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Interseeding Wide-Row Corn with Forage Cover Crops: Investigating System Potential for Expanded Economic Opportunities in Corn Production Systems

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Abstract: Intercropping forages with corn can improve cropping system productivity relative to single crop systems. However, limited light resources in 76 cm corn rows may impede successful forage establishment. This study assessed whether the combination of intercropped high value forage cover crops and wider corn rows could result in economically viable crop production systems in the Upper Midwest. A high value forage mixture was interseeded into standing corn at three working farms in the Rice and Goodhue Counties, MN, USA. Treatments were comprised of four row widths: 76 cm with no forage cover crop (best management practices, BMP), 76 cm with a forage cover crop (BMP + CC), 76 cm + CC, and two skip rows every fourth row (Balanced), and 152 cm + CC (WIDE). The WIDE, Balanced, and BMP + CC corn treatment reduced corn yields relative to the 76-cm treatments. However, the forage cover crop yields for all treatments optimized for light resources (Balanced and WIDE) ranged from 945 to 1865 kg ha^{-1} a forage quality (CP and RFV) equivalent to alfalfa. Our economic analysis revealed that high yielding, quality forage crops can offset up to 12.6% of economic losses caused by grain reductions. Wide-row intercropped systems may be economically viable for producers looking for opportunities to reintegrate their crop and livestock production systems, but further work is needed to refine this system for farm use.

Keywords: cover crops; economic tradeoffs; forage; *Zea mays L.*; row width

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1. Introduction

In the U.S. Upper Midwest, the industrialization of agriculture and lack of true integration between crop production and livestock grazing has led to a simplification of agricultural land use. As such, continuous, annual corn (*Zea mays* L.) and soybean (*Glycine max* L.) cropping systems have replaced more diverse long-term rotations and perennial pasture [1]. However, increased attention to environmental issues such as extreme weather events resulting in yield instability [2,3], the need to reduce nutrient and sediment loss [4,5], and a need for improved soil health [6,7] have led many Upper Midwest producers to reconsider their current farm practices [8]. Cover crops, which are characterized by a wide variety of environmental and economic benefits [9–11], are increasingly recommended to producers as a strategy to meet the above challenges.

Despite high levels of satisfaction with cover crops by users [12,13], adoption of the practice is low, with cover crops making up less than 3% of the total acreage in the Upper Midwestern states [14]. Economic uncertainty about cover crops remains one of the greatest barriers to adoption [15]. Although cover crops provide long-term economic benefits such as more efficient water and nutrient use [16], reduced compaction [17], and reduced pest and weed pressures [18,19], the upfront cost of changing farming practices [13,20] is a disadvantage that prevents producers from incorporating this practice into their operations. Increased focus by public and private researchers and non-profit organizations on ways to improve the near-term economic benefits of cover crops in the upper Midwest may hold the key to increasing its adoption.

Integrating cover crops as high-value forage sources with annual crop production systems may be an opportunity for cover crops to provide more immediate economic returns to producers [21]. Feed represents the greatest expense in animal operations [22,23]; as such, high-value forage cover crops that increase on-farm economic and environmental efficiency have been increasingly explored as a potential tool to improve resilience [24–26]. A study by Gabriel et al. [27] found that selling cover crop biomass as animal feed resulted in significantly larger economic benefits than the fertilizer saving benefits provided by cover crops. In addition, Drewnoski et al. [28] found that in cases of both spring and fall grazing, cover crops could offset production costs and, in many cases, result in economic returns exceeding the costs of establishment.

Despite the potential for economic gains, significant agronomic challenges must be overcome in order to successfully incorporate forage into row crop production systems. Interseeding, defined as planting a secondary crop during the vegetative growth stage of a commodity crop, is one strategy to incorporate forage cover crops into corn production systems and has been well-studied [28,29]. The ability of a secondary crop to acquire enough water, nutrients, and solar radiation is a significant limiting factor in the establishment and survival of interseeded forage cover crops [30]; in addition to competing with the secondary crop for water and nutrients, the primary crop may impede the delivery of adequate radiation to the cover crop upon canopy close. Prior to 1960, most corn produced in the United States was grown in row widths greater than 76 cm [31]. However, the current best management practices, which recommend a corn row width of 76-cm rows, provides a significant challenge for producers needing to achieve a successful forage crop [32]. Widening corn rows to allow for the more effective utilization of sunlight [32] for forage cover crops in an interseeding system is a novel approach, and may thus optimize the establishment and subsequent yield success.

Recent studies exploring the use of wide rows in corn systems are limited. Previous work has shown a neutral or negative corn grain yield in 152-cm rows compared to a traditional 76-cm row spacing [33–35]. However, a number of previous research projects exploring diversified production systems have found that planting forage crops adjacent to corn may improve the cropping system yield stability and resilience [36–38]. Clarity in both the agronomic and economic considerations of this novel system is required for researchers to endorse it for a wider audience. Therefore, this research was conducted with two main objectives: (1) quantify the total system outputs including grain yields, corn population, forage cover crop yield, and forage cover crop quality; and (2) develop enterprise budgets to evaluate the total value of the forage from the cover crop biomass and corn grain to assess the economic tradeoffs.

