A Comparative Analysis of Sorghum and Maize as Bioenergy Feedstock for the US Midwest: Compositional Attributes and System Nitrogen Dynamics

Monique Long

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The comparative production potential among annual cropping systems grown as bioenergy feedstock in the Eastern Cornbelt of the US Midwest is generally unknown. Two field experiments were conducted to evaluate the compositional attributes, agronomic and economic efficiencies, and environmental impacts of sorghum (*Sorghum bicolor* M.) and maize (*Zea mays* L.) as they relate to bioethanol production and nitrogen (N). A 3 site-year fertilizer rate study (0, 67, 135 and 202 kg N ha^{-1}) comparing five distinct sorghum hybrids/lines and a maize hybrid, was conducted to evaluate yields, carbohydrate pools, and associated theoretical ethanol (EtOH) yields. Post-harvest, dried stover was analyzed for carbohydrate partitioning and theoretical EtOH yield was calculated using conversion and efficiency factors for sugars as proposed by the National Renewable Energy Lab's state of technology report. Simple marginal accounting was conducted to determine the economic EtOH responses to incremental investments for N fertilizer by the hybrids/lines. A related study of system N balance, specifically focused on N removal in harvested tissue and N loss to subsurface drainage water, was conducted at Purdue University's Water Quality Field Station. The study compared continuous residue removal systems of sorghum and maize to grain-only maize-based systems, two of which included a soybean rotation. In the N rate study, sorghums had total aboveground biomass and EtOH yields that were either similar to, or higher than maize. The photoperiod sensitive sorghum had the highest biomass and EtOH yields, (30 Mg ha^{-1} dry wt. and over 12,000 L EtOH ha^{-1}). The lowest yielding sorghum hybrid/line was the commercial grain sorghum hybrid, which produced biomass and total EtOH yields (20 Mg ha^{-1} dry wt. and 7,000 L EtOH ha^{-1}) similar to maize. The concentrations and contents of total non-structural carbohydrates (TNCs) and total fibers (TFs) varied markedly among hybrids/lines. The concentration of TFs were negatively correlated to TNCs (r=-0.8). A higher content of EtOH convertible carbohydrates (TFs plus TNCs) was associated with a higher a non-convertible carbohydrate pool. Biomass yield was the main driver for EtOH yields, as the theoretical equations that were used suggests only minor differences in conversion efficiencies and rates among the different carbohydrate pools. The lowest N rate of 67 kg N ha^{-1} had the highest incremental increase in biomass yield for all sorghums. Consistent with this, the economic analyses also exhibited that this N rate (67 kg N ha^{-1}) had the largest marginal gain. When no N fertilizer was applied, the highest yielding sorghum hybrids/lines still had EtOH returns from stover as high as \$6000 ha^{-1}, compared to the grain hybrids which had \$<2000 ha^{-1} at 0N. The N balance study found that the bioenergy residue systems exported N quantities in the plant tissue that was approximately equivalent to the N applied as fertilizer (~180-200 kg ha^{-1}), which was more than the grain only systems. The grain-only rotated systems had significantly higher nitrate (NO_3-N) concentrations in the subsurface drainage water than the residue removed systems. Of the residue removed systems, only sorghum had significantly lower flow-weighted NO_3-N concentrations. Results suggest that the biological N fixation occurring in the soybean contributes to numerically higher N loads in the rotated systems compared to the continuous systems. From environmental, agronomic and economic viewpoints, our collective results demonstrate that while all hybrids/lines assessed in this study could be more efficient as a biomass feedstock for cellulosic EtOH production in the Eastern Cornbelt of the US, Midwest with lower N rates, sorghum is favorable comparably to maize.