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Nutrient Uptake Patterns of Five Sweet Sorghum Varieties to Estimate Harvest Removal Rates

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Abstract

Sweet sorghum (*Sorghum bicolor* (L.) Moench) is an emerging field crop with potentially greater ethanol production than corn (*Zea mays* L.). Currently, several ongoing investigations center on understanding the economic and agronomic yield potential of sweet sorghum, including varieties, soil fertility and water management. This two-year and five variety study seeks to document the nutrient uptake patterns of sweet sorghum harvested for ethanol production; such that, soil fertility specialists may develop nutrient harvest removal rates to improve soil fertility recommendations requiring crop maintenance rates. Sweet sorghum residues also have value as a soil surface protector from the impact of rainfall and subsequent soil loss via the erosion process. Depending upon variety, nitrogen total plant uptake ranges from 112 to 246 kg N/ha (100 to 220 lbs N/acre) across both years and across all varieties. Given that the stem component is the harvested material, approximately 15 to 35 percent of the total nitrogen plant uptake was field removed. Potassium rates of field removal were greater than that of nitrogen because total potassium nutrient uptake and the proportion of the total potassium in the stem component was also greater. Nutrient removal rates are documented N, P, K, Ca, Mg, S, Fe, Mn, B, Cu and Zn.

Keywords: sweet sorghum, nutrient uptake, nitrogen, potassium, ethanol production

INTRODUCTION

Sweet sorghum is a subtype of sorghum (*Sorghum bicolor* (L.) Moench), which in the continental United States is an annual having tall stems with substantial stem sugar contents [3, 4, 9]. Sorghum is a monocot (grass type plant) with C-4 photosynthetic capacity. Plant height typically ranges from 2.5 to 5 m (8 to 15+ feet) for most sweet sorghum cultivars. Cultivars may be identified by leaf shape, seed size and color, and panicle size and shape and juice content [3, 4, 9].

Several agricultural issues are becoming increasingly important in the United States and across the globe, with one key issue the emergence of lignocellulosic fuel production. There is concern and uncertainty involving the removal of the phytomass (the entire above the soil surface plant material) for fuel or industrial supply chain product development. Two immediate research initiatives include: (i) enhanced water erosion attributed to the removal of crop debris and the residue's ability to lessen the raindrop's kinetic energy and the subsequent reduction in soil structure integrity, and (ii) the loss of plant essential nutrients from the soil resource by phytomass removal.

In Nebraska, Wortmann et al [10] investigated the efficacy of sweet sorghum compared to corn for fuel ethanol production, noting that the smaller nitrogen requirements for sweet sorghum supported its usage for fuel ethanol. In Kansas, Blanco-Canqui et al [1] observed the influence of wheat (*Triticum aestivum* L.) and sorghum residue removal for cellulosic ethanol production on soil erosion potentials. They observed that the complete removal of the residue resulted in a 61% water runoff increase in wheat and 94 to 225% increase in water runoff in sorghum. Blanco-Canqui et al also observed increased sediment transport and soil reductions in soil organic carbon, total soil nitrogen and total soil phosphorus. In Texas, Booker et al [2] compared grain sorghum and cotton (*Gossypium hirsutum* L.), noting that nitrogen supported grain sorghum yield and, more importantly, that enhanced soil nitrogen supported a greater nitrogen increase in sorghum seed than for seedcotton. In Georgia, Sainju et al [8] conducted a large grain sorghum and cotton field trial involving multiple tillage treatments, multiple cover crop placements and various nitrogen fertilization rates. They reported that cover crops having forage legumes supported nitrogen uptake in sorghum. In Washington state, Kemanian et al [5] developed a model based on harvest index and the nutrient content of the residues to estimate nitrogen partitioning in four crops, including grain sorghum. In North Dakota, Krupinsky et al [6] investigated ten cropping systems, noting that spring wheat, proso millet (*Panicum miliaceum* L.) and grain sorghum were vary effective in supporting sufficient residue cover for conservation tillage.