2. Materials and Methods

2.1. Site Description

Field experiments were established over three consecutive years at three working farms in Rice County, MN, USA and Goodhue County, MN, USA: Cherry Grove Township, MN, USA (44°13′37″ N, 92°48′49″ W), Goodhue, MN, USA (44°24′42″ N, 92°41′36″ W; 44°24′31″, −92°41′41″ W), and Faribault, MN, USA (44°14′18″ N, 93°08′46″ W; 44°14′34″ N, 93°08′57″ W). At the Goodhue and Faribault location, three field experiments were imposed each year (2019–2021), while at the Cherry Grove Township Location, field experiments were imposed over two years (2019–2020). All sites were planted in soybean prior to the establishment of the experiments. Soils at the field experiment locations included a Kason Silt Loam (fine-loamy, mixed, superactive, mesic mollic oxyaquic hapludalf) at Cherry Grove Township, a Mt. Carroll-Hersey silt loam complex (fine-silty, mixed, superactive, mesic mollic hapludalfs) at Goodhue, MN, and a Marquis silt loam (fine-silty, mixed, superactive, mesic mollic hapludalfs) and Nerwoods loam (fine-silty, mixed, superactive, mesic mollic hapludalfs) at Fairbault, MN. In 2019, the soil pH was 6.2 and the average organic matter (OM) was 3.1% at Goodhue. The soil pH was 6.7 and OM was 4.1% at Faribault, and Cherry Grove Township had a soil pH of 6.2 and 2.7% OM. In 2021, the experimental sites were moved to adjacent fields. Soil pH was 6.2 and average organic matter (OM) was 2.7% at Goodhue and soil pH was 6.1% and OM was 3.7% at Faribault.

2.2. Weather Data

Precipitation data were obtained from the NOAA reporting weather stations at Goodhue County (Zumbrota, MN, USA) and Rice County, MN, USA (Faribault, MN, USA) and departures from the 30-year average (1981–2010) were calculated (Table 1). Due to the failure to collect the temperature data at the Zumbrota and Faribault NOAA reporting sites, the temperature data were obtained from the nearest NOAA reporting weather stations within 24 km of the Rice (Owatonna, MN, USA), and Goodhue County sites (Red Wing, MN, USA); departures from the 30-year average (1981–2010) were calculated (Table 2).

Table 1. Monthly precipitation data and departures from the normal during the 2019, 2020, and 2021 growing seasons at Rice and Goodhue Counties, MN, USA.

	Rice County			Goodhue County		
Month	**2019**	**2020**	**2021**	**2019**	**2020**	**2021**
			mm			
April	† 132.6(‡ +59.7)	31.2 (−41.7)	21.4 (−48.4)	118.9 (+33.8)	35.8 (−49.3)	20.8 (−64.3)
May	173.5 (+76.5)	143.5 (+46.5)	105.4 (−8.4)	140.2 (+45.0)	170.9 (+75.7)	109.0 (+13.7)
June	134.6 (+23.1)	205.5 (+93.7)	99.6 (−11.9)	144.3 (+25.7)	156.5 (+37.8)	38.1 (−80.5)
July	205.0 (+96.8)	109.5 (+1.3)	41.7 (−66.5)	166.4 (+58.4)	63.5 (−44.5)	43.9 (−64.0)
August	77.7 (−42.2)	103.1 (−17.0)	141.7 (+21.6)	65.0 (−58.9)	160.0 (+36.1)	207.5 (+83.6)
September	184.2 (+96.8)	99.1 (+11.7)	37.6 (−49.8)	183.1 (+86.6)	60.7 (−35.8)	42.2 (−54.4)
October	129.3 (+68.6)	82.3 (+21.6)	29.0 (−31.8)	136.4 (+73.9)	47.0 (−15.5)	49.3 (−13.2)

† Mean air temperature and accumulated precipitation were recorded from the NOAA weather station at Faribault, MN, USA and Zumbrota, MN, USA. ‡ Calculated departure from the 1981–2010 30-year accumulated precipitation data from the NOAA weather station at Faribault, MN, USA and Zumbrota, MN, USA (NOAA/NCEI, 2021).

Table 2. Monthly temperature data and departures from normal during the 2019, 2020, and 2021 growing seasons for the Rice * and Goodhue Counties, MN, USA.

	Rice County			Goodhue County		
Month	**2019**	**2020**	**2021**	**2019**	**2020**	**2021**
			°C			
April	† 6.8 (‡ −0.3)	5.4 (−1.6)	7.1 (+0.5)	7.3 (−0.3)	6.7 (−0.9)	7.9 (+0.3)
May	11.9 (−2.1)	13.5 (−0.4)	13.9 (+0.5)	12.0 (−2.5)	14.2 (−0.3)	14.6 (−0.2)
June	19.8 (−0.3)	21.9 (+1.9)	20.1 (+3.0)	20.1 (−0.1)	21.3 (+1.2)	23.3 (−5.7)
July	22.9 (+0.8)	23.4 (+1.3)	22.1 (+0.3)	23.3 (+0.9)	24.0 (+1.5)	22.7 (−0.4)
August	20.2 (−0.7)	21.7 (+0.8)	20.8 (+1.1)	20.6 (−0.6)	21.9 (+0.8)	22.0 (−1.5)
September	18.4 (+1.7)	15.6 (−1.1)	16.7 (+1.1)	18.4 (+1.6)	15.7 (−1.2)	17.6 (−1.3)
October	6.9 (−2.1)	5.5 (−3.6)	9.1 (+3.4)	8.1 (−1.3)	6.1 (−3.2)	12.6 (−5.9)

* Rice County data collected from the nearest neighboring county (Owatonna, MN, USA). † Mean air temperature and accumulated precipitation were recorded from the NOAA weather station at Owatonna, MN, USA and Red Wing MN, USA. ‡ Calculated departure from the 1981–2010 30-year accumulated precipitation data from the NOAA weather station at Owatonna, MN, USA and Red Wing, MN, USA (NOAA/NCEI, 2021).

