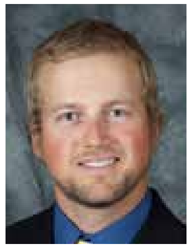
Feasibility of Integrating Cover Crops into Irrigated Barley



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Abstract

Cover crops are becoming more widely accepted as a viable management practice because of their ability to provide important environmental and soil health benefits. However, adoption of cover crops remains low in certain areas, and the high cost of cover crop integration into irrigated crop rotations appears prohibitive. This paper evaluates cover crop options and management practices to determine if different cover crop scenarios can provide additional income to producers.

INTRODUCTION

Poor irrigated cropland management can lead to stressed or strained soil, requiring changes in practices to retain or improve productivity. In order to maintain or improve soil health, agricultural producers must understand and utilize a variety of sustainable management practices to add resiliency to their farming operations. Hurisso et al., (2015) conducted an on-farm study in Wyoming's Bighorn Basin, where they found very low soil organic matter with sugarbeet-barley rotations. However, when compared to soils under more diverse cropping rotations (sugarbeet-barley-alfalfa-alfalfa), the resulting soils showed improved soil quality, which led to higher sucrose yields in the sugarbeet crop. While longer and more diverse crop rotations is one management tool producers may be able to use to help improve soil health, incorporating cover crops into the existing rotation is another to consider. The use of cover crops is increasing in popularity as an option to address poor soil health and improve soil quality. Cover crops, such as grasses, legumes, and forbs, are planted for seasonal cover and other conservation purposes (USDA-NRCS, 2010) and may offer agronomic benefits to systems with poor soil health (Hartwig and Ammon, 2002).

Cover crops are becoming increasingly popular in modern agriculture due to their potential to provide benefits to a cropping system (USDA-NRCS, n.d.) including, but not limited to, reduced erosion, increased soil organic matter, improved soil water holding capacity, forage production, and increased soil microbial biomass (Drewnoski et al., 2018). However, the biological benefit of cover crops isn't often immediately observed, making some producers question their economic benefit. Further, due to a short growing season, incorporating cover crops into modern cropping systems requires a greater need for timeliness of management (Drewnoski et al., 2018).

Producers may be hesitant to utilize cover crops for an entire growing season because of lost revenue that would have been realized from growing a cash crop in that field. In addition, if producing winter cover crops, which are planted at the end of a cash crop growing season, concerns over soil moisture depletion and water scarcity may hinder adoption of cover crop use. Another issue with a late season cover crop planting is that the limited growing season in semiarid, cold desert environments limits biomass growth and production potential.

DATA AND METHODS

This research examines the economic performance of different cover crops and management options as compared to the baseline of the absence of cover crops in a sugarbeet-barley rotation. Specifically, we compare the economic outcomes of three different cover crop types combined with three different cover crop management practices to a baseline scenario without any cover crops in the Big Horn Basin of Wyoming.

Study Area

The Bighorn Basin in the northern part of Wyoming is classified as a semiarid climate with 30-year (1981-2010) annual average precipitation of 6.80 inches and monthly average temperatures ranging from 7.7˚F to 85.5˚F (Western Regional Climate Center, 2016). The data included in our analysis come from research trials at the University of Wyoming Powell Research and Extension Center (PREC) and on six different farms in the Bighorn Basin, WY, and the lower Yellowstone River Basin, MT. The on-farm sites were selected after consultation with local extension educators, NRCS employees, local agronomists, and local producers. Previous research examining soil organic matter and nutrient content in the Bighorn Basin of Wyoming and surrounding areas found that the two-year rotation between sugarbeet and barley, combined with intensive tillage and irrigation, led to deteriorated soils. Further, Hurriso et al., (2014) found that the cessation of tillage alone did not prove to be sufficient for the recovery of soil organic matter within the study's 10-year time frame.

Treatments

The three cover crop types, along with planting and weed control protocols and the composition of the mix, were selected by a group of stakeholders that included cooperating farmers, MT and WY extension specialists, consulting agronomists, and a cover crop producer at a project inception meeting in June 2018.