In Kansas, Propheter and Staggenborg [7] observed the nutrient removal rates of dual purpose silage sorghum varieties, sweet sorghum, and corn (*Zea mays* L.) at two locations intended for lignocellulosic ethanol fuel production. They documented that total potassium uptake was cultivar sensitive and sweet sorghum generally showed greater nitrogen use efficiencies. Sweet sorghum was nitrogen fertilized at 168 to 180 kg N/ha at the two locations. Sweet sorghum (M81E) seed nutrient concentrations ranged from 20 to 28 kg N/ha, approximately 5 kg P/ha and approximately 7 kg K/ha. Dual purpose forage sorghums had greater seed nutrient concentrations, ranging from 74 to 90 kg N/ha, 16 to 21 kg P/ha and 15 to 78 kg K/ha. The stover ranged from 51 to 95 kg N/ha for the dual purpose forage sorghums to 103 to 182 kg N/ha for the sweet sorghum. Similarly, the stover ranged from 8 to 23 kg P/ha for the dual purpose forage sorghums to 15 to 41 kg P/ha for the sweet sorghum. For potassium the stover ranged from 175 to 294 kg K/ha for the dual purpose forage sorghums to 293 to 344 kg K/ha for the sweet sorghum.

The purpose of this manuscript is to describe the nutrient uptake patterns and the nutrient value of sweet sorghum residues. Residues produced by sweet sorghum have nutrient concentrations, that when returned to the soil, support: (i) sustainable agricultural practices, (ii) resist water erosion by raindrop interception, (iii) promote carbon sequestration, and (iv) limit off-field nutrient migration.

MATERIALS AND METHODS

Study Area and Design

The study area is in Cape Girardeau County (Missouri) and is located on at the David M. Barton Agriculture Research Center of Southeast Missouri State University. The soil is a member of the Wilbur series (Coarse-silty, mixed, superactive, mesic Fluvaquentic Eutrudepts), which consists of deep, somewhat poorly-drained soils having an Ochric-Cambic diagnostic horizon sequence. The climate is humid continental. Soil testing documented that the soil had a fertility index approaching 100%.

Five varieties of sweet sorghum (KNM, Theis, Topper, DA08, and M81E) were planted in early-June in 2012 and 2013 on a 0.77 meter (30 inch) row-spacing. Phosphorus and potassium fertilization was applied based on soil sampling. Nitrogen rates were 100 kg N/ha (90 lbs N/acre) applied as urea five weeks post-planting. Weed management was by hand. Tissue testing (N, P, K, Ca, Mg, S, Na, Fe, Mn, Zn, B, and Cu) and plant biomass accumulation were conducted at harvest. Plant organ sampling included total biomass and nutrient concentrations associated with culm (stem), leaf sheaths, leaf blades, and panicle, with total plant uptake and biomass accumulation estimated by the summation of the plant parts after the product of dry matter and nutrient concentrations. Biomass sampling involved randomly selecting four plants per plot from each of the five varieties. Manual separation of the plant parts was followed by drying at 70ºC for two days and then weighing. Population estimates were performed by counting all plants in a 3.1 meter row, which was replicated five times for each variety. The resultant plant population was approximately 33,000 plants per acre. All plant tissue analysis was performed by Mid-West Laboratories (Omaha, NE). Statistical analysis (mean, standard deviation, analysis of variance) was performed using Microsoft Excel.

RESULTS AND DISCUSSION

Assessment of the nutrient health is typically performed using appropriate plant organ sampling and plant tissue analysis. Sufficiency levels are routine nutrient bench-lines where plant tissue concentrations at or above the sufficiency levels infer adequate plant nutrition for each element. Using the sufficiency levels for grain sorghum [(http://www.clemson.edu/sera6/scsb394notoc.pdf)] (verified Oct 2016) and recognizing the sampled leaf blades are from the entire plant instead of the second leaf from the top of the plant and further recognizing that sweet sorghum is not grain sorghum, nitrogen is slightly deficient for all varieties and potassium is slightly deficient for the variety KNM. Phosphorus, Ca, Mg, Fe, Mn, Zn, Cu and Zn are considered sufficient. Sulfur sufficiency levels are not available; however, the sulfur tissue values appear acceptable. There exists a need for verified plant tissue sufficiency levels for sweet sorghum.

