Industrial Crops and Products 36 (2012) 555–559

Contents lists available at SciVerse ScienceDirect

Industrial Crops and Products

journal homepage: www.elsevier.com/locate/indcrop

Biomass, extracted liquid yields, sugar content or seed yields of biofuel feedstocks as affected by fertilizer☆

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ARTICLE INFO

Article history:
Received 13 October 2011
Received in revised form
16 November 2011
Accepted 18 November 2011
Available online 14 December 2011

Keywords:
Helianthus
Sorghum
Zea
Cultivar
Rate
Sweet corn
Variety

ABSTRACT

Harvesting products from plants for conversion into renewable resources is increasing in importance. Determination of nutrition requirements for the applicable crops is necessary, especially in regions where the biofuel feedstock crops have not been historically grown. Sunflower (*Helianthus annuus* L.), two hybrids and one variety; sweet and grain (milo) sorghums (both *Sorghum bicolor* L.), one variety each, and sweet corn (*Zea mays* var. *rugosa* Bonaf.), four cultivars, were provided the recommended and twice the recommended rate of fertilizer. Biomass, expressed liquid volumes and sugar contents of sweet sorghum and sweet corn were determined. Grain yields of milo and sunflower and oil content of sunflower were determined. Sweet corn stalk sugar levels were below what is expected from field corn (maize), and were not affected by fertilizer rate. Sweet sorghum biomass and sugar content were within expected ranges and not affected by fertilizer rate. Milo grain yields were higher with increased fertilizer. Seed yield in Sunflower, which was below expected levels, was inconsistently affected by fertilizer rate, years or varieties. Overall crops year and cultivar/variety had more effect on results than did fertilizer. There does not appear to be a reason to provide fertilizer above recommended rates in production of these crops.

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1. Introduction

Biofuel feedstock production is increasing and crops are sometimes established in areas where they historically have not been grown. Nutrition is one of the most important inputs of a crop production system. Fertilizer level affects establishment in any crop and is of importance in annual crops that require seed be placed in direct contact with soil. It is important that fertilizer levels be correct for early and continued plant development. It is also important that fertilizer requirements be determined for crops established in new production areas.

Sunflower (*Helianthus annuus* L.) and sweet sorghum and grain sorghum, milo, (both *Sorghum bicolor* L.) are row crops considered to have use as biofuel feedstocks which respond to fertilizer level in traditional production regions (Dahnke et al., 1992; Whitney, 1998; Almondares et al., 2009). Sweet sorghum is unique as a biofuel feedstock in that it contains simple sugars through much of its development that can be readily converted to ethanol through fermentation. In addition the remaining biomass present after stalks are crushed has the potential to be treated so complex sugars and other carbohydrates can be converted to ethanol when the technology becomes available on a commercial scale. Milo has the potential as a biofuel feedstock due to the starch stored in seed. The seed provide a biological package that allows the transport and long-term storage of material that can be converted to bioethanol.

Another possible candidate as a biofuel feedstock is sweet corn (*Zea mays* var. *rugosa* Bonaf.) grown for harvest of stalks, before ears are formed, from which sugars can be extracted. Fertilizer requirements for sweet corn harvested for the ears are understood (McCraw et al., 1987), but it is not clear if these requirements affect sugar content in stalks harvested for extracted sugars. Russo et al. (1998) determined that about 85 mg mL^{-1} of sugars was found in stalks of a "supersweet" cultivar at the silking (R1) stage as described by Ritchie and Hanway (1982), and values changed with plant development and senescence stage. Presumably senescence affects levels of simple and more complex sugars in other monocots including sweet sorghum. However, unlike for field and sweet corn senescence patterns in sorghum have not been extensively studied.

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0926-6690/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.indcrop.2011.11.019

Table 1
Typical analysis for pH, nutrients[a] on a dry basis, and electrical conductivity (EC) of chicken litter manure used.

pH	C	N	P_2O_5	K	Ca	Cu	Fe	Mg	Mn	Na	S	Zn	EC
8.2	679.3	51.4	31.9	52.2	113.9	0.1	52.9	18.8	1.2	3.1	13.1	0.3	2487

[a] C, N, P_2O_5, K, Ca, Cu, Fe, Mg, Mn, Na, S, and Zn are in kg Mg^{-1} and EC is in μS, analysis performed by the Oklahoma State University Soil, Water & Forage Analytical Laboratory, Stillwater, OK.

In some instances the crops may be grown where manure resources, which can be used to supply nutrition, are available. Crops use soil nutrients at various efficiencies. Crop residues can also supply nutrients when returned to the soil. Amount of nutrients supplied can affect both activities. It is necessary to determine whether fertilizer recommendations are sufficient for candidate crops so that biofuel feedstock production can be maximized and fertilizer assets used in an economical manner. This research was undertaken to clarify fertilizer requirements of traditional biofuel feedstock crops where the crops have not been traditionally grown and for crops that may potentially be used as biofuel feedstock crops.

