annual cover crop and its potential as a biofuel, coupled with the limited availability of commercial sorghum cultivars, formed the rationale for the present study. The purpose of this research was to identify *Sorghum sp.* accessions with potential for use as cover crops and/or biofuels. We hypothesized that the multi-stemmed accessions would segregate from the rest of the landraces based upon tiller number and regrowth following defoliation. We also hypothesized that several of the USDA landraces would be capable of producing large quantities of biomass and be tall.

2. Materials and Methods

2.1 Sorghum Accessions

Sorghum accessions were identified in the USDA's Genetic Resources Information Network (GRIN, 2013) by querying the Southern Regional Sorghum Germplasm Collection (Griffin, GA, USA) for accessions with large height, numerous tillers, and midrib moisture, in order to focus on accessions with potentially beneficial traits for use as a cover crop or biofuel. Representative commercial sudangrass accessions were obtained from Seeds of Change, NC+

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Organics, and Welter Seed and Honey American seed companies and were sold as either animal forage or cover crops (Table 1). Characteristics useful for biofuel and cover crops include: large unmown mass, large regrowth mass and large total mass.

Table 1. Name, source, species, origin, and given trait information of various sorghum accessions used in the experiment.

Name	Source[a]	Species	Origin	Given Traits[b]		
				Height (cm)	Tillers (# plant^{-1})	Midrib[c]
Akur Gok	PI 152591	*Sorghum bicolor*	Kenya	430	5	dry
Andiwo	PI 521346	*S. bicolor* (L.) Moench ssp. *drummondii*[d]	Kenya	346	-	dry
'Black African Sorghum'	Seeds of Change	*Sorghum bicolor*	Africa	275	-	-
Budy	PI 152611	*Sorghum bicolor*	Kenya	410	2-5	dry
FAO 49967	PI 562367	*Sorghum sp.*[e]	Kenya	185	1	juicy
IS22852	PI 570074	*Sorghum bicolor*	Sudan	500	2	dry
Juar 20	PI 164416	*Sorghum bicolor*	India	310	3	inter
Kamuria	PI 152955	*Sorghum bicolor*	Kenya	240	0	inter
Macro Chaeta 4	PI 563237	*Sorghum bicolor*	Kenya	167	2	dry
Muembe	PI 153877	*Sorghum bicolor*	Kenya	375	2	dry
Ndola	PI 152904	*Sorghum bicolor*	Kenya	285	1	inter
Ochuti	PI 521344	*S. bicolor* (L.) Moench ssp. *Drummondii*	Kenya	245	0	dry
Ogolo	PI 521341	*S. bicolor* (L.) Moench ssp. *Drummondii*	Kenya	275	-	dry
Orolo	PI 153830	*Sorghum bicolor*	Kenya	225	3	inter
'Special Effort'	Welter Seed	*S. bicolor* Moench x *S. sudanense* [Piper] Stapf.	USA	NA	NA	NA
Stoneville Synthetic	PI 542962	*Sorghum bicolor*	USA	NA	NA	NA
'Sweetleaf II'	NC+ Organics	*S. bicolor* Moench x *S. sudanense* [Piper] Stapf.	USA	NA	NA	NA

[a] Provenance numbers (PI) from USDA germplasm collection; Southern Regional PI Station, Griffin, GA, USA.

[b] Height, tiller number, and midrib description from USDA website information

(www.ars-grin.gov/npgs/searchgrin.html) or description of seed company.

[c] Midrib traits describe moisture content of midrib of leaf: dry, juicy, or intermediate (inter).

[d] Full name is *Sorghum bicolor* (L.) Moench ssp. d*rummondii* (Nees ex Steud.) De Wet ex Davids.

[e] Unknown species.