Dry Matter Production

Dry matter production is the accumulation of carbon-based material arising from the combined processes of net photosynthesis, nutrient uptake, water management, climatic influences and other factors. In this project, we are interested in the stem material and its nutrient content because the stem material is the harvested product for sweet sorghum syrup or ethanol production. In Missouri a sugarcane harvester is commonly employed to cut stalks, remove leaves and panicles. Only the stripped stems are field harvested.

Total stem dry matter production was greater for KNM in 2012, whereas total stem dry matter accumulation was greater for the remaining four varieties in 2013. For all varieties grown in 2012, the stem material possessed the greatest dry matter percentage relative to total plant dry matter (KNM at 78%, Theis at 73%, Topper at 70%, DA08 at 72%, and M81E at 78%) (Figure 1). For all varieties grown in 2013, the stem material also contained the greatest dry matter percentage relative to total plant dry matter (KNM at 69%, Theis at 54%, Topper at 67%, DA08 at 64%, and M81E at 61%). The greater dry matter percentage accumulation in the stem component in 2012 was most likely attributed to excessive heat and drought conditions that resulted in reduced grain formation.

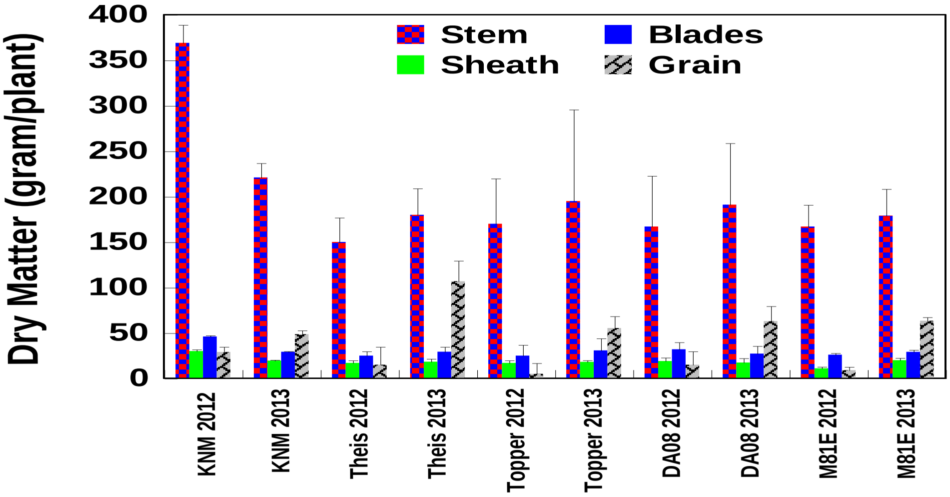

Figure 1. Mean dry matter accumulation at physiologic maturity for stem, leaf sheaths, leaf blades and panicle. The error bars are the associated standard deviations.

Nitrogen

In 2012, the nitrogen total accumulation for the combined leaf blade and leaf sheath represented the largest nitrogen pool, whereas the stem component demonstrated the smallest nitrogen pool. Conversely the 2013, the grain component represented the largest nitrogen pool. The total whole plant nitrogen uptake rate across varieties for 2012 was approximately 112 to 246 kg N/ha (100 to 220 lbs N/acre), whereas the whole plant nitrogen uptake for 2013 ranged from 134 to 190 kg N /ha (120 to 170 lbs N/acre). The percentage of nitrogen associated with the stem component in 2013 was greatest for variety ‘KNM’ (35%) and least for ‘Theis’ (15%). In both years, nitrogen uptake was greatest for ‘Theis’ and least for ‘M81E’. In all years and for all varieties the kg/ha ratio of nitrogen to stem dry weight was significantly smaller than for the leaf sheath, leaf blade and panicles.

