MONTANA STATE UNIVERSITY
College of Agriculture & Montana Agricultural Experiment Station

Department of Research Centers

39th ANNUAL RESEARCH REPORT

WESTERN TRIANGLE AGRICULTURAL RESEARCH CENTER

Montana Agricultural Experiment Station

Conrad, MT

2016 Crop Year

Submitted by:

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INTRODUCTION

The information and data reported are a collaboration of ongoing or new research projects located at or near Western Triangle Agricultural Research Center (WTARC) of Montana State University, College of Agriculture, Conrad, Montana. Many projects are conducted in cooperation with faculty members, research associates and Post-doctoral fellows from the Depts. of Plant Science and Plant Pathology (PSPP) and Land Resources and Environmental Science (LRES) located on the campus of Montana State University (MSU), and Agricultural Research Centers: Central (CARC), Northern (NARC), Eastern (EARC), Northwestern (NWARC) Southern (SARC) and Western (WARC) of the Dept. of Research Centers.

To simplify reading, trade or brand names of products, services, firms, or equipment are sometimes used. No endorsement of such names or firms is intended nor is criticism implied of those not mentioned.

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WTARC Advisory Committee and cooperating producers: Boyd Standley, Dan Picard, Jeff Farkell, Jerry Jerome, Kevin Bradley, Megan Mattson-Hedges, Phillip Hodgson, Rob Moog, Scott Inbody, Terry Alme, Dusty Jones, Mark Grubb, Phil Aschim, Steve Kellog, Dan Meuli, Jeremy Curry, Aaron Killion and Brian Aklestad.

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Summary of climatic data by month for the '15-16 crop year (September thru August) at the Western Triangle Agricultural Research Center, Conrad, MT.

Month and Year	Precipitation (inches) Current Year	Average (30 yr)	Difference	Mean Temperature (^oF) Current Year	Average (30 yr)	Difference
September, 2015	2.99	1.17	+1.82	55.1	57.0	-1.9
October, 2015	1.17	0.64	+0.53	47.5	44.9	+2.6
November, 2015	0.82	0.31	+0.51	31.0	31.9	-0.9
December, 2015	0.67	0.21	+0.46	24.2	24.0	+0.2
January, 2016	2.36	0.28	+2.08	23.5	23.2	+0.3
February, 2016	0.00	0.21	-0.21	36.1	24.7	+11.4
March, 2016	0.20	0.40	-0.20	37.6	33.0	+4.6
April, 2016	2.06	1.02	+1.04	45.1	42.7	+2.4
May, 2016	2.09	1.90	+0.19	49.9	51.5	-1.6
June, 2016	0.60	2.89	-2.29	61.3	59.4	+1.9
July, 2016	2.82	1.41	+1.41	64.7	66.8	-2.1
August, 2016	1.11	1.27	-0.16	63.3	66.0	-2.7
Total or Average	16.89	11.71	+5.18	44.9	43.7	+1.2

Last killing frost in spring (32^{o}F)

2016-------------------------------- May 12

Average 1986-2016-------------- May 16

First killing frost in fall (32^{o}F)

2016-------------------------------- September 13

Average 1986-2016-------------- September 24

Frost free period (days)

2016------------------------------ 124

Average-------------------------- 131

Maximum summer temperature------- 89^{o}F (August 16, 2016)

Minimum winter temperature------- -12^{o}F (December 26, 2015)

Varietal Testing Program

Winter wheat

Project Title: Winter wheat variety evaluations at Western Triangle Ag. Research Center

Principle Investigator: Gadi V.P. Reddy, Superintendent and Associate Professor of Entomology/Insect Ecology, Western Triangle Ag Research Center

Personnel: John H. Miller, Research Associate and Julie Prewett, Research Assistant, WTARC, Conrad, MT, and Phil Bruckner and Jim Berg, MSU Plant Science Dept., Bozeman, MT.

Cooperators: Bradley Farms, north of Cut Bank, MT
Brian Aklestad, north of Devon, MT
Aaron Killion, east of Brady, MT
Inbody Farms, northeast of Choteau, MT

Objectives: There are diverse cropping environments within the area served by Western Triangle Agricultural Research Center. Each off station location has its own unique environment and soils. Producers in the various locations are interested in variety performance in the local area. To this end the objective is to evaluate winter wheat varieties under the local conditions with respect to yield, test weight, plant height, and seed protein. The environmental conditions at the off station nurseries can vary greatly from those at WTARC. The research center strives to provide growers of the western triangle area unbiased information of various winter wheat varieties.

Methods: On station plots consist of the Intrastate, Advanced and Preliminary A nurseries. Off station winter wheat nurseries consist of 25 entries replicated three times, seeded with a four row plot seeder on one foot spacing. All plots were planted on no-till chemical fallow. Plots were trimmed, measured for length, and then harvested with a Hege 140 plot combine. Winter wheat seed was cleaned prior to collecting data. Wheat midge pheromone traps were installed at each off station plot.

Results: On station winter wheat plots began growing this spring in February as the soil and temperatures On station winter wheat data are presented in tables 1 thru 4, off station plots were harvested at Choteau, Cut Bank, Devon, and the ‘Knees’. The data are presented in Tables 5 thru 12. Soil test data is shown in Table 13.

At the research center, this years’ overall crop year temperatures were slightly higher than the 30 year average at the research center, being 1.2 degrees warmer than normal. With November being 0.9 degrees warmer that the 30 year average. December and January average temperatures were very close to the long term average. February was exceptionally warmer, with the temperature being 11.4 degrees warmer than the 30 year average. March and April were also warmer by 4.6 and 2.4 degrees above the 30 year average. May temperatures were cooler than the average by 1.6 degrees. June was also above average by 1.9 degrees. With July and August being slightly cooler than normal by 2.1 and 2.7 degrees.

Precipitation at the research center was surprising with 5.18 inches more moisture than the 30 year average. We received above average moisture the fall of 2015, resulting in good soil moisture at planting. September was 1.82 inches above the 30 year average. October through December were 0.5 inches of precipitation above normal. January was ahead of the average with 2.1 inches more than the normal precipitation. February was exceedingly dry reporting no moisture for the month. With March close behind only receiving 0.2 of inch. April brought some much needed moisture with about an inch above the 30 year average, while May was only slightly above the 30 year average. June precipitation was 2.3 inches below normal. July received 1.4 inches over the 30 year average for precipitation. The combination of heat and dry in June at the time the canola was flowering and setting pods, affected yield making growing conditions very poor for canola.

The chemical fallowed soils generally had good moisture while seeding winter wheat during the fall of 2015. Precipitation in September and October was above the 30 average, with a cooler September and a warmer October, and November was slightly cooler than normal.

Grain yields for the Intrastate nursery were about 8 bu/ac higher than the six year average and test weights were up about a pound and a half per bushel with respect to the six year average. Seed protein was 0.4 percent lower this year as compared to the six year average. The top yielding varieties were SY Monument, MT1138, and SY Wolf at 111.2, 111.2, and 109.5 bu/ac with each also having a test weight over 60 lbs/bu (Table 1).

Grain yields and test weights at Choteau were about 4 bu/ac higher and 2 lb/bu higher than the four year average. Seed protein at Choteau was 0.7 percent lower than the four year average. The top yielding varieties at Choteau include Cowboy, the Montana State University experimental line MT1348, and Keldin at 88.0, 82.5, and 82.5 bu/ac (Table 5 and 6). Grain yields and test weights at Cut Bank were 15.7 bu/ac higher and 1 lb/bu higher than the three year average. Seed protein at Cut Bank was 0.5 percent higher than the three year average. At Cut Bank, the top yielding wheat's were Keldin, SY Wolf, and WB3768 with yields of 95.1, 91.5,and 90.0 bu/ac (Table 7 and 8).

Grain yields and test weights at Devon were a little more than 20 bu/ac higher and 1 lb/bu higher than the four year average. Seed protein at Devon was about 2 percent lower than the four year average. Top yielders at Devon include Cowboy, Keldin, and the Montana State University experimental line MT1332 at 94.0, 91.3, and 90.8 bu/ac (Table 9 and 10). Grain yields and test weights at the 'Knees' were a little more than 23 bu/ac higher and 2 lb/bu lower than the five year average. Seed protein at the 'Knees' was 0.4 percent lower than the five year average. The top yielding varieties at the 'Knees' include Montana State University experimental line Keldin, Judee, and SY Clearstone 2CL at 121.9, 117.2, and 114.2 bu/ac (Table 11 and 12).

No insect incidence (wheat stem sawfly or wireworms) was noticed in any of the winter wheat varieties at Devon or Cut Bank. The plots at Choteau and the 'Knees' had sawfly cutting, and the plot at the 'Knees' had some stripe and tan rust. Because of the high number of parasitoids of the wheat stem sawfly at the research center very little cutting was observed. Insignificant amount of adult of wheat midge were found at the off station locations.

<u>**Summary:**</u> The data from the off station plots is supported by the local producers and advisory committee as well as the seed industry. It is planned to continue the off station variety plots at

the same locations as the environmental conditions at each location is unique to the western triangle area.

These data should be used for comparative purposes rather than using absolute numbers. Statistics are used to indicate that treatment or variety differences are really different and are not different due to chance or error. The least significant difference (LSD) and coefficient of variability (CV) values are useful in comparing treatment or variety differences. The LSD value represents the smallest difference between two treatments at a given probably level. The LSD at p=0.05 or 5 % probability level is usually the statistic reported, and it means that the odds are 19 to 1 that treatment differences by the amount of the LSD are truly different. The CV value measures the variability of the experiment or variety trial, and a CV greater than 15 % indicates a high degree of variability and less accuracy.

Funding Summary: Office of Special Projects will provide expenditure information. No other grants support this project.

MWBC FY2016 Grant Submission Plans: A similar project will be proposed for FY 2017. The continuation of on and off-station variety trials help elucidate researchers and farmers which varieties are better suited for that particular region in Montana.

Table 1. 2016 Intrastate Winter Wheat Variety Nursery, Western Triangle Ag. Research Center, Conrad, MT.

Variety or ID	Source	Solid Stem score*	Yield bu/ac	Test weight lb/bu	Heading Date Julian	Plant height inch	Protein %
SY Monument	Syngenta (ArgiPro), 2014		111.2	61.9	158.0	33.8	10.9
MT1138			111.2	60.8	159.0	35.8	11.7
SY Wolf	Syngenta (AgriPro), 2010		109.5	64.5	157.3	32.8	11.4
Keldin	WestBred, 2011		109.4	63.3	157.7	34.2	10.8
MT1460			108.6	63.2	160.0	35.7	11.5
WB4614	WestBred, 2013		107.4	63.6	157.3	33.3	11.6
Avery	Colorado, 2015		105.4	63.5	156.0	35.5	10.3
MT1444			105.3	63.0	158.7	34.7	11.3
MT1354			104.4	62.2	160.3	34.7	11.8
MT1465			104.2	62.6	158.3	32.7	11.8
Northern	MSU, 2015		103.5	61.6	161.0	34.9	11.7
MT1471			103.3	62.9	159.3	34.3	12.2
MTCL1131			103.3	62.4	160.0	37.1	11.8
BZ9W09-2212		19.9	102.3	61.3	159.7	33.1	11.7
Yellowstone	MSU, 2005		102.3	61.9	156.7	36.2	11.7
MT1443			102.0	63.7	160.3	35.8	11.8
MTS1407		21.3	101.7	63.1	158.3	29.4	12.5
Cowboy	Wyoming/Colorado, 2012		101.7	60.2	157.3	33.9	10.1
MTW1491			101.4	63.1	159.7	34.1	11.7
MT1348			101.3	63.3	158.3	33.8	11.4
MT1488			100.1	60.9	160.0	35.7	11.2
MT1478			99.9	63.0	158.0	34.2	11.5
MT1265			99.7	62.7	159.7	35.9	11.6
Byrd	Colorado Wheat Res. Fdn., 2011		99.6	62.4	154.0	32.8	10.8
WB3768	MSU/WestBred, 2013		98.8	62.1	161.0	37.8	11.7
Colter	MSU, 2013		98.1	62.2	160.3	35.0	11.7
SY Clearstone 2CL	MSU/Syngenta (AgriPro), 2012		97.7	62.7	157.7	35.6	11.8
MT1332			97.0	62.3	159.0	36.1	11.6
BZ9W09-2075			97.0	64.4	157.3	32.3	12.1
WB4623CLP	WestBred, 2014		96.6	62.3	159.0	33.1	12.6
MT1356			96.6	62.1	159.3	35.0	12.2
Broadview	Meridian Seeds, Alberta, 2009		96.2	62.6	159.7	34.6	11.3
Loma (MTS1224)	MSU, 2016	16.8	96.1	60.2	161.7	34.0	11.9
Decade	MSU/North Dakota, 2010		95.7	62.4	157.7	34.8	11.5
T158	Trio Research/Limagrain Cereals, 2009		95.5	64.0	153.0	32.0	11.8

Table 1 continued on next page

Table 1 continued

Variety and Class	Source	Solid Stem score*	Yield bu/ac	Test weight lb/bu	Heading Date Julian	Plant height inch	Protein %
Bearpaw	MSU. 2011	20.3	95.4	62.8	159.0	34.5	12.1
MT1446			95.0	63.3	160.0	34.0	11.6
MT1257			94.8	62.1	159.0	35.7	12.6
Brawl CL Plus	Colorado Wheat Res. Fdn., 2011		93.2	63.9	153.0	35.3	13.3
PSB13NEDH-14-71			92.0	62.7	155.7	32.1	12.0
Rampart	MSU, 1996	22.2	91.3	62.4	159.7	38.1	13.0
SY Sunrise	Syngenta (AgriPro), 2015		90.6	63.5	155.7	30.5	11.8
Judee	MSU, 2011	20.5	89.5	63.5	159.0	33.2	12.6
WB4059CLP	WestBred, 2013		88.7	62.7	153.3	31.4	12.9
CDC Falcon	Sask/WestBred, 1999	5.4	88.3	61.8	158.0	29.8	10.9
WB-Quake	WestBred, 2011	20.2	87.9	63.2	160.7	33.0	12.3
Freeman	Nebraska, 2013		86.4	60.8	154.7	31.8	11.8
Warhorse	MSU, 2013	21.6	84.6	62.1	159.3	31.6	12.1
Jerry	North Dakota, 2011		83.7	61.6	159.7	37.4	11.2
Mean		18.7	98.5	62.5	158.3	34.1	11.7
LSD (0.05)		1.7	11.9	1.7	138	2.0	0.8
C. V. (%)		5.1	7.0	1.5	0.7	3.3	3.8
P-value (Varieties)		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Planted: 9/22/15 on chemical fallow and harvested on 8/2/16.

Fertilizer: actual pounds/ac of N-P-K: 11-22-0 applied with seed and 40-0-20 broadcast at planting. 125 lbs N/ac as urea was broadcast on 3/8/2016. For fertilizer rates a yield goal of 70 bu/ac was used.

Herbicide: Huskie at 11.0 oz/ac and Axial XL at 16.4 oz/ac applied on 4/23/2016.

* Solid stem score of 19 or higher is generally required for reliable sawfly resistance, solid stem scores are for the plot located at WTARC.

CL = Clearfield System

Table 2. Six-year means, 2011 – 2016, Winter wheat varieties, Western Triangle Ag. Research Center, Conrad, MT.

Variety	Source	Solid stem* score	6-Year Means Yield bu/ac	Test Wt.	Height inch	Head date	Protein %	Winter survival class
CDC Falcon	CDC/WestBred	6.0	89.8	60.9	31.5	166.4	11.5	4
Yellowstone	MSU	-	99.3	60.6	34.8	167.9	11.6	4
Jerry	N. Dakota	-	83.4	60.2	37.8	167.6	11.9	5
Rampart	MSU	22.2	79.3	61.2	36.4	167.0	13.2	2
Decade	MSU/ND	-	90.1	61.3	33.0	164.2	12.3	4
Judee	MSU	20.5	87.0	62.7	33.2	165.5	12.3	2
Bearpaw	MSU	20.3	85.3	60.9	32.3	165.8	12.4	2
WB-Quake	WestBred	20.2	82.0	61.2	33.1	168.5	12.2	3
Warhorse	MSU	21.6	82.2	60.3	32.4	167.3	12.4	4
Colter	MSU	-	95.7	60.3	34.0	168.7	12.1	4
SY Wolf	Syngenta	-	100.2	62.5	31.0	164.5	11.9	3
Northern	MSU		99.5	60.7	34.1	168.7	12.0	3
SY Clearstone 2CL	SY/MSU	-	95.2	59.8	34.9	167.7	11.8	3
Loma	MSU	16.8	93.2	59.7	31.8	170.0	12.3	4
Mean		18.2	90.1	60.9	33.6	167.0	12.1	

* Solid stem score of 19 or higher is generally required for reliable sawfly resistance.
CL = Clearfield herbicide system.
Winter hardiness: 5 = high, 1 = low.

Table 3. 2016 Advanced Yield Nursery, Western Triangle Ag. Research Center, Conrad, MT.

ID or Variety	Class[1]	Yield (bu/ac)	Test weight lb/bu	Heading Date Julian	Plant height inch	Seed Protein %
MTS1589	s	104.4	63.7	159.3	31.7	11.0
MT1542		103.4	62.2	157.7	34.3	10.9
MTW1544	w	101.1	63.2	158.3	33.0	11.8
MTS1588	s	97.7	61.8	160.3	32.3	12.3
Yellowstone		97.6	62.0	159.3	34.7	11.5
MT1547		97.6	62.1	158.0	33.0	11.1
SY Wolf		97.2	63.2	157.3	31.3	11.3
MT1563		94.8	60.0	159.7	33.0	11.6
MT1507		94.4	62.4	158.3	34.0	10.8
MT1519		94.1	61.0	158.7	34.7	11.7
MTS1582	s	92.6	60.4	159.3	32.0	11.4
MT1564		91.4	62.0	155.3	33.3	11.4
MT1565		91.1	62.1	156.7	33.3	12.0
MTS1574	s	90.0	60.5	158.3	34.3	11.6
MT1540		89.6	63.5	160.0	34.3	11.2
MT1521		89.5	64.9	159.0	32.0	11.0
MTCL1502	cl	88.7	60.7	159.3	32.3	11.7
MT1551		88.5	61.3	159.3	32.7	12.5
MT1549		88.3	62.4	159.0	30.7	11.5
MTCL1503	cl	87.8	61.8	158.0	33.3	13.4
MTS1583	s	87.5	61.4	159.3	30.3	11.3
MTW1525	w	86.9	62.7	160.0	33.0	12.3
MT1514		86.1	62.9	157.7	32.7	11.6
MTS1573	s	86.1	61.6	157.0	32.7	12.0
MTS1572	s	84.9	61.1	158.0	31.7	12.1
MT1569		84.7	62.1	156.7	33.7	12.0
MTF1559	f	84.5	56.4	161.3	37.7	11.3
Decade		84.1	61.3	158.0	30.7	12.0
MT1536		83.3	60.1	157.0	33.3	11.2
MTS1584	s	81.9	61.6	159.3	31.0	10.4
MTS1571	s	81.8	61.3	157.7	33.7	12.0
Warhorse		81.5	60.8	159.0	32.7	12.5
MTS1580	s	81.5	61.2	156.3	33.3	12.1

Table 3. Continued on next page

Table 3 Continued

ID Or Variety		Yield bu/ac	Test weight lb/bu	Heading Date Julian	Plant height in	Protein %
Judee		79.3	62.5	157.3	33.3	11.4
MT1561		78.7	59.7	160.0	35.0	11.4
MTS1596	s	74.8	61.3	161.0	30.3	11.8
Mean		89.1	61.6	158.5	32.9	11.6
LSD (0.05)		12.5	1.8	1.4	3.0	ns
C.V. (%)		8.1	1.7	0.5	5.7	7.0
P-value (Varieties)		0.0009	<0.0001	<0.0000	0.0101	0.0898

Planted: September 22, 2015 on chemical fallow barley stubble and harvested on August 2, 2016.
Fertilizer, actual pounds/ac of N-P-K: 11-22-0 applied with seed and 40-0-20 broadcast at planting. 125 lbs/ac N as urea was broadcast on 3/8/2016. For fertilizer rates a yield goal of 70 bu/ac was used.
Herbicide: Huskie at 11.0 oz/ac and Axial XL at 16.4 oz/ac applied on 4/23/2016.
[1] Wheat Class: White = w, Solid Stem = s, Forage = f, and Clearfield = cf

Table 4. 2016 Preliminary A Variety Nursery, Western Triangle Ag. Research Center, Conrad, MT.

Variety	Yield bu/ac	Test weight lb/bu	Heading Date Julian	Plant height inch	Protein %
MTCL1636	128.9	61.5	159.5	34.0	10.7
MT1670	127.8	62.1	161.0	35.5	10.8
MT1671	125.8	62.1	160.5	33.5	10.7
MT1639	123.3	62.3	160.0	37.0	10.7
MT1642	122.6	61.9	161.5	35.0	11.2
MT1668	121.3	63.1	158.5	32.0	11.4
MT1647	119.9	61.0	161.5	34.5	10.8
MT1655	118.2	61.9	160.5	37.0	10.6
SY Wolf	116.6	63.4	156.5	34.5	11.2
MTW1644	116.5	62.4	156.5	34.0	11.8
MT1683	116.3	62.6	159.5	35.5	11.0
MT1654	113.1	62.0	156.0	31.0	11.2
Yellowstone	111.9	62.3	160.0	35.0	11.1
MT1686	111.7	62.4	156.5	35.5	11.8
MTV1681	111.1	61.3	160.0	33.0	11.3
MT1661	110.2	62.4	158.0	35.5	11.8
MTF1631	109.4	63.9	159.0	40.5	11.0
Judee	108.7	63.6	158.0	33.5	11.5
MTF1630	108.5	62.7	159.5	41.5	12.0
MT1666	107.6	62.1	155.0	33.0	11.3
MT1658	107.6	64.3	160.0	34.5	11.8
MT1678	107.6	62.5	157.0	33.0	12.4
MT1669	107.6	60.4	160.0	31.0	11.5
MT1675	107.6	60.9	157.5	35.0	11.5
MT1659	107.5	61.2	160.0	34.5	10.3
MT1650	107.1	60.8	158.0	33.0	12.0
MT1640	105.7	63.2	160.5	34.0	11.6
MT1651	105.4	61.3	160.5	31.5	12.0
MTCL1637	105.3	62.4	158.5	34.5	10.9
MT1652	105.1	62.4	161.0	32.5	11.4
MT1684	104.9	63.8	161.0	33.5	10.2
MTCL1632	104.8	62.8	158.5	36.5	12.1
MT1648	104.5	62.6	157.5	34.5	11.7
MTF1432	103.7	59.6	161.5	41.0	10.7
MT1665	103.3	61.2	159.5	32.5	12.1

Table 4 continued on next page

Table 4 continued

Variety	Yield (bu/ac)	Test Weight (lbs/bu)	Heading Date Julian	Plant Height inch	Protein (%)
MT1641	103.1	64.5	159.5	34.5	11.9
MT1674	102.8	62.3	157.0	35.5	11.4
MT1662	101.9	63.1	157.0	34.0	10.0
MT1682	101.8	60.6	157.5	32.0	12.7
MT1677	101.8	63.2	157.5	33.0	12.8
MTW1653	101.4	63.1	161.0	33.5	11.8
MT1679	101.4	60.4	161.0	37.0	11.4
MT1646	101.1	63.9	158.0	35.0	10.0
MT1667	100.1	62.2	160.0	33.0	11.4
MTF1435	99.7	62.0	160.5	42.5	11.2
MT1657	99.2	64.2	161.5	35.0	11.4
MTF1629	98.3	62.5	160.0	42.0	11.8
MT1656	98.0	60.5	161.0	33.5	11.8
MT1676	98.0	62.8	157.0	31.5	11.6
MT1685	97.3	60.7	160.0	33.0	11.1
MTCL1635	97.2	60.5	159.0	34.5	11.6
MTW1643	96.9	61.4	156.0	33.5	12.4
MT1664	96.1	62.3	159.5	32.5	11.5
MT1680	95.2	59.2	159.0	33.5	12.3
MT1673	95.1	60.5	157.5	33.5	11.3
MT1638	95.0	63.3	156.0	34.5	10.9
MTCL1633	94.0	61.0	160.5	37.0	12.3
MT1660	93.4	62.8	157.0	33.5	10.3
Decade	93.1	61.2	158.0	35.0	9.9
MT1663	91.9	61.3	160.0	34.5	11.5
MT1672	91.5	62.7	155.5	34.5	12.9
MTW1645	89.6	61.5	158.5	35.0	13.1
MTW1649	85.5	59.6	156.5	33.5	13.3
MTCL1643	84.9	62.0	158.0	34.5	13.4
Mean	105.0	62.1	158.9	34.6	11.5
LSD (0.05)	18.6	2.2	1.5	2.4	1.4
C. V. (%)	8.0	1.6	0.5	3.5	5.6
P-value (Varieties)	0.0007	0.0004	<0.0000	<0.0000	0.0007

Planted: September 23, 2015 on chemical fallow and harvested on August 2, 2016.
Fertilizer, actual pounds/ac of N-P-K: 11-22-0 applied with seed and 30-0-20 broadcast at planting. 125 lbs/ac N as urea was broadcast on 3/8/2016
Herbicide: Huskie at 11.0 oz/ac and Axial XL at 16.4 oz/ac applied on 4/23/2016.

Table 5. Off-station Winter Wheat variety trial located near the Choteau. Teton County. Western Triangle Ag. Research Center. 2016.

Variety	Yield bu/ac	Test Wt lb/bu	Height inch	Lodging %	Protein %
Cowboy	88.0	60.2	31.0	6.4	14.0
MT1348	82.5	61.2	32.7	19.7	14.3
Keldin	82.5	62.0	33.0	22.6	13.6
MT1254	82.0	60.0	33.0	8.1	14.1
SY WOLF	79.8	62.7	30.3	13.1	14.1
MT1265	79.2	59.6	34.0	7.8	14.4
MT1257	78.4	60.7	32.3	10.1	13.8
Yellowstone	78.2	60.2	34.0	13.6	14.3
MT1332	77.9	59.9	33.0	13.6	14.3
Colter	77.1	59.4	33.3	7.9	14.5
Loma	77.1	60.0	32.0	7.1	14.8
Judee	76.2	62.4	31.3	8.8	14.9
Northern	75.9	60.4	31.7	1.3	14.2
SY Clearstone 2CL	75.7	59.7	32.0	9.8	14.9
WB3768	75.7	60.3	34.3	21.7	14.5
MT1138	75.6	60.4	34.0	20.3	14.5
Mt1356	72.1	59.0	33.0	6.7	14.8
Decade	71.5	60.9	32.0	6.9	15.0
Warhorse	71.5	60.7	30.0	0.0	14.7
CDC Falcon	69.5	59.9	31.3	13.7	14.3
Jerry	65.1	59.6	35.0	13.5	14.1
Broadview	64.7	59.8	34.0	21.7	14.1
Rampart	64.1	61.3	33.7	6.3	15.2
Bearpaw	63.1	61.2	30.3	7.8	14.6
WB Quake	62.6	61.5	30.0	8.8	14.0
Mean	74.6	60.5	32.5	11.1	14.4
LSD (.05)	8.6	1.5	2.9	8.2	0.8
C.V. (%)	6.2	1.4	5.4	43.4	3.0
P-Value	<0.0001	<.00007	0.0235	<0.0001	0.0201

Cooperator and Location: Inbody Farms western Chouteau County.
Planted on 9/20/2015 on chemical fallow durum stubble. Harvested on 8/6/16.
Fertilizer, actual lbs/ac: 11-22-0 with seed at planting, 40-0-20 broadcast while planting. Spring top dressing took place on 3/5/15 with 96-0-0. For fertilizer rates a yield goal of 70 bu/ac was used.
Herbicide: Pre-plant sprayed with RT3 @ 16 oz/ac on 9/20/2015. Plots were sprayed on 6/13/16 with Axiel XL @ 16 oz/ac and Vendetta @ 2 pints per acre.
Conducted by MSU Western Triangle Ag. Research Center.

