Selection of herbaceous energy crops for sustainable agriculture

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Goals

Double cropping, a system in which more than one crop is produced per year in a land area, helps to increase food and feed production in the United States. But the impact of double cropping on production of biomass (crops grown to be converted to fuel) has not been evaluated. Such cropping systems have been successful in the eastern and southern United States. If they can be adapted to the relatively short growing season of the extremely large and agriculturally productive north-central region of the United States, biomass production potential can be greatly increased.

Because of the wide range of land types in this region, no one cropping system will be suitable for all sites. Prime farm land, for example, will support perennial, sod-forming crops such as alfalfa and reed canarygrass as well as annual row crops. Marginal, sloping land, however, is much better suited for cropping systems that feature perennial crops.

Intercropping involves growing more than one crop in an area at the same time. This system also offers potential for improving biomass production, especially on marginal, sloping lands. There, sod-forming, cool-season crops such as alfalfa interplanted with warm-season sorghums—which grow rapidly during midsummer when alfalfa may be semi-dormant—can be grown.

The objectives of this ongoing experiment included (1) comparing biomass production from various cropping combinations under sole, double, and intercropping systems; and (2) obtaining measurements of the quality of the biomass from each system in order to determine its efficiencies of combustion or conversion to liquid fuels. These measurements can also be used to indicate the amount of adverse combustion by-products in these crops.

Approach

Researchers used two sites: Iowa State University's Agronomy and Agricultural Engineering Research Center (AAERC), which offers low-erosive, highly productive row-crop land, at Ames, Iowa; and ISU's McNay Memorial Research Center (an erosive site with marginally productive soils, a 2-7 percent slope, and drought susceptibility) near Chariton, Iowa. Average frost-free periods for the sites are 160 and 165 days respectively.

The Leopold Center sponsored the evaluation of six of the 13 cropping combinations tested at both sites during the three years of the project. In all, nine species were used to establish these cropping systems: alfalfa, reed canarygrass, switchgrass, big bluestem, sweet sorghum, a sorghum-sudangrass hybrid, corn, soybeans, and winter rye.

The double-cropping tests included sweet sorghum and the sorghum-sudangrass hybrid during summer and winter rye grown during the fall, winter, and spring. (Sweet sorghum, an annual, accumulates high levels of soluble sugars in its stems. The hybrid is a forage plant commonly used for livestock feed.) The sorghums were planted in late May and harvested in late September. The rye, a winter annual, was planted in mid October and harvested in late May.

The intercropping tests used alfalfa or reed canarygrass established as perennial crops. A first cutting was harvested in late May for each; sorghum was then planted in rows within the sod.

Using four replications at each site, researchers also subjected the subplots in the study's split-plot arrangement (except for conventionally grown alfalfa and soybeans) to four commercial nitrogen (N) fertilizer application rates: 0, 62, 125, and 250 pounds (lb)/acre. Plots intercropped with reed canarygrass, alfalfa, and sorghum received either 62 or 125 lb/acre ofN.

The design of the demonstration treatments was such that many types of main-plot and subplot treatment comparisons could be made; this flexibility also allowed for "what if economic analyses.

Severe drought occurred in both locations in 1988 and 1989, but in 1990, rainfall during the growing season was 16 percent above normal at McNay *and 41 percent above normal at AAERC.*

Data collection methods varied by the cropping system type. Perennials were harvested by a flail-type, small-plot harvester. Row crops were harvested by a one-row forage chopper, and corn grain was hand harvested; stand counts were recorded after ear harvest and prior to stalk and leaf harvest in order to calculate population. Soybeans were harvested by combine.

The main energy components of biomass are the cell walls made of cellulose, hemicellulose, and lignin along with the protein and soluble sugars of the cell. Sweet sorghum, like sugar cane, accumulates large amounts of soluble sugars, which, when fermented with yeast, usually are equivalent to 550 gallons (gal.) of ethanol per acre. In addition, 893 lb/acre of the celluloses after hydrolysis and fermentation yields 70 gal. of ethanol per acre.