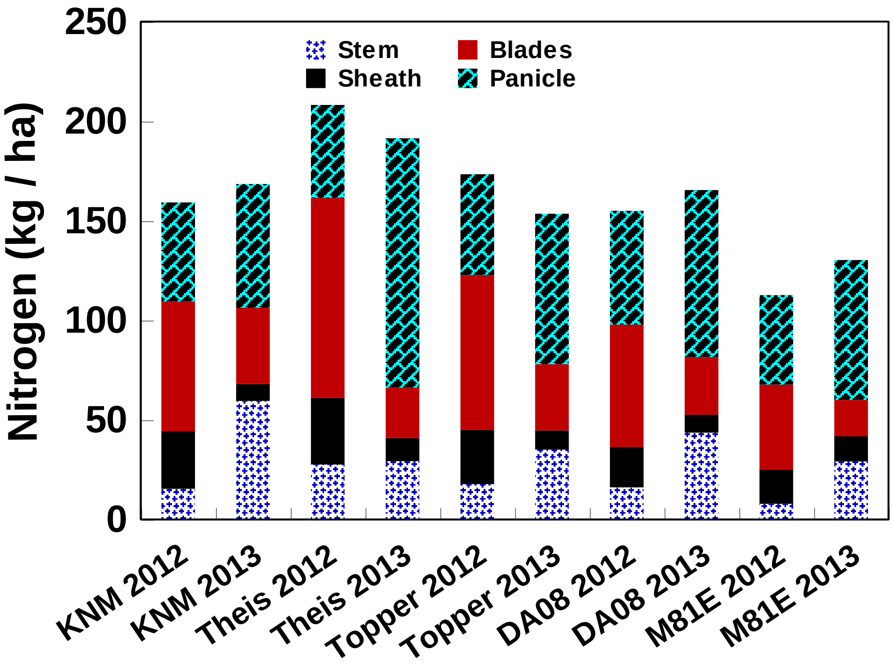

Figure 2. Accumulated mean nitrogen uptake at physiologic maturity for stem, leaf sheaths, leaf blades and panicle.

Phosphorus

In 2012, the phosphorus total accumulation for the combined leaf blade and leaf sheath represented the largest phosphorus pool, whereas the stem material demonstrated the smallest phosphorus pool. Conversely for 2013, the grain component represented the largest phosphorus pool for the varieties ‘Theis’, ‘DA08’, and ‘M81E’, whereas the varieties ‘KNM’ and ‘Topper’ showed the greatest phosphorus pool in the stem material. The percentage of phosphorus associated with the stem component was greatest for variety ‘KNM’ (44%) and least for ‘M81E’ (19%). In both years, phosphorus uptake was greatest for ‘Topper’ and least for ‘M81E’. The total whole plant phosphorus uptake rate for 2012 was approximately 22 to 49 kg P/ha (20 to 44 lbs P/acre), whereas the whole plant phosphorus uptake for 2013 ranged from 55 to 84 kg P/ha (50 to 75 lbs P/acre). In all years and for all varieties the kg/ha ratio of phosphorus to stem dry weight was significantly smaller than for the leaf sheath, leaf blade and panicles.

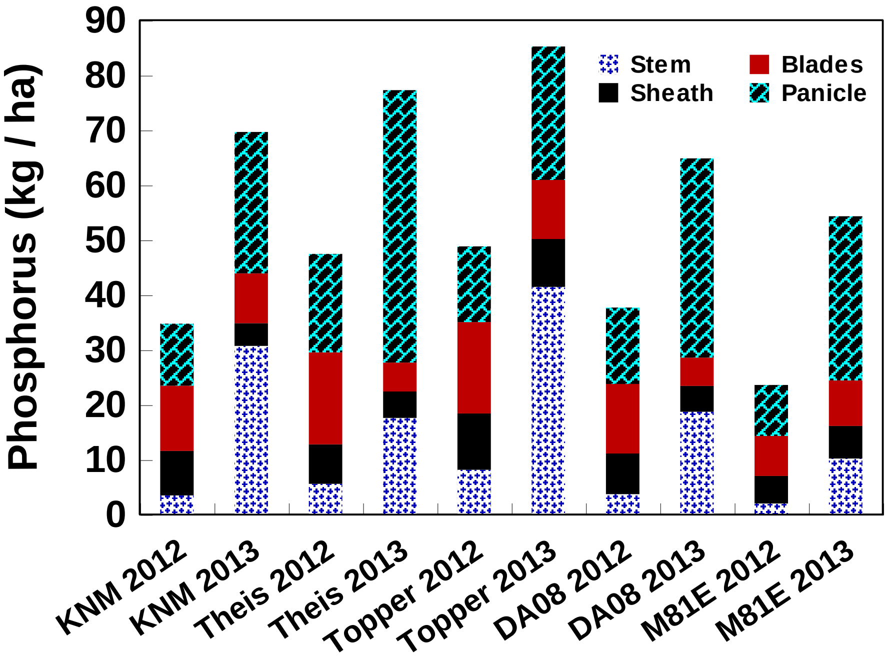

Figure 3. Accumulated mean phosphorus uptake at physiologic maturity for stem, leaf sheaths, leaf blades and panicle.

