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Effect of Tillage and Fertilization on Agronomics and Nutrient Uptake of Sweet Sorghum and Soil Test Extractable P and K after Four Years of a Monocrop Production System

Jifeng Li
Louisiana State University and Agricultural and Mechanical College, jli78@lsu.edu

EFFECT OF TILLAGE AND FERTILIZATION ON AGRONOMICS AND NUTRIENT UPTAKE OF SWEET SORGHUM AND SOIL TEST EXTRACTABLE P AND K AFTER FOUR YEARS OF A MONOCROP PRODUCTION SYSTEM

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Abstract

Sweet sorghum [*Sorghum bicolor* (L.) Moench] (SS) has been grown in the southern United States to produce syrup for many years. There is an interest in SS as a biofuel feedstock due to its high sugar content and high total biomass. Currently, little is known about the nutrient demand for SS or how it responds to tillage and fertilization. The objectives of this study were to: 1) evaluate the effects of tillage and phosphorus (P) and potassium (K) fertilization on SS agronomics, 2) evaluate nitrogen (N), P, and K uptake and nutrient partitioning in SS, 3) determine P and K maintenance fertilization rates for sugar and cellulosic ethanol production, and 4) evaluate the effects of tillage and maintenance fertilization on soil test extractable P and K at three depths after four years of a monocrop system. A split-plot, randomized complete block design with four replications was used to evaluate the effects of two tillage treatments (no-till system (NT) and conventional tillage (CT)) and two fertilization treatments (with “maintenance” (MF) and without “maintenance” (NMF)) on SS production from 2012 to 2015. The MF applied 45 and 67 kg ha^{-1} of P_2O_5 and K_2O, respectively. The CT decreased days to 50% heading and increased the initial plant population. The NT increased the number of harvestable stalks which were derived from tillers. The MF increased plant height, stalk diameter, total biomass, and stalk biomass. The NT increased the P removal rate in green leaves. The MF application increased K concentration of stalk, green leaves, and the total K removal rate of the whole plant. The MF increased the P removal rate in the stalk. A 75 Mg ha^{-1} of SS would remove 40 and 145 kg ha^{-1} of P_2O_5 and K_2O, respectively, when only the stalk is harvested. When the whole plant is removed, approximately 78 and 193 kg ha^{-1} of P_2O_5 and K_2O would be removed, respectively. The MF application increased soil test exactable P at the 15 to 30 cm soil depth. Soil test extractable K was not affected by tillage and fertilization across the different soil depths.

Chapter 1. Introduction

1.1 Background

Sorghum (*Sorghum bicolor* (L.) Moench) is considered to be the fifth most important crop in the world among cereal crops (Rooney et al., 2007). It is one of the main food productions for the people in the poorest region, especially in the most arid and marginal sub-tropical areas (Marengo et al., 2015). There are three sorghum-biotypes: grain sorghum (most commonly grown as a livestock food source), forage sorghum, and sweet sorghum. Sweet sorghum is a variant of grain sorghum, which was selected for its high sugar content at maturity (Carpita and McCann, 2008; Rooney et al., 2007; Vermerris, 2011). Sweet sorghum is also commonly considered as a biomass energy crop due to its high biomass (Zhang et al., 2010; Han et al., 2013). It can obtain a plant height over four meters and has a higher biomass yield potential (20 to 40 dry Mg ha^{-1}) as compared to grain sorghum (around 23 dry Mg ha^{-1}) (Turhollow et al., 2010).

Sweet sorghum has many advantageous agronomic properties that makes it attractive as bio-ethanol feedstock including a low nitrogen (N) requirement, short growth period, and is well-adapted across diverse environments. Sweet sorghum is often compared with sugarcane (*Saccharum* spp.) due to its high sugar content. Cutz et al. (2013) demonstrated that sweet sorghum has a huge bio-ethanol productive potential due to its Brix and concentration of fermentable sugars. The relatively high N use efficiency of sweet sorghum is helpful to garner attentions (Cassman and Liska, 2007). Sweet sorghum has a low N fertilizer requirement when compared with other bioenergy crops. Geng et al. (1989) demonstrated that sweet sorghum produced comparable biomass as corn (*Zea mays* L.) using 30% less N. In addition, sweet sorghum had a higher N use efficiency than corn when they received the same N fertilization rate. Sweet sorghum's high N use efficiency and low N requirement make sweet sorghum highly adaptable on different soils. Han et al. (2011) demonstrated that sweet sorghum had nutrient accumulation of 128 to 339 kg N ha^{-1}, 13 to 75 kg phosphorus (P) ha^{-1}, and 109 to 300 kg potassium (K) ha^{-1}, depending on cultivar. Among bioenergy crops, sweet sorghum is important because this type of sorghum has a high biomass yield potential, comparable sugar content with other sugar crops, and considerable potential energy output. Almodares and Hadi (2009) reported that the ratio of energy output of and energy input for sweet sorghum is considerably higher as compared with other traditional crops such as sugar beet (*Beta vulgaris*), sugarcane, wheat (*Triticum aestivum* L.), and corn. Sweet sorghum is also attractive as a biofuel feedstock because, unlike sugarcane, it is an annual (instead of a perennial) crop and can be rotated with other annual crops such as corn and soybeans due to its short growth period (Turhollow et al., 2010). Sweet sorghum has a great ability to tolerate poor environments. Under some environmental conditions, sweet sorghum can adapt better than other traditional bioenergy crops such as corn. Qu et al. (2014) indicated that sweet sorghum probably more tolerated to high temperatures, heavy rainfall, and acid soil as compared to corn. Because of these advantages, sweet sorghum is considered as an excellent choice to increase land use efficiency on relatively poor agricultural lands as compared to the more fertile lands where traditional bioenergy crops are often planted.

Sweet sorghum is thought to originate from just north of the equator in Africa. Traditionally, sweet sorghum attracted farmers because of its high sugar content which can be processed into syrup. Sweet sorghum was traditionally introduced to the United States for syrup production during the 1850's, and sweet sorghum syrup production peaked at about 136 million liters per year in 1946, when it was substituted for sugar during the World War II (Winberry, 1980; Hunter and Anderson, 1997).

Sweet sorghum as a bio-ethanol feedstock has garnered much attention in recent years. Sweet sorghum is currently being considered as an excellent source for ethanol production because its extractable juice contains high amounts of fermentable sugar and a lot of trace elements which are essential for yeast growth and ethanol fermentation (Laopaiboon et al., 2009). Sweet sorghum can yield more ethanol per unit area of land, especially under poor soil conditions as compared with other bio-ethanol producing crops because it is well-adapted to marginal growing conditions (Regassa and Wortmann, 2014). Vasilakoglou et al. (2011) also estimated that even under increased soil salinity and reduced irrigation, yields of bio-ethanol from sweet sorghum cultivars could still reach 7026 L ha^{-1}.

Development of bioenergy crops is becoming more and more important as greenhouse gas emission increases (Lemus and Lal, 2005). Sweet sorghum, as a developing bioenergy crop, is considered to be an excellent choice to satisfy bio-ethanol demands. Currently, two main methods are targeted to increase sweet sorghum bio-ethanol output: improving industrial technologies and increasing biomass yield. Some chemical pretreatments are used in the sweet sorghum fermentation procedure. However, it is difficult to improve the overall yield of ethanol from sweet sorghum by pretreatments because the stalk contains an appreciable amount of free sugar which can be depleted during pretreatments (Antonopoulou and Lyberatos, 2012). Increasing biomass yield is an effective method to improve the output of bio-ethanol from sweet sorghum, which may also directly increase the yield of fermentable sugars. Breeding technologies and agronomic management practices have both been used to increase the yield of sweet sorghum. The technologies for breeding, especially the technologies for genetic improvement, are helpful in increasing the yield of bio-ethanol because high fermentable sugar can be increased by modifying genes. For example, Yu et al. (2015) identified the differentially expressed micro RNAs in sweet sorghum stems and leaves during sugar accumulation, which can be used in sweet sorghum breeding. Agronomic management practices, as compared to advanced breeding technologies, such as tillage and fertilization, can also affect sweet sorghum yield (Roth et al., 2000; Erickson et al., 2012).

In 2012, almost 52.2 billion liters of biofuels was used for transportation, this accounted for around 7.1 percent of total fuels consumption (U.S. Bioenergy Statistics, 2016). Sweet sorghum is an excellent bio-ethanol crop which should be developed to satisfy increasing biofuel demands, especially as land resources become more limited.

1.2 Bioenergy Products and Biobased Products of Sweet Sorghum

Bioenergy products include bio-power (combustion energy or electricity) and biofuels (bio-ethanol or biogas). These bioenergy products can be produced from plant starch and cellulose. For example, cassava (*Manihot esculenta* Crantz) can be converted to bio-ethanol because it has high starch content (Wang et al., 2015). In Brazil, sugarcane bagasse is often burned for the generation of electricity because of bagasse's high cellulose content (Silva et al., 2014).

Bio-ethanol is one of the most important bioenergy products that can be produced from sweet sorghum. Generally, sweet sorghum's soluble sugar is fermented to produce ethanol. According to Ballesteros et al. (2004), sweet sorghum cellulosic materials after extraction can also be converted to ethanol. Kim and Day (2011) indicated that 1 Mg sweet sorghum can be fermented to 43 L ethanol using its sugar only; however, the ethanol conversion rate increases to 97 L per Mg of sweet sorghum when the soluble sugars, cellulose, and hemicellulose are used.

Most traditional bioenergy crops are considered as a food source in developing countries. Balat (2011) indicated that non-food related feedstocks, like sweet sorghum, have become more popular in recent years as compared with food-related or high starch feedstocks which were traditionally preferred by the bio-ethanol industry. Molaverdi et al. (2013) and Whitfield et al. (2012) demonstrated that sweet sorghum, as a non-food related bioenergy crop, is rich in many main ingredients what are needed for bio-ethanol and biogas production such as soluble sugars, insoluble carbohydrates, cellulose, and hemicelluloses. For this reason, sweet sorghum is becoming popular in developing countries. Even in the developed countries, it has garnered more attention due to the considerable economic benefits as compared to other bio-ethanol crops. Linton et al. (2011) and Basavaraj et al. (2013) analyzed the economics of sweet sorghum's bio-ethanol potential in the United States and in India, respectively, and reported that sweet sorghum has the potential to be developed as a viable feedstock for bio-ethanol and produces comparable bio-ethanol yields as corn.

Combustion energy for electricity is important bioenergy product that can be derived from sweet sorghum production. Bagasse of sweet sorghum is the raw feedstock of combustion energy, which is a byproduct of the sugar extraction procedure. The combustion energy of sweet sorghum bagasse is similar to sugarcane bagasse. However, sweet sorghum bagasse combustion can generate the electricity during the off-season of sugarcane, which makes sweet sorghum combustion attractive and economical. In Central America, Cutz (2014) tested a special strategy for a sugar mill where the sweet sorghum bagasse was burned for the generation of electricity during two months of the sugarcane off-season. The results showed that the strategy would have a 4.49 years period of payback time as compared with a payback period of 7.47 years from the mono-use of sugarcane bagasse (Cutz, 2014).

Biobased products are commercial or industrial products from renewable agricultural materials or forestry materials, which includes adhesives, construction materials, fibers, paper, landscaping materials, lubricants, plastic, paints, solvents, compost, and sorbents (Federal Biobased Products Preferred Procurement Program, 2006). These biobased products can be produced from whole or byproducts of agricultural materials such as plant fibers. Traditionally, because of industrial costs, biobased byproducts are frequently produced only on a small-scale; however, as environmental awareness increases, commodity products such as biobased polymers are now being produced at a large or commercial scale (Yu, 2014).

Sweet sorghum can be converted into biobased products not only because of its considerable sugar content, but also because of high cellulose content in its stalk. Whitfield et al. (2012) demonstrated that sweet sorghum, due to its high cellulose content, can be converted into paper, forage, silage, and combustion energy. These biobased products increase the economic efficiency of sweet sorghum and helps sorghum to be competitive with other traditional bioenergy crops. Due to sweet sorghum’s ability to produce multiple products and its competitive economic efficiency, it is currently popular in biobased industries.

1.3 Sweet Sorghum Agronomic Practices

Agronomic management practices are widely used to make agricultural production more efficient and increase crop yield. Among agronomic management practices, tillage and fertilization are the two most common practices used to increase crop yield. Irrigation, harvesting, residue management, weed control, and pest control are also helpful to maintain and improve crop yields. Agronomic practices can affect agricultural product quality and mineral element accumulation in crops.

Tillage and fertilization for sweet sorghum can significantly affect sorghum yields (Ahmed et al., 2014; Laddha and Totawat, 1997).Tillage is a useful agronomic practice which can be used to increase crop yield. Tillage is beneficial to seedbed preparation, crop establishment, seed germination, seedling emergence, weed control, insect control, plant pathogen control, and gaseous exchange (Mohammed, 2013). A no-till system can be used to maintain or increase soil organic matter. Minimizing soil disturbance is a feature of the no-till system (Save and Grow, 2011). Pittelkow et al. (2015) reported that the application of no-till on some crop farming systems is helpful to reduce soil erosion, decreases input costs, and sustains long-term crop productivity. Both tillage and no-till systems can be applied to sweet sorghum production. Both practices can have positive effects on sweet sorghum production. For example, conventional tillage can increase soil organic carbon in subsurface soils (Dou et al., 2008). Pittelkow et al. (2015) indicated that sweet sorghum grown in a no-till system produced higher yields as compared to conventional tillage when sweet sorghum was not irrigated. The choice of tillage practice should be determined based on the soil properties of the field. However, more information of the effect of tillage on sweet sorghum cropping system is needed.

Fertilization is widely used to satisfy nutrient demands and increase crop yield (He et al., 2015). Fertilization is the most effective method to increase soil potassium (K) and phosphorus (P) which are the primary nutrients that plants need to support many physiological functions (Li et al., 2015). Appropriate fertilization is important because sweet sorghum can decrease soil nutrient levels eventually with continuous cropping since biomass is removed at harvest. Adams et al. (2015) mentioned that sustainable agronomic management practices for sweet sorghum should include a fertilization strategy which will replenish the removed nutrients at harvest. Sweet sorghum can be harvested for different plant parts based on the bioenergy or biobased product targeted. This can result in soil nutrient removal rates. Therefore, an appropriate fertilization practice based on the targeted production is important in sweet sorghum production in order to provide sufficient nutrients to support plant development and maintain soil nutrient levels.

Sweet sorghum requires different harvesting methods based on the targeted end product. Two types of harvesting procedures commonly used for sweet sorghum production include whole plant harvesting (remove of all aboveground biomass) and stalk only harvesting. Stalk only harvesting is utilized mainly for sugar ethanol production. If cellulosic ethanol production, biogas, or combustion energy is the target product, the whole plant is harvested. Harvest time is also important for sweet sorghum production. Tsuchihashi and Goto (2004) demonstrated that the optimum harvest time for sweet sorghum was 103 days after sowing or 33 days after anthesis in Indonesia because sugar accumulation of sweet sorghum would be stable at that time.

Stalk only harvesting will leave plant residues in the field including leaves and seed heads. Sweet sorghum stalk only harvesting is helpful in maintaining soil fertility due to the increased plant residue which is returned to the soil and is available for decomposition then soil organic matter increased.

In addition to tillage and fertilization, other important agronomic practices for sweet sorghum include irrigation, weed control, and pest control. Normal rainfall totals typically satisfy the water requirement of sweet sorghum because it has excellent drought resistance and a low water requirement as compared to corn (Olukoya et al., 2015). Due to sweet sorghum adaptability across environments, some special irrigation strategies have been evaluated for sweet sorghum including irrigating with saline water (Ramos et al., 2012). Sweet sorghum utilizes the same weed control practice when it is planted on either fertile or marginal land (Zegada-Lizarazu and Monti, 2012). Pest control is simple for sweet sorghum when compared to sugarcane and sugar beet because it has fewer pest and disease problems (Prasad et al., 2007). Generally, most chemical pesticides can be applied on sweet sorghum except organophosphate pesticides because many varieties are sensitive to this class of chemicals (Guiying et al., 2000).

1.4 Soil Fertility for a Monocrop Sweet Sorghum Production System

Soil is a biologically active mixture of organic and mineral matter which has supported agricultural productions for over 10,000 years (Richter Jr, and Markewitz, 2001). The fertile soil is the prerequisite to support an agricultural ecosystem, healthy crop, and high quality crop productivity (Doran and Zeiss, 2000; Larson and Pierce, 1994).

Soil fertility relates to the available soil nutrients in the soil. Nutrient avaliability can be altered by agronomic practices such as fertilization and tillage (Berner et al., 2008; Steiner et al., 2007). Edwards et al. (1992) indicated that tillage and crop rotations had an effect on soil nutrient levels. Therefore, in order to maintain soil fertility levels, appropriate agronomic and fertility management practices should be designed based on the individual cropping system.

When sweet sorghum plant biomass is removed from the field without fertilization, soil nutrient levels decrease, especially in a monocroping system. According to Murrell (2005), the nutrient removal rates of P and K for grain sorghum stover (leaves and stalks) are 4.2 kg P_2O_5 and 21 kg K_2O per 1Mg stover removed. In order to maintain sufficient soil P and K for sweet sorghum, fertilizers of P and K should be applied to at least offset P and K removal rates of sweet sorghum.

Soil fertility can also be affected by soil organic matter and soil pH. Soil organic matter plays an important role to sustain soil fertility (Tiessen et al., 1994). Soil organic matter is a critical component of soils, which affects many reactions that occur in the soil system (Schnitzer and Khan, 1975). Increasing the organic matter content of a soil can be achieved by using reduced tillage systems (Oades, 1984; Six et al., 2000). Soil pH is a measurement of the acidity and alkalinity of the soil, which can affect the availability of many soil nutrients. Sweet sorghum yield and quality is adversely impacted when the soil pH is less than 5.0 or higher than 8.5 (Li et al., 2000).

Sweet sorghum can assist in satisfying the increasing bioenergy demands. Many agronomic sweet sorghum studies have been completed; however, more information is needed to determine optimum agronomic practices for sweet sorghum production in the southeastern U.S. Future agricultural research should focus on evaluating agronomic practices that have the potential to improve sweet sorghum production and maintain soil fertility.

1.5 References

Adams, C.B., J.E. Erickson, and M.P. Singh. 2015. Investigation and synthesis of sweet sorghum crop responses to nitrogen and potassium fertilization. *Field Crops Research* 178:1-7.

Ahmed, S.O., A.W.H. Abdalla, T. Inoue, A. Ping, and E.E. Babiker. 2014. Nutritional quality of grains of sorghum cultivar grown under different levels of micronutrients fertilization. *Food Chemistry* 159:374-380.

Almodares, A. and M.R. Hadi. 2009. Production of bioethanol from sweet sorghum: A review. *African Journal of Agricultural Research* 4:772-780.

Almodares, A., M.R. Hadi, H. Ahmadpour. 2008. Sorghum stem yield and soluble carbohydrates under phonological stages and salinity levels. *African Journal of Biotechnology* 7:4051-4055.

Balat, M. 2011. Production of bioethanol from lignocellulosic materials via the biochemical pathway: a review. *Energy Conversion and Management* 52:858-875.

Ballesteros, M., J.M. Oliva, M.J. Negro, P. Manzanares, and I. Ballesteros. 2004. Ethanol from lignocellulosic materials by a simultaneous saccharification and fermentation process (SFS) with Kluyveromyces marxianus CECT 10875. *Process Biochemistry* 39:1843-1848.

Basavaraj, G., P.P. Rao, K. Basu, C.R. Reddy, A.A. Kumar, P.S. Rao, and B.V.S. Reddy. 2013. Assessing viability of bio-ethanol production from sweet sorghum in India. *Energy Policy* 56:501-508.

Berner, A., I. Hildermann, A. Fliessbach, L. Pfiffner, U. Niggli, and P. Mäder. 2008. Crop yield and soil fertility response to reduced tillage under organic management. *Soil and Tillage Research*, 101(1):89-96.

Carpita, N.C., M.C. McCann. 2008. Maize and sorghum: genetic resources for bioenergy grasses. *Trends in Plant Science* 13:415-420.

Cassman, K.G. and A.J. Liska. 2007. Food and fuel for all: realistic or foolish?. *Biofuels, Bioproducts and Biorefining* 1:18-23.

Cutz, L. and D. Santana. 2014. Techno-economic analysis of integrating sweet sorghum into sugar mills: The Central American case. *Biomass and Bioenergy* 68:195-214.

Cutz, L., S. Sánchez-Delgado, U. Ruiz-Rivas, and D. Santana. 2013. Bioenergy production in Central America: integration of sweet sorghum into sugar mills. *Renewable and Sustainable Energy Reviews* 25:529-542.

Doran, J.W. and M.R. Zeiss. 2000. Soil health and sustainability: managing the biotic component of soil quality. *Applied Soil Ecology* 15:3-11.

Dou, F., A.L. Wright, and F.M. Hons. 2008. Dissolved and Soil Organic Carbon after Long-Term Conventional and No-Tillage Sorghum Cropping. *Communications in Soil Science and Plant Analysis* 39:667-679.

Edwards, J.H., C.W. Wood, D.L. Thurlow, and M.E. Ruf. 1992. Tillage and crop rotation effects on fertility status of a Hapludult soil. *Soil Science Society of America Journal*, 56:1577-1582.

Erickson, J.E., K.R. Woodard, and L.E. Sollenberger. 2012. Optimizing sweet sorghum production for biofuel in the southeastern USA through nitrogen fertilization and top removal. *Bioenergy Research* 5:86-94.

Federal Biobased Products Preferred Procurement Program. 2006. United States Department of Agriculture. *http://www.usda.gov/biobased* (accessed 18 Sept. 2015)

Geng, S., F.J. Hills, S.S. Johnson, and R.N. Sah. 1989. Potential Yields and On-Farm Ethanol Production Cost of Corn, Sweet Sorghum, Fodderbeet, and Sugarbeet. *Journal of Agronomy and Crop Science* 162:21-29.

Li, G., W. Gu, A. Hicks, and K.R. Chapman. 2000. Training manual for sweet sorghum. Food and Agriculture Organization of the United Nations (FAO), Bangkok, Thailand.

Han, K.J., W.D. Pitman, M. Kim, D.F. Day, M.W. Alison, M.E. McCormick, and G. Aita. 2013. Ethanol production potential of sweet sorghum assessed using forage fiber analysis procedures. *Gcb Bioenergy* 5:358-366.

Han, L. P., Y. Steinberger, Y.L. Zhao, and G.H. Xie. 2011. Accumulation and partitioning of nitrogen, phosphorus and potassium in different varieties of sweet sorghum. *Field Crops Research* 120:230-240.

He, Y.T., W.J. Zhang, M.G. Xu, X.G. Tong, F.X. Sun, J.Z. Wang, S.M. Huang, P. Zhu, and X.H. He. 2015. Long-term combined chemical and manure fertilizations increase soil organic carbon and total nitrogen in aggregate fractions at three typical cropland soils in China. *Science of the Total Environment* 532:635-644.

Hunter, E.L. and I.C. Anderson. 1997. Sweet sorghum. *Horticultural reviews* 21:73-104.

Kim, M. and D.F. Day. 2011. Composition of sugar cane, energy cane, and sweet sorghum suitable for ethanol production at Louisiana sugar mills. *Journal of Industrial Microbiology and Biotechnology* 38:803-807.