2.2 Field Study Location

The study was conducted in 2007 and 2008 using fourteen USDA landrace accessions and three commercial cultivars (Table 1). Field experiments were conducted at the University of Illinois' Vegetable Crops Research Farm in Champaign, Ill, USA, which experiences a humid continental climate with severe winters, no dry season, and hot summers. It is classified as a Dfa Köppen-Geiger classification (Climatemps, 2015) and a USDA Plant Hardiness Zone 5a. The soil type was a Flanagan silt loam (fine montmorillonitic, mesic Aquic Agridoll), with a soil pH between 6.5 and 7.1, soil organic matter content between 4.3% and 4.7%, and cation exchange capacity (CEC) between 12 meq/100 g and 16 meq/100 g. From June to October, the mean monthly temperatures ranged from 15.5^{o}C to 25.7^{o}C in 2007 and from 12.7^{o}C to 23.2^{o}C in 2008, while the total monthly precipitation ranged from 3.8 cm to 14.4 cm in 2007 and from 1.9 cm to 20.7 cm in 2008. On March 26 and 23 in 2007 and 2008, respectively, 129 kg ha^{-1} N, 113 kg ha^{-1} P, and 135 kg ha^{-1} K was broadcast applied to the experimental site. The site was disked using a tandem disk-harrow and rototilled to remove emerged weeds and prepare for planting on June 15 and 6 in 2007 and 2008, respectively.

2.3 Experimental Design

The experiment was conducted as a randomized complete block design with four replicates and two subsamples for each treatment. Treatments were the 17 sorghum accessions. Plots were 1.44 m^2 and contained two plants of a single accession, spaced 61cm between plants.

2.4 Plot Establishment

On June 20 and June 12 in 2007 and 2008, respectively eight seeds per plot (4 seeds in each planting hole) of each sorghum accession were hand seeded at a depth of 1.3 cm into freshly prepared soil and hand watered twice weekly until established (3 weeks after planting). At 14 days after planting (DAP), emergence was recorded as a ratio of seeds emerged to seeds planted (8) in each plot. At the same time, emerged seedlings were thinned to two plants per plot with a spacing of 61cm between plants. Weeds were managed using disking and hand-pulling. One plant per plot was defoliated 2.5 months after planting to evaluate regrowth and tillering after simulated mowing, and the other plant was allowed to grow until maturity.

2.5 Dependent Variables

At 79 DAP in 2007 and 82 DAP in 2008, when many of the landrace varieties were just beginning to flower, reaching their maximum size, one plant in each plot was cut at a height of 10 cm to measure regrowth and tillering ability. At 132 DAP in 2007 and 121 DAP in 2008, the experiment was terminated. Sorghum final free-standing height and final number of shoots were measured for both plants without defoliation and the regrowth of the cut plants. Sorghum free-standing height was measured from the soil surface to the tallest naturally occurring apex of leaves. Shoot numbers (tillers) were counted at the base of each plant. Shoots were cut at the soil surface, chipped in a chipper-shredder to allow easier handling,

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and weighed for wet mass. Five hundred gram subsamples of chipped shoots were dried at 70 ^{o}C until constant mass, and weighed. Total shoot dry mass was extrapolated from total fresh mass and subsample dry mass.

