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Research Article

Winter Wheat Row Spacing and Alternative Crop Effects on Relay-Intercrop, Double-Crop, and Wheat Yields

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In Missouri as well as much of the Midwest, the most popular double-cropping system was winter wheat (*Triticum aestivum* L.) followed by soybean (*Glycine max* (L.) Merr). These two crops can also be used in an intercrop system, but optimal row spacing was important to increase crop productivity. Research was conducted to evaluate (1) winter wheat inter- and double-crop production systems, using a variety of alternative crops, and (2) the impact of different wheat row spacings on intercrop establishment and yields within the various cropping systems. Field research was conducted during droughts in 2012 and 2013. Spacing of wheat rows impacted wheat yields by 150 kg ha^{-1}, as well as yields of the alternative crops. Narrower row spacings (150 kg ha^{-1}) and the double-crop system (575 kg ha^{-1}) increased yield due to the lack of interference for resources with wheat in 2013. Land equivalent ratio (LER) values determining productivity of intercrop systems of 19 and 38 cm row showed an advantage for alternative crops in 2013, but not 2012. This signified that farmers in Northeast Missouri could potentially boost yield potential for a given field and produce additional forage or green manure yields in a year with less severe drought.

1. Introduction

Double-cropping is a production system that includes the growth of two separate crops at different times in the same growing season. This typically involves harvesting one species followed immediately by planting another. Compared with mono-cropping systems, double-cropping has used climatic, land, labor, and equipment resources more efficiently and produced more total grain in some situations [1]. Double-cropping increased the amount of time land was used for crop production and increased potential profit [2].

In Missouri as well as much of the Midwest and Southern United States, the most popular double-cropping system was winter wheat (*Triticum aestivum* L.) followed by soybean (*Glycine max* (L.) Merr) [3]. Research comparing mono-crop and double-crop wheat systems using a variety of other crops such as soybean and grain sorghum (*Sorghum bicolor* L.) showed double-crop systems increased grain yield and net returns of the overall system [1, 3, 4]. These increases were attributed to greater resource utilization. In humid areas of South America, research found that double-crop systems reached water productivity (0.85 compared to 0.43 g m^{-2} mm^{-1}) and radiation productivity (0.22 g MJ^{-1} to 0.11 g MJ^{-1}) values that were almost two times greater than the sole crop [5]. Resource use was calculated as the product of the proportion of annual resources captured by crops to produce grain yield. Evaluating productivity of water and light, [6] found that double-cropping dramatically increased the productivity of radiation for both dry matter and yield on an annual basis.

Intercropping is the growth of two crops in the same field where the component crops were not necessarily sown at the same time nor harvested at the same time, but were grown simultaneously for a majority of their growing periods. Within an intercropping system, there was normally one main crop as well as one or more added crops often sown later in the season with the main crop being of primary importance for economic or food production reasons [7]. The most common advantage of intercropping was the production of greater yield on a given piece of land by making more efficient use of available resources. This could have been due to different rooting characteristics, canopy structure, height, and nutrient requirements or resource use at different times [7–13]. The point at which complementarity became competition among crops could be manipulated through management practices [9]. Row spacing could be critical in determining success of an intercrop as it impacted the crop's response to limiting factors such as light, soil moisture, and nutrients as well as the availability of resources.

Selecting an optimal row spacing was important to improve crop productivity as plants growing in too wide of a row may not efficiently utilize light, water, and nutrient resources. However, crops grown in too narrow rows may result in severe interrow competition. Row spacing also modified plant architecture, photosynthetic competence of leaves, and dry matter partitioning in several field crops [14]. Successful crop mixtures extended the sharing of available resources over time and space and exploited variation between component crops such as rates of canopy development, final canopy width and height, photosynthetic adaption of canopies to irradiance conditions, and rooting depth [7, 9].

Light interception was important in intercrop systems and was affected by the crop architecture and canopy structure. Generally, cereals were taller and shaded the component leguminous crop, which is why row spacing and plant arrangement influenced the success of the systems [8]. A single crop each year used only a small proportion of potentially available resources and calculations for the southeast Pampas area in Argentina which indicated that sole crops of wheat, corn, or soybean captured only 20–36% of the annual incident photosynthetically active radiation [15].

