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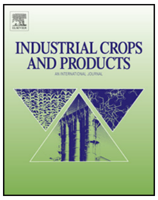

Double- and relay-cropping of energy crops in the northern Great Plains, USA

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ABSTRACT

In a growing developing world, innovative cropping systems are necessary to obtain continuous and sustainable supplies of food, feed, fuel, and bio-based products. Double- and relay-cropping systems are an option to produce biofuels, food, and biomass feedstock in a single season on the same land without sacrificing food security. Field studies were conducted between 2011 and 2013 in Prosper and Carrington, ND, and Morris, MN. Eleven crop sequences composed of double- and relay-cropping of forage sorghum (*Sorghum bicolor* L.), soybean (*Glycine max* (L.) Merr.), and maize (*Zea mays* L.), following winter camelina (*Camelina sativa* L.) were evaluated and compared with soybean, maize, and sorghum monocultures. Forage sorghum and camelina were used as theoretical feedstocks for energy production from biomass and oil, respectively. Camelina seed yield was 1415 and 940 kg ha^{-1} in Prosper and Carrington, respectively, when averaged across years. In Morris, camelina seed yield averaged 278, and 1745 kg ha^{-1} in 2012 and 2013, respectively. In the relay-cropping systems, the highest biomass yield (16.2 Mg ha^{-1}) was achieved with forage sorghum inter-seeded into standing camelina. As expected, all sorghum, soybean, and maize monocultures had higher biomass yield than the same crops in double- or relay-cropping with camelina. Energy efficiency was evaluated for double- and relay-cropping systems based on energy inputs and outputs. The forage sorghum seeded at a normal seeding date (NSD) and at the same time that it was seeded into the double-crop treatments (DSD) on fallow ground, and soybean seeded at a NSD had energy efficiencies of 17.8, 18.7, and 21.6, respectively, in Carrington. In Morris, forage sorghum and maize seeded at NSD had energy efficiencies of 42.6 and 34.7, respectively. Of the double- and relay-cropping systems, the camelina-forage sorghum relay treatment produced the highest energy efficiency at all three locations in both years. Forage sorghum seeded at NSD was the most energy efficient monocrop at all three locations. Both forage sorghum in monocrop and the camelina-sorghum relay treatment showed good potential for biofuel and energy feedstock production in the northern Great Plains.

1. Introduction

Most cropping systems in the northern Great Plains are valued in terms of grain yield and short-term (2–3 years) profitability. However, several recent studies of U.S. cropping systems suggest that cropping systems that focus primarily on grain yield and profit, may be neglecting other ecosystem services (Syswerda and Robertson, 2014; Schipanski et al., 2014; Werling et al., 2014).

Schipanski et al. (2014) demonstrated that increasing diversity by using cover crops in a 3-year soybean–wheat (*Triticum aestivum* L.)-maize cropping system could increase eight out of eleven ecosystem services without decreasing productivity. Another study, comparing the ecosystem services along a gradient of management intensity in grain row crops, observed large differences in the ecosystem services provided even while achieving similar net productivity (Syswerda and Robertson, 2014).

Double-cropping is defined as growing two crops in succession, in the same field, in the same season where the second crop is planted after the first crop is harvested (Hexen and Boxley, 1986) Relay-cropping is defined as a method of multiple cropping, where a crop is planted into an already established crop whereby the life

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cycles of the two crops overlap each other (Kline et al., 2003). This system allows the production of a second crop in the same field in areas where the growing season is short (Beuerlein, 2001). Both cropping systems are an example of temporal diversification usually intended to increase the land use efficiency and yield per unit of cropping area, while enhancing ecosystem services (Heaton et al., 2013). Double-cropping can be easily established in mild-climates to include two food crops or alternating food and bioenergy crops.

Double-cropping began in the United States in the mid-1940s and became more popular in the 1970s. Relatively long growing seasons and available precipitation favored development of double-cropping systems in the US southern and coastal states. Double-cropping systems are a way to increase annual dry matter production per season, protect the environment (Goff et al., 2010), return more organic residues to the soil than a single crop, improve soil structure (Murdock et al., 1997) and at the same time offer many other ecosystems services, such as enhance pollinator abundance, alter herbivory efficiency, and increase arthropod biodiversity (Nordlund et al., 1984; Loranger et al., 2013; McArt and Thaler, 2013).

The most common double-crop sequence in the southern US is a winter-cereal followed by soybean (Crabtree et al., 1990; Kyei-Boahen and Zhang, 2006), although other warm-season crops have been grown successfully. Several studies on double-cropping have been conducted previously in the Midwest. Heggenstaller et al. (2008, 2009),) reported an increase of 25% on total dry matter production for double-cropped triticale (*Triticosecale* x)-maize and triticale-sorghum-sudangrass (*Sorghum bicolor* var. *sudanense* L.) as compared with mono-cropped maize. Goff et al. (2010) compared biomass productivity for twelve sorghum varieties within a double-cropping or mono-cropping system and found no significant difference in productivity between the two systems. There is a need to identify alternative crops adequate for double-cropping that can fit into existing and common cropping systems with little or no added equipment cost, and with minimal changes in management, especially in the northern Great Plains (Pullins et al., 1995).

