Controlling Variables One Key to Closing Yield Gaps

Reducing variability induced by weather and soil type cited.

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Summary: *The factors that were tested include narrow-row spacing, plant population, balanced nutrition practices, including various timing of nitrogen (N), phosphorus (P) and potassium (K), and micronutrient applications; crop production with fungicide and insecticide application, plant growth regulator effects, and the use of precision Ag technology for maximizing yields, including a GreenSeeker meter for more precisely determining fertilizer N needs for grain sorghum. A high performing hybrid, NK7633 (Sorghum Partners), was used in all field experiments. Not withstanding the lack of treatment difference, the grain sorghum yield gap from a common practice to kitchen sink was 12 bu/A. In Rossville, KS (under irrigation) grain sorghum yields ranged from 101 to 151 bushels/A and from 38 to 99 bushels/A in Ottawa, KS (dryland). Rainfall was limited in Ottawa during the flowering and reproductive stages of growth, which limited yield potential quite drastically.*

The USA is among the top-5 producers around the world, together with Nigeria, India, Ethiopia, and Argentina. More than 75 percent of the sorghum production, in the central and south-central region known as the "Great Plains," is produced in the states of Kansas and Texas. Sorghum improvement in the last decades evolved at a lower rate as compared with corn. Thus, the influence of management practices (M component) on sorghum productivity need to be critically considered, but as a complex interaction between the genotype (G component) and environment (E component). A better understanding of sorghum response under diverse G x E x M scenarios would allow optimizing the use of all soil-plant resources, and then closing yield gaps by maximizing sorghum yield at each specific environment, soil by weather related.

Kansas grain sorghum producers currently face low attainable yields (as related to the yield potential). This project takes into account several of the factors that farmers are faced with in making decisions about quantifying the diverse interactions that can maximize the yields. The trial was implemented at three locations: one at East Central Kansas Experiment Field near Ottawa (KS), another at the Kansas River Valley Experiment Field near Rossville (KS), and another at the North Central Kansas Experiment Field near Scandia (KS).

Objectives

The objectives of the study were to:

- Identify management factors that contribute to high yields under different environments
- Examine dry mass and nutrient (N, P, and K) partitioning and movement between leaf and stem during the vegetative phase, and head, stem, and leaves during the reproductive phase (nutrient remobilization and reproductive nutrient uptake)
- Quantify the effect of diverse production systems in biomass and yield.

Site characteristics

Soil type at the Ottawa location was a Woodson silt loam. Rossville was an Eudora sandy loam. Scandia was a Crete silt loam.

Soil samples were taken before planting at Scandia and Ottawa to a total depth of 6 inches. Pre-season soil test results show contrasting features at the locations evaluated. The parameters analyzed were pH, Melich P, cation exchange capacity (CEC), organic matter (OM), and K availability (Table 1).

Experimental design. The study was conducted in field plots measuring 10 feet wide by 50 feet long at all locations. Each treatment was replicated five times in a randomized complete block design. The sorghum hybrid used was NK7633 (Sorghum Partners), a medium-full maturity, with excellent standability, stay-green and high yield potential. Eleven treatment combinations evaluated the effect of balancing nutrients and production practices for sorghum production (Table 2). Treatment 1 was the high-intensive use of these input combinations: "kitchen sink" with narrow-row spacing (15"), optimum plant population (40,000 to 50,000 pl/A), application of N using GreenSeeker technology, micronutrients, plant growth regulator (PGR), fungicide/insecticide, starter fertilizer (PK), and chloride application. Treatment 10 was the low-input treatment ("common farming practices") with wide row spacing (30"), lower plant population, and with a standard N application (planting fertilizer N application). Fertilizer N was applied pre-planting at each location using an anhydrous ammonia source. Further

Table 1: Pre-plant soil characterization at 0-6 inch depth at Rossville and Scandia sites