Optimum row spacing helped optimize tillering and ensured increased wheat yields [14]. Wheat sown under narrow-row spacing (15 cm) produced greater wheat yields due to a significant increase in productive tillers [14]. Narrow-row spacing increased interrow competition while a wider row spacing (30 cm) increased the number of grains per spike and 1000-grain weight, but did not compensate for the drastic decrease in productive tillers which resulted in decreased grain yields [14]. Similarly, Zhou et al. [16] found that wheat yields were highest for 14 cm row spacing with yields ranked 14 > 7 > 24.5 > 49 cm. However, Pandey et al. [17] reported that wheat cultivated in 20 cm rows produced significantly more effective tillers compared to 15 and 25 cm rows.

Plant spacing and row direction can also affect total weed suppression. During early growth stages, interference between crop and weed plants was commonly affected by the quality of reflected light [18]. The reflection of far-red photons by the stem of one plant lowered the red to far-red photon ratio of light experienced by the stems of neighboring plants [19]. This modified the light environment in the plant stem tissue, which resulted in increased stem elongation. As plants aged, the crop canopy closed and mutual shading further increased the competition for photosynthetic light [19]. The best results were obtained in an east-west row orientation with 20 cm rows and two hand-weedings. For that management regime, there was a 44% increase in crop growth and 21% increase in crop yield compared to a control [18]. Weed biomass was lower ($93\,g\,m^{-2}$) in narrow row spacing (18 cm) compared to wide row (36 cm) weed biomass ($107\,g\,m^{-2}$) [19]. In a wheat frost-seeded legume intercrop system, red clover (*Trifolium pretense* L.) and alfalfa (*Medicago sativa* L.) were frost-seeded into winter wheat and triticale, and the legume intercrop did not affect grain yield, but did reduce weed density and dry matter up to 40 days after harvest [20]. Champion et al. [21] reported that manipulation of the crop for weed suppression by reducing row width was less successful than increasing plant density in wheat only fields. The authors reported that narrow rows did not enhance shading and suppression of weed biomass; however, the research included wheat only and no intercrops.

Wheat rows in relay-intercropping, the system of intercropping where the intercrop is sowed at a later date than the main crop, are often wider than conventionally planted wheat in order to allow light for the subsequent intercrop. When intercropping clover into wheat, Thorsted et al. [22] found that interspecific competition during vegetative growth was reduced by increasing width of the rototilled strips from 7 to 14 cm, which resulted in greater grain yields and increased grain N uptake. However, when using wider rows without an intercrop, wider rows did not necessarily benefit yields. Over two years, four different wheat planting patterns were employed including conventional seeding [23]. There were no significant differences among treatments for total above ground dry matter, number of grains per area, grain weight, or grain yield. These findings indicated that there were no negative effects of wide-row planting on wheat yields [23]. However, other research showed that row spacing affected yields; narrow rows yielded more grain compared to wide rows. This suggested that closeness of planting enabled more efficient utilization of resources [21, 24].

The most common intercropping system is wheat and a legume such as soybean or red clover, as the nitrogen fixing properties of legumes work well with wheat and a subsequent rotational crop [7, 8, 25]. Research in Wisconsin demonstrated that red clover ($4200\,kg\,ha^{-1}$ aboveground biomass) was the most productive and reliable legume choice as a green manure crop when it was interseeded into winter wheat in early spring compared to hairy vetch ($3385\,kg\,ha^{-1}$) and crimson clover ($2050\,kg\,ha^{-1}$) [26]. In Michigan, red clover produced significantly more above and belowground biomass ($0.97–2.14\,kg\,ha^{-1}$) than fallow. Corn N biomass ($109.1–148.1\,kg\,ha^{-1}$) and grain yield ($5800–7200\,kg\,ha^{-1}$) were increased by including red clover when compared to fallow [26]. Nitrogen credit from red clover ($30–48\,kg\,N\,ha^{-1}$) was similar across management type with the first year of introduction to the conventional system providing an apparent $55\,kg\,N\,ha^{-1}$ [27]. Relay-cropping increased the average return to N investments across the N fertility gradient when estimating N and forage values of red clover biomass ($265–1380\,kg\,ha^{-1}$) compared to wheat [28].

