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Hanxiao Feng

Tong Wang

Shannon L. Osborne

Sandeep Kumar

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Yield and economic performance of crop rotation systems in South Dakota

Hanxiao Feng[1] | Tong Wang[2] | Shannon L. Osborne[3] | Sandeep Kumar[1]

[1] Dep. of Agronomy, Horticulture and Plant Science, South Dakota State Univ., Brookings, SD 57006, USA
[2] Ness School of Management and Economics, South Dakota State Univ., Brookings, SD 57006, USA
[3] USDA-ARS North Central Research Laboratory, 2923 Medary Ave., Brookings, SD 57006, USA

Correspondence
Shannon L. Osborne, USDA-ARS North Central Research Laboratory, 2923 Medary Ave., Brookings, SD 57006, USA.
Email: Shannon.Osborne@usda.gov

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Abstract
Crop yield and economic profitability, both highly dependent on local crop management, soil characteristics, and weather conditions, are among the most influential factors to consider when considering a cropping system. The objective of this study was to compare the economic returns of three different 4-yr diverse crop rotations with that of a 2-yr traditional crop rotation in eastern South Dakota. The rotations included were (a) corn (*Zea mays* L.)–soybean [*Glycine max* (L.) Merr.]–spring wheat (*Triticum aestivum* L.)–pea (*Pisum sativum* L.) (CSSwP), (b) corn–pea–winter wheat–soybean (CPWwS), (c) corn–oat (*Avena sativa* L.)–winter wheat–soybean (COWwS), and (d) corn–soybean (CS). Results showed that total cost for the CS rotation was 7.2, 14.9, and 18.2% greater than the COWwS, CSSwP, and CPWwS rotations, respectively. Whereas CS rotation had comparable corn yield with CSSwP and COWwS rotations, its soybean yield ranked the lowest among all the rotations. When N fertilizer application fell below the level necessary to achieve for yield maximization, the CS rotation demonstrated a lack of resilience as indicated by a continual decline in economic returns over time. In comparison, the CSSwP rotation demonstrated high resilience to reduced N fertilizer application rate, and its net revenue was the highest among all rotations and surpassed the CS. Our results suggest that extending the traditional CS rotation to the more diversified CSSwP rotation could simultaneously reduce input costs and overreliance on N fertilizer.

1 | INTRODUCTION

Corn (*Zea mays* L.)–soybean [*Glycine max* (L.) Merr.] (CS) rotation is the most commonly used rotation in the midwestern United States and can be attributable to factors such as simple management, similar equipment requirements between corn and soybean, and availability of genetic modified seed to control pest problems (Karlen et al., 2006; Yu et al., 2018). Relatively high market prices for corn and soybean also provide additional incentives for the expansion of planted corn and soybean acres (Meyer-Aurich et al., 2006). Despite the advantages to agricultural producers, the long-term usage of CS rotation potentially jeopardizes soil health and crop production by altering the soil microbial activities and other soil properties. Previous studies demonstrated that long-term use of CS rotation led to decline in soil organic C (Drinkwater et al., 1998), reduction in soil reactive N (Hall et al., 2019; Tomer et al., 2017), loss of soil aggregate stability (Zuber

Abbreviations: COWwS, corn–oat–winter wheat–soybean; CPWwS, corn–pea–winter wheat–soybean; CS, corn–soybean; CSSwP, corn–soybean–spring wheat–pea.

et al., 2015), and reduction in crop yield (Smith et al., 2008). Moreover, CS rotation can potentially reduce bacterial richness and diversity (Venter et al., 2016; Zhou et al., 2015) and fungal biodiversity and abundance (Ding et al., 2017), meanwhile posing the risk of long-term soil degeneration (Katsvairo & Cox, 2000; Yin et al., 2015). Therefore, heavy application of fertilizer and herbicide are often needed to optimize yield and economic benefits in simple crop rotation systems (Lassaletta et al., 2016; Lemaire et al., 2008), which renders simple production system overreliant on external inputs and vulnerable to increasing input prices.

Extending CS rotation to more diversified crop rotation systems has numerous environmental and economic benefits, including but not limited to building suitable environment for crop growth through soil fertility regulation (Gaudin, Tolhurst, et al., 2015), fully using various nutrients in the soil, and lowering the reliance on the commercial fertilizer inputs (Gaudin, Janovicek, et al., 2015; Van Eerd et al., 2014). For example, integrating leguminous plants into cropping systems can help add additional N to the soil (Lupwayi & Soon, 2016a, 2016b), which subsequently reduces input costs due to crops' improved ability to utilize nutrients (Ali et al., 2012). Additionally, diversified crop rotation systems potentially reduce economic losses by reducing pest and disease outbreak (Smith et al., 2008; Stanger et al., 2008) and minimize crop yield losses and yield variability caused by natural disasters (Di Falco & Chavas, 2006).