Potassium

In 2012, potassium uptake was greatest for the variety ‘Topper’, followed closely by ‘Theis’. The greatest potassium reservoir was associated with the stem material in 2013; however, the combined leaf sheath and leaf blade components exhibited the greatest potassium pool in 2012. In 2013, the percentages of potassium associated with the stem components by variety were ‘KNM” (63%), ‘Theis’ (51%), ‘Topper’ (70%), ‘DA08” (58%), and ‘M81E’ (48%). The total whole plant potassium uptake rate for 2012 was approximately 92 to 151 kg K/ha (82 to 135 lbs K/acre, whereas the whole plant potassium uptake for 2013 ranged from approximately 168 to 280 kg K/ha (150 to 250 lbs K/acre). In all years and for all varieties the kg/ha ratio of potassium to stem dry weight was significantly smaller than for the leaf sheath, leaf blade and panicles.

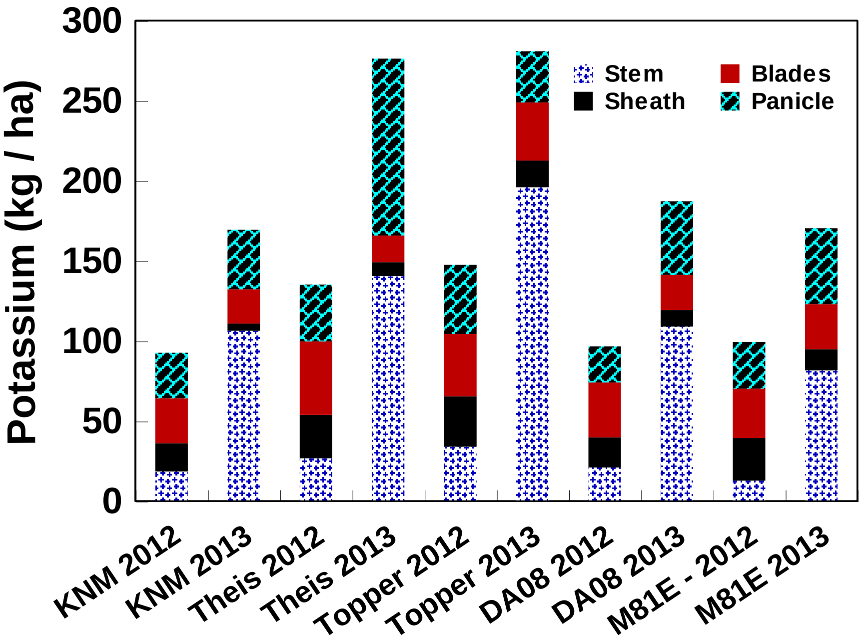

Figure 4. Accumulated mean potassium uptake at physiologic maturity for stem, leaf sheaths, leaf blades and panicle.

Sulfur

In 2012, the leaf blade exhibited the largest sulfur pool, whereas in 2013 the stem component, closely followed by the grain component, demonstrated the largest sulfur pool. In both years, sulfur uptake was greatest for ‘Topper’ and the least for ‘M81E’. In 2013, the percentage of sulfur associated with the stem components by variety were ‘KNM” (37%), ‘Theis’ (37%), ‘Topper’ (65%), ‘DA08” (41%), and ‘M81E’ (41%). The total whole plant sulfur uptake rate for 2012 was approximately 9 to 17 kg S/ha (8 to 15 lbs S/acre), whereas the whole plant sulfur uptake for 2013 ranged from approximately 13 to 25 kg S/ha (12 to 22 lbs S/acre). In all years and for all varieties the kg/ha ratio of sulfur to stem dry weight was significantly smaller than for the leaf sheath, leaf blade and panicles.