** = Solid stem sawfly-resistant (solid stem score of 19 or higher). * = Less preferred by sawfly (behavioral preference) in small plots. Conducted by MSU Western Triangle Ag. Research Center.

Table 6. Four-year means, Winter Wheat varieties, Choteau area, Teton County. 2012-2014 and 2016.

Variety Or ID	**	4-Year Mean Yield bu/ac	Test weight lbs/bu	Height inch	Protein %
Yellowstone	-	62.7	58.5	32.1	14.9
Colter	-	59.0	58.1	31.8	15.3
SY Clearstone 2CL	-	58.5	58.4	31.9	15.1
Judee	-	58.2	57.3	29.6	15.2
Northern (MT0978)	-	57.7	58.2	30.1	15.5
CDC Falcon	-	57.2	58.2	29.3	14.8
Decade	-	56.8	59.5	30.0	15.3
Bearpaw	**	56.0	59.8	29.7	14.9
Warhorse	**	54.8	58.6	29.0	14.9
WB-Quake	**	51.7	59.0	29.0	15.1
Rampart	**	50.0	59.6	32.8	15.7
Mean		56.6	58.6	30.5	15.1

** = Solid stem sawfly-resistant (solid stem score of 19 or higher).
Cooperator and Location: Inbody Farms, Teton County.
Conducted by MSU Western Triangle Ag. Research Center.

Table 7. Off-station Winter Wheat variety trial located north of Cut Bank, MT.
Glacier County. Western Triangle Ag. Research Center. 2016.

Variety	Yield bu/ac	Test Wt lb/bu	Height inch	Protein %
Keldin	95.1	59.5	32.1	13.6
SY Wolf	91.5	59.3	30.9	13.8
WB3768	90.0	60.3	33.9	14.3
MT1356	89.8	60.2	31.7	13.8
Cowboy	87.2	58.6	29.3	12.9
MT1138	85.0	59.2	32.9	14.1
Loma	84.3	59.2	29.6	14.1
Colter	83.9	58.9	31.3	15.0
MT1354	82.9	59.6	31.8	14.0
MT1332	82.8	59.2	30.9	14.1
MT1257	82.3	59.1	31.5	13.9
MT1348	81.2	58.7	30.5	13.4
Yellowstone	80.7	59.3	32.0	14.2
Northern	80.6	59.2	30.6	14.5
CDC Falcon	79.6	57.2	30.2	14.2
MT1265	78.1	59.1	32.3	14.3
SY Clearstone 2CL	77.5	58.7	33.1	13.9
Broadview	76.0	58.4	30.2	14.1
Judee	74.9	59.1	30.3	14.3
Decade	74.0	57.7	30.4	13.9
WB-Quake	71.2	58.5	31.5	14.4
Bearpaw	66.3	56.5	29.9	14.7
Rampart	65.3	58.3	35.6	15.5
Warhorse	64.6	58.4	29.1	15.0
Jerry	62.5	58.1	35.3	14.2
Mean	79.5	58.8	31.5	14.2
LSD (.05)	13.4	1.4	3.1	0.8
C.V. (%)	9.5	1.3	5.7	3.0
P-Value	<0.0001	0.0004	0.0044	0.0001

Cooperator and Location: Bradley Farms, northern Glacier County.
Planted on 9/24/2015 on chem-fallow. Harvested on 8/31/2016.
Fertilizer, actual lbs/ac: 11-22.5-0 with seed at planting, topdressed with 100-0-20 on 3/11/2016. For fertilizer rates a yield goal of 70 bu/ac was used.
Herbicide: Sprayed with Huskie @ 11 oz/ac and Axial XL at 16.4 oz/ac on 5/2/2016.
** = Solid stem sawfly-resistant (solid stem score of 19 or higher). * = Less preferred by sawfly (behavioral preference) in small plots.
Conducted by MSU Western Triangle Ag. Research Center.

Table 8. Three-year means, Winter Wheat varieties, Cut Bank area, northern Glacier County. 2014-2016.

Variety Or ID	**	3-Year Mean Yield bu/ac	Test weight lbs/bu	Height inch	Protein %
Yellowstone	-	70.6	57.6	32.1	13.5
Northern (MT0978)	-	68.5	58.2	30.7	13.8
Colter	-	68.4	58.1	31.1	13.7
Judee	-	66.3	58.6	29.4	13.5
CDC Falcon	-	65.8	56.0	29.3	13.6
Decade	-	64.6	57.2	29.6	13.4
Bearpaw	**	64.6	56.3	30.2	13.6
SY Clearstone 2CL	-	63.9	57.5	32.1	13.5
WB-Quake	**	57.7	57.9	30.5	13.4
Rampart	**	56.7	57.8	32.4	14.5
Warhorse	**	54.3	57.7	29.0	14.0
Mean		63.8	57.5	30.6	13.7

** = Solid stem sawfly-resistant (solid stem score of 19 or higher).
Cooperator and Location: Bradley Farms, Glacier County.
Conducted by MSU Western Triangle Ag. Research Center.

Table 9. Off-station Winter Wheat variety trial located near the Devon. Toole County.
Western Triangle Ag. Research Center. 2016.

Variety	Yield bu/ac	Test Wt lb/bu	Height inch	Protein %
Cowboy	94.0	61.2	60.5	10.3
Keldin	91.3	63.0	32.1	9.9
MT1332	90.8	61.5	33.0	10.1
Yellowstone	90.3	61.2	31.9	10.2
MT1354	89.9	62.2	31.7	9.8
MT1257	88.4	61.4	32.3	10.1
MT1356	88.2	61.7	31.9	10.4
MT1348	88.0	61.8	32.1	10.3
Northern	87.0	61.1	29.9	10.3
MT1138	86.7	61.3	32.2	10.0
SY Wolf	86.6	62.8	30.5	10.4
Loma	84.2	60.7	29.2	10.4
WB3768	84.2	61.2	32.9	11.5
Decade	83.9	61.2	31.0	10.5
Colter	83.4	61.1	30.7	11.0
Broadview	81.6	61.3	30.4	11.1
CDC Falcon	81.0	60.8	28.1	10.8
SY Clearstone 2CL	80.3	61.0	32.2	10.3
Rampart	78.7	60.9	33.1	11.3
Judee	78.6	61.7	30.2	11.3
Bearpaw	76.6	60.4	29.7	10.9
MT1265	76.3	60.4	32.3	10.8
Warhorse	74.3	61.8	29.7	11.4
WB Quake	72.7	60.6	28.8	11.4
Jerry	70.5	59.4	31.7	10.5
Mean	83.5	61.3	31.1	10.6
LSD (.05)	11.2	1.4	1.7	ns
C.V. (%)	7.3	1.3	3.0	7.3
P-Value	0.0002	0.0059	<0.0001	0.4090

Cooperator and Location: Brian Akelstad, Toole County.
Planted on September 17, 2015 on chemical fallow. Harvested on 7/28/2016.
Fertilizer, actual lbs/ac: 11-22-0 with seed at planting, 40-0-20 broadcast while planting. Spring topdressing took place on 3/10/16 with 77-0-0. For fertilizer rates a yield goal of 70 bu/ac was used.
Herbicide: Pre-plant sprayed with and RT3 @ 16 oz/ac on 9/17/2015. Sprayed with Huskie @ 11 oz/ac and Axial XL @ 16.4 oz/ac on 5/1/16.
** = Solid stem sawfly-resistant (solid stem score of 19 or higher). * = Less preferred by sawfly (behavioral preference) in small plots.
Conducted by MSU Western Triangle Ag. Research Center.

Table 10. Four-year means, Winter Wheat varieties, Devon area, Toole County. 2012-2014 and 2016.

Variety Or ID	**	4-Year Mean Yield bu/ac	Test weight lbs/bu	Height inch	Protein %
Northern (MT0978)	-	67.5	60.3	27.0	12.0
Yellowstone	-	66.9	59.8	29.6	12.0
Decade	-	65.6	61.1	28.3	12.1
Colter	-	64.3	60.3	29.5	12.4
CDC Falcon	-	62.1	59.7	26.5	12.3
SY Clearstone 2CL	-	61.8	59.8	29.6	11.9
WB-Quake	**	61.1	60.1	27.5	12.2
Bearpaw	**	61.0	60.0	26.5	12.8
Warhorse	**	58.7	60.4	27.3	12.4
Judee	-	58.2	60.7	26.6	12.9
Rampart	**	58.1	60.7	30.4	12.7
Mean		62.2	60.2	28.1	12.3

** = Solid stem sawfly-resistant (solid stem score of 19 or higher).
Cooperator and Location: Aklestad farms, Toole County.
Conducted by MSU Western Triangle Ag. Research Center.

Table 11. Off-station Winter Wheat variety trial located near the Knees. Chouteau County. Western Triangle Ag. Research Center. 2016.

Variety or ID	Yield bu/ac	Test Wt. lb/bu	Height inch	Lodging %	Protein %
Keldin	121.9	59.4	35.3	83.1	8.7
Judee	117.2	61.2	34.7	46.0	12.9
SY Clearstone 2CL	114.2	58.7	39.3	75.6	12.2
SY Wolf	104.2	59.3	33.9	52.7	11.9
MT1348	101.1	59.6	38.8	94.5	12.3
Yellowstone	99.5	56.9	37.1	80.7	11.9
MT1138	93.8	58.3	38.4	64.0	11.6
MT1332	93.2	57.3	37.0	97.0	13.0
MT1265	92.2	57.8	38.9	82.3	11.3
Broadview	92.1	57.6	36.9	57.3	12.3
Northern	90.2	56.8	37.7	37.1	12.3
Cowboy	89.2	57.9	35.2	95.7	12.4
MT1356	88.5	57.7	37.5	57.6	11.9
CDC Falcon	88.1	58.2	33.9	91.3	12.8
MT1257	87.3	57.9	36.5	88.4	13.0
Colter	86.0	58.0	36.8	97.6	13.0
WB-Quake	85.6	58.4	36.4	42.1	13.4
WB3768	85.0	57.3	39.9	97.7	12.0
Decade	83.5	58.1	33.1	51.1	12.5
Loma	83.1	55.9	35.2	23.8	13.6
Warhorse	81.4	58.2	35.2	0.0	13.2
MT1354	80.6	58.3	37.2	57.7	13.1
Jerry	68.4	57.8	41.9	92.4	12.0
Rampart	66.6	56.4	36.1	36.4	14.4
Bearpaw	66.1	56.0	35.7	11.5	12.5
Mean	90.3	58.0	36.7	64.5	12.4
LSD (.05)	20.5	ns	2.4	33.8	2.1
C.V. (%)	13.8	2.6	3.7	29.8	9.6
P-Value	0.0002	0.1287	<0.0001	<0.0001	0.0221

Cooperator and Location: Aaron Killion, western Chouteau County.
Planted on 9/10/15 on chem-fallow. Harvested on 8/1/16.
Fertilizer, actual lbs/ac: 11-22-0 with seed at planting, 40-0-20 broadcast while planting. Spring topdressing took place on 3/15/2016 with 121-0-0. For fertilizer rates a yield goal of 70 bu/ac was used.
Herbicide: Pre-plant sprayed with Olympus @ 0.6 oz/ac and RT3 @ 16 oz/ac on 9/10/2015. The plots were sprayed on 4/23/16 with Huskie @ 11 oz/ac and Axial XL @ 16.4 oz/ac.
Conducted by MSU Western Triangle Ag. Research Center.

Table 12. Five-year means, Winter Wheat varieties, Knees area, western Chouteau County. 2012-2016.

Variety Or ID	**	5-Year Mean Yield bu/ac	Test weight lbs/bu	Height inch	Protein %
SY Clearstone 2CL	-	75.3	59.1	32.7	12.8
Yellowstone	-	72.9	59.2	31.2	12.5
Northern (MT0978)	-	72.2	59.7	30.2	12.6
Judee	-	70.8	61.3	29.4	13.1
Colter	-	70.0	59.8	30.8	12.5
Decade	-	69.6	60.7	29.8	12.8
Warhorse	**	66.4	60.4	28.9	12.6
CDC Falcon	-	64.8	60.1	27.4	12.9
WB-Quake	**	62.8	60.3	29.1	12.9
Bearpaw	**	56.0	59.4	28.6	12.9
Rampart	**	53.7	59.9	30.2	13.5
Mean		66.7	60.0	29.9	12.8

** = Solid stem sawfly-resistant (solid stem score of 19 or higher).
Cooperator and Location: Aaron Killion, western Chouteau County.
Conducted by MSU Western Triangle Ag. Research Center.

Table 13. Soil test values for off-station and on-station plots, 2016.

Location	N (lbs/ac)[1]	Olsen-P (ppm)	K (ppm)	pH	OM (%)	EC (mmhos/cm)
Cut Bank	39.6	17	385	7.5	2.7	0.39
Devon	12.1	14	221	7.2	0.8	0.15
Knees	21.1	28	482	6.9	2.4	0.55
Choteau	44.5	7	412	8.1	2.3	0.82
WTARC	15.6	20	318	7.8	2.4	0.56

[1]Nitrogen soil samples were to a depth of four feet in one foot increments. All other soil tests were for zero to six inches in depth.
WTARC- Western Triangle Ag. Research Center

MONTANA STATE UNIVERSITY
College of AGRICULTURE & MONTANA AGRICULTURAL EXPERIMENT STATION

Spring wheat variety evaluations

<u>Title:</u> Spring wheat variety evaluations at Western Triangle Ag. Research Center

<u>Principle Investigator:</u> Gadi V.P. Reddy, Superintendent, Western Triangle Ag Research Center

<u>Personnel</u>: John H. Miller, Research Associate and Julie Prewett, Research Assistant WTARC, Conrad, MT, and Luther Talbert and Hwa-Young Heo, MSU Plant Science Dept., Bozeman, MT.

<u>Cooperators:</u> Bradley Farms, north of Cut Bank, MT
Brian Aklestad, north of Devon, MT
Aaron Killion, east of Brady, MT
Inbody Farms, northeast of Choteau, MT

Objectives: There are diverse cropping environments within the area served by Western Triangle Agricultural Research Center. Each off station location has its own unique environment and soils. Producers in the various locations are interested in variety performance in the local area. To this end the objective is to evaluate winter wheat varieties under the local conditions with respect to yield, test weight, plant height, and seed protein. The environmental conditions at the off station nurseries can vary greatly from those at WTARC. The research center strives to provide growers of the western triangle area unbiased information of various spring wheat varieties.

<u>Methods:</u> On station nursery is the Advance Yield Trial (AYT) with 64 entries replicated three times. Off station spring wheat nurseries consist of 20 entries replicated three times, seeded with a four row plot seeder on one foot spacing. All plots were planted on no-till chemical fallow. Plots were trimmed, measured for length, and then harvested with a Hege 140 plot combine. Spring wheat seed was cleaned prior to collecting data. Wheat midge pheromone traps were also installed at each off station plot.

Results: Results are tabulated in Tables 1 thru 13. Results are tabulated in Table 1 for the advanced spring wheat nursery and Table 2 is five year averages for selected varieties in the advanced spring wheat nursery. Table 3 is for the off station irrigated spring wheat nursery, with multi-year data presented in Table 4. Tables 5 thru 12 are for the off station locations, with Table 13 representing the data from the SM1 nursery and Table 14 containing soil test data.

At the research center, this years' overall crop year temperatures were slightly higher than the 30 year average at the research center, being 1.2 degrees warmer than normal. With November being 0.9 degrees warmer that the 30 year average. December and January average temperatures were very close to the long term average. February was exceptionally warmer, with the temperature being 11.4 degrees warmer than the 30 year average. March and April were also warmer by 4.6 and 2.4 degrees above the 30 year average. May temperatures were cooler than the average by 1.6 degrees. June was also above average by 1.9 degrees. With July and August being slightly cooler than normal by 2.1 and 2.7 degrees.

Precipitation at the research center was surprising with 5.18 inches more moisture than the 30 year average. We received above average moisture the fall of 2015, resulting in good soil moisture at planting. September was 1.82 inches above the 30 year average. October through December were 0.5 inches of precipitation above normal. January was ahead of the average with 2.1 inches more than the normal precipitation. February was exceedingly dry reporting no moisture for the month. With March close behind only receiving 0.2 of inch. April brought some much needed moisture with about an inch above the 30 year average, while May was only slightly above the 30 year average. June precipitation was 2.3 inches below normal. July received 1.4 inches over the 30 year average for precipitation.

The AYT yields ranged from 77.2 to 44.7 bu/ac, with an average of 59.8 bu/ac and 13.5 % seed protein. The 5 year yield and protein average for selected varieties in the AYT is 70.6 bu/ac and 13.5 % seed protein. Although, test weight was slightly lower than the 5 year average. The top yielding varieties were all Montana State University experimental entries. They are MT 1570, MT 1451, and MT 1320 with Vida being fourth on the list.

Top yielding varieties at Choteau were Duclair, Alum, and Montana State University line, MT 1401. The top three yielding varieties at Choteau were 39.3, 37.6, and 37.6 bu/ac, respectively (Table 5). Alum, Montana State University lines MT 1401, and MT 1316 were the high yielding varieties at Devon, 37.2, 36.6, and 34.5 bu/ac (Table 9) The 'Knees' high yielders at 25.5, 24.6, and 23.9 bu/ac, were Duclair, Alum, and Choteau. All entries at the 'Knees' were affected by stripe and tan rust. The best yielding varieties, at the Cut Bank location were Alum, Montana State University line MT1316, and Duclair. Yields at Cut Bank were 55.5, 52.6, and 48.1 bu/ac (Table7). The top yielders in the irrigated trial were Alum, at 98.9 bu/ac, Duclair at 90.4 bu/ac and Fortuna at 79.2 bu/ac (Table 3).

Yields in the irrigated off-station spring wheat trial ranged from 98.9 bu/ac to 56.3 bu/ac. When compared to the five year averages, the irrigated off-station spring wheat nursery had higher yields, with lower test weight, and slightly higher grain protein by 0.5% (Tables 3 and 4). At Devon the 2016 yield was up by 1.4 bu/ac from the five year average; with 2.2% lower grain protein and 1 lb/bu higher test weight than the five year average (Tables 9 and 10). The 'Knees' location had much lower yields, higher grain protein and much lower test weight when compared to the five year mean (Tables 11 and 12). All entries at the 'Knees' were affected by stripe and tan rust. Yields at Cut Bank ranged from 55.5 to 30.9 bu/ac, with slightly higher grain protein for the year, with slightly higher test weights (Tables 7 and 8).

The SM1 nursery has wheat that contains the gene to make it resistant to the wheat midge. Data are presented in Table 13. Soil test numbers can be found in Table 14.

No insect incidence (wheat stem sawfly or wireworms) was noticed in any of the spring wheat varieties at Devon or Cut Bank. The plots at Choteau and the 'Knees' had sawfly cutting, and the plot at the 'Knees' had stripe and tan rust. Because of the high number of parasitoids of the wheat stem sawfly at the research center very little stem cutting was observed. Insignificant amount of adult of wheat midge were found at the off station locations.

Summary: The data from the off station plots is supported by the local producers and advisory committee as well as the seed industry. It is planned to continue the off station variety plots at the same locations as the environmental conditions at each location is unique to the western triangle area. No insect incidence or damage was noticed in any of the varieties.

These data should be used for comparative purposes rather than using absolute numbers. Statistics are used to indicate that treatment or variety differences are really different and are not different due to chance or error. The least significant difference (LSD) and coefficient of variability (CV) values are useful in comparing treatment or variety differences. The LSD value represents the smallest difference between two treatments at a given probably level. The LSD at p=0.05 or 5 % probability level is usually the statistic reported, and it means that the odds are 19 to 1 that treatment differences by the amount of the LSD are truly different. The CV value measures the variability of the experiment or variety trial, and a CV greater than 15 % indicates a high degree of variability and less accuracy.

Funding Summary: Office of Special Projects will provide expenditure information. No other grants support this project.

MWBC FY2017 Grant Submission Plans: A similar project will be proposed for FY 2017. The continuation of on and off-station variety trials help to elucidate researchers and farmers which varieties are better suited for that particular region in Montana.

Spring Wheat Variety Notes & Comments

Western Triangle Agricultural Research Center, Conrad MT

Wheat Stem Sawfly Tolerant & Semi-tolerant Hard Red Spring Wheat Varieties:

Resistance (stem-solidness) among varieties ranges from low to high and varies with yearly climate differences; none have total resistance. Stem-solidness scores range from 5 (hollow) to 25 (completely solid). Solidness should be at least 19 to provide a reliable level of sawfly tolerance. However, some partially-solid stem varieties, such as Conan and Corbin, are less attractive to sawflies and show higher tolerance than expected for their level of stem solidness.

Agawam: See Hard White Spring Wheat. (Solid stem score = 23).

Choteau (MSU, 2004): Semi-dwarf with good straw strength. Height is 2” shorter than McNeal and 4” shorter than Fortuna. Stems very solid with good sawfly resistance (more solid than Fortuna). Sawfly resistance comparisons (max rating = 25): Choteau = 21, Fortuna = 19, Ernest = 16. Medium-early, 2 days later than Hank, 0.5 day later than Ernest & Fortuna, 2 days earlier than McNeal. High yield, similar to McNeal on both dryland and irrigated. Yields substantially higher than Ernest and Fortuna. Above average test wt (similar to Fortuna, and higher than McNeal). Moderate resistance to Septoria, and good resistance to most stem rust races. Protein above average. Normal gluten strength and good milling and baking quality. Fair Hessian fly tolerance. Some tolerance to root-lesion nematode.

Conan (WPB, 1998): Semidwarf. Solid stem score is low (10), but has low levels of sawfly-attractant cis-3-hexenylacetate, which increases sawfly resistance to medium. Medium maturity. Average yield and test weight. Some tolerance to Wheat Streak Mosaic Virus. Protein 0.5-0.9% higher than Rambo, and better protein quality than Rambo.

Corbin (WPB, 2006): Semidwarf height, 1” taller than Conan. Stem-solidness score = 10, medium sawfly resistance. Medium maturity, 1 day earlier than Conan. Average yield. Above-average test weight. Higher yield and test weight than Conan. Moderate resistance to stripe rust. Average protein.

Duclair (MSU, 2011): Solid stemmed hard red spring wheat, with stem solidness score of 20, slightly less than Choteau and slightly more than Fortuna. Yields were comparable to Choteau, Reeder, and Vida. Maturity is day earlier than Choteau. Plant heights average about 31 inches. Yields (66 bu/a) tend to be similar to Choteau (65 bu/a), Reeder (66 bu/a) and Vida (68 bu/a). The average test weight is 60 lbs/bu, with grain protein averaging 13.7%. Duclair showed good resistance to stripe rust at Kalispell in 2010.

Ernest (ND, 1995): Tall, weak straw. Medium sawfly resistance (solid stem score = 16). High level of sawfly-attractant cis-3-hexenylacetate. Moderately late maturing, slightly earlier than McNeal. Poor threshability. Tolerant to Far-go. Resistant to prevalent races of leaf & stem rust. Below average yield. High protein and test weight. Good quality.

Lillian (Sask.): Tall weak straw. Late heading. Partial stem solidness. Sawfly cutting for Lillian was 30% at Conrad 2008, compared to 65% for susceptible varieties. Below average test weight. Above average protein.

Fortuna (ND): Beardless, tall straw. Too tall for irrigated conditions, vulnerable to lodging. Good sawfly resistance (solid stem score = 19). Early maturity. Tolerant to Fargo. Very susceptible to Septoria. Medium to low yield except under severe sawfly conditions, where Fortuna often ranks high for yield. Susceptible to shattering, especially in conditions favoring development of large kernels. Average test weight and protein. Fair Hessian fly tolerance.

Triangle II (WestBred, bz9m1024, 2008): Clearfield version of Conan, 2-gene resistance. Stem solidness less than Conan. Yield 1 bu/ac higher than Conan, otherwise similar to Conan.

WB Gunnison (WestBred): Gunnison is intended to replace Conan and Corbin acres. Gunnison is hollow stemmed, but shows good tolerance to cutting by the wheat stem sawfly. The yield (55) is similar to Corbin and slightly higher than Conan. Average test weight is 60 lbs/bu, with grain protein levels of 13.8%, a bit lower than both Conan and Corbin. Average plant height is 30 inches with similar maturity to Conan and Corbin. Gunnison has moderate resistance to stripe rust.

Hollow-Stem, Wheat Stem Sawfly Intolerant Hard Red Spring Wheat Varieties:

Alsen (ND, 2004). Moderate Fusarium scab resistance (MR). Semi-dwarf height. Medium maturity. Average yield. High test weight. High protein. Very poor Hessian fly tolerance.

AP604CL (AgriPro-8): Medium height, med-early maturity. Average yield. Above average test weight & protein.

AP603CL (AgriPro): Two-gene IMI resistance for Clearfield System. Med-tall, med-late maturity. Below average yield. Above average test weight & protein. Medium scab tolerance.

Freyr (AgriPro-3, 2004): Semi-dwarf height. Good lodging resistance, but less than Norpro. Medium maturity, 2 days earlier than McNeal. Average yield. Above average test weight. Average protein. Fusarium Scab resistance slightly lower than for Alsen (MR). Stripe rust MR. Acceptable quality.

Hank (WestBred): Semi-dwarf height. Medium lodging resistance. Early heading, 3 days earlier than McNeal. Above average yield. Better shatter resistance than 926. Below average test weight. Good tolerance to dryland root rot, tolerant to Far-go. Protein above average. Good quality. Hessian fly tolerant (similar to Choteau).

Hanna (AgriPro): Fusarium Scab tolerant.

Jedd (WestBred, 2007): Clearfield System hard red with 2-gene resistance. BC-derived from Hank. Short semi-dwarf height, 3” shorter than Hank or Choteau. Medium heading. Above average yield and test weight, dryland or irrigated. Higher dryland yield than Hank. Average protein. High quality. Moderately susceptible to stripe rust. Tolerance to Hessian fly biotypes of Washington, but unknown for biotypes in Montana.

Kelby (AgriPro, 2006, AP06): Good scab tolerance. Semi-dwarf height, stiff straw. Early heading. Below average yield. Above average test weight and protein. Good foliar disease resistance.

Kuntz (AgriPro-7, 2006): Medium height and maturity. Average yield. Above avg test weight. Average protein.

McNeal (MSU, 1994): Red chaffed. Semi-dwarf. Good lodging resistance, but straw is less resilient, and is prone to breaking over in strong wind. Medium-late maturity. Fair tolerance to wheat streak mv (2.5 on scale of 1-3). Some tolerance to dryland root rot. Above average yield, similar to Reeder and Choteau. Average test weight. Very good quality with high protein and loaf volume. Medium-low Hessian fly tolerance. Some tolerance to root lesion nematode.

Norpro (AgriPro-1): Semi-dwarf, very strong straw. Medium-late maturity. Below avg yield and test weight. Average protein. Low flour yield and high ash. Not well-adapted for dryland in District 5 (Triangle), but **suitable for irrigated**.

ONeal (WestBred, bz999592, 2008): A McNeal/906R cross. Semi-dwarf height similar to McNeal. Head date similar to McNeal and one day later than Choteau. Above-average yield, 3-5 bu higher than McNeal and similar to Choteau. Average test weight, above-average protein. A high quality wheat for areas where McNeal is adapted. Hollow stemmed, but shows less sawfly damage than McNeal.

Outlook (MSU, 2002): Russian Wheat Aphid resistant, but susceptible to new biotype in 2004. Stiff straw, semi-dwarf, height equal to McNeal & Reeder. Med-late maturity = McNeal. Above average yield, similar to McNeal and Reeder. Below average test weight. Average protein. Quality acceptable, and superior to Reeder.