Nitrogen application at maximum economic rate (MERN) for wheat decreased economic benefits as well as possible system benefits of red clover. Red clover contribution to the total intercrop yield decreased with N applications greater than $40\,kg\,N\,ha^{-1}$; thus the authors argue that reduction of N rates can maximize economic returns for both wheat and red clover and increase profits for both species [28]. 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.). At the lowest temperature (−9°C), hairy vetch *Hungvillosa* had the largest relative biomass (75% of the control of 0°C) [29].

The objectives of this research were to evaluate (1) winter wheat inter- and double-crop production systems, using a variety of alternative crops, and (2) the impact of different wheat row spacings on intercrop establishment and yields within the various cropping systems. Wheat yields, both biomass and grain yields of alternative crops, and light interception data were taken to establish the results for this research. Working in various cropping systems that could potentially maximize resource efficiency would provide farmers in Northeast Missouri opportunities for increased incomes and maximum use of their inputs. This research seeks to provide information on alternative agriculture practices useful to the farmers in the area.

2. Materials and Methods

A field trial was initiated in the fall of 2011 and continued through 2013 at the University of Missouri Greenley Research Center near Novelty, Missouri (40°1′17″ N 92°11′24.9″ W). Soft red winter wheat, "MFA 2525," was planted in a split-plot design. The main plot was row spacing and cropping system, and subplot was alternative crop species. Four replications were planted in plots that were 3 by 9 m. On 3 October, 2011, 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). In plots that would contain wheat in 38 cm rows but had been planted in 19 cm rows, every other row was sprayed out using a hand held sprayer containing glyphosate at 1.06 kg a.i. ha^{-1} and nonionic surfactants at 0.25% vol./vol. The soil was a Kilwinning silt loam (fine, montmorillonitic, mesic Vertic Ochraqualfs). Wheat planted in October 2011 over-wintered and then was relay-intercropped (4 April) and double-cropped (16 June) in the spring of 2012 and harvested (15 June) in the summer of 2012. The second year of wheat was no-till drill seeded at 112 kg ha^{-1} in 19 cm and 38 cm rows using a Great Plains no-till drill (Great Plains Ag., Salina, KS) on 11 October, 2012. The soil was a Putnam silt loam (fine, montmorillonitic, mesic Vertic Albaqualfs). Wheat over-wintered and was relay-intercropped (29 April) and double-cropped (3 July) in the spring of 2013 and harvested on 3 July, 2013.

Diammonium phosphate and potassium chloride were broadcast at 35 kg N ha^{-1}, 89 kg P_2O_5 ha^{-1}, and 134 kg K_2O ha^{-1} on 3 October, 2012. Ammonium nitrate was broadcast spread on all plots at an amount of 111 kg N ha^{-1} on 27 March, 2012, and 22 March, 2013, using a hand held fertilizer spreader. On 4 April, 2012, and 2 February, 2013, cowpea (*Vigna unguiculata* L.) at 56 kg ha^{-1}, soybean at 440,000 seeds ha^{-1}, pea (*Pisum sativum* L.) at 34 kg ha^{-1}, hairy vetch (*Vicia villosa* L.) at 39 kg ha^{-1}, red clover (*Trifolium pretense* L.) at 11 kg ha^{-1}, grain amaranth (*Amaranthus hypochondriacus* L.) at 11 kg ha^{-1}, grain sorghum (*Sorghum vulgare* L.) at 11 kg ha^{-1}, and pearl millet (*Pennisetum glaucum* L.) at 17 kg ha^{-1} were broadcast seeded into the standing winter wheat. The alternative crops were chosen for a variety of reasons. Pea, cowpea, hairy vetch, and red clover are legume species and could add nitrogen to the soil [7]. Other crops including grain sorghum and grain amaranth have drought tolerance and could be harvested for grain to create additional income as there are potential markets for these crops in Missouri [30].

