a. Project Title:

Best nutrient and crop production management practices for studying nutrient dynamics under high-yielding sorghum

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c. Introduction with project justification

Sorghum improvement during the last six decades has been associated with targeted changes in genotype (G component) and management practices (M component), such as (a) fertilization rates, (b) irrigation, and (c) tillage practices (Duvick, 1999; Assefa and Staggenborg, 2010). At the plant-scale, crop improvement was documented to change (under irrigation) aboveground-biomass production (leaf:stem ratio, higher leaf mass), longer panicle length, reduction in peduncle length, and superior root mass (Assefa and Staggenborg, 2011). The environment (E component) exerts a large influence; thus, endpoint sorghum productivity may be considered the outcome of a complex G x E x M interaction.

However, little is understood about the relative contribution of each component (G x E x M) and their cross-play interaction to the plant traits [e.g. with a primary focus on the plant dry mass and nutrient uptake] that influence sorghum yield. A better understanding of the plant biomass, nutrient uptake and partitioning among vegetative and reproductive plant structures at multiple-growth stages and under diverse management practices will allow to optimize the use of all soil-plant resources, and then closing yield gaps (maximizing sorghum yield at each specific environment, soil by weather related).

Past research reported consistent improvements in sorghum yield when starter fertilizer (30 or 45 lbs/A of N, and 30 lbs P_2O_5/A) was applied as compared to no-starter check plots (Gordon and Whitney, 2002). Gordon and Pierzynski (1998) documented a 15 Bu/A yield increment for responding hybrids when the starter fertilizer was applied. The latter information also shed some light on crop growth changes, with a superior early-season growth and nutrient uptake (for N and P), a reduction on the average days to bloom (planting to bloom), and on the final grain moisture level. In a two-yr experiment (2006/07), application of inorganic N fertilizers accounted for 25% of sorghum yield improvement (Manhattan, KS) (Tucker, 2009). Diverse fertilizer N sources were compared at three-sites, application of UAN in combination with urease nitrification-inhibitor and slow release, and urea (conventional source) did not show any significant yield benefit (Texas) (Coker et al., 2012). For P, residual application of P (4 yrs) improved crop yields by about 7 Bu/A, accounting for more than 10% of the increase in productivity as compared when no P was applied (Ottawa, KS) (Janssen, 1994). In a long-term evaluation of P response (10-yr), the application of 40 lbs P_2O_5/A/yr accounted for about 10% of the overall sorghum yield improvement (Schlegel, 2012). For the same study, combined P and K applications increased yields 10 Bu/A (70 vs. 80 Bu/A) as compared when no fertilizer was applied (check plot). As compared to each individual nutrient application (N, P, and K), the single application of N showed the largest yield advantage in sorghum productivity. Lastly, when all N-P_2O_5-K_2O (120-40-40, balance application) were jointly applied, the N rate needed to maximize yields was reduced from 200 to 120 lbs/A (137 vs. 135 Bu/A, respectively, average 10-yr yield trends). From the micronutrient viewpoint, five elements are classified as the micronutrient metals (Fe, Zn, Mn, Cu, and Ni), and three are considered as other micronutrients (Cl, B, and Mo). From the micronutrient metals, Zn deficiency is common in corn and sorghum, while Fe deficiency was previously documented in corn, sorghum, and soybean crops. Copper and Ni deficiencies are not an issue in the state of Kansas, while Mn deficiency is of interest on soybean production (glyphosate x RR soybean interactions). From the rest of the micronutrients, Mo deficiency was documented in soybean (SE and South-Central Kansas); B occurs rarely on alfalfa (SE Kansas); while, Cl responses occur frequently for wheat, corn, and sorghum around the state. Thus, from the previous information the main three micronutrients that are more likely to show deficiency levels on sorghum production are Zn, Fe, and Cl. Information from Kansas documented positive and economic responses to the application of Cl (on overall, 95 vs. 103 Bu/A for check and 20 lbs/A NaCl or KCl, respectively) at eight of nine site-years (Lamond and Leikam, 2002; Mengel et al., 2009). When soil-applied, Fe and Zn fertilizer applications did not promote an effective improvement in the grain Fe and Zn concentrations (biofortification goal), but a positive association was found between Fe and Zn deposition in the grains for sorghum (India) (Kumar et al., 2011). To the present, less information is available regarding the potential contribution of Zn and Fe fertilizer applications to sorghum yield (Fe is more likely to show responses in the western region of the state, pH levels greater than 7.8 – alkaline soils-).