2. Materials and methods

Experiments were conducted on a Bernow (fine-loamy, silliceous, thermic, Glossic Paleudalf) soil at Lane, Okla., from late-May to mid-August 2009 and late-April to early-August 2010. Differences in planting dates were dictated by rainfall occurring prior to planting in 2009. The experiments were conducted on three non-contiguous fields of the same soil type about 300 m apart from each other. One field contained Sunflower (previous crop squash, *Cucurbita* spp.); the second field contained sweet corn (previous crop Mustard, *Brassica* spp.) and a third field contained sweet and grain sorghum (milo), which followed sorghum. In all fields overwintering wheat (*Triticum aestivum* L. subsp. *aestivum*), which was established between the previous crops and the experimental crops, was mowed in mid-March of each year and the residue left on the soil for two weeks before being incorporated into the soil.

Fertilizer rates were determined based on soil test results and state or regional recommendations (McCraw et al., 1987; Izekor and Porter, 2004; Zhang et al., 2009). Synthetic fertilizers were broadcast applied to soil in which sunflower and sweet corn were to be sown preplant at 95 or 190 kg ha^{-1} of synthetic N from ammonium nitrate. All P (80 kg ha^{-1}) from single super-phosphate and K (185 kg ha^{-1}) from muriate of potash, were applied preplant. To soil supporting sweet and grain sorghum two rates of chicken litter (3.36 or 6.72 Mg ha^{-1}; nutrient content Table 1) were broadcast applied preplant. In all fields the fertilizer material was incorporated using a Liliston rolling cultivator (Bush Hog Corp., Selma, Ala.) and final, flat, seedbeds formed using a multi-facet finishing tool (Do-All, Forrest City, AR).

All crops were established from seed in rows on 0.9 m centers. Plot sizes for crops were: sweet corn (each cv.), 4 m × 80 m; sorghum (sweet and grain), 9 m × 106 m, and sunflower (each variety), 8 m × 76 m. Sweet corn cvs. Florida Staysweet, Incredible, and Merit, and the forage sweet corn, cv. TC1101, were sown with an in-row spacing of 20 cm on 21 May 2009 and 26 April 2010. Grain sorghum, a field run mix, and the sweet sorghum, var. Della, were sown with an in-row spacing of 7 cm on 20 May 2009 and 27 April 2010. Sunflower varieties 657, 820OH, and a Peredovik (high oil) variety were sown 16 cm between plants on 22 May 2009 and 22 April 2010.

For sunflower and sweet corn the herbicide Dual (1.2 L ha^{-1}) was applied preplant in accordance with label directions. No synthetic herbicides were applied to sweet and grain sorghum. Sweet corn received 5 cm per week of water through precipitation and irrigation; sweet and grain sorghum were irrigated based on a minimum soil moisture reading of 35–40 kPa obtained with a soil moisture meter (model TEMP-200, Aquaterra, Fremont, CA). Sunflower was generally rain-fed with a single irrigation occurring once on 3 June 2010, the need for which was surmised from plant appearance.

Samples of sweet corn and sweet sorghum were harvested for biomass from 3.5 linear meters in a row from each replication. Sweet corn was harvested on 5 August 2009 and 21 July 2010; sweet sorghum was harvested on 18 August 2009 and 4 August 2010. Stalks were weighed and passed through a press manufactured at this station to express liquids. The volume and weight of expressed liquid was determined. Subsamples of expressed liquids were processed for quantification of sugars by high performance liquid chromatography (HPLC) by first centrifuging the liquid at 16,000 × *g* for 15 min at room temperature, diluting the liquid with distilled H_2O to the desired level, and filtering the diluted solution through a 0.45 μm cellulose filter. HPLC was carried out on a Varian ProStar (Vista, CA) ternary solvent system equipped with an autosampler and RI detector. Quantitative sugar profiles of the diluted subsamples were obtained with a 250 mm × 4 mm amino column (5 μm, Luna^{TM}, Phenomenex, Torrance, CA). Glucose, fructose, and sucrose, were eluted with an isocratic system of 80% acetonitrile/20% H_2O at a flow rate of 1 mL min^{-1} and a column temperature of 35 °C.

Grain sorghum and sunflower were harvested for seed yield with a Gleaner combine (Agro Corporation, Duluth, GA) over the entire plot excluding a guard row on either side. The grain sorghum was harvested on 24 August 2009 and 9 August 2010, and the sunflower on 21 September 2009 and 12 August 2010 to determine response to fertilizer level as it affected seed yield. Sunflower seed were fed into a screw press (model CLB-300, Cropland Biodiesel, Lynden, Wash.) in 2010 using heat at 93 °C to extract oil; the machine was not available in 2009.

Due to differences in production practices, plant habit, harvesting method, product of harvest, and time of harvest there were no direct comparisons between crops. All experiments were arranged in randomized complete block designs with three replications. The data were subjected to analysis of variance in SAS (ver. 9.1, SAS, Inc., Cary, NC). If interactions were significant they were used to explain results. If interactions were not significant means were separated with the Ryan–Einot–Gabriel–Welsch multiple *F* test.

3. Results

Average minimum and maximum temperatures and precipitation were in some instances different for the crops in 2009 and 2010 (Table 2). For sweet corn minimum and maximum air temperatures were lower in 2010 but precipitation was higher. For sorghum minimum temperature was slightly lower in 2010, but maximum temperature and precipitation were similar in both years. For milo minimum and maximum temperatures were similar in both years but precipitation was slightly higher in 2010. For sunflower minimum temperature was lower in 2010, maximum temperature was similar between years and precipitation lower in 2010. Due to weather plants were sown about 3 weeks later and harvested about 2 weeks later in 2009 than in 2010.