Volunteer barley is an easy method that many producers utilize by not tilling in the fall, but rather letting the volunteer regrowth produce biomass until the first freeze in late fall. However, this strategy does not always result in a good stand due to little barley seed being left after harvest. This is a low-cost option for producers because it doesn't require any additional seed purchase, and the only additional inputs for this scenario are discing the field to stimulate barley growth and subsequent irrigation of the regrowth. A major disadvantage to this scenario is no new forage species are introduced to the system, so biodiversity does not increase.

Replanted barley, which consists of volunteer barley and additional barley replanted after harvest at a rate of 75 lb ac^{-1}, is also a low-cost possibility for producers. In this scenario, the producer plants some harvested barley directly back into the field. When comparing to the volunteer barley option, there is potentially more biomass growth in the replanted scenario so that the agronomic effects could be increased. However, while additional biomass can help with the stand establishment and production, it can also potentially negatively affect the barley growth due to stunting from overcrowding. As with volunteer barley, a disadvantage to this scenario is no new forage species are introduced, so biodiversity is not improved.

An alternative cover crop mix consisting of volunteer barley, nematode-control radish (*Raphanus sativus L.*), flax (*Linum usitatissimum L.*), forage collards (*Brassica oleracea L.*), and common vetch (*Vicia sativa Roth*) was offered as an additional option. The diverse cover crop mix is important as it has the potential to improve biodiversity within the system. Also, including legumes in the mix introduces the opportunity to increase soil nitrogen levels due to nitrogen fixation. The cover crop mix is planted into the barley stubble as soon as possible after harvest. A potential issue with the cover crop mix is the volunteer barley establishing more quickly and vigorously than the cover crop species, negatively affecting growth of the selected species. If volunteer barley outcompetes the cover crop mix, the producers do not benefit from the species that were selected while still incurring the extra cost of the mix.

In addition to the three cover crop types, three management options were identified by the stakeholder group for this study: green manure, haying, and grazing. Green manure is a common management option where the above ground biomass is incorporated back into the soil, usually through plowing, as a means to increase soil organic matter (Pratt and Wingenbach, 2016). Plowing under the biomass is usually accomplished through heavy tillage, a management option that is believed to enhance soil health by returning more organic matter to the soil compared to other management options. In this scenario, producers improve soil microbe diversity, maintain or improve soil structure, and provide readily available nutrients to the subsequent crop. Here, the cover crop is grown exclusively for soil benefits and not for harvest or grazing. Rather than harvest or graze the cover crop, it is plowed into the soil. The largest disadvantage to the green manure scenario is lack of immediate financial return—producers pay the input costs on these cover crops and incur the cost of management (e.g., establishment costs and plowing the cover crop into the soil) and have no financial return that year. They assume that the benefits will come through improved soil fertility and improved yields in subsequent crops.

Haying is a popular option for producers because they receive immediate benefits from the cover crop as harvestable feed for livestock. In both the on-station and on-farm trials, the cover crop was grown until it was terminated by frost (late September/early October), at which point it was swathed and baled. The remaining residue is either incorporated or used as cover for the sugarbeet crop the following spring. In the study, minimal tillage was used to incorporate cover crop residues in the spring.

The management option of haying potentially provides the least benefit to the soil because you are removing most of the above ground biomass as hay and only incorporating the roots and residue into the soil. However, the roots and cover crop stubble still provide benefits to the soil by reducing erosion, trapping snow and rainfall to improve soil hydraulics, and maintaining or improving soil structure. Since the forage produced is an immediate benefit, this could aid in adoption of these practices in the short term, improving the long-term health and resilience of this system. The three cover crops averaged a dry matter crude protein of 15.92%, dry matter total digestible nutrient of nearly 70%, and a dry matter acid detergent fiber analysis of 28.56%. This allowed the cover crop hay to be sold at alfalfa hay prices, since nutrient composition from the cover crop hay is similar to alfalfa.