Soil parameters	Rossville	Scandia
Buffer pH (SMP)	7.4	6.6
Mehlich P (ppm)	22.7	27.2
Summation CEC (meq/100g)	5.6	28.5
OM (%)	1.2	2.8
K (ppm)	102.3	614.7

Table 2: Treatment description for all sites evaluated during the 2014 growing season

	Treatments										
	1 (KS)	2 (PD)	3 (RS)	4 (PD)	5 (F/I)	6 (Micros)	7 (PGR)	8 (NP)	9 (Cl)	10 (FP)	11 (KS+N)
Seeding rate	Optimum	Normal	Optimum	Optimum	Optimum	Optimum	Optimum	Optimum	Optimum	Normal	Optimum
Row Spacing	15"	15"	30"	15"	15"	15"	15"	15"	15"	30"	15"
N Program	GS	GS	GS	Standard	GS	GS	GS	GS	GS	Standard	GS
Fungicide/Insecticide	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes
Micronutrients	Fe, Zn	Fe, Zn	Fe, Zn	Fe, Zn	Fe, Zn	None	Fe, Zn	Fe, Zn	Fe, Zn	None	Fe, Zn
PGR	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes
Starter Fertilizer	NPKSZn	NPKSZn	NPKSZn	NPKSZn	NPKSZn	NPKSZn	NPKSZn	NP	NPKSZn	NP	NPKSZn
Chloride	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes
GreenSeeker + N	No	No	No	No	No	No	No	No	No	No	Yes

Table 3: Fertilizer application, nutrient amount, expressed in lbs per acre

Treatment #	N	Average GreenSeeker N	Total N	P2O5	K2O	S	Cl	Fe	Zn
	lbs per acre								
1	20	35	55	20	20	20	20	2	2
2	20	39	59	20	20	20	20	2	2
3	20	20	40	20	20	20	20	2	2
4	20	0	20	20	20	20	20	2	2
5	20	30	50	20	20	20	20	2	2
6	20	27	47	20	20	20	20	0	0
7	20	27	47	20	20	20	20	2	2
8	20	30	50	20	0	0	0	2	2
9	20	33	53	20	20	20	0	2	2
10	20	0	20	20	0	0	0	0	0
11	20	78	98	20	20	20	20	2	2

#All nutrients were applied at planting time, except for the extra N diagnosed via GreenSeeker technology (V5-V8 growth stage).

details about all treatment combinations can be visualized in Table 2. Fertilizer application by nutrient (expressed in lbs per acre) per treatment combination is presented in Table 3. Herbicides and hand weeding were used to maintain no weed interference for the entire season, and soil nutrient concentrations (other than N) were maintained above the recommended critical levels (through inorganic P/K applications).

In-season measurements for soil testing were collected during V-5 to V-8 (five to eight leaves) growing stages of the grain sorghum. Soil samples were taken at 0-6 inches and 0-24 inches. Information for Ottawa and Scandia is presented in Table 4. Nutrient levels were quite different for this sampling time at the Scandia location from the pre-season soil test results. Soil samples from Ottawa were taken at this time. No pre-season data are available for Ottawa. The numbers presented show the averages across all treatment combinations.

Stand counts were taken by counting the final number of plants emerged in four 17.5-foot sections of row in each plot. Plant population counts were taken approximately at V5 stage (40 days after planting). Final plant population at each site is presented in Table 5. Final plant numbers were achieved successfully with exception of some treatments at diverse locations. Plant uniformity was also a challenge faced with the use of drills for the narrow-row spacing (15") combinations. The treatments with 30-inch row spacing (treatments #3 and #10) have a greater plant population as compared with the 15-inch row spacing treatment combinations. Except for Scandia, (poor planting conditions), Rossville and Ottawa sites, the plant populations were close to the targeted one of 40,000 plants/A (Table 5).

