Agro-Economic Returns were Reduced for Four Years after Conversion from Perennial Forage

P.R. Miller,* A. Bekkerman, J.A. Holmes, C.A. Jones, and R.E. Engel

ABSTRACT

Perennial crops are increasingly converted to annual cropping systems as Conservation Reserve Program (CRP) contracts expire. We compared crop yields and net returns across 2013–2018 for no-till pulse crop-wheat (*Triticum aestivum* L.) (P-W) systems, preceded either by 10 yr of P-W or 10 yr of perennial cropping (P-W^{Per}) at Bozeman, MT. The perennial mixed species planting, dominated by alfalfa (*Medicago sativa* L.), was split into unharvested and annually harvested treatments 2005–2012. The 2013–2018 experimental design included both systems replicated as main plots, with 50 and 100% recommended available N rates as subplots. Precipitation was below average during three of the first four growing seasons, followed by two wetter than average years. The P-W^{Per} system had generally lower soil moisture and equal or greater nitrogen supply than the P-W. 'Haying off' (reduced harvest index) occurred in wheat grown 2 and 4 yr after conversion from perennial to annual cropping, which reduced grain yield, and increased grain protein. Crop yield losses in the P-W^{Per} system averaged 0.84 Mg ha^{-1} (28%) over 4 yr and two N rates. After adjusting grain prices using historical discounts and premiums for test weight and protein content at Montana grain elevators, P-W^{Per} net returns were reduced for four consecutive years in three economic scenarios, and for 2 yr in a fourth scenario by a 4-yr cumulative average of (USD) \$731 ha^{-1} (45%). We conclude annual crop yield and economic returns were compromised for 4 yr following 10 yr of an alfalfa-dominated perennial cropping system.

Core Ideas

- Ten years of perennial forage generally reduced economic returns for 4 yr of subsequent annual cropping by an average of 45%.
- Grain yield was more negatively affected by perennial cropping than protein yield.
- Long-term assessment may be required to capture economic benefits of improved soil quality.

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The USDA Conservation Reserve Program (CRP) began in 1986 to assist owners and operators conserve highly erodible cropland (USDA Food Security Act of 1985; USDA Economic Research Service, 1986) and provide farmers with an alternative income source by removing annual cropland from production and sowing perennial plant cover. Initially in the northern Great Plains region, perennial CRP stands were commonly grass monocultures such as crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.), but as seed supplies increased over time for other perennial species, more complex perennial plant mixtures were planted, typically including both native perennial grasses and forbs such as alfalfa (*Medicago sativa* L.). A minimum contract period was typically 10 yr. Montana cropland enrolled in CRP peaked at 1.4 million ha in 2007 and declined to 0.5 million ha in 2018 (Fig. 1) as farmers converted CRP land back to annual cropping. The reduction was in part due to sustained high wheat prices (making returns to wheat production higher than CRP payments) and changes by the USDA to the CRP program that decreased the amount and type of acres enrolled.

During the conversion of land back into annual crop production, producers called for information about optimal methods for conversion and likely yield effects on annual crops. Despite this demand, research into conversion of perennial stands to annual cropping is rare in semiarid regions of the northern Great Plains. Anecdotal opinions from farmers suggest that yield expectations should be reduced following CRP, compared with fields that have a history of annual cropping (Knutson, 2018). One study in southwestern Saskatchewan assessed the effects of 6 yr of crested wheatgrass, alfalfa, or spring wheat on 6 yr of subsequent spring wheat yields (Jefferson and Cutforth, 2005; Cutforth et al., 2010). One year of tilled fallow was used between the two 6-yr phases of this study, to transition from perennial to annual cropping. Despite receiving 115% of average precipitation during the intervening fallow year, both perennial stands reduced spring wheat yield by 25 to 35% in the subsequent year (year 2 since perennial forage) compared with a treatment with annual cropping history, due to reduced soil water available for crop growth. Crested wheatgrass did not have further legacy effects on subsequent spring wheat crops, but decreased yields of 9 to 23% were observed after alfalfa for 3 to 5 yr following conversion. Wheat grain protein following

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Abbreviations: CRP, Conservation Reserve Program; P-W, pulse crop–wheat alternate year cropping system; P-W^{Per} pulse, wheat alternate year cropping system preceded by 10 yr of perennial cropping.

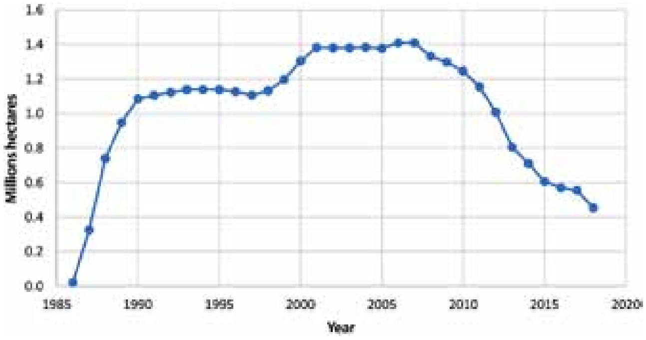

Fig. 1. Annual area enrolled in the USDA Conservation Reserve Program from 1986 to 2017 in Montana (USDA Farm Service Agency, 2017).

alfalfa, but not crested wheatgrass, was greater than in the continuous wheat rotation in all 6 yr, with an average increase of 14 g kg^{-1} and associated range of 4 to 51 g kg^{-1}.

Even less information about optimal CRP land conversion methods exists for Montana. In fact, to our knowledge, no such research has been reported. Consequently, Montana producers have implemented a wide range of conversion methods, including intensive tillage to no-tillage, various fertilization strategies and subsequent crops, and ranging from 0 to 2 yr of summerfallow following CRP, prior to sowing an annual crop (C. Doheny, personal communication, 2013). This study is the first to report multi-year legacy effects of perennial forage conversion to annual cropping in Montana. Our objective was to compare agro-economic performance over 6 yr for pulse-wheat (P-W) cropping systems preceded either by 10 yr of P-W or 10 yr of perennial cropping (P-W^{Per}), managed with 100 and 50% of recommended N to achieve yield goals. Our hypothesis was that crop yields would be greater following perennial cropping, due to increased soil organic matter reported for this treatment (Engel et al., 2017).