On 4 April, 2012, and 29 April, 2013, the same eight alternative crops were no-till seeded in 38 cm rows using a split-row planter (John Deere 7200, Moline, IL) into standing wheat with 19 and 38 cm rows. Finally, following wheat harvest all subplot crops were no-till, double-crop 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. There was no height data recorded in 2012 for alternative crops due to the lack of plant growth from dry conditions. Following the double-crop planting, emergence of the double-cropped alternative crops was recorded on 11 July, 2012, and 11 July, 2013.

Leaf area index (LAI) and light interception (LI) were recorded on 12 June, 2012, and 29 May, 2013, at wheat flag leaf. Data were recorded using a SunScan canopy analysis system (Delta-T, Burwell, Cambridge, UK). Light interception was calculated by measuring both incident and transmitted light through the canopy simultaneously. Intercepted light is the amount of the incident that was not transmitted. 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 yields were determined per plot. Alternative crops were hand weeded three times throughout the growing season following the harvest of the wheat. Alternative crops were hand harvested from a 0.3 by 0.75 m quadrat on 9 October 2012 and 2013. Yields were separated into grain and total plant dry matter. Land equivalent ratio (LER) values were calculated using wheat and alternative crop biomass data and the calculation LER = mixed $yield^1$/pure $yield^1$ + mixed $yield^2$/pure $yield^2$ [31]. 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 crop.

Data were subjected to ANOVA [32] and means separated using Fisher's Protected LSD ($P = 0.1$). LAI and LI data were analyzed comparing 19 and 38 cm row spacing. Wheat yields were combined over site-year in the absence of significant interactions, adjusted to 130 g kg^{-1} grain moisture prior to analysis, and evaluated across row spacing within alternative crops. Emergence, grain, and biomass yields of alternative crops were presented separately across row spacing and site years. LER values were presented separately for years due to an interaction and were evaluated for each alternative crop. Years were presented separately due to significant difference between years especially when yields were significantly impacted by drought in 2012 and compared among cropping systems.

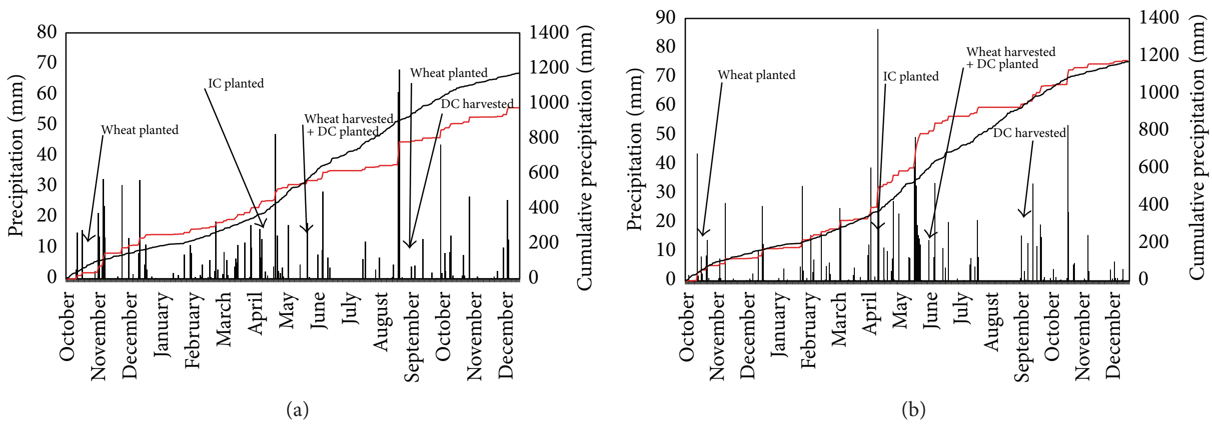

Figure 1: Daily (bar) and cumulative precipitation data for individual years (red line) and 10-year average (black line) for experiment from 2011 to 2012 (a) and 2012 to 2013 (b). Double-crop (DC), relay-intercrop (IC) planting, and harvest dates for wheat and alternative crops were labeled with arrows.

