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Inter- and Double-crop Yield Response to Alternative Crop Planting Dates

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Abstract

Planting date is an integral part of a successful double-crop system, and in intercropping it can affect crop yields. Cool-adapted species that can be frost-seeded benefit from an earlier planting date by taking advantage of unused light and space between rows of slow-growing spring or fall crops such as winter wheat. This research evaluated differences between early frost-seeding, mid-season relay-intercropping, and double-cropping planting dates of alternative crops (buckwheat, sunflower, radish, faba bean, and hairy vetch) on wheat and alternative crop yields. Field research took place in 2012 and 2013 near Novelty, Missouri. Wheat yields were affected by cropping system and alternative crop selection with significant differences up to 455 kg ha^{-1}. Alternative crop yields were harder to determine. In 2012, emergence occurred but drought precluded alternative crop yields for the frost-seeded and relay-intercrop systems. However, in 2013, planting date and cropping system affected alternative crops differently, with land equivalent ratio (LER) values showing an advantage for alternative crops when they survived past emergence. In both years, frost-seeding provided yield advantages among almost all alternative crops. This research shows that farmers could increase their yield potential for a given field and perhaps produce additional forage or green manure yields in a year with a less severe drought by using alternative crops.

Keywords: buckwheat; faba bean; double-crop; hairy vetch; inter-crop; wheat; radish; sunflower

1. Introduction

In double-crop production, farmers grow two separate crops at different times in the same growing season. Typically, farmers harvest one species and then plant another. Compared with mono-

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cropping, double-cropping used climatic, land, labor, and equipment resources more efficiently and produced more total grain (Crabtree, Prater, & Mbolda, 1990). Double-cropping increased the amount of time land was used for crop production and has increased profit potential (Pullins, Myers, & Minor, 1997). In Missouri as well as much of the Midwest and Southern United States, the most popular double-cropping system is winter wheat (*Triticum aestivum* L.) followed by soybean [*Glycine max* (L.) Merr].

Planting date is integral to a successful double-crop system because crop maturity date can greatly affect productivity (Sanford, Myhre, & Merwine, 1973). One approach is to use crops with alternative growth periods, such as winter wheat followed by a short season crop, such as soybean. This has worked well, since wheat was harvested during the summer and which allowed sufficient time for soybean to mature before a killing frost (Sanford *et al.*, 1973; Kyei-Boahen & Zhang, 2006). Using early maturing crops allowed for earlier planting of the overwintering crop (Kyei-Boahen & Zhang, 2006). Sanford *et al.* (1973) observed that no tillage, double-crop systems provided the least delay in establishing a second crop. The input costs of such systems, either with grain sorghum or soybean, were \$11 ha^{-1} less than conventional tillage. After 1 December, the rate of decline in yield with delayed sowing was about 1.3% per day for sole-crops and 0.5% per day for double-crops, emphasizing the importance of early establishment of the second crop (Caviglia, Sadras, & Andrade, 2011). Planting later can not only decrease competition for resources among plants but also make them more complementary. Planting date is an important consideration for water and light availability as well as for favorable temperatures for plant development (Midmore, 1993). Caviglia, Sadras, and Andrade (2004) reported that double-cropped wheat and soybeans used between 54-70% of the annual rainfall; however, only 40% of the incident photosynthetically active radiation (PAR). It was important in double-cropping to match the timing of crop cycles and rainfall cycles. Although soil can hold water and so offset the difference between water availability and demand, canopy size and structure at a given time determined the availability of PAR. Plant-available water affected winter wheat grain production when researching the effects of tillage and nitrogen rates on wheat production (Halvorson, Black, Krupinsky, & Merrill, 1999). No-till and minimal tillage yielded greater than conventional tillage, with grain yields of 2022 kg ha^{-1}, 1968 kg ha^{-1} and 1801 kg ha^{-1}, respectively (Halvorson *et al.*, 1999).

In intercrop production, farmers grow two crops in the same field. The crops may be sown and harvested at different times, though their life cycles overlap. Generally, there is an initial main crop and one or more additional crops sown later. The main crop is of primary importance for economic or food production reasons (Lithourgidis, Dordas, Damalas, & Vlachostergios, 2011a). Intercropping remains a common practice in developing areas, with small farms finding 20 to 60% greater productivity in harvestable products per unit area compared to mono-cropping (Lithourgidis *et al.*, 2011a). This was largely attributed to more efficient resource use, which is the primary benefit of intercropping.