2.3. Experimental Design

Field experiments were designed as a two-factor (i.e., corn row width and location), randomized complete block with three (2021) to four (2019, 2020) replications depending on the field-size constraints. The individual plot size was 18 m wide by 221 m in length.

The row width treatments included: 76 cm with no forage cover crop (BMP), 76 cm with forage cover crop (BMP + CC), 76 cm with forage cover crop and two skip rows every 4th row (Balanced), and 152 cm with forage cover crop (WIDE). Experiments were rain-fed. Each field experiment used conservation-tillage methods [39] to prepare the seedbed prior to planting (Table 3). Fertility management differed among locations (Table 3) but followed the management practices outlined by the University of Minnesota Crops Extension program [40]. All locations maintained the optimum fertility for corn production and were fertilized via a combination of N–P–K (as urea), and manure as recommended by soil testing prior to cash crop planting (Table 3). Corn planting date, variety, and harvest dates varied among the study locations (Table 3). The corn planting rate was 90,000 seeds ha^{-1} in 76-cm rows and 180,000 seeds ha^{-1} in 152-cm rows. Herbicide was applied pre- and post-emergence (Table 3). Forage cover crops were established mid-June in the V3–V4 growth stages (Table 3). Forage cover crops were broadcast or broadcast incorporated via tractor (Deer & Company, Moilene, IL) (Table 3).

All forage cover crop mixtures were selected for high forage biomass yields and ruminate nutritional quality along with the recommendations of regional seed suppliers for the two counties (Table 4).

2.4. Sampling & Analysis

Corn populations were calculated from late-September to mid-October (Table 3) by counting a three meter length of row at three locations in each plot. The corn grain yield was measured by hand-harvesting a three meter length of row at three locations in each plot. Seed moisture was determined and adjusted before analyses to 150 g kg^{-1}. Aboveground forage cover crop biomass was harvested on the same day as the corn population counts at three random locations in each plot using 0.5 m^2 quadrats designed to capture a sample representative of the spatial arrangement of corn and forage in each treatment. Weeds were included in sampling as forage biomass. All forage cover crop biomass samples were dried at 60 °C in a forced-air oven until constant mass, after which all samples were weighed. The dry forage cover crop biomass samples were ground to pass through a 6 mm screen using a Thomas Wiley mill (Thomas Scientific, Swedesboro, NJ, USA). The coarse ground samples were mixed, subsampled (~30 g), and ground to pass through a 1 mm screen using a Cyclotec Sample Mill (FOSS North America, Eden Prairie, MN, USA). Ground samples were analyzed for forage nutrient composition by a commercial forage testing laboratory (Equi-Analytical, Ithaca, NY) using the following methods: crude protein (CP) was calculated as the percentage of nitrogen multiplied by 6.25 [41]; NDF and acid detergent fiber (ADF) were measured using filter bag techniques [42–44]. Relative forage value (RFV) was subsequently calculated using equations described by Jeranyama and Garcia (2004).

Statistical analyses were performed using the MIXED procedure in the statistical software SAS (SAS Institute Inc., Cary, NC, USA). Fixed effects were location, row width treatment, and their interactions. Random effects were block nested within year by location and corresponding interactions with fixed effects. Means for all response variables were separated using Fisher's protected LSD at $\alpha = 0.05$.

The economic analysis used a decision tool and partial budget format (Table 5) to evaluate the differences in the costs and returns of wider than normal corn row widths (152 cm) with a cover crop planted between the rows when compared to the 76-cm rows. The cover crop forage was assumed to be grazed or mechanically harvested along with the corn stover. This wide-row scenario was compared with one of two base scenarios of 76-cm row widths. The base scenario included in the economic results below assume that only the corn grain is harvested, in contrast to the wide row scenario where the corn stover/forage mix is grazed. This comparison implies that the producer is only producing cash crops in the base scenario, and then somehow brings livestock (i.e., beef cows or backgrounding stock) onto the farm to graze in the wide row scenario.

Table 3. Field operations and pre-site preparation of the experimental sites across three locations from 2019–2021 in the Goodhue and Rice Counties, MN, USA.