Biomass determination was performed from five consecutive plants per plot at three diverse growth stages:

- V5
- Flowering
- Physiological maturity

Each individual plant was cut at the stem base and separated into different fractions: leaves and stem (vegetative), head, leaves, and stem (reproductive). Each fraction was separately chopped and dried to constant weight at 60o C. Nutrient concentrations are currently evaluated by a commercial lab.

Table 4: In-season soil test characterization at Ottawa and Scandia sites.

Soil parameters	Ottawa	Scandia
Buffer pH	6.3	6.7
Mehlich P (ppm)	15.4	14.1
CEC (meq/100g)	22.3	22.9
OM (%)	2.93	2.69
K (ppm)	113.8	281.3
N03-N (24") (ppm)	1.6	3.8
NH4-N (24") (ppm)	6.3	9.5
Ca (ppm)	3232.3	2851.7
Mg (ppm)	514.8	465.5
S (ppm)	5.4	9.2
Zn (ppm)	1.3	0.7
Mn (ppm)	21.6	59.5
Fe (ppm)	112.6	111.4
Cu (ppm)	2.1	1.8

Table 5: Stand counts for each treatment combination at all sites, 2014 growing season.

Treatments	Rossville	Ottawa	Scandia
	-plants in 17.5-ft row length-		
1	43.4	43.6	40.4
2	29.4	38.2	46.8
3	81.8	85.6	42.4
4	43.2	41.8	43.4
5	42.2	43.2	35.8
6	42.2	43.4	27
7	42.8	43	27.8
8	41.8	42.8	28.6
9	42.6	43.8	29
10	60.8	54.2	32.6
11	43.4	42.4	34.4
C.V.	3.49	12.32	36.72
P-value	<0.0001	<0.0001	0.1883

C.V. = coefficient of variation (%).

Table 6: Crop phenology in calendar dates for all sites, 2014 growing season.

Plant Phenology	Rossville	Scandia	Ottawa
Planting Date	19-May	22-May	26-May
V-5 growth stage	27-Jun	2-Jul	1-Jul
Flowering	1-Aug	4-Aug	8-Aug
Mid-Reproductive	29-Aug	2-Sep	11-Sep
Harvest	26-Sep	14-Nov	30-Sep

Yield information is expressed in bushels per acre adjusted to 12.5 percent moisture content. Yield was collected from the central two rows (30-in. row spacing) or four rows (15-in. row spacing) (5 ft. x 50 ft).

Grain harvest index was estimated as the ratio between the grain yield to the whole-plant biomass collected at maturity.

Crop Phenology was documented for each site as to properly identified changes in plant growth and nutrient uptake rates (Table 6). The time from planting to flowering was similar at all locations, with approximately 72 to 75 days of duration of this phonological time interval.

Weather information at all sites was recorded and seasonal precipitation distribution, expressed in inches, was documented throughout the entire growing season (from planting to harvest time) for the sorghum crop (Figure 1). At Ottawa, low precipitation (~3 inch) was registered from mid-July to mid-August, which affected the flowering period (greater grain abortion), with a similar situation for Scandia from mid-June to the end of July (Figure 1).

Results

Sorghum grain yields were highly variable within the treatments evaluated and between experiments. A descriptive statistic for the parameter was performed, which demonstrates the dispersion of the yield distribution from all replications at each site (Table 7). The site most impacted by the drought stress experienced during the flowering time was the Ottawa study (Figure 1) with high variability on minimum and maximum yield, which was documented in the high CV number (close to 24%, Table 7). Minimum CV% was recorded at Rossville, highly influenced by the irrigation component.

For Scandia, the treatments evaluated did not present any significant difference for the yield factor (P=0.89). One of the lowest grain yields, 103 bu/A, was obtained when common practices were implemented (treatment #10) whereas yield was maximized at 115 bu/A when the "kitchen sink" approach was employed (treatment # 1). Although treatment was not statistically significant, the grain sorghum yield gap was 12 bu/A when high (treatment #1) vs low (treatment #10) input costs were compared (Figure 2).