In northern areas in the USA and Europe where the season is much shorter, double-cropping is limited because there is not enough time for two crops to reach harvest maturity in the same season since the second crop is not planted until after the first crop is harvested. Thus, relay-cropping systems have a interesting niche in these areas. There are two main requirements for establishing a profitable multiple cropping sequence: i) adequate time is available for production of a second crop and ii) sufficient water is available to produce two crops, whether from stored soil moisture, precipitation, or irrigation. Winter camelina, an industrial oilseed, has been identified as an excellent crop for relay-cropping in the North Central U.S. (Gesch et al., 2014). Winter camelina is very winter hardy and matures early in the summer allowing the second crop (e.g., a food, feed, or energy crop) to thrive and produce good yields (Gesch and Archer 2013; Gesch et al., 2014). Also, it has been demonstrated that camelina can grown profitability both as a commodity and a biofuel feedstock (Keske et al., 2013).

With respect to energy production, one of the best ways to compare relay-and double-cropping systems with monocultures is by comparing the energy balance of each system. This method enables the cropping systems to be compared on the same unit basis. The energy balances for maize grain for ethanol, soybean for biodiesel, and other dedicated energy crops such as switchgrass (*Panicum virgatum* L.) (Schmer et al., 2008; Pimentel and Patzek, 2005), miscanthus (*Miscanthus x giganteus*) (Molenaar et al., 1996), and sorghum (Monti and Venturi, 2003) in monoculture are abundant in the literature; however, the energy balance of double- and relay- cropping systems is very limited. The only energy balance reference in double-cropping systems is from Tomasoni et al. (2011) which refers to crop sequences that included a winter cereal followed by maize in comparison with maize monoculture. In this study, the energy balance was superior for the double-cropping systems when compared with a maize monoculture.

The objective of this study was to determine the overall agronomic performance and energy balance of forage sorghum, maize, soybean, and winter camelina when using double- or relay- cropping systems for oil and biomass production in the North Central Region of the U.S.

2. Materials and methods

2.1. Experimental sites

Field experiments were located at two North Dakota State University (NDSU) research sites at Prosper (46°58′N, 97°3′W, elevation 280 m) and Carrington (47°30′N, 99°8′W, elevation 489 m), ND, and one location in Morris, MN. The soil type at Prosper is a Kindred–Bearden silty clay loam (Perella: fine-silty, mixed, superactive Typic Endoaquoll; Bearden: fine-silty, mixed, superactive, frigid Aeric Calciaquoll). The type soil in Carrington is Heimdahl loam (coarse-loamy, mixed, superactive, Frigid Calcic, Hapludolls). The Minnesota location was at the Swan Lake Research Farm located near Morris, MN (elevation 344 m; 45° 35′N, 95° 54′W) on a Barnes loam soil (fine-loamy, mixed, superactive, frigid Calcic Hapludoll). The previous crop in all three locations was either oat (*Avena sativa* L.) or spring wheat (*Triticum aestivum* L.) and the experiment was planted no-till into the previous year's crop residue.

2.2. Experimental design and management

The 11 cropping sequences evaluated are described in Table 1. In this study, double-cropping is defined as the seeding of a second crop (soybean or forage sorghum) after the winter annual crop (camelina) has been harvested. Relay-cropping is defined as the seeding of the second crop (forage sorghum or soybean) into the growing winter camelina stand before the stem elongation reached 15-cm in height or the growth stage 302, stem 20% of final length, according to the pehnological growth stage for camelina proposed by Martinelli and Galasso (2011). Check crops were seeded no-till on wheat or oat residue at normal seeding date (NSD) or at the same time as the double seeding date (DSD) but in plots without camelina (fallow). Fallow plots remained covered with wheat or oat residue until used for seeding the following spring/summer. In Prosper and Carrington maize was seeded at the same time as the maize in relay (RSD). In Morris, a soybean maturity group (MG) 00.1, early-maturing cultivar, was added to the treatments and seeded only as a double crop.

In Prosper and Carrington, the soybean cultivars used were: 1) late soybean cultivar (90 d) 15R07N (MG 0.7 Roundup Ready^{TM}) for the NSD, RSD, and relay-cropping sequences, and 2) early soybean cultivar (75 d) 11R01 (MG 0.1, Roundup Ready^{TM}) for the DSD and double-cropping treatments. The maize hybrid used was 56j86VT3 (90 d maturity, Roundup Ready^{TM}) both years. The forage sorghum was FS-05 in 2012 and the hybrid 'Pampa Verde' in 2013. There was no seed available of FS-05 in 2013. Both cultivars were the top producers in the 2012 cultivar trials conducted in Fargo and Prosper, ND. Both soybean and maize cultivars were glyphosate-tolerant.

In Morris, the soybean cultivars for the NSD and relay seeding were Northrup King NK-S13K2-RR (MG 1.3, Roundup Ready^{TM}), and Croplan R2T0041 (MG00.1, Roundup Ready^{TM}) for the DSD and double-crop treatments. The maize hybrid was Croplan 3114VT3 (92 d maturity, Roundup Ready^{TM}), and the forage sorghum cultivar was FS-05 in both years.