	Cherry Grove Township, MN		**Goodhue, MN**			**Faribault, MN**		
	2019	**2020**	**2019**	**2020**	**2021**	**2019**	**2020**	**2021**
Pre-plant preparation								
Total N	67 kg ha^{-1}	67 kg ha^{-1}	157 kg ha^{-1}	162 kg ha^{-1}	162 kg ha^{-1}	193 kg ha^{-1}	162 kg ha^{-1}	174 kg ha^{-1}
Total K + P	0 kg ha^{-1}	0 kg ha^{-1}	143 kg ha^{-1}	134 kg ha^{-1}	134 kg ha^{-1}	174 kg ha^{-1}	0 kg ha^{-1}	0 kg ha^{-1}
Total manure	10,089 kg ha^{-1}	10,089 kg ha^{-1}	0 kg ha^{-1}	0 kg ha $^{-1}$	0 kg ha^{-1}	10,592 kg ha^{-1}	10,592 kg ha^{-1}	10,592 kg ha^{-1}
Tillage implement	‡ Tigermate II	Tigermate II	Wilrich 3400	Wilrich 3400	Wilrich 3400	Tigermate II	Tigermate II	Tigermate II
Commodity Crop								
Corn variety	Golden Harvest 92 RM	Channel 99 RM	Gold Country 92−45R2P	Gold Country 102−88 RSS	Legacy 96d LC3617SSX-Rib	Wiffels 4190	Wiffels 2500	DK 5436
Herbicide, pre-emergence	0 kg ha^{-1}	0 kg ha^{-1}	0 kg ha^{-1}	0 kg ha^{-1}	0 kg ha^{-1}	0.11 kg ha^{-1} 2,4D	0 kg ha^{-1}	0 kg ha^{-1}
Herbicide, post-emergence	0.35 kg ha^{-1} glyphosate	0.35 kg ha^{-1} glyphosate	0.57 kg ha^{-1} glyphosate	0.57 kg ha^{-1} glyphosate	0.57 kg ha^{-1} glyphosate	0.29 kg ha^{-1} glyphosate	0.11 kg ha^{-1} 2,4D0.38 kg ha^{-1} glyphosate	0.04 kg ha^{-1} dicamba0.38 kg ha^{-1} glyphosate
Corn planting	6/3	4/23	6/3	4/23	5/15	5/5	4/23	4/6
Corn harvest	11/26	11/17	11/5	11/1	10/16	10/24	10/9	10/22
Cover Crop								
Cover crop rate	32 kg ha^{-1}	32 kg ha^{-1}	38 kg ha^{-1}	32 kg ha^{-1}	31 kg ha^{-1}	31 kg ha^{-1}	29 kg ha^{-1}	38 kg ha^{-1}
Cover crop method	B †	B	B + I	B + I	B + I	B + I	B+I	B+1
Cover crop planting	6/14	6/2	6/14	6/2	6/5	6/14	6/2	6/5
Cover crop harvest	10/18	9/29	10/17	9/29	9/29	10/17	9/29	9/29

† B, broadcast; B+I, broadcast incorporated ‡ Tigermate II, Case IH (Racine, WI, USA); Wilrich 3400, Wil-Rich Co. (Whapeton, ND, USA).

Table 4. Cover crop species mixture at each experimental site in the Goodhue and Rice Counties, MN, USA.

	Cherry Grove Township, MN		**Goodhue, MN**			**Faribault, MN**		
	2019	**2020**	**2019**	**2020**	**2021**	**2019**	**2020**	**2021**
Species	kg ha^{-1}		kg ha^{-1}			kg ha^{-1}		
Annual ryegrass, *Lolium multiflorum*	20.2	20.2	20.2	20.2	23.5	19.8	17.3	16.8
Red clover, *Trifolium pratense*	2.2	2.2	2.2	2.2	6.7	0	0	1.1
Crimson clover, *Trifolium incarnatum*	2.2	2.2	2.2	2.2	6.7	0	0	0
Berseem clover, *Trifolium alexandrinum*	0	0	0	0	0	0	1.7	0
Bayou kale, *Brassica oleracea sabellica*	0.6	1.1	1.1	0.6	0	2.2	2.2	2.2
Field radish, *Raphanus raphanistrum subsp. sativus*	1.1	1.1	1.1	1.1	0.5	0	1.1	0
Purple top turnip, *Brassica campestris*	2.2	2.2	2.2	2.2	0.5	1.1	1.1	1.1
Teff, *Eragrostis tef*	0	2.2	2.2	0	0	0	0	0
African cabbage, *Cleome gynandra*		0	0	0	0	1.1	1.1	1.1
Cow pea, *Vigna unguiculata*	0	0	0	0	0	5.6	24.7	22.4

The mix of forage cover crop and corn stover was valued based on the crude protein and TDN they contained, with the value per pound of crude protein and TDN if purchased as corn grain and 48% soybean meal. The expected price of corn and SBM were added by the user. As stover typically sells for less than corn and SBM containing the same quantity of these nutritional measures, it was discounted at a value determined by the user. The calculation also required the entry of the assumed corn grain yield at 76-cm rows for the normal row width, the reduction in corn grain yield in wide rows, and expected forage cover crop yield in wide rows; for our purpose, we used the experimental data averaged over all years and sites. Costs associated with the forage cover crop establishment, nutrient removal due to the stover harvest, and grazing or harvesting costs were included. Costs of growing the corn grain were not included in the analysis because they were the same in both scenarios.

Table 5. Revenue, costs, and net return of establishing and harvesting a stover–CC mix in the 152-cm corn rows.

		Grazed	**Harvested**
Cover crop yield after trampling or harvest loss	kg ha^{-1}	371.49	445.79
CC grazed or harvested/acre as fed	kg	239.82	287.79
Value of kg of CC as fed	kg	231,508.90	231,508.90
Value of 1 kg of CC DM before trampling or harvest loss	kg bu^{-1}	$0.03	$0.04
Extra CC gross revenue/acre over stover alone	ha	$27.31	$32.78
Cover crop establishment cost minus corn seed cost savings	ha	−$7.16	−$7.16
Extra CC grazing or baling cost above stover alone	ha	$0.00	−$6.81
Baling costkg of CC before loss	kg		$0.00
Net value/ kg before loss	kg	$0.03	$0.04
Total extra cost above stover alone	ha	−$7.16	−$13.97
Extra CC net return/acre over stover alone	ha	$20.15	$18.81
Stover or mix yield after trampling or harvest loss,	kg ha^{-1}	3145.38	3774.45
Stover–CC mix tons grazed or harvested as fed	kg		
Value of mixed stover-CC as fed	kg		
per bale, as fed	bale		$53.00
Stover and CC gross revenue/acre w/o grain	ha	$80.42	$96.50
Stover and CC gross revenue/acre with grain	ha	$462.20	$478.28
Cover crop establishment cost minus corn seed cost savings	ha	−$7.16	−$7.16
Fencing, watering, etc. if grazed, or stover baling costs if harvested	ha	−$7.69	−$27.18
Nutrient removal value for stover removal	ha	−$9.88	−$11.85
Total CC establish and mix harvest minus soil health benefit	ha	−$24.73	−$46.19
Stover & CC net return/acre before considering grain revenue	ha	$55.69	$50.31
Grain revenue/bu at $6.75/bu net of drying		$381.78	$381.78
Net return with grain	ha	$437.47	$432.09