Reeder (ND, 1999): Semi-dwarf height. Medium head date, slightly earlier than McNeal, but maturity slightly later than McNeal. The “stay-green” trait provides a longer grain-fill period and higher yield, as long as moisture is available. Similar to McNeal for agronomics. Above average yield. Average test weight and protein. Quality is below average. Susceptible to Everest W.O. herbicide. Very poor Hessian fly tolerance.

Vida (MT 0245): Semi-dwarf height, medium straw strength. Med-late maturity, heading = McNeal, but stays green 3 to 4 days later than McNeal. High yield, 4 bu over McNeal. Average test weight and protein, acceptable quality. Possible replacement for Outlook and Reeder (except Outlook would remain in use for RWA resistance). MR stripe rust and Septoria. Partially-solid stem (stem score = 11), slightly less than Conan & Ernest for sawfly tolerance.

Volt (WestBred, 2007): Semi-dwarf height. Late heading. Average yield on dryland, above-average yield on irrigated. Above avg test wt. Average protein. Good tolerance to stripe rust and Fusarium head blight. Wheat stem Sawfly cutting similar to McNeal. A high yield, disease resistant variety **for irrigated conditions**.

WestBred - See also Agawam, Conan, Corbin, Hank, Jedd, ONeal, Triangle II, Volt.

Hard White Spring Wheat

Protein of hard white wheat for bread baking needs to be higher than wheat required for noodle markets. Some varieties are dual-purpose and can be used for both bread and noodles. Although not a concern for bread baking quality, varieties with low levels of polyphenol oxidase (PPO) are desirable for noodles, since high PPO levels are associated with noodle discoloration. At present, all Montana hard white spring varieties are high PPO, and thus better suited for bread baking. Many hard white varieties sprout more readily than hard reds, especially those developed from Australian germ plasm. The pure white trait is difficult to maintain, as pollen from red wheats may pollinate a white variety, causing a mixture of red kernels. It is very important to clean the combine, storage bins and other grain handling equipment prior to harvest to avoid mixing white wheat with other wheats. Seeding equipment and seedbed must also be free of red wheats. Seeding rate should be 10% higher than for red wheat to reduce late tillers and thereby reduce green kernels.

Agawam (WestBred, 2005): Hard White. Semi-dwarf height. Sawfly resistant: solid stem score = 22, similar to that of Choteau, and has a low level of sawfly-attractant cis-3-hexenyl acetate. Early heading, similar to Explorer. Very high yield and test weight. Protein 1.4% lower than Explorer. Fair Hessian fly tolerance.

Blanca Grande (Gen Mills): Hard white. Short stiff straw. Early maturity. Medium high yield. High test weight and low protein.

Clarine (WestBred): Hard white. Clearfield system, 2-gene resistance. Very high milling/baking quality. A Clearfield version of Pristine. Available in 2009.

Explorer (MSU, 2002): Hard white, bread-baking type. Semi-dwarf, 2 inches shorter than McNeal. Slightly solid-stem, but not sufficient for sawfly resistance. Early maturing. Average yield and test weight. Very susceptible to Septoria, thus not recommended for far eastern Montana. High protein, and probably too high for noodles. Excellent bread baking quality.

Golden 86 (GP Seed & Research Inc, 1986): Hard white. Used by a commercial milling and baking firm north of Three Forks, Montana. High quality.

MTHW 9420 (MSU, 1999): Experimental for exclusive release. Medium height and maturity. Below average yield. Average test weight. Very susceptible to wheat streak mosaic virus. Excellent bread quality, but too high in protein for noodles.

Plata (Gen Mills): Hard white. Short stiff straw. Medium maturity. Medium yield & test wt. Med-low protein.

Pristine (WPB): Hard white. Semi-dwarf. 3 days earlier than McNeal. Yield = McNeal. Protein 0.5% < McNeal. Very high quality, and used for bread baking by industry in Mid-west. See also Clarine.

Durum

Durum is generally much more susceptible to wheat streak mosaic virus and Fusarium crown rot than spring wheat.

Quality durum has strong gluten. Growers who plan to grow weak-gluten varieties need to have a marketing organization identified that will purchase those varieties. Kernel color is a very important quality trait. Rainfall or irrigation after heading causes color loss (bleaching), but some varieties are less prone to color loss. Canadian varieties are screened for bleaching resistance. Such varieties are the preferred choice in areas of late-season rainfall. Varieties that lose color more readily may be okay for drier areas of Montana. Seeding rate for durum should be 30% higher than for spring wheat due to the larger durum kernel (fewer kernels per bushel). An additional seed-rate increase may be desirable to suppress late tillers and thereby decrease green kernels. Color score is important, and green kernels contribute to poor color and dockage. 23 to 29 seeds per square foot (approx 1.0 to 1.26 million seeds per acre) has normally been a good seeding rate for durum.

Alkabo (ND, 2006): Medium-tall height, very stiff straw. Medium maturity. Above average yield and test wt. Good quality.

Alzada (WestBred, 2005): Semi-dwarf height, short stiff straw. Early maturing. High yield, average test weight. Medium protein. Very good quality and gluten strength, and very good semolina color.

Avonlea (Can, 1997): Medium tall. Medium straw strength and lodging resistance. Early maturity. High yield and average test weight. Good quality and protein.

Dilse (ND): Medium height, late maturity. Below average yield. Average weight. High protein, excellent quality.

Divide: (ND, 2006): Medium-tall height, stiff straw. Medium maturity. Average yield. Above average test wt. Excellent quality.

Grenora (ND, 2006): Medium-tall height, stiff straw. Medium maturity. Average yield and test wt. Good quality.

Kyle (Canada, 1984): Very tall weak straw, poor lodging resistance. Very late maturing. Average yield and test weight, large kernel size. Kyle has the highest tolerance to color-loss (rain-bleaching). Above average protein. Strong gluten; good quality.

Lebsock (ND, 1999): Medium height, stiff straw. Late maturity. Below average yield. High test weight and excellent quality.

Levante (AllStar Seeds, 2007): Short semi-dwarf height. Early heading. Above average yield & test weight on dryland in 2007; and average performance on irrigated.

Maier (ND, 1998): Medium height, stiff straw, good lodging resistance. Medium maturity. Above-average yield. Medium large kernels, very high test weight. Average protein. Good milling quality.

Mountrail (ND,1998): Medium-tall, but stiff straw and fair lodging resistance. Medium-late maturity. Average yield and test weight. Medium large kernel and average protein. Medium quality, but kernel color more sensitive to late rain than some other varieties. (All durums are sensitive to late rain/irrigation relative to color loss).

Navigator (Can): Med short, but weak straw. Med late maturity. Medium test weight & protein, good quality.

Normanno (AllStar Seeds, 2007): Semidwarf height. Medium maturity. Average yield and below average test weight in 2007.

Pathfinder (Can): Med tall, weak straw. Med late maturity. Med test weight. Med low protein, good quality.

Pierce (ND): Medium-tall height and lodging resistance. Below average yield. High test weight. Average protein, good quality.

Plaza (ND): Med-short straw, med lodging resistance. Late maturity. Below-average yield on dryland; above-average yield on irrigated. Below average test weight. Low protein, medium quality.

Silver (MSU, 2011): Medium-short, with good lodging resistance, with maturity comparable to Alzada. Above average yield on dryland with slightly above average test weight on dryland and irrigated plots. Silver has average protein.

Strongfield (WestBred/Canada, 2005): Medium tall, med-late maturity. Above average yield. Average test weight. Above-average protein. Good color and quality. Low grain cadmium concentration.

Table 1. 2016 Spring Wheat Advanced Yield Nursery, Western Triangle Ag. Research Center, Conrad, MT.

ID or Variety	Yield bu/ac[1]	Test weight lb/bu[1]	Heading Date Julian	Plant height inch	Protein %
MT 1570	77.2	60.2	169.7	27.3	12.8
MT 1451	73.2	59.6	172.3	28.3	12.6
MT 1320	71.0	61.0	172.7	28.7	13.1
Vida	70.8	60.2	175.0	31.3	13.2
MT 1442	70.4	61.4	173.0	30.0	13.2
Agripr161	68.8	58.9	176.7	29.3	13.5
SY Valda	68.7	61.7	174.3	33.3	12.5
WPSP2-MCN	68.1	59.5	171.0	28.0	12.7
WF162	67.0	59.8	175.0	27.7	12.6
MT 1348	66.7	59.4	170.0	30.3	14.1
SY Ingmar	66.5	61.3	176.0	31.3	13.9
MT 1573	66.1	59.8	171.3	29.0	13.1
MT 1518	65.6	60.0	174.3	30.0	12.4
MT 1173	65.3	58.6	174.7	29.7	12.4
MT 1509	64.9	59.2	176.7	29.3	14.1
WF161	64.3	59.5	172.7	28.3	14.1
MT 1426	63.9	58.8	167.3	30.3	13.7
Alum	63.9	62.1	174.7	28.3	13.1
MT 1316	63.5	59.7	169.3	28.3	14.2
WB 163	63.5	60.4	175.3	28.3	11.7
MT 1455	63.4	59.8	170.0	28.0	13.8
LCS Prime	63.2	62.0	172.0	29.7	12.4
MT 1219	63.2	59.8	171.3	28.7	13.1
WB Gunnison	63.0	60.3	171.7	30.0	12.3
Corbin	62.6	61.3	171.7	29.0	13.1
Egan	62.3	60.0	172.0	29.7	14.6
MT 1506	62.0	60.0	170.7	29.7	14.3
Brennan	61.7	61.4	172.0	27.3	14.2
MT 1427	61.5	57.7	169.3	30.0	13.6
MT 1543	61.4	59.1	172.3	29.7	13.6
Reeder	60.5	60.5	173.7	29.0	13.9
MT 1538	60.4	58.3	173.7	29.0	13.1
WB 162	60.2	60.5	172.3	27.3	12.0
Fortuna	58.7	60.2	174.3	31.3	13.3
LimaGr162	58.2	61.8	171.3	27.7	14.3
MT 1447	58.1	60.0	171.0	29.0	14.1
WF163	58.1	58.5	176.7	30.0	13.3
LCS Pro	58.1	61.8	173.3	29.0	13.6

Table 1. Continued on next page

Table 1 Continued

ID or Variety	Yield bu/ac[1]	Test weight lb/bu[1]	Heading Date Julian	Plant height inch	Protein %
Choteau	57.6	59.1	172.3	28.3	13.4
MT 1525	57.5	61.9	174.0	29.7	13.0
SY Tyra	57.2	60.1	175.3	27.0	13.2
Duclair	57.1	57.5	169.7	29.3	13.6
WB9879CLP	56.4	59.1	174.3	28.7	14.0
MT 1512	56.0	60.0	172.7	30.0	13.9
MT 1523	55.2	60.0	171.7	31.0	13.0
MT 1510	55.2	58.6	170.7	26.3	13.8
MT 1517	55.1	59.5	172.7	29.3	13.6
MT 1415	55.0	61.5	172.7	26.7	14.3
MT 1574	54.9	58.8	173.3	28.3	14.7
MT 1401	54.8	61.0	169.3	29.7	14.0
MT 1542	54.5	60.1	171.0	27.3	13.8
SY Soren	54.2	60.6	174.7	29.0	14.1
MT 1572	53.9	60.4	173.7	28.3	14.0
MT 1533	53.0	58.1	173.7	28.0	14.9
MT 1519	52.9	59.6	174.7	28.3	13.9
MT 1514	52.2	57.4	176.3	29.0	13.9
MT 1511	51.9	59.1	175.7	27.0	14.2
McNeal	51.5	59.8	175.0	29.0	13.1
MT 1549	51.3	60.3	174.3	29.7	12.8
WB 161	49.1	61.8	169.0	26.7	14.2
MT 1531	48.5	60.5	174.7	31.3	13.3
Thatcher	47.1	59.4	176.3	29.7	13.0
MT 1556	46.6	60.8	172.0	27.7	13.5
MT 1565	44.7	58.2	175.7	28.0	13.7
Mean	59.8	59.6	172.9	29.0	13.5
LSD (0.05)	14.5	1.3	2.5	ns	0.8
C.V. (%)	15.0	1.1	0.9	7.7	3.7
P-value (Varieties)	0.0046	<0.0000	<0.0000	0.3979	<0.0000

Planted: 4/6/2016 on chemical fallow barley stubble and harvested on 8/17/2016.
Fertilizer: actual pounds/ac. of N-P-K: 11-22-0 applied with seed and a 204-0-20 blend of urea and potash was broadcast at planting. Fertilizer rates are based on a yield goal of 70 bu/ac.
Herbicide: The plot area was pre-plant sprayed with 32 oz/ac RT3 on 4/3/2016. Sprayed on 6/3/2016 with Bison @ 4 pts/ac, Axial XL @ 16.4 oz/ac, and Affinity @ 1.2 oz/ac.
Precipitation for growing season: 8.33 inches.
[1] Yield and test weight are adjusted to 13% seed moisture.
Conducted by MSU Western Triangle Ag. Research Center.

Table 2. 5-year Means, Advanced spring wheat varieties, Conrad, MT, 2016.

Variety	Yield bu/ac	Test Wt lb/bu	Head date	Height[1] inch	Protein %
Vida	76.1	60.2	178.4	32.0	12.9
Reeder	74.4	61.1	177.6	32.2	13.6
Corbin	73.0	61.3	176.5	30.5	13.3
Brennan	72.9	62.5	178.5	28.3	14.1
SY Tyra	72.6	61.3	178.1	27.5	12.5
McNeal	72.1	60.4	179.0	36.5	13.4
SY Soren	71.5	61.3	177.9	29.1	13.9
Duclair	70.0	59.0	175.2	30.8	13.5
WB9879CLP	69.5	60.4	178.2	30.0	13.8
WB Gunnison	68.3	61.6	176.8	30.3	12.8
Egan	68.0	60.1	177.8	31.0	14.4
Fortuna	65.1	61.0	178.1	36.5	13.5
Choteau	65.0	59.4	177.5	29.1	13.5
Means	70.6	60.7	177.7	30.7	13.5

[1] Four year average for the years 2012, 2014, 2015, 2016

Location: MSU Western Triangle Ag. Research Center, Conrad, MT.

Table 3. Off-station Irrigated Spring Wheat variety trial located, WTARC, MT. Pondera County. Western Triangle Ag. Research Center. 2016.

Variety	Class	Yield bu/ac[1]	Test Wt lb/bu[1]	Height inch	Protein %
Alum	-	98.9	61.6	33.0	12.8
Duclair	**	90.4	58.6	32.3	13.1
Fortuna	**	79.2	60.3	39.7	14.0
Egan	-	79.1	59.6	32.3	14.4
WB Gunnison	*	78.6	60.2	32.0	11.9
WB9879CLP	CL	77.2	58.5	33.0	13.4
MT 1348	-	76.8	59.8	34.7	13.1
Corbin	*	75.7	60.0	33.7	12.7
Reeder	-	75.4	60.9	37.0	11.7
SY Tyra	*	75.1	58.8	30.3	13.0
MT 1316	-	74.2	61.1	31.3	13.2
Vida	*	73.5	58.0	34.0	12.8
SY Soren	-	73.4	59.9	30.3	14.0
Choteau	**	68.1	57.2	31.7	13.3
MT1401	-	68.1	60.5	33.0	13.0
McNeal	-	67.9	57.4	34.7	12.4
MT 1173	-	67.8	55.5	36.0	12.6
Brennan	-	65.7	60.9	30.7	14.2
Mott	-	59.7	57.4	38.0	13.2
ONeal	-	56.3	55.3	34.3	13.1
Mean		74.1	59.1	33.6	13.1
LSD (.05)		8.1	1.5	1.9	0.7
C.V. 1 (%) (S/mean)*100		6.7	1.6	3.4	3.1
P-Value		<0.0000	<0.0000	<0.0000	<0.0000

Cooperator and Location: WTARC, Pondera County.
Planted on April 14, 2016 on chemical fallow barley stubble. Harvested on September 2, 2016.
Fertilizer: actual pounds/ac of N-P-K: 11-22-0 applied with seed and a 237-0-20 blend of urea and potash was broad cast at planting. Fertilizer rates are based on a yield goal of 80 bu/ac.
Herbicide: The plot area was pre-plant sprayed with 20 oz/ac RT3 4/14/2016. Sprayed on 6/3/2016 with Bison @ 4 pts/ac, Axial XL @ 16.4 oz/ac, and Affinity @ 1.2 oz/ac.
Growing season precipitation: 7.46 inches. Irrigation: 12.3 inches
** = Solid stem sawfly-resistant (solid stem score of 19 or higher).
* = Less preferred by sawfly (behavioral preference) in small plots.
CL= Clearfield
[1] Yield and test weight are adjusted to 13% seed moisture.
Conducted by MSU Western Triangle Ag. Research Center.

Table 4. 5-year means, on station irrigated spring wheat varieties, Conrad, MT, 2012-2016.

Variety	Yield bu/ac	Test Wt lb/bu	Height inch	Head[1] Date	Protein %
Duclair	93.2	61.1	30.1	184.2	14.3
WB Gunnison	88.3	62.5	31.7	186.1	13.7
SY Tyra	87.8	62.0	29.5	186.3	13.5
WB9879CL	86.6	61.3	33.1	185.9	12.8
Choteau	82.6	60.8	31.2	185.3	13.7
Corbin	80.5	62.4	32.8	185.4	13.4
Egan	80.2	61.4	32.5	186.4	15.0
Oneal	78.1	61.0	33.9	186.3	13.4
Vida	77.1	61.1	34.0	186.6	13.0
McNeal	76.8	61.1	33.1	186.0	12.8
Brennan	76.3	62.5	29.5	185.1	14.5
Reeder	74.5	62.2	33.9	186.1	13.5
Fortuna	71.1	61.8	39.0	186.1	13.5
Means	81.2	61.6	32.8	185.8	13.6

[1] Heading date is from 2011 to 2015 as there is no heading data for 2016 on the irrigated off station spring wheat trial.
Location: MSU Western Triangle Ag. Research Center, Conrad, MT.

Table 5. Off-station spring wheat variety trial located north of Choteau, MT. Teton County. Western Triangle Ag. Research Center. 2016.

Variety	Class	Yield[1] bu/ac	Test Wt[1] lb/bu	Height inch	Lodging %	Protein %
Duclair	**	39.3	55.6	27.7	2.7	15.5
Alum	-	37.6	57.4	28.3	7.3	15.1
MT1401	-	37.6	58.0	25.7	5.7	14.5
Vida	*	36.0	55.3	26.3	2.7	14.8
McNeal	-	35.7	53.7	28.3	13.3	15.2
MT1348	-	35.7	57.1	27.3	6.0	16.0
WB9879CLP	CL	35.5	55.0	26.7	0	15.4
Corbin	*	35.2	56.9	28.0	1.7	15.2
Choteau	**	35.0	56.3	27.3	1.0	15.3
Egan	-	34.4	55.6	26.0	13.3	16.4
Brennan	-	33.7	58.2	23.7	9.3	15.8
ONeal	*	33.0	55.2	29.0	3.3	15.3
MT1316	-	32.5	55.7	26.0	8.0	16.0
Reeder	-	32.5	56.0	28.0	10.0	15.6
MT1173	-	32.5	53.7	27.3	6.7	14.6
WB Gunnison	*	32.0	56.4	26.7	0	14.5
Fortuna	**	31.4	56.6	32.0	6.0	15.7
Mott	-	31.3	55.2	27.7	4.0	15.9
SY Soren	-	30.7	56.3	24.0	10.0	15.8
SY Tyra	*	30.7	56.6	23.0	11.7	14.7
Mean		34.1	56.1	26.9	6.1	15.4
LSD (.05)		5.6	0.9	3.1	6.5	0.7
C.V. 1 (%) (S/mean)*100		9.9	1.0	6.9	64.1	2.6
P-Value		NS	<0.0000	<0.0005	<0.0006	<0.0000

Cooperator and Location: Inbody Farms, Teton County.
Planted on 5/4/16 on chemical fallow. Harvested on 8/24/16
Fertilizer: actual pounds/ac of N-P-K: 11-22-0 applied with seed and a 165-22.5-20 blend of urea and potash was broadcast at planting. Fertilizer rates are based on a yield goal of 50 bu/ac.
Herbicide: The plots were sprayed with Huskie at 11 oz/ac and Axial XL at 16.4 oz/ac on 5/4/16
** = Solid stem sawfly-resistant (solid stem score of 19 or higher).
* = Less preferred by sawfly (behavioral preference) in small plots.
CL = Clearfield
[1] Yield and test weight are adjusted to 13% seed moisture.
Conducted by MSU Western Triangle Ag. Research Center.

Table 6. Five-year means, Spring Wheat varieties, Inbody, Teton County. 2012-2016.

Variety or ID	5-Year Mean			
	Yield bu/ac	Test weight lbs/bu	Height inch	Protein %
McNeal	44.3	56.7	29.6	15.8
Duclair	43.9	56.7	28.5	15.4
WB Gunnison	43.4	58.3	27.3	14.7
Egan	43.3	57.2	26.8	16.8
Vida	42.9	57.2	26.9	15.1
WB9879CLP	42.8	57.1	26.9	15.5
Oneal	42.2	57.6	28.5	15.9
Corbin	42.0	58.5	27.4	15.7
Brennan	41.5	59.8	25.4	15.6
Reeder	40.9	58.5	27.7	15.7
Choteau	40.5	57.1	26.5	15.7
SY Tyra	39.4	58.0	24.3	15.6
Fortuna	34.9	59.0	33.5	15.5
Mean	41.7	57.8	33.5	15.5

Cooperator and Location: Inbody Farms, Teton County.
Conducted by MSU Western Triangle Ag. Research Center.

Table 7. Off-station spring wheat variety trial located at the Cut Bank, MT. Glacier County. Western Triangle Ag. Research Center. 2016.

Variety	Class	Yield bu/ac[1]	Test Wt lb/bu[1]	Height inch	Lodging %	Protein %
Alum	-	55.5	60.0	30.0	6.7	14.0
MT1316	-	52.6	58.0	30.0	6.7	15.5
Duclair	**	48.1	56.0	29.3	15.0	14.7
Reeder	-	47.9	58.4	31.3	3.3	15.0
Egan	-	47.8	56.9	27.0	1.7	17.5
Corbin	*	47.5	58.1	29.3	3.3	14.5
WB Gunnison	*	47.2	58.0	29.0	13.3	13.0
Vida	*	45.5	57.0	29.3	3.3	14.7
MT1348	-	45.4	57.5	31.3	8.3	15.3
SY Tyra	*	45.0	55.3	27.7	0	14.0
Choteau	**	44.5	55.9	30.0	11.7	15.0
SY Soren	-	45.4	57.8	29.0	3.3	15.5
McNeal	-	42.8	53.9	31.3	5.0	13.9
WB9879CLP	CL	42.6	55.2	28.3	3.3	15.2
Fortuna	**	42.5	56.8	36.0	5.0	14.2
Brennan	-	42.0	58.4	27.3	5.0	16.4
MT1401	-	41.5	58.9	30.0	6.7	15.1
MT1173	-	36.1	51.5	32.0	6.7	13.8
Mott	-	34.8	54.7	30.3	3.3	14.7
ONeal	*	30.9	50.8	30.7	6.7	14.7
Mean		44.2	56.5	30.0	5.4	14.8
LSD (.05)		5.9	1.1	3.6	10.4	0.5
C.V. 1 (%) (S/mean)*100		8.0	1.2	7.2	116.0	2.1
P-Value		<0.0011	<0.0000	<0.0086	NS	<0.0000

Cooperator and Location: Bradley Farms, Glacier County.
Planted on 5/5/16 on chemical fallow. Harvested on 9/16/16
Fertilizer: actual pounds/ac of N-P-K: 11-22-0 applied with seed and a 148-22.5 20 blend of urea and potash was broadcast at planting. Fertilizer rates are based on a yield goal of 50 bu/ac.
Herbicide: The plots were sprayed with Huskie at 11 oz/ac and Axial XL at 16.4 oz/ac on 5/5/16
** = Solid stem sawfly-resistant (solid stem score of 19 or higher).
* = Less preferred by sawfly (behavioral preference) in small plots.
CL = Clearfield
[1] Yield and test weight are adjusted to 13% seed moisture.
Conducted by MSU Western Triangle Ag. Research Center.

Table 8. Five-year means, Spring Wheat varieties, Cut Bank, Glacier County. 2011-2016.

Variety or ID	5-Year Mean Yield bu/ac	Test weight lbs/bu	Height inch	Protein %
Duclair	52.1	56.0	30.1	14.1
WB Gunnison	52.1	52.1	29.3	13.0
Choteau	50.1	56.3	29.3	14.2
Corbin	48.4	58.3	29.8	13.5
Vida	47.9	56.8	30.6	13.6
Reeder	47.2	57.6	30.9	14.3
WB9879CL	47.1	56.2	29.4	14.4
Brennan	46.9	58.6	27.6	14.5
SY Tyra	45.9	56.1	27.4	13.1
Egan	45.2	56.8	28.7	16.0
McNeal	42.5	55.4	30.7	13.8
ONeal	39.6	54.0	30.5	14.4
Fortuna	39.0	58.3	35.5	14.2
Mean	46.5	56.8	30.1	14.0

Cooperator and Location: Bradley Farms, Glacier County.
Conducted by MSU Western Triangle Ag. Research Center.

Table 9. Off-station spring wheat variety trial located north of Devon, MT. Toole County. Western Triangle Ag. Research Center. 2016.

Variety	Class	Yield[1] bu/ac	Test Wt[1] lb/bu	Height inch	Protein %
Alum	-	37.2	61.3	25.3	11.7
MT1401	-	36.6	62.1	26.7	11.1
MT1316	-	34.5	59.8	24.0	12.3
Egan	-	34.1	58.5	25.3	12.8
MT1348	-	33.3	60.5	25.0	12.0
Duclair	**	33.0	58.7	24.3	11.9
WB Gunnison	*	33.0	60.0	25.7	10.9
MT1173	-	32.2	57.2	26.7	11.2
Reeder	-	32.0	59.9	26.0	11.6
Vida	*	31.7	59.2	25.7	11.6
Fortuna	**	31.3	59.8	30.3	12.1
Brennan	-	30.6	60.9	23.7	13.5
Choteau	**	29.5	59.3	23.3	12.7
SY Soren	-	29.2	59.4	24.0	12.7
WB9879CLP	CL	28.7	59.6	22.7	12.5
Mott	-	28.2	59.3	25.7	12.9
SY Tyra	*	28.1	59.3	23.0	12.1
McNeal	-	26.0	57.0	26.3	12.2
ONeal	*	25.6	59.0	26.3	11.6
Corbin	*	25.1	60.4	23.7	12.0
Mean		31.0	59.5	25.1	12.1
LSD (.05)		7.5	1.1	1.9	1.2
C.V. 1 (%) (S/mean)*100		14.6	1.1	4.6	6.3
P-Value		NS	<0.0000	<0.0000	<0.0167

Cooperator and Location: Brian Aklestad, Toole County.
Planted on 4/18/16 on chemical fallow. Harvested on 8/7/16
Fertilizer: actual pounds/ac of N-P-K: 11-22-0 applied with seed and a 108-22.5 20 blend of urea and potash was broadcast at planting. Fertilizer rates are based on a yield goal of 50 bu/ac.
Herbicide: The plots were sprayed with Huskie at 11 oz/ac and Axial XL at 16.4 oz/ac on 4/18/16
** = Solid stem sawfly-resistant (solid stem score of 19 or higher).
* = Less preferred by sawfly (behavioral preference) in small plots.
CL = Clearfield
[1] Yield and test weight are adjusted to 13% seed moisture.
Conducted by MSU Western Triangle Ag. Research Center.

Table 10. Five-year means, Spring Wheat varieties, Devon, Toole County. 2012-2016.