Besides nutrient fertilization, diverse complex interplay among management practices highly influences the decision making-process for producing grain sorghum. Among the different management practices to be considered (interacting with nutrient applications) are: hybrid, crop rotation, planting dates, plant density, row spacing, weed, insect and disease control. For example, higher plant density (from 10,000 to 40,000 pl/A) showed contrasting yield trends, with positive effects (14%) in some locations (e.g. Garden City) but neutral behavior in some others (Pidaran, 2012). Wider positive yield response range (from 7 to 24%) resulted with early planting (May) in different locations around Kansas (Belleville, Ottawa, Manhattan, and Hutchinson) (Maiga, 2012). From the same author, the row spacing effect on sorghum grain yield was also tested under diverse locations, with narrower row (10 vs. 30 inches) presenting a benefit in yield ranging from 3-14% when tested in different environments during the same season (Belleville, Ottawa, Manhattan, and Hutchinson).

The understanding of the sorghum nutrient partitioning for modern hybrids under the interaction between nutrient fertilizer applications and crop production practices (on-farm scale) should be pursued in depth. Information related to sorghum nutrient partitioning (N, P, and K) among different plant fractions [leaves, stem, and head (grain and the rest)] at multiple-growth stages was last published by Dr. Vanderlip (1993). This publication is still being used as the preferential reference for sorghum nutrient uptake and partitioning topics. The latter publication did not include S, Ca, Mg and micronutrient uptake and partition in sorghum. In recent years, more efforts were placed on updating and improving the understanding in nutrient (macro- and micro-nutrients) partitioning (among different plant components) on corn under diverse crop production practices (e.g. plant density and N rate) (Ciampitti et al., 2013A, B). Similar information is urgently needed for improving sorghum production and estimating crop nutrient levels needed per unit of yield produced and grain nutrient removal (at diverse yielding environments, dryland vs. irrigation) under diverse crop production practices. The latter can potentially very helpful in deciding the right nutrient fertilizer rate to be applied. In addition, changes in nutrient uptake timing (quantity taken up before or after blooming), rates (uptake per day between growth periods), and nutrient partitioning (leaf, stem, grain, and rest of the head) for modern sorghum hybrids at multiple-growth stages could provide some guidance as related to the best timing for nutrient application and crop response (specifically needed for micro-nutrients), and also increase the understanding of the nutrient demand for producing superior sorghum yield systems.

In summary, more research information is needed as related to the interactions among crop production practices and nutrient fertilization for optimizing inputs and maximizing sorghum yield at very diverse environments in the state of Kansas. In addition, previous information related to nutrient concentration in different plant tissue for sorghum in Kansas (and the region) needs to be updated (Vanderlip, 1993). Information for modern hybrids is scarce, and the effect of combined management practices on the nutrient partitioning process is relatively unknown. Balanced nutrient application for maximizing yields under crop management practices should be further studied for grain sorghum under diverse environments around the state.

d. Project goals and objectives:

The overall goal is to identify the effect of nutrient fertilizer applications and their interactions with crop practices that contribute to high yields, and to quantify how those practices impact yield formation and nutrient uptake processes. A secondary objective will be to quantify the yield potential for each particular environment evaluated, and to determine the contribution of the balanced nutrient fertilization and each specific crop management factor in reducing sorghum yield gaps (herein understood as the difference between the potential yield and the current farmer practice).

The specific research objectives for this investigation are to:

(1) provide Kansas growers with clear information about the effect of fertilizer applications (starter/ macro- N, P, K, S/ and micro-nutrients – Zn, Fe) and their interaction with diverse management practices for sorghum under diverse environments,

(2) identify management factors that contribute to high yields and investigate nutrient uptake requirement under different environments,

(3) update the information related to the dry mass, nutrient uptake and nutrient partitioning (leaf and stem during the vegetative-phase, and head, stem, and leaves during the reproductive phase) for modern sorghum hybrids under different environments and crop production practices,