MATERIALS AND METHODS

Site Description

This cropping systems study is located at the Montana State University A.H. Post Research Farm 10 km west of Bozeman, MT (45°40.358′ N, 111° 9.076′ W). The soil is a deep, well-drained Amsterdam silt loam (fine-silty, mixed, superactive, frigid Typic Haplustoll) with 88 g kg^{-1} sand, 825 g kg^{-1} silt, and 86 g kg^{-1} clay, pH 7.2–7.7, and 9.0 g kg^{-1} organic carbon in the surface 0.1-m soil layer measured at study initiation. The weather context for this study was drier than average for 3 of the first 4 yr of this 6-yr study, and wetter than average in the final 2 yr (Table 1). The 2012/2013 crop year (September–August) had 124 mm less than the 1981–2010 average precipitation, representing the second driest crop year at this field location since on-site records began in 1967 and followed the driest crop year (2011/2012 had 150 mm less than the 1981–2010 average precipitation). The inter-crop period of September 2012 to March 2013 was 69 mm drier than the 1981–2010 average and the month of April was 32 mm drier than average; however, precipitation during the crucial crop growth months of May, June, and July were within 1 SD of 30-yr average values. During 2013/2014, the September–March inter-crop period was 64 mm wetter than average, while all months during the growing season were less than 1 SD from 30-yr average values. Notable precipitation anomalies in 2014/2015 and 2015/2016 occurred in the key crop growth month of June, with 54 and 51 mm less rainfall than the 30-yr average. Thus, 2013–2016 was generally drier than average with unusual drought stress in 3 of 4 yr. Conversely, the inter-crop period was 115 and 135 mm wetter than average in 2016/2017 and 2017/2018, respectively, with near-average rainfall amounts in May, June, and August. In both of these years, July was drier than average with no effective precipitation received. Monthly anomalies for mean temperature (i.e., >1 SD away from 30-yr average values) during the 2013–18 crop growing seasons were consistently warmer than the 1981–2010 average: 1.9°C in July 2013; 2.4°C in October 2014; 3.4 and 2.8°C in June and October 2015, respectively; 2.5 and 2.9°C in April and June 2016, respectively; 2.8°C in July 2017; and 2.4°C in May 2018 (Table 1 or data not shown).

Experimental Design and Crop Management

This long-term cropping systems study was initiated fall 2002 (Miller et al., 2015), but this paper focuses on 2013–2018 after conversion of the perennial forage system to annual cropping. This cropping systems study was a single-phase crop rotation design that generally grew dicot crops in odd-numbered years and always wheat in even-numbered years in the annually cropped systems (Miller et al., 2015). Here we focus on two comparable cropping systems within a larger randomized complete block design that included eight fertilized cropping systems from 2013 to 2018 as main plots (7.3 × 22 m), split into subplots (3.6 × 22 m) with two N rates (50 and 100% of recommended total available soil N), and four replications. These two systems were preceded either by 10 yr of a pea (*Pisum sativum* L.)–wheat (i.e., P-W) system or by a perennial crop mixture split into unharvested and annually harvested (one cut per year) treatments (i.e., P-W^{Per}). We chose the P-W rotation to test perennial crop conversion because it was the most profitable cropping system in this study during the first 10 yr (Miller et al., 2015) and has been economically successful for Montana farmers (Tanaka et al., 2010; Burgess et al., 2012). Pea (spring or winter) was grown and harvested for seed in odd-numbered years from 2003 to 2015, and lentil (*Lens culinaris* Medik.), another cool-season pulse crop, was grown and harvested in 2017. Thus, the P-W designation was expanded for P to refer to 'pulse crop' instead of 'pea'.

The perennial forage was sown 15 May 2003 as an alfalfa (*Medicago sativa* L.)–grass mixture. Montana-adapted 'Ladak 65' alfalfa (Eslick et al., 1968) was sown with a 26-cm row spacing at 0.56 kg ha^{-1}, approximately 5–10% of the recommended seeding rate for pure stand alfalfa establishment in Montana. Three species of grass [45–35–20% mix, by weight, of 'Rosana' western wheatgrass (*Pascopyrum smithii* Rydb.), *Ladorne* green needlegrass (*Nassella viridula* Trin.), and 'Pryor' slender wheatgrass (*Elymus trachycaulus* Link)] were sown at a total rate of 7.1 kg ha^{-1}, alternating with rows of alfalfa with the same row spacing. Thus, the net row spacing between plant rows was 13 cm. Urea–nitrogen was applied at 30 kg N ha^{-1} in the seed row with the grass mixture, and a 1:1 blend of mono-ammonium phosphate (11–52–0) and potassium sulfate (0–0–50–18) at 112 kg ha^{-1}. After sowing, the soil surface was packed with a 1.8-m wide 0.61-m diam. land roller that weighed approximately 540 kg. Perennial stands were mowed 30 June and 21 July 2003 to manage annual weeds, principally prickly lettuce (*Lactuca serriola* L.). These plots were allowed to grow unharvested in

Table 1. Monthly precipitation and mean temperature values during the crop–year (September–August) at the MSU Post Farm, Bozeman, MT, 2003–2018.

	Precipitation						Temperature				
Crop year	S-A†	May	June	July	Aug.	Total	May	June	July	Aug.	Annual
	mm						°C				
2002/2003	204	55	61	4	15	343	10.8	14.9	21.3	20.1	7.2
2003/2004	137	67	57	38	41	341	10.6	14.2	19.7	17.3	7.0
2004/2005	188	29	77	27	44	366	9.4	12.8	20.1	18.6	7.3
2005/2006	265	44	78	19	17	421	10.8	15.1	21.5	18.8	7.5
2006/2007	224	126	65	2	15	438	12.3	15.9	23.4	19.2	7.5
2007/2008	226	84	68	33	18	426	10.2	14.4	19.7	19.3	6.4
2008/2009	218	41	67	71	38	437	12.1	14.0	18.5	18.2	6.8
2009/2010	180	86	119	10	45	443	8.3	13.8	18.6	18.0	6.1
2010/2011	219	80	82	22	25	427	9.3	14.1	19.3	19.9	6.3
2011/2012	176	45	18	15	7	261	10.4	15.9	21.4	20.5	8.4
2012/2013	103	81	72	18	13	287	11.5	15.6	20.9	20.4	7.6
2013/2014	254	51	83	10	4	402	11.8	13.9	20.2	18.3	6.5
2014/2015	229	74	17	40	22	383	10.5	18.1	19.1	19.5	8.2
2015/2016	222	69	20	31	22	363	10.9	17.6	19.4	19.2	8.1
2016/2017	318	65	57	3	14	456	11.5	15.9	21.8	19.4	7.5
2017/2018	338	74	91	5	32	540	13.3	15.3	19.1	18.1	6.3
LTA‡	203	71	70	36	32	412	10.9	14.7	19.0	18.4	6.7

† S-A, September–April, soil water recharge period.

‡ LTA, long-term average: 1981–2010 average at the MSU-Bozeman Experimental Farm (Bozeman 6W). Climate data obtained from National Weather Service station on site. (https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?mt1047).

2004; in 2005, the plots were split randomly into annually harvested (one cut per year) and unharvested subplots. Split management of the perennial forage plots is representative of the range of normal CRP practices, which would have forage harvest intensity ranging between the two intensities in the experimental plots (S. Smiley, Montana Farm Service Agency, personal communication, 2016). At a minimum, Montana producers are required to renovate CRP stands in the sixth year of a 10-yr contract and are permitted to harvest the entire field area for hay on a 4-yr interval (i.e., 50% of the field every 3 yr), or more often if emergency forage declarations dictate.