Laddha, K.C. and K.L. Totawat. 1997. Effects of deep tillage under rainfed agriculture on production of sorghum (Sorghum biocolor L. Moench) intercropped with green gram (Vigna radiata L. Wilczek) in western India. *Soil and Tillage Research* 43:241-250.

Laopaiboon, L., S. Nuanpeng, P. Srinophakun, P. Klanrit, and P. Laopaiboon. 2009. Ethanol production from sweet sorghum juice using very high gravity technology: Effects of carbon and nitrogen supplementations. *Bioresource Technology*, 100:4176-4182.

Larson, W.E. and F.J. Pierce. 1994. The dynamics of soil quality as a measure of sustainable management. Defining Soil Quality for a Sustainable Environment 37-51.

Lemus, R. and R. Lal. 2005. Bioenergy crops and carbon sequestration. *Critical Reviews in Plant Sciences* 24:1-21.

Li, P., X. Han, Y. Zong, H. Li, E. Lin, Y. Han, and X. Hao. 2015. Effects of free-air CO_2 enrichment (FACE) on the uptake and utilization of N, P and K in Vigna radiata. Agriculture, *Ecosystems, and Environment* 202:120-125.

Linton, J.A., J.C. Miller, R.D. Little, D.R. Petrolia, and K.H. Coble. 2011. Economic feasibility of producing sweet sorghum as an ethanol feedstock in the southeastern United States. *Biomass and Bioenergy* 35:3050-3057.

Marengo, M., F. Bonomi, A. Marti, M.A. Pagani, A.E.O. Elkhalifa, and S. Iametti. 2015. Molecular features of fermented and sprouted sorghum flours relate to their suitability as components of enriched gluten-free pasta. *LWT-Food Science and Technology* 63:511-518.

Mohammed, S.A.A., 2013. Contribution of weed control and tillage systems on soil moisture content, growth and forage quality of (Clitoria and Siratro) mixture under-rainfed conditions at Zalingei-western Darfur state-Sudan. *ARPN Journal of Science and Technology* 3:80-95.

Molaverdi, M., K. Karimi, M. Khanahmadi, and A. Goshadrou. 2013. Enhanced sweet sorghum stalk to ethanol by fungus Mucor indicus using solid state fermentation followed by simultaneous saccharification and fermentation. *Industrial Crops and Products* 49:580-585.

Murrell, T.S. 2005. Average nutrient removal rates for crops in the Northcentral Region. International Plant Nutrition Institute (IPNI). *http://www.ipni.net/northcentral/nutrientremoval* (accessed 15 Mar. 2016)

Oades, J.M. 1984. Soil organic matter and structural stability: mechanisms and implications for management. *Plant and Soil*, 76:319-337.

Olukoya, I.A., D. Bellmer, J.R. Whiteley, and C.P. Aichele. 2015. Evaluation of the environmental impacts of ethanol production from sweet sorghum. *Energy for Sustainable Development* 24:1-8.

Pittelkow, C.M., B.A. Linquist, M.E. Lundy, X. Liang, K.J. Van Groenigen, J. Lee, N. Van Gestel, J. Six, R.T. Venterea, and C. Van Kessel. 2015. When does no-till yield more? A global meta-analysis. *Field Crops Research* 183:156-168.

Prasad, S., A. Singh, N. Jain, and H.C. Joshi. 2007. Ethanol production from sweet sorghum syrup for utilization as automotive fuel in India. *Energy and Fuels* 21:2415-2420.

Qu, H., X.B. Liu, C.F. Dong, X.Y. Lu, and Y.X. Shen. 2014. Field performance and nutritive value of sweet sorghum in eastern China. *Field Crops Research* 157:84-88.

Ramos, T.B., N.L. Castanheira, M.C. Gonçalves, M.L. Fernandes, M.I. Januário, M.E. Lourenço, F.P. Pires, and J.C. Martins. 2012. Effect of combined use of brackish water and nitrogen fertilizer on biomass and sugar yield of sweet sorghum. *Pedosphere*, 22:785-794.

Regassa, T.H. and C.S. Wortmann. 2014. Sweet sorghum as a bioenergy crop: literature review. *Biomass Bioenergy* 64:348-355.

Richter Jr, D.D. and D. Markewitz. 2001. Understanding soil change: soil sustainability over millennia, centuries, and decades. Cambridge University Press.

Rooney,W.L., J. Blumenthal, B. Bean, and J.E. Mullet. 2007. Designing sorghum as a dedicated bioenergy feedstock biofuels. *Bioproducts Biorefining* 1:147–157.

Roth, C.M., J.P. Shroyer, and G.M. Paulsen. 2000. Allelopathy of sorghum on wheat under several tillage systems. *Agronomy Journal* 92:855-860.

Schnitzer, M. and S.U. Khan. 1975. Soil organic matter. *Elsevier,* Amsterdam.

Save and Grow: A Policymaker's Guide to the Sustainable Intensification of Smallholder Crop Production. 2011. Food and Agriculture Organization of the United Nations (FAO), Rome.

Silva, D.A.L., I. Delai, M.L.D. Montes, and A.R. Ometto. 2014. Life cycle assessment of the sugarcane bagasse electricity generation in Brazil. *Renewable and Sustainable Energy Reviews* 32:532-547.

Six, J., K. Paustian, E.T. Elliott, and C. Combrink. 2000. Soil structure and organic matter I. Distribution of aggregate-size classes and aggregate-associated carbon. *Soil Science Society of America Journal* 64:681-689.

Steiner, C., W.G. Teixeira, J. Lehmann, T. Nehls, J.L. V. de Macêdo, W.E. Blum, and W. Zech. 2007. Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. *Plant and soil* 291:275-290.

Tiessen, H., E. Cuevas, and P. Chacon. 1994. The role of soil organic-matter in sustaining soil fertility. *Nature* 371:783-785.

Tsuchihashi, N. and Y. Goto. 2004. Cultivation of sweet sorghum (Sorghum bicolor (L.) Moench) and determination of its harvest time to make use as the raw material for fermentation, practiced during rainy season in dry land of Indonesia. *Plant Production Science* 7:442-448.

Turhollow, A.F., E.G. Webb, and M.E. Downing. 2010. Review of sorghum production practices: Applications for bioenergy. Oak Ridge National Laboratory, Oak Ridge, Tennessee, 37831-6283.

U.S. Bioenergy Statistics: Overview. 2016. U.S. Department of Agriculture, Natural Resources Conservation Service. *http://www.ers.usda.gov* (accessed 18 Sept. 2015).

Vasilakoglou, I., K. Dhima, N. Karagiannidis, and T. Gatsis. 2011. Sweet sorghum productivity for biofuels under increased soil salinity and reduced irrigation. *Field Crops Research* 120:38-46.

Vermerris, W. 2011. Survey of genomics approaches to improve bioenergy traits in maize, sorghum and sugarcane free access. *Journal of Integrative Plant Biology* 53:105–119.

Wang, K., J.H. Zhang, P. Liu, H.S. Cao, and Z.G. Mao. 2014. Reusing a mixture of anaerobic digestion effluent and thin stillage for cassava ethanol production. *Journal of Cleaner Production* 75:57-63.

Whitfield, M.B., M.S. Chinn, and M.W. Veal. 2012. Processing of materials derived from sweet sorghum for biobased products. *Industrial Crops and Products* 37:362-375.

Winberry, J.J. 1980. The sorghum syrup industry: 1854-1975. *Agricultural History* 54:343-352.

Yu, H., L. Cong, Z. Zhu, C. Wang, J. Zou, C. Tao, Z. Shi, and X. Lu. 2015. Identification of differentially expressed microRNA in the stems and leaves during sugar accumulation in sweet sorghum. *Gene* 571:221-230.

Yu, J., 2014. Bio-based products from solar energy and carbon dioxide. *Trends in Biotechnology* 32:5-10.

Zegada-Lizarazu, W., and A. Monti. 2012. Are we ready to cultivate sweet sorghum as a bioenergy feedstock? A review on field management practices. *Biomass and Bioenergy* 40:1-12.

Zhang, C., G. Xie, S. Li, L. Ge, and T. He. 2010. The productive potentials of sweet sorghum ethanol in China. *Applied Energy* 87:2360-2368.

Chapter 2. Effect of Tillage and Fertilization on Sweet Sorghum Production

2.1 Introduction

The human society has been stimulated to develop renewable resources by the concerning for the security of oil supplement, the environment contamination of fossil fuels, and the greenhouse gas emissions (Hahn-Hägerdal et al., 2006). Bio-ethanol is one of the most common biofuels that can help to reduce environmental contamination associated with the use of fossil fuel. Bio-ethanol generally from agricultural raw materials has become popular as an alternative energy source to petroleum-based fuels because it is both renewable and environment friendly (Deesuth et al., 2015). Bio-ethanol is often produced from fermentable plant tissue by fermentation (Ni et al., 2007). Sweet sorghum (*Sorghum bicolor* (L.) Moench), which is rich in fermentable plant sugars, is considered as an important feedstock for fermentable bio-ethanol production (Balat and Balat, 2009). High yielding bio-ethanol crops are expected to increase as bio-ethanol demand increases and dependence on fossil fuels decline.

Tillage and fertilization strategies greatly influence biofuel crop yields. Tillage is defined as the mechanical to manipulate the soil for the purpose of crop production. Tillage affects soil pore space, soil temperature, water infiltration, agricultural economics, crop yields, and soil quality (Basso et al., 2003; Busari et al., 2015; Rasmussen, 1999). There are two commonly used tillage systems: conventional tillage (CT) and no-till (NT). Conventional tillage inverts soil, which helps to control weeds, incorporates organic material such as plant residues and manures, and loosens the top soil (Crittenden et al., 2015). The NT system has minimum soil disturbance as compared with CT. No-till soils have the potential to become more porous with time due to the creation of a stable soil structure, increases soil organic matter, and increases the level of macro and micro-pores directly connected to the soil surface over time (Huang et al., 2015).

Tillage practices are often used to alter soil structure for agricultural purposes. Soil structure influences many benefits including: retaining soil moisture content, increasing soil nutrient availability, and influencing microbial activities (Dexter, 1988; Elliott, 1986). Plant growth can be affected by alteration of soil structure through influencing root distribution, soil water availability, and soil nutrient availability (Pardo et al., 2000; Rampazzo et al., 1998). Generally, a stable soil structure can maintain or improve crop yield by retaining or increasing water-holding capacity, saturated hydraulic conductivity, and soil aeration (Jastrow and Miller, 1991; Karami et al., 2012).

Application of fertilizer is the most effective and often the most expensive management practice implemented in order to attain high crop productivity (Singh et al., 2015). An appropriate fertilization strategy is important in obtaining high biomass yields of bioenergy crops and subsequently high biofuel yields. Increasing nitrogen (N) fertilization rate has been shown to increase yield of corn stover, cob biomass, and bio-ethanol (Sindelar et al., 2012). Fertilization is also used as a common agronomic management practice to increase soil nutrient levels which are critical parameters to determine whether the soil is fertile or not (He et al., 2015). Moreover, Mbuthia et al. (2015) demonstrated that fertilization can not only affect soil nutrient level and crop biomass yields, but it can also affect the soil microbial community. However, agronomic practices such as fertilization, tillage, and biomass harvesting tend to affect soil nutrient level that originally existed in native ecosystems (McLauchlan, 2006). In addition, levels of soil nutrients can be decreased by harvesting crops over time without fertilization or improper fertilization (Sumithra et al., 2013).

The increasing bio-ethanol demand has stimulated research related to bio-ethanol crops. Unlike the traditional bio-ethanol producing crops such as maize (*Zea mays* L.) and sugarcane

(*Saccharum* spp.), sweet sorghum is considered a relatively new bio-ethanol crop and has recently attracted much attention. Sweet sorghum has readily fermentable sugars (sucrose, glucose, and fructose) in its high sugar content juice, starch, hemicellulose, and cellulose which can be used in both current sugar-based ethanol production and cellulosic ethanol production (Wu et al., 2010). Some developing countries, especially those countries with large populations and serious stress from environmental groups, such as India and China, would like to develop an advanced sweet sorghum industry. For example, the development of sweet sorghum in China is an agricultural policy option of the government and international agencies that aims at improving agricultural land use by promoting sustainable crops for development in semi-arid and other undeveloped lands (Gnansounou et al., 2005). Although sweet sorghum is currently a popular research topic, research regarding agronomic strategies is still limited, especially regarding tillage and fertilization. Therefore, the objectives of this study were to 1) evaluate the agronomic response of sweet sorghum to CT and NT systems, and 2) evaluate the impact of P and K fertilization on the sweet sorghum production.

2.2 Materials and Methods

A field experiment was conducted at the LSU Agricultural Center H. Rouse Caffey Rice Research Station South Farm (30^{o}10’ 43’’ N, 92^{o}21’15’’ W) in Crowley, Louisiana, from 2012 to 2015. Soil at the experimental site was classified as a Crowley silt loam soil (Fine, montmonillonitic, thermic Typic Albaqualf).

A split-plot, randomized complete block design with four replications was used to evaluate the effects of two tillage treatments (no-till system (NT) and conventional tillage (CT)) and two fertilization treatments (with ‘maintenance’ (MF) and without ‘maintenance’ (NMF)) on sweet sorghum production. Conventional tillage was accomplished by disking the soil to a depth of 15 cm two times followed by passing a cultipacker. The main plots were tillage systems while fertilization practices served as sub-plots. The ‘maintenance’ fertilizer treatment consisted phosphorus (P) fertilizer applied at a rate of 45 kg P_2O_5 ha^{-1} and a potassium (K) fertilizer applied at a rate of 67 kg K_2O ha^{-1}. The ‘maintenance’ rates were chosen based on the LSU AgCenter soil test recommendation for P and K for grain sorghum for a soil falling into the “medium” soil test extractable P (45 kg P_2O_5 ha^{-1}) and “low” soil test extractable K (68 kg K2O ha^{-1}) levels. The “maintenance” treatment used in this study is not based on the removal rates of P and K of sweet sorghum. Currently, true removal rates for sweet sorghum have not published. Soil test ratings for grain sorghum are shown in Table 2.1. Initial soil test results are presented in Table 2.2 and indicate that Mehlich-3 soil test P fell into the “high” soil test category, while soil K fell into the “low” category.

Fertilizers were mixed and hand broadcasted at planting. The P source used was triple super phosphate (0-46-0), while the K source used was the potash (0-0-60). All plots were surface broadcasted with N fertilizer at a rate of 101kg N ha^{-1} using urea (46-0-0) at the 6-leaf stage of development. All plots were tilled in 2012 which was considered as the ‘base year’. Plot size was 3.04 m x 9.12 m which included four drill rows with a row spacing of 0.76 m.

The sweet sorghum cultivar ‘Dura-Sweet’ was drill seeded at a rate of 150,000 seeds ha^{-1} to a depth of 1.3 cm. The planting and harvesting schedule was as follows: In 2012, the sweet sorghum was seeded on April 19 and harvested on August 15. In 2013, the sweet sorghum was seeded on April 23 and harvested on August 22. In 2014, the sweet sorghum was seeded on April 23 and harvested on September 4. In 2015, the sweet sorghum was seeded on May 5 and harvested on October12. Weed and pest control from 2012 to 2015 are presented in Table 2.3.

Table 2.1. Soil test ratings for grain sorghum on different types of silt loam soil based on the Mehlich 3 test extraction.

Element	Soil Type	Soil Texture	Very Low	Low	Medium	High
			———— mg kg^{-1} ————			
P	Alluvial and Upland	Silt Loam	< 10	10 - 20	20 - 35	> 35
K	Alluvial	Silt Loam	< 91	91 - 136	136 - 182	>205
K	Upland	Silt Loam	< 80	80 - 125	125 - 182	>205

Table 2.2. Initial soil organic matter content, concentration of soil test extractable P and K, and pH of soil used for sweet sorghum trials on tillage and fertilization across different depths at Crowley in 2012 pre-plant†.

Soil depth (cm)	SOM‡	Soil test extractable P	Soil test extractable K	pH
	%	———— mg kg^{-1} ————		
0-7.5	2.24	91	90	5.3
7.5-15	1.61	69	54	5.4
15-30	0.96	15	37	5.8

† Initial soil organic matter content, Mehlich-3 soil test extractable P and K, and soil pH prior to trial initiation in 2012.
‡ SOM represents soil organic matter as determined by the combustion method

Table 2.3. List of the chemicals for sweet sorghum weeds and pests control used in Crowley from 2012 to 2015.

Year	Time	Herbicide (rate)	Time	Insecticide (rate)
2012	Apr 20	Atrazine 4L (4.7 L ha^{-1}), Dual Magnum (1.8 L ha^{-1}),	May 18	Karate (0.2 L ha^{-1})
	May 22	Permit, Facet (0.05 L ha^{-1}), Atrazine (1.2 L ha^{-1}), Dual Magnum (1.3 L ha^{-1}), Facet (0.4 L ha^{-1})	May 23	Karate (0.2 L ha^{-1})
2013	Mar 22	Charger Mas (1.8 L ha^{-1}), Atrazine 4L (4.7 L ha^{-1})		
	Apr 23	Glyphosate (3.5 L ha^{-1})		None
	May 9	Charger Mas (1.8 L ha^{-1}), Atrazine 4L (3.8 L ha^{-1})		
2014	Mar 21	Glyphosate (3.5 L ha^{-1})	May 23	Belt(0.3 L ha^{-1})
	May 12	Charger Max (1.8 L ha^{-1}), Atrazine 4L (3.8 L ha^{-1})	Jul 1	Transform (0.08 L ha^{-1})
	May 27	Charger Max (1.8 L ha^{-1})	Jul 29	Transform (0.09 L ha^{-1})
2015	Jun 5	Glyphosate, Facet (3.3 L ha^{-1}), Atrazine (2.4 L ha^{-1}), Charger Max (1.8 L ha^{-1}), Permit (0.08 L ha^{-1}), COC (1.4 L ha^{-1})	Jul 21	Transform (0.08 L ha^{-1})
			Aug 27	Belt (0.15 L ha^{-1}), Acephate (0.6 L ha^{-1}), Leverage 360 (0.2 L ha^{-1}), COC (1.2 L ha^{-1})

The sweet sorghum plant population was determined each year by counting the number of plants from a 3-m linear section of the second drill-row at the 3-leaf stage of development. The 3-m linear row where the plant population was taken was marked with two plot stakes at the time the plant population was determined. Aboveground plant samples were collected from the second drill-row within the 3 m marked area at the soft-dough stage of development. Plant samples were weighed, counted, and separated into four plant parts: seed head, stalk, green leaves, and brown leaves (mature leaves). Whole stalk samples were then sent to the LSU Agricultural Center Sugar Research Station Sucrose Laboratory in St. Gabriel, Louisiana, to determine sugar Brix content. The term "Brix" technically means a measurement of the mass ratio of soluble sugar to solution, which is widely used to estimate a crops' sugar content (Audilakshmi et al., 2010). Other selected agronomic parameters included total biomass (Mg ha^{-1}, wet), stalk biomass (Mg ha^{-1}, wet), plant height (cm), stalk diameter (mm), days to 50% heading day, plant population (plants ha^{-1}), harvestable stalk population (stalks ha^{-1}), tiller percentage (% tiller; difference ratio between plant population at the 3-leaf stage of development and the harvestable stalk population), Brix (^{o}Bx, 1 g of soluble sugar in 100 g of solution), and an estimation of fermentable solids (Mg ha^{-1}; solids in extraction juice which can be fermented). The plant population was calculated using the following equation:

Plant population = PN * (one hectare / SA) [Eq. 2.1]

Where:

PN = plant number from the sampled area at the three-leaf stage of development.

SA = sample area (2.32 m^2).

The harvestable stalk population was calculated using the following equation:

Harvestable stalk population = SN * (one hectare / SA) [Eq. 2.2]

Where:

SN = stalk number from sampled area at harvest

The total biomass (Mg ha^{-1}, wet) was calculated using the following equation:

Total biomass = PW* (one hectare / SA)/1000 [Eq. 2.3]

Where:

PW = whole plant weight from sampled area at harvest, kg

The stalk biomass (Mg ha^{-1}, wet) was calculated using the following equation:

Stalk biomass = SW* (one hectare / SA)/1000 [Eq. 2.4]

Where:

SW = stalk weight from sampled area at harvest, kg

The fermentable solid (Mg ha^{-1}, wet) was calculated using the following equation:

Fermentable solids = Stalk biomass* Brix value * 0.9 [Eq. 2.5]

Where:

0.9 is an estimate of the sugar content which will be extracted 90% during processing

The estimated tiller percentage (%) was calculated using the following equation:

Estimated tiller percentage = (HS - PP) / HS * 100 [Eq. 2.6]

Where:

HS = harvestable stalk population

PP = plant population

All data were pooled over years and subjected to analysis of variance (ANOVA) with SAS 9.4 software (SAS Institute, 2012). The PROC MIXED procedure was used in SAS in order to make inferences concerning tillage (T) and fertilization (F) across years (Carmer et al., 1989). Year was used as a random effect parameter testing all interactions of tillage and fertilization (T x F). Tillage, fertilization and the interaction of tillage and fertilization were used as fixed effects. Means were compared using the Tukey-kramer to determine any significant differences at alpha (α) < 0.05. The appendix of this thesis shows analysis of variance for each year analyzed separately.

2.3 Results and Discussion

The results of analysis of variance for the effects of T, F and their interaction T x F on selected sweet sorghum agronomics pooled over years is presented in Table 2.4. The treatment means of the effects of tillage systems and fertilization practices on sweet sorghum agronomics are shown in Table 2.5.

The main effect of F and the T x F interaction on days to 50% heading was not significant (Table 2.4). However, days to 50% heading was significantly affected by the effect of T (P = 0.030). Days to 50% heading increased from 105 days under CT to 107 days under NT (Table 2.5). Currently, limited research exists on the effect of tillage on sweet sorghum heading. However, Escalada and Plucknett (1977) indicated that high N fertilization delays heading of grain sorghum as much as 4 to 6 days due to continued vegetative growth caused by the high N application. In the current study, plots of CT and NT were applied with same rate of N fertilizer (101kg N ha^{-1}) at the 6-leaf stage of development each year. In this experiment, the soil surface was cracked at the time of N application in most years, allowing the N to move into the deeper soil prior to rainfall events which would have allowed the cracks to close and protect the N. This could possible make the N available for utilization by the sweet sorghum grown under NT and thus prolonging vegetative growth.

The main effect of F and the T x F interaction on sweet sorghum plant population at the 3-leaf stage of development was not significant (Table 2.4). However, sweet sorghum plant population was significantly (P = 0.046) affected by the effect of T. Plant population of sweet sorghum increased from 104,272 plants ha^{-1} under NT to 112,848 plants ha^{-1} under CT (Table 2.5). Potter et al. (1996) demonstrated that CT increased grain sorghum plant population as compared to NT during the three years of study. In addition, the least significant difference (LSD) between comparison of CT and NT was 13,800, 6,400, and 5,400 plants $ha^{-1}$for 1992, 1993, and 1994, respectively. The grain sorghum plant population LSD range from 5400 to 13800 plants ha^{-1} supported the sweet sorghum plant population result of current study which was 8,576 plants ha^{-1}.

The effect of F, T, and the T x F interaction on sweet sorghum harvestable stalk population was not significant (Table 2.4). Mean harvestable stalk population ranged from 111,078 to 119,246 stalks ha^{-1} across all treatments.