2.6 Data Analysis

Data were analyzed using Canonical Discriminant Analysis (CDA) and a nonhierarchical clustering method on the seven continuous variables (unmown height, regrowth height, unmown dry mass, regrowth dry mass, unmown tiller number, regrowth tiller number, and emergence). These analyses were conducted using the CANDISC and FASTCLUS procedures in SAS (SAS Institute; Cary, North Carolina, USA). In CDA, a classification variable (sorghum accessions) and measured traits were analyzed to derive canonical variables (SAS Institute, 1999a; Yeater *et al*., 2004). Canonical variables were used to group the accessions into clusters with small within-cluster variation relative to between-cluster variation. Mean values of canonical variables (group centroids) were then used to calculate distances between centroid values of each group called the Mahalanobis distance (D^2) (Yeater *et al*., 2004). Then, a *k*-means approach was used in a nonhierarchical clustering procedure (FASTCLUS) to assign all accessions to similar clusters (SAS Institute, 1999b). In addition to CDA and clustering, the accessions with the best ability to produce biomass and height and to regrow after mowing were identified using Fisher's Protected LSD and three-dimensional scattergrams. Accessions were compared to an ideotype of sorghum that would best suppress weeds and act as a biofuel based upon: 1) tall height, 2) large quantity of biomass, 3) ability to regrow to tall height, and 4) ability to regrow large quantity of biomass. All continuous and ordinal data were analyzed as linear mixed models using the MIXED Procedure of SAS. Both repeats and block were random factors, while sorghum accession was a fixed factor. For all dependent variables, degrees of freedom were adjusted using the Satterthwaite correction (Littell, *et al*. 2002), and normality of the raw data and residuals was evaluated using the UNIVARIATE procedure of SAS. When factors were significant, means were separated with Fisher's Protected LSD Test at an alpha = 0.05 using the PDMIX800 macro (Saxton, 1998). The scattergrams were constructed using the G3D procedure in SAS to evaluate overall unmown and regrowth plant stature and traits with greatest potential for cover cropping and biofuel use. Overall unmown plant growth was determined from the parameters of dry mass, number of tillers, and final height of sorghums grown to experiment termination without defoliation. Plant growth after mowing was determined from the parameters of dry mass, number of tillers, and height of the defoliated plants when the experiment was terminated.

3. Results and Discussion

3.1 CDA Clustering

Canonical discriminant analysis discriminated between sorghum accessions. The first two canonical variates accounted for 86% of among-sorghum accession variance. The canonical correlation was 0.97 between accessions and the first canonical variate, and canonical correlation was 0.82 between accessions and the second canonical variate, suggesting that these canonical variates can explain much of the differences in accessions. The first canonical discriminant function was influenced by loadings from unmown tiller number, regrowth tiller number, and regrowth biomass. The second canonical discriminant function was dominated by loadings from regrowth height, unmown height, and regrowth biomass. The first canonical variate has the most discriminatory power in separating class variables. The traits that loaded for the two canonical variates suggest the sorghum accessions differ most in their tillering and regrowth after defoliation. An accession that would function well as a cover crop should regrow from tillering stems following mowing because it increases competitive ability, modifies the cover crop canopy, and allows for repeated mowing (Foley, 1999). The two canonical variates were used to cluster the accessions into three groups (Figure 1). The Mahalanobis distances were 90 between clusters I and II, 17.7 between clusters I and III and 77.1 between clusters II and III. All pairwise differences between clusters were significant (P = <0.0001). Cluster groups display smaller within-cluster phenotypic variation than among-cluster phenotypic variation (Teshome *et al*., 1997; Vaylay and van Santan, 2002). Accessions in clusters I and III contained USDA sorghum accessions and one commercial cultivar (‘Black African Sorghum’). ‘Black African Sorghum’ was sold by Seeds of Change as a tall, early maturing, sorghum for use as a cover crop. Clusters I and III differed from each other mainly due to differences in height and regrowth biomass due to loadings of traits in canonical variate 2. Accessions in cluster II were two commercially-available hybrid sudangrass cultivars (‘Special Effort’ and ‘Sweetleaf II’) and the USDA’s Stoneville Synthetic sorghum that produce many tillers; all three accessions originated in the USA. ‘Special Effort’ and ‘Sweetleaf II’ sudangrass are marketed for their ability to produce many tillers and to regrow after grazing.