Intercrop systems can be planted simultaneously or staggered to take advantage of cool- and warm-season species. Staggering planting dates modified the relative periods of complementarity and competition, and influenced the component crop's yield potential (Midmore, 1993). In general, the crop planted first had a competitive advantage over the intercrop because of its previous access to limiting factors. The several types of intercrop systems vary in their spatial and temporal arrangements. Systems include mixed intercropping, alternate-row intercropping, within-row intercropping, strip intercropping, and relay-intercropping (Lithourgidis *et al.*, 2011a). Planting time of an intercrop can greatly affect crop yields. Thus, farmers can manage the competition for resources through careful planning of planting times of the second crop (Midmore, 1993). Traditionally, planting of cereal-grain intercrops into wheat was performed using broadcast over-seeding or through inter-row planting with machinery.

Frost-seeding is the practice of broadcasting a small-seeded legume into an established stand of winter wheat during late winter to establish a cover crop understory in the wheat crop at no expense to the wheat (Hesterman, Griffin, Williams, Harris, & Christenson, 1992; Mutch, Martin, & Kosola, 2003). Frost seeding was a common and cost-effective method of broadcasting seed as an intercrop (Singer, Casler, & Kohler, 2006). The practice, also called 'cracked soil surface' seeding, broadcasts seed into cracks in the field caused by freezing (Stute & Shelley, 2008). Frost seeded crops, especially legumes, can provide not only forages for livestock but also nitrogen for the intercrop (Blaser, Singer, & Gibson, 2007). This makes intercropping attractive to growers looking for cost-effective production systems (Mutch *et al.*, 2003). Nitrogen accumulation was 107 to 196 kg N ha^{-1} at three locations in East Lansing, Michigan for frost-seeded red clover (*Trifolium pretense* L.) into winter wheat (Hesterman *et al.*, 1992). As measured by the fertilizer replacement value (FRV), red clover frost-seeded into wheat was valued at over 111 kg N ha^{-1}. The amount of N contribution was affected by the N accumulated by the legume, which was influenced by the length of time between legume seeding date and termination of the cover crop (Hesterman *et al.*, 1992). In Ohio, Ngalla & Eckert (1987) reported a contribution equivalent of 56 to 67 kg N ha^{-1} from frost-seeded red clover into wheat for the subsequent corn (*Zea mays* L.) crop.

Various factors including crop species, growth stage, duration of freezing temperature, soil moisture, type, compaction, and freezing and thawing sequences contributed to a complex pattern that determines a species' frost tolerance (Badaruddin & Meyer, 2001). For instance, winter annual legumes that reached early flowering stages exhibited poor frost resistance (Brandsæter, Smeby, Tronsmo, & Netland, 2000). Hardening is a physiological change of a plant with cold temperature treatment (commonly termed as vernalization). Hardening is a plant's physiological change with cold temperature treatment (commonly termed as vernalization). Hardening increased seedling survival of forage legumes [alfalfa (*Medicago sativa* L.), red clover, sweetclover (Melilotus officinalis Lam.), alsike clover (*Trifolium. hybridium* L.), white clover (*Trifolium repens* L.), sainfoin (Onobrichis viciifolia Scop)], soybean and field pea (*Pisum sativum* L.) by up to 40% when compared to unhardened seedlings, which resulted in 2-40% less survival at -4 to -8^{0}C (Badaruddin & Meyer, 2001).

Cool-adapted species such as winter wheat that can be frost-seeded into in order to take advantage of unused light and space between rows during slow-growth in the spring or fall, making an earlier planting date more beneficial (Midmore, 1993). In Wisconsin, interseeded red clover captured 90 days of sunlight that was unused in a sole-crop rotation (Stute & Shelley, 2008). Seeding clover or other forage legumes after wheat harvest was more risky due to potential for dry conditions and a shorter growing season, which made interseeding or frost-seeding attractive (Stute & Shelley, 2008). However, delayed planting of warm-season dry beans (*Phaseolus vulgaris* L.) reduced risk of spring frost, a hazard for spring-seeded grains and forage legumes that may occur from early April through the first part of June in the northern Great Plains (Badaruddin & Meyer, 2001). Conversely, the risk of a killing fall frost was increased by delayed planting in environments with short growing seasons (Badaruddin & Meyer, 2001). In Ohio, double-cropped red clover following wheat showed no benefit because of insufficient biomass accumulation (Ngalla & Eckert, 1987). In Ontario, however, relay-cropping red clover into winter wheat provided a longer period for establishing red clover (Gaudin, Janovicek, Martin, & Deen, 2014). Additionally, properly managed interseeded red clover did not reduce wheat yield or interfere with harvest (Stute & Shelley, 2008).