Management of the P-W rotation began in autumn 2002 (i.e., winter pea) as reported previously in Miller et al. (2015). Management protocol was similar throughout the history of the P-W rotation and so details are emphasized for the 2013–2018 period (Table 2). The perennial system was terminated 15 June 2012, with glyphosate applied at 1260 g a.e. ha^{-1}. In 2013, after 10 yr of perennial crop growth, the perennial plots were converted to the P-W$^{\text{Per}}$ rotation. 'Stirling' spring green pea was grown in 2013, 'Melrose' Austrian winter pea in 2015, and 'Avondale' green lentil in 2017. 'Vida' Dark Northern spring wheat was grown in 2014 and 2018, and 'Yellowstone' Hard Red winter wheat in 2016, fertilized at 50 and 100% of recommended N rates for wheat. Full (i.e., 100%) recommended rates of available N (soil nitrate N + fertilizer N) were considered to be 50 kg Mg^{-1} of target wheat yield. Recommended rates for

Table 2. Harvest date, forage yield, and nitrogen content of perennial crops, and aboveground biomass of unharvested perennial crops (i.e. CR, conservation reserve) and moist soil depth under perennial crops compared with the pea-wheat rotation at the MSU Post Farm, Bozeman, MT, 2003–2012.

					Spring moist soil depth†		
Year	Harvest date	Forage yield	Nitrogen	Biomass	Forage	CR	Pea–wheat
		Mg ha^{-1}	g kg^{-1}	Mg ha^{-1}		m	
2003	NA†‡	NA	NA	NA		Not measured	
2004	NA†‡	NA	NA	NA	0.83 a‡		0.81 a
2005	8 July	6.0	21	7.0	0.97 b§		1.27 a
2006	23 June	7.7	18	7.0	0.80 b§		1.16 a
2007	21 June	6.8	26	6.3		Not measured	
2008	15 July	4.5	20	4.9		Not measured	
2009	9 July	3.7	17	5.0		Not measured	
2010	28 July	1.9	19	4.9	0.57 b¶	1.24 a	1.27 a
2011	18 July	4.2	17	6.5	0.99 b	1.03 b	1.26 a
2012	18 June	5.9	27	4.2	0.36 b	0.88 a	0.96 a

† Moist soil depth measured with a 1.4-m long blunt probe each year between 13 Apr and 15 May. Within years, means followed by the same letter do not differ according to Fisher's Protected LSD ($P < 0.10$).

‡ Perennial crop mixture was not harvested in the seedling year or the following year.

§ Location of probe was not recorded for harvested vs unharvested side of plot.

¶ Soil surface was so dry 15 May that the probe would not penetrate in two of four reps. Thus, values of zero were recorded.

Hard Red winter and Dark Northern spring wheat grown in Montana are 43 and 55 kg N Mg^{-1} of target wheat yield, respectively (Jacobsen et al., 2005), but we elected to use one intermediate rate for both types of wheat. Based on previously attained yields at this site, spring and winter wheat yields were targeted at 4.0 and 6.0 Mg ha^{-1}, respectively, on a 12% grain moisture basis. Urea–N application was banded 5–7.5 cm below and to the side of the seed row, with rates accounting for soil nitrate levels measured to a 0.6-m depth prior to wheat planting, N contained in seed-placed monoammonium phosphate, and assumed pea N mineralization credits of 30 kg N ha^{-1}. No additional N mineralization credit was taken for the previous alfalfa-dominated perennial system. Seeding rates (live seeds) were 80 m^{-2} for pea, 120 m^{-2} for lentil, and 200 m^{-2} for wheat. Each year, crops received 100 kg ha^{-1} of a 50:50 blend of monoammonium phosphate and potassium sulfate placed in the furrow with the seed. Peat powder rhizobial inoculant was placed in the seed row with pea or lentil. A commercial custom-fabricated 1.8-m-wide no-till plot seeder, with double-disk openers for seed (rear rank) and fertilizer (front rank) application (Fabro Enterprises Ltd., Swift Current, Canada) was used and row spacing alternated from 26 cm in odd-years to 30 cm in even years to minimize hair-pinning of wheat straw at pulse crop seeding. Seeding depth was generally 2.5 cm below the top of the moist soil to a maximum depth of 5 cm. Field activity log, seeding rates, and pesticide applications appear in Table 3 for both systems.

Crop and Economic Data Collection

Perennial plant biomass was not measured in 2003 (seedling year) or in 2004. Thereafter, from 2005 to 2012, both the annually harvested and never-harvested half of each plot was sampled by placing a square 1-m^2 quadrat on either end of the plot and clipping to ground level on the never-harvested side, and to approximately a 9-cm height on the harvested side to measure forage yield. Only live plant biomass was collected, and alfalfa biomass was measured separately from the grass biomass in only 2 yr, 2006 and 2012. In both years, alfalfa biomass averaged 80% of total biomass, consistent with visual observations of stand domination by alfalfa. Weed biomass was generally trivial. Plant samples were placed in a forced-air dryer at 50°C for a minimum of 72 h, and then weighed ‘hot’ out of the oven to capture dry weight, and ground to pass a 1-mm sieve prior to analysis of N concentration with a combustion analyzer (TruSpec CN, LECO Corp, St. Joseph, MI).

From 2013 to 2018, plant biomass was measured by cutting shoots to the soil surface after physiological maturity in two subsamples per subplot that combined to represent 2 m^{-2} in area. Biomass samples were dried at 50°C to obtain dry matter weight, and then passed through a mechanical thresher to obtain seed yield for the purpose of measuring harvest index values. Harvest index was the proportion of grain to shoot biomass. Grain yield was determined by machine harvesting a single strip in each subplot approximately 1.5-m wide and calculating the exact area from the number and measured length of harvested crop rows. If necessary, grain samples were dried at 50°C for 72 h. Dry grain samples were cleaned and dry weight determined by either measuring the grain moisture content with an Infratec 1241 Grain Analyzer (Foss of North America, Eden Prairie, MN) or in a representative subset of oven-dried samples for each crop. Grain N content of wheat was measured with the Infratec 1241 Grain Analyzer and pea by LECO combustion and reported on a dry matter basis. A conversion factor of 5.7 was used to convert from grain N to protein in wheat and 6.25 for pea and lentil (Jones, 1941).