3. Results and Discussion

3.1. Environmental Conditions. Annual precipitation for 2011-2012 was below average and was average for 2012-2013 compared to precipitation data from the last 10 years (Figure 1). During the wheat growing season in 2011-2012 from planting in October through winter total rainfall was 252 mm (Figure 1(a)). Total precipitation for 2012 was 722 mm; however, there was only 215 mm of rainfall from May through August, 60 mm of which occurred on the last day of August. Total precipitation in 2012 was 262 mm below the 10-year average for the alternative crops (Figure 1(a)). In 2013, total precipitation was 1003 mm and again from June through August there was only 140 mm of rainfall with no rain in August for the alternative crops (Figure 1(b)).

During the summer of 2012, temperatures were abnormally high with an average temperature of 23.7°C from May through August and 30.7°C was the average high temperature (data not presented). In comparison, 2013 was a relatively cool summer with an average temperature through the summer of 21.2°C and an average high temperature of 27.3°C. Due to below average rainfall as well high average temperatures in 2012, research completed in the growing years of 2011-2012 and 2012-2013 was conducted under dry summer conditions and extreme drought conditions for 2011-2012.

3.2. Light Interception. Light interception was 3% greater in 19 cm wide wheat rows than 38 cm rows in 2011-2012 and similar in 2012-2013 (Table 1). With narrower row spacing, there were probably more wheat plants in the field allowing for greater interception of light. For the 2011-2012 growing season, 19 cm wide rows also had a greater leaf area index compared with 38 cm rows. Leaf area index was not different in 2013.

Research has shown that light interception was important in intercrop systems and was affected by the crop architecture and canopy structure [8, 15, 19]. Similarly, Borger et al. [19] found that light interception by crops increased in narrow row spacing by 63% to 70% compared to wide rows, while Champion et al. [21] reported that light interception measurements taken throughout the growth cycle at 10 cm above ground level varied for different row spacings.

Table 1: Light interception (LI) and leaf area index (LAI) of wheat planted in 19 and 38 cm wide rows.

Wheat row spacing	2012		2013	
	LI	LAI	LI	LAI
	%			
19 cm row	77	2.7	89	3.6
38 cm row	74	2.4	85	4.0
LSD ($P = 0.1$)	2	0.2	NS	NS

Table 2: Wheat yield response averaged across years to relay-intercrops planted into 19 and 38 cm row spacings and following 19 cm wheat with no mechanical damage that was subsequently double-crop seeded in 2012 and 2013.

Crop	Cropping system		
	Relay-intercrop		Double-crop
	19 cm	38 cm	19 cm
	kg ha^{-1}		
Cowpea	4425	3775	4715
Pearl millet	4120	4070	4665
Sorghum	4340	4195	4625
Amaranth	4105	4035	4375
Soybean	4105	3925	4640
Red clover	4055	4105	4660
Hairy vetch	3935	3960	4675
Pea	4150	3835	4725
LSD ($P = 0.1$)		435	

3.3. Wheat Yields. There were no year interactions for wheat yields across both years (2011-2012 and 2013-2013), but the main effect of row spacing affected yield ($P = 0.06$) (Table 2). Wheat yields were 100 kg ha^{-1} to 980 kg ha^{-1} above average wheat yields for Missouri [33]. Wheat yields were 4375 to

Table 3: Alternative crop emergence in intercrop and double-crop systems on 17 May, 2012, and 5 June, 2013.