Wortmann et al. (2010) indicated that sweet sorghum planted with seeding rates of 7.5, 12.5, 17.5 seeds m^{-2} within a 0.75 m row spacing had similar harvestable stalk populations at harvest. This was possibly due to the increased number of tillers which compensated the low seed rates. In this study, the sweet sorghum seed rate was 150,000 seeds ha^{-1} which is

Table 2.4. Analysis of variance for the effect for tillage, fertilization, and the interaction of tillage and fertilization on days to 50% heading, plant population, harvestable stalk population, tiller percentage, plant height, stalk diameter, total biomass, stalk biomass, fermentable solids, and Brix content for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA (2012 - 2015). Data pooled over years (2012 - 2015).

Effect	Days to 50% heading†	Plant population	Harvestable stalk population	Tiller percentage‡	Plant height	Stalk diameter (at base of plant)	Total biomass	Stalk biomass	Brix	Fermentable solids
	———————— *P* value ————————									
Tillage (T)	0.030	0.046	0.873	0.004	0.862	0.172	0.840	0.606	0.546	0.750
Fertilization (F)	0.460	0.538	0.084	0.136	0.010	0.010	0.030	0.011	0.474	0.058
T x F	0.965	0.721	0.873	0.946	0.580	0.431	0.267	0.796	0.855	0.721

† 50% heading is the number of days after emergence until 50% of the panicles have emerged from the boot.

‡ Tiller percentage represents that the % of the harvestable stalks that were derived from tillers. The value was calculated by taking the difference in the plant population at the 3-leaf stage of the development and the harvestable stalk population and dividing by the harvestable stalk population.

Table 2.5. Effect of tillage, fertilization, and the interaction of tillage and fertilization on mean days to 50% plant heading, plant population, harvestable stalk population, tiller percentage, plant height, stalk diameter, total biomass, stalk biomass, fermentable solids, and Brix content of sweet sorghum grown on a Crowley silt loam soil, Crowley, LA (2012 - 2015). Data pooled over years (2012 - 2015).

Effect	Days to 50% heading†	Plant population	Harvestable stalk population	Tiller percentage	Height	Stalk diameter	Total biomass	Stalk biomass	Brix	Fermentable solids
	days	Plants ha^{-1}	Stalks ha^{-1}	%	cm	mm	— Mg ha^{-1} —		^{o}Bx	Mg ha^{-1}
Tillage										
CT‡	105 b§	112,848 a	115,162 a	2.00 b	340 a	17.7 a	68.5 a	53.6 a	13.5 a	6.31 a
NT	107 a	104,272 b	115,842 a	9.61 a	340 a	17.2 a	68.0 a	52.7 a	13.6 a	6.40 a
Fertilization										
MF	106 a	107,267 a	111,759 a	3.89 a	346 a	18.0 a	70.7 a	55.5 a	13.5 a	6.61 a
NMF	106 a	109,853 a	119,246 a	7.72 a	334 b	17.0 b	65.8 b	50.8 b	13.6 a	6.11 a
Interactions										
CT x MF	105 a	110,806 a	111,078 a	0.00 a	348 a	18.1 a	69.7 a	55.7 a	13.4 a	6.52 a
CT x NMF	105 a	114,890 a	119,246 a	4.01 a	333 a	17.4 a	67.2 a	51.5 a	13.6 a	6.12 a
NT x MF	106 a	103,727 a	112,439 a	7.78 a	344 a	17.9 a	71.7 a	55.3 a	13.6 a	6.69 a
NT x NMF	107 a	104,816 a	119,246 a	11.44 a	335 a	16.6 a	64.3 a	50.1 a	13.7 a	6.11 a

† 50% heading is the number of days after emergence until 50% of the panicles have emerged from the boot. Tiller percentage represents that the % of the harvestable stalks that were derived from tillers. The value was calculated by taking the difference in the harvestable stalk population and the plant population at the 3-leaf stage of development then dividing by the harvestable stalk population.

‡ CT and NT are conventional and no-till tillage systems, respectively. MF and NMF are with and without ‘maintenance’ fertilization, respectively.

§ Means followed by the same letter are not significantly different ($P < 0.05$).

approximately 15 seeds m^{-2} within a row spacing 0.76 m which was in the seed rate range of 7.5 to 17.5 seeds m^{-2}.In addition to sweet sorghum seed rate and row spacing of the current study, the result of harvestable stalk population was in agreement with the results of Wortmann et al. (2010).

The number of stalks at harvest that derived from tillers (tiller percentage) was not significantly affected by F and the T x F interaction (Table 2.4). However, sweet sorghum tiller percentage was significantly affected by T ($P = 0.004$). The NT increased the mean number of stalks at harvest that derived from tillers (tiller percentage) by 7.61% as compared with CT (Table 2.5). Many cereals such as rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), and grain sorghum produce tillers which contribute to an increase crop yield due to an increase in panicle and biomass density as compared to plants which do not tiller (Conway and Toenniessen, 1999; Jewiss, 1972; Khush, 1999). One explanation of why NT produced more harvestable stalks as compared to CT would be that CT had a higher plant population at the 3-leaf stage of development (112,848 plants ha^{-1}) as compared to NT (104,272 plants ha^{-1}). Tillering can be affected by many factors including initial plant population, plant genetics, agronomic management, and soil nutrient levels (Berenguer and Faci, 2001; Escalada and Plucknett, 1977; Hart et al., 2001; Krishnareddy et al., 2009; Porter et al., 1996; Unger and Wiese, 1979). Escalada and Plucknett (1977) showed that high N rate resulted in increased tillering of grain sorghum as compared with low N levels. In the current trial, the cracked soil surface of NT plots, may have allowed the N to move into deeper soil contributing to more available N to the NT plots as compared to CT plots. Since sweet sorghum grown under NT possibly had more available N which, in turn, may have influenced the increased tillers observed in the NT treatment as compared to the CT treatment.

Plant height of sweet sorghum is a critical agronomic parameter used to evaluate the growth of sweet sorghum because it relates to both plant biomass and sugar yield. The main effect of T and the T x F interaction on sweet sorghum plant height was not significant (Table 2.4). However, sweet sorghum plant height was significantly affected by the effect of F (P = 0.010). The mean plant height of sweet sorghum was increased by 12 cm when MF was applied as compared with NMF (Table 2.5).

A large stalk diameter of sweet sorghum is helpful to resist lodging. The main effect of T and the T x F interaction on sweet sorghum stalk diameter was not significant (Table 2.4). However, sweet sorghum stalk diameter was significantly affected by the main effect of F (P = 0.010). The MF increased the mean stalk diameter of sweet sorghum by 1.0 mm as compared with NMF (Table 2.5).

The increased plant height and stalk diameter of sweet sorghum receiving MF also had a significant effect on sweet sorghum total biomass and stalk biomass as compared with NMF when pooled over years. The total biomass of sweet sorghum is important because the total aboveground biomass of sweet sorghum would be used for ethanol production. The effect of T and the T x F interaction on sweet sorghum total biomass yield was not significant (Table 2.4). However, the effect of F on sweet sorghum total biomass was significant (P = 0.030). The MF increased the mean total biomass of sweet sorghum by 4.9 Mg ha^{-1} as compared with NMF (Table 2.5).

When sweet sorghum is produced for sugar ethanol production, only the stalks are harvested and remaining biomass is returned to the soil. Sweet sorghum stalk biomass was not affected by the effect of T and the T x F interaction (Table 2.4). Sweet sorghum stalk biomass was significantly affected by the effect of F (P = 0.011). The MF increased the mean stalk biomass of sweet sorghum by 4.7 Mg ha^{-1} as compared with NMF (Table 2.5). Wortmann et al. (2010) estimated that 1 Mg sweet sorghum stalk biomass increases sugar ethanol production by 48 L. Kim and Day (2011) indicated that 1 Mg sweet sorghum total biomass can be converted to 122 L ethanol production using its juice, cellulose, and hemicellulose. Therefore, the increased stalk biomass of 4.7 Mg ha^{-1} in current study may have increased sugar ethanol production by 226 L ha^{-1}, while the increased total biomass of 4.9 Mg ha^{-1} may have increased sugar and cellulosic ethanol production by 598 L ha^{-1}. The increased biomass observed in this study tends to come from the stalk, not the seed heads and leaves because the yield of seed head and leaves under MF was 15.2 Mg ha^{-1}, while the yield of seed and leaves under NMF was 15.0 Mg ha^{-1}.

Fertilizer NPK is commonly applied to sorghum to stimulate vegetative growth, satisfy demands of high plant height, increase stalk diameter, and increase biomass (Ayub et al., 2002; Muchow and Davis, 1988; Sawargaonkar et al., 2013; Zaongo et al., 1997). Almodares et al. (2008) evaluated the effect of combined N and K fertilization and N fertilization alone on sweet sorghum agronomics. The results of Almodares et al. (2008) supported the current study which showed that sweet sorghum fertilized both N and K had greater plant height, stalk diameter, total biomass, and stalk biomass at soft-dough stage of development when compared with N fertilization alone. In this experiment, the initial soil test extractable P and K determined based on Mehlich-3 procedure in 2012 at the upper 7.5 cm soil fell into the “high” soil test category and “low” category, respectively (Table 2.4 and 2.5). The significant effect of MF on sweet sorghum plant height, stalk diameters, total biomass and stalk biomass may have enhanced by the additional of K fertilizer. Prior fertilization of K can positively affect plant growth because K is important for plant photosynthesis, protein synthesis, enzyme activation, cell expansion, and stomatal movements (Mäser et al., 2002).

Brix is a measure of the mass ratio of soluble sugar to water, commonly used to estimate the sugar content of crop. Sweet sorghum Brix was not significantly affected by F, T, or the T x F interaction (Table 2.4). Soileau and Bradford (1985) reported that sweet sorghum Brix do not consistently relate to applied N, P, and K fertilizers. Kovács and Gyuricza (2012) tested the effect of three tillage treatments (plough at the depth of 22 to 25 cm, cultivation at the depth of 10 to 14 cm, disc harrow at the depth of 16 to 20 cm), and no-till treatment on sweet sorghum Brix. The findings of Kovács and Gyuricza (2012) indicated that tillage did not affect sweet sorghum Brix content. The results agreed with the current study. In this experiment, mean sweet sorghum Brix content was 13.4 and 13.7 ^{o}BX across different treatments. Almodares and Hadi (2009) found that the Brix content among 36 sweet sorghum cultivars ranged from ^{o}BX.

Fermentable solid is an estimate of the fermentable sugar content of sweet sorghum after sugar extraction. The main effect of F, T, and the T x F interaction on sweet sorghum fermentable solids was not significant (Table 2.4). Sweet sorghum fermentable solids ranged from 6.11 to 6.69 Mg ha^{-1} across different treatments. Sweet sorghum fermentable sugar (calculated using Brix * extracted juice) does not consistently relate to applied N, P, and K fertilization (Soileau and Bradford, 1985).

2.4 Conclusions

Tillage systems altered sweet sorghum agronomics. In this study, tillage significantly affected the sweet sorghum's days to 50% heading, plant population, and tiller percentage. Conventional tillage consistently decreased sweet sorghum's days to 50% heading by 2 days, while increased the initial plant population by 8,576 plants ha^{-1}. No-till increased the number of harvestable stalks that were derived from tillers. None the less, the stalk population at harvest was similar across both CT and NT systems.

Fertilization significantly affected sweet sorghum height, stalk diameter, total biomass, and stalk biomass. 'Maintenance' fertilization increased sweet sorghum height by 12 cm, stalk diameter by 1 mm, total biomass by 4.9 Mg ha^{-1}, and stalk biomass by 4.7 Mg ha^{-1}. The increased stalk biomass increased sugar ethanol production by an estimated 226 L ha^{-1}, while the increased total biomass increased sugar and cellulosic ethanol production by an estimated 598 L ha^{-1}. These increases can be potentially attributable to the additional K fertilizer since the initial soil test indicated that it was low in soil test extractable K. Fertilization is important in order to improve sweet sorghum height, stalk diameter, total biomass, and stalk biomass when soil nutrients are limiting.

2.5 References

Almodares, A., R. Taheri, M. Chung, and M. Fathi. 2008. The effect of nitrogen and potassium fertilizers on growth parameters and carbohydrate contents of sweet sorghum cultivars. *Journal of Environmental Biology* 29:849-852.

Almodares, A. and M.R. Hadi. 2009. Production of bioethanol from sweet sorghum: A review. *African Journal of Agricultural Research* 4:772-780.

Asgharipour, M.R. and M. Heidari. 2011. Effect of potassium supply on drought resistance in sorghum: plant growth and macronutrient content. *Pakistan Journal of Agricultural Sciences* 48:197-204.

Audilakshmi, S., A.K. Mall, M. Swarnalatha, and N. Seetharama. 2010. Inheritance of sugar concentration in stalk (Brix), sucrose content, stalk and juice yield in sorghum. *Biomass and Bioenergy* 34:813-820.

Ayub, M., M.A. Nadeem, A. Tanveer, and A. Husnain. 2002. Effect of different levels of nitrogen and harvesting times on the growth, yield and quality of sorghum fodder. *Asian Journal of Plant Science* 1:304-307.

Balat, M. and H. Balat. 2009. Recent trends in global production and utilization of bio-ethanol fuel. *Applied Energy* 86:2273-2282.

Basso, B., L. Sartori, M. Bertocco, and G. Oliviero. 2003. Evaluation of variable depth tillage: economic aspects and simulation of long term effects on soil organic matter and soil physical properties. Precision agriculture. Wageningen Academic Publisher, Wageningen, Netherlands, 61-67.

Berenguer, M.J. and J.M. Faci. 2001. Sorghum (Sorghum bicolor L. Moench) yield compensation processes under different plant densities and variable water supply. *European Journal of Agronomy* 15:43-55.

Busari, M.A., S.S. Kukal, A. Kaur, R. Bhatt, and A.A. Dulazi. 2015. Conservation tillage impacts on soil, crop and the environment. *International Soil and Water Conservation Research* 3:119-129.

Carmer, S.G., W.E. Nyquist, and W.M. Walker. 1989. Least significant differences for combined analyses of experiments with two-or three-factor treatment designs. *Agronomy Journal* 81:665-672.

Conway, G. and G. Toenniessen. 1999. Feeding the world in the twenty-first century. *Nature* 402:C55-C58.

Crittenden, S.J., N. Poot, M. Heinen, D.J.M. van Balen, and M.M. Pulleman. 2015. Soil physical quality in contrasting tillage systems in organic and conventional farming. *Soil and Tillage Research* 154:136-144.

Deesuth, O., P. Laopaiboon, P. Klanrit, and L. Laopaiboon. 2015. Improvement of ethanol production from sweet sorghum juice under high gravity and very high gravity conditions: Effects of nutrient supplementation and aeration. *Industrial Crops and Products* 74:95-102.

Dexter, A.R. 1988. Advances in characterization of soil structure. *Soil and Tillage Research* 11:199-238.

Elliott, E.T. 1986. Aggregate structure and carbon, nitrogen, and phosphorus in native and cultivated soils. *Soil Science Society of America Journal* 50:627-633.

Escalada, R.G. and D.L. Plucknett. 1977. Ratoon cropping of sorghum. III. Effect of nitrogen and cutting height on ratoon performance. *Agronomy Journal* 69:341-346.

Gnansounou, E., A. Dauriat, and C.E. Wyman. 2005. Refining sweet sorghum to ethanol and sugar: economic trade-offs in the context of North China. *Bioresource Technology* 96:985-1002.

Hahn-Hägerdal, B., M. Galbe, M.F. Gorwa-Grauslund, G. Lidén, and G. Zacchi. 2006. Bio-ethanol–the fuel of tomorrow from the residues of today. *Trends in Biotechnology* 24:549-556.

Hart, G.E., K.F. Schertz, Y. Peng, and N.H. Syed. 2001. Genetic mapping of Sorghum bicolor (L.) Moench QTLs that control variation in tillering and other morphological characters. *Theoretical and Applied Genetics* 103:1232-1242.

He, Y.T., W.J. Zhang, M.G. Xu, X.G. Tong, F.X. Sun, J.Z. Wang, J.Z. Wang, S.M. Huang, P. Zhu, and X.H. He. 2015. Long-term combined chemical and manure fertilizations increase soil organic carbon and total nitrogen in aggregate fractions at three typical cropland soils in China. *Science of the Total Environment* 532:635-644.

Huang, M., T. Liang, L. Wang, and C. Zhou. 2015. Effects of no-tillage systems on soil physical properties and carbon sequestration under long-term wheat–maize double cropping system. *Catena* 128:195-202.

Jastrow, J.D. and R.M. Miller. 1991. Methods for assessing the effects of biota on soil structure. *Agriculture, Ecosystems, and Environment* 34:279-303.

Jewiss, O.R. 1972. Tillering in grasses - its significance and control. *Grass and Forage Science* 27:65-82.

Karami, A., M. Homaee, S. Afzalinia, H. Ruhipour, and S. Basirat. 2012. Organic resource management: Impacts on soil aggregate stability and other soil physico-chemical properties. *Agriculture, Ecosystems, and Environment* 148:22-28.

Kim, M. and D.F. Day. 2011. Composition of sugar cane, energy cane, and sweet sorghum suitable for ethanol production at Louisiana sugar mills. *Journal of Industrial Microbiology and Biotechnology* 38:803-807.

Khush, G.S. 1999. Green revolution: preparing for the 21st century. *Genome* 42:646-655.

Krishnareddy, S.R., B.A. Stewart, W.A. Payne, and C.A. Robinson. 2009. Grain sorghum tiller production in clump and uniform planting geometries. *Journal of Crop Improvement* 24:1-11.

Kovács, G.P. and C. Gyuricza. 2012. The impact of different tillage systems and nutrient levels on the biomass and Brix values of sweet sorghum (Sorghum bicolor L. Moench). *African Journal of Agricultural Research* 7:3800-3805.

Mäser, P., M. Gierth, and J.I. Schroeder. 2002. Molecular mechanisms of potassium and sodium uptake in plants. *Plant and Soil* 247:43-54.

Mbuthia, L.W., V. Acosta-Martinez, J. Debryun, S. Schaeffer, D. Tyler, E. Odoi, M. Mpheshea, F. Walker, and N. Eash. 2015. Long term tillage, cover crop, and fertilization effects on microbial community structure, activity: Implications for soil quality. *Soil Biology and Biochemistry* 89:24-34.

McLauchlan, K. 2006. The nature and longevity of agricultural impacts on soil carbon and nutrients: a review. *Ecosystems*, 9:1364-1382.

Muchow, R.C. and R. Davis. 1988. Effect of nitrogen supply on the comparative productivity of maize and sorghum in a semi-arid tropical environment II. Radiation interception and biomass accumulation. *Field Crops Research* 18:17-30.

Ni, M., D.Y. Leung, and M.K. Leung. 2007. A review on reforming bio-ethanol for hydrogen production. *International Journal of Hydrogen Energy* 32:3238-3247.

Pardo, A., M. Amato, F.Q. Chiaranda. 2000. Relationships between soil structure, root distribution and water uptake of chickpea (Cicer arietinum L.). Plant growth and water distribution. *European Journal of Agronomy* 13:39– 45.

Porter, L.K., R.F. Follett, and A.D. Halvorson. 1996. Fertilizer nitrogen recovery in a no-till wheat-sorghum-fallow-wheat sequence. *Agronomy Journal* 88:750-757.

Potter, K.N., J.E. Morrison, and H.A. Torbert. 1996. Tillage intensity effects on corn and grain sorghum growth and productivity on a Vertisol. *Journal of Production Agriculture* 9:385-390.

Rampazzo, N., W.E.H. Blum, and B. Wimmer. 1998. Assessment of soil structure parameters and functions in agricultural soils. *Bodenkultur* 49:69– 84.

Rasmussen, K.J. 1999. Impact of ploughless soil tillage on yield and soil quality: a Scandinavian review. *Soil and Tillage Research* 53:3-14.

Sawargaonkar, G.L., M.D. Patil, S.P. Wani, E. Pavani, B.V.S.R. Reddy, and S. Marimuthu. 2013. Nitrogen response and water use efficiency of sweet sorghum cultivars. *Field Crops Research* 149:245-251.

Sindelar, A.J., J.A. Lamb, C.C. Sheaffer, H.G. Jung, and C.J. Rosen. 2012. Response of corn grain, cellulosic biomass, and ethanol yields to nitrogen fertilization. *Agronomy Journal*, 104:363-370.

Singh, S.R., D.K. Kundu, M.K. Tripathi, P. Dey, A.R. Saha, M. Kumar, I. Singh, and B.S. Mahapatra. 2015. Impact of balanced fertilization on nutrient acquisition, fibre yield of jute and soil quality in New Gangetic alluvial soils of India. *Applied Soil Ecology* 92:24-34.

Soileau, J.M. and B.N. Bradford. 1985. Biomass and sugar yield response of sweet sorghum to lime and fertilizer. *Agronomy Journal* 77:471-475.

Sumithra, R., M. Thushyanthy, and T. Srivaratharasan. 2013. Assessment of soil loss and nutrient depletion due to cassava harvesting: A case study from low input traditional agriculture. *International Soil and Water Conservation Research* 1:72-79.

Unger, P.W. and A.F. Wiese. 1979. Managing irrigated winter wheat residues for water storage and subsequent dryland grain sorghum production. *Soil Science Society of America Journal* 43:582-588.

Wortmann, C.S., A.J. Liska, R.B. Ferguson, D.J. Lyon, R.N. Klein, and I. Dweikat. 2010. Dryland performance of sweet sorghum and grain crops for biofuel in Nebraska. *Agronomy Journal* 102:319-326.

Wu, X., S. Staggenborg, J.L. Propheter, W.L. Rooney, J. Yu, and D. Wang. 2010. Features of sweet sorghum juice and their performance in ethanol fermentation. *Industrial Crops and Products* 31:164-170.

Zaongo, C.G.L., C.W. Wendt, R.J. Lascano, and A.S.R. Juo. 1997. Interactions of water, mulch and nitrogen on sorghum in Niger. *Plant and Soil* 197:119-126.

Chapter 3. Effect of Tillage and Fertilization on Nutrient uptake of Sweet Sorghum Production

3.1 Introduction

Essential plant nutrients are those elements which are needed to support plant growth and development. At least17 essential nutrients are needed to maintain plant growth including nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), zinc (Zn), iron (Fe), manganese (Mn), copper (Cu), boron (B), chlorine (Cl), molybdenum (Mo), carbon (C), hydrogen (H), oxygen (O), and nickel (Ni). Plant nutrients can be separated into four types: primary (N, P, and K), secondary (S, Ca, and Mg), micronutrients (B, Cl, Mn, Fe, Zn, Cu, Mo, and Ni), and non-fertilizer elements (C, H, and O). Nitrogen, P, and K are defined as primary nutrients because these nutrients are needed by plants in the greatest amount. The sources of plant nutrient elements are derived from the soil but C, H, and O. Levels of nutrients in the soil have a major effect on plant growth and soil fertility (Gruhn et al., 2000). The availability of plant nutrients greatly depends on the amount of soil nutrients, the mode of available soil nutrient uptake, and the properties of the soil (Barber 1995). The availability of plant nutrients are impacted by soil chemical and physical properties such as the mineral content, amount of organic matter, depth to bedrock, water permeability, water holding capacity, and water drainage (Fernández and Hoeft, 2009). Climate is another factor which can affect the level of plant nutrients because some soil activities such as remineralization can be altered by climate variations (Gilmartin et al., 1990).