The last management option that was considered for this research was grazing the cover crops. Livestock grazing returns via Animal Unit Days, like haying, can provide immediate revenue (or cost savings for livestock producers) and in turn increase the likelihood of adoption of cover crops. Many producers find it hard to overcome the time and money investment in cover crops alone (Hayden et al., 2018), and integration of livestock can overcome these challenges in a manner that can lead to increased soil quality and overall agroecosystem resilience (Carvalho et al., 2018). Rakkar & Blanco-Canqui (2018) have shown that moderate grazing may increase soil organic matter (SOM) content compared to no grazing, however overgrazing can decrease SOM content in the long term. Bardgett et al., (2001) reported that high stocking rates and grazing intensity can have negative impacts on soil properties, which is an important aspect to consider from a management standpoint. Also, with the removal of aboveground cover crop biomass for forage, the benefits to soil quality can still be realized and can provide extra income to producers (Franzluebbers & Stuedemann, 2014). The extra income associated with grazing leases can help to encourage farmers to adopt cover crops even with the extra costs (Sulc & Tracy, 2007). In this study, cattle begin to graze the cover crop after growth stops in late October/early November.

Unlike haying, where biomass is strictly removed, livestock remove biomass in grazing but also add organic matter back through manure. The recycled nutrients in the form of manure can have a positive effect on soil fertility (Liebig et al., 2012), returning about 75-85% of the forage nutrients back to the soil (Whitehead, 2000). The biggest disadvantage to incorporating livestock into a cover crop system is time and management. Producers are often short on labor and time, and an additional enterprise such as cattle or sheep may not be feasible. Renting out the cover cropped areas to other producers who already own livestock may be an acceptable option. In this scenario, a grazing fee is charged by the landowner to the livestock owner for the cover crop grazed.

Our study includes nine total combinations of treatments, three different cover crop strategies paired with three different uses of each cover crop option. Using data gathered from both on-station and on-farm trials as well as custom rate and economic and market data, nine separate partial budgets were created to evaluate all management combinations (Table 1).

Establishment

The on-station experiment was initiated during the barley phase of a long-term bean-barley-sugarbeet rotation experiment established at PREC in 2014 with conservation and conventional tillage treatments. Three replications of each of the 12 crop-tillage-irrigation treatments were grown each year, resulting in 36 plots, each 13.5-m wide by 37-m long. After barley harvest, three cover crop treatments (volunteer barley (VB), replanted barley (RB), cover crop mix (CC)) were established as split plots (hayed, not hayed) in the conservation tillage replications and allowed to grow until late fall when they were terminated by frost. A no-cover-crop control plot was established in the adjacent conventional tillage plots. Sugarbeet was planted the following spring on the cover crop plots.

For on-farm scenarios, all farms that were selected for the study implemented both conservation tillage and cover crop use for several years prior to the study. The on-farm plots consisted of one acre of the cover crop mix planted by each farmer within a larger field of barley stubble. Treatments included the three cover crop types in split plots, where biomass was removed by haying or grazing from one split and not removed from the other. The volunteer barley plots were established by leaving a strip adjacent to the cover crop without replanting barley into the barley regrowth. The replanted barley plots were established by the producers that already replanted barley in their fields. The cover crop mix was the same as the on-station mix with the same establishment methods (Bush, 2020).

The plots were grazed or hayed depending on the producer's current management practices. If the treatments were grazed, a 4- by 7-m grazing exclosure was built with steel fence panels to prevent biomass removal from small plots across the three cover crop types. If hayed, the same area that was enclosed at the grazed site was left uncut in the producer's field. This amounted to six treatments on each farm for a total of 48 on-farm plots. Each farm was considered a replicate and one forage sample was collected from each treatment for each sampling time (Bush, 2020).

Partial Budgets

A partial budgeting approach was used to quantify how the nine combinations of cover crops and management options compare to the baseline scenario of sugarbeet-barley rotation without cover crops. There are four major components of a partial budget: additional costs, reduced income, additional income, and reduced costs. By subtracting the additional costs and reduced income from the additional income and reduced costs, we can estimate the difference in net income from the proposed change. It is important to note that partial budgets show relative gains and losses to income resulting from a certain change in production, not absolute profitability.

All field operations and production data used in the partial budgets were averaged across the research and on-farm trials that participated in each cover crop/management combination. Reported market prices for malt barley, corn, alfalfa, sugarbeet, feed barley, and pasture rent per Animal Unit Month were collected from USDA-NASS (USDA-NASS, 2017a-e). Other costs, such as fencing, were estimated by average local prices. Fencing is assumed to be a single strand electric fence and is based on a square 50-acre field, with estimated fencing costs at $19.34 per acre. All historical prices were deflated to 2019 dollars using the producer price index (PPI) (U.S Department of Labor, 2019). For a full list of costs and filed operations, see Asay (2021).