Crop	2012					2013				
	Relay-intercrop			Double-crop		Relay-intercrop			Double-crop	
	19 cm	38 cm	No wheat	19 cm	LSD ($P = 0.1$)	19 cm	38 cm	No wheat	19 cm	LSD ($P = 0.1$)
	1000 plants ha^{-1}									
Cowpea	0	0	0	1429	299	267	0	0	1725	67
Pearl millet	27	0	0	1456	459	0	0	0	458	88
Sorghum	0	0	0	3181	1080	81	54	647	1051	333
Amaranth	0	0	0	9167	406	0	0	0	512	358
Soybean	81	108	1132	1833	297	1402	1510	2076	1375	524
Red clover	566	1456	27	593	1190	3396	4259	9111	4178	2290
Hairy vetch	350	997	1402	2156	604	3909	4259	10432	2615	1670
Pea	674	593	1563	917	242	122	1267	1856	943	490

4725 kg ha^{-1} in 2012 and 2013 for the double-crop system planted in 19 cm rows and were greater when compared with relay-intercropping at either row spacing for pearl millet, soybean, red clover, hairy vetch, and pea. Wheat yields for double-cropped soybeans were 535 kg ha^{-1} greater than wheat that was relay-intercropped in 19 cm rows and 715 kg ha^{-1} greater than wheat that was relay-intercropped in 38 cm rows. Double-cropped red clover wheat yields were 555 and 605 kg ha^{-1} greater compared to relay-intercropping at 38 cm and 19 cm, respectively. Similarly, when pea was used as a double-crop wheat yields were greater than the 38 cm row (715 kg ha^{-1}) and the 19 cm intercrop system (740 kg ha^{-1}). Finally, intercropping hairy vetch decreased yields 575 kg ha^{-1} in 19 cm wheat and 890 kg ha^{-1} in 38 cm wheat compared to double-crop hairy vetch. Relay-intercropping cowpea into 38 cm wheat reduced yields compared to 19 cm relay-intercrop and double-crop systems 655 and 940 kg ha^{-1}, respectively (Table 2). There were no differences in wheat yields for grain sorghum or grain amaranth. Double-cropping may have resulted in greater wheat yields due to physical damage from intercropping. Ngalla and Eckert [34] reported a 4% reduction to wheat due to physical damage to wheat. Double-cropping may have also produced greater wheat yields due to the lack of competition for resources from intercrops [9, 22]. For soybean, 38 cm row spacing decreased wheat yields 180 kg ha^{-1} compared to 19 cm rows in either cropping system. This may have been due to competiveness of soybean preventing tillering of wheat that was associated with wider row spacings [17]. Hairy vetch had greater wheat yields in double-cropped systems (4680 kg ha^{-1}) than either row spacing in the intercrop system (4330 kg ha^{-1} for 19 cm rows and 4150 kg ha^{-1} for 38 cm rows) which was probably due to crop interference.

Research has shown that row spacing can help optimize wheat yields; however, results have differed depending on the selection of narrow or wide row spacing [14, 17, 21]. Wheat sown under narrow row spacing (15 cm) produced greater wheat yields due to a significant increase in productive tillers [14]. Wider row spacing (30 cm) increased the number of grains per spike and 1000-grain weight, but could not compensate for the drastic decrease in productive tillers which decreased grain yields [14]. Similarly, Zhou et al. [16] found that wheat yields were greatest for 14 cm spacing with yields ranked 14 > 7 > 24.5 > 49 cm row spacing. However, Pandey et al. [17] reported that wheat cultivated at 20 cm row spacing produced significantly more effective tillers as compared to 15 cm row spacings. Thorsted et al. [22] found that interspecific competition during vegetative growth was reduced by increasing width of the rototilled strips from 7 to 14 cm, and research completed by [23] indicated that there were no negative effects of wide-row planting on wheat yields. Conversely, narrow rows yielded more grain than wide rows, suggesting that closeness of planting enabled more efficient utilization of resources [21, 24]. Finally, wheat yields may have been affected by row orientation due to impacts on light interception and photosynthetic efficiency [17, 19]. The effect of row orientation varied with latitude and seasonal tilt of the earth [19]. For example, wheat crops planted east-west in Western Australia had 24% greater yields than those oriented north-south and 51% lower weed biomass [19].