The most common intercropping system was wheat and a legume such as soybean because legumes' nitrogen fixing properties work well with wheat and a subsequent rotational crop (Danso, Zapata, & Hardarson, 1987; Fujita, Ofosu-Budu, & Ogata, 1992; Lithourgidis *et al.*, 2011a; Mariotti, Masoni, Ercoli, & Arduini, 2012; Akhtar *et al.*, 2010; Naudin, Corre-Hellou, Pineau, Crozat, & Jeuffroy, 2010; Pelzer *et al.*, 2012; Tosti & Guiducci, 2010). In the Midwestern U.S., drought-tolerant crops such as sunflower could be harvested for grain to create additional income for existing local markets. Sunflowers may also reduce weeds in these cropping systems (Nelson, Bliefert, Smoot, Bryant, & Harder, 2000). Buckwheat, which often has been grown as a soil cover and green manure, produced modest amounts of biomass (Myers & Meinke, 1994). Phosphorus was more available with buckwheat to component crops (Myers & Meinke, 1994). Rapid growth of buckwheat may allow it to be planted as a double-crop and reduce risk associated with early frost and add economic value (Nelson *et al*., 2000). Buckwheat's rapid growth may allow it to be planted as a double-crop and so reduce early-frost risk and add economic value (Nelson *et al*., 2000). Results of a winter annual legume experiment showed that hairy vetch cultivars, especially cv. 'Hungvillosa', exhibited the best frost resistance compared to yellow sweet clover [Melilotus officinalis (L.) Pall.] (Brandsæter *et al.*, 2000). At the lowest evaluated temperature (-9^{0}C), hairy vetch had the greatest relative biomass (75% of the control at 0^{0}C) (Brandsæter *et al.*, 2000). Finally, forage radish boasts myriad benefits from improved soil aeration, weed suppression, nutrient capture, and possible yield increases to the rotational grain crops (Sojka, Karlen, & Busscher, 1991; Constantin *et al.*, 2010; Lawley, Weil, & Teasdale, 2011; Sapkota, Askegaard, Lægdsmand, & Olesen, 2012). Limited research has evaluated interseeding of these various alternative crops for cover and grain production in wheat cropping systems in the Midwestern U.S. This study's objective was to evaluate the production differences between early broadcast frost-seeding, mid-season relay-intercropping, and late double-cropping planting dates of alternative crops (buckwheat, sunflower, radish, faba bean, and hairy vetch) on wheat yields as well as alternative crop yields.

2. Method

2.1. Site Description and Experimental Design

A field trial was initiated in the autumn of 2011 and repeated in the autumn of 2012 at the University of Missouri Greenley Memorial Research Center near Novelty (40°1'17" N 92°11'24.9" W). The experiments were arranged in a split-plot design with four replications. Plots were 3 by 12 m. The main plot was planting time/cropping system, and sub-plot was the alternative crop species.

2.2. Plant Materials and Crop Agronomy

'MFA2525' wheat was no-till drill seeded at 112 kg ha^{-1} in 19 cm rows using a Great Plains no-till drill (Great Plains Ag., Salina, KS). During the study's first year, the soil type was a Kilwinning silt loam (fine, montmorillonitic, mesic, Vertic Ochraqualfs). Wheat was planted on 3 October 2011 over-wintered, and in 2012 alternative crops were frost-seeded (4 March, tillering), relay-intercropped (4 April, flag-leaf), and double-cropped (16 June). Wheat was harvested (15 June) in the summer of 2012 (Figure 1a). During the study's second year, the soil was a Putnam silt loam (fine, montmorillonitic, mesic Vertic Albaqualfs). Wheat was planted on 11 October 2012 over-wintered, and in 2013 alternative crops were frost-seeded (21 February), relay-intercropped (29 April, tillering), and double-cropped (3 July, flag-leaf). Wheat was harvested on 3 July (Figure 1b).