Monte Carlo Simulation

To include the impact of historical price variation on financial outcomes, Monte Carlo simulations (@RISK, Palisade Corporation, 2010) were used to estimate expected changes in returns of each cover crop and management combination as compared to the control. This tool also allowed the use of historical data to fit data to a probability distribution. The batch fit tool fit probability distributions to multiple data series (Palisade Corporation, 2010). Table 2 shows the average of observed adjusted prices, along with distributional parameters for all variables that were found using the batch fit process (Palisade Corporation, 2010). The batch fit tool also returned a matrix of correlations calculated between multiple data series to evaluate which series were related and to what degree (Table 3). The matrix of correlation was also used by the model when randomly drawing variables, so that all variables were still correctly correlated to one another.

The relative gain/losses associated with each of the cover crop and management options were compared to the control over 100,000 simulations, using random draws for prices based on the parameter values in Tables 2 and 3. Tukey's LSD test was used to compare differences of means of the 100,000 iterations across scenarios.

RESULTS INCLUDING SUGARBEET YIELD IMPACTS

The mean, 5th percentile value (5th %), and 95th percentile value (95th %) of the 100,000 observations of the Monte Carlo simulation for each partial budget are listed in Table 4. These values represented the gain or loss to net income (average) as compared to relative profitability to standard farming practices with no cover crops. All scenarios differed from one another at the 5% level (Tukey's LSD).

It is important to note that much of the negative impact seen in the partial budget results was due to decreases in the subsequent sugarbeet crop yield. Table 5 shows all the sugarbeet yield impacts from the field trials included in the partial budgets. The average sugarbeet yield after the cover crop was 27.11 tons per acre, an average decrease of 2.92 tons per acre in sugarbeet yield the year after cover crops were grown.

RESULTS EXCLUDING SUGARBEET YIELD IMPACTS

When using replanted barley as the cover crop and then incorporating the biomass as green manure, removing the effects of the decreased sugarbeet yield changed the loss to net income of RB GM from $360.80 to a net loss of only $31.83. In this situation, assuming the 20-year average sugarbeet price of $53.49, a producer would need to see a yield increase of 0.60 tons per acre to breakeven in one year.

The expected loss or gain to net income for all nine scenarios assuming no impact to sugarbeet yield are listed in Table 6. Green manure still had a loss to net income across all three cover crop options, due to the lack of any immediate financial returns. Haying the cover crop presented a gain to net income across all three cover crops as the cover crop hay can be sold, increasing net revenue. Grazing had a negative result for net income when using the cover crop mix and replant barley options, as grazing revenues were not high enough to cover the cover crops' establishment and fencing costs. However, grazing the volunteer barley had a positive net income because volunteer barley had such low establishment costs that the grazing revenues were able to surpass the costs and create a gain to net income.

We also calculated the breakeven yields for low, average, and high prices using the first quartile (25%) $47.88, average (50%) $53.49, and third quartile (75%) $59.55 prices for historical sugarbeet prices, which can be seen in Table 7. Across all price scenarios CCHAY, VBHAY, VBGRZ, and RBHAY do not require a yield boost to breakeven. In these scenarios, revenues from either haying or grazing were large enough that they could compensate for drops in sugarbeet yields and still have a positive impact to the net income as compared to the baseline. The other five scenarios, however, required an increase in yield, ranging from 0.29 tons per acre to 1.35 tons per acre, to cover the costs associated with cover crops. This represented an increase in subsequent sugarbeet yield of 0.97% to 4.5% based on the control yields from this study.

This implies that total tons harvested per acre would need to increase from the control group of 30.03 tons per acre to a range of 30.32 tons per acre to 31.38 tons per acre, depending on which cover crop and management option was used.

While there are few published studies that report potential yield increases in sugarbeet from cover cropping practices, this increase may be feasible given the study by Miguez and Bollero (2005), which reported that a biculture (combination of legume and grass species) winter cover crop increased corn yields by 27%. However, there is also a study that concludes there may be a 10% reduction in wheat yield following a cover crop (Nielson et al., 2015). There is also a study that determined cover crops had no compromising or beneficial impacts on soybean and wheat yields (Hunter et al., 2019). It is apparent that there is no clear consensus on how much of a yield boost should occur following cover crops, or if a yield boost should be expected at all.