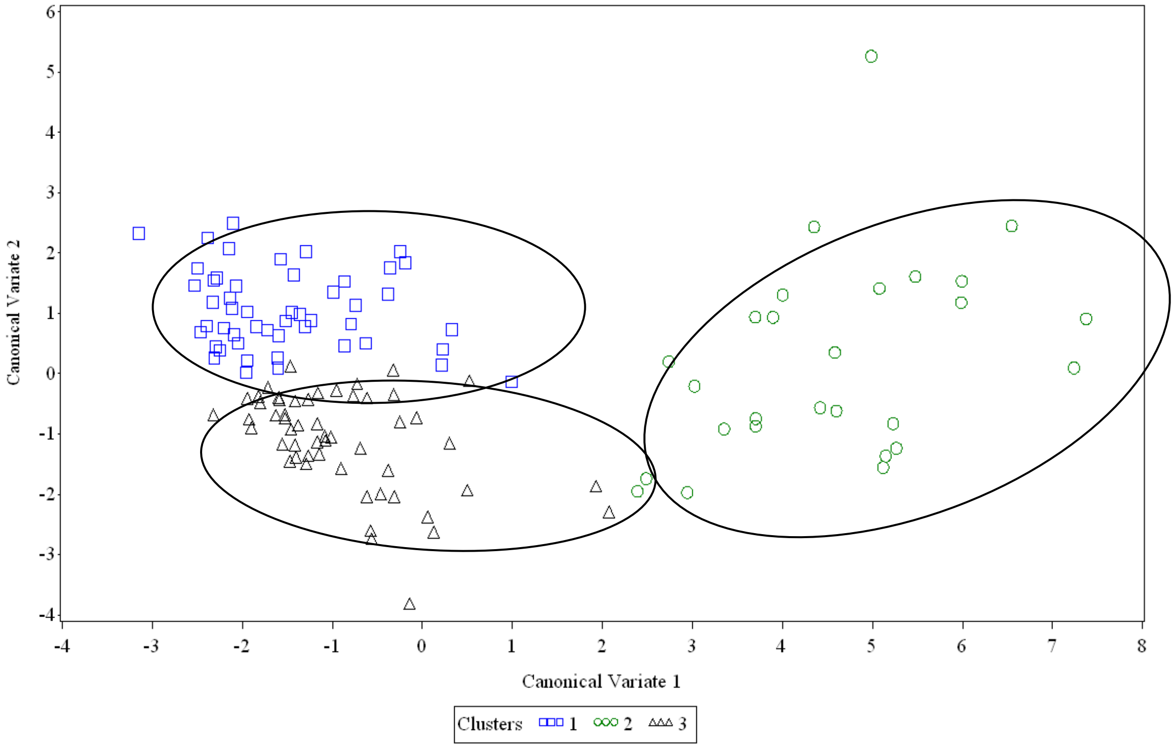

Figure 1. Scattergram of the Three Cluster Groupings on the Two Canonical Discriminant Functions for Sorghum Accessions.

Cluster groups were determined by PROC FASTCLUS in SAS using Mahalanobis Distance

(D^2) of the centroid values of two canonical variables. Seventeen accessions grown in both years were used in the cluster analysis. Cluster I includes Andiwo, FAO49967, Muembe, Ndola, Ochuti, and Ogolo. Cluster II includes ‘Special Effort,’ Stoneville Synthetic, and ‘Sweetleaf II’. Cluster III includes Akor Gok, ‘Black African Sorghum,’ Budy, IS22852, Juar 20, Kamuria, Machro Chaeta 4, and Orolo.

3.2 Emergence

Percent emergence was greatest using LSD for ‘Black African Sorghum,’ ‘Sweetleaf II,’ Muembe, Ochuti, Machro Chaeta 4, Kamuria, and Andiwo, averaging 77.6% (Table 2). Among the other commercial accessions, ‘Special Effort’ and Stoneville Synthetic averaged 50% emergence and four of the USDA sorghums averaged below 50% emergence, for unknown reasons. The seed from the USDA accessions may have been old, needing to be renewed.

Table 2. Effect of sorghum accession on emergence, averaged across 2007 and 2008 runs of the experiment.

Name	Emergence (%)
Akur Gok	43
Andiwo	75
‘Black African Sorghum’	85
Budy	52
FAO49967	36
IS22852	48
Juar 20	51
Kamuria	75
Macro Chaeta 4	76
Muembe	78
Ndola	51
Ochuti	77
Ogolo	59
Orolo	22
‘Special Effort’	46
Stoneville Synthetic	54
‘Sweetleaf II’	77
LSD within column	22.7***[a]

[a] P-value of ANOVA, where *P<0.05, **P<0.01, and ***P<0.001.