3. Results

3.1. Corn Performance

The average corn population was greatest for the BMP (85,719 plants ha^{-1}) followed by the BMP + CC (80,953 plants ha^{-1}), balanced (77,313 plants ha^{-1}), and WIDE (73,380 plants ha^{-1}) treatments. Corn grain yield was influenced by an interaction of location and row width ($p < 0.001$). BMP outperformed all treatments at the Cherry Grove Township (10,335 kg ha^{-1}) and Goodhue (10, 830 kg ha^{-1}), resulting in 27 to 34% greater yield than the balanced or WIDE treatments (Figure 1). At Faribault, BMP + CC (14,433 kg ha^{-1}) resulted in 10% greater yield than WIDE (12,988 kg ha^{-1}) (Figure 1). No difference was found between the BMP and WIDE yields at Faribault (Figure 1). The BMP grain yields were 12% lower than the county averages at the Goodhue County locations (Cherry Grove Township and Goodhue, MN, USA) and 15% higher than the county averages at the Rice County location (Faribault, MN, USA).

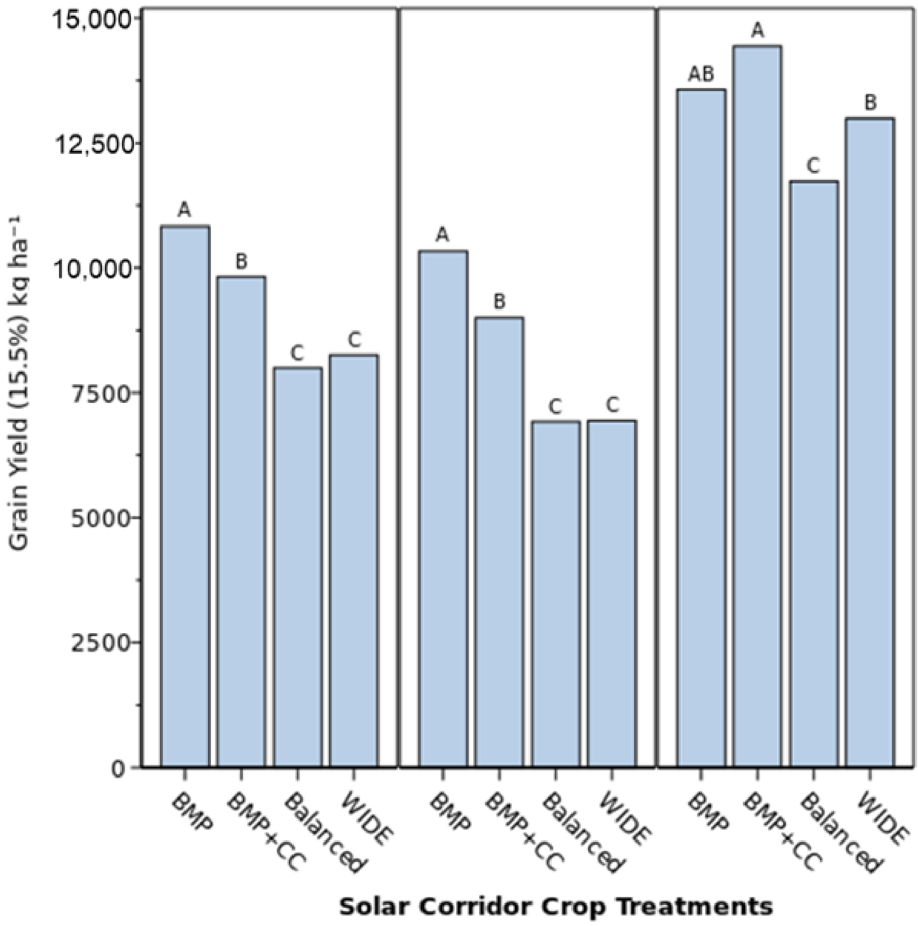

Figure 1. Row treatment and location effect on the grain yield at Goodhue, MN (**left**), USA Cherry Grove Township, MN (**center**), and Faribault, MN, USA **(right)**. BMP, 76-cm without cover crop; BMP + CC, 76-cm row with cover crop; Balanced, 76-cm with cover crops and two skip rows every fourth row; WIDE, 152-cm rows with cover crop. All mean separation values were based on Fisher's protected LSD at $\alpha = 0.05$.