Diammonium phosphate and potassium chloride were broadcast at 35 kg N ha^{-1}, 89 kg P2O5 ha^{-1}, and 134 kg K2O ha^{-1} to the entire plot area on 3 October 2012. Ammonium nitrate was broadcast applied to all plots at 111 kg N ha^{-1} 27 March 2012 and 22 March 2013 using hand held fertilizer spreaders. On 4 March 2012 and 21 February 2013, buckwheat (*Fagopyrum esculentum* L.) at 62 kg ha^{-1}, 'Tillage radish' (*Raphanus sativus* L.) at 6.7 kg ha^{-1}, sunflower (*Helianthus annuus* L.) at 5.6 kg ha^{-1}, hairy vetch (*Vicia villosa* L.) at 39 kg ha^{-1}, and faba bean (*Vicia faba* L.) at 225 kg ha^{-1} were broadcast seeded into the standing winter wheat. The five alternative crops were drill seeded using a split-row planter (John Deere 7200, Moline, IL) on 4 April 2012 and 29 April 2013 in 38 cm rows into standing wheat. Finally, following wheat harvest, all five alternative crops were drill seeded using a split-row planter (John Deere 7200, Moline, IL) on 16 June 2012 and 3 July 2013. Emergence of the alternative crops and stand counts were evaluated on 17 May 2012 and 5 June 2013. Heights were recorded on 9 July 2013. In 2012, no height data were recorded for the alternative crops, due to no plant growth from the extremely dry conditions. Following the double-crop planting, emergence of the double-cropped alternative crops was recorded on 11 July 2012 and 2013. Double-crop plots were left untouched, with only wheat serving as a control to the broadcasted and intercropped treatments.

The alternative crops were chosen for varied reasons. Faba bean and hairy vetch are legumes that could add nitrogen to the soil (Lithourgidis *et al.*, 2011a). Other crops, including sunflowers, are drought-tolerant and could be harvested for grain to create additional income for existing markets. Wheat was harvested on 15 June 2012 and 3 July 2013 using a 1.5 m head on a Wintersteiger plot combine (Wintersteiger Delta, 4910 Ried, Austria, Dimmelstrasse 9), and yield was adjusted to 130 g kg^{-1} prior to analysis. Alternative crops were hand-weeded three times throughout the growing season following wheat harvest. Alternative crops were hand-harvested from a 0.3 by 0.75 m quadrat on 9 October 2012 and 2013 and dried prior to collecting weights. Yields were separated into grain and total plant dry matter. Land equivalent ratio (LER) values were calculated using wheat and alternative crop data as: LER = mixed yield1/pure yield1 + mixed yield2/pure yield2 (Malézieux *et al.*, 2009). The resulting value indicated the amount of land needed to grow both crops together compared with the amount of land needed to grow a mono-crop of each.

2.3. Data Analysis and Interpretation

Data were subjected to ANOVA (SAS Institute, 2010) and means were separated using Fisher's Protected LSD (P = 0.1). Wheat yields were combined over years in the absence of significant interactions, and an analysis evaluated cropping systems within alternative crops. For alternative crops, yields were presented separately for each year due to a significant interaction between years; especially when 2012 yields were significantly impacted by drought (United States Drought Monitor, 2015) and data were compared for different planting dates.

3. Results

3.1. Environmental Conditions

In 2012, annual precipitation was 267 mm below average compared to the last 10 years (Figure 1a). During the wheat growing season in 2011-2012, total rainfall was 252 mm; however, from May through August there was only 215 mm of rainfall. On the last day of August 2012, 60 mm of precipitation occurred from the storms following Hurricane Isaac, which helped with grain fill of plants that had survived the summer. In 2013, total precipitation was 1003 mm, with only 140 mm of precipitation from June through July and none in August (Figure 1b). Although total precipitation in 2013 was similar to the 10-year average (984 mm), the lack of rain in August produced a 'flash drought' during grain fill that diminished yield of most summer annuals.

During the summer of 2012, temperatures were abnormally high. The average temperature was 23.7°C from May through August, with an average high temperature of 30.7°C (data not presented). In contrast, 2013 was relatively cool, with an average summer temperature of 21.2°C and an average high temperature of 27.3°C (data not presented). Due to below average rainfall and high average temperatures, the results of this research during 2012-2013 were representative of severe drought conditions that can occur in this region and extreme drought conditions for 2011-2012 (United States Drought Monitor, 2015).