3.3 Biomass, Height, and Tillers

The greatest unmown dry mass plant^{-1} and unmown height was in several of the USDA landrace accessions (Muembe, Ochuti, Ogolo, Ndola, and Andiwo, averaging 1700 g plant^{-1} and 275 cm), as well as commercially available ‘Sweetleaf II’ (Table 3, Figure 2). Several USDA landrace accessions (Andiwo, Ogolo, and Ndola) were close to the ideotype for an unmown sorghum cover or biofuel crop, offering potential for breeding on the basis of unmown dry biomass and height, two parameters useful for a cover and biofuel crop (Figure 2). Three multi-stemmed accessions (‘Sweetleaf II,’ ‘Special Effort,’ and Stoneville Synthetic, averaging 117 g plant^{-1}) that clustered together using CDA and scattergrams had the greatest regrowth dry mass plant^{-1} (Table 3, Figure 3). 'Sweetleaf II' and 'Special Effort' had the greatest combined regrowth height, regrowth biomass, and regrowth tillers of the 17 accessions (Figure 3), suggesting they were good starting places for regrowth breeding, but are hybrids. Additionally, 'Special Effort,' and 'Sweetleaf II,' cultivars grouped together near the ideotype for an ideal cover crop (Figure 4), yet both could be improved by increasing unmown height and biomass, to make them equally useful for biofuel purposes.

Table 3. Effect of sorghum accession on unmown and regrowth height, unmown and regrowth biomass, and unmown and regrowth tillers, averaged across 2007 and 2008 runs of the experiment.

Name	Height[a] (cm)		Biomass[b] (g plant^{-1})		Tillers (# plant^{-1})	
	Unmown	Regrowth	Unmown	Regrowth	Unmown	Regrowth
Akur Gok	238	38	1372	4	7.5	2.7
Andiwo	314	94	1517	73	5.6	8.9
'Black African Sorghum'	231	76	880	37	7.5	8.3
Budy	201	52	1337	13	7.1	3.7
FAO49967	255	69	1456	39	7.5	8.4
IS22852	228	34	1201	6	9.3	2.7
Juar 20	216	105	480	41	9.0	9.9
Kamuria	215	59	898	16	5.0	3.1
Macro Chaeta 4	199	92	625	129	6.1	12.4
Muembe	260	38	1820	23	13.8	12.4
Ndola	282	64	1683	27	9.8	8.9
Ochuti	248	80	1780	51	5.9	6.6
Ogolo	271	80	1703	79	13.8	16.5
Orolo	210	75	1212	44	14.4	23.3
'Special Effort'	220	126	1039	182	30.8	41.9
Stoneville Synthetic	169	96	786	103	30.8	42.5
'Sweetleaf II'	247	130	1763	231	34.1	47.4
LSD within column	41.1***[d]	32.4***	457.1***	77.0***	5.3***	10.7***

[a] Height measured from ground to tallest free-standing leaf.

[b] Biomass measured on a plant-clump basis.

[c] Variances between years were not statistically significant for any dependent variable, so years were combined for analysis.

[d] P-value of ANOVA, where *P<0.05, **P<0.01, and ***P<0.001.