Variety or ID	5-Year Mean			
	Yield bu/ac	Test weight lbs/bu	Height inch	Protein %
Vida	35.7	58.6	24.9	13.6
Duclair	34.6	57.3	24.7	14.1
WB Gunnison	34.6	58.9	24.3	13.8
Reeder	34.3	59.2	25.6	14.3
Egan	33.7	57.1	25.3	15.3
Brennan	31.9	59.6	22.7	15.0
Choteau	31.3	58.3	23.2	14.5
Corbin	31.0	58.8	24.5	14.2
Oneal	30.9	59.4	24.6	14.4
Fortuna	30.7	58.7	28.5	14.5
McNeal	30.5	57.4	26.0	14.7
SY Tyra	30.0	59.2	22.1	13.7
Mean	32.4	58.6	24.8	14.3

Cooperator and Location: Aklestad Farms, Toole County.
Conducted by MSU Western Triangle Ag. Research Center.

Table 11. Off-station spring wheat variety trial located at the Knees area, Chouteau County. Western Triangle Ag. Research Center. 2016.

Variety	Class	Yield[1] bu/ac[2]	Test Wt[1] lb/bu[2]	Height inch	Lodging %	Protein %
Duclair	**	25.5	48.8	19.0	9.0	14.9
Alum		24.6	49.1	21.7	56.7	15.3
Choteau	**	23.9	48.6	21.7	5.3	14.4
Egan	-	22.7	47.4	24.0	58.3	17.2
Corbin	*	22.3	49.4	23.3	28.7	14.5
WB Gunnison	*	21.7	51.2	23.3	1.7	13.5
MT1348		20.4	50.7	31.3	10.0	14.7
MT1316	-	20.4	45.1	23.0	80.7	16.2
MT1401		19.6	50.8	23.7	6.7	14.6
McNeal	-	18.9	44.0	26.0	73.3	14.6
Reeder	-	18.8	47.1	24.6	36.7	14.8
Fortuna	**	18.6	49.2	28.0	8.7	15.7
Brennan	-	16.8	49.1	23.3	65.0	17.6
Vida	*	16.6	45.9	23.7	25.0	14.9
SY Soren	-	16.4	46.9	22.3	78.3	16.7
ONeal	*	15.9	44.6	23.3	71.7	14.0
WB9879CLP	CL	14.5	45.7	25.7	2.7	10.1
Mott	-	14.4	45.9	23.0	32.0	16.3
SY Tyra	*	14.0	42.1	22.3	9.0	17.0
MT1173	-	10.0	42.1	24.3	48.3	14.7
Mean		18.9	47.2	23.9	34.9	15.0
LSD (.05)		7.9	3.1	8.7	42.5	4.2
C.V. 1 (%) (S/mean)*100		20.6	3.2	21.9	60.2	13.9
P-Value		0.0012	<0.0000	NS	<0.0000	NS

Cooperator and Location: Aaron Killion, Chouteau County.
Planted on 4/22/16 on chemical fallow. Harvested on 8/22/2016
Fertilizer: actual pounds/ac of N-P-K: 11-22-0 applied with seed and a 165-22.5-20 blend of urea and potash was broadcast at planting. Fertilizer rates are based on a yield goal of 50 bu/ac.
Herbicide: The plots were sprayed with Huskie at 11 oz/ac and Axial XL at 16.4 oz/ac on 4/22/16
** = Solid stem sawfly-resistant (solid stem score of 19 or higher). * = Less preferred by sawfly (behavioral preference) in small plots. CL = Clearfield
[1] Yield and test weight are adjusted to 13% seed moisture.
[2] Severe stripe and some yellow rust, and wheat powdery mildew. All varieties had some level of infection.
Conducted by MSU Western Triangle Ag. Research Center.

Table 12. Five-year means, Spring Wheat varieties, Knees area, Chouteau County. 2011-2016.

Variety or ID	5-Year Mean			
	Yield bu/ac[1]	Test weight lbs/bu	Height inch	Protein %
Duclair	44.7	56.1	25.7	14.2
Vida	42.4	56.3	26.6	14.2
WB Gunnison	42.1	58.4	26.1	14.0
Egan	41.1	56.7	25.4	16.1
Choteau	40.9	56.9	24.7	14.4
WB9879CL	39.7	56.9	25.7	13.5
Reeder	39.4	57.7	26.6	14.7
McNeal	39.3	55.7	27.7	14.5
Brennan	39.0	57.8	24.6	15.6
Corbin	38.3	57.3	26.4	14.4
SY Tyra	36.3	55.2	23.7	14.4
Oneal	35.6	56.6	26.8	13.9
Fortuna	33.3	57.8	30.6	15.5
Mean	39.3	56.8	26.3	14.5

Cooperator and Location: Aaron Killion, Chouteau County.
[1]Yields were affected by stripe and tan rust for the 2016 crop year. All varieties had some level of infection.
Conducted by MSU Western Triangle Ag. Research Center.

Table 13. Off-station spring wheat SM1 trial located near the Valier. Pondera County. Western Triangle Ag. Research Center. 2016.

Variety	Yield bu/ac[1]	Test Wt lb/bu[1]	Height inch	Protein %	Midge Head	Lodging %
MT 1573	55.6	56.6	28.3	14.4	0	0.5
Egan	67.0	56.6	32.3	15.1	0	3.7
MT 1572	62.9	55.6	32.3	14.9	0.3	0.5
MT 1574	63.7	55.2	31.0	13.8	0.3	6.8
MT 1570	58.4	54.2	30.3	14.6	0.3	0.5
Hank	51.0	53.4	31.7	14.1	0.7	0.5
Mean	59.7	55.3	31.0	14.5	0.3	2.1
LSD (.05)	ns	ns	ns	ns	ns	ns
C.V. 1 (%) (S/mean)*100	13.7	2.7	6.1	6.1	182.0	144.2
P-Value	0.2609	0.1246	0.1704	0.4846	0.6113	0.1191

Cooperator and Location: Crawford Farms, Valier, MT.
Planted on May 4, 2016 on re-crop spring wheat stubble. Harvested on September 15, 2016.
Total fertilizer, actual lbs/ac:256 pounds of nitrogen, 22 pounds of phosphorus, 20 pounds of potassium, and 24 pounds of sulphur.
Pre-plant sprayed with RT3 @ 18 oz/ac, and sprayed post-plant with Rimfire Max @ 4 oz/ac, Brox M @ 16 oz/ac and 4 oz/ac propiconazole.
[1] Yield and test weight are adjusted to 13% seed moisture.
Conducted by MSU Western Triangle Ag. Research Center.

Table 14. Soil test values for off-station and on-station plots, 2016.

Location	N (lbs/ac)[1]	Olsen-P (ppm)	K (ppm)	pH	OM (%)	EC (mmhos/cm)
Cut Bank	39.6	17	385	7.5	2.7	0.39
Devon	12.1	14	221	7.2	0.8	0.15
Knees	21.1	28	482	6.9	2.4	0.55
Choteau	44.5	7	412	8.1	2.3	0.82
WTARC	15.6	20	318	7.8	2.4	0.56

[1]Nitrogen soil samples were to a depth of four feet in one foot increments. All other soil tests were for zero to six inches in depth.
WTARC- Western Triangle Ag. Research Center

MONTANA STATE UNIVERSITY
College of AGRICULTURE & MONTANA AGRICULTURAL EXPERIMENT STATION

Barley

Title: Spring barley variety evaluation at Western Triangle Ag. Research Center

Principle Investigator: Gadi V.P. Reddy, Superintendent and Associate Professor of Entomology/Insect Ecology, Western Triangle Ag Research Center

Personnel: John H. Miller, Research Associate and Julie Prewett, Research Assistant WTARC, Conrad, MT, and Jamie Sherman and Liz Elmore, MSU PSPP Dept., Bozeman, MT.

Cooperators: Bradley Farms, north of Cut Bank, MT
Brian Aklestad, north of Devon, MT
Aaron Killion, east of Brady, MT
Inbody Farms, northeast of Choteau, MT

Objectives: There are diverse cropping environments within the area served by Western Triangle Agricultural Research Center. Each off station location has its own unique environment and soils. Producers in the various locations are interested in the variety performance in the local area. To this end the objective is to evaluate spring barley varieties under the local conditions with respect to yield, test weight, plant height, plump seed, thin seed and seed protein. The environmental conditions at the off station nurseries can vary greatly from those at WTARC. The research center strives to provide growers of the western triangle area unbiased information of various spring barley varieties.

Methods: Barley was separated into malt/feed and hull-less varieties. On station nurseries consist of dryland and irrigated intrastate malt/feed barley, 49 entries, and dryland and irrigated hull-less barley, 16 entries. Off station barley nurseries consist of 16 entries replicated three times, seeded with a four row plot seeder on one foot spacing. All plots were planted on no-till chemical fallow. Plots were trimmed, measured for length, then harvested with a Hege 140 plot combine. Spring barley seed was cleaned prior to collecting data.

Results: Table 1 and 2 are data from the dryland intrastate malt/feed barley trial. Tables 3 and 4 are for the irrigated intrastate malt/feed barley nursery. Tables 5 thru 14 are for off station barley nurseries and tables 15 and 16 are for the dryland and irrigated hull-less intrastate nurseries. Table 17 contains soil test values.

At the research center, this years' overall crop year temperatures were slightly higher than the 30 year average at the research center, being 1.2 degrees warmer than normal. With November being 0.9 degrees warmer that the 30 year average. December and January average temperatures were very close to the long term average. February was exceptionally warmer, with the temperature being 11.4 degrees warmer than the 30 year average. March and April were also warmer by 4.6 and 2.4 degrees above the 30 year average. May temperatures were cooler than the average by 1.6 degrees. June was also above average by 1.9 degrees. With July and August being slightly cooler than normal by 2.1 and 2.7 degrees.

Precipitation at the research center was surprising with 5.18 inches more moisture than the 30 year average. We received above average moisture the fall of 2015, resulting in good soil moisture at planting. September was 1.82 inches above the 30 year average. October through December were 0.5 inches of precipitation above normal. January was ahead of the average with 2.1 inches more than the normal precipitation. February was exceedingly dry reporting no moisture for the month. With March close behind only receiving 0.2 of inch. April brought some much needed moisture with about an inch above the 30 year average, while May was only slightly above the 30 year average. June precipitation was 2.3 inches below normal. July received 1.4 inches over the 30 year average for precipitation.

Yields for the dryland intrastate malt/feed nursery ranged from 74.2 to 116.4 bu/ac with an average test weight of 52.8 bu/ac. Plump average was 98.5 % with an average of 9.8 % seed protein (Table 1). Irrigated intrastate malt/feed nursery had a range of 85.1 to 136.3 bu/ac with an average test weight of 51.7. The nursery averaged 97.8% plump and 9.9 % seed protein (Table 2).

The hull-less dryland barley intrastate nursery had an average yield of 56.5 bu/ac with an average test weight of 58.0 lbs/bu and 11.4 % grain protein. Yields in the hull-less dryland barley ranged from 23.4 bu/ac for Purple Prairie and 69.9 bu/ac for the Montana State University entry MT110061 (Table 15). Irrigated hull-less barley trial had an average yield of 68.1 bu/ac and an average test weight of 57.1 lbs/bu and 12.3% average seed protein. Yields in the hull-less irrigated barley ranged from 39.0 bu/ac for Purple Prairie and 83.5 bu/ac entry X0626-T22 (Table 15).

Yields for the irrigated off station spring barley nursery, averaged 104.4 bu/ac, with an average kernel plumpness of 95.7%, a mean protein of 9.6%, and an average test weight of 50.3 lb/bu (Table 5). Four year means for the irrigated off station nursery are tabulated in Table 6.

Grain yields averaged 75.2 bu/acre at the Knees, 56.6 bu/ac north of Devon, 71.4 bu/ac at the Choteau site, and 75.1 bu/ac at the site north of Cut Bank. Kernel plumpness averaged 88.3 % and test weight averaged 48.6 lbs/bu at the Devon site while kernel plumpness averaged 70.8% and test weight averaged 42.5 lbs/bu at the Knees. Choteau kernel plumpness was 80.7 % and test weight averaged 46.7 lbs/bu. The nursery at Cut Bank averaged 49.6 lb/bu, 95.5% plumps, with 14.2 % seed protein (Tables 7 thru 14).

Top yielding varieties at the Knees were Conrad, Hays, and Hockett, yields were 98.0, 95.6, and 85.0 bu/ac. Whereas the top yielding barleys north of Devon were Champion, Conrad, and Hays they yielded 64.3, 61.7, and 59.9 bu/ac. Yielding highest at the Choteau site were Champion, the Montana State University experimental entry MT124555, and Hays with yields of 83.0, 77.8 and 77.7 bu/ac. High yielding varieties at Cut Bank were Champion, 99.4 bu/ac, Moravian 115, 91.8 bu/ac and the Montana State University experimental entry MT124555, 86.0 bu/ac (Tables 7 thru 14).

No insect incidence (wheat stem sawfly or wireworms) was noticed in any of the barley varieties, on or off station. Insignificant amount of adult of wheat midge were found at the off station locations.

Summary: The data from the off station plots is supported by the local producers and advisory committee as well as the seed industry. It is planned to continue the off station variety plots at

the same locations as the environmental conditions at each location is unique to the western triangle area. No insect incidence or damage was noticed in any of the varieties.

These data should be used for comparative purposes rather than using absolute numbers. Statistics are used to indicate that treatment or variety differences are really different and are not different due to chance or error. The least significant difference (LSD) and coefficient of variability (CV) values are useful in comparing treatment or variety differences. The LSD value represents the smallest difference between two treatments at a given probably level. The LSD at p=0.05 or 5 % probability level is usually the statistic reported, and it means that the odds are 19 to 1 that treatment differences by the amount of the LSD are truly different. The CV value measures the variability of the experiment or variety trial, and a CV greater than 15 % indicates a high degree of variability and less accuracy.

Funding Summary: Office of Sponsored Programs will provide expenditure information. No other grants support this project.

MWBC FY2017 Grant Submission Plans: A similar project will be proposed for FY 2017. The continuation of on and off-station variety trials help to elucidate researchers and farmers which varieties are better suited for that particular region in Montana.

Barley Variety Notes & Comments

Western Triangle Agricultural Research Center, Conrad, MT

Baroness (WestBred): 2-row feed. Short straw and good lodging resistance; 2.5" shorter than Harrington. Equal or slightly later maturity than Harrington. High yield when tested in favorable moisture conditions. Average test weight. Stripe rust resistant.

Boulder (WestBred, 2005): 2-row feed. Composite-cross, non-Baroness derived. Height similar to Haxby. Heading 1 day later than Haxby, and 1 day earlier than Baroness. High yield, similar to Haxby. High test weight, 0.5 lb less than Haxby. Replacement for Baroness and Xena.

Challenger (WestBred, 2008): 2-row feed. Above average yield and test weight. Average height and maturity.

Champion (WestBred, 2007): 2-row feed. Medium stiff straw. Heading one day later than Haxby and Boulder. Very high yield, greater than for Boulder & Baroness. High test weight, 1 lb less than Haxby.

Charles: 2-row malt. Grown as a winter barley in Idaho, but has very low winter hardiness. Winter survival on tillage-fallow at Conrad was 40% in 2007, and 10% in 2008.

Conlon (ND, 1996): 2-row malt. Medium height, weak straw. Early maturity, 1-2 days earlier and higher test weight than Bowman. Developed for areas of heat & drought stress. High resistance to net blotch; susceptible to spot blotch & Fusarium head blight.

Conrad (Busch Ag): 2-row malt, Busch Agr Resources. About 2 inches shorter than Harrington. Medium maturity, similar maturity as Harrington. Higher yield than Harrington. Slightly higher test weight and plump than Harrington.

Copeland (Sask. Canada, 1999): 2-row malt. Better straw strength and earlier maturity than Harrington. Similar yield, test weight, and plump than Harrington. Net blotch resistant. Scald & Septoria susceptible.

Craft (MT970116; MSU, 2006): 2-row malt. Taller than Harrington & Merit. 2 days earlier heading than Harrington, but later heading than Hockett. High yield, test weight, & plump. Moderate stripe rust resistance. Susceptible to net blotch. European style of malt enzyme activity for microbrew market. AMBA approved for organic malt production.

Drummond (ND 15477): 6-row malt. Stronger straw than other 6-row malt types. Improved yield over Morex, Robust and Foster. Plump higher than Morex.

Eslick (MSU, 2005): 2-row feed. Height 1” taller than Baroness, 1” shorter than Haxby. Heading date similar to Harrington, and 1-2 days later than Haxby. Yield similar to Baroness and Haxby. Test wt = Baroness, greater than Harrington, and 2# less than Haxby. Eslick has superior performance in areas of ample moisture, while Haxby is preferred where lower moisture conditions are expected.

Geraldine (MT960101; MSU, Miller Brewing): 2-row malt for Miller Brewing Co. One day later heading than Harrington. Good performance on irrigated conditions; below average performance on dryland. Moderate stripe rust resistance.

Harrington (Sask. Can): 2-row malt. Medium height; medium weak straw. Medium-late maturity. Sensitive to hot dry areas; yields good in moist areas. Can sprout or germinate (internal falling number) at a lower moisture content than other varieties.

Haxby (MSU, 2002): 2-row feed. 3 inches taller and two days earlier than Baroness. Among highest yielders in Triangle Area. Highest test weight of all varieties. High feed quality. Non-Baroness derived, providing good diversity. Haxby has superior yield performance in lower moisture conditions, while Eslick has a yield advantage in high moisture conditions.

Hays (MSU, 2004): Hooded 2-row forage. Shorter than Haybet and more resistant to lodging. Higher grain yield than Haybet. Low test weight. Higher forage yield than Haybet and Westford (8%). Harvest between heading stage and 5 days post-heading for highest protein. Caution: any cereal grain grown for hay should be tested for nitrate level prior to cutting. Nitrates decrease during grain filling, but in drought conditions, nitrates may be high all season, unless irrigation is available.

Hockett (MSU, MT910189): 2-row malt for dryland. 4 days earlier than Harrington, and retains plump on dryland much better than Harrington. 5 bu/a higher yield than Harrington. Very susceptible to stripe rust.

Kendall (Can): 2-row malt. High irrigated yield.

Lacey (M98, MN 1999): 6-row malt. Intended to replace Robust. Height intermediate between Robust & Stander. Lodging resistance greater than Robust, but less than Stander.

Legacy (Busch Ag): 6-row malt. 2 to 4 inches taller than Harrington. Higher yield than Morex and Robust, but lower than Harrington. Has 30% resistance to vomatoxin. Very susceptible to stripe rust.

Merit (Busch Ag): 2-row malt. Late maturing, too late for dryland. Lodges easier than Harrington, but yields higher. Very high diastatic power for excellent malting ability. Net blotch resistance, and moderate Scald resistance.

Metcalfe (Manitoba Canada, 1994): 2-row malt. Replacement for Harrington in Canada. Medium straw strength. Latitude sensitive - higher yield, test weight and plump than Harrington in Canada, but similar to Harrington in Montana. Similar protein as Harrington. Medium-late, slightly earlier to head than Harrington. Moderate resistance to spot-form net blotch. Susceptible to scald and Septoria.

Stellar (ND16301, 2005): 6-row malt. Medium-short. Good straw strength and widely adapted across North Dakota. Medium maturity. High plump and low protein. Excellent malt quality. Moderate spot-blotch resistance. Net-blotch susceptible.

Stockford (WestBred, 2005). 2-row hooded hay barley. Height is 2" taller than Hays. Heading is 2 days earlier than Hays. Forage yield is similar to Hays and Haybet. Harvest between heading stage and 5 days post-heading for highest protein. Caution: any cereal grain grown for hay should be tested for nitrate level prior to cutting (see note for Hays).

Tradition (Busch Ag,): 6-row malt. Stiffer straw than Legacy, good lodging resistance. Higher yield, test weight and plump than Legacy and other 6-row varieties. Very susceptible to stripe rust.

Xena (WPB bz594-19): baroness/stark cross. 2-row feed. Two inches taller and better boot emergence than Baroness. Lodging resistance equal to Baroness. Late maturity, similar to Baroness. Better adapted to dryland than Baroness, (higher test wt and plump than Baroness on dryland). Equal or better yield than Baroness on dryland.

"BG Barley": A food barley classification, and includes waxy hulless and waxy covered varieties. Beta glucan levels of BG varieties are 50% higher than for oats or pearled barley. Grain yields are generally lower than other barley varieties. End-use includes various foods, including rice-extender, 'Heart Balance Cereal' etc.

Table 1. Intrastate barley, malt/feed variety trial, WTARC, Conrad 2016.

Variety	Yield bu/ac[1]	Test Wt lb/bu[1]	Plump %	Thin %	Protein %	Head Date	Height inch
Odyssey	116.4	52.0	98.5	0.5	8.58	178.0	23.0
08ARS116-91	114.2	52.8	98.5	0.4	10.15	174.0	24.7
Growler	111.9	51.7	98.7	0.3	8.94	174.0	25.0
ME08032-156	111.7	52.4	98.5	0.4	9.43	176.0	22.3
Vespa	107.1	52.6	98.7	0.3	9.45	178.3	23.7
MT124555	106.0	53.8	99.0	0.4	10.02	175.0	25.0
08ARS028-20	104.5	52.4	98.0	0.4	9.21	176.3	23.3
MT124243	103.7	51.9	98.4	0.5	9.52	174.3	25.7
Synergy	103.5	51.5	98.9	0.3	9.54	173.0	24.3
Haxby	103.4	54.5	98.5	0.3	11.57	173.3	27.7
Genie	103.3	52.9	97.9	0.6	9.04	176.0	23.3
Balster	102.9	50.7	98.5	0.3	9.23	174.3	23.3
Hockett	102.9	53.8	99.2	0.3	10.33	171.0	24.7
08ARS012-79	102.3	52.4	98.4	0.5	9.28	172.7	26.7
MT124688	101.5	53.2	97.7	0.7	9.58	173.7	26.3
MT100120	101.1	53.4	98.9	0.6	9.68	174.7	27.3
Champion	101.1	54.2	98.3	0.5	11.03	172.0	26.0
Overture	100.6	51.6	97.3	0.8	8.51	175.7	22.3
Westminster	99.8	52.9	98.2	0.6	9.35	175.0	23.7
MT124728	99.7	53.0	98.5	0.5	10.97	172.7	25.3
MT124016	99.6	53.2	98.0	0.5	9.56	173.0	23.7
11WA-107.43	98.6	53.5	98.5	0.4	10.33	171.7	24.3
10WA117.17	97.9	52.5	98.6	0.5	9.32	175.3	22.6
MT090193	97.1	52.7	98.7	0.3	10.35	174.3	27.0
Copeland	96.4	53.2	98.2	0.6	9.99	177.7	24.0
08MT-63	96.3	53.4	97.9	0.5	9.95	171.7	27.3
08MT-95	96.1	52.5	98.5	0.4	9.92	174.3	25.3
MT124457	95.5	53.4	99.0	0.4	10.83	173.3	25.3
MT124716	95.1	53.4	98.6	0.4	11.40	173.7	24.7
08MT-19	94.6	54.0	99.0	0.3	10.50	175.0	25.7
MT100126	94.5	54.0	98.9	0.3	9.00	175.0	26.7
Harrington	94.4	53.2	98.4	0.4	9.37	173.7	23.3
08MT-15	93.7	52.6	98.3	0.5	9.30	175.7	21.3
MT124073	93.5	52.9	98.5	0.3	10.63	173.0	27.7
MT090190	93.2	52.5	99.0	0.3	8.93	173.7	26.3
MT124582	92.7	53.5	99.1	0.3	10.04	171.3	25.3
Metcalfe	92.2	52.3	98.1	0.6	10.24	173.0	25.0
MT124454	92.0	53.7	99.0	0.4	10.41	172.0	27.3

Table 1 continued on next page

Table 1. Continued

Variety	Yield bu/ac[1]	Test Wt lb/bu[1]	Plump %	Thin %	Protein %	Head Date	Height inch
MT124645	91.2	52.8	98.7	0.4	9.58	173.0	25.7
MT090182	91.1	52.8	98.2	0.4	8.92	175.0	26.7
ME08053-050	90.8	52.7	98.7	0.5	10.30	172.0	23.0
MT124118	86.4	53.0	98.0	0.5	10.20	172.3	24.3
10WA-117.24	84.3	51.7	98.6	0.4	9.14	172.0	24.0
MT124069	80.9	52.2	98.1	0.5	9.11	176.3	24.3
MT124112	77.3	51.8	98.7	0.4	9.86	169.0	24.0
MT124673	76.3	52.8	98.7	0.5	9.81	172.0	24.7
MT124411	76.1	52.3	98.5	0.5	11.51	170.0	24.0
MT124663	74.2	51.6	99.4	0.3	10.23	170.0	24.3
Mean	96.5	52.8	98.5	0.4	9.83	173.7	24.8
LSD (0.05)	23.0	1.5	1.0	0.3	1.2	2.6	3.4
C.V. (s/mean)*100	12.0	1.4	0.5	38.7	6.3	0.9	8.5
P-value (0.05)	0.0023	<0.0000	0.0048	0.0096	<0.0000	<0.0000	0.0268

Planted April 7, 2016 on chemical fallow barley stubble. Harvest August 12, 14, 2016. Rained on the 12th of August.
Fertilizer, actual (lbs/ac): 11-22-0 place with seed at planting, 13-0-20 broadcast while seeding.
Fertilizer rates are based on achieving malt grade barley.
Growing season precipitation: 8.05 inches.
Pre-plant sprayed with RT3 at 32 oz per acre on 4/8/15. The plot was sprayed with Bison @ 4 pts/ac and 16.4 oz/ac of Axial XL on 6/3/16.
[1] Yield and test weight are adjusted to 13% seed moisture.
Location: MSU Western Triangle Ag Research Center, Conrad, MT.

Table 2. 5-year Means, intrastate dryland barley (malt/feed) varieties, WTARC, Conrad, MT, 2012-2016.

Variety	Yield bu/ac	Test Wt lb/bu	Plump %	Thin %	Protein %	Plant height	Head date
Champion	106.1	53.8	94.1	2.2	9.9	29.6	178.0
Harrington	96.1	51.1	91.9	3.0	10.0	28.4	179.5
Haxby	92.9	54.5	93.0	3.3	10.2	29.1	178.4
Hockett	97.8	53.2	96.3	1.6	10.1	28.5	177.5
Metcalfe	91.0	51.7	91.6	3.1	10.1	29.8	178.3
Mean	96.8	52.9	93.4	2.6	10.1	29.1	178.4

Location: MSU Western Triangle Ag. Research Center, Conrad, MT.

Table 3. Irrigated intrastate malt/feed barley variety trial, Conrad 2016.