In Ottawa, the cropping system approach did not influence sorghum grain yields, which may be related to the low yield potential explored in this location (reproductive-stage drought stress) (P =0.99).

In Rossville, the maximum yield gap documented between the highest-yielding treatment ("kitchen sink" without chloride application, treatment 9) and lowest-yielding scenario (check, treatment 10) was close to 20 bu/A (135 vs 114 bu/A, respectively). The diverse systems evaluated did not differ in sorghum grain yield, with a slightly

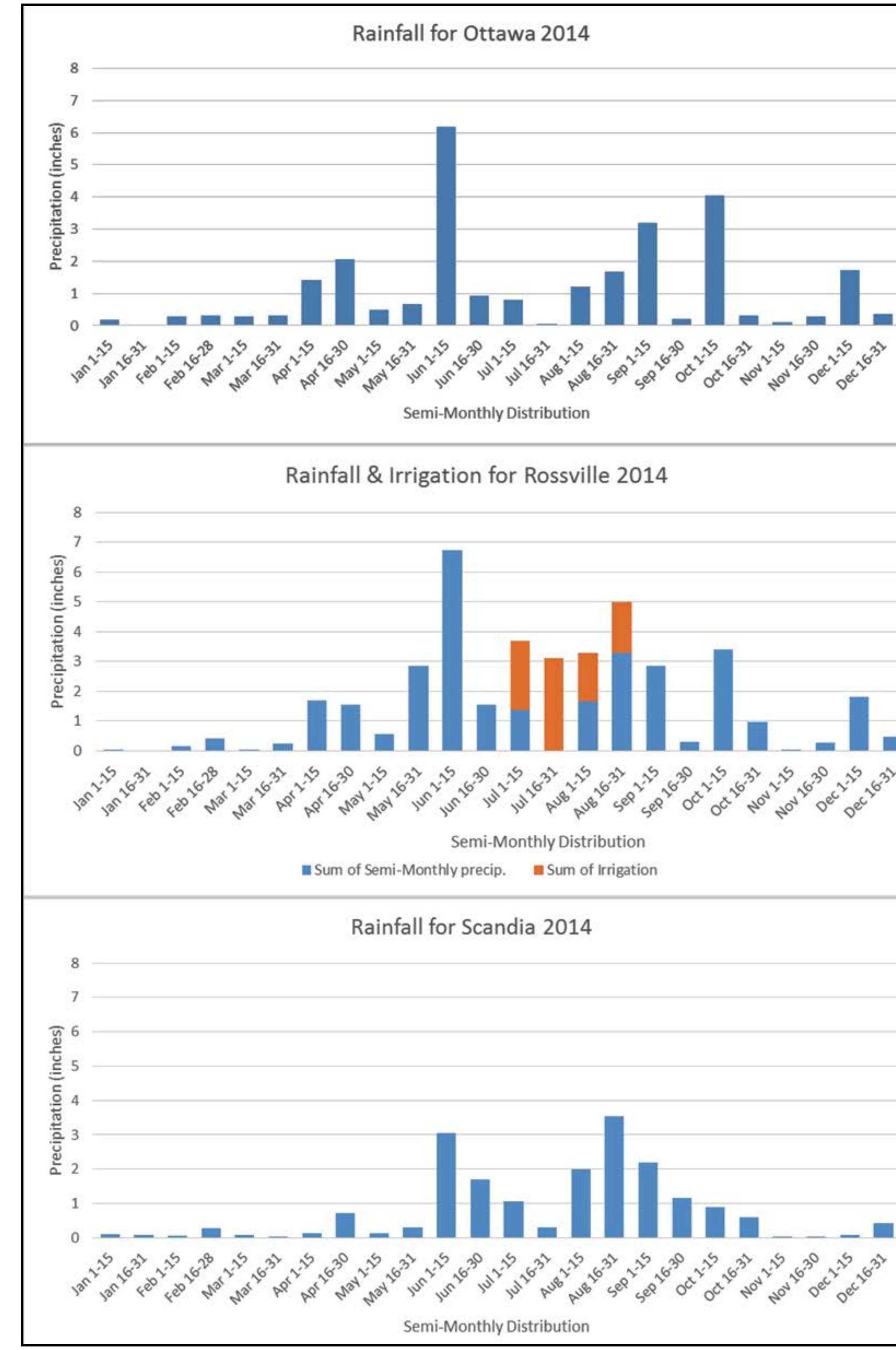

Figure 1. *Seasonal precipitation distribution (expressed in inches per 15-day time interval) at Ottawa, Rossville, and Scandia sites for sorghum crop during the 2014 growing season.*

Table 7: Descriptive statistics (mean, minimum, maximum, and coefficient of variation, CV) on yield parameter, expressed in bushels per acre, for all sites, 2014 growing season.

Field Site	Mean Yield	Min. Yield	Max. Yield	Coefficient of Variation
	- bushels per acre-			%
Scandia	109	82	139	13.7
Rossville	129	101	151	8.3
Ottawa	68	38	99	23.8

statistically significant yield difference from all treatments versus the check (P = 0.07), a common-practice approach (treatment 10), Figure 2.

Grain harvest index (HI) did not show any significant trend at Scandia and Ottawa, with overall grain HI values below 55 units. At Rossville, grain HI for treatment #1 was greater than 60 units, which demonstrates a superior biomass partition to the grain as compared with the whole plant biomass (above-ground biomass) (Figure 3). The farmer practice (FP, treatment #10) depicted the lowest grain HI coefficient, 56 units. The lowest efficiency in partitioning biomass to the grain was correlated to the inferior yield obtained for this treatment (FP, treatment #10) at the end of the growing season (Figure 3).

Individual plants were measured (approximately 1,500 plants for two sites) in nondestructive areas for each treatment combination. Various morpho-physiological measurements were taken primarily at V5 (vegetative period) and at R1 stages (reproductive period). The plant height measured from the stem base to the collar of the uppermost leaf and stem diameter by recording maximum diameter at the stem base. The information collected from the plant height and stem diameter was used to calculate the allometric relationship between the per-plant stem volume [estimated via the cylindrical

"Further site x year evaluation is needed to confirm findings."

formula-based, stem volume calculation = 3.1416 *(stem diameter/2)* plant height].

This approach was previously used for estimating biomass for corn, but as far as the extent of our knowledge, it was never implemented for sorghum. The stem volume parameter (calculated using the plant height and stem diameter measured at flowering) was correlated with the per-plant dry mass values obtained in sorghum plants for all treatment combinations at Scandia and at Ottawa (Figure 4). The correlation presented for the above-mentioned association can be used as a pragmatic