Crop yield is an important factor to consider when choosing a cropping system (Katsvairo & Cox, 2000). Various studies found that diverse crop rotations maintained or improved crop yields compared with the simple monocropping or short CS rotation. For example, Davis et al. (2012) reported that corn–soybean–small grain/red clover (*Trifolium pratense* L.) rotation and corn–soybean–small grain–alfalfa (*Medicago sativa* L.)–alfalfa rotation increased corn and soybean yields by 4 and 9%, respectively, compared with the CS system. Similarly, Borrelli et al. (2014) found that corn yield under continuous corn treatment was significantly lower than that of corn in a triennial rotation (grain maize–barley [*Hordeum vulgare* L.]/maize–Italian ryegrass [*Lolium multiflorum* Lam.]/maize). Cavigelli et al. (2013) conducted a study in Maryland to compare management effects of different crop rotation systems on crop yield and economic return and found that the corn yield in a 6-yr rotation system (corn/rye [*Secale cereale* L.]–soybean–3 yr of alfalfa) was significantly greater than those under the 3-yr rotation (corn/rye–soybean–wheat [*Triticum aestivum* L.]/vetch [*Vicia sativa* L.]) and the 2-yr rotation (corn/rye–soybean/vetch). Additionally, Sindelar et al. (2016) found that replacing the CS rotation with corn–oat (*Avena sativa* L.)/clover–grain sorghum [*Sorghum bicolor* (L.) Moench]–soybean in the western Corn Belt near Ithaca, NE, under no-till system could improve corn yield.

Core Ideas

- Traditional corn–soybean rotation lacks resilience in economic performance at low N application rates.
- Diverse crop rotations achieve greater soybean yields than traditional corn–soybean rotation.
- Corn–soybean–spring wheat–pea rotation reduces input cost and improves economic returns.

Another important factor to consider when making crop management decisions is economic returns (Al-Kaisi et al., 2016). Previous research has reached inconsistent conclusions on the economic returns of different diversified cropping systems. A long-term (20 yr) study conducted in Ontario, Canada, by Meyer-Aurich et al. (2006) concluded that diversified crop rotation reduced net revenue variation and, therefore, was more resilient towards the crop production risks when compared with monocropping system. Similarly, a study conducted in Iowa demonstrated that the diversified corn–soybean–small grain/red clover rotation and corn–soybean–small grain–alfalfa–alfalfa rotation with lower N fertilizer input rates maintained similar economic returns as CS rotation at the fertilizer application rate based on soil test results (Davis et al., 2012). In contrast, the economic analysis of seven different cropping systems (continuous corn, continuous alfalfa, corn–alfalfa, CS, 2 yr of alfalfa following 3 yr of corn, corn–soybean–corn–oat/alfalfa–alfalfa–alfalfa, and corn–soybean–corn–oat/alfalfa–alfalfa) conducted on a Rozetta silt loam soil (fine-silty, mixed, superactive, mesic Typic Hapludalfs) in southwestern Wisconsin revealed that CS was the most cost-effective rotation with the highest net revenue compared with other rotations across all levels of N fertilizer application rates (0, 56, 112, or 224 kg N ha^{-1}) (Stanger et al., 2008).

Understanding crop yield and economic performances of different cropping systems facilitate producers' decision in selecting crop rotation systems. However, little information regarding the economic performance of diversified crop rotations is available in a transitional climate zone such as eastern South Dakota. Therefore, the objective of this study was to compare three 4-yr diverse crop rotations with the 2-yr CS rotation, using 4 yr of experimental data (2013–2016) from a long-term experiment established in fall 2000. We aim to identify the economically and environmentally sustainable cropping systems by comparing crop yields, production costs, gross and net revenues, and benefit/cost ratios across different crop rotation systems.

TABLE 1 Crop rotations under different management systems in the field experiment from 2013 to 2016 conducted in Brookings, SD

Rotations[a]	2013	2014	2015	2016
CPWwS	Corn	Pea	Winter wheat	Soybean
	Pea	Winter wheat	Soybean	Corn
	Winter wheat	Soybean	Corn	Pea
	Soybean	Corn	Pea	Winter wheat
CSSwP	Corn	Soybean	Spring wheat	Pea
	Soybean	Spring wheat	Pea	Corn
	Spring wheat	Pea	Corn	Soybean
	Pea	Corn	Soybean	Spring wheat
COWwS	Corn	Oat	Winter wheat	Soybean
	Oat	Winter wheat	Soybean	Corn
	Winter wheat	Soybean	Corn	Oat
	Soybean	Corn	Oat	Winter wheat
CS	Corn	Soybean	Corn	Soybean
	Soybean	Corn	Soybean	Corn

[a]CPWwS, corn–pea–winter wheat–soybean; CSSwP, corn–soybean–spring wheat–pea; COWwS, corn–oat–winter wheat–soybean; CS, corn–soybean.