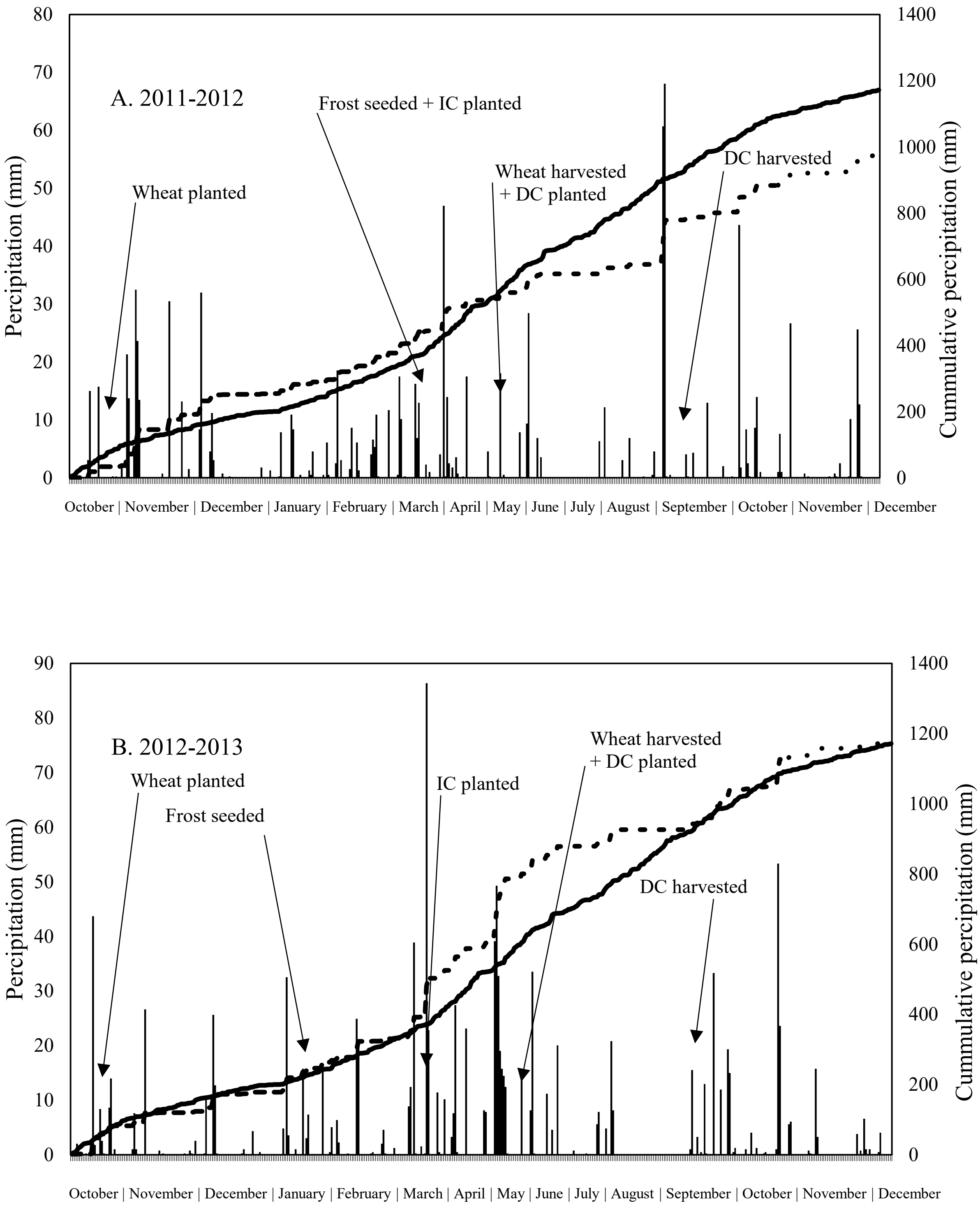

Figure 1. Daily (bar) and cumulative precipitation data for individual years (dash line) and 10-year average (solid line) for experiment form 2011-2012 (**A**) and 2012-2013 (**B**). Double-crop (DC), relay-intercrop (IC) planting and harvest dates for wheat and alternative crops are labeled with arrows.