Agronomic management practices, like tillage and fertilization, are commonly used to improve plant nutrient availability for crops. Tillage can affect plant nutrient availability by altering soil physical and chemical properties. Tillage usually disturbs at least 15 to 25 cm of surface soil and replaces the stratified surface soil with a homogeneous tilled zone. The tilled soil will have somewhat uniform soil physical characteristics and residue distribution as compared with soil without tillage (Altieri, 1999). Soil tillage can affect chemical movement and plant growth due to changes in soil hydraulic properties, soil organic matter, soil losses, and soil spatial viability (McDowell and McGregor, 1984; Strudley et al., 2008; Tsegaye and Hill, 1998; Unger, 1991;). Tillage provides many benefits to plants including improving root growth. Improper tillage can in some cases, adversely affect plant nutrient availability because levels of soil N, P, and K may be influenced by soil structure disturbance (Dick, 1983; Havlin et al., 1990; Holanda et al., 1998). Many field trials have shown the beneficial effects of tillage on traditional crops; however, limited research exists which focus on the tillage responses of the newly developed bioenergy crops.

Fertilization can affect the availability of plant nutrients by increasing soil nutrient levels. However, soil nutrient level can be continuously decreased by some agronomic operations such as harvesting. Fertilization is commonly used to offset the removal of nutrients by agronomic activities. Fertilizers such as urea, potash, and super triple phosphate are applied to replenish the levels of soil N, P, and K which were removed by harvesting (Jenkinson et al., 1985; Pote et al., 1996; Troeh and Thompson, 2005).

Sweet sorghum is a newly developed bioenergy crop which has garnered much attention. Appropriate agronomic practices for sweet sorghum production are needed in order to improve sweet sorghum production. Currently, research regarding agronomic practices for sweet sorghum is still limited. Therefore, the objectives of this study were to 1) evaluate the effect of tillage and fertilization on nutrient uptake of sweet sorghum, and 2) estimate the removal and fertilization rates of P_2O_5 and K_2O targeted to different products based on a certain sweet sorghum yield.

3.2 Materials and Methods

Experimental design and treatment information were previously described in Chapter 2. Aboveground sweet sorghum samples were collected from the second drill-row within the 3 m marked area at the soft-dough stage of development. Plant samples were weighed and partitioned into four parts: seed head, stalk, green leaves, and brown leaves (mature leaves). All tissue samples were placed in a drying oven to remove moisture. The dried samples were ground, evenly mixed, chemically digested and analyzed. A total of 64 plant samples were sent to Soil Testing Laboratory in SPESS (School of Plant, Environmental, and Soil Science of LSU), Baton Rouge, Louisiana, for Inductively Coupled Plasma (ICP) plant nutrient analysis to determine sweet sorghum tissue concentration of P and K (%, based on the weight of each tissue part). ICP procedure is routinely used in various research areas including environmental, life sciences, food, material, and chemical (Amman, 2007). Total combustion analysis was conducted in LSU AgCenter H. Rouse Caffey Rice Research Station in Crowley, Louisiana, to determine sweet sorghum tissue concentration of N. Other selected parameters included nutrient removal rate of N, P, and K (g kg^{-1}, based on weight of whole plant), distribution of N, P, and K (%, based on nutrient weight of whole plant), P_2O_5 removal rate (kg Mg^{-1}), and K_2O removal rate (kg Mg^{-1}). The N, P, and K removal rate of sweet sorghum (g kg^{-1}) was calculated using the following equation:

Nutrient removal rate = $(X_{\%} * W_{TP} * 10) / W_{whole}$ [Eq. 3.1]

Where:

$X_{\%}$ = sweet sorghum N, P, and K concentration in each tissue part

W_{TP} = weight of each tissue part

W_{whole} = weight of whole plant

The N, P, and K distribution (%) was calculated using the following equation:

Nutrient distribution = W_{Ntp} / W_{Nw} *100% [Eq. 3.2]

Where:

W_{Ntp} = nutrient weight of each tissue part

W_{Nw} = total nutrient weight of whole plant

The P_2O_5 removal rate (kg Mg^{-1}) was calculated using the following equation:

P_2O_5 removal rate = R_P * 2.29 [Eq. 3.3]

Where:

R_P = P removal rate

2.29 = kg P_2O_5 per 1 kg P

The K_2O removal rate (kg Mg^{-1}) was calculated using the following equation:

K_2O removal rate = R_K * 1.2 [Eq. 3.4]

Where:

R_K = K removal rate

1.2 = kg K_2O per 1 kg K

All data were pooled over years and subjected to analysis of variance (ANOVA) with SAS 9.4 software (SAS Institute, 2012). The PROC MIXED procedure was used in SAS in order to make inferences concerning tillage (T) and fertilization (F) across years (Carmer et al., 1989). Year was used as a random effect parameter testing all interactions of tillage and fertilization (T x F). Tillage, fertilization and the interaction of tillage and fertilization were used as fixed effects. Means were compared using the Tukey-kramer to determine any significant differences at alpha (α) < 0.05. The appendix of this thesis shows analysis of variance for each year analyzed separately.

3.3 Results and Discussion

3.3.1 Effect of Tillage and Fertilization on Sweet Sorghum Nutrient Tissue Concentration

Nutrient tissue concentration represents the nutrient content of a plant tissue part rather than a whole plant. It relates to the plant nutrient uptake. Analysis of variance results for the effects of T, F and their interaction T x F on selected sweet sorghum nutrient tissue concentration pooled over years is presented in Table 3.1. The treatment means of the effects of tillage systems and fertilization practices on sweet sorghum nutrient tissue concentration are shown in Table 3.2.

3.3.1.1 Effect of Tillage and Fertilization on Sweet Sorghum Tissue Concentration of N

Nitrogen concentration of sweet sorghum in each tissue part was not affected by F, T, and the T x F interaction (Table 3.1).

Locke and Hons (1988) indicated that the N uptake of grain sorghum was not affected by CT or NT; however, it was significantly affected by fertilization. This may account for the limited response of sweet sorghum N concentration to tillage. The limited effect of F on N concentration of sweet sorghum tissue part was possibly due to the same N fertilization rate applied on all plots.

Jones (1983) demonstrated that the N concentration of grain sorghum seed head fell in a range from 1.02% to 3.20% among different N fertilization rates. In the current study, the N concentration of sweet sorghum seed head was from 1.68% to 1.74% across four treatments which also fell into the range of Jones (1983).

Table 3.1. Analysis of variance for the effect of tillage, fertilization, and the interaction of tillage and fertilization on N, P, and K concentration of seed head, stalk, green leaves, and brown leaves for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA (2012 - 2015). Data pooled over years (2012 - 2015).

Plant Tissue Part	Effect	N	P	K
		——— *P* Value ———		
Seed head	Tillage (T)	0.062	0.356	0.695
	Fertilization (F)	0.572	0.234	0.214
	T x F	0.716	0.415	0.201
Stalk	T	0.893	0.370	0.415
	F	0.839	0.087	0.005
	T x F	0.787	0.258	0.184
Green Leaves	T	0.268	0.139	0.144
	F	0.928	0.330	<0.001
	T x F	0.588	0.954	0.049
Brown Leaves	T	0.114	0.129	0.855
	F	0.957	0.023	0.192
	T x MF	0.760	0.300	0.008

3.3.1.2 Effect of Tillage and Fertilization on Sweet Sorghum Tissue Concentration of P

The main effect of F, T, and the T x F interaction on P concentration of sweet sorghum seed head, stalk and green leaves was not significant (Table 3.1). The main effect of T and the T x F interaction on P concentration of brown leaves was not significant; however, P concentration of brown leaves was significantly affected by F ($P = 0.023$). The NMF increased the mean P concentration of sweet sorghum brown leaves by 0.02% as compared with CT (Table 3.2).

Currently, the effect of F on P concentration of sweet sorghum brown leaves is unknown. Phosphorus is a mobile nutrient in plant which will translocate from young leaf to old leaf through phloem transport.

Table 3.2. Effect of tillage, fertilization, and the tillage and fertilization interactions on mean N, P, and K concentration of seed head, stalk, green leaves, and brown leaves for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA (2012 - 2015). Data pooled over years (2012 - 2015).

Effect	Seed Head			Stalk			Green Leaves			Brown Leaves		
	N	P	K	N	P	K	N	P	K	N	P	K
	%											
Tillage												
CT[†]	1.68 a[‡]	0.34 a	0.43 a	0.31 a	0.09 a	0.62 a	1.16 a	0.24 a	0.77 a	0.84 a	0.12 a	0.23 a
NT	1.74 a	0.33 a	0.42 a	0.31 a	0.10 a	0.58 a	1.20 a	0.26 a	0.80 a	0.90 a	0.13 a	0.23 a
Fertilization												
MF	1.70 a	0.33 a	0.43 a	0.31 a	0.10 a	0.67 a	1.18 a	0.25 a	0.83 a	0.87 a	0.11 b	0.24 a
NMF	1.72 a	0.34 a	0.41 a	0.31 a	0.09 a	0.53 b	1.18 a	0.26 a	0.74 b	0.87 a	0.13 a	0.22 a
Interactions												
CT x MF	1.68 a	0.34 a	0.45 a	0.31 a	0.10 a	0.72 a	1.17 a	0.24 a	0.84 a	0.85 a	0.12 a	0.26 a
CT x NMF	1.69 a	0.34 a	0.40 a	0.31 a	0.08 a	0.52 a	1.14 a	0.25 a	0.70 b	0.84 a	0.12 a	0.19 b
NT x MF	1.73 a	0.32 a	0.42 a	0.31 a	0.10 a	0.62 a	1.19 a	0.26 a	0.83 a	0.90 a	0.12 a	0.22 ab
NT x NMF	1.76 a	0.34 a	0.42 a	0.32 a	0.09 a	0.54 a	1.21 a	0.27 a	0.78 ab	0.91 a	0.14 a	0.24 ab

† CT and NT are conventional and no-till tillage systems, respectively. MF and NMF are with and without ‘maintenance’ fertilization, respectively.

‡ Means followed by the same letter are not significantly different ($P < 0.05$).

Vreugdenhil (1985) indicated that K deficiency may adversely affect phloem transport because the effect of K on phloem transport are maintaining pH in plant sieve tubes, providing the osmotic potential in the sieve tubes, and maintaining the photosynthates transportation rate. The NMF may cause a K deficiency for sweet sorghum because the initial soil K was considered low in the study (Table 2.1 and 2.2). Other limited differences of P concentration by F may be caused by the initial high soil P content at the surface soil (Table 2.1 and 2.2).

Schwab et al. (2006) indicated that the effect of T on P uptake of grain sorghum was not significant among moldboard plow, reduced tillage, and NT; however, the P uptake was increased by P fertilization. The result of Schwab et al. (2006) possibly supported the effect of T on P concentration in the current study.

3.3.1.3 Effect of Tillage and Fertilization on Sweet Sorghum Tissue Concentration of K

The main effect of the T x F interaction on K concentration of sweet sorghum seed head, stalk, and green leaves was not significant (Table 3.1). Potassium concentration of sweet sorghum each tissue part was not affected by T. The main effect of F on K concentration of sweet sorghum seed head and brown leaves was not significant.

In addition, the main effect of F on K concentration of sweet sorghum stalk ($P = 0.005$) and green leaves ($P < 0.001$) was significant. The MF treatment increased the mean K concentration of sweet sorghum stalk and green leaves by 0.14% and 0.09%, respectively, as compared with NMF (Table 3.2). Han et al. (2011) demonstrated that sweet sorghum had higher K uptake in stalk and leaves as compared with seed head under same fertilization rate of K. In current experiment, the effect of F on K concentration of stalk and green leaves may account for the measured nutrient uptake of stalk and leaves at a same fertilization rate of 67 kg K_2O ha^{-1}.

The main effect of the T x F interaction on K concentration of sweet sorghum green leaves (P = 0.049) and brown leaves (P = 0.008) was significant. The CT x MF interaction had the highest K concentration of green leaves (0.84%) as compared with the interaction of CT x NMF (0.70%), NT x MF (0.83%), and NT x NMF (0.78%). The significant effect of the T x F interaction on K concentration of sweet sorghum green leaves was probably caused by the significant effect of F (P < 0.001).

The K tissue concentration of brown leaves under CT x MF had the highest content (0.26%) as compared with the interaction of CT x NMF (0.19%), NT x MF (0.22%), and NT x NMF (0.24%). This significant effect on K concentration of sweet sorghum brown leaves can be attributed to the effect of F (P = 0.192).

The main effect of T on K concentration of sweet sorghum was not significant. Currently, limited papers focus on the effect of T on K concentration of sweet sorghum. Schwab et al. (2006) mentioned that tillage did not affect P uptake of grain sorghum when P fertilizers applied. Potassium and P are considered as immobile nutrient within soil system. Therefore, the limited effect of T on K concentration of sweet sorghum may be accounted for by the ‘maintenance’ fertilization used.

3.3.2 Effect of Tillage and Fertilization on Sweet Sorghum Nutrient Removal Rate of N, P, and K

The nutrient removal rate represents that the amount of nutrient element is removed by harvested 1 kg biomass. The nutrient removal rate relates to nutrient uptake. Analysis of variance results for the effects of T, F and their interaction T x F on selected sweet sorghum nutrient removal rate pooled over years is presented in Table 3.3. The treatment means of the effects of tillage systems and fertilization practices on sweet sorghum nutrient removal rate are shown in Table 3.4.

Table 3.3. Analysis of variance for the effect of tillage, fertilization, and the interaction of tillage and fertilization on N, P, and K removal rate of seed head, stalk, green leaves, and brown leaves for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA (2012 - 2015). Data pooled over years (2012 - 2015).

Plant Tissue	Effect	N	P	K
		——— *P* Value ———		
Whole Plant	Tillage (T)	0.393	0.348	0.542
	Fertilization (F)	0.245	0.826	0.001
	T x F	0.415	0.140	0.077
Seed head	T	0.585	0.482	0.695
	F	0.088	0.156	0.214
	T x F	0.241	0.282	0.201
Stalk	T	0.872	0.836	0.388
	F	0.729	0.024	0.003
	T x F	0.909	0.395	0.225
Green Leaves	T	0.198	0.047	0.114
	F	0.212	0.111	0.493
	T x F	0.410	0.504	0.218
Brown Leaves	T	0.722	0.263	0.980
	F	0.846	0.005	0.677
	T x MF	0.288	0.799	0.111

3.3.2.1 Effect of Tillage and Fertilization on Sweet Sorghum N Removal Rate

Nitrogen removal rate of sweet sorghum for each tissue part was not affected by F, T, and the T x F interaction (Table 3.3). This was similar to the results measured for N concentration of sweet sorghum. The results of Locke and Hons (1988) may support the limited effect of T on N removal rate due to tillage did not affect grain sorghum N uptake. The limited effect of F on N removal rate of sweet sorghum was possibly due to the same N fertilization rate applied on all plots.

Han et al. (2011) demonstrated a range of N removal rate (7.4 to 13.3g kg^{-1}) among five sweet sorghum cultivars of Chuntian-2, Zaoshu-1, Lvneng-3, Italy, and M-81E under 120 kg N ha^{-1}. The sweet sorghum N removal rate of whole plant in the current study was in a rage of 5.62 to 5.83 g kg^{-1} (Table 3.4). The low N removal rate measured in the current study was likely due to the N fertilization rate of 101 kg N ha^{-1} used in this study.

3.3.2.2 Effect of Tillage and Fertilization on Sweet Sorghum P Removal Rate

The main effect of F, T, and the T x F interaction on P removal rate of sweet sorghum whole plant and seed head was not significant (Table 3.3). Tillage and the T x F interaction did not affect P removal rate of sweet sorghum stalk and brown leaves. Phosphorus removal rate of sweet sorghum green leaves was not affected by F and the T x F interaction.

The main effect of F on P removal rate of sweet sorghum stalk was significant (P = 0.024). The MF treatment increased the mean P removal rate of sweet sorghum stalk by 0.08 g kg^{-1} as compared with NMF (Table 3.4). The effect of F on P removal rate of stalk may be supported by Schwab et al. (2006) because P uptake was increased by P fertilizer applied.

The main effect of F on P removal rate of sweet sorghum brown leaves was significant (P = 0.005). The NMF increased the mean P removal rate of sweet sorghum brown leaves by 0.03 g kg^{-1} as compared with MF. This was similar as the P tissue concentration of sweet sorghum brown leaves. The reported study by Vreugdenhil (1985) may support the measured effect of F on P removal rate of brown leaves possibly due to K deficiency under NMF.

The main effect of T on P removal rate of sweet sorghum green leaves was significant (P = 0.047). The NT increased the mean P removal rate of sweet sorghum green leaves by 0.06 g kg^{-1} as compared with CT.

Table 3.4. Effect of tillage, fertilization, and the tillage x fertilization interactions on mean N, P, and K removal rate of seed head, stalk, green leaves, and brown leaves for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA (2012 - 2015). Data pooled over years (2012 - 2015).

Effect	Whole plant			Seed head			Stalk			Green leaves			Brown leaves		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
	g kg^{-1}														
Tillage															
CT†	5.62a‡	1.34a	5.95a	1.36a	0.28a	0.43a	2.25a	0.66a	4.47a	1.35a	0.28b	0.90a	0.66a	0.11a	0.22a
NT	5.80a	1.38a	5.74a	1.41a	0.27a	0.42a	2.23a	0.66a	4.16a	1.48a	0.34a	1.02a	0.67a	0.12a	0.22a
Fertilization															
MF	5.58a	1.35a	6.44a	1.30a	0.26a	0.43a	2.27a	0.70a	4.88a	1.35a	0.29a	0.98a	0.67a	0.10b	0.23a
NMF	5.83a	1.37a	5.25b	1.48a	0.29a	0.41a	2.21a	0.62b	3.74b	1.48a	0.33a	0.94a	0.66a	0.13a	0.22a
Interactions															
CT x MF	5.58a	1.37a	6.86a	1.33a	0.28a	0.45a	2.29a	0.72a	5.27a	1.32a	0.28a	0.97a	0.64a	0.10b	0.25a
CT x NMF	5.66a	1.30a	5.05a	1.39a	0.29a	0.40a	2.22a	0.60a	3.68a	1.37a	0.30a	0.84a	0.68a	0.12ab	0.20a
NT x MF	5.59a	1.34a	5.01a	1.27a	0.23a	0.42a	2.25a	0.69a	4.50a	1.37a	0.31a	1.00a	0.70a	0.11ab	0.21a
NT x NMF	6.02a	1.43a	5.46a	1.57a	0.30a	0.42a	2.21a	0.64a	3.81a	1.59a	0.36a	1.04a	0.65a	0.13a	0.24a

† CT and NT are conventional and no-till tillage systems, respectively. MF and NMF are with and without 'maintenance' fertilization, respectively.

‡ Means followed by the same letter are not significantly different ($P < 0.05$).

Muchow (1988) also reported that high N rate stimulated grain sorghum leaf growth then nutrient uptake increased, which supports the effect of tillage on P removal rate of sweet sorghum green leaves. In this study, the soil surface was cracked at the time of N application in most years, allowing the N to move deeper into the soil prior to rainfall events which would have allowed the cracks to close and protect the N. This could possible make the N available for utilization by the sweet sorghum grown under NT and thus prolonging vegetative growth.

The limited effects of T on P removal rate of seed head, stalk, and brown leaves may be supported by Schwab et al. (2006) because tillage did not affect P uptake of grain sorghum.

3.3.2.3 Effect of Tillage and Fertilization on Sweet Sorghum K Removal Rate

The main effect of F, T, and the T x F interaction on K removal rate of sweet sorghum seed head, green leaves, and brown leaves was not significant (Table 3.3). Potassium removal rate of sweet sorghum whole plant and stalk was not affected by T and the T x F interaction.

Fertilization significantly affected the K removal rate of sweet sorghum whole plant (P = 0.001) and stalk (P = 0.003). The MF increased the mean K removal rate of sweet sorghum whole plant and stalk by 1.19 g kg^{-1} and 1.14 g kg^{-1}, respectively, as compared with NMF (Table 3.4). The effect of F on K removal rate of whole plant and stalk was similar as the effect of F on K concentration of stalk. Results of Han et al. (2011) may support the measured effect of F on K removal rate of whole plant and stalk due to the high K uptake in stalk under K fertilization as compared to seed head.

The main effect of T on K removal rate of sweet sorghum was not significant. This was similar as the effect of T on K tissue concentration. Therefore, the results of Schwab et al. (2006) may support the effect of T on K removal rate because P and K are considered as immobile nutrient within soil system.

3.3.3 Effect of Tillage and Fertilization on N, P, and K Distribution in Sweet Sorghum

Plant nutrient distribution represents the nutrient uptake ratio in each plant tissue part. The nutrient distribution relates to nutrient uptake and occupation in each plant tissue part. Analysis of variance results for the effects of T, F and their interaction T x F on selected sweet sorghum nutrient distribution pooled over years is presented in Table 3.5. The treatment means of the effects of tillage system and fertilization practices on sweet sorghum nutrient distribution are shown in Table 3.6.

3.3.3.1 Effect of Tillage and Fertilization on N Distribution in Sweet Sorghum

Nitrogen distribution in sweet sorghum parts was not affected by F, T, and the T x F interaction (Table 3.5). This result was followed by the results of sweet sorghum N concentration and N removal rate. Results of N distribution in sweet sorghum were probably supported by Locke and Hons (1988) because tillage did not affect N uptake of grain sorghum.

Under CT system, approximately 24.7% of N was contained in the seed head, 39.5% in the stalk, 23.6% in the green leaves, and 12.2% of N was contained in the brown leaves, respectively (Table 3.6). As compared with CT, sweet sorghum under NT had a lower N distribution in dry stalk; approximately 24.6% of N was contained in the seed head, 38.5% in the stalk, 24.9% in the green leaves, and 12.0% of N was contained in the brown leaves, respectively.

Under MF practice, approximately 23.6% of N was contained in the seed head), 40.2% in the stalk, 23.7% in the green leaves, and 12.5% of N was contained in the brown leaves, respectively (Table 3.6). As compared with MF, sweet sorghum under NMF had a lower N distribution in dry stalk; approximately 25.7% of N was contained in the seed head, 37.7% in the stalk, 24.8% in the green leaves, and 11.8% of N was contained in the brown leaves, respectively.

Table 3.5. Analysis of variance for the effect of tillage, fertilization, and the interaction of tillage and fertilization on N, P, and K distribution of seed head, stalk, green leaves, and brown leaves for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA (2012 - 2015). Data pooled over years (2012 - 2015).

Plant Tissue	Effect	N	P	K
		–––––––––	P value	–––––––––
Seed head	Tillage (T)	0.926	0.348	0.790
	Fertilization (F)	0.174	0.281	0.040
	T x F	0.231	0.623	0.393
Stalk	T	0.581	0.428	0.013
	F	0.182	0.038	0.002
	T x F	0.398	0.975	0.432
Green Leaves	T	0.208	0.025	0.003
	F	0.301	0.199	0.017
	T x F	0.609	0.828	0.889
Brown Leaves	T	0.731	0.626	0.234
	F	0.297	0.035	0.234
	T x F	0.166	0.328	0.714

Average N distribution in a sweet sorghum whole plant across different tillage and fertilization was: 25% of N in seed head, 39% of N in stalk, 24% of N in green leaves, and 12% of N in brown leaves. Wiedenfeld (1984) demonstrated that 10.5% to 39.8% of N was in sweet sorghum seed head, 42.9% to 48.6%of N was in leaves, and 17.3% to 40.9% of N was in stalk depending on sweet sorghum cultivars at a fertilization rate of 112 kg N ha^{-1}. The current results of sweet sorghum N distribution fell in the range of Wiedenfeld (1984).