Sugarbeet yield is not measured in quantity only, but also quality through sugar content of the sugarbeet crop. Sugar content of the control plots averaged to be 15.14%, with the average sugar content of all test plots at 15.16%. There was no statistically significant difference between the control plots and the test plots, nor was there a statistically significant difference in sugar content between all cover crop management scenarios. The lack of a statistically significant difference in sugar content leads us to conclude that a boost in yield quality is not to be expected, yet a boost in yield quantity may be possible.

SUMMARY AND CONCLUSIONS

Debate remains whether cover crops improve subsequent crop yield. Our assumptions can provide some insight on the potential impacts cover crops have on sugarbeet yields and farm profitability, for example, we can show which scenario is most profitable, accounting for the sugarbeet yield effects realized by our study. We can also show the sugarbeet yield required for each of the potential cover crop and management options. However, a producer must have a clear goal for incorporating cover crops before comparing the expected outcomes of various strategies to help guide adoption of cover crop type and management option.

Based on the impacts to subsequent yields of sugarbeet observed in this study, from a maximum profit perspective, producers should choose to hay replanted barley (RBHAY) as that combination of cover crop type and management is expected to provide the highest gain to net revenue. RBHAY increased expected net revenue by over $485 per acre on average. This is not $485 per acre in profit, but rather a $485 per acre increase in profit compared to a no cover crop control. RBHAY has an expected average net revenue nearly $200 per acre higher than the second-best option of haying the cover crop mix (CCHAY), which has an average gain to net revenue of nearly $300 per acre. RBHAY's net revenue is almost $850 per acre higher than that of the green manuring the replanted barley (RBGM), which had the greatest average loss to net revenue of over $360 per acre.

The preferred cover crop/management option may change, however, if the producer's goal is simply improving soil health. This goal would focus less on the immediate economic impacts of cover crops and more on the agronomic benefits of management. Scenarios including green manure or grazing would likely be more suitable for these conditions, given that both management options offer returns to the soil as opposed to haying, which simply removes biomass. Green manure returns all the grown biomass back into the soil and increases soil organic matter levels (Pratt and Wingenbach, 2016). Grazing does remove biomass, however, and unlike haying, livestock also add organic matter back through manure. The recycled nutrients in the form of manure can have a positive effect on soil fertility (Liebig et al., 2012). Recycled nutrients could also help to return about 75-85% of the nutrients back to the soil (Whitehead, 2000).

The cover crop mix yielded the most forage at 1.75 tons per acre, while volunteer barley and replanted barley yielded 1.68 tons per acre and 1.39 tons per acre, respectively. This data would then suggest that the cover crop mix would be most beneficial to soil if the entirety of forage biomass was used for green manure or grazed with the nutrient cycling effects of livestock. Under this assumption, either cover crop green manure (CCGM) or cover crop graze (CCGRZ) would be the most likely scenarios to improve soil health.

With the data available, we can conclude which cover crop option is best for each management option, as well as which management option is best for each cover crop option. If the management option of green manure is incorporated into production cycles, then the cover crop mix would offer the best results regarding net revenue. If haying is the management option of choice, then replanted barley should be the cover crop option used. When grazing the cover crop, the cover crop mix again offers the best result in net revenue. When choosing the best management option for each cover crop option, haying has the best net revenue for all cover crop options compared to the other management options.

Since there is no clear consensus on cover crops' effects on subsequent yields, the sugarbeet yield data were removed from the partial budgets to estimate the required sugarbeet yield impacts required to cover the costs of cover crop inclusion in a standard barley/sugarbeet rotation. This analysis allowed the cover crop management options to be ranked by their cost effectiveness regarding impacts to sugarbeet yield. The sugarbeet yield in subsequent years required for breakeven can be seen in Table 8. Changes in prices would not affect the rankings of these scenarios, but it would affect the breakeven yield amounts. Haying volunteer barley (VBHAY) proves to be the most cost-effective scenario as it requires the lowest sugarbeet yield to breakeven. However, producers should use their own discretion to choose which scenario best fits their production system and management goals. For example, producers who need additional livestock feed may prefer any of the haying or grazing as opposed to those that implement green manure.