3.2. Wheat Yields

Wheat yields were 105 kg ha^{-1} below to 730 kg ha^{-1} above average wheat yields for Missouri (USDA National Agriculture Statistics Service [NASS], 2010). Wheat with relay-intercropped alternative crops yielded 480 to 570 kg ha^{-1} less than wheat where the alternative crop was double-cropped or frost-seeded (Table 1). However, no significant reduction was observed where no crop was interseeded in wheat (4010 kg ha^{-1}), indicating that intecrop interference reduced yields. For buckwheat, sunflower, radish and hairy vetch, both double-crop planting and frost-seeding produced greater yields than relay-intercropping by 430-640 kg ha^{-1}, 395-445 kg ha^{-1}, 360-475 kg ha^{-1}, 455-730 kg ha^{-1}, respectively (Table 1). Hairy vetch had the greatest yield loss (730 kg ha^{-1}) for double-cropping (no injury or competition) compared to intercropping. Hairy vetch performed well in the region as an intercrop in dry conditions and often had complete ground cover that suppressed weeds such as common waterhemp (Amaranthus rudis Saur.) (visual observation). Because hairy vetch was the most productive crop, it may have provided greater resource competition with wheat in frost-seeding and intercropping, which decreased wheat yields.

Table 1. Wheat yields for frost-seeded (FS), relay-intercropped (IC) and double-cropped (DC) systems in 2012 and 2013 for various alternative crops in upstate Missouri. Date were combined over years.

	Planting date		
Crops	FS	IC	DC
	--------- kg ha^{-1} -------		
Buckwheat	4465	3825	4255
Sunflower	4335	3890	4285
Radish	4255	3895	4370
Faba bean	4385	3630	4090
Hairy Vetch	4100	3645	4375
Wheat	4190	4010	4260
LSD (*P*=0.1)	--------- 290 ---------		

3.3. Alternative Crop Yields

Due to the severe drought in 2012, alternative crops in the frost-seeded and intercrop systems died from plant interference. The intercrops, which emerged (Table 2) before the 15 June wheat harvest, all died. The double-crop planting system produced greater biomass yields, ranging from 10 kg ha^{-1} for faba bean to 2995 kg ha^{-1} for radish (Table 3). Thus, across alternative crops, the double-cropping system yielded significantly greater than the early frost-seeded or intercrop-planted systems.

Table 2. Alternative crop emergence across frost-seeded (FS), relay-intercropped (IC) and double-cropped (DC) systems on 15 June for 2012 and 2013

	2012				2013			
Alternative Crop	FS	IC	DC	LSD (*P*=0.1)	FS	IC	DC	LSD (*P*=0.1)
	------------------------------------ 1000 plants ha^{-1} --------------------------------							
Buckwheat	108	1914	4771	1460	0	404	5391	372
Sunflower	0	0	620	415	0	81	3720	740
Radish	782	1887	782	1570	0	728	2291	325
Faba bean	917	997	0	393	0	674	0	338
Hairy vetch	485	2318	1779	1140	0	2830	2561	1860

Alternative crops generally yielded greater in 2013 than 2012, except double-cropped buckwheat, radish, faba bean, and hairy vetch (Table 3). In 2012, there was no yield for frost-seeded or relay-planted intercrops, but in 2013 total biomass reached up to 515 kg ha^{-1} for hairy vetch in the frost-seeding system and 840 kg ha^{-1} in the relay-intercropped system. Early rainfalls in May and June fostered intercrop growth before drought set in later in the summer (Figure 1). Some alternative crops were unsuccessful in the frost-seeding and relay-intercropping systems (buckwheat and sunflower), but produced some biomass in the double-crop system (Table 3). Radish biomass was 575 to 1005 kg ha^{-1} greater in intercrop and double-crop systems compared with frost-seeding.

Table 3. Dry biomass yields of alternative crops across frost-seeded (FS), relay-intercropped (IC) and double-cropped (DC) systems for both years.

	2012				2013			
Alternative crop	FS	IC	DC	LSD (*P*=0.1)	FS	IC	DC	LSD (*P*=0.1)
				kg ha^{-1}				
Buckwheat	0	0	425	385	0	0	425	115
Sunflower	0	0	1030	590	0	0	2405	550
Radish	0	0	2995	650	195	770	1200	450
Faba bean	0	0	10	9	0	340	0	455
Hairy vetch	0	0	930	275	515	840	680	210

Biomass yields of hairy vetch were greatest in a relay-intercropping system (840 kg ha^{-1}) compared to frost-seeding (515 kg ha^{-1}). This was probably due to better seed-to-soil contact in establishment (visual observation). As a vining plant, hairy vetch worked well in the intercropping system. Wheat plants provided structure for continued growth of hairy vetch which allowed for greater yields. Faba bean also varied from patterns of the other alternative crops. In the relay-intercrop system, faba bean produced 340 kg ha^{-1} but did not produce biomass in the frost-seeded or double-cropped system (Table 3).