2 | MATERIALS AND METHODS

2.1 | Study site

A long-term no-till crop rotation experiment was established in fall 2000 at the Eastern South Dakota Soil and Water Research Farm near Brookings, SD (44°19′ N, 96°46′ W; 500-m elevation), located at Hardiness Zone 4b (https://planthardiness-ars-usda-gov.nal.idm.oclc.org/PHZMWeb). On average, the research site receives annual precipitation and average temperature of 616 mm and 6.15 °C, respectively (NOAA, 2019). Soil was classified as Barnes clay loam soil (fine-loamy, mixed, superactive, frigid calcic Hapludolls), with more detailed soil characteristic information available in Lehman et al. (2017). Experiment treatments included three 4-yr diverse crop rotations and a conventional 2-yr CS rotation, which were (a) corn–soybean–spring wheat–pea (*Pisum sativum* L.) (CSSwP), (b) corn–pea–winter wheat–soybean (CPWwS), (c) corn–oat–winter wheat–soybean (COWwS), and (d) CS. The experimental design was a randomized complete block design using four replications with each crop phase presented each year. The dimension for each plot was 6 m wide by 15 m long. This experiment was initiated in 2000 with every 4-yr period serving as a complete rotation cycle. The data for this study were collected during the fourth complete rotational cycle (2013–2016) for the four previously mentioned rotations. Treatment structure for different management systems during the study period is reported in Table 1.

In 2013, the beginning year of our study cycle, 100 kg N ha^{-1} was applied as urea ammonium nitrate to each corn plot, 115 kg N ha^{-1} as ammonium nitrate was applied to each oat plot, and 130 kg N ha^{-1} was applied as ammonium nitrate to each of the winter wheat and spring wheat plots. Thereafter, N fertilizer application rate was determined based on fall soil testing results and recommendations from South Dakota State University soil testing laboratory with an 85% of crop yield goal (corn = 7.84 Mg ha^{-1}; winter wheat = 4.03 Mg ha^{-1}; spring wheat = 3.36 Mg ha^{-1}; oat = 3.94 Mg ha^{-1}), with the exception that no fertilizer was applied in the pea and soybean phases of each rotation. Fertilization was reduced to allow the soil to maintain crop production and soil health through a self-regulating system rather than an artificially created environment that involves heavy application of commercial fertilizer (Liebman et al., 2008). Herbicide was applied for weed control during crop growing season when needed. Supplemental Table S1 lists the timing of fertilizer and herbicide application to all crop rotations. The crops were harvested with a plot combine (Massey Ferguson 8-XP, Kincaid Equipment Manufacturing), and yields were calculated using the associated electronic weigh bucket. The grain moisture was measured with a grain analysis computer (Dickey-John GAC2000). More detailed information of this experiment can be found in Lehman et al. (2017) and Osborne et al. (2020).

2.2 | Economic analysis

The total production costs considered in this study consist of machinery operation, fertilizer and herbicide, and seed. The machinery operations and harvesting charges were based on the average values obtained from Iowa custom rate cost survey between 2013 and 2016 (Edwards et al., 2013, 2014; Plastina et al., 2015, 2016), with the machinery costs for each crop listed in Supplemental Table S2. Soybean planting and harvesting costs information were used as substitutes for pea due to similar operation processes between the two. Prices received for all crops during studied years (2013–2016) were obtained from the National Agricultural Statistics Service (NASS) database (Supplemental Table S3). The prices of all crops were based on annual crop sale prices in South Dakota, except for pea, for which the North Dakota annual sale prices were used due to the price unavailability in South Dakota. The average of annual sale prices from 2013 to 2016 was used for each crop in the analysis. Average seed and fertilizer prices for all crops from 2013 to 2016 were based on the crop budgets for North Dakota (https://www.ag.ndsu.edu/farmmanagement/crop-budget-archive) due to unavailability of these prices in South Dakota (Supplemental Table S4). Herbicide active ingredient percentage and their average prices from 2013 to 2016 were obtained from *South Dakota Pest Management Guide Manual*. Crop insurance was not considered in this paper, as our objective is to identity which crop rotation system was more competitive without the intervention of insurance.

The gross revenue (US\$ ha^{-1}) for each crop in each rotation was calculated by multiplying the specific crop yield with the corresponding market price. The annual production cost (\$ ha^{-1}) for each rotation was computed by summing up the production costs of all crops in the rotation on a per-hectare basis and then dividing by four and two for the 4-yr rotations and 2-yr rotation, respectively, to obtain the system production cost on a per-hectare basis. The net revenue for each rotation was calculated as the difference between gross revenue and production cost.