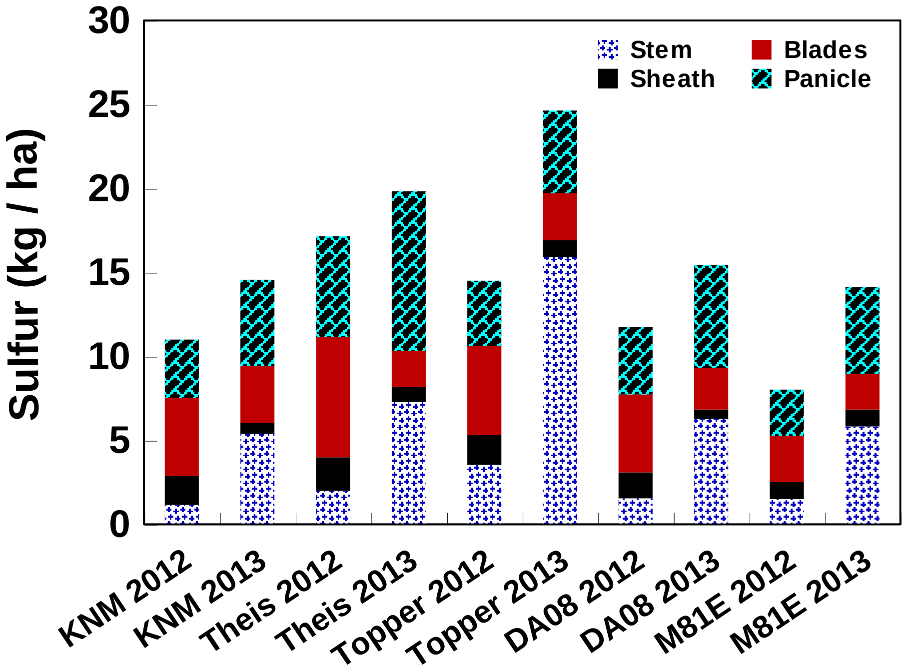

Figure 5. Accumulated mean sulfur uptake at physiologic maturity for stem, leaf sheaths, leaf blades and panicle.

Magnesium

Magnesium uptake in 2012 and 2013 demonstrated that the variety 'Theis' had the highest magnesium uptake in both years, followed by 'DA08' in 2012 and 'KNM' in 2013. Magnesium was rather evenly partitioned among the leaf blade, leaf sheath and panicle in 2012, whereas magnesium showed an overall greater absolute magnesium accumulation (except for the variety Topper) and magnesium was increasingly partitioned in the panicle component. The total whole plant magnesium uptake rate for 2012 was approximately 27 to 48 kg Mg/ha (24 to 43 lbs Mg/acre), whereas the whole plant magnesium uptake for 2013 ranged from 34 to 48 kg Mg/ha (30 to 43 lbs Mg/acre).