3.3.3.2 Effect of Tillage and Fertilization on P Distribution in Sweet Sorghum

The main effect of the T x F interaction on P distribution in sweet sorghum was not significant (Table 3.5). Phosphorus distribution in sweet sorghum seed head, stalk, and brown leaves was not affected by T. The main effect of F on P distribution in sweet sorghum seed head and green leaves was not significant. Schwab et al. (2006) may agree with the limited responses of P distribution in sweet sorghum seed head, stalk, and brown leaves to tillage.

The P distribution in sweet sorghum green leaves was significantly affected by T (P = 0.025). The NT increased the mean P distribution in sweet sorghum green leaves by 4.0% as compared with CT (Table 3.6).

In addition, the main effect of F on P distribution in stalk (P = 0.038) and brown leaves was significant (P = 0.035). The MF increased the mean P distribution in sweet sorghum stalk leaves by 4.0% as compared with NMF. The NMF increased the mean P distribution in sweet sorghum brown leaves by 1.6% as compared with MF.

The significant effect of T and F on P distribution in sweet sorghum was similar as the effect of T and F on P removal rate of stalk, green leaves, and brown leaves. The results of P distribution in sweet sorghum green leaves may be supported by Muchow (1988) due to the similar effect of T on P removal rate of green leaves. The effect of F on P distribution in stalk may be supported by Schwab et al. (2006) because the P uptake was increased by P fertilization applied. Vreugdenhil (1985) may support the effect of F on P distribution in brown leaves possibly due to K deficiency under NMF.

Under CT system, approximately 22.6% of P was contained in the seed head (Table 3.6), 47.2% in the stalk, 22.4% in the green leaves, and 7.8% of P was contained in the brown leaves, respectively. As compared with CT, sweet sorghum under NT had a lower P distribution in dry stalk; approximately 20.7% of P was contained in the seed head, 45.4% in the stalk, 26.4% in the green leaves, and 7.5% of P was contained in the brown leaves, respectively.

Under MF practice, approximately 20.6% of P was contained in the seed head (Table 3.6), 49.1% in the stalk, 23.4% in the green leaves, and 6.9% of P was contained in the brown leaves, respectively. As compared with MF, sweet sorghum under NMF had a lower P distribution in dry stalk; approximately 22.5% of P was contained in the seed head, 43.4% in the stalk, 25.8% in the green leaves, and 8.3% of P was contained in the brown leaves, respectively.

Average P distribution in a sweet sorghum whole plant across different tillage and fertilization was: 22% of P in seed head, 46% of P in stalk, 24% of P in green leaves, 8% of P in brown leaves. Wiedenfeld (1984) demonstrated that 13.0% to 37.3% of P was in sweet sorghum seed head, 32.2% to 38.6% of P was in leaves, and 24.1% to 54.3% of P was in stalk depending on sweet sorghum cultivars under a fertilization rate of 112 kg N ha^{-1}. The results of Wiedenfeld (1984) supported the current sweet sorghum P distribution.

3.3.3.3 Effect of Tillage and Fertilization on K Distribution in Sweet Sorghum

The main effect of T x F interaction on K distribution in sweet sorghum each part was not significant (Table 3.5).The main effect of T on K distribution in sweet sorghum seed head and brown leaves was not significant. The K distribution in sweet sorghum browns leaves was not affected by the effect of F. The limited effect of T on K distribution in seed head and brown leaves may be supported by Schwab et al. (2006) as similar as the effects of T on K removal rate and concentration.

In addition, the K distribution in sweet sorghum stalk was significantly affected by the effect of F ($P = 0.002$). The MF increased the mean K distribution in sweet sorghum stalk by 4.6% as compared with NMF (Table 3.6). The effect of F on K distribution in sweet sorghum stalk may be supported by Han et al. (2011) due to higher K uptake in stalk and leaves as compared with seed head.

Table 3.6. Effect of tillage, fertilization, and the interaction of tillage and fertilization on mean N, P, and K distribution of seed head, stalk, green leaves, and brown leaves for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA (2012 - 2015). Data pooled over years (2012 - 2015).

Effect	Seed Head			Stalk			Green Leaves			Brown Leaves		
	N	P	K	N	P	K	N	P	K	N	P	K
	%											
Tillage												
CT†	24.7 a‡	22.6 a	7.5 a	39.5 a	47.2 a	72.3 a	23.6 a	22.4 b	16.5 b	12.2 a	7.8 a	3.7 a
NT	24.6 a	20.7 a	7.4 a	38.5 a	45.4 a	69.2 b	24.9 a	26.4 a	20.0 a	12.0 a	7.5 a	3.4 a
Fertilization												
MF	23.6 a	20.6 a	6.2 b	40.2 a	49.1 a	73.1 a	23.7 a	23.4 a	17.0 b	12.5 a	6.9 b	3.7 a
NMF	25.7 a	22.5 a	8.4 a	37.7 a	43.4 b	68.5 b	24.8 a	25.8 a	19.7 a	11.8 b	8.3 a	3.4 a
Interactions												
CT x MF	24.6 a	22.0 a	6.8 a	40.0 a	50.0 a	74.3 a	23.3 a	21.2 a	15.4 a	12.1 a	6.9 a	3.6 a
CT x NMF	24.8 a	23.2 a	7.8 a	39.0 a	44.5 a	70.5 a	23.9 a	23.6 a	17.8 a	12.4 a	8.7 a	3.9 a
NT x MF	22.6 a	19.1 a	6.3 a	40.5 a	48.2 a	72.0 a	24.1 a	25.5 a	18.7 a	12.8 a	7.2 a	3.0 a
NT x NMF	26.5 a	22.3 a	8.6 a	36.5 a	42.6 a	66.5 a	25.7 a	30.8 a	21.4 a	11.3 a	7.9 a	3.6 a

† CT and NT are conventional and no-till tillage systems, respectively. MF and NMF are with and without ‘maintenance’ fertilization, respectively.

‡ Means followed by the same letter are not significantly different ($P < 0.05$)

The K distribution in sweet sorghum stalk and green leaves was significantly affected by T (P = 0.013 and P = 0.003, respectively). The CT increased the mean K distribution in stalk leaves by 3.1% as compared with NT. The NT increased the mean K distribution in green leaves by 3.5% as compared with CT.

Potassium distribution in sweet sorghum seed head and green leaves was significantly affected by F (P = 0.040 and P = 0.017, respectively). The NMF increased the mean K distribution in sweet sorghum seed head by 2.2% as compared with MF. The NMF increased the mean K distribution in sweet sorghum green leaves by 2.7% as compared with MF.

The reasons for the significant effects of T and F on K distribution are unclear excluded the effect of F on K distribution in stalk and green leaves. It may be accounted for the formula Eq. 3.2 due to the different K removal rate of whole plant across tillage and fertilization and the similar K removal rate of sweet sorghum tissue part. The K removal rate of whole plant can be considered as the total nutrient weight of 1 kg sweet sorghum. So K removal rate of whole plant can be considered as the denominator of the Eq. 3.2 to calculate the K distribution in 1 kg sweet sorghum. When the similar K removal rate of sweet sorghum tissue part was divided by the K removal rate of whole plant, the value of the K removal rate of whole plant may affect the K distribution in the tissue part. In the current study, Potassium removal rate of whole plant under MF and NMF was 6.44 g kg^{-1} and 5.25 g kg^{-1}, respectively, while the removal rates under CT and NT was 5.95 g kg^{-1} and 5.74 g kg^{-1}, respectively.

Under CT system, approximately 7.5% of K was contained in the seed head, 72.3% in the stalk, 16.5% in the green leaves, and 3.7% of K was contained in the brown leaves, respectively (Table 3.6). As compared with CT, sweet sorghum under NT had a lower K distribution in dry stalk; approximately 7.4% of K was contained in the seed head, 69.2% in the stalk, 20.0% in the green leaves, and 3.4% of K was contained in the brown leaves, respectively.

Under MF practice, approximately 6.2% of K was contained in the seed head, 73.1% in the stalk, 17.0% in the green leaves, and 3.7% of K was contained in the brown leaves, respectively (Table 3.6). As compared with MF, sweet sorghum under NMF had a lower K distribution in dry stalk; approximately 8.4% of K was contained in the seed head, 68.5% in the stalk, 19.7% in the green leaves, and 3.4% of K was contained in the brown leaves, respectively.

Average K distribution in a sweet sorghum whole plant across different tillage and fertilization was: 7% of K in seed head, 71% of K in stalk, 18% of K in green leaves, 4% of K in brown leaves.

3.3.4 Estimated Fertilizer Removal Rates and Recommendation 'Maintenance' Fertilization Rates for Sweet Sorghum Production

Fertilizer removal rate is the amount of fertilizer removed from field by harvesting 1 Mg crops. Sweet sorghum has two harvestings: whole plant harvesting and stalk only harvesting. If sweet sorghum is targeted as the feedstock for cellulosic and sugar ethanol production, whole plant harvesting (total aboveground biomass removed) will be adopted. If sugar ethanol production only is the target product, stalk of sweet sorghum will only be needed only. The amount of fertilizer removed from sweet sorghum will be different when different harvesting methods used. In this experiment, a hypothetical dry matter yield of total biomass was set to 25 Mg ha^{-1} (approximately 75 Mg ha^{-1} wet). Wortmann et al. (2010) demonstrated that even the yield of sweet sorghum stalk biomass can be over 75 Mg ha^{-1} wet. Estimated fertilizer removal rates and recommendation 'maintenance' fertilization rates of P_2O_5 and K_2O are shown in Table 3.7.

The calculation results indicated that P_2O_5 removal rate was 3.1 kg P_2O_5 per Mg dry whole plant when whole plant was harvested. However, if the high sugar content juice is expected as the feedstock for fermentation, removal rate of P_2O_5will be 1.6 kg P_2O_5 Mg^{-1} because only sweet sorghum stalks were removed and other plant tissues will be left in the field. Based on two different removal rates, two recommendation 'maintenance' fertilization rates for P_2O_5were estimated at a dry matter yield of 25 Mg ha^{-1}: 78 kg P_2O_5 ha^{-1} and 40 kg P_2O_5 ha^{-1} for whole plant harvesting and stalk only harvesting, respectively.

Table 3.7. Estimated removal and 'maintenance' fertilization rates of P_2O_5 and K_2O based on a mean dry matter yield of 25 Mg ha^{-1} when harvesting as a fermentable sugar source (stalk only removed) or as a biomass feedstock (whole plant removed) for sweet sorghum in Crowley.

	Harvesting strategy	Estimated nutrient removal rate (based on dry weight)	Estimated 'maintenance' fertilization rate (25 Mg ha^{-1})
		kg Mg^{-1}	kg ha^{-1}
P_2O_5	Whole plant	3.1	78
	Stalk only	1.6	40
K_2O	Whole plant	7.7	193
	Stalk only	5.8	145

Two K_2O removal rates were 7.7 kg K_2O Mg^{-1} and 5.8 kg K_2O Mg^{-1} for whole plant harvesting and stalk only harvesting, respectively. Based on the two removal rates, two recommendation 'maintenance' fertilization rates for K_2O were estimated at a dry matter yield of 25 Mg ha^{-1}: 193 kg K_2O ha^{-1} and 145 kg K_2O ha^{-1} for whole plant harvesting and stalk only harvesting, respectively.

Murrell (2005) estimated that the nutrient removal rates of sorghum stover (leaves and stalks) which will remove 4.2 kg P_2O_5 and 21 kg K_2O, respectively, when harvest 1Mg sorghum stover. The lower P and K removal rate in this study may be accounted for the sweet sorghum cultivar.

3.4 Conclusions

Tillage systems can alter sweet sorghum nutrient uptake. In this study, tillage significantly affected the P removal rate and distribution of sweet sorghum green leaves. No-till consistently increased P removal rate and distribution of sweet sorghum green leaves by 0.06 g kg^{-1} and 4.0%, respectively.

Fertilization significantly affected sweet sorghum nutrient uptake. In this study, fertilization significantly affected sweet sorghum concentration, removal rate, and distribution of both P and K. ‘Maintenance’ fertilization increased K concentration of stalk by 0.14%, K concentration of green leaves by 0.09%, K removal rate of whole plant by 1.19 g kg^{-1}, K removal rate of stalk by 1.14 g kg^{-1}, K distribution in stalk by 4.6%, P removal rate of stalk by 0.08 g kg^{-1}, and P distribution in stalk by 5.7%. Without ‘maintenance’ fertilization positively affected P concentration of brown leaves by 0.02%, P removal rate of brown leaves by 0.03 g kg^{-1}, and P distribution in brown leaves by 1.4%.

The increases by MF for sweet sorghum whole plant, stalk, and green leaves can be potentially attributable to ‘maintenance’ fertilization applied which enhanced the nutrient uptake of sweet sorghum. However, those increases by NMF for sweet sorghum brown leaves can be potentially caused by K deficiency. Since the initial soil test indicated that the soil was low in soil test extractable K, fertilization is important in order to improve sweet sorghum nutrient uptake when soil nutrients are limiting.

A sweet sorghum yield of 75 Mg ha^{-1} (around 25 Mg ha^{-1} dry) would remove approximately 40 and 145 kg ha^{-1} of P_2O_5 and K_2O, respectively, when only the stalk is removed from the field. With the same yield, approximately 78 and 193 kg ha^{-1} of P_2O_5 and K_2O would be removed, respectively, when sweet sorghum whole plant is harvested.

3.5 References

Altieri, M.A. 1999. The ecological role of biodiversity in agroecosystems. *Agriculture, Ecosystems, and Environment* 74:19-31.

Ammann, A.A. 2007. Inductively coupled plasma mass spectrometry (ICP MS): a versatile tool. *Journal of Mass Spectrometry* 42:419-427.

Barber, S.A. 1995. Soil nutrient bioavailability: a mechanistic approach. 2nd edition. *John Wiley*. New York

Carmer, S.G., W.E. Nyquist, and W.M. Walker. 1989. Least significant differences for combined analyses of experiments with two-or three-factor treatment designs. *Agronomy Journal* 81:665-672.

Dick, W.A. 1983. Organic carbon, nitrogen, and phosphorus concentrations and pH in soil profiles as affected by tillage intensity. *Soil Science Society of America Journal* 47:102-107.

Fernández, F.G. and R.G. Hoeft. 2009. Managing soil pH and crop nutrients. Illinois agronomy handbook. 24th edition. *University of Illinois*, Urbana 91-112.

Gilmartin, M., D. Degobbis, N. Revelante, and N. Smodlaka, N. 1990. The mechanism controlling plant nutrient concentrations in the northern Adriatic Sea. *Internationale Revue der gesamten Hydrobiologie und Hydrographie* 75:425-445.

Gruhn, P., F. Goletti, and M. Yudelman. 2000. Integrated nutrient management, soil fertility, and sustainable agriculture: current issues and future challenges. International Food Policy Research Institute, Washington, DC, USA.

Han, L.P., Y. Steinberger, Y.L. Zhao, and G.H. Xie. 2011. Accumulation and partitioning of nitrogen, phosphorus and potassium in different varieties of sweet sorghum. *Field crops research* 120:230-240.

Havlin, J.L., D.E. Kissel, L.D. Maddux, M.M. Claassen, and J.H. Long. 1990. Crop rotation and tillage effects on soil organic carbon and nitrogen. *Soil Science Society of America Journal* 54:448-452.

Holanda, F.S.R., D.B. Mengel, M.B. Paula, J.G. Carvaho, and J.C. Bertoni. 1998. Influence of crop rotations and tillage systems on phosphorus and potassium stratification and root distribution in the soil profile. *Communications in Soil Science and Plant Analysis* 29:2383-2394.

Jenkinson, D.S., R.H. Fox, and J.H. Rayner. 1985. Interactions between fertilizer nitrogen and soil nitrogen—the so-called 'priming' effect. *Journal of Soil Science* 36:425-444.

Jones, C.A. 1983. A survey of the variability in tissue nitrogen and phosphorus concentrations in maize and grain sorghum. *Field Crops Research* 6:133-147.

Locke, M.A. and F.M. Hons. 1988. Fertilizer placement effects on seasonal nitrogen accumulation and yield of no-tillage and conventional tillage sorghum. *Agronomy Journal* 80:180-185.

McDowell, L.L. and K.C. McGregor. 1984. Plant nutrient losses in runoff from conservation tillage corn. *Soil and Tillage Research* 4:79-91.

Muchow, R.C. 1988. Effect of nitrogen supply on the comparative productivity of maize and sorghum in a semi-arid tropical environment I. Leaf growth and leaf nitrogen. *Field Crops Research* 18:1-16.

Murrell, T.S. 2005. Average nutrient removal rates for crops in the Northcentral Region. International Plant Nutrition Institute (IPNI). *http://www.ipni.net/northcentral/nutrientremoval* (accessed 15 Mar. 2016).

Pote, D.H., T.C. Daniel, P.A. Moore, D.J. Nichols, A.N. Sharpley, and D.R. Edwards. 1996. Relating extractable soil phosphorus to phosphorus losses in runoff. *Soil Science Society of America Journal* 60:855-859.

Schwab, G.J., D.A. Whitney, G.L. Kilgore, and D.W. Sweeney. 2006. Tillage and phosphorus management effects on crop production in soils with phosphorus stratification. *Agronomy journal* 98:430-435.

Strudley, M.W., T.R. Green, and J.C. Ascough. 2008. Tillage effects on soil hydraulic properties in space and time: State of the science. *Soil and Tillage Research* 99:4-48.

Troeh, F.R. and L.M. Thompson. 2005. Soils and soil fertility, 5th edition. Blackwell, Iowa.

Tsegaye, T. and R.L. Hill. 1998. Intensive tillage effects on spatial variability of soil test, plant growth, and nutrient uptake measurements. *Soil Science* 163:155-165.

Unger, P.W. 1991. Organic matter, nutrient, and pH distribution in no-and conventional-tillage semiarid soils. *Agronomy Journal* 83:186-189.

Vreugdenhil, D. 1985. Source-to-sink gradient of potassium in the phloem. *Planta*, 163:238-240.

Wiedenfeld, R.P. 1984. Nutrient requirements and use efficiency by sweet sorghum. *Energy in agriculture* 3:49-59.

Wortmann, C.S., A.J. Liska, R.B. Ferguson, D.J. Lyon, R.N. Klein, and I. Dweikat. 2010. Dryland performance of sweet sorghum and grain crops for biofuel in Nebraska. *Agronomy Journal* 102:319-326.

Chapter 4. Effect of Tillage and Fertilization on Soil Test Extractable Phosphorus and Potassium for Sweet Sorghum Production across Different Soil Depths

4.1 Introduction

Generally, Soil is considered as the top layer of the crust of earth, which is made up of organic matter, minerals, water, air, and living organisms (Van-Camp et al., 2004). A fertile soil is considered as an important resource for agriculture. Therefore, maintaining soil fertility is important.

Soil fertility is the capacity of soil to support the plant growth for agricultural productivity and quality (Abbott and Murphy, 2007). Maintaining adequate soil nutrient level is one of the most effective ways to keep agronomic productivity at a satisfactory level. Continuous cropping system without the addition of fertilizer nutrients can adversely affect soil fertility by depletion soil nutrients (Matson et al., 1998). Fortunately, the impacts of soil nutrient depletion can be offset by appropriate agronomic practices which can help maintain and restore soil fertility (Tilman et al., 2002).

Levels of soil nitrogen (N), phosphorus (P), and potassium (K) provides an index of the fertility of the soil to support plant growth. Tillage is an agronomic practice that can affect soil fertility. Lal (1995) indicated that tillage systems can be used to incorporate fertilizer into the root zone which may affect soil nutrient availability and soil pH. Lal (1991) also demonstrated that soil fertility depletion is accelerated when soil structure is frequently disturbed by tillage operations. Valboa et al. (2015) estimated that tillage had a major impact on soil carbon storage due to effects on residue decomposition rate, organic carbon dynamics, microbial abundance, N mineralization, and soil nutrient availability. Lal (1993) reported that improper application of tillage could cause soil organic matter depletion and decreased soil fertility.

Fertilization is another most commonly used method to maintain or build up soil nutrient level. Cope (1981) demonstrated that P and K fertilization was important to maintain the soil P and K level and the crop yield on an over 50 years cropping system.

Maintaining soil fertility is important for sweet sorghum production. However, few experiments have focused on the effect of tillage and fertilization on sweet sorghum production and soil fertility. Therefore, the objectives of this study were to 1) evaluate the influence of tillage on soil fertility on a Crowley silt loam soil used for sweet sorghum production after four years of a monocrop production system, and 2) estimate the effect of 'maintenance' fertilization on soil fertility of a Crowley silt loam soil on sweet sorghum production after four years of a monocrop production system.

4.2 Materials and Methods

Experimental design and treatment information were previously described in Chapter 2. Soil samples were collected from all the plots prior to planting in 2012. All plots were soil sampled after every harvest from 2012 to 2015. Each plot was sampled from the depth of 0 to 30 cm using a hand probe. Six soil samples were taken randomly from the four rows in each plot. Each soil sample was divided into three depths: 0 - 7.5 cm, 7.5 – 15 cm, and 15 - 30 cm. Soil samples were air dried and ground to pass 2.0 mm sieve. All the collected samples were sent to Soil Testing Laboratory in School of Plant, Environmental, and Soil Science, Louisiana State University for the soil routine Mehlich-3 testing and organic matter analysis. Soil test extractable P and K were extracted by Mehlich-3 solution and then analyzed the concentration using Inductively Couple Plasma (ICP). Soil pH was measured in slurry of 1 to 2 soil and water ratio. Soil organic carbon was analyzed by the method of Walkey-Black.

All data were pooled over years and subjected to analysis of variance (ANOVA) with SAS 9.4 software (SAS Institute, 2012). The PROC MIXED procedure was used in SAS in order to make inferences concerning tillage (T) and fertilization (F) across years (Carmer et al., 1989). Year was used as a random effect parameter testing all interactions of tillage and fertilization (T x F). Tillage, fertilization and the interaction of tillage and fertilization were used as fixed effects. Means were compared using the Tukey-kramer to determine any significant differences at alpha (α) < 0.05. The appendix of this thesis shows analysis of variance for each year analyzed separately.

4.3 Results and Discussion

The analysis of variance results for the effects of T, F and their interaction T x F on selected parameters pooled over years is presented in Table 4.1. Means of the effects of tillage system and fertilization practices on soil properties are shown in Table 4.2.

In a soil depth from 0 to 7.5 cm, the main effect of F and the T x F interaction on soil organic matter was not significant (Table 4.1), while soil organic matter was significantly affected by T (P = 0.035). Soil organic matter increased from 2.19% under CT to 2.29% under NT (Table 4.2). Soils taken from 7.5 to 15 cm, the effect of T, F, and the T x F interaction on organic matter content was not significant, whereas the effect of T significantly affected organic matter content in the depth of 15 to 30 cm. No-till increased organic matter content by 0.08% as compared to CT. The effect of F and the T x F interaction on soil organic matter was not significant.