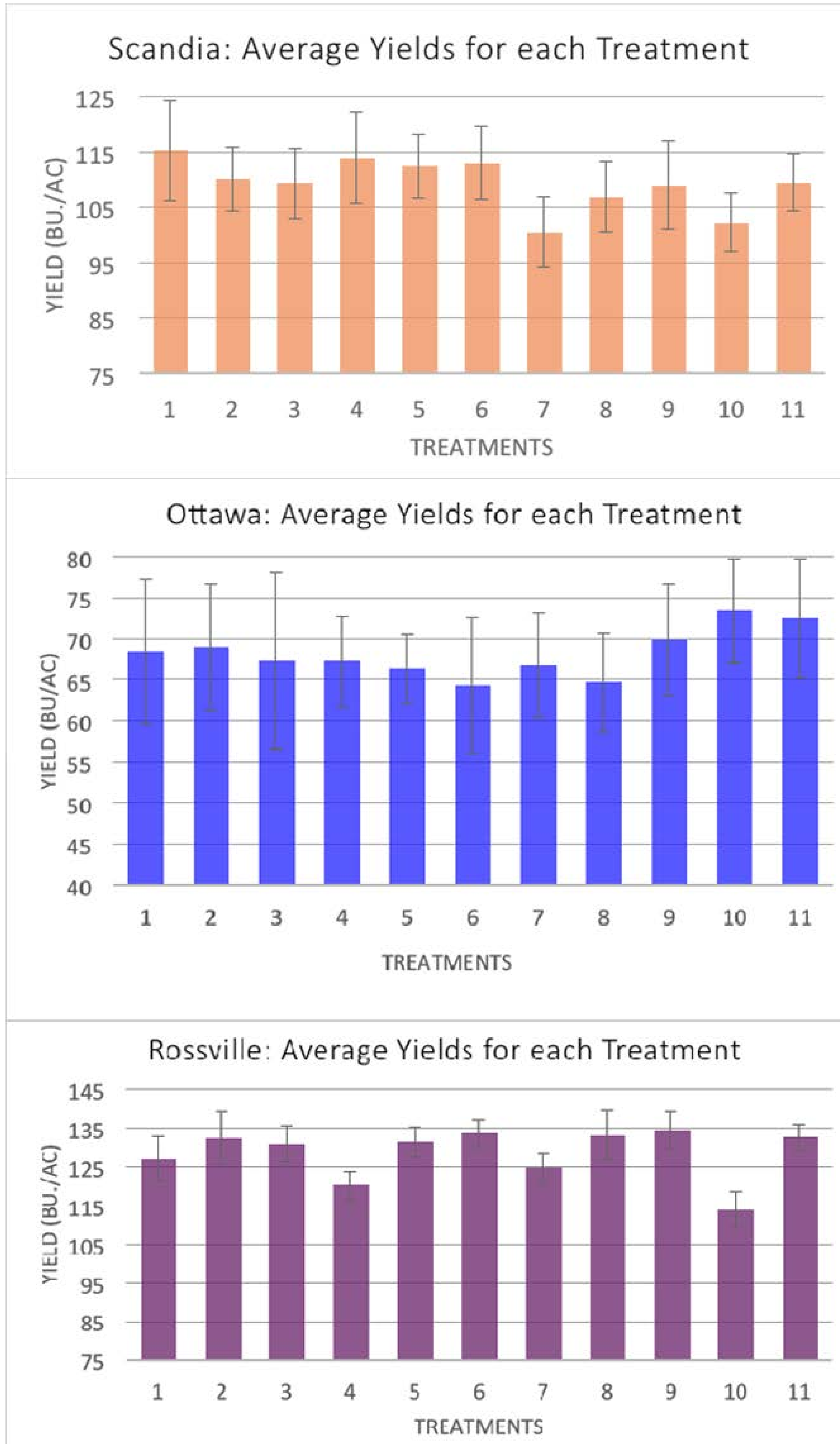

Figure 2. *Sorghum grain yield, in bu./acre, under diverse cropping systems approaches at Scandia, Ottawa, and Rossville, 2014 growing season. Treatment description: 1= Kitchen Sink (KS); 2= Plant Density (PD); 3= Row Spacing (RS); 4= Pre-plant nitrogen only (Pre-N); 5= Fungicide/Insecticide (F/I); 6= Micronutrients (Micros); 7= Plant Growth Regulator (PGR); 8= N and Phosphorous (P) (NP); 9= Chloride (Cl); 10= Farmer Practices (FP); 11= KS + extra 50 lbs N/acre (KS+N).*