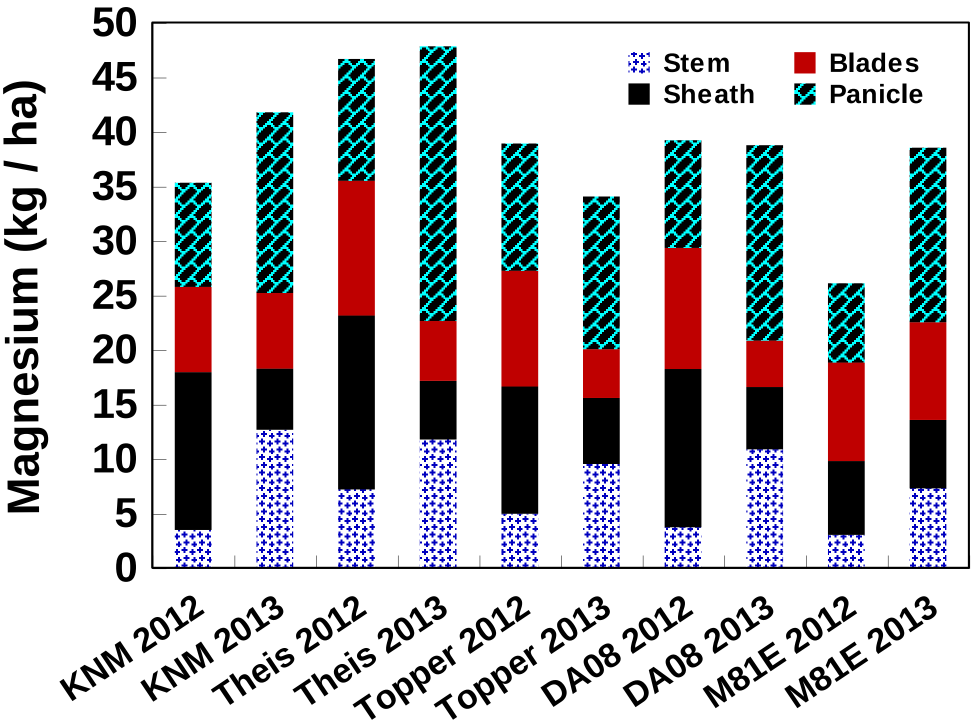

Figure 6. Accumulated mean magnesium uptake at physiologic maturity for stem, leaf sheaths, leaf blades and panicle.

Calcium

In 2012, the leaf sheaths and leaf blades represented the largest calcium reservoirs, whereas in 2013, the calcium pools were greater for the leaf blades and stem components. The total calcium uptake was similar for both 2012 and 2013. In 2012 ‘Theis’ and ‘Topper’ had the greater total calcium uptake patterns, whereas in 2013 ‘KNM’ had the greater absolute calcium uptake patterns. The total whole plant calcium uptake rate for 2012 was approximately 29 to 59 kg Ca/ha (26 to 53 lbs Ca/acre), whereas the whole plant calcium uptake for 2013 ranged from 45 to 69 kg Ca/ha (40 to 62 lbs Ca/acre).

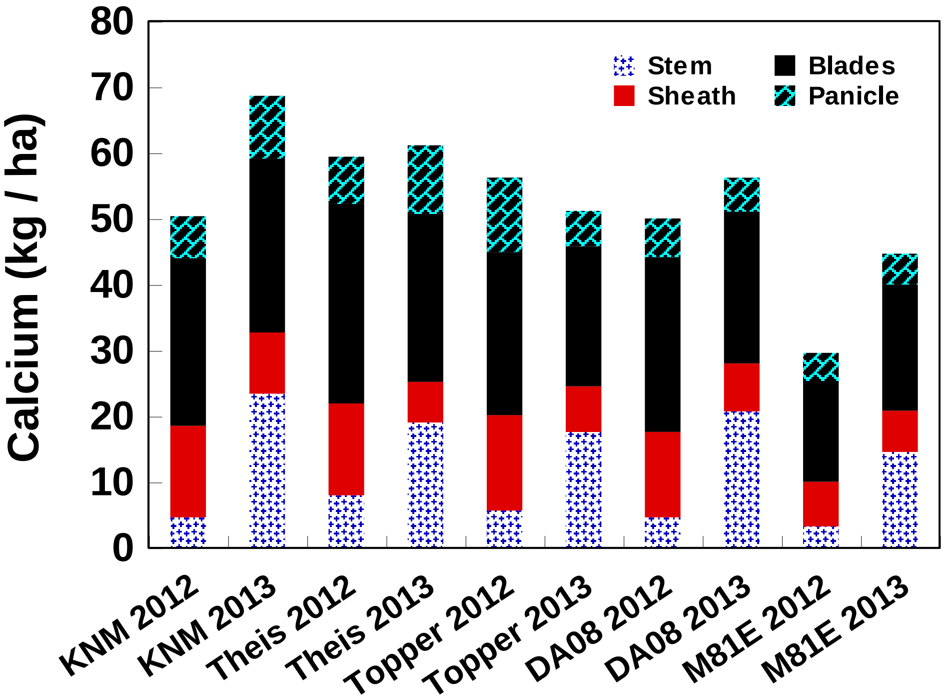

Figure 7. Accumulated mean calcium uptake at physiologic maturity for stem, leaf sheaths, leaf blades and panicle.