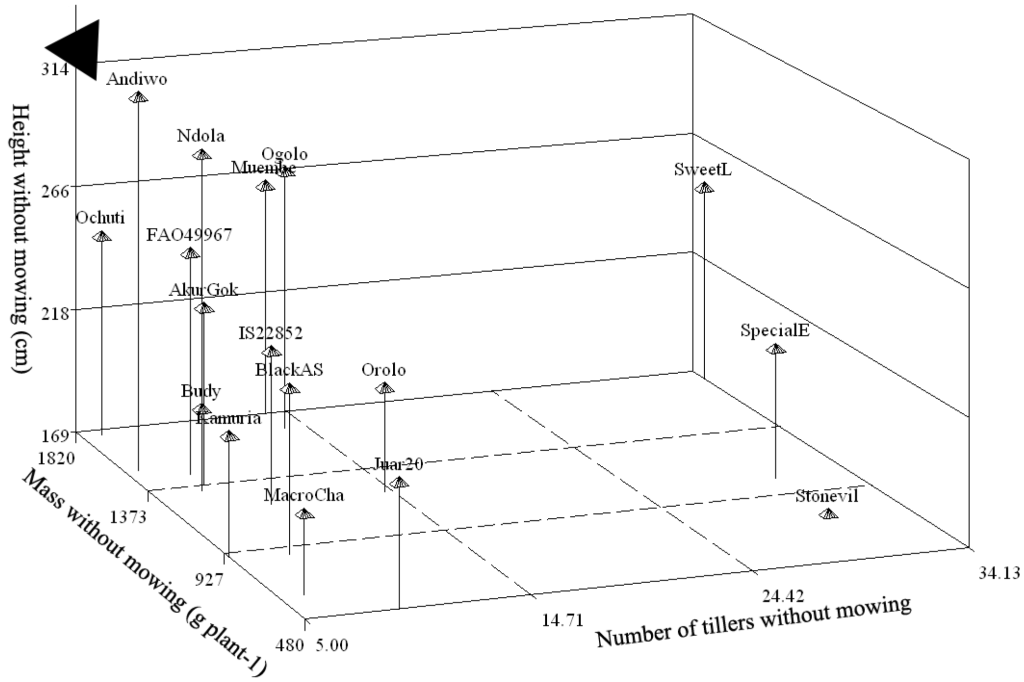

Figure 2. Scattergram of 17 Sorghum Accessions Clustered by Unmown Parameters (Unmown Tiller number, Unmown Dry Biomass, and Unmown Height), Averaged Across 2007 and 2008 Runs of the Experiment.

Black triangle represents sorghum ideotype for use as a cover crop or biofuel feedstock. Unmown data were collected 126 DAP.