Alternative crops produced very little grain yield in the cropping systems that were evaluated during drought conditions (Table 4). In 2012, frost-seeded crops or intercrops died after establishment and so produced no yield. Buckwheat (65 kg ha^{-1}) was the only alternative crop that produced grain yield in the double-crop system. This may have been due to dormant seeds that emerged when conditions were favorable since buckwheat grows quickly in the fall (Myers & Meinke, 1994). Similarly, double-cropping was the only system to produce alternative crop grain yields in 2013 (Table 4). In the double-crop system, the alternative crops did not have to compete with wheat and had greater vegetative growth, which produced grain yields.

Table 4. Grain yields of alternative crops across frost-seeded (FS), relay-intercropped (IC), and double-cropped (DC) systems for 2012 and 2013.

	2012				2013			
Alternative crop	FS	IC	DC	LSD (*P*=0.1)	FS	IC	DC	LSD (*P*=0.1)
				kg ha^{-1}				
Buckwheat	0	0	64.4	45.8	0	0	51.4	27.5
Sunflower	0	0	0	0	0	0	494.6	241.2
Radish	0	0	0	0	0	0	0	0
Faba bean	0	0	0	0	0	0	0	0
Hairy vetch	0	0	0	0	0	0	0	0

3.4. LER Values

A land equivalent ratio (LER) shows the efficiency of intercropping for using the environmental resources compared with mono-cropping by comparing yields from growing two or more species together with yields from growing the same crops as a mono-crop (Malézieux *et al.*, 2009; Lithourgidis *et al.*, 2011b). An LER greater than 1.0 indicated inter-cropped systems were advantageous, whereas an LER less than 1.0 showed a yield disadvantage (Malézieux *et al.*, 2009; Lithourgidis *et al*., 2011b). Drought greatly affected LER values in 2012. All LER values were below 1.0 for the intercrop system across alternative crops, due to no alternative crop production in the relay-intercrop system (Table 5). However in 2013, with alternative crop production, across all alternative crops, with the exception of relay-intercropped buckwheat or faba bean, all LER values were above 1.0.

Table 5. Land equivalent ratios (LER) for frost-seeded (FS) and relay-intercropped (IC) systems of wheat and alternative crops in 2012 and 2013

	2012			2013		
	FS	IC	LSD (*P*=0.1)	FS	IC	LSD (*P*=0.1)
Buckwheat	1.12	0.96	0.21	1.01	0.92	0.05
Sunflower	1.01	0.83	0.26	1.01	1.02	0.08
Radish	0.99	0.88	0.16	1.15	1.53	0.55
Faba bean	1.07	0.92	0.53	N/A[†]	N/A	N/A
Hairy Vetch	0.96	0.82	0.33	1.56	2.19	0.93

[†]N/A= Not available. There were no faba bean yields in 2013 to calculate an LER value.

4. Discussion

4.1. Wheat Yields

Studies show that frost-seeding cover crops into standing wheat normally do not reduce wheat yields. Janke, Hofstetter, Volak, and Radke (1987) observed no effect on wheat yields when hairy vetch was broadcast or drill-seeded into standing wheat. In Michigan, frost-seeding and interseeding alfalfa and red clover had no effect on wheat yields that ranged from 2535 to 4335 kg ha^{-1} (Hesterman *et al.*, 1992). In Southwest Michigan, frost-seeding red clover into winter wheat left wheat yields unaffected and reduced common ragweed (1100-2100 kg ha^{-1}) (Mutch *et al.*, 2003). Thus, the study's findings of wheat yields being higher in the frost seedin system across alternative crop type correlate with the literature. Ngalla & Eckert (1987) reported that frost-seeding reduced wheat yields slightly (4%), which they attributed to physical damage from machinery associated with frost-seeding and not red clover interference. Similar experiences were observed during this research. While although frost-seeding did not reduce wheat yields, relay-intercrop seeding of alternative crops (visual observation) caused mechanical damage to standing wheat (Figure 2), thus potentially leading to reduced wheat yields. Therefore, wider wheat row spacings (Nelson, Massey, & Burdick, 2011) may be needed to reduce damage. However, no significant reduction was observed where no crop was interseeded in wheat (4010 kg ha^{-1}), indicating that intecrop interference reduced yields.