Saffigna et al. (1989) indicated that the soil organic matter was significantly increased by NT in the 10 cm surface layer as compared to CT across a grain sorghum cropping system. Meki et al. (2013) also demonstrated that soil organic matter was retained by NT in the top 10 cm of the soil while soil organic matter was decreased by CT in the same depth. In the current study, the initial mean level of soil organic matter was 2.24% in the upper 7.5 cm (Table 2.2).The initial content of soil organic matter was higher than CT (2.19%) but lower than NT (2.29%) across all plots pooled over years in the same depth. These results were supported by Saffigna et al. (1989) and Meki et al. (2013). The decomposed sweet sorghum residues such as seed head and leaves after harvest were source of soil organic matter in this experiment. No-till can maintain a better soil environment for plant tissue decomposition as compared with CT because NT have many advantages in improving soil organic matter content such as lower temperature, higher microbial activity, and more uniform soil properties (Álvaro-Fuentes et al., 2012; Celik et al., 2011; Derpsch et al., 2010; Madejón et al., 2009; Moussa-Machraoui et al., 2010; Naudin et al., 2010; Sombrero and Benito, 2010). In addition, Meki et al. (2013) indicated that NT had positively affected the soil organic matter content within the top 40 cm soil. The result of Meki et al. (2013) was supported the effect of T on soil organic matter at the depth of 15 to 30 cm.

The effect of F on soil organic matter was not significant at any depths. Haynes and Naidu (1998) reported that fertilization may increase soil organic matter but usually after over 7 years' application. Therefore, the experiment time may account for the minimal effect of fertilization on soil organic matter.

In the top 30 cm of the soil, the main effect of T, F, and the T x F interaction on soil K content and soil pH was not significant (Table 4.1). In the upper 30 cm of the soil, the effect of T on soil P content was not significant.

Table 4.1. Analysis of variance for the effect for tillage, fertilization, and the interaction of tillage and fertilization on soil organic matter, soil test extractable P and K, and soil pH for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA (pre-plant - 2015). Data pooled over years (pre-plant - 2015).

Effect	0 - 7.5 cm				7.5 - 15 cm				15 - 30 cm			
	SOM	P	K	pH	SOM	P	K	pH	SOM	P	K	pH
	P value											
Tillage (T)	0.035	0.834	0.937	0.218	0.167	0.910	0.866	0.657	0.008	0.290	0.252	0.360
Fertilization (F)	0.377	0.112	0.111	0.291	0.909	0.731	0.819	0.222	0.147	0.033	0.574	0.179
T x F	0.061	0.340	0.215	0.360	0.183	0.099	0.694	0.467	0.162	0.032	0.631	0.432

Table 4.2. Effect of tillage, fertilization, and the interaction of tillage and fertilization on mean soil organic matter, soil test extractable P and K, and soil pH for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA (2012 - 2015). Data pooled over years (2012 - 2015).

Effect	0 - 7.5 cm				7.5 - 15 cm				15 - 30 cm			
	OM	P	K	pH	OM	P	K	pH	OM	P	K	pH
	%	mg kg^{-1}			%	mg kg^{-1}			%	mg kg^{-1}		
Tillage												
CT†	2.19 b‡	83 a	93 a	5.4 a	1.64 a	60 a	74 a	5.6 a	1.05 b	14 a	80 a	5.9 a
NT	2.29 a	82 a	93 a	5.3 a	1.60 a	60 a	75 a	5.5 a	1.13 a	17 a	76 a	5.8 a
Fertilization												
MF	2.22 a	85 a	95 a	5.4 a	1.62 a	61 a	75 a	5.6 a	1.07 a	18 a	77 a	5.9 a
NMF	2.26 a	81 a	91 a	5.3 a	1.62 a	60 a	74 a	5.5 a	1.11 a	13 b	79 a	5.7 a
Interactions												
CT x MF	2.13 a	86 a	97 a	5.5 a	1.62 a	62 a	75 a	5.7 a	1.01 a	14 ab	80 a	6.0 a
CT x NMF	2.26 a	80 a	89 a	5.3 a	1.66 a	58 a	73 a	5.5 a	1.10 a	14 ab	80 a	5.8 a
NT x MF	2.32 a	83 a	94 a	5.3 a	1.62 a	59 a	74 a	5.6 a	1.13 a	21 a	75 a	5.8 a
NT x NMF	2.27 a	82 a	93 a	5.3 a	1.58 a	62 a	75 a	5.5 a	1.14 a	12 b	78 a	5.7 a

† CT and NT are conventional and no-till tillage systems, respectively. MF and NMF are with and without ‘maintenance’ fertilization, respectively.

§ Means followed by the same letter are not significantly different ($P < 0.05$).

Singh et al. (2012) estimated that the return of sweet sorghum residues of leaves and seed heads to the soil had potentially offset the removal nutrients due to soil organic matter increased. The limited effects of T and F on soil test extractable P and K may be accounted for the retained soil organic matter content and ‘maintenance’ fertilization in the current study.

Currently, the effect of T and F on soil pH on sweet sorghum is unclear. Pocknee and Sumner (1997) indicated that soil pH was inconsistently affected by soil organic matter which was decomposed from plant residues.

In the depth from 15 to 30 cm, the main effect of F (P = 0.033) and the T x F interaction (P = 0.032) on soil test extractable P was significant (Table 4.1). ‘Maintenance’ fertilization increased soil test extractable P by 5 mg kg^{-1} as compared to NMF (Table 4.2). The NT x MF interaction had the highest P content (21 mg kg^{-1}), while the NT x NMF interaction had the lowest P content (12 mg kg^{-1}) at the same depth. The T x MF and T x NMF interactions had similar P content (15 mg $kg^{-1}$and 14.1 mg kg^{-1}, respectively). The effect of F and the interaction T and F on soil test extractable P may be accounted for the P fertilizer applied on the soil surface each year.

Fig 4.1 shows the effect of the T and F interaction on soil organic matter, soil test extractable P and K, and soil pH across soil depth.

Soil organic matter decreased with increasing soil depth across all treatments (Fig 4.1a). At a depth of 0 to 7.5 cm, soil organic matter under NT x MF was higher than other treatments. At a depth of 15 to 30 cm, NT x MF and NT x NMF had higher soil organic matter content than CT x MF and CT x NMF. The NT system significantly increased soil organic matter in the current study. Meki et al. (2013) indicated that the difference of soil organic matter content between NT and CT was caused by the disturbance of the soil through plowing.

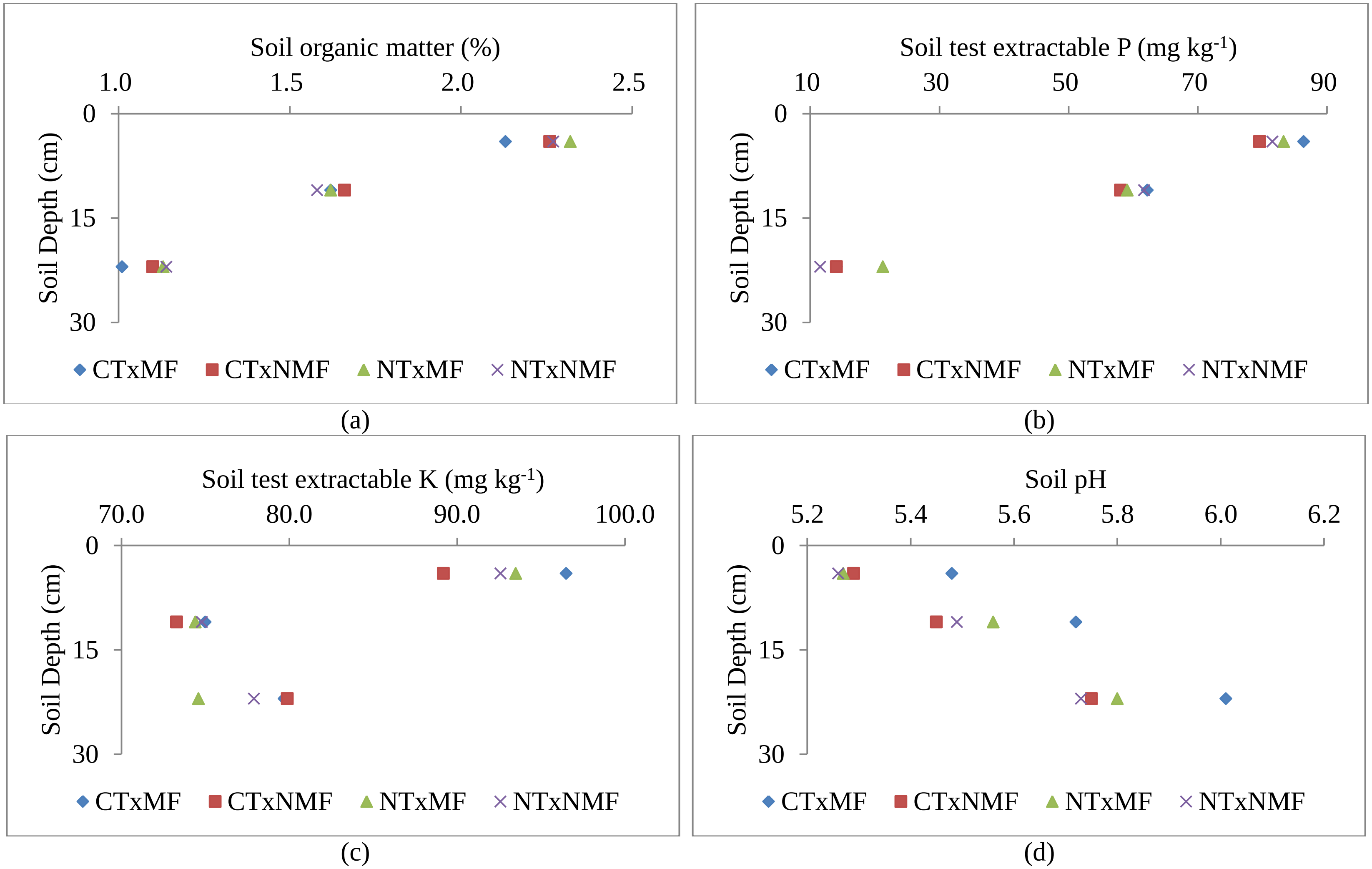

Fig. 4.1. The effect of tillage and fertilization interaction on soil organic matter (a), soil test extractable P (b) and K (c), and soil pH (4.1 d) for sweet sorghum grown on a Crowley silt loam soil across different soil depths, Crowley, LA (2012 to 2015). Data pooled over years (2012 to 2015).

Soil test extractable P decreased with increasing soil depth across all treatments (Fig 4.1b). In the top 15 cm of the soil, CT x MF had higher soil test extractable P as compared with the other three treatments. At the 15 to 30 cm depth, NT x MF had the highest soil test extractable P. The MF application increased soil test extractable P in the upper 30 cm of the soil in the current study.

The content of soil test extractable K decreased with s increasing soil depth (Fig 4.1c). At the 0 to 7.5 cm soil depth, CT x MF had the highest soil test extractable K. At the 15 to 30 cm soil depth, NT x MF had the highest soil test extractable P. Potassium is an immobile nutrient within soil system. Therefore, the highest soil test extractable K at the 0 to 7.5 cm depth was probably due to K fertilization applied on the soil surface.

Soil pH increased with increasing soil depth across all treatments (Fig 4.1d). Dick (1983) also demonstrated that soil pH increased with increasing soil depth under NT and CT with N, P, and K fertilization. CT x MF had the highest soil pH at the 0 to 30 cm depth. At the 0 to 7.5 cm and 15 to 30 cm depth, NT x NMF had the lowest soil pH. Blevins et al. (1977) and Moschler et al. (1973) indicated that soil pH of the surface soil decreases under NT as compared to CT when N fertilizer continuously applied.

4.4 Conclusions

Tillage significantly affected soil organic matter content. At the 0 to 7.5 cm soil depth, NT significantly increased soil organic matter by 0.1% as compared with CT. At the 15 to 30 cm depth, soil organic matter increased from 1.05% under CT to 1.13% under NT. The increases soil organic matter can be potentially be attributed to the NT system which can provide a better environment for residue decomposition than CT.

Fertilization increased the soil nutrient content. The soil test P content at the 15 to 30 cm depth significantly increased from 12.9 ppm under NMF to 17.7 ppm as under MF. This increase was most likely due to the surface broadcast P fertilization of the 'maintenance' fertilization treatment.

4.5 References

Abbott, L.K., and D.V. Murphy. 2003. Soil biological fertility: a key to sustainable land use in agriculture. Springer, Berlin Heidelberg, New York.

Álvaro-Fuentes, J., F.J. Morell, D. Plaza-Bonilla, J.L. Arrúe, and C. Cantero-Martínez. 2012. Modelling tillage and nitrogen fertilization effects on soil organic carbon dynamics. *Soil and Tillage Research* 120:32-39.

Blevins, R.L., G.W. Thomas, and P.L. Cornelius. 1977. Influence of no-tillage and nitrogen fertilization on certain soil properties after 5 years of continuous corn. *Agronomy Journal* 69:383-386.

Carmer, S.G., W.E. Nyquist, and W.M. Walker. 1989. Least significant differences for combined analyses of experiments with two-or three-factor treatment designs. *Agronomy Journal* 81:665-672.

Celik, I., Z.B. Barut, I. Ortas, M. Gok, A. Demirbas, Y. Tulun, and C. Akpinar. 2011. Impacts of different tillage practices on some soil microbiological properties and crop yield under semi-arid Mediterranean conditions. International Journal of Plant Production 5:237-254.

Derpsch, R., T. Friedrich, A. Kassam, and H. Li. 2010. Current status of adoption of no-till farming in the world and some of its main benefits. *International Journal of Agricultural and Biological Engineering* 3:1-25.

Dick, W.A. 1983. Organic carbon, nitrogen, and phosphorus concentrations and pH in soil profiles as affected by tillage intensity. *Soil Science Society of America Journal* 47:102-107.

Haynes, R.J. and R. Naidu. 1998. Influence of lime, fertilizer and manure applications on soil organic matter content and soil physical conditions: a review. *Nutrient Cycling in Agroecosystems* 51:123-137.

Lal, R. 1991. Soil structure and sustainability. *Journal of Sustainable Agriculture* 1:67-92.

Lal, R. 1995. Tillage systems in the tropics: Management options and sustainability implications. Food and Agriculture Org Soil Bulletin No.71. Rome, Italy.

Madejón, E., J.M. Murillo, F. Moreno, M.V. López, J.L. Arrue, J. Alvaro-Fuentes, and C. Cantero. 2009. Effect of long-term conservation tillage on soil biochemical properties in Mediterranean Spanish areas. *Soil and Tillage Research* 105:55-62.

Matson, P.A., R. Naylor, and I. Ortiz-Monasterio. 1998. Integration of environmental, agronomic, and economic aspects of fertilizer management. *Science*, 280:112-115.

Meki, M.N., J.L. Snider, J.R. Kiniry, R.L. Raper. and A.C. Rocateli. 2013. Energy sorghum biomass harvest thresholds and tillage effects on soil organic carbon and bulk density. *Industrial Crops and Products* 43:172-182.

Moschler, W.W., D.C. Martens, C.I. Rich, and G.M. Shear. 1973. Comparative lime effects on continous no-tillage and conventionally tilled corn. *Agronomy Journal* 65:781-783.

Moussa-Machraoui, S. B., F. Errouissi, M. Ben-Hammouda, and S. Nouira. 2010. Comparative effects of conventional and no-tillage management on some soil properties under Mediterranean semi-arid conditions in northwestern Tunisia. *Soil and Tillage Research* 106:247-253.

Naudin, K., E. Gozé, O. Balarabe, K.E. Giller, and E. Scopel. 2010. Impact of no tillage and mulching practices on cotton production in North Cameroon: a multi-locational on-farm assessment. *Soil and Tillage Research* 108:68-76.

Pocknee, S. and M.E. Sumner. 1997. Cation and nitrogen contents of organic matter determine its soil liming potential. *Soil Science Society of America Journal* 61:86-92.

Saffigna, P.G., D.S. Powlson, P.C. Brookes, and G.A. Thomas. 1989. Influence of sorghum residues and tillage on soil organic matter and soil microbial biomass in an Australian Vertisol. *Soil Biology and Biochemistry* 21:759-765.

Singh, M.P., J.E. Erickson, L.E. Sollenberger, K.R. Woodard, J.M.B. Vendramini, and J.R. Fedenko. 2012. Mineral composition and biomass partitioning of sweet sorghum grown for bioenergy in the southeastern USA. *Biomass and Bioenergy* 47:1-8.

Sombrero, A. and A. de Benito, A. 2010. Carbon accumulation in soil. Ten-year study of conservation tillage and crop rotation in a semi-arid area of Castile-Leon, Spain. *Soil and Tillage Research* 107:64-70.

Tilman, D., K.G. Cassman, P.A. Matson, R. Naylor, and S. Polasky. 2002. Agricultural sustainability and intensive production practices. *Nature* 418:671-677.

Valboa, G., A. Lagomarsino, G. Brandi, A.E. Agnelli, S. Simoncini, R. Papini, N. Vignozzi, and S. Pellegrini. 2015. Long-term variations in soil organic matter under different tillage intensities. *Soil and Tillage Research* 154:126-135.

Van-Camp, L., B. Bujarrabal, A.R. Gentile, R.J. A. Jones, L. Montanarella, C. Olazabal, and S.K. Selvaradjou. 2004. Reports of the Technical Working Groups Established under the Thematic Strategy for Soil Protection. Office for Official Publications of the European Communities, Luxembourg.

Chapter 5. Conclusion

The objective of this study was to evaluate the effect of tillage and fertilization on sweet sorghum production and soil fertility. Also, to estimate the recommendation 'maintenance' fertilization rates for the sugar ethanol production only and the cellulosic and sugar ethanol production. Two tillage treatments (no-till system (NT) and conventional tillage (CT)) and two fertilization treatments (with 'maintenance' (MF) and without 'maintenance' (NMF)) were used for sweet sorghum production.

This study showed that tillage and fertilization significantly affected sweet sorghum agronomics. Sweet sorghum's days to 50% heading, plant population, and tiller percentage were affected by tillage. CT consistently decreased sweet sorghum's days to 50% heading by 2 days, while increased the initial plant population by 8,576 plants ha^{-1}. NT increased the number of harvestable stalks that were derived from tillers. On the other hand, MF increased sweet sorghum height by 12 cm, stalk diameter by 1 mm, total biomass by 4.9 Mg ha^{-1}, and stalk biomass by 4.7 Mg ha^{-1}. The increases stalk biomass and total biomass lead to the yield of sweet sorghum ethanol production increases. Based on these different conversion rates (1 Mg stalk = 48 L ethanol production and 1 Mg total biomass = 122 L ethanol production), the increased stalk biomass of 4.7 Mg ha^{-1} in current study may increase sugar ethanol production only by 226 L ha^{-1}, while the increased total biomass of 4.9 Mg ha^{-1} may increase sugar and cellulosic ethanol production by 598 L ha^{-1}. These results indicated that tillage and fertilization are important to sweet sorghum production.

Nutrient uptake of sweet sorghum was also significantly affected by tillage and fertilization. No-till consistently increased P removal rate and P distribution of green leaves. 'Maintenance' fertilization increased K concentration of stalk, K concentration of green leaves, K removal rate of whole plant, K removal rate of stalk, K distribution in stalk, P removal rate of stalk, and P distribution in stalk. In the other hand, NMF positively affected P concentration of brown leaves, P removal rate of brown leaves, and P distribution in brown leaves. Since the initial soil test indicated that the soil was low in soil test extractable K, fertilization is important in order to improve sweet sorghum nutrient uptake when soil nutrients are limiting.

Based on results of nutrient uptake, a sweet sorghum yield of 75 Mg ha^{-1} (around 25 Mg ha^{-1} dry) would remove approximately 40 and 145 kg ha^{-1} of P_2O_5 and K_2O, respectively, when only the stalk is removed from the field. With the same yield, approximately 78 and 193 kg ha^{-1} of P_2O_5 and K_2O would be removed, respectively, when sweet sorghum whole plant is harvested.

Soil fertility significantly responded to tillage and fertilization within sweet sorghum monocrop system. No-till system significantly increased soil organic matter in the soil depth of 0 to 7.5 cm and in the depth of 15 to 30 cm. Soil test extractable P in the depth of 15 to 30 cm significantly increased by MF, while soil test extractable K was not affected by tillage and fertilization across different soil depths.

The outcome of this study suggested that tillage and fertilization are useful to improve sweet sorghum agronomics, nutrient uptake, and soil fertility. Conventional tillage was an effective way to increase the initial plant population, while NT increased the number of harvestable stalks which were derived from tillers and improved soil organic matter on the surface soil. ‘Maintenance’ fertilization was recommended for increasing sweet sorghum biomass, enhancing nutrient uptake, and maintaining soil test extractable P and K. The estimated fertilizer removal rates in this study will be useful to maintain soil test extractable P and K for sweet sorghum production on a Crowley silt loam soil.

Appendix

Table A.1. Analysis of variance for the effect for tillage, fertilization, and the interaction of tillage and fertilization on days to 50% heading, plant population, harvestable stalk population, tiller percentage, plant height, stalk diameter, total biomass, stalk biomass, fermentable solids, and Brix content for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2012.

Effect	days to 50% heading†	Plant population	Harvestable stalk population	Tiller percentage‡	Plant height	Stalk diameter (at base of plant)	Total biomass	Stalk biomass	Brix	Fermentable solids
	———————— *P* value ————————									
Tillage (T)	1	0.842	0.753	0.884	0.024	0.194	0.406	0.803	0.906	0.143
Fertilization (F)	1	0.270	0.102	0.674	0.721	0.405	0.304	0.695	0.839	0.017
T x F	1	0.144	0.033	0.552	0.475	0.258	0.936	0.582	0.650	1.000

† 50% heading is the number of days after emergence until 50% of the panicles have emerged from the boot.

‡ Tiller percentage represents that the % of the harvestable stalks that were derived from tillers. The value was calculated by taking the difference in the plant population at the 3-leaf stage of the development and the harvestable stalk population and dividing by the harvestable stalk population.

Table A.2. Effect of tillage, fertilization, and the interaction of tillage and fertilization on mean days to 50% plant heading, plant population, harvestable stalk population, tiller percentage, plant height, stalk diameter, total biomass, stalk biomass, fermentable solids, and Brix content of sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2012.

Effect	days to 50% heading†	Plant population	Harvestable stalk population	Tiller percentage	Height	Stalk diameter	Total biomass	Stalk biomass	Brix	Fermentable solids
	days	Plants ha^{-1}	Stalks ha^{-1}	%	cm	mm	— Mg ha^{-1}	—	°Bx	Mg ha^{-1}
Tillage										
CT‡	89 a	88,754 a	91,476 a	2.87 a	401 a	20.6 a	83.6 a	65.5 a	7.23 a	12.3 a
NT	89 a	90,387 a	93,654 a	3.51 a	384 b	19.3 a	79.2 a	64.3 a	7.30 a	12.6 a
Fertilization										
MF	89 a	94,199 a	98,555 a	4.12 a	394 a	19.6 a	84.1 a	65.8 a	7.20 a	12.1 b
NMF	89 a	84,942 a	86,576 a	2.26 a	391 a	20.4 a	78.6 a	63.9 a	7.32 a	12.7 a
Interactions										
CT x MF	89 a	87,120 a	89,298 a	2.49 a	405 a	20.8 a	86.1 a	67.7 a	7.30 a	12.0 a
CT x NMF	89 a	90,387 a	93,654 a	3.26 a	398 a	20.5 a	81.0 a	63.2 a	7.15 a	12.6 a
NT x MF	89 a	101,277 a	10,7811 a	5.76 a	382 a	18.4 a	82.1 a	63.9 a	7.10 a	12.3 a
NT x NMF	89 a	79,497 a	79,497 a	1.27 a	385 a	20.3 a	76.2 a	64.7 a	7.49 a	12.9 a

† 50% heading is the number of days after emergence until 50% of the panicles have emerged from the boot. Tiller percentage represents that the % of the harvestable stalks that were derived from tillers. The value was calculated by taking the difference in the plant population at the 3-leaf stage of the development and the harvestable stalk population and dividing by the harvestable stalk population.