Variable costs included published biocide costs (North Dakota State University, 2018; or actual costs for insecticide or fungicidal seed treatments), fertilizer (semi-annual average fertilizer sales prices reported to Montana Department of Agriculture and accessed by request only; Montana Department of Agriculture, personal communication, 2013–2018), all field equipment use (Haugen, 2016), and seed (based on price quotes from nearby Montana seed companies, J. McDonnell, Circle S Seeds, Three Forks, MT, personal communication, 2013–2018). Crop prices were set based on 3-yr averages centered on July of the harvest year, because producers are able to forward contract or hold on to inventory until suitable market conditions emerge. In 2017, a 2-yr average price was used for lentil owing to the fact that lentil oxidizes with time in storage, which causes downgrading. Thus, farmers do not have the ability to inventory lentil seed as long as other crops, such as pea and wheat. The green pea price used in 2013 was based on USDA weekly reported national prices for dry pea for 2012 ([USD]$346 Mg^{-1}) and 2013 ($329 Mg^{-1}) (USDA AMS, 2018a). To ensure that local market conditions were taken into account, the regional prices were then averaged with the local 2014 delivered price ($294 Mg^{-1}, J. McDonnell, Circle S Seeds, Three Forks, MT, personal communication, 2013–2018). The nationally posted prices were adjusted upward by $22 Mg^{-1} to reflect a historically typical premium for green vs. the more commonly grown yellow pea, and adjusted downward by $37 Mg^{-1} to reflect assumed trucking costs. Austrian winter pea prices used in 2015 ($546 Mg^{-1} delivered to the elevator) were based on a 2-yr time period from January 2014 to December 2015 based on actual price quotes (also from Circle S Seeds, personal communication, 2013–2018). The price of Austrian winter pea is typically sufficiently high that producers endeavor to sell immediately after harvest. The green lentil price used in 2017 was based on USDA average weekly reported national prices for green lentil from September 2016 through August 2018 ($547 Mg^{-1}) (USDA AMS, 2018a). These lentil prices are based on cleaned and bagged lentils delivered to a local seed processing facility. Thus, we subtracted the cost of cleaning and bagging (M. DeVries, Barber Seed Service Ltd., Denton, MT, personal communication, 2016), which was reported to be $72 Mg^{-1}.

Wheat crop prices were based on the same 3-yr time frame but based on the average of grain elevator market data in Montana (GeoGrain, 2018; USDA AMS, 2017), except for spring wheat in 2018, when an 18-mo average price (i.e., the first half of the 3-yr average) was used for spring wheat to expedite publication of this study. This compromise in methodology was considered somewhat trivial in its effect on economic results. Prices were then adjusted for protein and test weight premiums and discounts, based on 12 yr of market data from 42 grain elevators in Montana. These data were used to estimate protein premia/discount equations for determining the adjustments based on specific protein levels. Because elevators price protein premiums/discounts in years when there are sufficient quantities of wheat with high protein content and years when there is a deficit of high-protein wheat, separate Flat (sufficient

Table 3. Field activity log and pesticide application for the pea – wheat cropping system at Bozeman, MT, 2012–2018.

Field log	Activity
12 Oct. 2012	Sample soil for nitrate-N to 0.6-m depth
25 Apr. 2013	Spray pre-plant herbicide: [*N*-(phosphonomethyl)glycine] at 630 g a.e. ha^{-1}
26 Apr. 2013	Seed Stirling green pea at 80 plants m^{-2} (161 kg ha^{-1}) with 26-cm row spacing
2 May 2013	Spray saflufenacil [*N*′-{2-chloro-4-fluoro-5-[1,2,3,6-tetrahydro-3-methyl-2,6-dioxo-4-(trifluoromethyl)pyrimidin-1-yl] benzoyl}-N-isopropyl-N-methylsulfamide] at 17 g a.e. ha^{-1}
3 May 2013	Sample moist soil depth with 1.4-m blunt steel push rod
5 Aug. 2013	Harvest with 1.8-m wide plot harvester
21 Oct. 2013	Sample soil for nitrate-N to 0.6-m depth
20 Apr. 2014†	Spray pre-plant herbicides: glyphosate [*N*-(phosphonomethyl)glycine] at 630 g a.e. ha^{-1} + saflufenacil [*N*′-{2-chloro-4-fluoro-5-[1,2,3,6-tetrahydro-3-methyl-2,6-dioxo-4-(trifluoromethyl)pyrimidin-1-yl]benzoyl}-N-isopropyl-N-methylsulfamide] at 17 g a.e. ha^{-1}
21 Apr. 2014	Seed Vida spring wheat at 200 plants m^{-2} (66 kg ha^{-1}) with 30-cm row spacing and 7-cm offset urea–N band
1 May 2014	Sample moist soil depth with 1.4-m blunt steel push rod
31 May 2014	Spray in-crop herbicide: clodinafop-propargyl [prop-2-ynyl (2R)-2-[4-(5-chloro-3-fluoropyridin-2-yl)oxyphenoxy] propanoate] at 47 g a.e. ha^{-1} + 2,4-D amine [(2,4-dichlorophenoxy)acetic acid] at 370 g a.e. ha^{-1}
3 Sept. 2014	Harvest with 1.8-m wide plot harvester
8 Sept. 2014	Spray pre-plant herbicides: glyphosate [*N*-(phosphonomethyl)glycine] at 840 g a.e. ha^{-1} + saflufenacil [*N*′-{2-chloro-4-fluoro-5-[1,2,3,6-tetrahydro-3-methyl-2,6-dioxo-4-(trifluoromethyl)pyrimidin-1-yl]benzoyl}-N-isopropyl-N-methylsulfamide] at 17 g a.e. ha^{-1}
8 Sept. 2014	Seed Melrose winter pea at 80 plants m^{-2} (130 kg ha^{-1}) with 26-cm row spacing
4 May 2015	Spray insecticide to control pea leaf weevil: Lambda-cyhalothrin [1:1 mixture of (S)-α-cyano-3-phenoxybenzyl-(Z)-(1R,3R)-3-(2-chloro-3,3,3-trifluoroprop-1-enyl)-2,2-dimethylcyclopropane carboxylate and(R)-α-cyano-3-phenoxybenzyl (Z)-(1S,3S)-3-(2-chloro-3,3,3-trifluoroprop-1-enyl) -2,2-carboxylate] at 14 g a.e. ha^{-1} carboxylate and(R)-α-cyano-3-phenoxybenzyl (Z)-(1S,3S)-3-(2-chloro-3,3,3-trifluoroprop-1-enyl) -2,2-dimethylcyclopropane carboxylate chloro-3,3,3-trifluoroprop-1-enyl) -2,2-dimethylcyclopropane carboxylate and(R)-α-cyano-3-phenoxybenzyl (Z)-(1S,3S)-3-(2-chloro-3,3,3-trifluoroprop-1-enyl) -2,2-dimethylcyclopropane carboxylate*N*-(phosphonomethyl)glycine] at 630 g a.e. ha^{-1}
4 May 2015	Spray in-crop herbicide: clethodim [(E)-(+)-2-[1-[[(3-chloro-2-propenyl)oxy]imino]propyl-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one] at 140 g a.e. ha^{-1}
9–20 July 2015. 2015	Harvest with 1.8-m wide plot harvester
27 Aug 2015	Sample soil for nitrate-N to 0.6-m depth and total soil water to 0.9-m depth
14 Sept. 2015	Seed *Yellowstone* winter wheat at 250 plants m^{-2} (78 kg ha^{-1}) with 30-cm row spacing and 7-cm offset urea–N band
Sept. 2015‡	Spray pre-emerge herbicide: 2,4-D amine [(2,4-dichlorophenoxy)acetic acid] at 370 g a.e. ha^{-1}
19 Apr. 2016	Spray in-crop herbicides: pyroxsulam [*N*-(5,7-dimethoxy-[1,2,4]triazolo[1,5-a]pyrimidin-2-yl)-2-methoxy-4-(trifluoromethyl) pyridine-3-sulfonamide]@ 15.4 g a.e. ha^{-1} + florasulam [*N*-(2,6-difluorophenyl)-8-fluoro-5-methoxy-[1,2,4]triazolo[1,5-c] pyrimidine-2-sulfonamide]] at 2.5 g a.e. ha^{-1} + fluroxypr {[(4-amino-3,5-dichloro-6-fluoro-2-pyridinyl)oxy]acetic acid} at 90 g a.e. ha^{-1} + dicamba [3,6-dichloro-2-methoxybenzoic acid] at 233 g a.e. ha^{-1}
3-4 Aug. 2016	Harvest with 1.8-m wide plot harvester
8 Aug. 2016	Spray post-harvest herbicide for prickly lettuce (*Lactuca serriola*) control: glyphosate [*N*-(phosphonomethyl)glycine] at 630 g a.e. ha^{-1}
26 Sept. 2016	Spray post-harvest herbicide for downy brome (*Bromus tectorum*) control: glyphosate [*N*-(phosphonomethyl)glycine] at 630 g a.e. ha^{-1}
21 Oct. 2016	Sample soil for nitrate-N to 0.6-m depth and total soil water to 1.8-m depth
25 Apr. 2017	Spray pre-seed herbicide: glyphosate [*N*-(phosphonomethyl)glycine] @ 630 g a.e. ha^{-1} + pendimethalin [3,4-dimethyl-2,6-dinitro-N-pentan-3-ylaniline at 1590 g a.e. ha^{-1}]
26 Apr. 2017	Seed Avondale green lentil at 120 plants m^{-2} (56 kg ha^{-1}) with 26-cm row spacing
31 May 2017	Spray in-crop herbicide for monocot weed control and insecticide for pea leaf weevil control: clethodim [(E)-(+)-2-[1-[[(3-chloro-2-Propenyl)oxy]imino]propyl-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one] at 140 g a.e. ha^{-1} + lambda-cyhalothrin [1:1 mixture of (S)-α-cyano-3-phenoxybenzyl-(Z)-(1R,3R)-3-(2-chloro-3,3,3-trifluoroprop-1-enyl) -2,2-dimethylcyclopropane carboxylate and(R)-α-cyano-3-phenoxybenzyl (Z)-(1S,3S)-3-(2-chloro-3,3,3-trifluoroprop-1-enyl) -2,2-carboxylate] at 14 g a.e. ha^{-1}
10–16 Aug. 2017	Harvest with 1.8-m wide plot harvester
25 Aug. 2017	Spray post-harvest lentil stubble: glyphosate [*N*-(phosphonomethyl)glycine] at 840 g a.e. ha^{-1}
26 Mar. 2018	Sample soil for nitrate-N to 0.6-m depth and total soil water to 0.9-m depth
19 Apr. 2018	Spray pre-seed lentil stubble: glyphosate [*N*-(phosphonomethyl)glycine] at 840 g a.e. ha^{-1}
20 Apr. 2018	Seed Vida spring wheat at 200 plants m^{-2} (67 kg ha^{-1}) with 26-cm row spacing for all but tilled fallow system
30 May 2018	Spray for dicot weed control: florasulam [N-(2,6-difluorophenyl)-8-fluoro-5-methoxy-[1,2,4]triazolo[1,5-c]pyrimidine-2-sulfonamide] at 45 g a.e. ha^{-1} + fluroxypyr [((4-amino-3,5-dichloro-6-fluoro-2-pyridinyl)oxy)acetic acid, 1-methylheptyl ester] at 1300 g a.e. ha^{-1}
23 Aug. 2018	Harvest with 1.8-m wide plot harvester