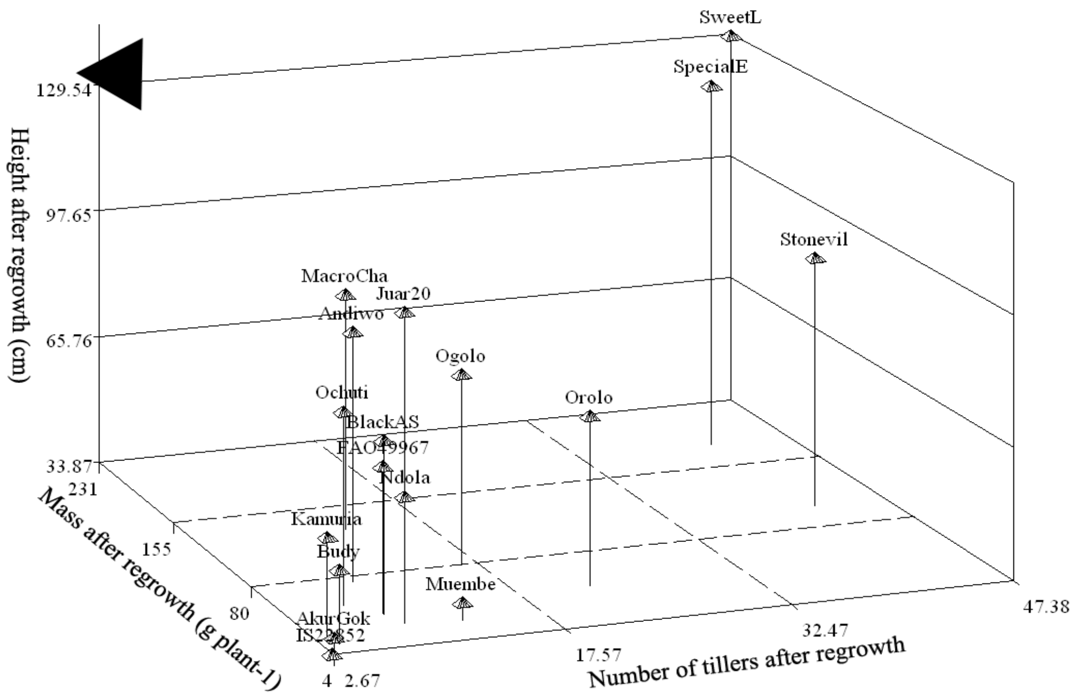

Figure 3. Scattergram of 17 Sorghum Accessions Clustered by Regrowth Parameters (Regrowth Tiller Number, Regrowth Dry Biomass, and Regrowth Height), Averaged Across

2007 and 2008 Runs of the Experiment.

Black triangle represents sorghum ideotype for use as a cover crop or biofuel feedstock. Regrowth data were collected 46 days after mowing.

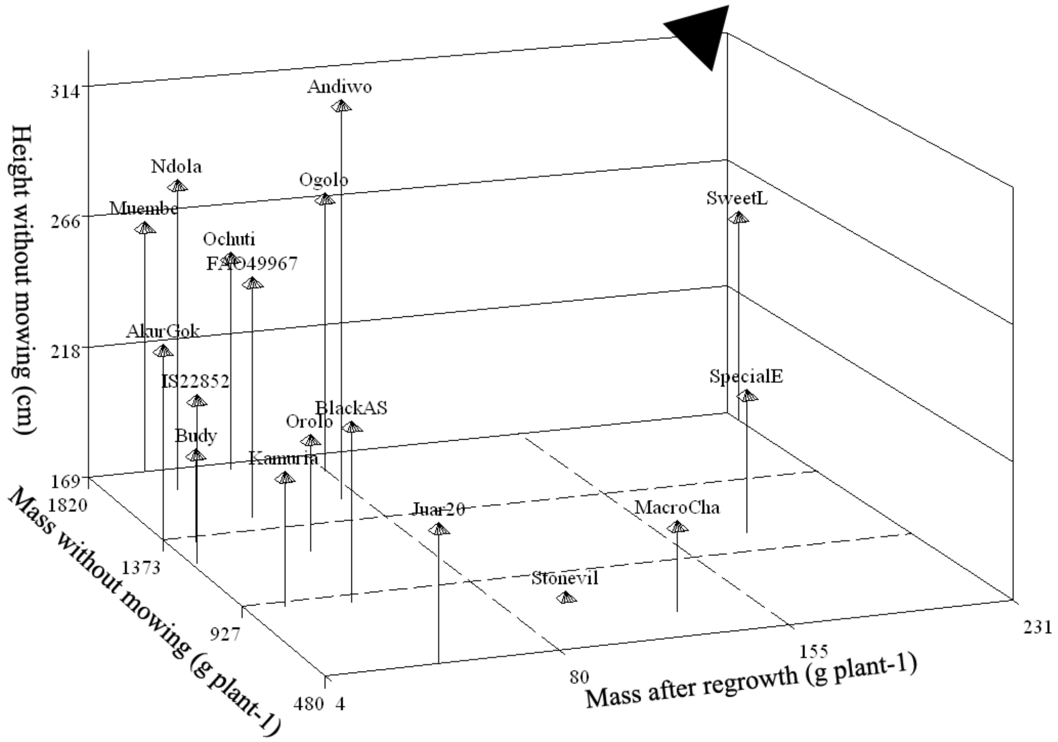

Figure 4. Scattergram of 17 Sorghum Accessions Clustered by Ideal Cover Crop Parameters (Unmown Height, Unmown Dry Biomass, and Regrowth Dry Biomass) Averaged Across 2007 and 2008 Runs of the Experiment.

Black triangle represents sorghum ideotype for use as a cover crop. Unmown data were collected 126 DAP and regrowth data were collected 46 days after mowing.