(4) train a graduate student (M.S. student has been already recruited). Scientists trained to work with real plants in actual field situations are essential to increase our understanding of the complexity of further sorghum yield gains under during a time of growing global need for crop production as feed, food, fuel, and fiber.

e. <u>Procedures</u>

The main field experiments for testing separate or interacting effects will be planned for 3 locations in 2 years. Possible locations include Manhattan (Reading silt loam), Hutchinson (Funmar-Taver loam), Scandia (Crete silt loam; irrigated), and/or Ottawa (Woodson silt loam to silt clay loam). Hybrids will be selected from the 2013 National Sorghum Producers Yield Contest and KS Grain Sorghum Performance Test Results (e.g. DEKALB DKS53-67 or Pioneer 84G62). The hybrid may also remain to be investigated in 2015 for the sake of continuity and to study the influence of year (i.e. climate) on sorghum hybrid response to the treatments evaluated.

All sites will have 5 replications, with 3 replications for destructive plant sampling (e.g. plant biomass determination). Herbicides and hand weeding will be used to maintain no weed interference for the entire season. Soil nutrient concentrations (other than N) will be maintained above the recommended critical levels (through inorganic P/K applications). Thus, a proper initial soil characterization (e.g. soil organic matter, pH, CEC, N, P, and K concentration) will be performed at each of the specific sites evaluated. The field experiments will be arranged in a 'knock-out' design with a total of eleven treatment combinations (see below table):

1- **"Kitchen Sink"** (all factors at the optimum level – optimum Seeding Rate, narrow row spacing, GreenSeeker-N, foliar Insecticide/ fungicide, Micronutrients (Cl, Fe, Zn), Starter N-P-K-S, and Plant Growth Regulator);

2- **Plant Density** (all factors at the optimum level, except seeding rate – farmer seeding rate will be implemented);

3- **Row Spacing** (all factors at the optimum level, except farmer row spacing will be implemented, 30" row);

4- **Fluid N** (all factors at the optimum level, except that N will be applied at pre-planting without following GreenSeeker-N recommendation);

5- **Foliar Fungicide/Insecticide** (all factors at the optimum level, except that foliar fungicide/ insecticide application will be omitted);

6- **Foliar Micronutrient** (all factors at the optimum level, without application of micronutrients, Cl, Zn, Fe);

7- **Plant Growth Regulator** (all factors at the optimum level, without PGR);

8 – **Starter** (all factors at the optimum level, without N-P-K-S as starter);

9 – **Chloride** (all factors at the optimum level, without Cl);

10- **Famer Practice** (farmer seeding rate and row spacing, standard N program – all N applied at pre-plant, without application of foliar fungicide/ insecticide, micronutrients, PGR, and chloride- the starter is only NP);

11- **Kitchen Sink + N** (all factors at the optimum level, plus extra in-season N units added for guaranteeing that the GreenSeeker N Program is not limiting final N supply).

	Treatments										
	1	2	3	4	5	6	7	8	9	10	11
Seeding rate	Optimum	Normal	Optimum	Optimum	Optimum	Optimum	Optimum	Optimum	Optimum	Normal	Optimum
Row spacing	20"	20"	30"	20"	20"	20"	20"	20"	20"	30"	20"
N Program	GS	GS	GS	Standard	GS	GS	GS	GS	GS	Standard	GS
Fungicide	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes
Foliar Micros	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	Tes
Starters	NPKSZn	NPKSZn	NPKSZn	NPKSZn	NPKSZn	NPKSZn	NPKSZn	only 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

The experimental layout to be tested was designed as a novel approach to evaluate the individual contribution of each management practice to the yield potential and the actual farmer yield (also determining exploitable yield gap).

For each specific location/environment, optimum and farmer seeding rates will be determined based on previous research information, and in consultation with the extension agent cooperators as to understand more precisely the "average" farmer-seeding rate for each region. Optimum seeding rate tend to be around 40 to 60,000 pl/A for sorghum; while farmers tend to over-seed sorghum to 60 to 90,000 pl/A. For the row spacing factor, conventional 30 inch spacing ("wider rows") will be compared with the 10 or 20 inches (depending on the location) row spacing ("narrow rows").