† Glyphosate rate was doubled for the P-W$^{\text{Per}}$ system to increase injury to remnant alfalfa plants.

‡ P-W$^{\text{Per}}$ system only to increase injury to remnant alfalfa plants.

Table 4. Soil water and nitrate-N measurements associated with crops grown 2013, 2014, and 2016–2018, in the pulse-wheat (P-W) and pulse-wheat following 10 yr of perennial forage 2003–2012 (P-W^{Per}) cropping systems, managed with two N rates at Bozeman, MT. Bolded values differ within N rate according to orthogonal contrasts ($P < 0.10$).

	2013		2014		2016			2017		2018	
	Spring pea		Spring wheat		Winter wheat			Lentil		Spring wheat	
System	Moist† soil depth	Soil‡ NO_3-N	Moist soil depth	Soil NO_3-N	Total§ soil water	Soil NO_3-N	Total¶ soil water	Moist soil depth	Soil NO_3-N	Total§ soil water	Soil NO_3-N
	m	kg ha^{-1}	m	kg ha^{-1}	cm	kg ha^{-1}	cm	m	kg ha^{-1}	cm	kg ha^{-1}
					100% recommended rate N						
P-W	0.62	55	**1.19**	164	12.8	75	**20.7**	1.29	21	26.2	**19**
P-W^{Per}#	0.67	55	**1.05**	120	11.9	102	**18.3**	1.31	21	24.9	**37**
					50% recommended rate N						
P-W	**0.75**	**12**	**1.27**	58	12.2	52	**22.3**	1.30	**11**	25.4	17
P-W^{Per}#	**0.38**	**25**	**0.99**	82	11.7	64	**18.6**	1.31	**35**	26.6	22

† Spring moist soil depth measured 3 May 2013, 1 May 2014, and 2 May 2017 with a 1.4-m blunt steel rod.

‡ Nitrate-N measured to 0.6-m depth 12 Oct. 2012, 21 Oct. 2013, 27 Aug. 2015, 21 Oct. 2016, and 26 Mar. 2018 corresponding to 2013, 2014, 2016, 2017, and 2018 crops, respectively.

§ Total pre-plant soil water measured by core extraction to 0.9-m depth 27 Aug. 2015 and 26 Mar. 2018.

¶ Total post-harvest soil water measured by core extraction to 1.8-m depth 21 Oct. 2016.

N fertilization did not occur in this system until wheat crops in 2014, 2016, and 2018. '100%' and '50%' N rates were assigned to unharvested and harvested perennial forage treatments 2005–2012, respectively. P, pulse crop; W, wheat; Per, perennial forage or reserve.

protein year) and Steep (deficit protein year) grain protein discount equations were estimated. These equations were previously published in Miller et al. (2015). Further, for all crops we assumed trucking costs for 80 km to move wheat from the field to market consistent with reports in neighboring states (Vachal and Tolliver, 2001; Clark et al., 2003; NDSU, 2013) and based on a survey of actual trucking costs in the Rocky Mountain region (USDA AMS, 2018b). To be conservative, the trucking distance for pulse crops was assumed to be double the distance for wheat. Cumulative present value of net returns were calculated using real discount rates, $r = (\mathrm{i}-\pi)/[(1+\pi)]$, where 'i' is the nominal rate to borrow and 'π' is the inflation rate. Nominal interest rates represent the US average effective interest rates for non-real estate loans made to farmers between 2013 and 2018 (Federal Reserve Bank of Kansas City Agricultural Finance Databook, Table A.5; US Department of the Treasury, 2018), and inflation rates are from the US Bureau Labor Statistics. For the 2013–2018 sample period, the real discount rates ranged between 0.61% and 1.82%.