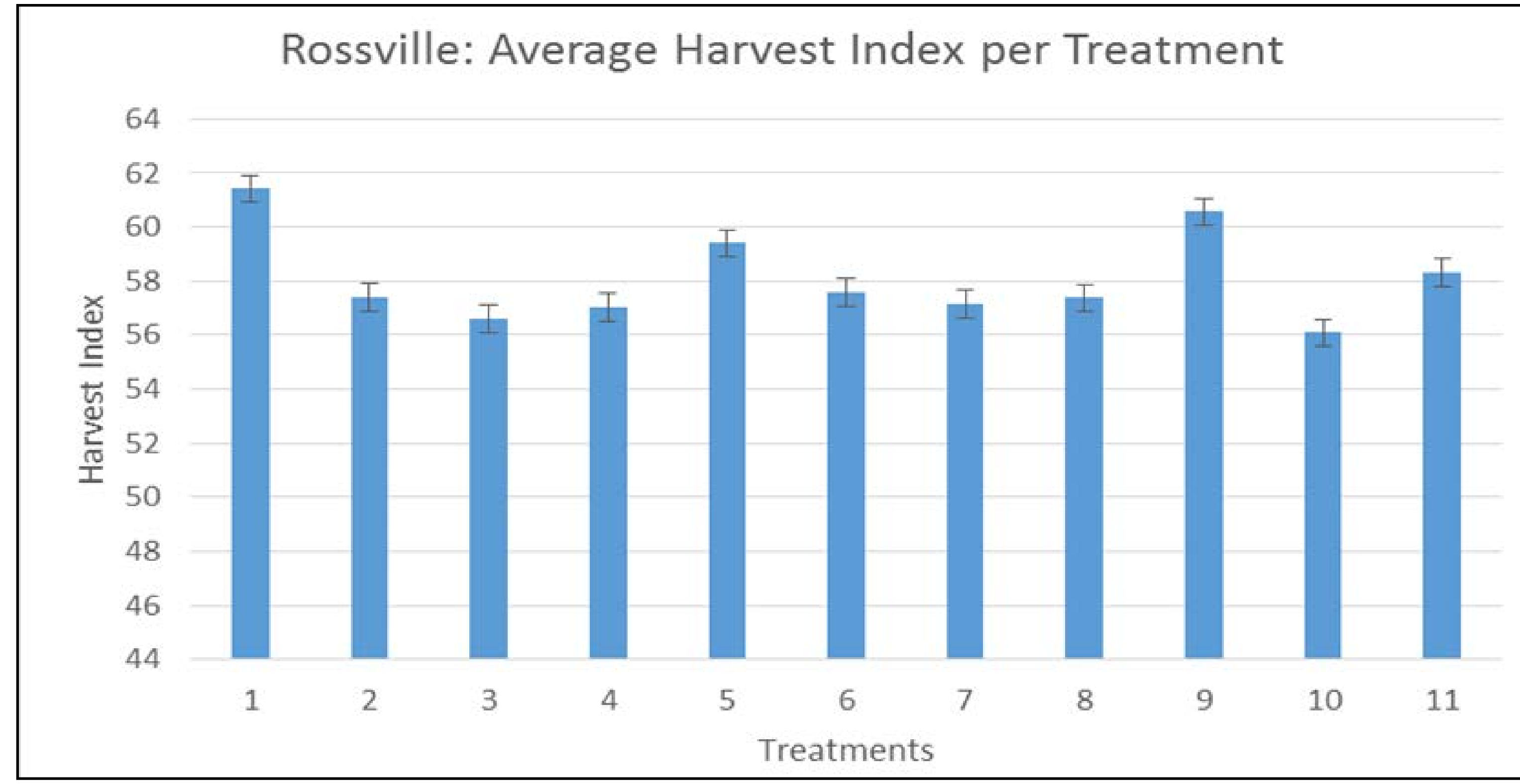

Figure 3. *Sorghum grain harvest index, estimated as the grain yield to the whole-plant biomass ratio, under diverse cropping systems approaches for the Rossville site during the 2014 growing season. Treatment description: 1= Kitchen Sink (KS); 2= Plant Density (PD); 3= Row Spacing (RS); 4= Pre-plant nitrogen only (Pre-N); 5= Fungicide/Insecticide (F/I); 6= Micronutrients (Micros); 7= Plant Growth Regulator (PGR); 8= N and Phosphorous (P) (NP); 9= Chloride (Cl); 10= Farmer Practices (FP); 11= KS + extra 50 lbs N/acre (KS+N).*

tool for estimating plant growth rates under diverse production practices for sorghum crops.