4. Conclusions

4.1 Sorghum's Potential as a Cover Crop

Regrowth mass and height is an important trait for summer annual cover crops to increase competitive ability, canopy diversity, and tolerance to mowing (Foley, 1999; Teasdale, 1998). Ability to regrow after mowing allows for increased mulch production, which can smother weeds. Of the three multi-stemmed accessions, 'Sweetleaf II' had greater number of unmown and regrowth tillers, unmown and regrowth mass, and regrowth height than 'Special Effort' or Stoneville Synthetic. Yet, regrowth ability alone does not maximize competitive ability. Initial unmown height and biomass (within first 2.5 months after planting) are also important for increased weed control (Murphy *et al.*, 2008), and were best exhibited by several of the USDA landrace sorghums such as Andiwo and Ogolo, consistent with Stefaniak *et al*. (2012), who found that biomass yields of biomass sorghums and sweet sorghums were greater than sorghum-sudangrass hybrids. The inbred parents of ‘Sweetleaf II’ and several of the USDA landrace sorghums might be a good starting point for breeding programs to increase both unmown and regrowth height and biomass of sudangrass cover crops. A combination of Andiwo’s and Ogolo’s unmown height and unmown biomass with ‘Sweetleaf II’s’ regrowth biomass could produce a cover crop with excellent overall competitive ability and regrowth potential following defoliation. Improvements to these accessions for use as cover crops should target: increasing emergence, reducing lodging, increasing unmown biomass and height, and increasing secondary traits, such as allelopathy.

4.2 Sorghum’s Potential as a Biofuel Crop

Assuming the feasibility of converting lingo-cellulose to usable fuels or using dried biomass directly in power plants, biofuel feedstock breeding on the basis of unmown mass (Saballos, 2008) could target these African USDA accessions. If multiple defoliations were desired for the biomass crop production, regrowth biomass production found in the multi-stemmed accessions would be the best for future research and crosses with the USDA landraces (Saballos, 2008).

4.3 Future Directions

Overall, CDA and nonhierarchical clustering, LSD, and scattergrams consistently discriminated sorghum accessions on the basis of phenotypic traits and commercial breeding. ‘Sweetleaf II,’ ‘Special Effort,’ and Stoneville Synthetic were in one cluster, while USDA sorghum accessions were in two different clusters that were similar in tillering to each other, yet differed in regrowth height, unmown height, and regrowth biomass. These three accessions of multi-stemmed commercial sorghums originating in the USA with excellent regrowth potential are a good starting point for farmers to use in cover cropping applications and for breeders to improve upon as summer annual cover crops. Increased cover crop growth, biomass production, and canopy production has been shown to be directly related to weed suppression (Foley, 1999). Our research has built upon the work of Rooney *et al*. (2007), Saballos (2008), and Venuto and Kindiger (2008) to distinguish USDA landrace accessions such as Muembe, Ochuti, Ogolo, Ndola, Andiwo, and Orolo, which would be excellent candidates for biofuel breeding and/or could be improved upon for regrowth potential as summer annual cover crops because of their height and biomass potential. But, their limited regrowth would not be favorable for multiple harvests. Crosses between USDA landraces and the multi-stemmed accessions could lead to a sorghum cover crop with great unmown biomass and height and ability to regrow following mowing, and would approximate a sorghum cover crop ideotype. Previous research on several sorghum accessions confirmed that sorghum had the lowest cost per ton of biomass produced compared to switchgrass, big bluestem, alfalfa, and reed canary grass (Hallam *et al*., 2001). This research has confirmed that several of the USDA’s accessions of landrace sorghums would be useful for biomass breeding (Stefaniak *et al*., 2012) and the effectiveness of CDA for rapid clustering of accessions for targeted traits (Teshome *et al*., 1997). Future research should examine optimal plant spacing, seeding density, and plant populations in field scale experiments for biofuel production (Goff *et al*., 2010).

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