3.2. Forage Cover Crop Performance

The forage crop biomass was influenced by location ($p = 0.04$) and row treatment ($p < 0.001$). Balanced treatments resulted in the greatest forage biomass of all treatments (Figure 2), with a biomass ranging from 1593 to 1856 kg ha^{-1} with an average value of 1725 kg ha^{-1}. The WIDE treatment production ranged from 945 to 1210 kg ha^{-1} with an average value of 1077 kg ha^{-1}. BMP + CC treatment production ranged from 189.29 to 474.43 kg ha^{-1} with an average value of 331.86 kg ha^{-1}. The RFV of the forage crops was influenced by an interaction of location and row width ($p = 0.049$) (Figure 3). At Cherry Grove Township, Balanced resulted in greater RFV than BMP + CC and WIDE. At Faribault, both WIDE and Balanced resulted in greater RFV than BMP + CC. Differences between the row treatments were not found at Goodhue. The CP concentration was impacted by the location ($p < 0.001$). The CP concentration was greatest at Faribault at 23.4%. No difference was found between Cherry Grove Township and Goodhue, which reported CP concentrations at 15.1 and 15.8%, respectively.

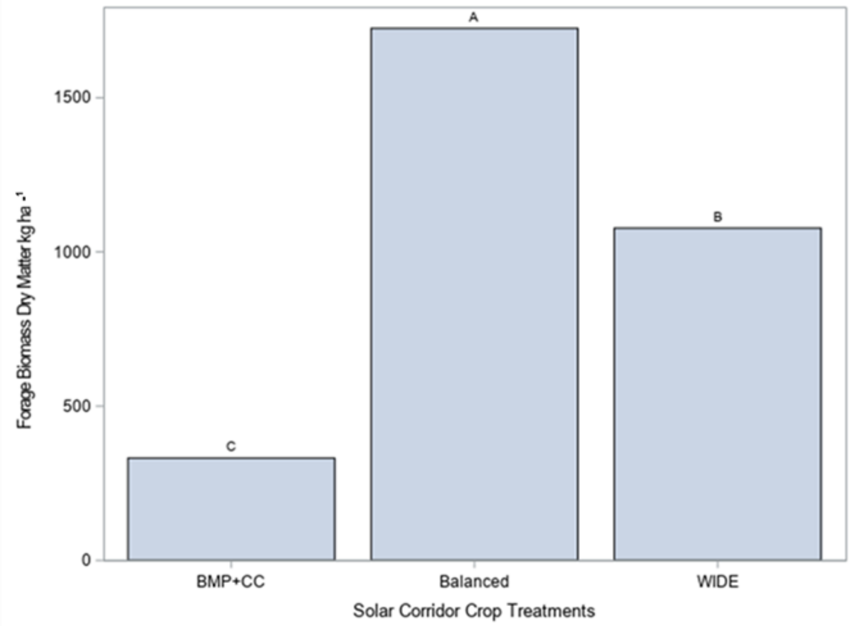

Figure 2. Row treatment and location effect on the relative forage biomass averaged across three locations in southeast MN, USA. BMP + CC, 76-cm rows with cover crop; Balanced, 76-cm with cover crops and two skip rows every fourth row; WIDE, 152-cm rows with a cover crop. All mean separation values were based on Fisher's protected LSD at α = 0.05.

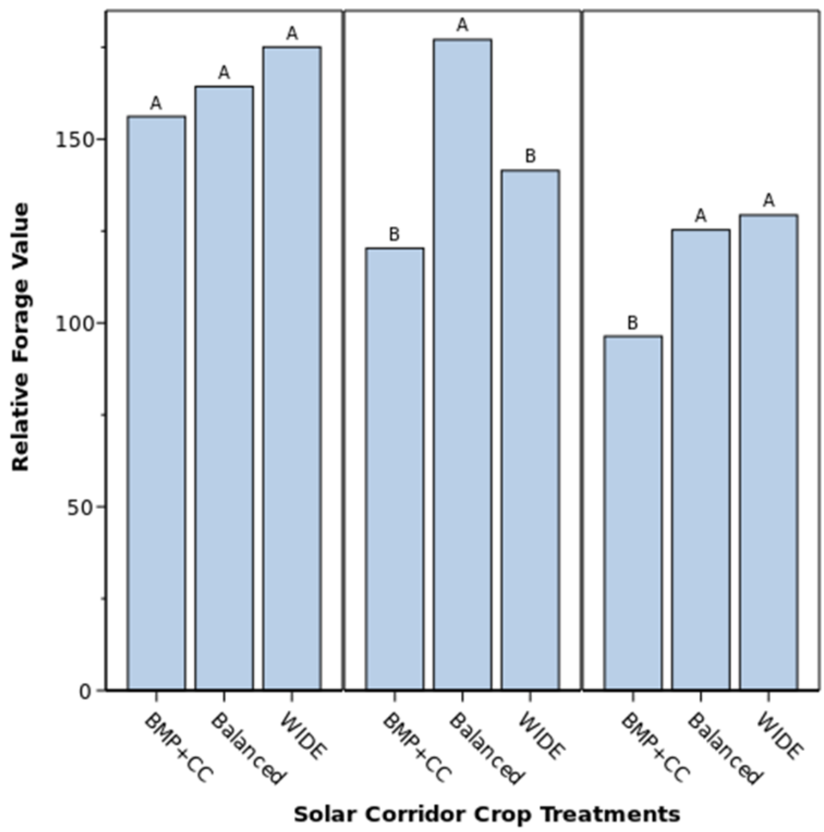

Figure 3. Row treatment and location effect on the relative forage value at Goodhue, MN, USA (**left**), Cherry Grove Township (**center**), MN, USA, and Faribault, MN, USA (**right**). BMP + CC, 76-cm rows with a cover crop; Balanced, 76 cm with a cover crop and two skip rows every fourth row; WIDE, 152-cm rows with a cover crop. All mean separation values were based on Fisher's protected LSD at α = 0.05.