4.2. Alternative Crop Yields

The severe drought during the summer of 2012 probably burdened the intercrop with too much competition for water and light with the standing wheat (Midmore, 1993; Coll, Cerrudo, Rizzalli, Monzon, & Andrade, 2012). The intercrops died after emergence which was probably due to lack of water and extreme heat, which was exacerbated by interference with wheat. Thus greater yields in the double-cropping system may have occurred due to planting crops later, allowing them to receive water at important establishment and maturation points that intercrops planted earlier did not receive. In addition, late-summer temperatures decreased, allowing growth during more favorable conditions (an average temperature of 22.4°C from planting to harvest). Finally, because wheat had been harvested, the alternative crops did not have to compete for water and other resources such as light (Nelson, Meinhardt, & Smoot, 2010).

Figure 2. Damage to wheat from machinery during relay-intercrop planting in 2012

Depending on the type of alternative crop, planting time and environmental factors may have played different roles. In earlier studies, radish growth and production was sensitive to planting date and temperature (Pandey, Singh, Singh, Rai, & Singh, 2009; Alam, Farooque, Nuruzzaman, & Uddin, 2010; Lawley *et al.*, 2011; Ebrahimi, Hassandokht, & Payvast, 2013). The frost-seeding system may have been less successful for radishes due to cooler temperatures and time of season when radish seed was broadcast seeded. However, hairy vetch has been utilized in a frost-seeding system and can withstand colder temperatures (Brandsæter & Netland, 1999). The double-crop planting date, 9 July, may have been late enough in the season that average temperatures were too high for good growth and development. Brandsæter and Netland (1999) found hairy vetch had the greatest biomass production in both fall (287,000 Mg ha^{-1}) and spring (3,118,000 Mg ha^{-1}), greater soil cover (95-100%), and reduced total weed biomass compared to other cover crops.

4.3. Land Equivalent Ratio

Drought greatly affected LER values in 2012. All LER values were below 1.0 for the intercrop system across alternative crops, due to no alternative crop production in the relay-intercrop system.

This was reasonable since the intercrop system failed, and wheat was the marketable product. Interestingly, buckwheat (1.12), sunflower (1.01), and faba bean (1.01) had LER values greater than 1.0 in the frost-seeding system. Although frost-seeded alternative crops emerged, except for sunflower (Table 2), all frost-seeded alternative crops died and did not produce biomass or grain yields. LER values above 1.0 may have occurred due to less establishment of alternative crops in the frost-seeded system when compared relay-intercropping due to less soil-to-seed contact. If emergence of alternative crops was reduced, competition with wheat may have been low enough to allow for strong enough wheat yields to produce LER values at or above 1.0.

In 2013, there was successful alternative crop production in the relay-intercropping system, except for buckwheat and sunflower (Tables 3 and 4). Across all alternative crops, with the exception of relay-intercropped buckwheat or faba bean, all LER values were above 1.0. For the frost-seeded system, all alternative crops had values above 1.0 except faba bean. Hairy vetch had the greatest LER value (2.19). This corresponded with visual observations of high levels of hairy vetch production. By producing positive LER values representing yield advantages of the intercropping system, using intercrops as forages or green manures may benefit farmers' production systems during years with low rainfall and high temperatures.

5. Conclusions

This research was conducted during drought conditions in the summers of 2012 and 2013. Winter wheat yields were not impacted as the majority of its lifecycle was completed during traditionally wetter periods of the year; however, alternative crop yields were poor in 2012. Cropping system and alternative crop selection impacted wheat yields. In 2012, although emergence occurred, there were no alternative crop yields for the frost-seeded and relay-intercrop system due to drought. However, planting date and cropping system affected alternative crops differently in 2013. Relay-intercrop and double-crop system increased yields for radish while relay-intercropping had greater yields for hairy vetch and faba bean. Land equivalent ratio values determining productivity of crop systems showed there was no yield advantage for the relay-intercropping system for any alternative crops in 2012. In 2013, LER values showed an advantage for all alternative crops with the exception of intercropped buckwheat and faba bean. Frost-seeding provided yield advantages in both years with the exception of radish and hairy vetch in 2012 and faba bean in 2013. This signified that farmers in Northeast Missouri could potentially boost their yield potential for a given field and perhaps produce additional forage or green manure yields in a year with a less severe drought by using several alternative crops, but the effectiveness will depend on the cropping system that was employed.

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