Similar procedure will be followed for defining the nutrient fertilization rates (NPKS) to be applied at each environment/management practice evaluated. The fertilizer N source to be employed will be liquid or fluid urea ammonium nitrate (UAN, 28-0-0) for either pre-plant or planting and in-season N applications (GreenSeeker-N management). For P, the fertilizer source to be used will be preferentially the ammonium polyphosphate (APP, 10-34-0), while potassium (e.g. liquid formulations 10-0-0-24) will be utilized as a primary nutrient fertilizer source for K nutrient. Sulfur will be added as ammonium thiosulfate (ATS, 12-0-0-26). The starter fertilizer rate to be applied will be related to the target yield for that specific environment (around 20 lb/A).

The starter fertilizer will be surface dribbled on the row of the sorghum crop. The correction for N with the GreenSeeker will be implemented at about 8 to 10 leaves (for sensing the N status of the crop), and a sufficient N rate (UAN) will be added as determined by the sorghum N rate algorithm calculator developed by Dave Mengel (K-State University). The starter fertilizer will be applied at planting.

Foliar micronutrients will be applied when the sorghum reaches the five-leaf stage (V5), and the elements to be explored are iron (Fe) and zinc (Zn). Micronutrient rates, fertilizer source, and placement will be defined for each environment/management practice. For Fe, FeHEDTA (N-hydroxyethyl-ethylenediamine triacetic acid) will be applied at rates of 0.2 lbs/A. For Zn, foliar chelate EDTA Zn will be applied at a rate of 0.2 lbs/A. For Cl, the fertilizer rate to be applied of KCl will be around 10-20 lbs Cl/A and it will be applied with the starter fertilizer at planting time. Except for the Cl, foliar micronutrients (Fe and Zn) will be applied with backpack sprayers at each individual plot-scale or with the equipment present at each experimental research station.

The plant growth regulator (e.g. Ethephon or 1-MCP) could potentially act modifying the plant growth with different impacts as related to the crop growth stage at which the product is applied. For the plant growth regulator applications: two different timings will be considered in environments prone to early-vegetative drought stress, 1. early-vegetative-phase (at 5th leaf collar visible), and 2. mid-reproductive-phase (at soft-dough). In less-susceptible drought sites, a single application of plant growth regulator during the early-reproductive will be pursued. The plant growth regulator will be applied with backpack sprayers at each individual plot-scale or with the equipment presented at each experimental research station.

Foliar fungicides will be applied during the reproductive-phase (around soft and hard dough, 70-to-80 days after crop emergence). A fungicide with an active ingredient in the "strobilurin" fungicide class (i.e. azoxystrobin, pyraclostrobin, or trifloxystrobin) could be potentially used as the fungicide treatment. Strobilurin fungicides are moderately new to the commercial crop industry with a broad spectrum of disease control. The insecticide to be applied (jointly with the fungicide) will be the chlorpyrifos (e.g. Lorsban 4E), which can be employed to control greenbugs, sorghum midge, corn earworm, sorghum webworm, fall armyworms, and grasshoppers, among others. Foliar fungicides/

insecticides will all be added with backpack sprayers at each individual plot-scale or with the equipment present at each experimental research station.

Proposed Measurements:
The measurements proposed for the investigation of the biomass, yield and nutrient uptake and nutrient remobilization dynamics within sorghum plants will include:

(a) Accurate meteorology measurements at each site (minimum of light intensity, hourly temperatures, precipitation, relative humidity, wind speed).

(b) Plant populations for at least four 17.5 foot sections (1/1000th of an acre) in each plot at two phenological stages (during early vegetative and before harvest).

(c) Soil nutrient concentration (macro- and micro-nutrient analysis) pre-planting and nitrate levels when N is applied (nitrate + ammonium).

(d) Leaf Area Index (LAI) at 5th leaf collar visible, at half-bloom, and at physiological maturity. Leaf area could be derived via a LiCOR 2200.

(e) Chlorophyll (SPAD) readings will be taken in parallel as LAI measurements (at 5th leaf collar visible, at half-bloom, and at physiological maturity).

(f) Progression of bloom, and 50% bloom dates (estimation from 10 plants per plot).

(g) Total aboveground biomass, nutrient concentration, and nutrient uptake will be determined at 5th leaf collar visible, half-bloom, and physiological maturity (3 growth stages). Plants will be separated into stem and leaves during the vegetative-phase, and grain, leaf and stem during the reproductive-phase. Assuming the plants can be combined into a single composite sample after high temperature drying, all plant samples will be finely ground to pass a 1 mm screen before lab analyses. A minimum of 6 plants per plot will be included for all biomass sampling.