3.4. Alternative Crop Yields. Due to the severe drought in 2012, alternative crops in the intercrop system died due to plant interference. While the intercrops emerged (Table 3) prior to wheat harvest on 15 June, all of the intercrops eventually died. There was a severe drought during the summer of 2012 and the intercrop system was burdened by too much competition for water with wheat [9, 15]. The intercrops died after emergence probably due to lack of water and extreme heat, which was exacerbated by interference with wheat. The double-crop planting produced biomass yields ranging from 145 kg ha^{-1} for red clover to 20,295 kg ha^{-1} for sorghum (Table 4). With a later planting date, crops received water at important establishment and maturation points that was not available to intercrops earlier in the season. In addition, temperatures started to decrease at the end of the summer, meaning that growth occurred during slightly cooler temperatures (an average temperature of 22.4°C from planting to harvest). Finally, the alternative crops planted in the double-crop system did not have to compete with wheat for water and other resources.

Table 4: Dry biomass yields of alternative crops for 2012 and 2013.

Crop	2012					2013				
	Relay-intercrop			Double-crop		Relay-intercrop			Double-crop	
	19 cm	38 cm	No wheat	19 cm	LSD ($P = 0.1$)	19 cm	38 cm	No wheat	19 cm	LSD ($P = 0.1$)
	kg ha^{-1}									
Cowpea	0	0	0	2370	740	770	1065	440	2715	1190
Pearl millet	0	0	0	3310	345	0	805	0	1315	735
Sorghum	0	0	0	20295	19835	3470	2930	17155	5395	2755
Amaranth	0	0	0	1590	470	40	265	0	930	335
Soybean	0	0	0	3250	470	715	820	2670	2520	1660
Red clover	0	0	0	145	125	375	930	1120	250	400
Hairy vetch	0	0	0	1110	285	1790	1165	1850	770	690
Pea	0	0	0	565	225	35	465	0	695	640

Table 5: Alternative crop grain yields for wheat row spacing in 2012 and 2013.

Crop	2012					2013				
	Relay-intercrop			Double-crop		Relay-intercrop			Double-crop	
	19 cm	38 cm	No wheat	19 cm	LSD ($P = 0.1$)	19 cm	38 cm	No wheat	19 cm	LSD ($P = 0.1$)
	kg ha^{-1}									
Cowpea	0	0	0	0	0	0	39	16	4	52
Pearl millet	0	0	0	125	45	0	82	0	257	106
Sorghum	0	0	0	470	235	450	675	2059	337	698
Amaranth	0	0	0	410	275	22	50	0	462	70
Soybean	0	0	0	560	365	32	163	859	172	505
Red clover	0	0	0	0	0	0	0	18	0	23
Hairy vetch	0	0	0	0	0	0	0	0	0	0
Pea	0	0	0	0	0	0	0	0	36	47

Alternative crops yielded greater in 2013 for relay-intercrops compared to 2012 with the exception of pearl millet, amaranth, and pea in some spacings. In 2012, there was no yield for intercrops, but in 2013 total biomass reached 17,155 kg ha^{-1} for sorghum. Early rainfalls in May and June and cooler summer temperatures allowed for greater intercrop growth before a "flash drought" occurred late in the summer. There were trends that occurred across alternative crops. With the exception of hairy vetch, alternative crops generally yielded greater either in the double-crop system (cowpea, amaranth, and pea) or in the no wheat (grain sorghum and clover) or 38 cm intercrop system (pearl millet) (Table 4). This most likely occurred because of reduced competition for resources due to either no wheat being present or greater distance between the wheat rows for the alternative crop.

Hairy vetch was the exception with greater biomass yields of 1020 kg ha^{-1} for 19 cm row spacing intercrop and 1080 kg ha^{-1} for no wheat compared to 19 cm double-crops. As a vining plant, hairy vetch probably benefitted in the 19 cm rows from having wheat stalks closer which provided it with physical support, since hairy vetch is often a frost seeded species [35] and can withstand colder temperatures. However, double-crop planting on 9 July may have caused average temperatures to be too high for good growth of hairy vetch. Visual observations noted that hairy vetch performed very well in Northeast Missouri as an intercrop, often forming ground cover and good biomass production that suppressed weeds such as common waterhemp (*Amaranthus rudis* Saur.) (visual observation).