Variety	Yield bu/ac[1]	Test Wt lb/bu[1]	Plump %	Thin %	Protein %	Head Date	Height in.	Lodging %
Overture	136.3	51.1	98.5	0.4	8.68	176.3	27.0	23.3
Vespa	130.7	51.6	97.5	0.8	9.45	178.3	26.0	20.0
Genie	124.0	52.7	98.1	0.7	9.54	176.0	25.3	30.0
Odyssey	123.7	51.0	97.9	0.9	9.38	178.0	24.7	25.0
ME08032-156	119.4	51.2	97.7	0.6	9.56	176.0	25.7	25.0
MT124688	117.7	52.2	97.4	0.9	9.27	173.7	33.0	26.7
Growler	117.0	50.6	97.2	1.1	10.22	174.0	33.7	40.0
Westminster	116.6	51.8	98.7	0.2	9.28	175.0	28.3	30.0
MT124243	115.3	51.2	97.4	0.8	9.06	174.3	33.3	16.7
MT100120	114.1	52.1	98.6	0.4	9.18	174.7	34.3	11.7
MT090190	113.1	52.5	98.0	0.5	9.38	173.7	34.7	20.0
MT124016	113.0	51.3	97.9	0.8	9.57	173.0	29.7	36.7
Balster	112.7	50.7	98.1	0.4	10.24	174.3	29.3	20.0
Hockett	112.1	52.2	98.5	0.4	10.17	171.0	30.0	70.0
MT124728	112.1	52.0	97.9	0.7	10.73	172.7	29.7	15.0
ME08053-050	111.9	51.7	98.3	0.6	10.85	172.0	30.0	20.0
MT100126	111.8	52.5	97.8	0.7	9.26	175.0	34.7	11.7
MT124555	111.6	51.8	98.4	0.4	9.72	175.0	31.0	30.0
08MT-19	110.7	52.6	98.5	0.3	10.45	175.0	32.0	30.0
Copeland	109.4	51.5	98.0	0.9	10.07	177.7	33.7	40.0
MT090193	108.9	51.6	98.3	0.5	9.37	174.3	33.7	11.7
08ARS116-91	108.8	51.4	95.7	1.2	10.45	174.0	29.0	26.7
MT124118	108.0	53.0	98.3	0.6	10.38	172.3	31.3	30.0
08ARS028-20	108.0	50.9	97.4	0.7	9.43	176.3	27.0	25.0
MT124457	107.7	53.7	98.2	0.5	10.82	173.3	32.3	26.7
MT124716	106.7	51.9	98.3	0.5	10.20	173.7	31.0	16.7
08MT-15	106.6	51.8	98.4	0.5	9.33	175.7	26.3	28.3
08ARS012-79	106.3	51.6	96.5	1.3	9.88	172.7	30.3	36.7
08MT-63	106.1	51.5	96.3	1.5	9.41	171.7	30.7	40.0
Synergy	105.5	49.5	98.9	0.3	9.50	173.0	31.3	33.3
MT124112	104.3	51.5	98.1	0.6	9.90	169.0	30.7	11.7
MT090182	103.8	51.9	97.6	0.6	8.91	175.0	33.3	11.7
Harrington	103.8	52.0	96.8	1.1	10.17	173.7	31.3	70.0
10WA-117.17	103.7	51.0	96.4	1.2	10.14	175.3	32.3	76.7
MT124069	103.6	51.4	98.2	0.6	9.25	176.3	34.0	20.0
MT124454	103.5	53.2	98.1	0.7	11.43	172.0	31.0	25.0
MT124582	102.0	52.3	96.3	1.3	10.46	171.3	31.0	36.7
Haxby	100.9	51.5	98.3	0.6	11.06	173.3	31.3	40.0

Table 3 continued on next page

Table 3. Continued

Variety	Yield bu/ac[1]	Test Wt lb/bu[1]	Plump %	Thin %	Protein %	Head Date	Height inch	Lodging %
MT124073	100.8	51.4	98.3	0.5	9.67	173.0	33.7	23.3
Metcalfe	100.4	51.9	97.3	0.9	9.83	173.0	33.0	33.3
11WA-107.43	100.4	51.7	97.9	0.4	9.89	171.7	29.7	23.3
MT124673	99.5	51.7	97.8	0.6	10.13	172.0	29.0	11.7
MT124645	98.3	51.7	98.4	0.5	9.34	173.0	33.3	20.0
MT124663	97.8	51.0	98.7	0.3	10.75	170.0	31.0	10.0
Champion	93.1	51.3	96.9	0.8	9.56	172.0	30.7	56.7
MT124411	91.3	51.4	96.9	0.9	10.23	170.0	30.0	11.7
08MT-95	86.9	51.0	98.8	0.4	11.22	174.3	32.7	31.7
10WA-117.24	85.1	50.8	97.3	0.7	10.48	172.0	36.0	63.3
Mean	108.0	51.7	97.8	0.7	9.9	173.7	30.9	29.0
LSD	12.6	0.8	1.3	0.5	1.1	2.5	2.8	20.1
CV	7.2	1.0	0.9	49.5	6.6	0.9	5.5	42.7
P-value (0.05)	<0.0000	<0.0000	0.0002	0.0008	<0.0000	<0.0000	<0.0000	<0.0000

Planted on May 2, 2016 in chemical fallow barley stubble. Harvested on September 2, 2016.
Fertilizer, actual (lbs/a): 11-22-0 place with seed at planting, 53-0-20 broadcast while seeding.
Fertilizer rates are based on achieving malt grade barley.
Growing season precipitation: 6.62 inches. Irrigated with 12.3 inches of water.
Herbicide: Pre-plant sprayed with RT3 at 32 oz/ac on 5/1/2016. The plot was sprayed with Bison @ 4 pts/ac and 16.4 oz/ac of Axial XL on 6/3/16.
[1] Yield and test weight are adjusted to 13% seed moisture
Location: MSU Western Triangle Ag Research Center, Conrad, MT.

Table 4. 5-year Means, Intrastate Irrigated Barley varieties, WTARC, Conrad, MT, 2012-2016.

Variety	Yield bu/ac	Test Wt lb/bu	Plump %	Thin %	Plant Height	Protein %	Head date
Champion	107.0	52.5	96.8	0.8	30.2	9.4	183.6
Metcalfe	102.7	50.9	97.1	1.2	62.4	10.5	123.0
Haxby	101.9	51.8	96.3	1.3	30.3	9.9	183.1
Hockett	98.6	51.7	96.9	1.1	29.7	10.7	183.3
Harrington	98.0	50.3	95.3	1.9	29.9	10.5	185.5
Mean	100.8	51.5	96.4	1.3	30.2	10.2	184.1

Location: MSU Western Triangle Ag. Research Center, Conrad, MT.

Table 5. 2016 Irrigated off station barley variety trial, Conrad, MT.

Variety	Yield bu/ac[1]	Test Wt lb/bu[1]	Height inch	Plump %	Thin %	Protein %	Lodging %
Rawson	124.4	51.7	25.7	97.2	0.9	8.85	10.0
Eslick	121.4	51.5	28.7	93.4	1.1	9.27	43.3
Moravian 115	121.1	49.4	23.7	97.5	0.9	9.21	16.7
Conrad	117.6	51.4	31.0	97.5	0.8	9.67	20.0
Champion	116.5	51.7	30.0	96.4	0.8	9.38	30.0
MT090190	115.2	52.3	35.0	98.0	0.5	8.73	6.7
MT100120	113.5	51.8	35.0	97.8	0.6	8.71	3.3
Merit	113.4	49.8	32.7	96.7	1.0	9.41	13.3
Harrington	112.9	51.2	31.0	96.9	1.1	9.96	35.0
MT100126	111.6	52.6	34.7	98.1	0.4	9.19	3.3
MT090182	110.7	51.8	33.7	95.5	0.5	8.68	5.0
Hays	110.2	48.3	32.7	90.5	4.5	9.83	36.7
Stockford	109.5	50.7	33.7	96.1	1.4	9.83	6.7
Hockett	106.8	52.0	30.3	97.9	0.7	9.41	60.0
Genesis	98.9	48.9	31.3	98.5	0.4	9.27	10.0
Metcalfe	97.8	50.8	33.3	96.0	1.7	9.78	33.3
Haxby	97.7	51.5	30.0	97.5	0.6	9.57	20.0
Lavina	94.0	47.5	34.0	89.3	4.6	9.82	30.0
MT124555	93.7	49.9	30.7	96.2	1.1	10.22	23.3
Pinnacle	93.6	50.9	32.7	95.0	0.7	9.28	3.3
Copeland	92.4	51.0	30.3	98.2	0.6	9.10	46.7
Haybet	91.7	46.8	34.3	83.6	4.5	12.34	86.7
Craft	87.3	51.3	33.0	96.9	1.0	9.62	50.0
Conlon	86.0	50.7	28.7	99.1	0.4	11.21	30.0
Stepford	72.1	42.5	33.7	93.8	2.2	10.16	56.7
Mean	104.4	50.3	31.7	95.7	1.3	9.6	27.2
LSD (.05)	17.9	1.4	2.3	4.2	0.8	0.96	28.9
C.V. (s/mean)*100	10.5	1.6	4.4	2.7	38.5	6.05	64.8
P-Value	<0.0000	<0.0000	<0.0000	<0.0000	<0.0000	<0.0000	<0.0000

Planted on May 2, 2016 into chemical fallow barley stubble. Harvested on September 2, 2016.
Fertilizer, actual (lbs/a): 11-22-0 place with seed at planting, 53-0-20 broadcast while seeding.
Fertilizer rates are based on achieving malt grade barley.
Growing season precipitation: 6.62 inches. Irrigation = 12.3 inches
Pre-plant sprayed with RT3 at 32 oz/ac on 5/1/2016. The plot was sprayed with Bison @ 4 pts/ac and 16.4 oz/ac of Axial XL on 6/3/16.
[1] Yield and test weight are adjusted to 13% seed moisture.
Location: MSU Western Triangle Ag Research Center, Conrad, MT.

Table 6. 4-year Means, Irrigated off station barley varieties, Conrad, MT, 2012, 2014-2016.

Variety	Yield bu/ac	Test Wt lb/bu	Plump %	Thin %	Protein %	Plant height
Champion	120.4	52.2	95.7	1.5	11.2	32.9
Conrad	115.2	51.3	96.6	1.3	10.6	30.7
Haxby	111.3	52.9	96.1	1.5	10.9	31.5
Metcalfe	108.2	50.9	95.5	1.8	11.1	32.9
Harrington	107.8	50.1	96.4	2.6	11.1	32.1
Hockett	101.5	52.0	96.3	1.2	10.7	30.7
Mean	110.7	51.6	96.1	1.6	10.9	31.8

Location: MSU Western Triangle Ag. Research Center, Conrad, MT.

Table 7. Off-station spring barley variety trial located in the Choteau area. Teton County. Western Triangle Ag. Research Center, 2016.

Variety	Yield[1] bu/ac	Test Wt[1] lb/bu	Plump %	Thin %	Plant Height inch	Protein %
Champion	83.0	49.1	90.0	2.9	25.3	13.1
MT124555	77.8	48.6	92.2	1.8	27.0	12.8
Hays	77.7	45.3	71.6	9.7	23.7	14.7
Lavina	77.5	45.2	70.0	8.9	25.7	14.2
Haxby	73.5	48.9	88.7	3.1	26.0	13.6
Moraviana115	73.2	45.1	88.3	2.6	19.7	14.7
MT090182	71.6	47.8	84.6	3.7	24.7	12.6
Metcalfe	71.6	47.3	86.9	3.3	25.0	14.3
Harrington	70.3	45.9	84.2	3.4	24.7	14.2
Hockett	70.1	47.4	80.4	7.4	26.7	13.3
MT090190	69.6	47.1	86.7	3.7	27.0	12.2
Merit	69.0	45.6	76.7	6.1	25.0	15.3
MT100126	68.9	47.6	84.8	4.0	28.7	12.8
Conrad	66.3	45.7	82.9	5.1	24.3	15.1
MT100120	65.0	47.0	87.1	3.8	27.7	12.2
Haybet	57.8	44.0	35.7	19.4	28.0	15.3
Average	71.4	46.7	80.7	5.6	25.6	13.8
LSD (.05) =	7.9	1.7	6.9	4.1	3.0	0.8
C.V. =	6.7	2.2	5.1	44.6	7.1	3.5
P-Value (0.05)	0.0002	<0.0000	<0.0000	<0.0000	0.0005	<0.0000

Cooperator and Location: Inbody Farms, Teton County.
Planted: May 4, 2016 on chem-fallow. Harvested: August 24, 2016.
Fertilizer, actual lbs/a: 11-22.5-0 with seed at planting. 17-0-20 was applied as a broadcast while seeding.
Herbicide: Pre-plant sprayed with RT3 at 32 oz/ac on 5/1/2016. Plots were sprayed on 6/2/16 with Vendetta at 2 pts/ac and Axial XL at 16.4 oz/ac.
[1] Yield and test weight are adjusted to 13% seed moisture
Conducted by MSU Western Triangle Ag. Research Center.

Table 8. Five-year means, Barley varieties, Choteau area, Teton County 2012-2016.

Variety Or ID	5-Year Mean					
	Yield bu/ac	Test weight lbs/bu	Plump %	Thins %	Height inch	Protein %
Champion	72.3	50.9	79.0	6.8	27.1	13.7
Haxby	66.8	51.3	85.2	7.8	25.8	14.2
Metcalfe	64.7	49.0	84.7	6.6	25.9	15.0
Harrington	61.0	47.9	62.7	11.4	25.0	15.4
Hockett	64.7	49.4	80.2	10.5	26.3	14.9
Conrad	62.0	48.9	81.3	8.7	24.9	15.6
Mean	65.3	49.6	78.9	8.6	25.8	14.8

Conducted by MSU Western Triangle Ag. Research Center.

Table 9. Off-station spring barley variety trial located in the Cut Bank area. Glacier County. Western Triangle Ag. Research Center, 2016.

Variety	Yield[1] bu/ac	Test Wt[1] lb/bu	Plump %	Thin %	Plant Height inch	Protein %
Champion	99.4	50.8	94.8	2.5	25.0	14.4
Moravian115	91.8	50.2	98.1	0.6	20.3	13.5
MT124555	86.0	50.1	97.5	1.0	26.3	13.8
MT090190	82.1	49.1	95.9	1.7	27.7	13.9
Hockett	81.8	50.8	97.8	0.9	27.3	13.7
MT100120	79.8	49.4	95.9	2.0	28.7	12.9
MT100126	79.7	50.2	96.4	1.5	26.7	13.2
Metcalfe	75.9	51.0	97.6	0.8	27.0	14.9
Harrington	75.2	50.6	96.3	1.5	26.7	14.5
Conrad	73.4	50.0	98.3	0.6	23.3	15.7
Haxby	73.4	50.5	97.2	1.2	26.3	14.8
MT090182	73.0	48.9	96.2	1.4	27.3	12.8
Lavina	69.6	47.9	89.3	3.6	25.7	15.1
Merit	69.6	48.9	97.4	0.9	25.3	14.0
Hays	51.7	48.7	93.4	2.4	25.0	14.9
Haybet	39.1	46.3	85.3	4.4	30.7	16.8
Average	75.1	49.6	95.5	1.7	26.2	14.2
LSD (.05) =	14.5	1.3	2.3	1.3	2.8	0.9
C.V. =	11.6	1.6	1.5	45.8	6.5	3.9
P-Value (0.05)	<0.0000	<0.0000	<0.0000	<0.0000	<0.0000	<0.0000

Cooperator and Location: Bradley Farms, Glacier County.
Planted: 5/5/2016 on chemical fallow barley stubble. Harvested: 9/16/2016.
Fertilizer, actual lbs/a: 11-22.5-0 with seed at planting. 0-0-20 was applied as a broadcast while seeding.
Herbicide: Pre-plant sprayed with RT3 at 32 oz/ac on 5/2/2016.
[1] Yield and test weight are adjusted to 13% seed moisture
Conducted by MSU Western Triangle Ag. Research Center.

Table 10. Three-year means, Barley varieties, Cut Bank area, Glacier County 2013, 2015-2016.

Variety Or ID	3-Year Mean					
	Yield bu/ac	Test weight lbs/bu	Plump %	Thins %	Height inch	Protein %
Champion	71.0	51.4	93.5	2.8	26.1	13.7
Hockett	67.8	51.3	96.8	1.3	26.9	13.7
Harrington	62.2	50.1	94.6	2.1	26.8	14.1
Haxby	61.4	51.5	95.8	1.6	26.8	13.8
Conrad	60.8	51.4	95.8	1.7	24.8	14.9
Metcalfe	59.9	50.7	95.4	1.7	26.6	14.1
Mean	63.9	51.1	95.3	1.9	26.3	14.0

Conducted by MSU Western Triangle Ag. Research Center.

Table 11. Off-station spring barley variety trial located in the Devon, Toole County. Western Triangle Ag. Research Center, 2016.

Variety	Yield[1] bu/ac	Test Wt[1] lb/bu	Plump %	Thin %	Plant Height inch	Protein %
Champion	64.3	49.9	90.9	2.7	21.3	11.0
Conrad	61.7	48.9	94.6	1.4	21.0	10.9
Hays	59.9	46.6	74.9	9.9	19.3	10.5
MT090182	59.5	49.3	93.4	1.5	23.0	9.6
MT100120	59.4	49.6	95.1	2.7	22.7	9.7
Moravian115	58.8	47.2	90.3	3.0	16.3	11.0
Hockett	58.5	48.5	89.0	5.0	22.7	10.2
MT124555	58.2	50.6	95.0	1.7	20.7	10.7
Merit	57.9	47.3	90.3	2.6	20.0	10.0
Lavina	56.6	48.1	84.8	2.5	21.3	9.3
Metcalfe	54.7	48.4	88.4	3.4	21.7	10.7
MT090190	53.0	48.9	95.2	1.6	21.3	9.7
MT100126	52.9	48.6	91.4	2.6	23.0	10.4
Harrington	52.2	48.5	82.1	6.0	20.7	10.7
Haxby	51.8	49.9	84.7	4.0	22.7	10.8
Haybet	45.9	47.0	72.6	7.1	25.0	10.7
Average	56.6	48.6	88.3	3.7	21.4	10.4
LSD (.05)	8.2	2.2	11.4	4.6	1.8	ns
C.V. (%)	8.7	2.7	7.8	61.3	5.1	6.7
P-Value (0.05)	0.0134	0.0322	0.0043	0.0049	<0.0000	0.0761

Cooperator and Location: Brian Aklestad Farms, Toole County.
Planted: 4/18/2016 on chemical fallow winter wheat stubble. Harvested: 8/7/2016.
Fertilizer, actual lbs/a: 11-22.5-0 with seed at planting. 27-0-20 was applied as a broadcast while seeding.
Herbicide: Pre-plant sprayed with RT3 at 32 oz/ac on 4/18/2016. Plots were sprayed on 5/1/16 with Huskie at 11 oz/ac and Axial XL at 16.4 oz/ac.
[1] Yield and test weight are adjusted to 13% seed moisture
Conducted by MSU Western Triangle Ag. Research Center.

Table 12. Four-year means, Barley varieties, Devon area, Toole County 2012, 2014-2016.

Variety	4-Year Mean					
Or ID	Yield bu/ac	Test weight lbs/bu	Plump %	Thins %	Height inch	Protein %
Champion	60.1	50.7	84.0	6.4	21.3	12.0
Conrad	56.0	49.2	91.0	4.2	21.1	12.7
Haxby	51.2	49.8	81.4	8.3	22.0	12.1
Hockett	50.5	49.2	87.0	5.2	21.9	12.3
Harrington	48.8	47.8	81.0	8.9	21.2	13.1
Metcalfe	47.3	48.2	88.1	4.8	22.0	12.7
Mean	52.3	49.1	85.4	6.3	21.6	12.5

Conducted by MSU Western Triangle Ag. Research Center.

Table 13. Off-station spring barley variety trial located in the Knees area. Western Chouteau County. Western Triangle Ag. Research Center. 2016.

Variety	Yield bu/ac[1]	Test Wt lb/bu[1]	Plump %	Thin %	Plant Height inch	Protein %
Conrad	98.0	45.6	84.9	6.2	22.3	13.8
Hays	95.6	44.0	77.8	9.0	27.3	13.8
Hockett	85.0	46.5	79.4	9.8	28.3	12.8
Harrington	82.9	44.7	76.7	10.8	29.3	13.5
Metcalfe	81.1	43.9	79.8	9.0	29.0	14.6
Lavina	80.5	42.3	63.3	15.7	28.7	13.7
Merit	79.4	42.5	72.4	14.2	29.3	14.6
Moravian115	78.2	42.0	81.5	9.4	30.7	13.5
MT124555	77.5	44.3	82.7	8.4	30.0	12.6
MT100120	68.5	40.6	63.6	19.9	29.3	12.5
Champion	67.8	41.0	53.5	26.2	31.0	13.2
MT090182	64.2	40.0	62.5	20.1	29.7	12.2
MT090190	63.3	39.4	70.7	15.4	28.7	11.9
Haxby	63.0	43.5	69.8	17.2	30.0	13.4
Haybet	60.9	41.9	49.4	19.3	26.7	14.6
MT100126	57.0	38.2	64.2	19.2	31.3	12.9
Average	75.2	42.5	70.8	14.4	28.9	13.3
LSD (.05)	20.6	1.7	9.0	6.0	4.3	0.8
C.V.	16.6	2.5	7.6	25.0	9.0	3.6
P-Value (0.05)	0.0070	<0.0000	<0.0000	<0.0000	0.0476	<0.0000

Cooperator and Location: Aaron Killion, western Chouteau County.
Planted: 4/22/2016 on chemical fallow winter wheat stubble. Harvested: August 22, 2016.
Fertilizer, actual lbs/a: 11-22.5-0 with seed at planting. 8-0-20 was applied as a broadcast while seeding.
Herbicide: Sprayed with RT3 at 32 oz/a 4/22/2016. Plots were sprayed on 6/2/16 with Vendetta at 2 pt/ac and Axial XL at 16.4 oz/ac.
[1] Yield and test weight are adjusted to 13% seed moisture
Conducted by MSU Western Triangle Ag. Research Center.

Table 14. Five-year means, barley varieties, Knees area, Chouteau county 2012-2016.

Variety Or ID	5-Year Mean					
	Yield bu/ac	Test weight lbs/bu	Plumps %	Thins %	Height inch	Protein %
Harrington	70.7	47.2	86.5	5.3	26.1	12.9
Hockett	69.5	48.8	87.1	5.1	26.3	12.3
Conrad	69.2	47.7	87.8	4.0	23.7	13.0
Metcalfe	68.8	47.1	87.8	4.4	26.4	13.2
Champion	67.8	47.6	79.9	8.7	26.6	12.4
Haxby	67.8	49.1	83.0	6.6	26.0	12.4
Mean	69.0	47.9	85.3.	5.7	25.8	12.7

Conducted by MSU Western Triangle Ag. Research Center.

Table 15. Hull-less dryland intrastate barley variety trial, Conrad 2016.

Variety	Yield bu/ac	Test Wt lb/bu	Plump %	Thin %	Protein %	Head Date	Height inch
MT110061	69.9	56.9	80.1	2.6	10.8	172.7	26.0
X0626-T229	68.0	56.1	88.6	2.0	11.5	172.7	24.0
09WA-265.12	67.9	59.3	89.8	2.8	9.5	174.3	26.7
MT110065	67.2	59.3	83.7	2.5	10.9	176.0	26.0
PI596299	62.2	48.4	92.8	2.9	11.6	175.5	24.3
MT110066	61.2	58.9	76.6	3.2	12.1	174.3	24.7
X07G30-T131	59.7	59.1	94.3	3.4	10.4	170.7	27.0
MT110139	59.4	61.0	96.8	1.0	10.4	172.7	26.0
X05013-T1	58.6	59.9	95.5	0.8	10.4	171.0	23.0
MT110008	57.5	56.8	91.4	1.6	11.0	172.7	27.3
MT110016	56.6	60.0	90.3	1.9	11.8	170.0	24.0
MT110009	55.5	57.7	92.4	1.4	10.3	171.7	26.7
MT110097	50.7	53.7	97.5	0.8	13.3	171.7	26.0
MT110141	45.5	57.8	97.5	0.5	13.7	170.0	25.3
PPB-TS2	39.8	62.0	94.8	1.0	13.1	170.5	23.7
Purple Prairie	23.4	60.5	79.2	5.7	-	167.7	23.3
Mean	56.5	58.0	90.1	2.1	11.4	172.1	25.3
LSD	15.4	1.7	6.5	1.7	1.0	ns	ns
CV (%)	16.4	1.7	4.3	48.0	5.3	3.1	8.2
P-value (0.05)	0.0001	<0.0000	<0.0000	0.0001	0.0000	0.9465	0.2292

Planted on April 4, 2016 on chemical fallow barley stubble. Harvested on August 17, 2016.
Fertilizer, actual (lbs/a): 11-22-0 place with seed at planting, 13-0-20 broadcast while seeding.
Fertilizer rates are based on achieving malt grade barley.
Growing season precipitation: 8.05 inches.
Herbicide: The plot area was pre-plant sprayed with 32 oz/ac RT3 on 4/3/2016. Sprayed on 6/3/2016 with Bison @ 4 pts/ac, Axial XL @ 16.4 oz/ac, and Affinity @ 1.2 oz/ac.
Location: MSU Western Triangle Ag Research Center, Conrad, MT.

Table 16. Hull-less irrigated intrastate barley variety trial, Conrad 2016.

Variety	Yield bu/ac	Test Wt lb/bu	Plump %	Thin %	Protein %	Head Date	Height inch	Lodging %
X0626-T22	83.5	55.0	86.0	3.2	12.3	172.7	28.0	56.7
X07G30-T1	78.4	59.4	94.2	1.7	11.4	170.7	30.7	46.7
X05013-T1	78.2	59.7	95.0	4.3	11.5	171.0	31.3	20.0
09WA-265.12	76.9	59.4	89.2	3.1	9.8	174.3	34.0	43.3
MT110066	74.7	56.4	56.7	6.6	13.0	174.3	30.7	56.7
MT110016	74.6	58.4	87.7	3.5	11.8	170.0	31.3	76.7
MT110008	73.8	56.8	90.9	2.6	11.1	172.7	31.7	40.0
MT110065	73.3	56.5	69.5	5.0	11.3	176.0	32.3	30.0
MT110097	72.9	52.6	93.4	2.6	13.3	171.7	31.7	50.0
PI596299	69.9	47.7	90.1	4.0	12.0	175.5	25.7	76.7
MT110009	68.1	57.6	93.8	1.0	11.8	171.7	35.0	46.7
MT110061	67.2	57.2	61.8	7.1	13.0	172.7	32.7	43.3
MT110139	65.1	56.3	79.1	9.2	10.4	171.3	33.0	90.0
MT110141	51.0	56.4	92.4	1.9	14.9	170.0	33.0	86.7
PPB-TS2	46.4	60.7	77.9	9.0	15.1	170.5	32.0	95.0
Purple Prairie	39.0	61.2	70.2	10.3	15.1	165.0	31.3	40.0
Mean	68.1	57.1	83.3	4.7	12.3	171.9	31.5	56.1
LSD	12.2	1.3	7.6	3.3	1.4	10.7	2.7	30.1
CV (%)	8.8	1.1	4.5	34.7	5.6	3.0	5.2	32.2
P-value (0.05)	<0.0000	<0.0000	<0.0000	<0.0000	<0.0000	NS	<0.0000	0.0002

Planted on May 5, 2016 on chemical fallow barley stubble. Harvested on September 2, 2016.
Fertilizer, actual (lbs/a): 11-22-0 place with seed at planting, 12-0-20 broadcast while seeding.
Fertilizer rates are based on achieving malt grade barley.
Growing season precipitation: 6.62 inches. Irrigated with 12.3 inches of water.
Herbicide: Pre-plant sprayed with RT3 at 32 oz/ac on 5/1/2016. The plot was sprayed with Bison @ 4 pts/ac and 16.4 oz/ac of Axial XL on 6/3/16.
Location: MSU Western Triangle Ag Research Center, Conrad, MT.

Table 17. Soil test values for off-station and on-station plots, 2016.

Location	N (lbs/ac)[1]	Olsen-P (ppm)	K (ppm)	pH	OM (%)	EC (mmhos/cm)
Cut Bank	39.6	17	385	7.5	2.7	0.39
Devon	12.1	14	221	7.2	0.8	0.15
Knees	21.1	28	482	6.9	2.4	0.55
Choteau	44.5	7	412	8.1	2.3	0.82
WTARC	15.6	20	318	7.8	2.4	0.56

[1]Nitrogen soil samples were to a depth of four feet in one foot increments. All other soil tests were for zero to six inches in depth.
WTARC- Western Triangle Ag. Research Center

MONTANA STATE UNIVERSITY
College of AGRICULTURE & MONTANA AGRICULTURAL EXPERIMENT STATION

Canola

Project Title: Canola variety and Green and Grow evaluations at Western Triangle Ag. Research Center

Principle Investigator: Gadi V.P. Reddy, Superintendent and Associate Professor of Entomology/Insect Ecology, Western Triangle Ag Research Center

Personnel: John H. Miller, Research Associate and Julie Prewett, Research Assistant WTARC, Conrad, MT, and Brooke Bohannon, MSU/MAES, Northwestern Ag. Research Center, Creston, MT.

Objectives: To evaluate canola varieties grown at Western Triangle Ag. Research Center.