(h) Grain harvest index based on 10-plant samples removed from an area with the correct treatment-specific plant population from each plot after physiological maturity.

(i) Grain yield -seed mass from plot harvest- and grain moisture (harvested by plot combines).

In the technology transfer side, all the information generated from this project will be utilized in different avenues for research and extension purposes (conference papers, field days, K-State Sorghum Schools, KARA Summer School, training for extension agents, farmers, and agronomists). In addition to the previous, an extension publication will be prepared as a sub-product of this research project ("Sorghum: nutrient needs for maximizing yields"). Finally research will be published in peer-reviewed journal articles.

f. Duration of the project (number of years):

The project will start May-June 2014 for a continuation of 2 growing seasons (2014/15). The first year information will be finish at the end of the summer crop growing season (October 2014) for on-field measurements and yield information. The second season will start around May-June 2015. Information will be collected during the summer season (in-season measurements for SPAD, leaf area, stand counts, biomass, and harvested yield components), and nutrient concentration and uptake will be determined after biomass samples are processed (dried, grounded, and sent to the lab for nutrient concentration analyses), which usually will take place during or after the growing season. If funding is available, we can continue this project for one extra growing season (2016).

g. <u>Expected outputs and outcomes:</u>

Understanding the complex interactions between nutrient and crop production practices and environments and their relationships with achieving high sorghum yields is one of the main goal of this research project. In addition, this project is expected to provide some guidance in more precisely identifying nutrient recommendations to support high yield sorghum production for the state of Kansas.

An expected result is to identify and to quantify the nutrient and crop production practices that contribute to high yields. In addition, quantification of yield potential and yield gap (yield potential minus yield under yield obtained under current farmer practice) in the different environments is another expected outcome. At present, several uncertainties still exist related to combinations of management practices under diverse environments that will maximize sorghum yield. Therefore, this project will be able to extend information to sorghum growers about the main crop production and nutrient factors that constrain sorghum production under different environments.

An updated nutrient partitioning curve and nutrient remobilization, content, and removal is expected from this research project. The last research information related to this topic was published by Dr. Vanderlip in 1993, and still is the primary source of information for sorghum nutrient uptake, growth and development not only for the state of Kansas but also for the entire Great Plains region. This piece of the information is critical for moving forward sorghum yields and needs to be updated.

h. Project Budget:

May 1, 2014 – April 30, 2015 (1 yr)

A MS student will be associated to this project, which will be primarily supported by other primary funding sources. The student started in January 2014, and will take the lead on this project with the plan to finish all years of the research experiments.

Salaries, Wages, and Fringe Benefits	**-**
Travel **- Travel to Research Plots**	 **$ 2,500**
Materials, Supplies, Contractual Services **- Field Materials** **- Summer Help**	 **$ 1,500** **$ 2,400**
Partial Support – Nutrient Cost	**$ 3,600**
Other Direct Costs	**-**
TOTAL REQUEST	**$ 10,000**

Budget Justification:

Travel Cost (for biomass sampling/field measurements to all 2 locations) $2,500
Manhattan-Hutchinson (round-trip), 250 miles, 7 trips in one season = 1,750 miles
Manhattan-Ottawa (round-trip), 212 miles, 7 trips in one season = 1,484 miles
Manhattan-Belleville (round-trip), 200 miles, 7 trips in one season = 1,400 miles
Extension, field days, and tour meetings (related to the project), 366 miles.
Total of 5,000 miles @ $0.50/mile = $2,500

Field materials and summer help: Sample bags, stakes, flags, and some other tools - $1,500 ($500 per location).

Summer Help: Support for visiting scholar salary $1,200 per month (total 2 months).