‡ CT and NT are conventional and no-till tillage systems, respectively. MF and NMF are with and without 'maintenance' fertilization, respectively.

§ Means followed by the same letter are not significantly different ($P < 0.05$).

Table A.3. Analysis of variance for the effect for tillage, fertilization, and the interaction of tillage and fertilization on days to 50% heading, plant population, harvestable stalk population, tiller percentage, plant height, stalk diameter, total biomass, stalk biomass, fermentable solids, and Brix content for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2013.

Effect	days to 50% heading†	Plant population	Harvestable stalk population	Tiller percentage‡	Plant height	Stalk diameter (at base of plant)	Total biomass	Stalk biomass	Brix	Fermentable solids
	———— *P* value ————									
Tillage (T)	0.491	0.603	0.401	0.037	0.571	0.896	0.047	0.011	0.018	0.251
Fertilization (F)	0.123	0.306	0.469	0.656	0.136	0.068	0.812	0.128	0.225	0.758
T x F	0.362	0.113	0.196	0.507	0.429	0.454	0.183	0.531	0.647	0.918

† 50% heading is the number of days after emergence until 50% of the panicles have emerged from the boot.

‡ Tiller percentage represents that the % of the harvestable stalks that were derived from tillers. The value was calculated by taking the difference in the plant population at the 3-leaf stage of the development and the harvestable stalk population and dividing by the harvestable stalk population.

Table A.4. Effect of tillage, fertilization, and the interaction of tillage and fertilization on mean days to 50% plant heading, plant population, harvestable stalk population, tiller percentage, plant height, stalk diameter, total biomass, stalk biomass, fermentable solids, and Brix content of sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2013.

Effect	days to 50% heading†	Plant population	Harvestable stalk population	Tiller percentage	Height	Stalk diameter	Total biomass	Stalk biomass	Brix	Fermentable solids
	days	Plants ha^{-1}	Stalks ha^{-1}	%	cm	mm	— Mg ha^{-1} —		^{o}Bx	Mg ha^{-1}
Tillage										
CT‡	97 a	145,926 a	132,314 a	-0.44 a	315 a	18.8 a	84.2 a	66.1 a	6.40 a	10.8 a
NT	98 a	140,481 a	139,937 a	-10.36 b	320 a	18.8 a	73.8 b	56.8 b	5.25 b	10.2 a
Fertilization										
MF	97 a	137,759 a	132,858 a	-4.43 a	324 a	19.3 a	79.6 a	64.0 a	6.09 a	10.6 a
NMF	98 a	148,649 a	139,392 a	-6.37 a	311 a	18.3 a	78.4 a	58.9 a	5.55 a	10.4 a
Interactions										
CT x MF	97 a	131,769 a	123,057 a	-7.95 a	325 a	19.4 a	81.4 a	67.6 a	6.57 a	10.8 a
CT x NMF	97 a	160,083 a	141,570 a	-12.78 a	305 a	18.1 a	87.0 a	64.6 a	6.23 a	10.7 a
NT x MF	98 a	143,748 a	142,659 a	-0.92 a	323 a	19.1 a	77.7 a	60.3 a	5.62 a	10.3 a
NT x NMF	99 a	137,214 a	137,214 a	0.05 a	317 a	18.5 a	69.9 a	53.3 a	4.88 a	10.1 a

† 50% heading is the number of days after emergence until 50% of the panicles have emerged from the boot. Tiller percentage represents that the % of the harvestable stalks that were derived from tillers. The value was calculated by taking the difference in the plant population at the 3-leaf stage of the development and the harvestable stalk population and dividing by the harvestable stalk population.

‡ CT and NT are conventional and no-till tillage systems, respectively. MF and NMF are with and without 'maintenance' fertilization, respectively.

§ Means followed by the same letter are not significantly different ($P < 0.05$).

Table A.5. Analysis of variance for the effect for tillage, fertilization, and the interaction of tillage and fertilization on days to 50% heading, plant population, harvestable stalk population, tiller percentage, plant height, stalk diameter, total biomass, stalk biomass, fermentable solids, and Brix content for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2014.

Effect	days to 50% heading†	Plant population	Harvestable stalk population	Tiller percentage‡	Plant height	Stalk diameter (at base of plant)	Total biomass	Stalk biomass	Brix	Fermentable solids
	—— *P* value ——									
Tillage (T)	0.254	0.844	0.216	0.108	0.013	0.583	0.001	0.002	0.001	0.513
Fertilization (F)	0.667	0.336	0.119	0.359	0.083	0.096	0.110	0.066	0.082	0.603
T x F	0.758	0.011	0.005	0.893	0.206	0.071	0.358	0.320	0.227	0.733

† 50% heading is the number of days after emergence until 50% of the panicles have emerged from the boot.

‡ Tiller percentage represents that the % of the harvestable stalks that were derived from tillers. The value was calculated by taking the difference in the plant population at the 3-leaf stage of the development and the harvestable stalk population and dividing by the harvestable stalk population.

Table A.6. Effect of tillage, fertilization, and the interaction of tillage and fertilization on mean days to 50% plant heading, plant population, harvestable stalk population, tiller percentage, plant height, stalk diameter, total biomass, stalk biomass, fermentable solids, and Brix content of sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2014.

Effect	days to 50% heading†	Plant population	Harvestable stalk population	Tiller percentage	Height	Stalk diameter	Total biomass	Stalk biomass	Brix	Fermentable solids
	days	Plants ha^{-1}	Stalks ha^{-1}	%	cm	mm	— Mg ha^{-1} —		^{o}Bx	Mg ha^{-1}
Tillage										
CT‡	98 a	99,644 a	114,345 a	13.2 a	325 a	17.1 a	63.1 b	49.3 b	7.19 b	16.6 a
NT	101 a	101,277 a	125,780 a	18.9 a	349 a	17.6 a	86.7 a	65.1 a	9.71 a	16.3 a
Fertilization										
MF	99 a	96,377 a	112,712 a	14.5 a	345 a	18.2 a	79.7 a	61.3 a	8.97 a	16.6 a
NMF	100 a	104,544 a	127,413 a	17.6 a	330 a	16.6 a	70.1 a	53.1 a	7.92 a	16.3 a
Interactions										
CT x MF	98 a	107,811 a	121,968 ab	11.9 a	328 a	16.9 a	65.3 a	51.3 a	7.36 a	16.7 a
CT x NMF	98 a	91,476 a	106,722 b	14.6 a	323 a	17.4 a	61.0 a	47.3 a	7.01 a	16.6 a
NT x MF	100 a	84,942 a	103,455 b	17.1 a	362 a	19.5 a	94.2 a	71.4 a	10.59 a	16.5 a
NT x NMF	101 a	117,612 a	148,104 a	20.6 a	336 a	15.8 a	79.2 a	58.9 a	8.84 a	16.0 a

† 50% heading is the number of days after emergence until 50% of the panicles have emerged from the boot. Tiller percentage represents that the % of the harvestable stalks that were derived from tillers. The value was calculated by taking the difference in the plant population at the 3-leaf stage of the development and the harvestable stalk population and dividing by the harvestable stalk population.

‡ CT and NT are conventional and no-till tillage systems, respectively. MF and NMF are with and without 'maintenance' fertilization, respectively.

§ Means followed by the same letter are not significantly different ($P < 0.05$).

Table A.7. Analysis of variance for the effect for tillage, fertilization, and the interaction of tillage and fertilization on days to 50% heading, plant population, harvestable stalk population, tiller percentage, plant height, stalk diameter, total biomass, stalk biomass, fermentable solids, and Brix content for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2015.

Effect	days to 50% heading†	Plant population	Harvestable stalk population	Tiller percentage‡	Plant height	Stalk diameter (at base of plant)	Total biomass	Stalk biomass	Brix	Fermentable solids
	———	———	———	———	——— *P* value ———	———	———	———	———	———
Tillage (T)	0.305	<0.001	0.074	0.079	0.366	0.037	0.038	0.039	0.078	0.404
Fertilization (F)	0.816	0.936	0.049	0.051	0.222	0.002	0.485	0.372	0.405	0.881
T x F	0.421	0.936	0.653	0.853	0.538	0.342	0.575	0.654	0.650	0.881

† 50% heading is the number of days after emergence until 50% of the panicles have emerged from the boot.

‡ Tiller percentage represents that the % of the harvestable stalks that were derived from tillers. The value was calculated by taking the difference in the plant population at the 3-leaf stage of the development and the harvestable stalk population and dividing by the harvestable stalk population.

Table A.8. Effect of tillage, fertilization, and the interaction of tillage and fertilization on mean days to 50% plant heading, plant population, harvestable stalk population, tiller percentage, plant height, stalk diameter, total biomass, stalk biomass, fermentable solids, and Brix content of sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2015.

Effect	days to 50% heading†	Plant population	Harvestable stalk population	Tiller percentage	Height	Stalk diameter	Total biomass	Stalk biomass	Brix	Fermentable solids
	days	Plants ha^{-1}	Stalks ha^{-1}	%	cm	mm	— Mg ha^{-1}	—	^{o}Bx	Mg ha^{-1}
Tillage										
CT‡	136 a	117,068 a	122,513 a	2.25 a	319 a	14.5 a	42.9 a	33.6 a	4.47 a	14.7 a
NT	138 a	849,42 b	104,000 a	16.50 a	306 a	13.2 b	32.4 b	24.5 b	3.35 a	15.1 a
Fertilization										
MF	137 a	100,733 a	102,911 b	1.34 a	322 a	15.0 a	39.3 a	30.9 a	4.16 a	15.0 a
NMF	138 a	101,277 a	123,602 a	17.40 a	303 a	12.7 b	36.1 a	27.2 a	3.66 a	14.9 a
Interactions										
CT x MF	135 a	116,523 a	109,989 a	-6.5 a	333 a	15.4 a	45.9 a	36.3 a	4.85 a	14.8 a
CT x NMF	137 a	117,612 a	135,036 a	11.0 a	305 a	13.7 a	40.0 a	30.9 a	4.08 a	14.7 a
NT x MF	139 a	849,42 a	95,832 a	9.2 a	311 a	14.6 a	32.8 a	25.4 a	3.47 a	15.2 a
NT x NMF	138 a	849,42 a	112,167 a	23.8 a	301 a	11.8 a	32.1 a	23.6 a	3.24 a	15.2 a

† 50% heading is the number of days after emergence until 50% of the panicles have emerged from the boot. Tiller percentage represents that the % of the harvestable stalks that were derived from tillers. The value was calculated by taking the difference in the plant population at the 3-leaf stage of the development and the harvestable stalk population and dividing by the harvestable stalk population.

‡ CT and NT are conventional and no-till tillage systems, respectively. MF and NMF are with and without 'maintenance' fertilization, respectively.

§ Means followed by the same letter are not significantly different ($P < 0.05$).

Table A.9. Analysis of variance for the effect for tillage, fertilization, and the interaction of tillage and fertilization on N, P, and K concentration of seed head, stalk, green leaves, and brown leaves for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2012.

Plant Tissue Part	Effect	N	P	K
		——— *P* Value ———		
Seed head	Tillage (T)	0.393	0.515	0.130
	Fertilization (F)	0.937	0.515	0.598
	T x F	0.753	0.285	0.242
Stalk	T	0.894	0.103	0.288
	F	0.894	0.369	0.061
	T x F	0.566	0.276	0.035
Green Leaves	T	0.734	0.323	0.720
	F	0.929	0.699	0.004
	T x F	0.708	0.816	0.025
Brown Leaves	T	0.243	0.221	0.276
	F	0.338	0.824	0.790
	T x MF	0.181	0.175	0.013

Table A.10. Effect of tillage, fertilization, and the interaction of tillage and fertilization on mean N, P, and K concentration of seed head, stalk, green leaves, and brown leaves for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2012.

Effect	Seed Head			Stalk			Green Leaves			Brown Leaves		
	N	P	K	N	P	K	N	P	K	N	P	K
	%											
Tillage												
CT†	1.80 a‡	0.33 a	0.38 a	0.40 a	0.11 a	0.81 a	2.07 a	0.32 a	0.84 a	0.71 a	0.15 a	0.32 a
NT	1.65 a	0.35 a	0.34 a	0.40 a	0.09 a	0.72 a	2.09 a	0.31 a	0.83 a	0.79 a	0.13 a	0.27 a
Fertilization												
MF	1.83 a	0.33 a	0.36 a	0.40 a	0.11 a	0.84 a	2.08 a	0.31 a	0.90 a	0.71 a	0.14 a	0.30 a
NMF	1.82 a	0.35 a	0.35 a	0.40 a	0.10 a	0.68 a	2.09 a	0.32 a	0.78 b	0.78 a	0.14 a	0.29 a
Interactions												
CT x MF	1.81 a	0.34 a	0.40 a	0.42 a	0.13 a	0.98 a	2.08 a	0.32 a	0.95 a	0.72 a	0.16 a	0.40 a
CT x NMF	1.79 a	0.33 a	0.36 a	0.38 a	0.10 a	0.63 b	2.06 a	0.33 a	0.74 b	0.69 a	0.14 a	0.25 a
NT x MF	1.85 a	0.33 a	0.33 a	0.38 a	0.09 a	0.71 ab	2.08 a	0.31 a	0.85 ab	0.71 a	0.11 a	0.21 a
NT x NMF	1.86 a	0.37 a	0.35 a	0.41 a	0.09 a	0.73 ab	2.11 a	0.31 a	0.81 ab	0.87 a	0.14 a	0.33 a

† CT and NT are conventional and no-till tillage systems, respectively. MF and NMF are with and without ‘maintenance’ fertilization, respectively.
‡ Means followed by the same letter are not significantly different ($P < 0.05$).

Table A.11. Analysis of variance for the effect for tillage, fertilization, and the interaction of tillage and fertilization on N, P, and K concentration of seed head, stalk, green leaves, and brown leaves for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2013.

Plant Tissue Part	Effect	N	P	K
			———— *P* Value ————	
Seed head	Tillage (T)	0.138	0.038	0.567
	Fertilization (F)	0.469	0.098	0.032
	T x F	0.036	0.726	0.520
Stalk	T	0.768	1.000	0.007
	F	0.612	1.000	0.138
	T x F	0.688	0.646	0.411
Green Leaves	T	0.190	0.174	0.165
	F	0.154	0.711	0.111
	T x F	0.068	0.711	0.969
Brown Leaves	T	0.267	1.000	0.951
	F	0.338	0.419	0.214
	T x MF	0.258	0.587	0.309

Table A.12. Effect of tillage, fertilization, and the interaction of tillage and fertilization on mean N, P, and K concentration of seed head, stalk, green leaves, and brown leaves for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2013.

Effect	Seed Head			Stalk			Green Leaves			Brown Leaves		
	N	P	K	N	P	K	N	P	K	N	P	K
	%											
Tillage												
CT†	1.80 a‡	0.36 a	0.50 a	0.35 a	0.04 a	0.43 a	0.67 a	0.22 a	0.66 a	1.68 a	0.09 a	0.13 a
NT	1.93 a	0.30 b	0.48 a	0.33 a	0.04 a	0.28 b	0.75 a	0.24 a	0.62 a	1.80 a	0.09 a	0.12 a
Fertilization												
MF	1.90 a	0.36 a	0.53 a	0.35 a	0.04 a	0.39 a	0.75 a	0.22 a	0.67 a	1.79 a	0.08 a	0.14 a
NMF	1.84 a	0.31 a	0.45 b	0.33 a	0.04 a	0.32 a	0.67 a	0.23 a	0.61 a	1.68 a	0.09	0.11 a
Interactions												
CT x MF	1.74 a	0.38 a	0.56 a	0.35 a	0.05 a	0.48 a	0.66 a	0.22 a	0.69 a	1.67 a	0.08 a	0.13 a
CT x NMF	1.87 a	0.34 a	0.45 a	0.34 a	0.04 a	0.37 ab	0.69 a	0.22 a	0.64 a	1.69 a	0.09 a	0.12 a
NT x MF	2.06 a	0.33 a	0.51 a	0.35 a	0.04 a	0.30 ab	0.85 a	0.23 a	0.64 a	1.92 a	0.09 a	0.15 a
NT x NMF	1.81 a	0.27 a	0.45 a	0.31 a	0.05 a	0.27 b	0.65 a	0.25 a	0.59 a	1.68 a	0.09 a	0.10 a

† CT and NT are conventional and no-till tillage systems, respectively. MF and NMF are with and without ‘maintenance’ fertilization, respectively.
‡ Means followed by the same letter are not significantly different ($P < 0.05$).

Table A.13. Analysis of variance for the effect for tillage, fertilization, and the interaction of tillage and fertilization on N, P, and K concentration of seed head, stalk, green leaves, and brown leaves for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2014.

Plant Tissue Part	Effect	N	P	K
		———— *P* Value ————		
Seed head	Tillage (T)	0.962	0.703	0.764
	Fertilization (F)	0.300	0.061	0.822
	T x F	0.061	0.785	0.764
Stalk	T	0.935	0.672	0.894
	F	0.468	0.887	0.009
	T x F	0.468	0.672	0.810
Green Leaves	T	0.264	0.444	0.228
	F	0.985	0.686	0.009
	T x F	0.556	0.912	0.970
Brown Leaves	T	0.184	0.285	0.683
	F	0.965	0.483	0.169
	T x MF	0.455	0.949	0.759

Table A.14. Effect of tillage, fertilization, and the interaction of tillage and fertilization on mean N, P, and K concentration of seed head, stalk, green leaves, and brown leaves for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2014.

Effect	Seed Head			Stalk			Green Leaves			Brown Leaves		
	N	P	K	N	P	K	N	P	K	N	P	K
	%											
Tillage												
CT†	1.68 a‡	0.30 a	0.36 a	0.27 a	0.07 a	0.40 a	1.01 a	0.20 a	0.57 a	0.48 a	0.08 a	0.08 a
NT	1.68 a	0.31 a	0.37 a	0.27 a	0.07 a	0.41 a	1.16 a	0.22 a	0.61 a	0.56 a	0.10 a	0.09 a
Fertilization												
MF	1.65 a	0.28 a	0.37 a	0.26 a	0.07 a	0.48 a	1.08 a	0.20 a	0.64 a	0.52 a	0.09 a	0.11 a
NMF	1.71 a	0.33 a	0.37 a	0.27 a	0.07 a	0.34 b	1.08 a	0.22 a	0.54 b	0.52 a	0.10 a	0.07 a
Interactions												
CT x MF	1.71 a	0.28 a	0.36 a	0.27 a	0.07 a	0.47 a	1.04 a	0.19 a	0.62 a	0.50 a	0.08 a	0.11 a
CT x NMF	1.66 a	0.32 a	0.37 a	0.27 a	0.07 a	0.34 a	0.97 a	0.20 a	0.52 a	0.46 a	0.09 a	0.06 a
NT x MF	1.60 a	0.29 a	0.38 a	0.26 a	0.07 a	0.49 a	1.12 a	0.22 a	0.66 a	0.54 a	0.10 a	0.11 a
NT x NMF	1.76 a	0.34 a	0.37 a	0.28 a	0.07 a	0.33 a	1.20 a	0.23 a	0.56 a	0.58 a	0.11 a	0.08 a

† CT and NT are conventional and no-till tillage systems, respectively. MF and NMF are with and without ‘maintenance’ fertilization, respectively.

‡ Means followed by the same letter are not significantly different ($P < 0.05$).

Table A.15. Analysis of variance for the effect for tillage, fertilization, and the interaction of tillage and fertilization on N, P, and K concentration of seed head, stalk, green leaves, and brown leaves for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2015.

Plant Tissue Part	Effect	N	P	K
		–––––––––––	*P* Value	–––––––––––
Seed head	Tillage (T)	0.311	0.944	0.576
	Fertilization (F)	0.116	0.027	0.910
	T x F	0.038	0.366	0.348
Stalk	T	0.544	0.019	0.709
	F	0.049	0.166	0.315
	T x F	0.760	0.499	0.814
Green Leaves	T	0.236	0.126	0.042
	F	0.271	0.410	0.136
	T x F	0.090	0.654	0.211
Brown Leaves	T	0.023	0.151	0.279
	F	0.041	0.206	0.631
	T x MF	0.159	0.809	0.119

Table A.16. Effect of tillage, fertilization, and the interaction of tillage and fertilization on mean N, P, and K concentration of seed head, stalk, green leaves, and brown leaves for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2015.

Effect	Seed Head			Stalk			Green Leaves			Brown Leaves		
	N	P	K	N	P	K	N	P	K	N	P	K
	%											
Tillage												
CT†	1.45 a‡	0.37 a	0.46 a	0.24 a	0.14 a	0.85 a	0.88 a	0.24 a	1.01 b	0.52 a	0.16 a	0.37 a
NT	1.50 a	0.37 a	0.48 a	0.25 a	0.18 a	0.92 a	0.81 a	0.27 a	1.16 a	0.46 b	0.20 a	0.43 a
Fertilization												
MF	1.44 a	0.35 b	0.47 a	0.23 b	0.17 a	0.98 a	0.81 a	0.25 a	1.14 a	0.47 b	0.17 a	0.41 a
NMF	1.52 a	0.39 a	0.47 a	0.26 a	0.15 a	0.79 a	0.87 a	0.27 a	1.03 a	0.52 a	0.20 a	0.39 a
Interactions												
CT x MF	1.47 a	0.36 a	0.48 a	0.22 a	0.16 a	0.97 a	0.90 a	0.23 a	1.11 a	0.51 ab	0.15 a	0.43 a
CT x NMF	1.44 a	0.39 a	0.44 a	0.26 a	0.12 a	0.74 a	0.86 a	0.26 a	0.92 a	0.53 a	0.18 a	0.32 a
NT x MF	1.41 a	0.34 a	0.46 a	0.23 a	0.19 a	0.99 a	0.73 a	0.27 a	1.17 a	0.42 b	0.18 a	0.40 a
NT x NMF	1.60 a	0.40 a	0.51 a	0.26 a	0.18 a	0.85 a	0.89 a	0.28 a	1.15 a	0.51 ab	0.22 a	0.46 a

† CT and NT are conventional and no-till tillage systems, respectively. MF and NMF are with and without 'maintenance' fertilization, respectively.

‡ Means followed by the same letter are not significantly different ($P < 0.05$).

Table A.17. Analysis of variance for the effect for tillage, fertilization, and the interaction of tillage and fertilization on N, P, and K removal rate of seed head, stalk, green leaves, and brown leaves for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2012.