Methods: All plots were planted into no-till chemical fallow barley stubble using a 4-row plot drill with spacing set to one foot. Plots were trimmed, measured for length, and then harvested with a Hege 140 plot combine. Canola seed was cleaned prior to collecting data.

Results: The canola nursery averaged 19 bu/ac (Table 1). Test weight averaged 51.2 lbs/bu with mean seed oil content of 45.5%. There was no lodging or shatter to report in the canola nurseries. Highest yields in bu/ac were HyClass 930 having 23.2, DKL30-20R at 22.9, G49773 with 22.8, HyClass 972 at 22.3, and HyClass 970 in the amount of 22.3 respectfully.

Green and Grow seed treatment trial was subjected to the same conditions as the canola variety trial. The Green and Grow product was used as seed treatment on HyClass 930 canola. There were no differences between seed treated with Green and Grow and the untreated control (Table 2). Higher than normal temperatures in June with lower than normal precipitation, hindered yield and possible treatment affects.

This years' overall crop year temperatures were slightly higher than the 30 year average at the research center, being 1.2 degrees warmer than normal. With November being 0.9 degrees warmer that the 30 year average. December and January average temperatures were very close to the long term average. February was exceptionally warmer, with the temperature being 11.4 degrees warmer than the 30 year average. March and April were also warmer by 4.6 and 2.4 degrees above the 30 year average. May temperatures were cooler than the average by 1.6 degrees. June was also above average by 1.9 degrees. With July and August being slightly cooler than normal by 2.1 and 2.7 degrees.

Precipitation was surprising with 5.18 inches more moisture than the 30 year average. We received above average moisture the fall of 2015, resulting in good soil moisture at planting. September was 1.82 inches above the 30 year average. October through December were 0.5 inches of precipitation above normal. January was ahead of the average with 2.1 inches more than the normal precipitation. February was exceedingly dry reporting no moisture for the month. With March close behind only receiving 0.2 of inch. April brought some much needed moisture with about an inch above the 30 year average, while May was only slightly above the 30 year average. June precipitation was 2.3 inches below normal. July received 1.4 inches over the 30 year average for precipitation. The combination of heat and dry in June at the time the canola was flowering and setting pods, affected yield making growing conditions very poor for canola.

A similar project will be proposed for FY 2017. The continuation of canola variety trials help elucidate researchers and farmers which varieties are better suited for that particular region in Montana.

Table 1. Statewide Industry Canola Variety Trial - Dryland, No-Till Chemical Fallow. Western Triangle Ag. Research Center, Conrad, MT. 2016.

Variety	Herbicide System	Seed Yield bu/ac	Seed Yield lb/ac	Test Weight lb/bu	Oil %	Julian date Flowering	Plant Height inch	Plant per ft^2
HyClass 930	RR	23.2	1160.1	51.4	47.7	170.0	34.0	7.3
DKL30-20R	RR	22.9	1190.5	52.0	47.0	166.5	34.8	8.5
G49773	RR	22.8	118.17	51.7	47.0	170.3	34.8	8.9
HyClass 972	RR	22.5	1127.2	52.1	45.6	172.5	34.0	7.3
HyClass 970	RR	22.3	1113.0	51.7	46.5	169.5	35.0	8.6
G35153	RR	21.6	1118.4	52.4	46.3	170.3	34.0	8.0
InVigor 5440	LL	21.4	1068.1	52.0	45.4	172.5	37.3	8.4
InVigor L140P	LL	21.0	1049.1	51.9	45.1	175.5	37.0	9.1
HyClass 955	RR	20.8	1041.2	51.1	47.1	168.3	32.5	7.2
DKL70-10R	RR	20.7	1077.8	51.0	45.6	171.0	35.0	8.2
6074 RR	RR	20.1	1043.6	51.5	46.4	173.3	35.0	8.4
6080 RR	RR	19.8	1024.1	50.3	46.3	171.5	37.5	6.8
InVigor L130	LL	19.7	984.2	52.0	45.8	172.0	37.5	10.3
CXP15522	SU	18.9	975.6	50.8	45.6	175.3	34.8	7.8
G49720	RR	18.2	944.2	51.5	46.0	170.8	35.0	9.0
BY16-768	RR	17.9	925.5	49.8	46.2	170.0	35.8	7.7
C1516	SU	17.6	910.8	52.2	44.2	174.8	34.3	8.9
CXP15507	SU	16.8	870.3	50.8	45.0	175.5	36.0	7.4
CXP15513	SU	16.7	963.5	51.5	46.0	176.0	35.3	8.6
C1511	SU	16.3	838.1	49.6	43.8	171.8	34.5	8.2
NCH13G046	RR	15.3	767.3	51.0	42.1	171.8	32.8	7.2
Empire	none	15.2	789.0	51.5	44.8	171.5	31.3	8.1
Arriba	none	14.3	743.4	50.5	45.3	171.8	31.8	8.3
GT50	RR	14.3	740.4	49.3	41.7	170.5	31.3	8.5
Cara	none	12.6	652.6	49.8	45.4	172.5	33.0	6.6
Mean		18.9	980.0	51.2	45.5	171.8	34.6	8.1
LSD (α = 0.05)		4.9	256.0	1.3	1.3	1.6	2.7	ns
CV (%)		18.5	18.5	1.8	2.0	0.7	5.5	24.4
P-value (0.05)		<0.0001	<0.0001	<0.0000	<0.0001	<0.0000	<0.0000	0.8277

RR: Roundup ready, LL: Liberty link, SU: sulfonylurea
Grain yield and test weight is adjusted to a uniform moisture content of 8%.
Grain protein, grain oil, and oil yield are reported on a dry matter basis.
Seeding Date: 4/21/2016 Swathed Date: 8/16/16 Thrashing Date: 8/24/2016
Fertilizer (actual lbs/ac): 79-22-20-20
Preplant sprayed with Roundup RT3 at 32 oz/ac on April 3, 2016.
Previous crop: Chemical fallow barley stubble.
Location: MSU Western Triangle Ag. Research Center, Conrad, MT.

Table 2. Green and Grow seed treatment on canola. Western Triangle Ag. Research Center, Conrad, MT. 2016.

Variety	Herbicide System	Seed Yield bu/ac	Seed Yield lb/ac	Test Weight lb/bu	Oil %	Julian date Flowering	Plant Height inch	Plant per ft^2
G and G 201	RR	17.4	899.8	47.8	45.3	172.0	28.5	5.6
G and G 200	RR	18.8	729.2	47.7	45.5	172.3	27.3	7.8
G and G 202	RR	16.1	626.7	47.3	45.4	171.3	27.8	5.7
Mean		17.4	751.9	47.6	45.4	171.8	27.8	6.3
LSD (α = 0.05)		ns	ns	ns	ns	ns	ns	ns
CV (%)		10.6	46.5	1.0	0.9	0.3	8.7	27.7
P-value (0.05)		0.8139	0.5682	0.5296	0.7853	0.0963	0.7703	0.2214

RR: Roundup ready
Grain yield and test weight is adjusted to a uniform moisture content of 8%.
Grain protein, grain oil, and oil yield are reported on a dry matter basis.
Seeding Date: 4/12/2016 Swathed Date: 8/16/16 Thrashing Date: 8/24/2016
Fertilizer (actual lbs/a): 79-22.2-20-20
Preplant sprayed with Roundup RT3 at 32 oz/ac on April 3, 2016.
Previous crop: Chemical fallow barley stubble.
Location: MSU Western Triangle Ag. Research Center, Conrad, MT.

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Soil Test Values

Table 3. Soil test values for off-station and on-station plots, 2016.

Location	N (lbs/ac)[1]	Olsen-P (ppm)	K (ppm)	pH	OM (%)	EC (mmhos/cm)
Cut Bank	39.6	17	385	7.5	2.7	0.39
Devon	12.1	14	221	7.2	0.8	0.15
Knees	21.1	28	482	6.9	2.4	0.55
Choteau	44.5	7	412	8.1	2.3	0.82
WTARC	15.6	20	318	7.8	2.4	0.56

[1]Nitrogen soil samples were to a depth of four feet in one foot increments. All other soil tests were for zero to six inches in depth.
WTARC- Western Triangle Ag. Research Center

Entomology/Insect Ecology Program

Entomopathogenic Nematodes Combined with Adjuvants Presents a New Potential Biological Control Method for Managing the Wheat Stem Sawfly, *Cephus cinctus* (Hymenoptera: Cephidae)

Principle Investigator: Gadi V.P. Reddy

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Aim of the Study

We tested the hypothesis, in the laboratory and the field that treating wheat stubble with entomopathogenic nematodes (EPNs) solutions containing adjuvants will result in higher wheat stem sawfly (WSS) mortality compared to EPN treatments mixed with water alone.

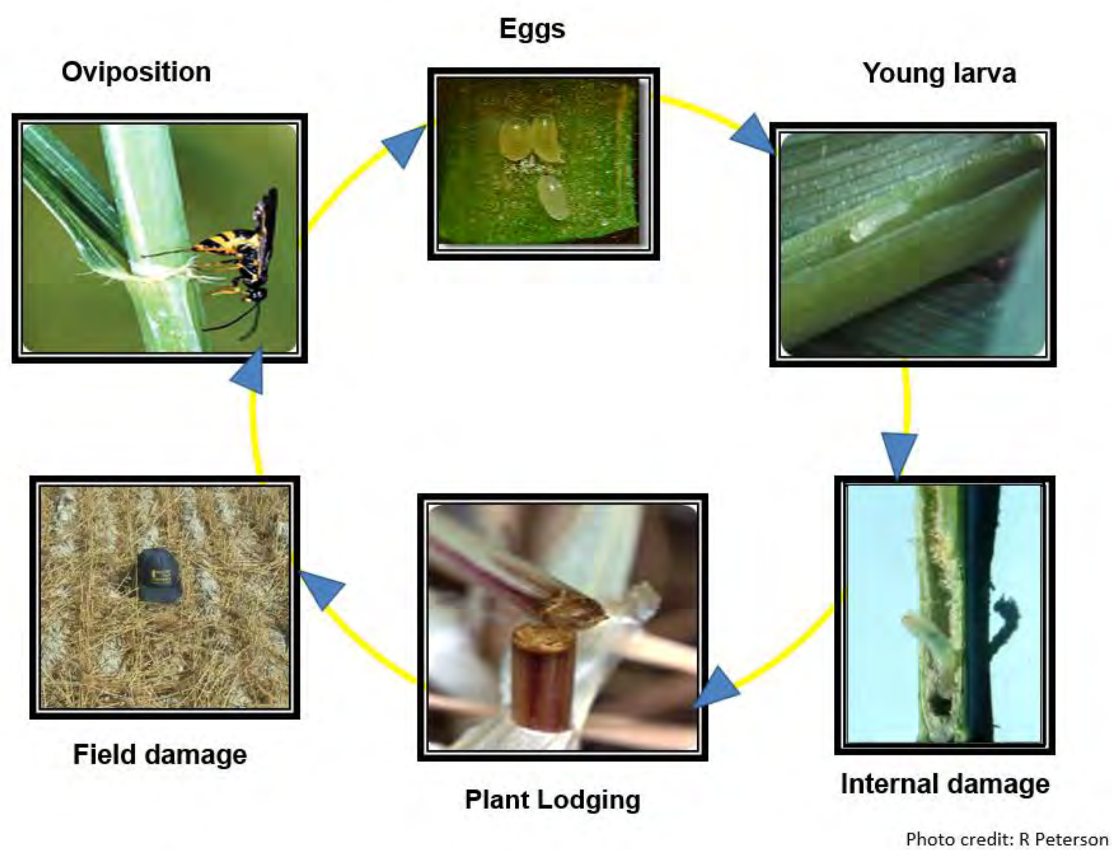

Fig. Life cycle of wheat stem sawfly

Materials and Methods

EPN infection assay

To determine if WSS was susceptible to EPN infection, diapausing WSS larvae were exposed to three species of EPNs: *Heterorhabditis indica, Steinernema kraussei,* and *Steinernema feltiae*. Wheat stubble containing overwintering WSS was collected from a harvested Judee winter wheat field in Teton County, Montana (N47° 52.1916' W112° 35.5956'). Permission to collect wheat stubble samples was granted by local private landowners: James Bjelland (Podera county, MT), Ken Johnson (Podera county, MT) and Dan Schuler (Teton county, MT). The research activities reported here did not involve, pose a risk to, or harm any endangered or protected species. Using a scalpel, wheat stems were sliced open along the long axis and larvae were gently removed with forceps or a dissecting needle. Care was taken not to injure the larvae during removal and all larvae were inspected under a stereomicroscope to ensure they had no prior injuries that could affect their mortality or susceptibility to infection by EPNs. EPNs were obtained from Becker Underwood Inc. (now BASF Corp., Ames IA) and stored at 4° C.

Seventy-five WSS larvae were placed singularly in 55mm plastic Petri dishes (Bioplast Manufacturing L.L.C., Bristol, PA) containing two pieces of moistened 55mm Whatman® filter paper (GE Healthcare Bio-Sciences, Malborough, MA). To test different concentrations of infective juveniles (IJs) against WSS, IJs from each EPN species were added to distilled water at concentrations of 200, 400, 800 and 2000 IJs/ml. Using a pipette, EPNs were applied by placing a 25ul droplet of EPN solution onto the filter paper next to the WWS larva – EPN application rates were 50, 100, 200, and 500 IJ/larva. Five WSS larvae were treated with each EPN solution (3 EPNs × 4 concentrations × 5 larvae). Applications using 25ul of distilled water without nematodes served as negative controls. After treatment, Petri dishes were sealed with Parafilm M® (Bemis Company Inc., Neenah, WI) and moved to a 25° C incubator.

Larval mortality was assessed every day, for three days following EPN applications. Dead larvae were immediately moved to fresh Petri dishes lined with moist filter paper. EPN infected WSS larvae rapidly turn reddish-brown in color; thus, they can be easily distinguished from uninfected larvae. EPN infections were confirmed using the "white trap" method (White 1927). After 7 days, all white traps were evaluated for the presence of IJs under a stereomicroscope. Following mortality assessments, the experiment was repeated (N=2) to confirm the results. Daily percent mortalities were averaged within treatments to obtain mean larval percent mortalities two and three days after EPN exposure.

Adjuvant absorbance assay

To test the ability of different chemical solutions to absorb into the hydrophobic plugs, we made artificial plugs from natural plug material and measured the rate of absorbance for each solution. Artificial plugs were used because there is a large amount of variability in the size of natural plugs (0.2-1.0 mg) and natural plugs are extremely fragile and crumble easily during removal. Wheat stubble containing WSS larvae were collected from two harvested Judee winter wheat fields in Pondera county MT (N48° 10.567' W111° 32.872'; N48° 11.397' W111° 25.843') and one in Teton county MT (N47° 52.360' W111° 40.324'). Dirt and debris were removed from each stem and clean stems were kept in 473 ml plastic deli containers; deli containers with stems were stored in an incubator at 8° C. To create the artificial plugs, ~200 natural plugs were removed from the wheat stubble and ground into a powder of uniform consistency. Plug material was slightly moistened with distilled water and the open ends of Wilmad-Lab Glass® capillary tubes, which approximated the size of a wheat stem (2.2 mm ID, 2.5 mm OD; SP Industries Inc., Warminster, PA), were gently pushed into the moistened plug material. Artificial plugs were allowed to dry overnight inside the capillary tubes; plugs were removed from the tubes the following day. Artificial plugs were 4-5 mm in length and weighed an average of 3.1 mg.

Nine commercial adjuvants (Adigor®, Advantage®, Alypso®, Penterra®, R-11®, Silwet L-77®, Sun Ag Oil®, Sunspray 11N®, and Syl-Tac®) were mixed according to the manufacturers' recommendations; Barricade (Barricade International Inc, Hobe Sound, FL), Tween 80®, Triton X-100®, and Urea (Thermo Fisher Scientific, Waltham, MA) were mixed at concentrations of 1.0%, 1.0%, 1.0% and 5.0% respectively (Table 1). Because Sun Ag Oil and Sunspray 11N contain mostly mineral oil, which does not readily dissolve in water, 0.05% Triton X-100 was added to both as an emulsifier. 5.0 ml of each solution was poured into 55 mm glass petri dishes – distilled water served as the control. Artificial plugs were released singularly into each solution and a stop watch recorded the time (seconds) required for the plugs to become completely saturated – recording did not continue past 300 sec. The assay was performed three times (N=3) for each solution (Table 2) and absorbance times were averaged to obtain mean saturation times.

Laboratory assay of EPNs with carrier solutions

To determine if EPN solutions containing different chemical additives would allow EPNs to pass through the plug formed by the WSS and come into contact with the insect, we applied carrier solutions containing EPNs to the tops of wheat stubs. Although *H. indica* was previously found to cause high mortality in WSS larvae (Table 3), *H. indica* was not used for further testing because this species prefers warm moist environments and is generally only found in tropical or subtropical climates. *H. indica* was replaced with *S. riobrave* because this species survives in dryer climates – such as the semi-arid climate of the northern Great Plains. Pilot trials tested six species of EPNs (*H. bacteriophora, S. carpocapsae, S. feltiae, Steinernema glaseri, S. kraussei,* and *Steinernema riobrave*). However, only *H. bacteriophora, S. feltiae, and S. riobrave* produced significant mortality (>30%), thus, subsequent trials only included these three species. All species of EPNs used in this experiment were commercially available and included both cruisers and ambushers. Commercial availability of an EPN was an important selection criterion because we wanted to test only species that growers could readily obtain in large numbers.

Distilled water and thirteen different chemical carrier solutions were prepared according to Table 1 and stored at 4° C. *H. bacteriophora, S. feltiae, and S. riobrave* were obtained from a commercial supplier (Sierra Biological, Pioneer CA) and stored at 4° C. EPNs were allowed to equilibrate to room temperature (22° C) before being added to 4 ml of each carrier solution. Solution volumes were adjusted to achieve concentrations of approximately 2000 IJ/ml.

Soil was collected from an onsite field plot, rocks and other debris were removed manually, and distilled water was added to bring the soil moisture level to ~30%. The soil was sterilized at 125° C for 45 mins in an autoclave. Previously collected wheat stubble, which housed diapausing WSS, was removed from cold storage (8° C) and 15-20 individual stems were inserted into 473 ml deli cups containing approximately 150 ml of the moist autoclaved soil. Using disposable pipettes, solutions containing EPNs were mixed thoroughly and applied to the wheat stems by placing a single droplet (~20 ul) on top of the stem's plug. To determine if WSS were previously infected by naturally occurring EPNs, subsets of stems were treated with distilled water containing no EPNs (negative control). The order of treatment applications was randomized and treated stems were incubated at 25^{o} C in a growth chamber (14:10 L/D, 50% RH) for 7 days.

Following incubation, stems were sliced open with a scalpel along the long axis and larvae or pupae were carefully removed with forceps or a dissecting needle. Both larvae and pupae were found because the insects were slowly developing during the four months in cold storage. Individuals that appeared infected with EPNs were dissected under a stereomicroscope to confirm the presence of EPNs; individuals that appeared healthy were placed in small 59 ml portion cups and monitored for seven days for latent signs of infection. WSS percent mortalities were calculated from groups of 15-20 stems contained in each deli cup. The assay was subsequently repeated two more times on different dates (N=3). Mortality was assessed for a total of 1173 larvae and 288 pupae (15-20 stems × 14 carrier solutions × 3 EPNs × 3 repetitions). Percent mortalities from each repetition were averaged within treatments (carrier solutions × EPNs) to obtain mean percent mortality values.

Field trials of EPNs with carrier solutions

The previous experiment demonstrated that Penterra, Silwet L-77, Sunspray 11N, and Syl-Tac performed better at allowing EPNs to enter stems compared to all other adjuvants, thus, these four carrier solutions, as well as, Barricade and distilled water were selected for field tests. Although water and Barricade were not top performers in the laboratory assay, they were included in our field tests because EPNs are typically mixed with water for spray applications, and Barricade has been used successfully to increase the efficiency of EPNs against above-ground insects. All three species of EPNs were tested with the six different carrier solutions at three field locations (3 × 6 × 3 Randomized Complete Block design) – untreated stems served as negative controls to determine if any WSS were infected with indigenous EPNs. In early May 2016, field plots were established in three previously harvested (fall 2015) Judee winter wheat fields; two locations (Bjelland Farm and Johnson Farm) in Pondera county MT (N48^{o} 10.567' W111^{o} 32.872'; N48^{o} 11.397' W111^{o} 25.843') and one location (Schuler Farm) in Teton county MT (N47^{o} 52.360' W111^{o} 40.324'). Permission to conduct field trials was granted by local private landowners as mentioned above. Soil type at each location consisted of silty clay loam. Field plots were 1 m^2 and contained 3-4 rows of wheat stubble. The corners of the plots were marked with orange painted wooden stakes. To minimize variation in WSS densities [21], plots were arranged linearly approximately equal distances from the edges of the fields. Individual plots were spaced ~8.0 m apart to avoid effects from overspray or migration of EPNs and plot order was randomized at each location.

Carrier solutions were prepared fresh and EPNs added at a concentration of 1000 IJs/ml –the lower EPN concentration more closely simulated real-life application conditions. After adding EPNs, treatment solutions were kept at 8^{o} C prior to transporting to the field sites in order to conserve the EPN's energy reserves and minimize their temperature related stress response. In the field, 100 ml of the treatment solutions were added to 3.79 L pressurized hand sprayers (H.D. Hudson Manufacturing Company Chicago, IL) – this volume also more closely simulated real-life application conditions of. All sprayers were pressurized with 25 pumps of the handle (>100 psi) which provided enough pressure to apply the more viscous 1.0 % Barricade but still below 200 psi which can cause mortality to EPNs. To standardize the spray rate and spray pattern, a single spray nozzle was interchanged between sprayers for all treatments. The nozzle was adjusted to provide an even cone-shaped spray pattern ~15 cm wide at a height of 15-20 cm. Between each treatment, the nozzle was rinsed for 3 sec each with soapy water, then tap water, which thoroughly removed any remaining solution from the previous treatment. Treatment solutions were applied evenly to each plot by holding the tip of the nozzle ~15-20 cm above the soil level and moving the nozzle back and forth in a sweeping motion until the liquid was exhausted. To minimize UV exposure and high daytime temperatures, treatment solutions were applied just before sunset. Average air temperatures during treatment applications were 17.2° C, 15.2° C, and 17.2° C at the Bjelland, Johnson, and Shuler Farms, respectively. Average daily air temperatures and daily RH for the five day treatment periods were 10.6° C; 79% RH, 10.0° C; 78% RH, and 12.2° C; 81% RH at the Bjelland, Johnson, and Shuler Farms, respectively.

Five days after treatment, five clumps of wheat stubble were randomly collected from each plot and placed in clean zip-lock bags during transport back to the laboratory. Rainy conditions (0.85 cm / day, May 20-22) during collecting caused the wheat clumps to be soggy, thus wheat clumps were allowed to dry for ~24 hrs before separating. Stems containing diapausing larvae or pupae were removed from the wheat clump, cleaned of dirt and debris, and placed in 473 ml plastic deli containers. Stems were stored at 8° C until they could be assayed for the presence of EPNs (<5 days). Twenty stems (various lengths) from each plot were randomly selected and carefully sliced open with a scalpel to expose the larvae (248 total) or pupae (827 total). All larvae and pupae were assayed for mortality. Dead larvae or pupae were dissected under a stereomicroscope to look the presence of EPNs; individuals that appeared healthy were placed in small 59 ml portion cups and observed for 7 days for latent signs of infection. WSS percent mortality was calculated for each treatment plot, at each location, and percent mortalities were averaged across locations (N=3) to obtain mean percent mortality values for all treatments (carrier solutions × EPNs).

Data analysis

Many factors can cause mortality in WSS populations (*e.g.* environment conditions, parasitoids, fungi, pathogens, etc.). Therefore, treatment percent mortalities from both laboratory and field tests were adjusted using the Schneider-Orelli formula to correct for percent mortalities found in control samples. Initial two-way analysis of variance (ANOVA) showed no significant percent mortality differences in larvae vs. pupae (P=0.12), thus larval and pupal mortalities were pooled among treatments (EPNs × solutions).

For the laboratory experiment, treatment (EPNs × solutions) percent mortalities from each repetition were treated as independent samples (N=3). Two-way ANOVA was used compare differences in WSS percent mortalities among treatments. The ANOVA model (R^2=0.47, P<0.0001) for the laboratory experiment included "*EPN species*" and "*carrier solution*" as predictor variables. The "*EPN × solution*" interaction term was not significant (P=0.552) and was removed from the model. Post-hoc multiple comparisons (Dunnett's test, α=0.05) were used to determine differences in WSS mortality when stems were treated with EPNs mixed with chemical carrier solutions vs. EPNs mixed with distilled H_2O (control). Tukey's Honest Significant Difference (α=0.05) was used to test for WSS mortality differences among the three EPNs.

For the field experiment, treatment (EPNs × solutions) percent mortalities from each location were treated as independent samples (N=3). Two-way ANOVA was used to compare differences in WSS percent mortalities among treatments. The ANOVA model (R^2=0.59, P<0.0001) included "*farm*", "*EPN species*", and "*EPN × farm*" interaction term as predictor variables – "*carrier solution*" was not significant. Post-hoc multiple comparisons (Tukey's HSD, α=0.05) were used to test for differences in WSS percent mortality for all three predictor variables. All analyses were carried out in JMP v. 12 (SAS Institute, Cary, NC).

Results

EPN infection assay

This test confirmed that three species of EPNs have the ability to infect and kill WSS larvae. *H. indica* proved to be the most virulent species because WSS mortality was 100% after day 2 for all concentrations of IJs (Table 3). High concentrations of *S. feltiae* (200, 500 IJ/larva) also produced 100% mortality by day 3. The highest mortality achieved by *S. kraussei* was 60%, making it the least virulent of the EPNs tested. EPN related differences in WSS mortality suggest that WSS is more susceptible to infection and death from *H. indica* and *S. feltiae*, compared to *S. kraussei*.

Adjuvant absorbance assay

Water alone does not readily absorb into plugs formed by the WSS, therefore, we tested a variety of commercially available adjuvants including: surfactants, wetting agents, oils, and a humectant (Barricade) for their ability to increase absorption. Artificial plugs released into distilled water required more than 5 min to become completely saturated. Plugs would float on the surface of the water for a considerable amount of time (~2-3 min) before the water would begin to absorb – affirming the hydrophobic nature of the plug material. The amount of time required for the plugs to be completely saturated in the different solutions was variable (Table 2); however, saturation occurred most rapidly in R-11 (4.2 ± 0.03 sec). Plugs were also saturated quickly in Syl-Tac and Adigor (6.5 ± 0.85 and 12.4 ± 3.58 sec, respectively). This result indicates that chemical additives would allow EPN suspensions to absorb into the plug >50× more rapidly than EPN suspensions made with water alone.

Laboratory assay of EPNs with carrier solutions

This assay demonstrated that certain chemical additives improved the ability of EPNs to penetrate the plug and infect the residing WSS larvae or pupae. On average, WSS mortality was significantly higher (F=9.49, df=12, P<0.0001) when EPNs were mixed with Penterra (P=0.015), Silwet L-77 (P=0.043), Sunspray 11N (P=0.002), or Syl-Tac (P=0.008), compared to EPNs mixed with distilled water (Fig 1) – two of these solutions (Silwet L-77, and Syl-Tac) contained silicone-based polymers. There were also EPN related differences in WSS mortality (F=6.69, df=2, P=0.002). On average *S. riobrave* and *S. feltiae* inflicted 50.5% and 47.1% mortality, respectively – significantly higher (P=0.002, P=0.019) than 35.0% mortality from *H. bacteriophora*. This result indicates that *S. riobrave* and *S. feltiae* are better at penetrating the plug and infecting diapausing WSS than *H. bacteriophora*.