Soil Data Collection

Some years near 1 May (actual dates ranged from 13 Apr. to 15 May) the depth of moist soil was determined using a 1.4-m (54-inch) Paul Brown soil moisture probe (Brown, 1959) that had been modified (additional 0.3 m in length and a standard blunt ball without corkscrew at the tip). The probe was inserted three times per subplot and the depth of moist soil was recorded in a systematic pattern starting near the front of the plot in the south-central seeder pass and proceeding diagonally at intervals toward the rear of the plot in the north-central seeder pass. These three values were averaged to estimate the depth of wet soil per subplot. In 2007–2009 and 2015, due to very wet spring soil conditions, initial probing occurred at maximum depth and so was discontinued (Tables 2 and 4). During those 4 yr, the September–April precipitation totals were above the 1981–2010 average (205 mm) by 12 to 37 mm. During the last 2 yr of this study this intercrop period was even wetter, 115 and 135 mm greater than average (Table 1). Soil nitrate N was measured 12 Oct. 2012, 21 Oct. 2013, and 27 Aug. 2015 in 0.3-m increments to a depth of 0.6 m by collecting two cores per subplot (composited into one sample) with a truck-mounted hydraulic probe. Soil was dried (50°C), extracted with 1 *M* KCl, and analyzed for nitrate with Cd reduction (Willis, 1980) using a Lachat Flow Autoanalyzer (Lachat Instruments, Loveland, CO).

Statistical Analyses

We used a *P*-value of 0.10, unless otherwise specified. Statistical analyses were conducted using JMP 8 (SAS Institute, 2008) using the standard least squares linear regression ANOVA model appropriate to balanced designs without missing data. Prior to 2013, the experimental site included seven fertilized annual cropping systems, each split into two N availability rates (50 and 100% of recommended) during wheat cropping phases (Miller et al., 2015), and one perennial crop system. During 2003–2006, spring moist soil depth was compared between the perennial system (regardless of harvest management in 2005 and 2006) and the pea–wheat system only at the main plot level to illustrate general soil moisture differences between the perennial and annual cropping systems (Table 2). During 2010–2012, the perennial plots were further considered by harvest management, and the subplot level of standard error was used to discriminate among means. Since moist soil depth between the high and low N rates did not differ for the P-W system, we reported one value to represent that system (Table 2).

After 2012, eight cropping systems were considered since the perennial crop system was converted to a fertilized annual crop system. The annually harvested side was assigned the 50% N subplot treatment, while the unharvested side was assigned the 100% N treatment. In the ANOVA model, blocks were considered random while cropping system and N availability rate were 'fixed.' For most parameters in most years after 2012, model variance associated with N availability ranged from 5 to 100 times greater than the model variance explained by cropping system, and the interaction of N availability and cropping system was often significant. Thus, analyses were rerun separately by N availability, with only cropping system and block in the model. The P-W and P-W^{Per} systems were then compared within each N rate by single degree of freedom orthogonal

Table 5. Seed yield and protein for four crops grown 2013–2018 in the pulse–wheat (P–W) and pulse–wheat following 10 yr of perennial forage 2003–2012 (P–W^{Per}) cropping systems, managed with two N rates at Bozeman, MT. Bolded values differ within N rate according to orthogonal contrasts ($P < 0.10$).†

	2013		2014		2015		2016		2017		2018	
	Spring pea‡		Spring wheat		Winter pea		Winter wheat		Spring lentil		Spring wheat	
System	Yield	Prot.	Yield	Prot.	Yield	Prot.	Yield	Prot.	Yield	Prot.	Yield	Prot.
	Mg ha^{-1}	g kg^{-1}	Mg ha^{-1}	g kg^{-1}	Mg ha^{-1}	g kg^{-1}	Mg ha^{-1}	g kg^{-1}	Mg ha^{-1}	g kg^{-1}	Mg ha^{-1}	g kg^{-1}
100% recommended rate N												
P–W	2.10	264	4.29	153	**1.28**	nm	**5.36**	**150**	1.37	251	5.67	142
P–W^{Per}‡	1.51	286	3.37	183	**0.89**	nm	**3.73**	**167**	1.28	249	5.62	143
50% recommended rate N												
P–W	**1.58**	280	3.56	**126**	**1.41**	nm	**4.78**	**96**	1.47	251	**3.41**	**135**
P–W^{Per}‡	**1.08**	287	3.20	**149**	**0.93**	nm	**2.90**	**148**	1.49	248	**4.08**	**144**

† nm, not measured; P, pulse; Per, perennial forage or reserve; W, wheat.

‡ N fertilization did not occur in this system prior to 2014. '100%' and '50%' N rates were assigned to unharvested and harvested perennial forage treatments 2005–2012, respectively.

contrasts, when appropriate. When data were collected broadly for all systems (e.g., moist soil depth, soil nitrate, wheat yield and quality, economic costs, and net returns), ANOVA included seven to eight systems depending on the time period (i.e., before or after 2012) and parameter measured. Analyses for pulse crop yields, protein, and associated economic returns included only two systems that grew pea for grain (P-W and P-W^{Per} in 2013 and 2015), and four systems that grew lentil in 2017.

RESULTS AND DISCUSSION

Perennial Crop Effects on Soil Water and Nitrogen

Our measurements of soil water and N were intermittent, and variable among sampling dates for the specific methodology employed. Nonetheless, comparison of spring moist soil depth (i.e., Brown probe depth) showed that the depth of moist soil under the perennial crop system was equal or less than the P-W system in 2005 and 2006 (Table 2). Moist soil depth was not measured again until 2010–2012 (years 8 to 10) of perennial crop growth where moist soil depth under perennial crop management was again equal or less than under the P-W system. Given the much longer seasonal growth of the perennial system, this is not surprising. In 2 of these 3 yr, moist soil depth in the perennial system was notably shallower under the harvested vs. unharvested treatment. This was likely due to reduced soil surface evaporation from remnant standing vs. harvested perennial vegetation. However, since this comparison was not an objective for this study, this specific comparison was ignored in analyses after 2012.

This pattern of diminished soil moisture under the perennial system continued after conversion to annual cropping (Table 4). In 2013, only the P-W^{Per} system where perennial forage had been harvested was drier than the P-W system. In spring 2014, P-W^{Per} was drier than P-W at both N rates (i.e., and both former harvest treatments), and, in 2016, post-harvest remnant soil water showed an average of 30 mm less water under P-W^{Per}. Measured soil nitrate N to a 0.6-m depth showed that the P-W^{Per} system had equal or greater soil nitrogen than the P-W system, but was statistically significant in only three of 10 comparisons (Table 4).