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Table 1. Different Budget Scenarios

		Management Option	
		Green Manure (GM)	Hay (HAY)	Graze (GRZ)
Cover Crop Option	Pure Cover Crop Mix (CC)	1 - CC/GM	2 - CC/HAY
	Volunteer Barley (VB)	4 - VB/GM	5 - VB/HAY
	Replant Barley (RB)	7 - RB/GM	8 - RB/HAY

Table 2. Price Distribution Parameters Used in Monte Carlo

Data Series	Barley	Corn	Alfalfa	Sugarbeet	Feed Barley	Pasture Rent
Average	4.63	4.04	148.58	53.49	3.55	20.08
Best Fit	Uniform	Triangle	Pareto	Normal	Triangle	Uniform
SD	0.9893	1.0993	32.5276	9.8157	0.8428	2.7193

Table 3. Correlations of Price Data Used in @RISK Analysis

Correlation	Barley	Corn	Alfalfa	Sugarbeet	Feed Barley	Pasture rent/ac
Barley	1.000					
Corn	0.851	1.000				
Alfalfa	0.632	0.626	1.000			
Sugarbeet	-0.234	0.065	-0.304	1.000		
Feed Barley	0.463	0.679	0.567	0.232	1.000	
Pasture rent/ac	-0.534	-0.762	-0.299	-0.238	-0.608	1.000

Table 4. Distributions of Profitability by Scenario in @RISK

Scenario	Average	SD	CV	5th %	95th %
CC GM	-$196.87[a]	$24.24	-0.12	-$236.75	-$157.00
CC HAY	$299.84[b]	$56.08	0.19	$240.47	$396.50
CC GRZ	-$292.85[c]	$53.57	-0.18	-$381.27	-$204.85
VB GM	-$253.13[d]	$43.29	-0.17	-$324.33	-$181.93
VB HAY	$89.83[e]	$63.08	0.70	$23.02	$202.55
VB GRZ	-$424.26[f]	$85.60	-0.20	-$565.28	-$283.61
RB GM	-$360.80[g]	$60.68	-0.17	-$460.76	-$260.92
RB HAY	$485.21[h]	$66.59	0.14	$392.24	$593.32
RB GRZ	-$352.48[i]	$67.60	-0.19	-$463.99	-$241.53

Note: Superscript letters denote significance at the 0.05 level

Table 5. Subsequent Sugarbeet Crop Yield Changes when Including Cover Crops as Compared to the Control			
	GM	**HAY**	**GRZ**
CC	-2.47	2.5	-5.07
VB	-4.41	-2.12	-8.37
RB	-6.15	6.35	-6.26

Table 6. Average Net Income or Loss for Each Scenario Assuming no Impact to Subsequent Sugarbeet Yields			
	GM	**HAY**	**GRZ**
CC	-64.75	166.11	-21.65
VB	-17.23	228.23	23.47
RB	-31.83	145.54	-1.58

Table 7. Sugarbeet Yield Change Required to Breakeven across Low, Average, and High Sugarbeet Prices			
Scenario	**Low**	**Average**	**High**
CC GM	1.35	1.21	1.09
CC HAY	-3.47	-3.11	-2.79
CC GRZ	0.45	0.40	0.36
VB GM	0.36	0.32	0.29
VB HAY	-4.77	-4.27	-3.83
VB GRZ	-0.49	-0.44	-0.39
RB GM	0.66	0.60	0.53
RB HAY	-3.04	-2.72	-2.44
RB GRZ	0.03	0.03	0.03

Table 8. Breakeven Subsequent Sugarbeet Yield Required to Cover Costs Associated with Cover Crop Management Scenarios Assuming Average Crop Prices		
Rank	**Scenario**	**Sugarbeet Breakeven Yield (tons/ac), Average Prices**
1	VB HAY	25.76
2	CC HAY	26.92
3	RB HAY	27.31
4	VB GRZ	29.59
5	RB GRZ	30.06
6	VB GM	30.35
7	CC GRZ	30.43
8	RB GM	30.63
9	CC GM	31.24