2.3 | Statistical analysis

The data were analyzed using PROC GLIMMIX procedures in SAS software program (SAS version 9.4; SAS Institute, 2017), where crop rotation was considered as fixed effect, and year and replication were considered as random effects. Mean separation was calculated using Tukey–Kramer grouping when necessary. Statistical differences were stated at the 5% significance level.

3 | RESULTS AND DISCUSSION

3.1 | Production cost

The total cost for the 2-yr CS rotation ranked the highest among all crop rotations (\$432.88 ha^{-1} yr^{-1}) (Table 2). Specifically, total cost of the CS rotation was 7.2, 14.9, and 18.2% greater than that of the COWwS, CPWwS, and CSSwP rotations, respectively, and this trend is consistent throughout the 4-yr study period (Figure 1). High total cost for CS rotation was largely attributable to higher corn and soybean seed prices than those of small grains, followed by higher machinery costs (planting and harvesting costs) for soybean and corn in comparison with small grains (Table 2). Among the three 4-yr rotations, fertilizer application cost for COWwS rotation was greater than those under CPWwS and CSSwP rotations (Table 2), as three crops (corn, oat, and winter wheat) in the rotation required additional N fertilizer inputs. The total cost was the lowest for CSSwP and CPWwS, potentially because rotating two legume and two nonlegume crops increased the crop utilization of nutrients and N supply and, therefore, reduced the demand for fertilizer. An annual basis comparison showed total costs of all crop rotations declined from year 2013 to 2014 but increased afterwards due to the highest fertilizer input in 2013 and the lowest fertilizer input in 2014 for all crops (Figure 1).

TABLE 2 Total cost for corn–pea–winter wheat–soybean (CPWwS), corn–soybean–spring wheat–pea (CSSwP), corn–oat–winter wheat–soybean (COWwS), and corn–soybean (CS) rotations averaged across 2013–2016

Production costs	CPWwS	CSSwP	COWwS	CS
	US\$ ha^{-1}			
Machinery	192.46	194.50	188.65	208.21
Seed	94.66	94.66	94.39	142.48
Fertilizer	51.57	48.77	88.36	47.01
Herbicides	38.08	28.36	32.47	35.18
Total cost	376.76c[a]	366.29c	403.87b	432.88a

[a]Different letters for total cost show significant differences among different cropping systems ($p < .05$).

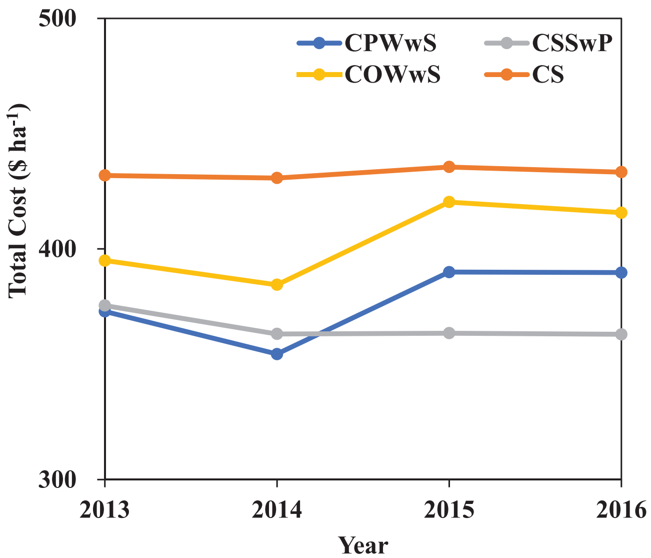

FIGURE 1 Annual total cost for four different cropping systems (corn–pea–winter wheat–soybean [CPWwS], corn–soybean–spring wheat–pea [CSSwP], corn–oat–winter wheat–soybean [COWwS], and corn–soybean [CS]) from 2013 to 2016

TABLE 3 Crop yield grown in corn–pea–winter wheat–soybean (CPWwS), corn–soybean–spring wheat–pea (CSSwP), corn–oat–winter wheat–soybean (COWwS), and corn–soybean (CS) rotations averaged over years 2013–2016

Crop rotation	CPWwS	CSSwP	COWwS	CS
	Mg ha^{-1}			
Corn	5.27c[a]	6.36a	5.99b	6.18ab
Soybean	2.41a	2.44a	2.31a	2.05b
Spring wheat	–	2.32	–	–
Winter wheat	2.84a	–	2.76a	–
Pea	2.54b	3.06a	–	–
Oat	–	–	3.04	–

[a]Different letters within each crop phase show significant differences among different cropping systems ($p < .05$).