Field trials of EPNs with carrier solutions

In the field, solutions containing *S. feltiae* and 0.1% Penterra increased WSS mortality up to 29% in harvested winter wheat stubble. On average, solutions containing *S. feltiae* increased WSS mortality (5.1%) more than *H. bacteriophora* or *S. riobrave* (F=6.87, df=2, P=0.003; Fig 2), and *S. feltiae* combined with Penterra, resulted in the highest average mortality (9.78%; Table 4). However, *S. feltiae's* effectiveness varied extensively across the three locations (Table 5); hence, location also had a significant effect on WSS mortality (F=14.71, df=2, P<0.0001). WSS percent mortality was higher at the Schuler farm compared to the other locations (P<0.0001). Multiple comparisons of the *EPN × farm* interaction showed that *S. feltiae* was more effective at the Schuler farm (15.5%) compared to all other EPN-location combinations (F=9.95, df=4, P<0.0001); no significant location-related mortality differences were found for *H. bacteriophora* or *S. riobrave*. These results indicate that spraying winter wheat stubble with solutions containing *S. feltiae* mixed with 0.1% Penterra may result in a significant decrease in the number of developing WSS larvae and pupae.

Acknowledgements

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References

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Table 1. Adjuvant: product name, manufacturer, main chemical ingredients, and formulation.

Product Name	Manufacturer	Chemical Ingredients	Adjuvant Added	Volume H_2O (ml)	Solution Conc. (%)
Adigor	Syngenta Crop Protection, LLC.	fatty alcohol alkoxylate	0.5 ml	99.5	0.5
Advantage	Wilbur-Ellis Co.	ammonium alky ether sulfate	0.78 ml	99.22	0.8
Alypso	Precision Laboratories, LLC.	alkyl polyglucoside ester	0.31 ml	99.69	0.3
Barricade	Barricade International, Inc.	sodium polyacrylate + modified vegetable oil	1.0 ml	99.0	1.0
Penterra	Geoponics, Inc.	propylene glycol	0.13 ml	99.87	0.1

R-11	Wilbur-Ellis Co.	alkylphenol ethoxylate, butyl alcohol, dimethylpolysiloxane	0.78 ml	99.22	0.8
Silwet L-77	Helena Chemical Co.	siloxane polyalkyleneoxide copolymer	0.1 ml	99.9	0.1
Sun Ag Oil	HollyFrontier Refining, LLC.	mineral oil + additives (50-100 light, 0-50 heavy)	1.0 ml	99.0	1.0
Sunspray 11N	HollyFrontier Refining, LLC.	mineral oil + additives (20-30 light, 70-80 heavy)	1.0 ml	99.0	1.0
Syl-Tac	Wilbur-Ellis Co.	modified vegetable oil + silicone polymer	0.39 ml	99.61	0.4
Triton X-100	Thermo Fisher Scientific, Inc.	polyethylene oxide polymer	1.0 ml	99.0	1.0
Tween 80	Thermo Fisher Scientific, Inc.	polyethylene glycol sorbitan monooleate	1.0 ml	99.0	1.0
Urea	Thermo Fisher Scientific, Inc.	carbamide	5.0 g	100	5.0

Table 2. Number of seconds required for three artificial plugs (avg. length: 4-5 mm; avg. mass: 3.1 mg) to become completely saturated when placed in 5.0 ml of carrier solution. Recordings were stopped after 300 seconds had elapsed.

	Saturation Time (Sec)		
Solution	Trial 1	Trial 2	Trial 3
Adigor	7.4	20.6	9.2
Advantage	>300	>300	>300
Alypso	129.7	117.4	148.5
Barricade	>300	>300	>300
Distilled H_2O	>300	>300	>300
Penterra	14.4	13.1	11.3
R-11	4.1	4.2	4.2

Silwet L-77	24.6	14.2	27.7
Sun Ag Oil	56.6	79.8	72.5
Sunspray 11N	44.3	70.3	52.1
Syl-Tac	6.3	4.9	8.3
Triton X-100	>300	>300	>300
Tween 80	>300	276	>300
Urea	>300	>300	>300

Table 3. Average (mean ± SE) percent mortality (N=5) of wheat stem sawfly larvae (*Cephus cinctus*) treated with three species of EPNs (*Heterorhabditis indica, Steinernema feltiae,* and *Steinernema kraussei*), 2 days and 3 days after exposure.

	S. feltiae		*H. indica*		*S. kraussei*	
IJs /larva	Day 2	Day 3	Day 2	Day 3	Day 2	Day 3
0	0 ± 0.0	0 ± 0.0	0 ± 0.0	0 ± 0.0	0 ± 0.0	0 ± 0.0
50	60 ± 21.9	80 ± 17.9	100 ± 0.0	100 ± 0.0	20 ± 17.9	40 ± 21.9
100	40 ± 21.9	60 ± 21.9	100 ± 0.0	100 ± 0.0	40 ± 21.9	60 ± 21.9
200	20 ± 17.9	100 ± 0.0	100 ± 0.0	100 ± 0.0	40 ± 21.9	80 ± 17.9
500	80 ± 17.9	100 ± 0.0	100 ± 0.0	100 ± 0.0	40 ± 21.9	60 21.9

Table 4. Average (mean ± SE), minimum, and maximum percent field mortality (N=3) of wheat stem sawfly (*Cephus cinctus*) from wheat stubble treated with three species of EPNs (*Heterorhabditis bacteriophora, Steinernema feltiae,* and *Steinernema riobrave*) combined with different carrier solutions.

		% Mortality		
Adjuvant	EPN species	Average	Minimum	Maximum
Distilled H_20	*H. bacteriophora*	0.0 ± 0.0	0.0	0.0
	S. feltiae	4.2 ± 4.2	0.0	12.7
	S. riobrave	0.0 ± 0.0	0.0	0.0
Barricade	*H. bacteriophora*	3.9 ± 3.9	0.0	11.7
	S. feltiae	4.2 ± 4.2	0.0	12.7
	S. riobrave	0.0 ± 0.0	0.0	0.0
Penterra	*H. bacteriophora*	3.9 ± 3.9	0.0	11.7
	S. feltiae	9.7 ± 9.7	0.0	29.1
	S. riobrave	0.0 ± 0.0	0.0	0.0
Silwet L-77	*H. bacteriophora*	0.0 ± 0.0	0.0	0.0
	S. feltiae	6.1 ± 6.1	0.0	18.2
	S. riobrave	2.5 ± 1.6	0.0	5.6
Sunspray 11N	*H. bacteriophora*	4.1 ± 3.5	0.0	11.1
	S. feltiae	4.2 ± 4.2	0.0	12.7
	S. riobrave	0.6 ± 0.6	0.0	1.8
Syl-Tac	*H. bacteriophora*	2.6 ± 2.6	0.0	7.7
	S. feltiae	2.4 ± 2.4	0.0	7.3
	S. riobrave	0.0 ± 0.0	0.0	0.0

Table 5 Average (mean ± SE), minimum, and maximum percent field mortality (N=3) of wheat stem sawfly (*Cephus cinctus*) from wheat stubble treated with three species of EPNs (*Heterorhabditis bacteriophora, Steinernema feltiae,* and *Steinernema riobrave*) at three different locations.

		% Mortality		
Farm	EPN species	Average	Minimum	Maximum
Bjelland	*H. bacteriophora*	1.3 ± 1.3	0.0	7.7
	S. feltiae	0.0 ± 0.0	0.0	0.0
	S. riobrave	0.3 ± 0.3	0.0	1.9
Johnson	*H. bacteriophora*	1.9 ± 1.9	0.0	11.1
	S. feltiae	0.0 ± 0.0	0.0	0.0
	S. riobrave	0.9 ± 0.9	0.0	5.6
Schuler	*H. bacteriophora*	4.1 ± 2.4	0.0	11.7
	S. feltiae	15.5 ± 3.1	7.3	29.1
	S. riobrave	0.3 ± 0.3	0.0	1.8

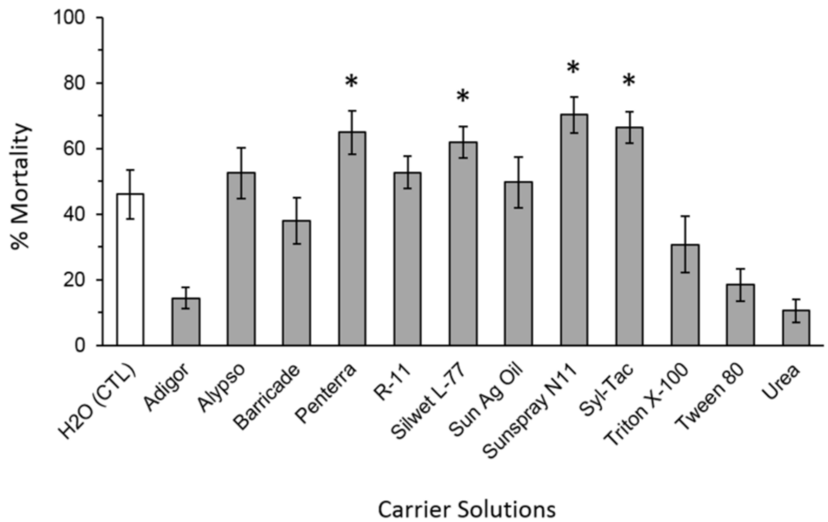

Fig. 1. Mortality of wheat stem sawfly (*Cephus cinctus*) from wheat stubble treated with three species of EPNs (*Heterorhabditis bacteriophora, Steinernema feltiae,* and *Steinernema riobrave*) combined with different carrier solutions. Percent mortalities were pooled across EPN species and bars represent average percent mortality (mean ± SEM) for each treatment solution (N=9). Asterisks indicate significant differences in percent mortality (Dunnett's test, α=0.05) compared to controls (H_2O).

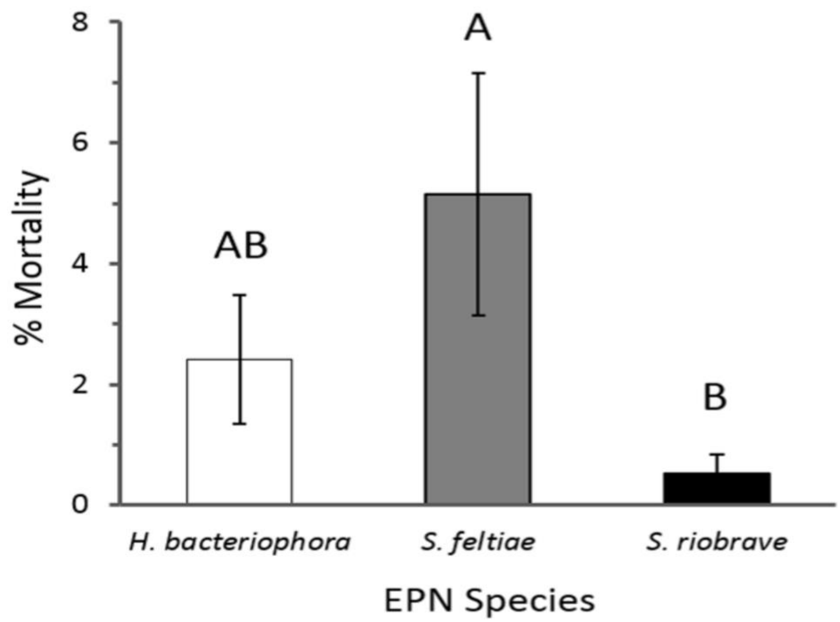

Fig. 2. Mortality of wheat stem sawfly (*Cephus cinctus*) from field wheat stubble treated with three species of EPNs (*Heterorhabditis bacteriophora, Steinernema feltiae,* and *Steinernema riobrave*). Percent mortalities were pooled across EPN species and bars represent average percent mortality (mean ± SEM) for each species (N=18). Different letters indicate significant differences in percent mortality (Tukey's HSD, α=0.05).

Evaluation of Reduced Risk Insecticides for Management of Wireworms (Coleoptera: Elateridae) on Spring Wheat

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Aim of the Study

The aim of this study to examine the several commercial or non-commercial reduced risk insecticides for their potential to manage wireworms' pest problem in a spring wheat crop in the Golden Triangle area of Montana.

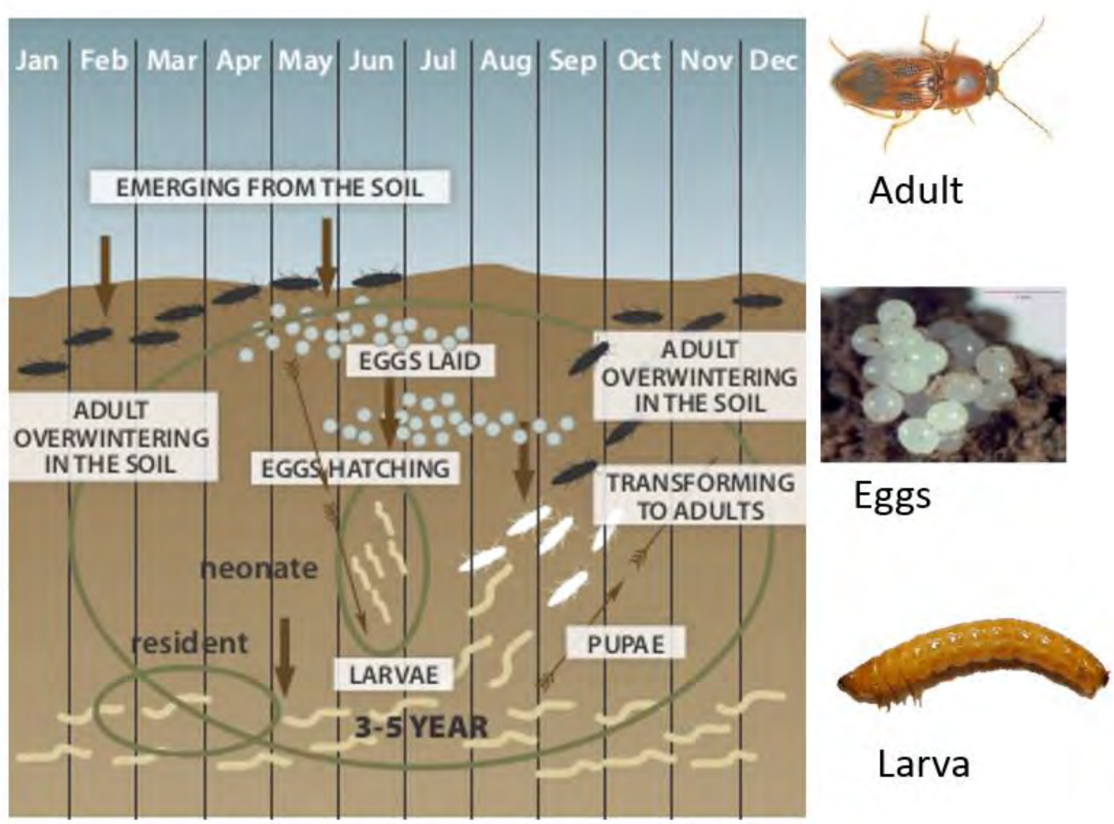

Fig. Life cycle of wireworm

Materials and Methods

Study sites

Before starting experiments, we extensively sampled wireworms at each farm site using soil digging and bait traps (Reddy et al. 2014) to confirm the presence of adequate densities of wireworms for the study. The experiments were carried out in two growers' fields at Ledger (N48^o 18'26.9244 W111^{o}51'34.4376) and Valier (N48^o 18'37.4148 W112^o 25'19.0956) in the 'Golden Triangle' area of Montana from April-September, 2015 and 2016. Experimental plots were seeded on 16 April and 16 May in 2015 and 2016 respectively at Ledger, and on 28 April and 31 May in 2015 and 2016 respectively at Valier location.

The hard red spring wheat variety 'Duclair' (using certified foundation seed) was seeded at a rate of 22 seeds per 30 cm with a four-row plot drill spaced 0.3 m at both locations. Before seeding, the herbicide glyphosate (RT3®, Monsanto Company, St. Louis, MO) was applied at the rate of 2.5 L/ha for weed control, following regional farming practice. Fertilizer (N, P, and K) was applied at a ratio of 224.2, 0, and 22.4 kg/ha by broadcast application during planting, and an additional fertilizer application (N, P, and K at a ratio of 12.3, 25.2, and 0 kg/ha) applied through the seed plot drill. The experimental plots received 5 cm of water via overhead irrigation whenever needed. The first irrigation was done 30 days after treatments.

Reduced risk insecticide application

The insecticides and rates used were based on manufacturer's recommendations (see Tables 1 and 2, for 2015 and 2016 respectively). Some of the treatments and formulations that failed to reduce wireworm numbers or to protect plants stand in 2015 were not included in 2016 study (Table 2). For treatments application methods in 2015, imidacloprid (Gaucho ® 600) was applied as a seed treatment. No fungicide was added to the seeds treated with Gaucho. Gaucho + *Beauveria bassiana* GHA (Mycotrol ESO®) and Gaucho + *Metarhizium brunneum* (Met52 EC®) were applied in rows by spraying Mycotrol and Met52 as soil drenching at the base of the seed treated Gaucho plants. The granular formulation of the entomopathogen *B. bassiana* ANT-03 (BioCeres G®) was applied by placing 21.6 g of product in gelatin shot glasses (66 ml) and applied to each row by hand. In 2016, Gaucho and a heat-killed formulation of the bacterium *Burkholderia* spp. strain A396 (Venerate XC®) were applied as seed treatments. A formulation of the bacterium *Chromobacterium subtsugae* (Grandevo SC®), Met52 formulated as microsclerotial and corn grit granule, and the organophosphate insecticide phorate (Thimet 20-G®) were applied as in-furrows. All other treatment combinations used in 2015 and 2016 (see Tables 1 and 2) were mixed in the tank and applied in rows as soil drenches. About 92 ml of water was applied per row with sprays. Spray treatments were applied to plots with a SOLO 4 gallon backpack sprayer # 425 (SOLO, Newport News, VA) with flat spray nozzle, 144.8 kPa (21.0 psi) valve, and calibrated at 816.89 L/ha. The spray applications were made 14 days after seeding.

Experimental design

The experimental design was a randomized complete block design (RCBD) with four replications. The plot sizes were 3.6 m × 1.2 m separated by 0.60 m buffer zones to avoid cross contamination of treatments. The numbers of standing plants, larval wireworm populations and seed yield in each plot were recorded to assess effectiveness of the treatments.

Plant stand count sampling

Emerged wheat seedlings were counted in a 1 m strip in the middle of the centermost two rows of each plot. The starting and ending points of the sample areas were marked with plastic labels so that the same seedlings could be recounted just before and again after treatments. In 2015, wheat seedlings were counted at 7, 14 or 28 days after treatments and for 2016 at 28 days after treatments.

Larval wireworm sampling

"Stocking bait" traps, described here below (Reddy et al. 2014), were used to detect wireworms and to estimate their relative abundance. The stocking bait traps were evenly placed along the center of each plot, spaced 1 m between baits. To make the baits, about 90 g wheat seed was placed in a nylon stocking, which was then tied shut with a string, leaving a tail end of about 30 cm. These traps were immersed in water for 24 h for the grain to start germinating before using being placed in the field, to make them attractive to wireworms. The baits were placed in holes 7 - 15 cm deep and positioned so as to maximize the contact of the grain mixture with the soil as much as possible. The strings were left above the soil surface to help relocate the traps later. The traps were then covered with about 3 - 5 cm of soil. A 12 × 12 cm piece of black polythene was then placed on the covered holes and 4 metal pegs were used to secure these piece of polyethene to the soil.

In 2015, three stocking traps, spaced 1 m apart, were placed in the middle row of each plot. These traps were deployed one week before the spray applications. Just before treatments were applied, one trap from each plot was removed just to estimate the pre-treatment wireworm density in plots (one bait per plot, with 4 baits per treatment, for four replicates of the pre-treatment sampling). The second and third traps were removed 14 and 28 days after treatments. Larvae found in traps were counted in the laboratory. Similar procedure was used for 2016 wireworm samplings, except that two stocking bait traps per plot were used with one sampling before treatments and another at 28 days after treatments. Furthermore, identification of wireworm species composition was performed in 2016 by using morphological keys described by Etzler et. al (2013)

Yield and protein assessment

A Hege 140 plot combine was used to sample the plots for yield assessment. Wheat seeds were cleaned with a seed processor (Almaco, Nevada, IA) and weighed on a scale to determine yield at the WTARC seed laboratory in Conrad, MT. The protein content of seed was determined with NIR grain analyzer IM 9500 (Perten Instruments, Springfield, IL).

Statistical analyses

The data were analyzed using SAS 9.4 (SAS 2012). Data on number of plant and larval numbers were analyzed using ANCOVA (analysis of covariance). Treatment differences were tested using Fisher's Least Significant (LSD) Test.

Results

Plant stand count

Irrespective of treatments, locations or years, plant stand counts generally decreased with time as the growing season progressed (Table 3 - 4). Pre-treatment plant stand counts per meter for 2015 varied from 26.4 to 56.6 and 20.1 to 36.1 respectively at the Valier and Ledger locations (Table 3) and the corresponding value for 2016 being 14.4 to 26.8 and 41 to 50.9 respectively (Table 4).
In 2015, the reduced risk insecticide treatments had shown significant effect on plant stand counts of wheat seedling at 28 days after treatments at Ledger and Valier locations. Among treatment plots, the significantly higher plant stand counts was observed for the seed treatment with Gaucho (20.3) and rest of the treatments with no significant difference(Table 4), when compared to the water control (14.6) at Ledger Location. Interestingly at Valier location, not only the Gaucho treatment (20.3) but also Mycotrol + Met52 (20.3), and Mycotrol + Gaucho (20.0) treatments had significantly
stand counts when compared to the water control treatment (13.6).

In 2016, reduced risk insecticides that previously (2015 study) lacked significant effects on plant stand counts over water control treatment were discarded from this study and, new other reduced risk insecticides along with Gaucho and Entrust were tested for study. Overall, the study depicted that treatments had a significant effect on plant stand counts per meter at Ledger location (F = 1.92; df = 33, 239; P = 0.00), while non-significant effect of treatments at Valier location (F = 0.98; df = 33, 239; P = 0.50). However, when plant stand counts from reduced risk insecticide treatments were compared over water control treatment in post application sampling dates at Ledger location (LSD test), no significant difference or even a significantly lower plant stand counts in some of reduced risk insecticide treatments were observed over water control treatment. Consequently, the study of 2016 indicated non-significant effect of reduced risk insecticides on plant stand count at both field locations.

Wireworm populations

Wireworms were successfully captured in baited stocking traps in all treatments regardless of locations with exception of no wireworms recorded in Met52 + Entrust treatment at Ledger location in pre-treatment sampling of 2015. The mean number of wireworm populations per baited trap varied from 0.8 to 4 and 1.8 to 5.3 at Ledger and Valier location respectively in 2015. In 2016, similar mean number of wireworms (0.3 to 4.3) (with exception of no wireworms noticed in Thimet 20-G treatment) was recorded at Ledger location, while very low number (< 0.8) of wireworms recorded at Valier location.

Overall significant differences were observed in wireworm populations at both locations: Valier and Ledger in 2015. Across the treatment levels, as an unexpected, the significantly higher population of wireworms were observed in some of the reduced risk insecticide treatment plots over water treatment plots at 14 or 28 days after treatment at Ledger location. Treatments- Met52 (5.5) + Entrust, M-1 low (5.0), and Entrust (4) had significantly higher wireworm population over water control treatment (1.6) at 14 days after treatment. Similarly, at 28 days after treatment, Mycotrol treatment had significantly higher wireworm population of 4.0 when compared to the water control (1.0).

In 2016, overall treatments had no significant effects on number of wireworms trapped on baits among plots at both locations: Valier (F = 1.12; df = 11, 35; P = 0.37) and Ledger (F = 1.20; df = 11, 35; P = 0.32). Across the treatments, the mean number of wireworm populations per baited trap varied from 0 to 0.8 and 0.3 to 1.3 at Ledger and Valier location respectively at 28 days after treatment.

Wireworm species composition

The identification of wireworm species composition was performed in 2016 at both research locations- Valier and Ledger. Overall, three wireworm species- *Limonius californicus*, *Hypnoidius bicolor* and *Aeolus mellilus* were observed regardless of study locations. However, in both locations, *H. bicolor* was the most predominant species followed by *L. californicus* and *A. mellilus* at both sampling times- before and 28 days after treatments. The total number of *H. bicolor*, *L. californicus* and *A. mellilus* recorded at Ledger location were 57, 8 and 2 respectively and the comparing value for Valier being 24, 12 and 4 respectively.

Yield

Wheat yield for 2015 varied from 2448 to 3541 kg/ha and 3436 to 4743 kg/ha respectively at the Valier and Ledger locations (Table 5) and the corresponding value for 2016 being 514 to 762 kg/ha and 1017 to 1867 kg/ha respectively (Table 6). The treatments had shown significant effect on wheat yield for 2015 at Valier and Ledger locations, while for 2016 only significant effect of treatments was observed at Ledger location. There was a tendency for relatively higher grain yield when wheat plots were treated with Entrust followed by Mycotrol ESO + Entrust WP, BioCeres GR, Met 52 +Gaucho 600 and M-1 at Valier 2015, but no significant differences were observed when compared over water control treatment (Table 5). In contrast, at Ledger location in 2015, yields in Xpulse (4743.7 kg/ha) and Met52+ Gaucho (4420 kg/ha) treatment plots were significantly higher over water control treatment (3498 kg/ha). Similarly at Ledger location in 2016, Xpectro treatment improved wheat yield over water control treatment and rest of the treatments with no significant difference over control treatment.

Acknowledgements

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Table 1 Materials and rates of application in each treatment, 2015.