Plant Tissue	Effect	N	P	K
			––––––––––––– *P* Value –––––––––––––	
Whole Plant	Tillage (T)	0.976	0.085	0.278
	Fertilization (F)	0.967	0.518	0.052
	T x F	0.510	0.236	0.028
Seed head	T	0.718	0.875	0.591
	F	0.979	0.925	0.746
	T x F	0.789	0.593	0.454
Stalk	T	0.943	0.125	0.347
	F	0.846	0.352	0.072
	T x F	0.535	0.274	0.041
Green Leaves	T	0.920	0.524	0.638
	F	0.765	0.524	0.193
	T x F	0.883	0.776	0.370
Brown Leaves	T	0.361	0.066	0.119
	F	0.510	0.895	0.700
	T x MF	0.894	0.693	0.140

Table A.18. Effect of tillage, fertilization, and the interaction of tillage and fertilization on mean N, P, and K removal rate of seed head, stalk, green leaves, and brown leaves for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2012.

Effect	Whole plant			Seed head			Stalk			Green leaves			Brown leaves		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
	g kg^{-1}														
Tillage															
CT†	6.77a‡	1.50a	7.67a	1.10a	0.21a	0.23a	3.22a	0.90a	6.43a	2.20a	0.34a	0.89a	0.25a	0.06a	0.12a
NT	6.76a	1.31a	6.91a	1.17a	0.22a	0.21a	3.19a	0.73a	5.77a	2.18a	0.32a	0.86a	0.23a	0.04a	0.08a
Fertilization															
MF	6.78a	1.44a	8.01a	1.13a	0.21a	0.22a	3.25a	0.86a	6.76a	2.16a	0.32a	0.93a	0.23a	0.05a	0.10a
NMF	6.76a	1.37a	6.57a	1.13a	0.21a	0.21a	3.16a	0.77a	5.44a	2.22a	0.34a	0.83a	0.25a	0.05a	0.09a
Interactions															
CT x MF	6.95a	1.60a	9.22a	1.13a	0.22a	0.25a	3.42a	1.00a	7.86a	2.16a	0.33a	0.98a	0.24a	0.06a	0.14a
CT x NMF	6.60a	1.40a	6.11b	1.07a	0.20a	0.21a	3.02a	0.79a	5.00b	2.25a	0.36a	0.81a	0.26a	0.05a	0.09a
NT x MF	6.61a	1.28a	6.80ab	1.14a	0.20a	0.20a	3.08a	0.73a	5.67ab	2.17a	0.32a	0.88a	0.22a	0.04a	0.06a
NT x NMF	6.91a	1.34a	7.02ab	1.19a	0.23a	0.22a	3.29a	0.74a	5.88ab	2.20a	0.33a	0.84a	0.23a	0.04a	0.09a

† CT and NT are conventional and no-till tillage systems, respectively. MF and NMF are with and without ‘maintenance’ fertilization, respectively.

‡ Means followed by the same letter are not significantly different ($P < 0.05$).

Table A.19. Analysis of variance for the effect for tillage, fertilization, and the interaction of tillage and fertilization on N, P, and K removal rate of seed head, stalk, green leaves, and brown leaves for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2013.

Plant Tissue	Effect	N	P	K
		––––––––––––––– *P* Value –––––––––––––––		
Whole Plant	Tillage (T)	0.951	0.216	0.009
	Fertilization (F)	0.584	0.743	0.080
	T x F	0.274	0.370	0.395
Seed head	T	0.225	0.020	0.092
	F	0.385	0.531	0.417
	T x F	0.308	0.352	0.109
Stalk	T	0.930	0.972	0.008
	F	0.482	0.808	0.103
	T x F	0.497	0.755	0.513
Green Leaves	T	0.577	0.184	0.973
	F	0.876	0.721	0.615
	T x F	0.411	0.838	0.973
Brown Leaves	T	0.407	0.279	0.554
	F	0.279	0.541	0.554
	T x MF	0.119	0.395	0.479

Table A.20. Effect of tillage, fertilization, and the interaction of tillage and fertilization on mean N, P, and K removal rate of seed head, stalk, green leaves, and brown leaves for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2013.

Effect	Whole plant			Seed head			Stalk			Green leaves			Brown leaves		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
	——— $g\ kg^{-1}$ ———														
Tillage															
CT†	6.45a‡	1.08a	4.47a	1.95a	0.41a	0.57a	2.30a	0.30a	2.84a	1.03a	0.31a	0.97a	1.16a	0.07a	0.10a
NT	6.47a	0.99a	3.43b	1.76a	0.26b	0.43b	2.27a	0.29a	1.95b	1.14a	0.38a	0.96a	1.30a	0.05a	0.08a
Fertilization															
MF	6.58a	1.04a	4.27a	1.78a	0.35a	0.53a	2.39a	0.30a	2.64a	1.07a	0.33a	1.00a	1.33a	0.06a	0.10a
NMF	6.34a	1.02a	3.63a	1.92a	0.32a	0.47a	2.18a	0.29a	2.15a	1.10a	0.35a	0.93a	1.14a	0.06a	0.08a
Interactions															
CT x MF	6.33a	1.12a	4.93a	1.96a	0.45a	0.67a	2.30a	0.31a	3.18a	0.94a	0.31a	1.00a	1.12a	0.06a	0.10a
CT x NMF	6.57a	1.03a	4.00a	1.94a	0.37a	0.47a	2.30a	0.29a	2.50a	1.13a	0.31a	0.93a	1.21a	0.07a	0.10a
NT x MF	6.83a	0.97a	3.60a	1.61a	0.26a	0.40a	2.48a	0.29a	2.11a	1.21a	0.36a	1.00a	1.54a	0.06a	0.10a
NT x NMF	6.12a	1.01a	3.25a	1.91a	0.27a	0.46a	2.06a	0.30a	1.80a	1.08a	0.39a	0.92a	1.07a	0.05a	0.07a

† CT and NT are conventional and no-till tillage systems, respectively. MF and NMF are with and without 'maintenance' fertilization, respectively.

‡ Means followed by the same letter are not significantly different ($P < 0.05$).

Table A.21. Analysis of variance for the effect for tillage, fertilization, and the interaction of tillage and fertilization on N, P, and K removal rate of seed head, stalk, green leaves, and brown leaves for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2014.

Plant Tissue	Effect	N	P	K
		——————— *P* Value ———————		
Whole Plant	Tillage (T)	0.235	0.557	0.677
	Fertilization (F)	0.202	0.244	0.018
	T x F	0.263	0.879	0.914
Seed head	T	0.462	0.419	0.339
	F	0.209	0.120	0.156
	T x F	0.601	0.795	0.815
Stalk	T	0.591	0.364	0.899
	F	0.829	0.562	0.006
	T x F	0.914	0.364	0.612
Green Leaves	T	0.190	0.271	0.176
	F	0.217	0.170	0.527
	T x F	0.205	0.346	0.218
Brown Leaves	T	0.176	0.052	0.627
	F	0.269	1.000	0.119
	T x MF	0.372	0.530	0.894

Table A.22. Effect of tillage, fertilization, and the interaction of tillage and fertilization on mean N, P, and K removal rate of seed head, stalk, green leaves, and brown leaves for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2014.

Effect	Whole plant			Seed head			Stalk			Green leaves			Brown leaves		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
	$g\ kg^{-1}$														
Tillage															
CT†	4.88a‡	1.07a	3.92a	1.36a	0.25a	0.29a	1.91a	0.52a	2.89a	1.23a	0.24a	0.68a	0.38a	0.06a	0.07a
NT	5.50a	1.15a	4.09a	1.59a	0.30a	0.35a	1.85a	0.46a	2.85a	1.60a	0.31a	0.81a	0.45a	0.08a	0.08a
Fertilization															
MF	4.85a	1.03a	4.54a	1.27a	0.22a	0.27a	1.90a	0.51a	3.46a	1.24a	0.24a	0.71a	0.45a	0.07a	0.10a
NMF	5.52a	1.19a	3.47b	1.68a	0.33a	0.37a	1.87a	0.47a	2.28b	1.59a	0.32a	0.77a	0.38a	0.07a	0.05a
Interactions															
CT x MF	4.83a	1.00a	4.44a	1.24a	0.20a	0.25a	1.93a	0.51a	3.39a	1.23a	0.23a	0.71a	0.43a	0.06a	0.09a
CT x NMF	4.92a	1.14a	3.41a	1.48a	0.30a	0.33a	1.90a	0.53a	2.40a	1.22a	0.26a	0.65a	0.32a	0.05a	0.04a
NT x MF	4.87a	1.06a	4.64a	1.31a	0.24a	0.30a	1.86a	0.51a	3.53a	1.24a	0.24a	0.72a	0.46a	0.08a	0.10a
NT x NMF	6.13a	1.24a	3.54a	1.88a	0.37a	0.41a	1.85a	0.41a	2.17a	1.96a	0.38a	0.90a	0.45a	0.09a	0.06a

† CT and NT are conventional and no-till tillage systems, respectively. MF and NMF are with and without 'maintenance' fertilization, respectively.
‡ Means followed by the same letter are not significantly different ($P < 0.05$).

Table A.23. Analysis of variance for the effect for tillage, fertilization, and the interaction of tillage and fertilization on N, P, and K removal rate of seed head, stalk, green leaves, and brown leaves for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2015.

Plant Tissue	Effect	N	P	K
		–––––––––––––––	*P* Value	–––––––––––––––
Whole Plant	Tillage (T)	0.731	0.031	0.525
	Fertilization (F)	0.076	0.898	0.208
	T x F	0.390	0.573	0.624
Seed head	T	0.506	0.700	0.521
	F	0.334	0.092	0.580
	T x F	0.541	0.649	0.601
Stalk	T	0.762	0.040	0.811
	F	0.197	0.088	0.254
	T x F	0.651	0.572	0.851
Green Leaves	T	0.588	0.105	0.124
	F	0.598	0.535	0.721
	T x F	0.280	0.876	0.453
Brown Leaves	T	0.075	0.226	0.686
	F	0.011	0.016	0.784
	T x MF	0.638	0.859	0.170

Table A.24. Effect of tillage, fertilization, and the interaction of tillage and fertilization on mean N, P, and K removal rate of seed head, stalk, green leaves, and brown leaves for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2015.

Effect	Whole plant			Seed head			Stalk			Green leaves			Brown leaves		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
	——— $g\ kg^{-1}$ ———														
Tillage															
CT†	4.38a‡	1.70b	7.75a	1.03a	0.26a	0.33a	1.57a	0.91b	5.73a	0.92a	0.26a	1.08a	0.84a	0.27a	0.61a
NT	4.48a	2.09a	8.53a	1.16a	0.28a	0.38a	1.60a	1.17a	6.05a	1.01a	0.34a	1.44a	0.72a	0.31a	0.65a
Fertilization															
MF	4.13a	1.91a	8.93a	1.01a	0.24a	0.33a	1.52a	1.14a	6.68a	0.93a	0.28a	1.30a	0.68b	0.24b	0.62a
NMF	4.73a	1.89a	7.35a	1.19a	0.30a	0.38a	1.66a	0.94a	5.10a	1.01a	0.31a	1.22a	0.88a	0.34a	0.65a
Interactions															
CT x MF	4.22a	1.76a	8.84a	1.00a	0.24a	0.33a	1.49a	1.05a	6.64a	0.97a	0.25a	1.20a	0.76ab	0.22a	0.67a
CT x NMF	4.54a	1.64a	6.66a	1.07a	0.29a	0.33a	1.66a	0.78a	4.82a	0.88a	0.27a	0.95a	0.92a	0.31a	0.56a
NT x MF	4.05a	2.06a	9.02a	1.01a	0.24a	0.34a	1.56a	1.24a	6.71a	0.88a	0.32a	1.40a	0.60b	0.26a	0.57a
NT x NMF	4.92a	2.13a	8.03a	1.30a	0.32a	0.43a	1.65a	1.10a	5.39a	1.14a	0.36a	1.49a	0.83ab	0.36a	0.73a

† CT and NT are conventional and no-till tillage systems, respectively. MF and NMF are with and without ‘maintenance’ fertilization, respectively.

‡ Means followed by the same letter are not significantly different ($P < 0.05$).

Table A.25. Analysis of variance for the effect for tillage, fertilization, and the interaction of tillage and fertilization on soil organic matter, soil test extractable P and K, and soil pH for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2012.

Effect	0 - 7.5 cm				7.5 - 15 cm				15 - 30 cm			
	SOM	P	K	pH	SOM	P	K	pH	SOM	P	K	pH
	——— *P* value ———											
Tillage (T)	0.786	0.688	0.041	0.565	0.004	0.946	0.520	0.811	0.894	0.898	0.475	0.533
Fertilization (F)	0.382	0.906	0.033	0.649	0.513	0.682	0.568	0.622	0.225	0.347	0.865	0.590
T x F	0.207	0.893	0.801	0.536	0.213	0.627	0.772	0.759	0.811	0.465	0.255	0.747

Table A.26. Effect of tillage, fertilization, and the interaction of tillage and fertilization on mean soil organic matter, soil P and K, and soil pH for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2012.

Effect	0 - 7.5 cm				7.5 - 15 cm				15 - 30 cm			
	OM	P	K	pH	OM	P	K	pH	OM	P	K	pH
	%	mg kg^{-1}			%	mg kg^{-1}			%	mg kg^{-1}		
Tillage												
CT†	1.92 b‡	96 a	70 b	5.4 a	1.42 a	66 a	50 a	5.6 a	0.86 a	15 a	47 a	5.9 a
NT	1.95 a	98 a	76 a	5.2 a	1.29 b	66 a	53 a	5.5 a	0.88 a	15 a	50 a	5.7 a
Fertilization												
MF	1.89 a	97 a	76 a	5.4 a	1.34 a	67 a	53 a	5.6 a	0.81 a	17 a	48 a	5.9 a
NMF	1.98 a	98 a	70 b	5.3 a	1.37 a	65 a	51 a	5.5 a	0.93 a	13 a	49 a	5.7 a
Interactions												
CT x MF	1.81 a	96 a	73 ab	5.5 a	1.38 ab	68 a	52 a	5.7 a	0.79 a	16 a	49 a	6.0 a
CT x NMF	2.03 a	96 a	67 b	5.3 a	1.46 a	64 a	49 a	5.5 a	0.93 a	15 a	46 a	5.8 a
NT x MF	1.97 a	98 a	79 a	5.2 a	1.30 ab	66 a	53 a	5.5 a	0.83 a	18 a	47 a	5.8 a
NT x NMF	1.93 a	99 a	73 ab	5.3 a	1.27 b	66 a	52 a	5.5 a	0.92 a	11 a	52 a	5.7 a

† CT and NT are conventional and no-till tillage systems, respectively. MF and NMF are with and without 'maintenance' fertilization, respectively.

§ Means followed by the same letter are not significantly different ($P < 0.05$).

Table A.27. Analysis of variance for the effect for tillage, fertilization, and the interaction of tillage and fertilization on soil organic matter, soil test extractable P and K, and soil pH for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2013.

Effect	0 - 7.5 cm				7.5 - 15 cm				15 - 30 cm			
	SOM	P	K	pH	SOM	P	K	pH	SOM	P	K	pH
	P value											
Tillage (T)	0.184	0.691	0.467	0.768	0.813	0.845	0.451	0.754	0.210	0.094	0.465	0.831
Fertilization (F)	0.619	0.066	0.002	0.433	0.359	0.939	0.748	0.715	0.645	0.056	0.529	0.615
T x F	0.065	0.951	0.868	0.707	0.031	0.989	0.875	0.656	0.050	0.211	0.522	0.717

Table A.28. Effect of tillage, fertilization, and the interaction of tillage and fertilization on mean soil organic matter, soil P and K, and soil pH for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2013.

Effect	0 - 7.5 cm				7.5 - 15 cm				15 - 30 cm			
	OM	P	K	pH	OM	P	K	pH	OM	P	K	pH
	%	mg kg^{-1}			%	mg kg^{-1}			%	mg kg^{-1}		
Tillage												
CT†	2.21 a‡	61 a	73 a	5.3 a	1.70 a	42 a	41 a	5.6 a	1.12 a	13 a	43 a	5.9 a
NT	2.38 a	60 a	71 a	5.3 a	1.68 a	43 a	43 a	5.5 a	1.19 a	19 a	41 a	5.9 a
Fertilization												
MF	2.26 a	65 a	78 a	5.4 a	1.73 a	43 a	42 a	5.6 a	1.14 a	19 a	43 a	6.0 a
NMF	2.33 a	56 a	66 a	5.2 a	1.66 a	42 a	41 a	5.5 a	1.16 a	12 a	41 a	5.8 a
Interactions												
CT x MF	2.05 a	65 a	80 a	5.5 a	1.65 a	42 a	41 a	5.8 a	1.05 a	14 a	45 a	6.0 a
CT x NMF	2.37 a	57 a	67 a	5.2 a	1.76 a	42 a	40 a	5.5 a	1.19 a	11 a	41 a	5.8 a
NT x MF	2.48 a	64 a	77 a	5.3 a	1.82 a	43 a	43 a	5.5 a	1.23 a	24 a	41 a	5.9 a
NT x NMF	2.29 a	55 a	65 a	5.2 a	1.55 a	43 a	42 a	5.5 a	1.14 a	13 a	41 a	5.8 a

† CT and NT are conventional and no-till tillage systems, respectively. MF and NMF are with and without ‘maintenance’ fertilization, respectively.

§ Means followed by the same letter are not significantly different ($P < 0.05$).

Table A.29. Analysis of variance for the effect for tillage, fertilization, and the interaction of tillage and fertilization on soil organic matter, soil test extractable P and K, and soil pH for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2014.

Effect	0 - 7.5 cm				7.5 - 15 cm				15 - 30 cm			
	SOM	P	K	pH	SOM	P	K	pH	SOM	P	K	pH
	——— *P* value ———											
Tillage (T)	0.116	0.808	0.689	0.543	0.261	0.020	0.363	0.956	0.241	0.704	0.203	0.818
Fertilization (F)	0.932	0.221	0.351	0.822	0.238	0.236	0.731	0.525	0.749	0.222	0.224	0.626
T x F	0.124	0.566	0.867	0.685	0.587	0.241	0.635	0.785	0.749	0.353	0.858	0.626

Table A.30. Effect of tillage, fertilization, and the interaction of tillage and fertilization on mean soil organic matter, soil P and K, and soil pH for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2014.

Effect	0 - 7.5 cm				7.5 - 15 cm				15 - 30 cm			
	OM	P	K	pH	OM	P	K	pH	OM	P	K	pH
	%	mg kg^{-1}			%	mg kg^{-1}			%	mg kg^{-1}		
Tillage												
CT†	2.42 a‡	70 a	159 a	5.5 a	1.88 a	53 a	168 a	5.8 a	1.30 a	10 a	208 a	6.0 a
NT	2.62 a	71 a	155 a	5.4 a	1.83 a	47 b	157 a	5.8 a	1.36 a	12 a	190 a	6.0 a
Fertilization												
MF	2.53 a	73 a	152 a	5.5 a	1.88 a	51 a	161 a	5.9 a	1.32 a	14 a	191 a	6.1 a
NMF	2.52 a	68 a	162 a	5.5 a	1.83 a	49 a	165 a	5.7 a	1.34 a	8 a	207 a	5.9 a
Interactions												
CT x MF	2.33 a	72 a	153 a	5.6 a	1.89 a	55 a	163 a	5.9 a	1.30 a	11 a	198 a	6.2 a
CT x NMF	2.51 a	69 a	166 a	5.5 a	1.87 a	50 a	173 a	5.6 a	1.30 a	10 a	217 a	5.9 a
NT x MF	2.72 a	75 a	151 a	5.4 a	1.87 a	47 a	158 a	5.8 a	1.35 a	18 a	183 a	6.0 a
NT x NMF	2.52 a	68 a	159 a	5.4 a	1.80 a	47 a	156 a	5.7 a	1.38 a	7 a	197 a	6.0 a

† CT and NT are conventional and no-till tillage systems, respectively. MF and NMF are with and without 'maintenance' fertilization, respectively.

§ Means followed by the same letter are not significantly different (P < 0.05).

Table A.31. Analysis of variance for the effect for tillage, fertilization, and the interaction of tillage and fertilization on soil organic matter, soil test extractable P and K, and soil pH for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2015.

Effect	0 - 7.5 cm				7.5 - 15 cm				15 - 30 cm			
	SOM	P	K	pH	SOM	P	K	pH	SOM	P	K	pH
	——— *P* value ———											
Tillage (T)	0.468	0.855	0.944	0.222	0.601	0.994	0.762	0.871	0.068	0.676	0.961	0.766
Fertilization (F)	0.990	0.251	0.055	0.669	0.415	0.605	0.861	0.572	0.935	0.613	0.401	0.343
T x F	0.368	0.261	0.028	0.742	1.000	0.333	0.318	0.789	0.551	0.376	0.906	0.750

Table A.32. Effect of tillage, fertilization, and the interaction of tillage and fertilization on mean soil organic matter, soil P and K, and soil pH for sweet sorghum grown on a Crowley silt loam soil, Crowley, LA, 2015.

Effect	0 - 7.5 cm				7.5 - 15 cm				15 - 30 cm			
	OM	P	K	pH	OM	P	K	pH	OM	P	K	pH
	%	mg kg^{-1}			%	mg kg^{-1}			%	mg Mg^{-1}		
Tillage												
CT†	2.19 a‡	94 a	72 a	5.3 a	1.62 a	74 a	61 a	5.5 a	1.09 a	18 a	64 a	5.7 a
NT	2.26 a	95 a	72 a	5.1 a	1.58 a	74 a	63 a	5.4 a	1.24 a	20 a	64 a	5.6 a
Fertilization												
MF	2.22 a	100 a	78 a	5.2 a	1.57 a	73 a	63 a	5.5 a	1.16 a	21 a	66 a	5.8 a
NMF	2.22 a	90 a	67 a	5.2 a	1.63 a	76 a	62 a	5.3 a	1.16 a	17 a	61 a	5.5 a
Interactions												
CT x MF	2.23 a	103 a	84 a	5.4 a	1.59 a	756 a	64 a	5.6 a	1.07 a	16 a	67 a	5.9 a
CT x NMF	2.14 a	85 a	61 a	5.3 a	1.64 a	73 a	58 a	5.5 a	1.11 a	19 a	61 a	5.5 a
NT x MF	2.21 a	96 a	71 a	5.1 a	1.55 a	70 a	61 a	5.4 a	1.26 a	25 a	66 a	5.7 a
NT x NMF	2.30 a	95 a	73 a	5.1 a	1.61 a	79 a	65 a	5.4 a	1.21 a	16 a	61 a	5.5 a

† CT and NT are conventional and no-till tillage systems, respectively. MF and NMF are with and without ‘maintenance’ fertilization, respectively.

§ Means followed by the same letter are not significantly different (P < 0.05).

Vita

Jifeng Li was born in Guangxi, China. In August 2005 he attended Guangxi University, in Nanning, Guangxi. In May 2009 he obtained his bachelor degree of Science in Chemistry and stared to work with the East Asia Sugar Group. In August 2013 Jifeng began his Masters graduate research at Louisiana State University in the School of plant, Environmental, and Soil Sciences. He worked with Dr. Dustin Harrell on tillage and fertilization practices for sweet sorghum production. His thesis tittle was “Effect of Tillage and Fertilization on Agronomics and Nutrient Uptake of Sweet Sorghum and Soil Test Extractable P and K after Four Years of a Monocrop Production System”.