TABLE 4 Net revenue for each crop in four crop rotations (corn–pea–winter wheat–soybean [CPWwS], corn–soybean–spring wheat–pea [CSSwP], corn–oat–winter wheat–soybean [COWwS], and corn–soybean [CS]) averaged across 2013–2016

Net revenue	CPWwS	CSSwP	COWwS	CS
	US$ ha^{-1}			
Corn	185.01c[a]	333.18a	282.52b	307.57ab
Soybean	538.85a	548.09a	500.33a	409.53b
Spring wheat	–	140.72	–	–
Winter wheat	150.05a	–	114.96b	–
Pea	454.68b	598.36a	–	–
Oat	–	–	205.99	–

[a]Different letters within each crop phase show significant differences among different cropping systems ($p < .05$).

3.2 | Crop yield

Crop yield varied across the different crop rotation systems, as indicated by average crop yields from 2013 to 2016 (Table 3). During the 4-yr study period, CSSwP rotation on average had significantly higher corn yield than the other 4-yr rotations. In contrast, CPWwS rotation had the lowest corn yield, which was 17.1, 14.7, and 12.0% lower than those of CSSwP, CS, and COWwS rotations, respectively. Such difference in corn yield across different 4-yr rotations could be attributed to synergy between corn and pea as corn following pea produced greater yield than corn following soybean. Anderson (2011, 2012) also found that corn grain yield was higher when the previous crop was pea, in comparison with soybean and spring wheat, and that the increase in corn yield could be attributed to increased microbial activity, resource use efficiency, and resistance to weeds.

Yields for soybean grown in all three 4-yr rotations (CPWwS, CSSwP, and COWwS) were significantly higher than soybean yield in the 2-yr CS rotation (Table 3). In this regard, our results were consistent with findings of previous literature. For example, Hunt et al. (2019) reported that diversified crop rotations (corn–soybean–oat/clover and corn–soybean–oat/alfalfa–alfalfa) increased soybean yield by 23.1 and 26.9%, respectively, compared with the traditional 2-yr CS rotation. Furthermore, increased soil nutrient (NO_3–N) availability in diverse crop rotations is beneficial for soybean production (Riedell et al., 2013). Compared with CS rotation, diverse crop rotations lower soybean disease outbreak risk (Hunt et al., 2019) and thus promote soybean yield.

Pea yield in CSSwP rotation was 20.5% higher compared with that in CPWwS rotation (2.54 Mg ha^{-1}). The preceding crops in these two rotations—namely, spring wheat and corn—had different root length densities at crop anthesis (Osborne et al., 2020), which may have led to different crops uptake of water and nutrients and altered the quantity and activity of microorganisms, and therefore resulted in different grain yields for the subsequently planted crops. The yield of winter wheat following pea in CPWwS was numerically higher than that following small grain in COWwS, though not statistically different.

3.3 | Economic returns and profitability comparison among crop rotations

3.3.1 | Profitability of specific crops

Net revenue of crops in different crop rotation systems, as indicated in Table 4, generally followed similar trends as crop yields in Table 3. A comparison across different crops indicated that legume crops (soybean and pea) were generally more profitable than corn, with pea generating comparable net revenue to soybean. Small grains were the least profitable crops in the rotations. In particular, winter and spring wheats generated less than one-third of the net revenue of soybean in the same rotation, whereas oats generated a net revenue that is less than one half of that for soybean. This could be due to the relatively lower market price, lower yield stability and the higher fertilizer cost for small grains when compared with legume crops. Similar findings were reported by Archer et al. (2018), who showed that oats, spring wheat, and winter wheat were less profitable than soybean and pea, because the average prices for soybean ($414 Mg^{-1}) and pea ($316 Mg^{-1}) were around 30.6–115.6% higher than that of oats ($192 Mg^{-1}), spring wheat ($242 Mg^{-1}), and winter wheat ($211 Mg^{-1}). Moreover, crop production cost of soybean (ranging from $310 to 332 ha^{-1}) and pea (ranging from $334 to 374 ha^{-1}) were much lower than those of oat ($415 ha^{-1}), spring wheat (ranging from $428 to 448 ha^{-1}), and winter wheat (ranging from $422 to 444 ha^{-1}). Net revenue for wheat was lower than that of corn and soybean due to its relatively low productivity and market price. Cai et al. (2019) and Stanger et al. (2008)