Perennial Crop Effects on Crop Yield and Quality and on Net Returns

Pea yields were reduced in the P-W^{Per} system by an average of 0.55 Mg ha^{-1} (30%) and 0.44 Mg ha^{-1} (32%) in 2013 and 2015, respectively, 1 and 3 yr after conversion to the annual cropping system (Table 5). This response may be related to differences in soil water, with the depth of moist soil in spring 2013 or 2015 shallower for the P-W^{Per} system in three of four cases (Table 4). However, pea has been reported to root shallowly (i.e., ~0.6 m) at this location (Miller and Holmes, 2012) and the moist soil depths in 2015 exceed 0.6 m considerably. Stand density was not measured but there were not obvious visual differences in plant populations of pea between the systems, nor weed infestations or disease symptoms present. There was a very low density (~one plant 5–10 m^{-2}) of remnant alfalfa plants that would have provided some competition with pea, but yield losses >30% do not seem consistent with such low alfalfa densities. Pea protein levels were high in the P-W^{Per} system, and spring soil nitrate N was greater for the P-W^{Per} system in one instance, so reduced soil N or compromised N_2 fixation do not seem reasonable explanations. In 2017, lentil yields did not differ between systems (Table 5).

In wheat, remnant alfalfa plants were suppressed with herbicide to remove potential competition influence on yield (Table 3). In 2014, spring wheat yield was limited by low precipitation in July, and in 2016, winter wheat yield was limited by low precipitation in June (Table 1), coincident with the grain fill period. In 2014, spring wheat yield exceeded the 4.0 Mg ha^{-1} yield target only for the P-W system at the 100% N rate, and winter wheat (2016) did not attain its yield goal of 6.0 Mg ha^{-1} for either N rate or cropping system (Table 5). The chief contribution of summerfallow in Montana is enhanced soil moisture (Tanaka et al., 2010). Two other cropping systems included at this site were tilled and no-till (i.e., 'chem') fallow present in the same years as the pulse crops, and alternated similarly with wheat. Yield from these fallow-based systems in the same study exceeded wheat yield of the P-W system by an average of 0.65 and 0.83 Mg ha^{-1} in 2014 and 2016, respectively, suggesting soil water limited yield in both years (data not shown). Differences in subsoil water have been shown to cause significant yield differences in wheat in Australia, causing study authors there to conclude that deep soil water (>1 m) was three times more valuable than shallow soil water (Kirkegaard et al., 2007). Wheat yields were reduced in the P-W^{Per} system, compared with the P-W system, by an average of 0.64 Mg ha^{-1} (16%) and 1.75 Mg ha^{-1} (35%) in 2014 and 2016, respectively (Table 5), reflective of differences in moist soil depth (Table 4). Grain protein content has been related to the yield sufficiency plateau for wheat, whereby at protein concentrations below a critical threshold

Table 6. Annual costs and net returns (NR) to land and management (excluding crop insurance and all government program payments) for six crops grown 2013–2018 in the pulse–wheat (P–W) and pulse–wheat following 10 yr of perennial forage 2003–2012 (P–W$^{\text{Per}}$) cropping systems, managed with two N rates at Bozeman, MT. Bolded values differ within N rate according to orthogonal contrasts ($P < 0.10$).

	2013		2014			2015		2016			2017		2018		
	Spring pea		Spring wheat			Winter pea		Winter wheat			Lentil		Spring wheat		
				NR					NR					NR	
System†	Cost	NR	Cost	Flat‡	Steep	Cost	NR	Cost	Flat	Steep	Cost	NR	Cost	Flat	Steep
	US$ ha^{-1}														
	100% recommended rate of available N														
P–W	323	**340**	361	**592**	**656**	427	**446**	427	**326**	**422**	367	**118**	327	340	322
P–W$^{\text{Per}}$	354	**68**	440	**310**	**487**	427	**183**	435	**84**	**210**	404	**80**	322	339	323
	50% recommended rate of available N														
P–W	323	**352**	300	328	**143**	427	**539**	354	**259**	91	367	**155**	289	**156**	**120**
P–W$^{\text{Per}}$	354	**221**	335	319	**305**	427	**210**	371	**32**	79	404	**95**	284	**227**	**219**

†P, pulse crop; W, wheat; Per, perennial crop.

‡ 'Flat' and 'Steep' refer to wheat protein discount schedules explained in the methodology section.

yield is considered to be limited by N availability. Using the protein inflection point of 147 g kg^{-1} (Engel et al., 1999; Selles and Zentner, 2001) for spring wheat and 121 g kg^{-1} (Engel et al., 2006) for winter wheat, the results indicate that N availability limited yield in the 50% N rate of the P-W system in 2016 (and 2018) only. If wheat yields for the P-W$^{\text{Per}}$ system are compared only to the 100% rate of N in the P-W system (deemed to be N-sufficient for yield based on these protein benchmarks), then there was a measurable shortfall of 0.92 Mg ha^{-1} (21%) for spring wheat in 2014 and 1.63 Mg ha^{-1} (30%) for winter wheat in 2016.

Conversely, in 2018, spring wheat yields far exceeded the yield target of 4.0 Mg ha^{-1} at the 100% N rate (Table 5). In 2018, wheat yields on fallow in this study averaged 0.25 Mg ha^{-1} less than P-W, indicating soil water did not limit yield (data not shown). The crop year of 2017/2018 had the second greatest total annual precipitation (540 mm) recorded in the last 50 yr at this location despite no effective rainfall received between 29 June and 4 Aug. 2018 (Table 1). This was powerful testament to the ability of spring wheat to generate seed yield when reliant on available stored soil water. Conversely, N availability was a limiting factor with protein values consistently below the critical threshold of 147 g kg^{-1}. Although not compared formally, apparently wheat yields at 50% N availability averaged 1.90 Mg ha^{-1} less than those at 100% of targeted N availability. In 2018, spring wheat yields did not differ between systems at the 100% rate of available soil N, and the P-W$^{\text{Per}}$ system yielded 0.67 Mg ha^{-1} greater, with 9 g kg^{-1} greater grain protein, at the 50% nitrogen rate, indicative of greater soil N mineralization 6 yr after conversion to annual cropping.

Rather than limiting yield by N availability, it appeared that N supply following the alfalfa-dominated perennial stand exacerbated 'haying off' due to excess N availability early in the growing season promoting vigorous vegetative growth without sufficient water to sustain a larger yield trajectory (van Herwaarden et al., 1998). Indeed, visual observations were of lusher wheat vegetation in the P-W$^{\text{Per}}$ system until anthesis, but earlier scorching of the flag leaves due to terminal summer drought in 2014 and 2016. Harvest index values support these observations with average values of 0.363 (2014) and 0.325 (2016) in the P-W$^{\text{Per}}$ system, compared with average values of 0.490 (2014) and 0.393 (2016) in the P-W system (data not shown). Grain protein values were consistently in the yield sufficiency range in the P-W$^{\text{Per}}$ system; thus, when total protein yield (i.e., grain yield × protein concentration) was considered, differences between the systems were much smaller (Table 5). Under the 100% rate of N, protein yield did not differ between cropping systems in 2014 or 2018, but was 23% less for P-W$^{\text{Per}}$ in 2016. At the 50% rate of N, protein yield did not differ between systems in 2014 or 2016 (data not shown), and was 28% greater for the P-W$^{\text{Per}}$ system in 2018, indicating strong N supply from the decaying alfalfa roots throughout the 6 yr of this study. This is consistent with a report by Cutforth et al. (2010) where wheat grain protein was elevated for each of 6 yr following termination of a 6-yr old alfalfa stand, compared with continuous wheat, in southwestern Saskatchewan. In our study, stabilization of crop yields was coincident with the receipt of much greater than normal intercrop precipitation prior to years 5 and 6 (i.e., 115 and 135 mm greater than average). It must be noted that this 6-yr study began in much drier than average conditions, following the driest crop year in 50 yr at this location (2012) and initiated during the second driest crop year (2013). However, these precipitation amounts equated to typical values for the major cropping region of north central Montana (Padbury et al., 2002), where the greatest CRP area exists, and so may provide useful information for farmers there who are considering replacement of perennial stands with annual cropping. Stabilization of yield losses was coincident with two unusually wet intercrop periods prior to the 2017 and 2018 growing seasons, and the second wettest crop year (2018) at this location in the last 50 yr. Nonetheless, this reinforces the dominant role of precipitation in this dryland cropping region for successfully transitioning from perennial to annual cropping.