Summing up

The 2014 sorghum growing season presented early-season challenges in plant uniformity and biomass conversion due to late-season drought.

At Rossville when water was a non-limiting factor, yield variability (expressed as a CV%) was minimized and yield advantage between the farmer practice and the use of a balanced approach ("kitchen sink") was maximized. Yield gain was primarily related to whole-plant biomass and biomass conversion (measured via grain HI).

This study demonstrates that closing sorghum yield gaps can be partially achieved when variability induced via weather and/or soil type is reduced. When water was not limiting sorghum yields, a balanced nutrient application and optimization of production practices did increase grain sorghum yields ("kitchen sink" vs. "farmer practice"). Evaluation of nutrient uptake and partitioning in different plant fractions is critical for properly understanding the effect of diverse practices.

Balanced nutrient application for maximizing yields under crop management practices should be further studied for grain sorghum under diverse environments. Further site x year evaluation is needed to confirm the findings that high-yielding grain sorghum systems can be maximized via balancing nutrient applications and pushing production intensity (e.g. narrowing rows).

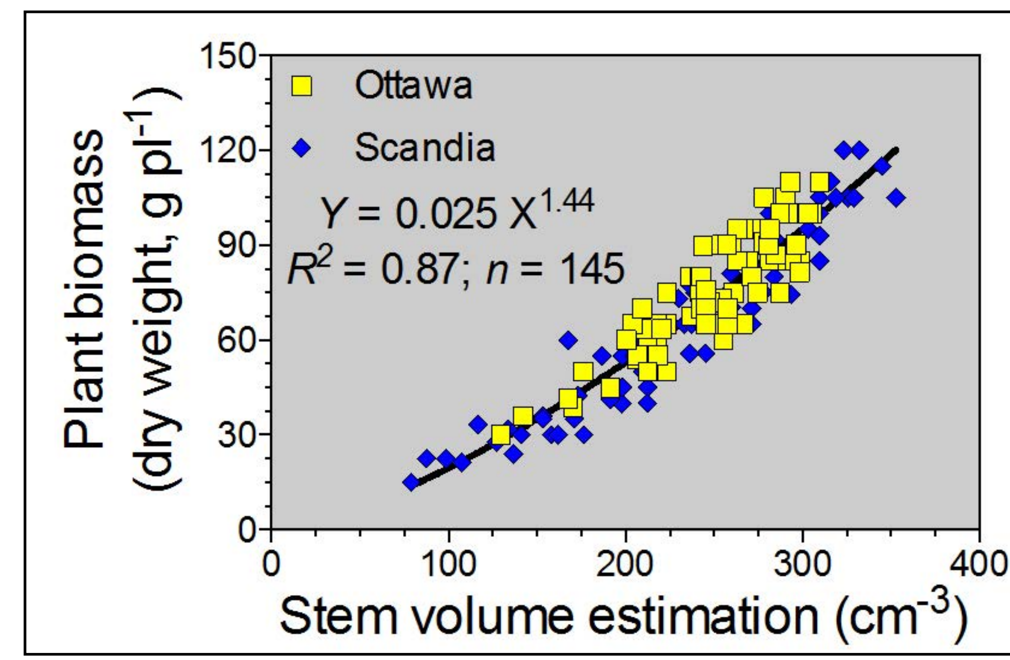

Figure 4. *Plant biomass versus stem volume calculation, implemented via determination of the stem diameter (maximum diameter at stem base) and plant height (distance from soil surface [stem base] to the collar of the uppermost extended leaf) at the flowering stage for sorghum crop at Ottawa and Scandia sites, 2014 season.*

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