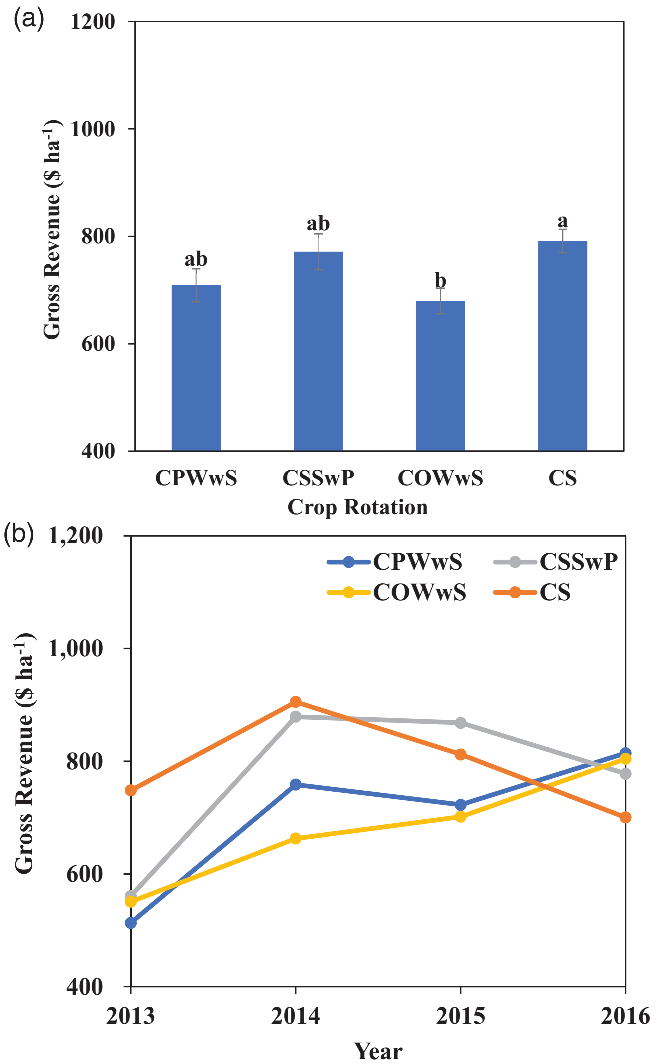

FIGURE 2 (a) Four-year average gross revenue and (b) annual gross revenue for four different cropping systems (corn–pea–winter wheat–soybean [CPWwS], corn–soybean–spring wheat–pea [CSSwP], corn–oat–winter wheat–soybean [COWwS], and corn–soybean [CS]) from 2013 to 2016. Different letters represent significant differences between cropping systems ($p < .05$) in Panel a. Error bars represent mean ± standard error

also concluded that corn and soybean prices were major contributors to higher economic returns for CS rotation in comparison with diversified crop rotations that include oats and alfalfa.

3.3.2 | Economic returns of crop rotation systems

Results for the rotation systems revenue indicated a significant difference among the 4-yr average gross revenue for three 4-yr rotation systems and the 2-yr rotation system (Figure 2a). Results showed that gross revenue of CS rotation was the highest (\$791.43 ha^{-1}), followed by CSSwP rotation (\$771.38 ha^{-1}), CPWwS (\$708.92 ha^{-1}) and COWwS (\$679.82 ha^{-1}), respectively. Our results showed consistency with Khaliq et al. (2012), who reported that gross revenue of wheat–corn–wheat rotation was greater than that of wheat–fallow–wheat and wheat–mung bean [*Vigna radiata* (L.) R. Wilczek]–wheat rotations, due to the higher monetary benefits of corn than of mung bean.

The results also revealed that the gross revenue for CS rotation in 2013 and 2014 was the highest among all rotations, yet a sharp drop occurred thereafter, and CS rotation ranked the lowest in gross revenue as of 2016. Specifically, the gross revenues of CPWwS, CSSwP, and COWwS rotations were 16.3, 11.1, and 14.9% higher, respectively, than that of CS rotation in 2016 (Figure 2b). This suggested that the gross revenue achieved by CS rotation is highly contingent on fertilizer application rate, or soil fertility conditions. Fertilizer, especially N, is a key factor in determining crop yield and economic return, which is essential for crop growth and production as it provides nutrients and maintains soil fertility (Stanger et al., 2008). However, overfertilization can lead to the N surplus translocated in environment through liquid or gaseous form and cause water and soil pollution, greenhouse gas emission problem, and imbalanced ecosystem (Sutton et al., 2013). A similar result was also reported by Coulter et al. (2011), who showed that CS rotation had comparable crop yield performance with that of diverse crop rotation (oat/alfalfa–alfalfa–corn–soybean) at high fertilization rate. However, when the fertilizer application was insufficient or the soil was less productive, the diversified crop rotations performed better (Berzsenyi et al., 2000; Jagadamma et al., 2008).