Materials and Supplies:
Biomass sampling, nutrient (N, P, K, S, Zn, and Fe) plus soil analyses
(11 treatments - 3 replications – n plant fractions - 3 growth stages – 3 sites/yr)
Vegetative (V5 stage) / 2 fractions= leaf and stem (11 x 3 x 2 x 3 = 198 samples in total)

Flowering (R1 stage) / 3 fractions = leaf + stem + head (11 x 3 x 3 x 3 = 297 samples in total)

Maturity / 3 fractions = leaf + stem + head (11 x 3 x 3 x 3 = 297 samples in total)

Total for multi-growth stages and experimental sites is 792 samples in total (per year)

Soil sampling (organic matter, pH, CEC, P and K): 3 sites/yr x 3 replications (before planting)

Nitrate and ammonium samples: 3 sites/yr x 3 replications x 2 timings (at V5 and half-bloom)

Partial support for the nutrient cost $3,600.- The final cost will exceed $10,000.-

References:

Assefa, Y., and S.A. Staggenborg. 2010. Grain sorghum yield with hybrid advancement and changes in agronomic practices from 1957 through 2008. Agron. J. 102:703-706.

Assefa, Y., and S.A. Staggenborg. 2011. Phenotypic changes in grain sorghum over the last five decades. J. Agron. Crop Sci. 197:249-257.

Ciampitti, I.A., S.T. Murrell, J.J. Camberato, and T.J. Vyn. 2013A. Maize nutrient accumulation and partitioning in response to plant density and nitrogen rate: I. Macronutrients. Agron. J. 105:783–795.

Ciampitti, I.A., and T.J. Vyn. 2013B. Maize nutrient accumulation and partitioning in response to plant density and nitrogen rate: II. Calcium, Magnesium, and Micronutrients. Agron. J. 105:1–13.

Coker, D.L., M.L. McFarland, T.L. Provin, D.R. Pietsch, and A.H. Abrameit. 2012. Grain sorghum yield response to slow-release nitrogen fertilizers and additives. 2012 ASA-CSSA-SSSA International Annual Meetings. Cincinnati, Ohio.

Duvick, D. N., 1999: Heterosis: feeding people and protecting natural resources. In: J. G. Coors, and S. Pandey, eds. The Genetics and Exploitation of Heterosis in Crops, pp. 25. Society of Agronomy and Crop Science Society of America, Inc., Madison, WI, USA.

Gordon, W.B., and D.A. Whitney. 2002. Starter fertilizer application effects on reduced and no-tillage grain sorghum production. Better Crops 86:10-15.

Gordon, W.B., and G.M. Pierzynski. 1998. Corn and grain sorghum hybrid responsiveness to starter fertilizer combinations. Symposium Proceedings, Fluid Fertilizer Foundation, Manchester, MO, p. 31-37.

Janssen, K.A. 1994. Residual effects from phosphorus fertilizer applications in two tillage systems. In: Kansas Fertilizer Research, 1994. Compiled by: Marc Johnson. 52-54p.

Kumar, A.A., B.V.S. Reddy, B. Ramaiah, K.L. Sahrawat, and W.H. Pfeiffer. 2011. Options for enhancing grain iron and zinc concentrations in sorghum. 3rd International Zinc Symposium. Improving Crop Production and Human Health. October, 2011. Hyderabad, India.

Lamond, R., and D. Leikam. 2002. Chloride in Kansas: Plant, Soil and Fertilizer Considerations. Bulletin MF-2570, Kansas State University Ag. Experiment Station and Extension Service.

Maiga, A. 2012. Effects of planting practices and nitrogen management on grain sorghum production. Ph.D. Dissertation. Kansas State University. Manhattan, KS. 193p.

Mengel, D., R. Lamond, V. Martin, S. Duncan, D. Whitney, and B. Gordon. 2009. Chloride fertilization and soil testing – update for major crops in Kansas. Better Crops 93:20-22.

Pidaran, K. 2012. Effect of planting geometry, hybrid maturity, and population density on yield and yield components in sorghum. MS Thesis. Kansas State University. Manhattan, KS 145p.

Schlegel, A. 2012. Long-term nitrogen and phosphorus fertilization of irrigated grain sorghum. In: Kansas Fertilizer Research, 2012. Compiled by: Dorivar Ruiz Diaz. 89-91p.

Tucker, A.N. 2009. Managing nitrogen in grain sorghum to maximize N use efficiency and yield while minimizing producer risk. M.S. Thesis. Kansas State University. Manhattan, KS. 152p.

Vanderlip, R.L. 1993. How a Sorghum Plant Develops. Kansas Extension Circular. C-447.