3.3. Economic Analysis

Upon adding the price of corn kg ha^{-1}, cost of corn drying, price of 48% ton as feed, base corn seed expense at 152-cm, cover crop establishment cost, fertilizer costs, nutrient removal costs, and deducting fencing and watering, baling, and trampling/harvest efficiency loss, the total net return of stover, forage crop, and grain was \$437 ha^{-1} if grazed and \$432 ha^{-1} if mechanically harvested (Table 5), indicating that it is profitable to establish and harvest a stover and forage mixture. However, there was a negative difference in the net return from the 76-cm row spacing with no forage crop relative to the 152-cm row spacing with grazed forage, with a loss of −\$28 ha^{-1} (Table 6).

Table 6. Calculation of the yield required to cover the cost of growing the cover crop and reduced yield of corn caused by increasing the row width.

		† 76-cm Rows	152-cm Rows	Difference
Corn grain yield	kg ha^{-1}	11,634.44	9540.24	−2094.20
Stover yield after trampling or harvest loss	kg ha^{-1}	0.00	4426.51	4426.51
Cover crop yield	kg ha^{-1}	*	592.81	592.81
Cover crop–stover mix yield	kg ha^{-1}	*	5019.32	5019.32
Stover or mix value	\$ kg^{-1}	60,297.91	80,524.96	20,227.04
Revenue	\$ ha^{-1}	465.58	462.20	−3.38
Cost related to the stover or mix	\$ ha^{-1}	0.00	24.73	24.73
Net return	\$ ha^{-1}	465.58	437.47	−28.11
Breakeven corn yield reduction if CC yield is 1077 kg ha^{-1}	%	12.6		
Breakeven CC yield if the corn yield reduction is −18.0%	kg ha^{-1}	2045.05		

† 76-cm rows no cover crop, stover not utilized; 152-cm rows with cover crop, stover utilized.*, not applicable.

Averaged across site and year, this study resulted in an average corn grain yield of 11.7 Mg ha^{-1}, an 18% reduction in corn yields in 152-cm rows relative to the 76-cm rows, and forage yield of 1077 kg ha^{-1}; based on these inputs, the breakeven corn grain reduction yield was calculated to be 12.6% (Table 6). To fully offset the corn grain reduction yield at 18%, forage crops would have to reach a yield of 2045 kg ha^{-1}. A model was subsequently built to determine the net return difference from the base normal row width scenario with a grain yield of 11.7 Mg ha^{-1} (Figure 4). The point at which no net return ha^{-1} was gained began at losses of greater than 12.6%.

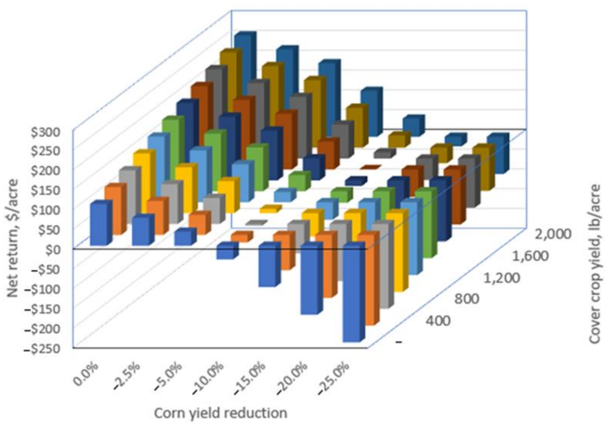

Figure 4. Net return difference from the base 76-cm row width scenario of 11.7 Mg ha^{-1} corn grain when the stover is not baled or grazed. X and Y axes represent changes in the corn and cover crop yields, while the Z axis (vertical) shows the changes in net return/acre that resulted from each yield combination.

4. Discussion

4.1. Corn Performance

Across the locations, the average corn populations for the WIDE and Balanced treatments were 5–10% lower than the population ranges for maximum profitability, as recommended by the University of Minnesota, respectively [45]. In this study, we kept the per corn seeding rate consistent on a per hectare basis between treatments so that the seeding rates in the WIDE treatment were double that of the BMP treatments. Because of this, a decrease in plant spacing within the WIDE rows may have contributed to the reduced yield. Clearly, more work is needed to determine the optimal corn seeding rates and spatial arrangements for the 152-cm corn rows, as no best practice recommendations currently exist.

As expected, the WIDE and Balanced treatments resulted in reduced corn yields per acre relative to the BMP treatments (Figure 1). Previous work by Nelson [34] found that grain yields were 14–39% greater in the 76-cm rows than in the 152-cm intercropped wide rows in a given year, corroborating the findings of this study [34]. Similarly, Ottman and Welch [46] reported a 17% yield reduction in central Illinois, and researchers in southeast North Dakota found a 13% yield reduction in NSDU [47] with 152-cm twin-row corn compared to a narrower row spacing. It was surprising that no difference was found between the BMP and WIDE rows at Faribault. However, weed pressure may have contributed to the reduced grain yield in some of the wide row treatment plots.

It also appears that wide-row systems are currently characterized by some variability in grain production. Nelson reported in the same study that 76-cm and 152-cm intercropped rows also resulted in similar grain yields in one year of their study [34]. More research is needed to determine if such yield variability is common in 152-cm rows. Lower than average yield in BMP treatments at Goodhue and Cherry Grove Township was likely due to the precipitation deficits in July 2020 and 2021 in Goodhue County (Table 1); previous work has reported than water deficits can reduce the corn nitrogen use efficiency [48].