3.3.3 | Profitability of crop rotation systems

The net revenue of crop rotation systems was presented in Figure 3a. Higher gross revenue does not always lead to greater net revenue due to the differing amount of input costs. For instance, CS rotation has higher gross revenue than CSSwP rotation, yet CS might not be more economically profitable than CSSwP rotation, as higher total costs incurred by CS rotation offset its economic advantage. A comparison of annual net revenues among the rotation systems revealed that although CS was the most profitable among all the studied rotations in 2013, thereafter CSSwP became the economically superior rotation. By 2016, net revenue of all three 4-yr diverse rotations surpassed that of the traditional 2-yr CS rotation (Figure 3b), which is largely attributable to the highest total cost yet the lowest corn and soybean yields of CS rotation among all studied rotations. The CSSwP rotation has the highest 4-yr average net revenue (\$405.10 ha^{-1}), which was 13.0, 22.0, and 46.8% higher than the CS, CPWwS, and COWwS

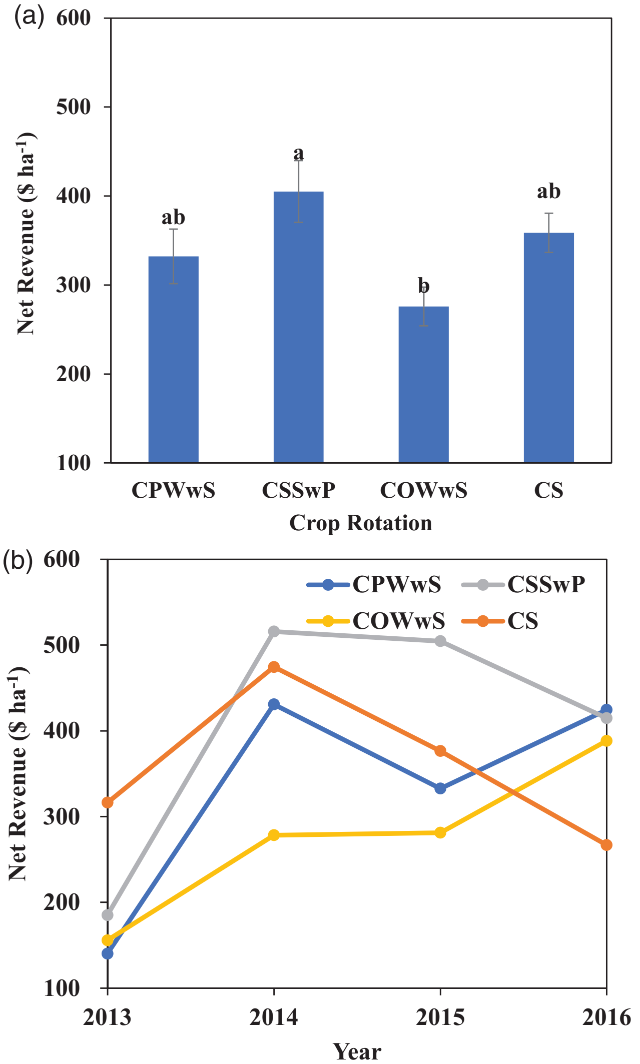

FIGURE 3 (a) Four-year average net revenue and (b) annual net revenue for four different cropping systems (corn–pea–winter wheat–soybean [CPWwS], corn–soybean–spring wheat–pea [CSSwP], corn–oat–winter wheat–soybean [COWwS], and corn–soybean [CS]) from 2013 to 2016. Different letters represent significant differences between cropping systems ($p < .05$) in Panel a. Error bars represent mean ± standard error