For estimating net returns over variable costs, the largest differences in costs were due to fertilizer N application in the wheat years (Table 5) because this input accounts for approximately 25–40% of variable costs in wheat production (USDA-ERS, 2018). For pea, urea fertilizer was not applied, and since there are no protein discounts in the pulse crops grown here, economic returns closely reflect yields (Table 6). However, grain protein is an important factor for price determination of wheat in Montana. Flat and Steep protein discount schedules were both considered, as reported in Miller et al. (2015). Further adjustment of net returns based on low grain test weight discounts served as a trivial economic factor, which was more than offset by a concomitant increase in grain protein. At the 100% rate of N, 2014 economic returns for spring wheat from the P-W system were \$282 ha^{-1} and \$169 ha^{-1} greater than P-W$^{\text{Per}}$ when considered at the 'flat' and 'steep' protein discount schedules, respectively, showing a substantial narrowing of returns when the N uptake of the P-W^{Per} system was more highly valued. This phenomenon was observed to a lesser degree for winter wheat in 2016, when net returns were \$242 ha^{-1} and \$212 ha^{-1} greater for the P-W system at the 'flat' and 'steep' protein discounts, respectively. By 2018, net returns for both systems were identical. A similar pattern was observed through wheat years at the 50% N rate, but because N was deliberately made more limiting to crop growth, the P-W^{Per} system provided \$162 ha^{-1} greater returns under a steep protein discount scenario in 2014, and \$71 to \$99 ha^{-1} greater returns under both protein discount schedules in 2018.

Despite strong variability in annual net returns between treatments when considered by protein discount schedule/N fertility context, cumulative present value 4-yr net returns averaged \$731 ha^{-1} less (45%) for the P-W^{Per} system across protein discount schedules and fertilizer N rates compared to P-W (Table 6). Cumulative present value net returns stabilized after 4 yr under three scenarios, and in 3 yr under the scenario with 50% of recommended available N and a steep protein discount schedule for wheat, ranging from from ~\$300 to ~\$1,000 ha^{-1} less for the P-W^{Per} system (Fig. 2).

Soil quality was increased after 10 yr of perennial cropping, as indicated by sustained crop N uptake at low N fertility rates and increased soil organic carbon and nitrogen (Engel et al., 2017), necessitating a longer term view of the total economic impact. This study likely would have benefited from assuming a multi-year soil N credit from the perennial cropping phase, which would have reduced fertilizer costs and potential 'haying off' due to excess N availability. This study is planned to run at least six additional years to measure longer term rotational impacts of a perennial crop. Further, this study examined only one method for converting from perennial to annual cropping, intended to preserve maximal soil quality. Research into alternative conversion methods, measuring short- and long-term economic impacts is needed.

CONCLUSION

Conversion from an alfalfa-dominated perennial stand to an annual pulse–wheat cropping system resulted in substantial yield loss over the course of 4 yr, averaging 28% across 4 yr and two N rates. Yield loss stabilized after 4 yr, coincident with receipt of 115 mm greater than average intercrop precipitation. Increased wheat N uptake following the perennial stand limited losses in protein yields, averaging 15% less at 100% of recommended N and no loss at 50% of recommended N. Loss in annual net returns for the P-W^{Per} system stabilized after 4 yr in three scenarios, and after 3 yr in the remaining scenario of 50% of recommended N availability and steep wheat protein discount schedules. Cumulative 4-yr net returns for the P-W^{Per} system averaged \$731 ha^{-1} less (45%) across fertility N rates and protein discount schedules. This suggests that short-term (i.e., 4 yr) profit reduction associated with converting from perennial cropping to annual cropping can be substantial in the semiarid northern Great Plains, especially under low precipitation.

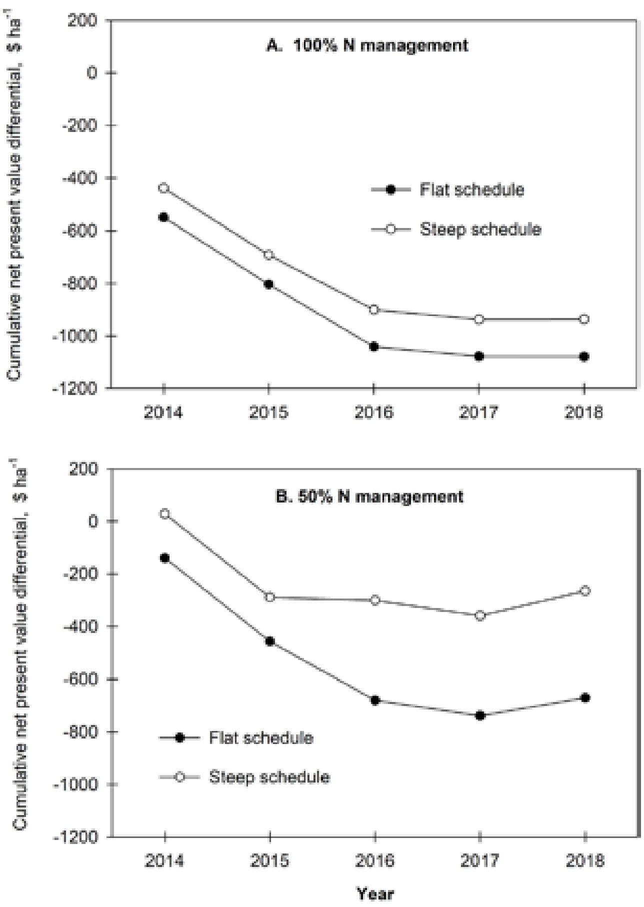

Fig. 2. Cumulative net present value returns from 2013 to 2018 in pulse crop–wheat alternate year cropping system (P-W) and wheat alternate year cropping system preceded by 10 yr of perennial cropping (P-W^{Per}) cropping systems at Bozeman, MT. 'Flat' and 'Steep' refer to wheat price discount schedules based on protein content.

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