4.2. Forage Crop Performance

Similar to grain yield, forage cover crop biomass results relative to treatment were as expected. Given the space limitations and competition for resources with the primary crop, it is not surprising that BMP + CC yielded 70–80% lower than the WIDE and Balanced treatments, respectively. Forage yields intercropped in 76-cm rows have been mixed. For example, Belfry and Van Eerd [49] reported high cover crop biomass at corn harvest (725 and 1352 kg DM ha^{-1}) for winter rye and hairy vetch, respectively, while Caswell et al. [50] reported rye–clover cover crop mixtures relayed in 76 cm corn resulted in only 100–400 kg ha^{-1} of biomass·. Previous work by Lyon et al. [51] in an analysis of 23 sites in the Great Plains Region of the U.S. found that skip row plantings (i.e., Balanced) could both decrease the corn grain yield and increase the yield depending on the planting pattern, while a study by Allen [52] in the same region found no impact of a skip row planting arrangement on the corn yield. Clearly, more work is needed to add clarity to the yield impacts of Balanced treatments. Both the Balanced and WIDE treatments have previously both been shown to improve light infiltration and plant access to soil water [38–40], which likely contributed to the high yields. It is not surprising that the Balanced treatment resulted in greater biomass than the WIDE treatment, given that Balanced treatments resulted in an additional 30 cm in the cover crop planting width relative to the WIDE treatments.

Forage quality was assessed in terms of CP and RFV. The subsequent impact of row-width on RFV was variable across location. However, the WIDE and Balanced treatments consistently resulted in 150–200 and 125–275 RFV, respectively (Figure 3). These values are consistent with those of early-bloom to late-bud alfalfa [53]. Additionally, WIDE RFV consistently surpassed the RFV of well-eared corn silage (136), as reported in the literature [53]. Although little research exists on the relationship between cereal rye, cowpea, and other forage crop species included in this study and row spacing, previous research has found that temperature, light interception, and light intensity influences the nutritive value [48–50]. These environmental qualities of wide and skip-row plantings likely account for the performance of the Balanced and WIDE row forage quality.

In contrast to RFV, the CP concentration was only found to have been impacted by location in this study. Weather likely accounted for the differences seen between locations; the CP concentration varies by temperature and precipitation [54], and in June and July, precipitation was greater at Faribault than at Goodhue and Cherry Grove Township (Table 1). Overall, the forage quality results are promising as they support previous studies that found intercropping corn with forage crops resulted in greater nutritive value than monocropped forage or commodity crops [55,56]. Producers have increasingly relied on silage corn due to its ability to reliably produce greater forage yields than a highly nutritive crop like alfalfa [57], and this system may provide an appealing alternative given its ability to provide an alternative feed option and environmental benefits without forage yield loss.

4.3. Economic Analysis

With our economic analysis, we sought to determine whether producers would make the transition from cash crops to livestock for the sake of making the wide rows economically attractive. To our knowledge, this is the first study to examine the economic feasibility of transitioning from 76-cm to 152-cm corn rows. Work by LaCanne and Lundgren [58] reported that fields under regenerative management had a 29% lower grain production but 78% higher profits over traditional corn production systems; similarly, our work revealed that regenerative management in the form of forage double-cropping had the potential to offset low grain production as a result of wide rows. This finding is critical, as previous work by Roesch-McNally et al. [13] reported that multiple farmers feel caught between achieving conservation goals and concern over low yields [13].

In this study, our analysis showed that high yielding, high quality cover crop forages at 1252 kg ha^{-1} pounds per acre dry matter) can offset up to 12.6% of corn grain reduction through forage production, without accounting for environmental benefits known to result from incorporating forage cover crops. If grazing is the goal, this may be an acceptable tradeoff, as livestock can capture additional value on that land. Based on our findings, we suggest that the profitability of the wide-row system is the most attractive in a situation where the corn stover was not previously utilized; wide rows will result in less economic incentive when the corn stover would have been utilized regardless.

As the most profitable scenario is one in which the producer is adding livestock from a previously grain-only operation, wide row spacing practices may best be recommended to new farmers or farmers looking for opportunities to diversify operations. Interest among consumers and corporations in regenerative grazing practices has noticeably increased over the past 5 years [59,60]; our findings may provide an entry point for producers looking to incorporate regenerative agricultural practices. Future work should investigate the addition of economic tools that can quantify the economic value of the soil health benefits resulting from the re-integration of animal and commodity crop systems.

5. Conclusions

The primary goal of this research was to explore the tradeoffs between traditional (76 cm) and wide (152 cm) rows of corn interseeded with forage crops. Across all of our treatments, we found that the 76-cm rows consistently outperformed the 152-cm rows in corn grain production. However, we also found that the 152-cm rows (WIDE) and 76-cm rows with two skip rows (Balanced) resulted in 70–80% greater forage yield than the 76-cm rows with traditional planting patterns (BMP + CC) due to their ability to allow for significant light interception. Furthermore, we found that the forage produced in this study was of greater nutritional quality than the corn silage. Given the success of the interseeded forage crop, we discovered that interseeded forage in this study could offset more than 10% of the grain losses. Taken together, these findings demonstrate that 152-cm forage cover crop systems can be successfully deployed and managed by early-adopter producers. However, given the limited literature, there is a significant need to evaluate this system across more sites and years. The development of BMP for wide-row corn will need to be developed before agricultural practitioners will be able to recommend this cropping system for a large number of producers in the Midwest.

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