Micronutrients

Micronutrient uptake patterns (Table 1) reveal differences in plant components and varieties. As expected, the total removal rate of the micronutrients is rather small. The micronutrient uptake rates were greatest for iron (0.87 to 1.03 kg Fe/ha or 0.78 to 0.92 lbs Fe/acre) and manganese (1.02 to 1.47 kg Mn/ha or 0.91 to 1.32 lbs Mn/acre) and somewhat smaller for zinc (0.47 to 0.85 kg Zn/ha or 0.42 to 0.76 lbs Zn/acre) and the least for boron and copper (less than 0.12 kg/ha or 0.1 lb/acre). In general, the grain component has the greatest reservoir for iron, whereas manganese and zinc have greater accumulations in the grain and stem components. The micronutrient uptake patterns in 2012 were similar to the 2013 micronutrient patterns (2012 data not displayed).

Table 1. Micronutrient partitioning in 2013 sweet sorghum varieties (kg / ha)

Iron

Variety	Stem	Sheath	Blades	Grain	Total
KNM	0.27	0.11	0.30	0.35	1.03
Theis	0.18	0.10	0.19	0.56	1.03
Topper	0.46	0.10	0.17	0.27	0.99
DA08	0.20	0.07	0.19	0.53	0.99
M81E	0.13	0.11	0.20	0.42	0.87

Manganese

Variety	Stem	Sheath	Blades	Grain	Total
KNM	0.29	0.24	0.21	0.36	1.10
Theis	0.53	0.27	0.25	0.44	1.48
Topper	0.51	0.27	0.17	0.18	1.13
DA08	0.31	0.21	0.25	0.25	1.01
M81E	0.54	0.27	0.27	0.17	1.24

Zinc

Variety	Stem	Sheath	Blades	Grain	Total
KNM	0.20	0.04	0.08	0.27	0.59
Theis	0.31	0.06	0.05	0.37`	0.78
Topper	0.38	0.06	0.07	0.20	0.70
DA08	0.35	0.08	0.08	0.35	0.85
M81E	0.18	0.06	0.04	0.20	0.48

B and Cu are less than 0.12 kg / ha

Influence of Climate

The year 2012 was a period of heat stress and drought conditions, whereas 2013 was considered typical for Missouri (Table 2). For most cultivars and for most nutrients in 2012 the amount of nutrients transferred from vegetative growth to the panicle was hindered by insufficient grain development. Thus dry weight accumulation and nutrient pools in the leaf and stem components were influenced accordingly. Phosphorus, K, and S showed greater absolute plant uptake in 2013, suggesting that the more favorable growing conditions supported the observed nutrient accumulation.

Table 2. Precipitation (centimeters) in 2012 and 2013

Month	2012	2013	Average
Jan	8.7	12.7	8.8
Feb	6.4	11.3	9.3
Mar	11.4	10.3	12.0
Apr	5.0	11.3	11.8
May	2.7	5.5	13.3
Jun	3.2	21.4	10.4
Jul	7.2	8.2	10.3
Aug	1.3	12.9	8.0
Sep	22.0	1.3	8.5
Oct	8.0	10.0	10.2
Nov	4.8	16.0	12.2
Dec	4.6	14.0	10.9
Total	84.4	135.0	125.9

Source [https://www.google.com/?gws_rd=ssl#q=agebb+missouri+agriculture+weather] (Verified 15 October 2016)

CONCLUSION

Clearly, the value of residues from any cropping system depends on the (i) amount of residue produced /hectare, (ii) the nutrient content of the residues, and (iii) the residue management, including the type and timing of the post-harvest tillage. This study focuses on the nutrient value of residues derived from ethanol-based sweet sorghum production. Given that the stem material is removed from the field for processing, the sweet sorghum grain and leaf material remain in the field as residue. Admittedly, mechanical harvest may progress to the point where the grain may also be harvested, thus impacting the nutrient removal rates.

The harvest removal of stem material will remove the majority of the residue dry weight; however, the field-remaining residue composed of leaf material (sheath and blades) and grain recovers the majority of the nitrogen, phosphorus, magnesium, calcium, iron, manganese and zinc. Potassium and sulfur were preferentially returned to the soil in residues only in 2012. Thus these estimates of nutrient values associated with the residues are vital to securing soil fertility programs and soil fertilizer recommendations that provide inputs to designing cost effective nutrient management programs.

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