For example, the cellulosesfrom monocropped sweet sorghum were near 8,034 lb/acre when well fertilized; this equates to 630 gal. ethanol. The double-croppedsystemyielded the equivalent of 770 gal. ethanol.

Findings

The greatest biomass yield—11.9 tons (T) per acre—was produced by sweet sorghum double-cropped with winter rye at McNay in 1990. Yields in excess of 8.92 T/acre were produced in 1990 by sweet sorghum alone at both AAERC and McNay, the sudangrass hybrid at McNay, and double-cropped sorghum (both sweet and the hybrid) with winter rye again at both locations. By comparison, highest yields of the perennial crops were 5.6 T/acre for alfalfa at AAERC in 1989,5.26 T/acre for reed canarygrass at McNay in 1990, 5.3 T/acre for big bluestem at AAERC in 1990, and 5.93 T/acre for switchgrass at AAERC in 1990.

Alfalfa and sorghum were least sensitive to drought; double-crop system yields were more sensitive in general to drought than sole cropping system yields. Systems with annual species produced more biomass than did those with perennial species. These researchers found too that *annual species were much more productive than the perennial ones.*

Double-cropped sorghum required more N for maximum yields than sorghum grown alone. Only when high amounts of N were applied and rainfall was normal to above normal during critical parts of the growing season did double-cropped systems out-yield the sole sorghum system. Researchers observed that sweet sorghum—in addition to producing high yields of cellulose (the inert, complex carbohydrate that makes up the bulk of a plant's cell walls)—offers great potential for ethanol production because of its high levels of soluble carbohydrates.

Alfalfa, reed canarygrass, switchgrass, and big bluestem provided biomass yields slightly over half that of the sorghums. The perennial grasses store carbohydrates in their roots and also produce mature seed heads.

Intercropping sorghum into alfalfa raised yields over alfalfa grown alone. Moreover, this system required little or no N and provided constant ground cover; in addition, growth of the sorghum did not reduce winter survival of the alfalfa. However, the researchers discovered that intercropping sorghum into reed canarygrass showed no yield advantage over reed canarygrass grown alone; they suspect some type of phytotoxicity, or poisoning interaction, between the reed canarygrass and the growth of the sorghums.

Implications

The results of three years of study at two very different sites, and widely varying weather patterns ranging from severe drought and heat to above-normal rainfall, allowed researchers to test how the 13 cropping systems studied respond to a wide range of weather and soil environments. They were thus able to develop a data base broader than that originally envisioned.

Sole cropping of sorghums is a poor practice because when the crop is harvested in mid-September, the soil is extremely vulnerable to erosion until mid July of the following year. Thus, double-cropping of sorghums with rye appears to be an environmentally acceptable way to produce sorghum, with the potential for higher biomass yields than if sorghum were solely cropped. *Planting winter rye in late September after sorghum harvest provides adequate ground cover during the fall and helps to hold winter snowfall.*

In spring, the rye forms a very early sod; after its harvest, residue and stubble continue to protect the soil until the sorghum gets established. Although fall-seeded rye depletes available soil N and fertilizer N and thus has a negative effect on sorghum yields during dry spring conditions, it could be harvested early to decrease this impact—if there is low moisture carry-over from fall rains—without much risk of soil loss.

Nationally, switchgrass has been emphasized as an environmentally sound biomass crop choice because it produces relatively high yields of fermentable fiber for ethanol production, and, as a perennial, it protects the soil. Even so, drawbacks include its relatively high demand for N fertilizer and potential establishment difficulties.

Maximizing the potential for growing biomass crops is important because Iowa currently imports 98 percent of its energy and because Iowa farmers are seeking to diversify their farming systems. Cash crops other than those used for feed offer unique economic benefits; biomass holds promise for giving Iowa a "third crop" to replace some corn as well as use land now idled.

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Sweet sorghum interplanted in alfalfa.