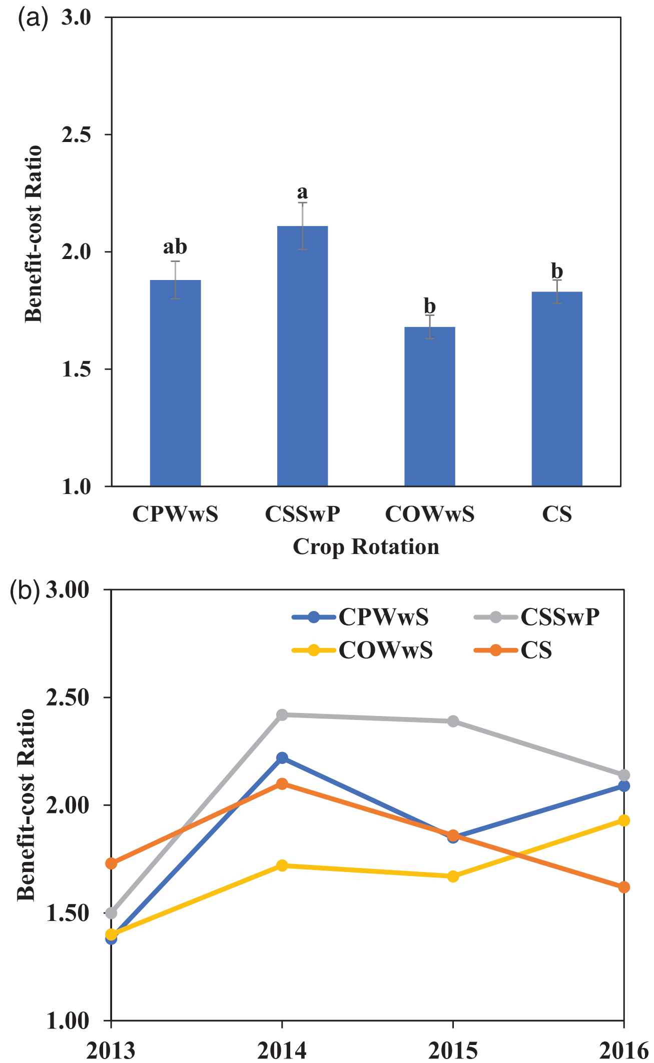

FIGURE 4 (a) Four-year average benefit-cost ratio and (b) annual benefit/cost ratio for four different cropping systems (corn–pea–winter wheat–soybean [CPWwS], corn–soybean–spring wheat–pea [CSSwP], corn–oat–winter wheat–soybean [COWwS], and corn–soybean [CS]) from 2013 to 2016. Different letters represent significant differences between cropping systems ($p < .05$) in Panel a. Error bars represent mean ± standard error

rotations, respectively (Figure 3a). The highest net revenue of CSSwP could be attributable to the comparatively low requirement for fertilizer, herbicides, relatively high yields, and market prices for all crops in this rotation.

In addition to the net revenue, benefit/cost ratio, calculated as the ratio of gross revenue to total cost, could also be used to help farmers select the economically feasible crop rotation (Chanda et al., 2019 ; Junaid & Ali, 2015). In our study, average benefit/cost ratio varied significantly among different crop rotation systems (Figure 4a). Similar to the net revenue, the benefit/cost ratio for CSSwP rotation was significantly higher than those of the other three rotations due to its lower input costs and higher crop yield. The average benefit/cost ratio for CPWwS ranked second among all the rotations, whereas COWwS and CS rotation had the lowest benefit/cost ratio. The annual benefit/cost ratio of each cropping system over the 4-yr study period demonstrated a trend similar to that of net revenue (Figure 4b). Even though the benefit/cost ratios of the CSSwP and CPWwS rotations were lower than that of the CS rotation in 2013, this trend was reversed over the next 3 yr of the study, indicating that these two 4-yr rotations were more economically resilient than CS rotation when less N fertilizer was applied. Among all rotation systems, the benefit/cost ratio of COWwS remained the lowest for all the years except for 2016, when it surpassed that of the CS rotation. The benefit/cost ratio results demonstrated that, compared with the other studied rotation systems, the CSSwP rotation system was more resilient with an insufficient external nutrient supply. Although both COWwS and CSSwP are 4-yr rotations, their economic performances were substantially different, likely because the net revenues of both legume pea and spring wheat in CSSwP were higher than those of oat and winter wheat, whereas total cost of CSSwP was lower than that of COWwS rotation.

4 | CONCLUSION

This study was conducted in eastern South Dakota to compare the crop yield and economic performance responses among the traditional CS rotation and three 4-yr diversified crop rotations. The results demonstrated that corn yield of CSSwP rotation was greater than those of the other 4-yr rotations, yet comparable with that of CS rotation. We found that all the 4-yr diversified crop rotations generated greater soybean yields than the 2-yr traditional CS rotation. Regarding economic performance, CSSwP rotation stands out from the other rotations both in terms of net revenue and benefit/cost ratio. Even though CS rotation demonstrated superior economic performance with sufficient fertilizer input, its benefit/cost ratio and net revenue on an annual basis indicated a lack of economic resilience at the reduced amount of N fertilizer. Our results suggested that extending the traditional CS rotation to the more diversified CSSwP rotation could help reduce reliance towards N fertilizer input, meanwhile increasing system resilience and economic profitability.

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AUTHOR CONTRIBUTIONS

Hanxiao Feng: Conceptualization; Formal analysis; Writing-original draft. Tong Wang: Conceptualization; Methodology; Supervision; Writing-review & editing. Shannon L. Osborne: Conceptualization; Formal analysis; Methodology; Supervision; Writing-review & editing. Sandeep Kumar: Conceptualization; Writing-review & editing; Funding acquisition.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ORCID

Tong Wang https://orcid.org/0000-0002-2363-4634
Shannon L. Osborne https://orcid.org/0000-0003-3458-3251
Sandeep Kumar https://orcid.org/0000-0002-2717-5455

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