There were only four alternative crops that produced grain yield in the double-crop system in 2012 including pearl millet (125 kg ha^{-1}), grain sorghum (470 kg ha^{-1}), amaranth (410 kg ha^{-1}), and soybean (560 kg ha^{-1}) (Table 5). Cropping system affected alternative crop grain yields in 2013 (Table 5). For pearl millet and amaranth, grain yields were 175 to 412 kg ha^{-1} greater in the double-crop system compared to either row spacing in the intercrop system. Similarly, grain yields were greatest for sorghum and soybean in the mono-crop system with no wheat. In both the mono-crop, no wheat system and the double-crop system the alternative crop did not have to compete with wheat for resources.

3.5. Land Equivalent Ratio. A LER shows the efficiency of intercropping for using the environmental resources compared with mono-cropping and compares yields obtained by

Table 6: Land equivalent ratios (LER) for intercropping of wheat and all alternative crops for 19 and 38 cm row spacing.

Crop	2012			2013		
	19 cm	38 cm	LSD ($P = 0.1$)	19 cm	38 cm	LSD ($P = 0.1$)
Cowpea	0.94	0.74	0.38	1.34	1.21	0.71
Pearl millet	0.8	0.87	0.41	0.97	1.40	0.77
Grain sorghum	1.01	1.00	0.26	1.26	1.28	0.42
Amaranth	0.97	0.96	0.14	1.01	1.25	0.55
Soybean	0.87	0.90	0.28	1.23	1.19	0.16
Clover	0.91	1.03	0.22	1.32	1.76	0.24
Hairy vetch	0.78	0.81	0.26	3.12	2.39	1.09
Pea	0.83	0.77	0.16	1.02	1.51	1.23

growing two or more species together with the yields of growing the same crops as a mono-crop [31, 36]. A LER greater than 1.0 indicated intercropped systems were advantageous, whereas a LER less than 1.0 showed a yield disadvantage [31, 36]. Drought greatly impacted LER values in 2012. Due to no intercrop production after wheat harvest (by midsummer), with the exception of grain sorghum and clover in 38 cm rows, all LER values were below 1.0 (Table 6). This was reasonable since the relay-intercrop system failed leaving only wheat yields as the marketable product. However, the double-crop system did provide some yield. Thus this pure yield would increase the LER value of the field by producing two yields in one growing season when compared with the mono-crop system.

Interestingly, there was successful alternative crop production in the relay-intercropping system in 2013 and LER values across all alternative crops, with the exception of pearl millet, were above 1.0 (Table 6). Hairy vetch had the greatest LER value across row spacing with 1.2 to 2.15 greater LER values compared with all intercrops. This corresponded with visual observations of large amounts of hairy vetch biomass production. In addition, 19 cm spacing LER was significantly greater than 38 cm row spacing. By producing positive LER values representing yield advantages of the intercropping system, using intercrops as forages or green manures, may potentially benefit farmers' production systems in years with low rainfall and temperatures (2013) but not in years with low rainfall and high temperatures (2012).

4. Conclusion

This research was conducted during extreme drought conditions in 2011-2012 and flash drought in 2012-2013. 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 decreased with the lowest establishment and survival in 2012. Spacing of wheat rows impacted wheat yields, as well as the type of cropping system for some alternative crops. In 2012, there were no alternative crop yields for the relay-intercrop or mono-crop system due to extreme drought conditions; however, wider row spacings or the double-crop system increased yield due to interference for resources with wheat in 2013. Land equivalent ratio values determining productivity of intercrop systems of 19 and 38 cm row spacing compared with sole-cropping systems showed that, with the exception of grain sorghum and 38 cm row spacing clover, there was no yield advantage for the intercropping system for any alternative crops in 2012. In 2013, LER values showed an advantage for all alternative crops with the exception of pearl millet in 19 cm spacing. 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.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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