Treatment	**Active ingredient**	**Rate (ml/L)**	**Source**
Water	-	-	-
Gaucho 600[a]	imidacloprid	70.98/45.35 kg seed	Bayer Crop Science, Raleigh, NC
Entrust WP[b]	spinosad	0.091	Dow AgroSciences LLC, Indianapolis, IN
M-1 (25g/L)	*Metarhizium brunneum*	0.09	LidoChem NJ
Met52 EC	*Metarhizium brunneum* F52	0.72	Novozymes Biologicals (Salem, VA)
Mycotrol ESO	*Beauveria bassiana* GHA	0.72	LAM International (Butte, MT)
Mycotrol ESO + Met52 EC	*B. bassiana* + *M. brunneum*	0.36 + 0.36	As mentioned above
Mycotrol ESO + Aza-Direct	*B. bassiana* + azadiracthin	0.36 + 0.72	As mentioned above
Mycotrol ESO + Entrust	*B. bassiana* + spinosad	0.36 + 0.0455	As mentioned above
Mycotrol ESO + Gaucho 600[c]	*B. bassiana* + imidacloprid	0.36 + 35.49	As mentioned above
Met52 EC + Aza-Direct	*M. brunneum* + azadiracthin	0.36 + 0.72	As mentioned above
Met52 EC + Entrust	*M. brunneum* + spinosad	0.36 + 0.0455	As mentioned above

Met52 EC + Gaucho 600	*M. brunneum* + imidacloprid	0.36 + 0.0785	As mentioned above
M-1 (50g/L)	*Metarhizium brunneum*	0.18	LidoChem NJ
Xpectro OD	pyrethrin + *B. bassiana GHA*	2.5	LAM International (Butte, MT)
BioCeres GR[d]	*B. bassiana ANT-03*	20	Anatis Bioprotection, (St.-Jacques-le-Mineur Quebec, Canada)
XPul se OD	*B. bassiana GHA* + azadirachtin	0.72	LAM International (Butte, MT)

Table 1. contd.
[a], Gaucho 600, seed treatment application rate unit (ml/45.35 kg seed).
[b], Entrust WP, application rate unit (g/L).
[c], Gaucho 600, seed treatment application rate unit (35.49 ml/45.35 kg seed).
[d], BioCeres GR, application rate unit (20 g/m^2)

Table 2 Material, rate, and method of application in each treatment, 2016

Treatment	**Active ingredient**	**Rate (ml/L)**	**Source**
Water	-	-	-
Gaucho	imidacloprid	70.98/45.35 kg seed	Bayer Crop Science
Entrust	spinosad	0.091	Dow Agro Science LLC, Indianapolis, IN
Aza-Direct	azadirachtin	1.43	Gowan Company
PyGanic1.4 EC	pyrethrin	1.45	McLaughlin Gormley King Company (Minneapolis, MN)
Grandevo SC	(*Chromobacterium subtsugae*)	1.36 kg/acre (3 lbs/acre)	Marrone Bio Innovations, Davis, CA
Venerate XC	Heat Killed *Burkholderia sp. srain A396*	532.32/45.35 kg seed (3784 ml/acre)	Marrone Bio Innovations, Davis, CA
Met52 Microsclerotial granules	*M. brunneum*	9.07 kg/acre (20 lbs/acre)	USDA Sidney, MT
Met52 Corn grit granules	*M. brunneum*	9.07 kg/acre (20 lbs/acre)	USDA Sidney, MT
Xpectro OD	pyrethrin + *B. bassiana GHA*	2.5	LAM International (Butte MT)
T11	Thimet 20-G	1.134 kg/acre (2.5 lbs/acre)	Amvac Chemical Corporation
T12	Thimet 20-G	2.27 kg/acre (5.0 lbs/acre)	Amvac Chemical Corporation

Table 3 Plant stand count of wheat seedling treated with reduced risk insecticides at Ledger and Valier, 2015

Treatment	**Plant stand count/m**			
	Ledger		**Valier**	
	PT[a]	**28 DPT[b]**	**PT[a]**	**28 DPT[b]**
Water	36	14.6 bcde	29.9	13.6 bcd
Gaucho 600	36.1	23.9 a	56.6	20.3 a
Entrust WP	30.3	11.4 e	35.1	15.3 abcd
M-1 Low	26.0	15.3 bcde	26.4	10.6 d
M-1 High	36.0	12.5 de	34.1	15.9 abcd
Met52 EC	30.4	12.8 de	27.9	16.0 abc
Mycotrol ESO	28.1	20.4 a	29.1	11.3 cd
Mycotrol ESO + Met52 EC	27.5	12.5 de	40.8	20.3 a
Mycotrol ESO + Aza-Direct	28.4	16.8 bcde	41.4	16.3 abc
Mycotrol ESO + Entrust WP	27.4	13.3 cde	46.4	17.4 ab
Mycotrol ESO + Gaucho 600	25.5	14.1 bcde	40.4	20.0 a
Met52 EC + Aza-Direct	26.5	11.1 e	28.8	13.1 bcd
Met52 + Entrust WP	25.5	19.6 abc	29.4	12.6 bcd
Met52 EC + Gaucho 600	28.9	20.4 a	39.4	14.4 bcd
Xpectro OD	26.1	14.1 bcde	28.9	14.5 bcd
BioCeres	20.1	15.5 bcde	26.6	12.6 bcd
Xpulse OD	31.2	18.0 abcd	32.1	15.5 abcd

Means within a column followed by the same letter are not significantly different at $P < 0.05$.
[a], PT, pre foliar and granular application (21 days after planting).
[b], 28 DPT, days after foliar and granular application (49 days after planting).
Table 4 Plant stand count of wheat seedlings treated with reduced risk insecticides at Ledger and Valier, 2016

Table 4 Plant stand count of wheat seedling treated with reduced risk insecticides at Ledger and Valier, 2016

Treatment	**Plant stand count/m**							
	Ledger				**Valier**			
	PT[a]	**7 DPT[b]**	**14 DPT[c]**	**28 DPT[d]**	**PT[a]**	**7 DPT[b]**	**14 DPT[c]**	**28 DPT[d]**
Water	50.3	36.3 ab	45.1 a	33.6 abcde	26.8	22.1 ab	20.9 a	17.1 ab
Gaucho 600	41.4	41.8 ab	45.6 a	26.4 de	22.9	22.9 ab	21.1 a	18.8 a
Entrust WP	46.8	45.8 a	42.4 abcd	29.8 bcde	14.4	21.6 ab	19.4 a	18.8 a
Aza-Direct	41	37.1 ab	34.3 bcd	30.4 bcde	20	22.1 ab	16.6 a	15.9 ab
PyGanic1.4 EC	41.4	31.8 b	45.8 a	28.4 cde	20.8	26.1 a	22.6 a	18.5 a
Grandevo SC	44.1	40.3 ab	43.8 ab	24.9 e	21.4	23.1 ab	18.9 a	15.0 ab
Venerate XC	47.9	43.5 ab	41.0 abcd	39.3 ab	14.9	23.0 ab	21.8 a	19.1 a
Met52 Microsclerotial G	50.9	33.9 ab	43.0 abc	26.9 de	24.5	19.1 b	22.0 a	19.5 a
Met52 Corn grit G	43.8	38.5 ab	38.5 abcd	32.4 abcde	21.9	22.9 ab	17.9 a	17.6 ab
Xpectro OD	47.6	39.3 ab	36.4 abcd	41.9 a	16.9	20.0 ab	19.8 a	13.4 b
Thimet 20-G	43.1	33.6 ab	33.9 cd	35.6 abcd	18	20.1 ab	22.1 a	17.6 ab
Thimet 20-G	46.6	35.1 ab	33.1 d	37.8 abc	23.3	25.4 ab	19.6 a	16.3 ab

Table 5 Wireworm catch per baited trap on wheat seedling plots treated with reduced risk insecticides, 2015

Treatment	**Ledger**			**Valier**		
	PT[a]	**14 DPT**[b]	**28 DPT**[c]	**PT**[a]	**14 DPT**[b]	**28 DPT**[c]
Water	4	1.6 cd	1.0 b	2.1	1.1 ab	1.1 a
Gaucho 600	2.5	1.8 bcd	1.0 b	5	0.8 ab	1.5 a
Entrust WP	0.3	4.0 ab	1.0 b	5.3	0.8 ab	0.3 a
M-1 Low	2	5.0 ab	0.8 b	4.5	1.3 ab	0.5 a
M-1 High	2	2.3 abcd	2.5 ab	4	0.5 ab	0.8 a
Met52 EC	2	1.8 bcd	1.5 ab	1.8	0.3 b	1.0 a
Mycotrol ESO	2	0.3 d	4.0 a	4	0.8 ab	1.0 a
Mycotrol ESO + Met52 EC	1.8	2.3 abcd	1.5 ab	4	1.8 a	0.5 a
Mycotrol ESO + Aza-Direct	0.8	1.8 bcd	0.5 b	2.8	0.8 ab	1.3 a
Mycotrol ESO + Entrust WP	0	3.0 abcd	0.0 b	1.8	0.3 b	1.3 a
Mycotrol ESO + Gaucho 600	1	1.5 cd	0.8 b	3.3	0.8 ab	1.0 a
Met52 EC + Aza-Direct	1	2.3 abcd	1.5 ab	4	0.3 b	1.0 a
Met52 + Entrust WP	1.5	5.5 a	2.5 ab	4.5	1.0 ab	0.0 a
Met52 EC + Gaucho 600	1.5	3.3 abcd	0.8 b	4.3	0.3 b	0.3 a
Xpectro OD	1.3	2.8 abcd	1.3 b	2.8	0.8 ab	0.5 a
BioCeres GR	1	2.3 abcd	1.5 ab	2.5	1.5 ab	1.0 a
Xpulse OD	0.8	1.0 cd	0.5 b	3	0.3 b	1.3 a

Table 6 Wireworm catch per baited trap on wheat seedling plots treated with reduced risk insecticides, 2016

Treatment	**Ledger**		**Valier**	
	PT[a]	**28 DPT**[b]	**PT**[b]	**28 DPT**[b]
Water	2.3	0.8 a	0	1.0 a
Gaucho 600	0.75	0.0 a	0.3	0.3 a
Entrust WP	1	0.0 a	0.3	0.3 a
Aza-Direct	0.8	0.0 a	0.5	1.0 a
PyGanic1.4 EC	0.5	0.8 a	0.5	0.3 a
Grandevo SC	0.3	0.0 a	0	0.3 a
Venerate XC	4.3	0.5 a	0	1.3 a
Met52 Microsclerotial G	2	0.3 a	0	1.3 a
Met52 Corn grit G	0.5	0.3 a	0.8	0.5 a
Xpectro OD	0.8	0.0 a	0.3	0.5 a
Thimet 20-G	0	0.0 a	0.3	0.3 a
Thimet 20-G	1.3	0.0 a	0	0.8 a

Means within a column followed by the same letter are not significantly different at $P < 0.05$.
[a], PT, pre foliar and granular application (28 days after planting).
[b], 28 DPT, days after foliar and granular application (45 days after planting).

Table 7. Yield of wheat seedlings treated with reduced risk insecticides at Valier and Ledger 2015

Treatment	Location			
	Ledger		Valier	
	Yield (kg/ha)	Protein (%)	Yield (kg/ha)	Protein (%)
Water	3498.5 c	13.13 a	2832.4 ab	14.21 ab
Gaucho 600	4133.1 abc	13.14 a	2336.3 b	14.74 ab
Entrust WP	4060.7 abc	13.11 a	3541.3 a	14.85 ab
M-1 Low	3813.3 bc	13.22 a	3027.6 ab	15.06 a
M-1 High	3608.4 bc	13.0 a	2914.3 ab	15.15 a
Met52 EC	3445.9 c	13.48 a	3111.2 ab	14.24 ab
Mycotrol ESO	4033.1 abc	12.93 a	3013.6 ab	13.96 b
Mycotrol ESO + Met52 EC	3990.7 abc	13.38 a	2512.9 b	14.73 ab
Mycotrol ESO + Aza-Direct	3650.5 bc	13.39 a	2636.3 ab	14.24 ab
Mycotrol ESO + Entrust WP	3759.0 bc	13.42 a	3162.8 ab	14.62 ab
Mycotrol ESO + Gaucho 600	3952.6 abc	13.29 a	2920.2 ab	14.94 a
Met52 EC + Aza-Direct	3703.2 bc	13.34 a	2349.1 b	14.75 ab
Met52 + Entrust WP	3627.0 bc	13.28 a	2448.1 b	14.72 ab
Met52 EC + Gaucho 600	4420.4 ab	12.67 a	3112.0 ab	14.77 ab
Xpectro OD	3436.2 c	13.49 a	2965.2 ab	14.62 ab
BioCeres GR	3659.5 bc	12.78 a	3121.9 ab	14.76 ab
Xpulse OD	4743.7 a	12.65 a	2651.7 ab	14.61 ab

Table 8. Yield of wheat seedlings treated with reduced risk insecticides at Valier and Ledger 2016

Treatment	**Location**			
	Ledger		**Valier**	
	Yield (kg/ha)	**Protein (%)**	**Yield (kg/ha)**	**Protein (%)**
Water	577.4 abcd	15.9 abc	1301.1 a	16.2 a
Gaucho 600	528.1 bcd	15.4 abcd	1177.6 a	16.7 a
Entrust WP	514.5 cd	15.5 abcd	1330.4 a	16.4 a
Aza-Direct	637.9 abcd	15.3 cd	1319.0 a	16.2 a
PyGanic 1.4 EC	677.3 abc	15.9 ab	1325.1 a	15.4 a
Grandevo SC	439.0 d	15.0 d	1762.8 a	15.5 a
Venerate XC	635.7 abcd	15.4 abcd	1017.0 a	16.8 a
Met 52 Microsclerotial Granules	708.4 abc	15.4 bcd	1867.6 a	15.7 a
Met 52 Corn Grit Granules	626.0 abcd	15.3 cd	1264.2 a	15.2 a
Xpectro OD	762.7 a	15.2 d	1335.4 a	16.0 a
Thimet 20-G (2.5 lbs/Acre)	745.4 ab	15.3 abcd	1350.6 a	16.5 a
Thimet 20-G (5.0 lbs/Acre)	669.1 abc	16.0 a	1379.0 a	16.2 a

Evaluation of Trap Crops for the Management of Wireworms in Spring Wheat in Montana

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Aim of the Study

The aims of the study were to examine the effect of seven trap crops pea, lentil, canola, corn, durum, barley and wheat for their attractiveness to wireworm in spring wheat crop.

Fig. Trap crops evaluated for wireworms management

Materials and Methods

Trials sites

The field trials were conducted at two sites: Ledger (48.2583° N, 111.8257° W) and Valier (48.3078° N, 112.2498° W) in the Golden Triangle region of Montana, from May to August in both 2015 and 2016. These fields are well known for being infested with wireworms. Valier soil is a sandy loam while that of Ledger is silt and clay, rich in humus. Spring wheat is the main crop grown in these fields for the past few years.

Exp. #1. Effectiveness of trap crops in field trials

Experimental design

The study area of 40 ×12.6 m was established and divided into 42 experimental units each measuring 1.2 × 4.8 m. A complete randomized block design with seven treatments and six replications was used. The blocks were separated by 1 m buffers and the two plots within each block were separated by 0.45 m. Each experimental plot had four rows with row to row distance of 0.3 m. The main crop (spring wheat) was planted in the first and third rows and the trap crop was planted in the second and fourth rows. The seven treatments were Montech pea (T1), Hyeless 955 canola (T2), sweet corn (T3), Montrail durum (T4), Metealfa barley (T5), Green Land lentil (T6), and Duclair wheat as control (T0) respectively. Minimum tillage was done and a four-row seed driller was used. The rate of sowing was 22, 26, 26 and 24 seeds per 0.3 m for wheat, lentil, barley, and durum, respectively. Similarly, 7 and 53 seeds/m were panted for corn and pea, respectively. The herbicide ammonium sulphate (AMS) was broadcasted at the time of sowing at 2.24 kg /ha as were fertilizers at an N, P and K ratio of 224.2, 0, and 22.4 kg /ha.

Sampling for plant damage and wireworm density

To determine the level of crop damage from wireworms, the number of plants or seedlings in each plot was measured randomly using the 1 m line intercept method (Canfield 1941; Jonasson 1988). From two rows of wheat in a plot, three plant counts were collected. The same method was applied to the various trap crops intercropped with the wheat. Wheat plants were categorized as healthy or damaged. Healthy ones were those without any damage while plants that were wilting or yellowish in appearance or had an overall shorter plant height were considered damaged. In both fields, counts were first made two weeks after sowing, then at weekly intervals for four weeks, then at 2-week intervals for three more times, for a total of eight sampling dates.

To determine the density of wireworm larvae, destructive soil sampling was done, using a metallic sampling device, 15 cm square shape. Samples were taken at random from each row within the plots. Samples were placed in plastic bags, labelled and brought to the Research Centre, where they were processed and the number of wireworms in each sample recorded. Wireworms from samples were placed in small plastic pots filled with sphagnum moss and stored in a refrigerator at 8 °C. Later, they were identified using the keys of wireworm described by Etzler et. al (2013) and some of them were used for the shade house experiment. The soil samples were collected right after the plant count was taken. Eight soil sample readings were collected from both sites.

Exp. #2. Determination of optimal spacing for trap crops

Location and experimental design

These trials were conducted in 2016 at the same two locations of Valier and Ledger. A complete randomized block design was again used, with spacing treatments of 0.25, 0.5, 0.75, and 1 m, between wheat (control), pea and lentil, each replicated four times. Pea, lentil and wheat (control) were randomly assigned to plots within each block. There were 48 plots in total, each 4 m^2. The blocks and the plots within each block were separated by 1.5 m. The crop cultivar used were Montech pea, lentil and Duclair wheat, respectively. Crops were manually sown at the same rate used for the first field trials. Due to climatic reasons, plots were sown in late May; in Ledger, on the third week and in Valier, on last week of May.

Sampling for plant and wireworm density

Plant counts was taken using the 1 m line intercept method from randomly selected rows of wheat and trap crop. In each experimental unit, counts were made from one randomly selected wheat and one trap crop row for each counting event. The first count was taken two weeks after sowing. The following three counts were taken at weekly intervals at both sites. The last two count readings were taken at two week intervals, for a total of six plant counts taken from both sites.

Wireworm larvae were sampled by destructive soil sampling using a 0.15 m^3 metal sampler to sample wireworm larvae in the soil. In each experimental plot, two samples were taken at random, one each from randomly selected wheat row and trap crop row. These samples were bagged, labelled, brought to the Research Centre, manually went through each bag and the number of wireworms recorded. Larvae were kept in plastic pots filled with peat moss and held in a refrigerator at 8 °C. The soil sample was collected after the plant count was taken.

Exp. #3. Shade house bioassay

Shade house bioassays were conducted at the Western Triangle Agriculture Research Centre in Conrad, Montana in August 2016. An average room temperature of 18 to 22 °C was maintained throughout the experiment. Assay units were square plastic flower pots filled with potted soil mixture of soil, sphagnum moss and sand in ratio 4:2:1; dimension of each pot was 10.5 cm square and 9.2 cm deep. The experiment had three treatments: Montech pea, lentil and Duclair wheat (control), i.e., pea vs wheat, lentil vs wheat and wheat vs wheat with four replications of each and conducted over two time frames: 4 days and 10 days. Five grams of wheat seed were planted in the middle of two opposite sides and five grams of pea or lentil were planted in the middle of the other two sides. Nine larvae of *L. californicus* of similar length (1.5 cm) were then released in the center of the pot. On days 4 and 10 of the respective assays, the potting mixture in each pot was divided into nine equal sections, comprised of the four corners, the four sides and the center, the location of wireworms determined.

Statistical analysis

Analysis of variance (ANOVA) was used to analyze data in R-software version 3.1.3. For both field trials, we used date of sampling as a blocking factor and performed ANOVA. Tukey HSD post-hoc at 95% confidence interval was used for pair-wise comparison among treatments. Values of $P < 0.05$ were considered significant. Paired t-test at 95% confidence interval was used to analyze the difference for wireworm numbers trapped among treatments. Chi-square tests of fitness were performed for the greenhouse bioassays and *P*-values < 0.05 were considered significant.

Results

Exp. #1a. Effect of trap crops on damage levels in field spring wheat

In both years, at the Valier field location significance differences in wheat plants damage (%) were found among trap crops (in 2015, $F = 9.01$, $df = 6$, and $P<0.01$ and in 2016, $F = 15.54$, $df = 6$, and $P<0.01$). In 2015, except for the barley ($P>0.05$) and canola ($P>0.05$) treatments, significance differences were found between tested trap crops and the control (Figure.1.). Likewise, in 2016 damage levels in wheat plants intercropped with pea ($P<0.01$), lentil ($P<0.01$), and corn ($P<0.05$) were significantly lower than in the wheat monoculture control (Figure.2.). In Valier, in both years, pea ($P<0.01$) and lentil ($P<0.01$) treatments showed the lowest damage in wheat plants

Similarly, in both years, at the Ledger field location, significance differences were observed in damage (%) in spring wheat intercropped with trap crops ($F = 59.49$, $df = 6$, and $P = <0.01$ in 2015; and $F = 13.68$, $df = 6$, and $P <0.01$ in 2016). In 2015, except for in the barley ($P>0.05$) trap crop treatment, significant differences were detected in damage (%) in spring wheat plants intercropped with other trap crops ($P < 0.05$) compared to the wheat monoculture control. Damage to wheat plants was significantly lower in the pea ($P <0.01$) and lentil ($P <0.01$) treatments than in the other treatments ($P <0.05$) (Figure. 1). In 2016, except for the durum ($P >0.05$) significance differences were found between trap crops and control ($P <0.05$). Moreover, significantly lower damage (%) in wheat plants intercropped with pea ($P <0.01$) and lentil ($P <0.01$) trap crop treatments than other ($P <0.05$) was observed (Figure. 2). In both years, regardless of location, wheat plant damage % was higher in first four weeks of sampling, then decreased, and leveled off. The germination of treatment corn were very low.

Exp. #1b. Effect of trap crops on wireworm densities in field spring wheat

In 2015 and 2016, at the Valier field location significance differences in wireworm numbers were found between the soil samples taken from wheat rows intercropped with different trap crops and control (in 2015, $df = 6$, $P <0.01$ and in 2016, $df = 6$, $P <0.05$). However, significantly lower numbers of wireworm were observed only for wheat intercropped with treatment pea ($t = 3.41$, $P <0.05$ in 2015, and $t = 3.24$, $P <0.05$ in 2016). While comparing the wireworm numbers recorded from the different trap crops rows with control wheat rows we found significant lower number of wireworms in corn rows (P<0.05 in both years) and canola (P<0.05 in 2016) than trap crop pea.

In both years, at the Ledger field location significance differences in wireworm numbers were found between soil samples collected from wheat rows intercropped with trap crops and control (in 2015, df = 6, P< 0.01 and in 2016, df = 6, P< 0.05). However, significant low wireworm numbers was recorded from the soil samples of wheat rows intercropped with treatment pea (t = 3.993, P <0.05 in 2015, and t = 3.16, P <0.05 in 2016). Moreover while comparing the wireworm numbers recorded from the different trap crops rows with control wheat rows we found significant lower number of wireworms in corn rows (P<0.05 in both years) than trap crop pea.

In both years, wireworm numbers in soil core samples were high until the fifth sampling date after which wireworm numbers declined. In 2015, we collected a total of 693 and 380 wireworms in Valier and Ledger respectively (Figure. 3 and 4). In 2016, we collected 301 wireworms in Valier among which 25 were *Aeolus mellillus*, 117 *Hypnoidus bicolor*, and 159 *Limonius californicus*. In Ledger, 262 numbers of wireworms were collected from soil sample among which 15 were *Aeolus millillus*, 125 *Hypnoidus bicolor* and 124 *Limonius californicus.*

Exp. #2a. Effect of trap crops and spacing on wheat plant density

At Valier, wheat plant counts showed significant differences between trap crops (df= 2, F= 158.8, P<0.01) and between different spacing levels (df= 3, F= 58, P<0.01). Significantly higher numbers of wheat plants per meter were recorded in plots intercropped with pea (P<0.01) and lentil (P<0.01) compared to control wheat plots (Figure. 5). At intercropping spacing of 0.25 and 0.5 m between the trap crops and spring wheat significantly more wheat plants were found than at 0.75 and 1m spacing's (Figure. 6). Moreover, a significant interaction was observed between trap crops and spacing levels (df= 6, F= 131.61, P<0.01) which is presented in Table 1.

At the Ledger field location, significant differences in wheat plant density was found among trap crops (df= 2, F=33.66, P<0.01) and spacing levels (df=3, F= 4.36, P<0.01). While pea and lentil treatments did not differ significantly from each other, wheat density in the plots intercropped with pea and lentil was significantly higher than that in the control (P<0.01) which is shown in Figure. 5. Wheat density was significantly higher at 0.75 m spacing than at 0.25 m (P<0.01), but wheat plant numbers were not significantly different among the 0.75, 0.5 and 1 m spacing levels (Figure. 6). Moreover, there was significant interaction between of spacing and trap crop (df=6, F=3.53, P<0.01) (Table 2).

Exp. #2b. Effect of trap crops species and spacing on wireworm density

At the Valier field location, the number of wireworm collected from wheat rows intercropped with different trap crops showed significant differences (df= 5, F= 5.87, P<0.01), but no differences were observed for the different spacing levels used and interaction between trap crops and spacing level was non significance. Wireworm numbers in wheat rows intercropped with pea (P=0.05) or lentil (P<0.01) were significantly lower than in rows of the control monoculture. From the soil samples, we collected 209 numbers of wireworms which were 11 *Aeolus millillus*, 70 *Hypnoidus bicolor* and 128 *Limonius californicus*.

At the Ledger field location, there were no significant differences among trap crops and spacing levels for the numbers of wireworm recorded from the soil samples in wheat rows intercropped with different trap crops at different spacing levels, P value more than 0.05 for both factors. There was no any significant interactions between trap crops and spacing levels. We found 178 numbers of wireworms from the soil samples among which 15 were *Aeolus millillus,* 73 *Hypnoidus bicolor* and 90 *Limonius californicus*.

Exp. #3. Effect of trap crops on feeding habits in shade-house potted plants

In a shade-house bioassay, wireworm distribution within pots found by sampling on the 4th day after seeding showed significant differences between wheat intercropped with pea, lentil or wheat as a control grown in pots. Pea ($P<0.01$) and lentil ($P<0.01$) seeded with wheat both trapped significantly more wireworm than the control. Similar results were obtained on the 10th day, with both pea ($P<0.01$) and lentil ($P<0.01$) trapping more wireworms than the control (Table. 3). We never found wireworms evenly distributed across all nine sections of the pot, confirming that wireworm are not randomly distributed in the soil.

Acknowledgements

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References

Etzler, F. E (2013) Identification of economic wireworms using traditional and molecular methods. M.S. thesis dissertation, Montana State University, Bozeman, Montana

Table 1. Interaction between intercropping spacing and trap crops in Valier, Montana in 2016

[y] ns = not significant, * and ** indicate significant interactions at P <0.05 and 0.01, respectively according to three way ANOVA, Tukey HSD.
[z] P = Pea, L = Lentil, and W = Wheat.

Treatments	0.25 P[z]	0.25L	0.25W	0.5 P	0.5 L	0.5W	0.75 P	0.75 L	0.75 W	1 P	1 L	1W
0.25 P	X	X	X	X	X	X	X	X	X	X	X	X
0.25 L	ns[y]	X	X	X	X	X	X	X	X	X	X	X
0.25 W	**	**	X	X	X	X	X	X	X	X	X	X
0.5 P	ns	ns	**	X	X	X	X	X	X	X	X	X
0.5 L	ns	ns	**	ns	X	X	X	X	X	X	X	X
0.5 W	**	**	ns	**	**	X	X	X	X	X	X	X
0.75 P	ns	ns	**	ns	ns	**	X	X	X	X	X	X
0.75 L	ns	ns	**	ns	ns	**	ns	X	X	X	X	X
0.75 W	**	**	**	**	**	**	**	**	X	X	X	X
1 P	**	**	ns	**	**	ns	**	**	**	X	X	X
1 L	**	**	ns	**	**	ns	**	**	**	ns	X	X
1 W	**	**	**	**	**	**	**	**	ns	**	**	X

Table 2. Interaction between intercropping spacing and trap crops in Ledger, Montana in 2016

Treatments	0.25 P[z]	0.25 L	0.25 W	0.5 P	0.5 L	0.5 W	0.75 P	0.75 L	0.75 W	1 P	1 L	1W
0.25 P	X	X	X	X	X	X	X	X	X	X	X	X
0.25 L	ns[y]	X	X	X	X	X	X	X	X	X	X	X
0.25 W	*	ns	X	X	X	X	X	X	X	X	X	X
0.5 P	ns	ns	**	X	X	X	X	X	X	X	X	X
0.5 L	ns	ns	**	ns	X	X	X	X	X	X	X	X
0.5 W	ns	ns	ns	**	**	X	X	X	X	X	X	X
0.75 P	ns	ns	**	ns	ns	*	X	X	X	X	X	X
0.75 L	**	**	**	*	*	**	**	X	X	X	X	X
0.75 W	ns	ns	ns	*	*	ns	ns	**	X	X	X	X
1 P	ns	ns	**	ns	ns	*	ns	**	ns	X	X	X
1 L	ns	ns	*	ns	ns	*	ns	**	ns	ns	X	X
1 W	ns	ns	ns	ns	ns	ns	ns	**	ns	ns	ns	X

[y] ns = not significant, * and ** indicate significant interactions at $P < 0.05$ and 0.01, respectively according to three way ANOVA, Tukey HSD.

[z] P = Pea, L = Lentil, and W = Wheat.

Table 3. Mean number of wireworms found in different regions of soil from plastic pots sown with wheat and trap crops in the bioassay. Chi-square values are at α 0.05.

	Pea			Lentil			Wheat		
Treatment	Pea	Wheat	Nothing	Lentil	Wheat	Nothing	Wheat(T)	Wheat	Nothing
4 DAS	3.75	3.25	2.00	4.00	2.75	2.25	3.00	2.50	3.25
P-value		0.0002			0.006			0.223	
10 DAS	3.75	2.00	2.75	4.00	2.25	2.25	2.75	2.75	3.25
P-value		0.008			0.006			0.24	

Figure. 1.

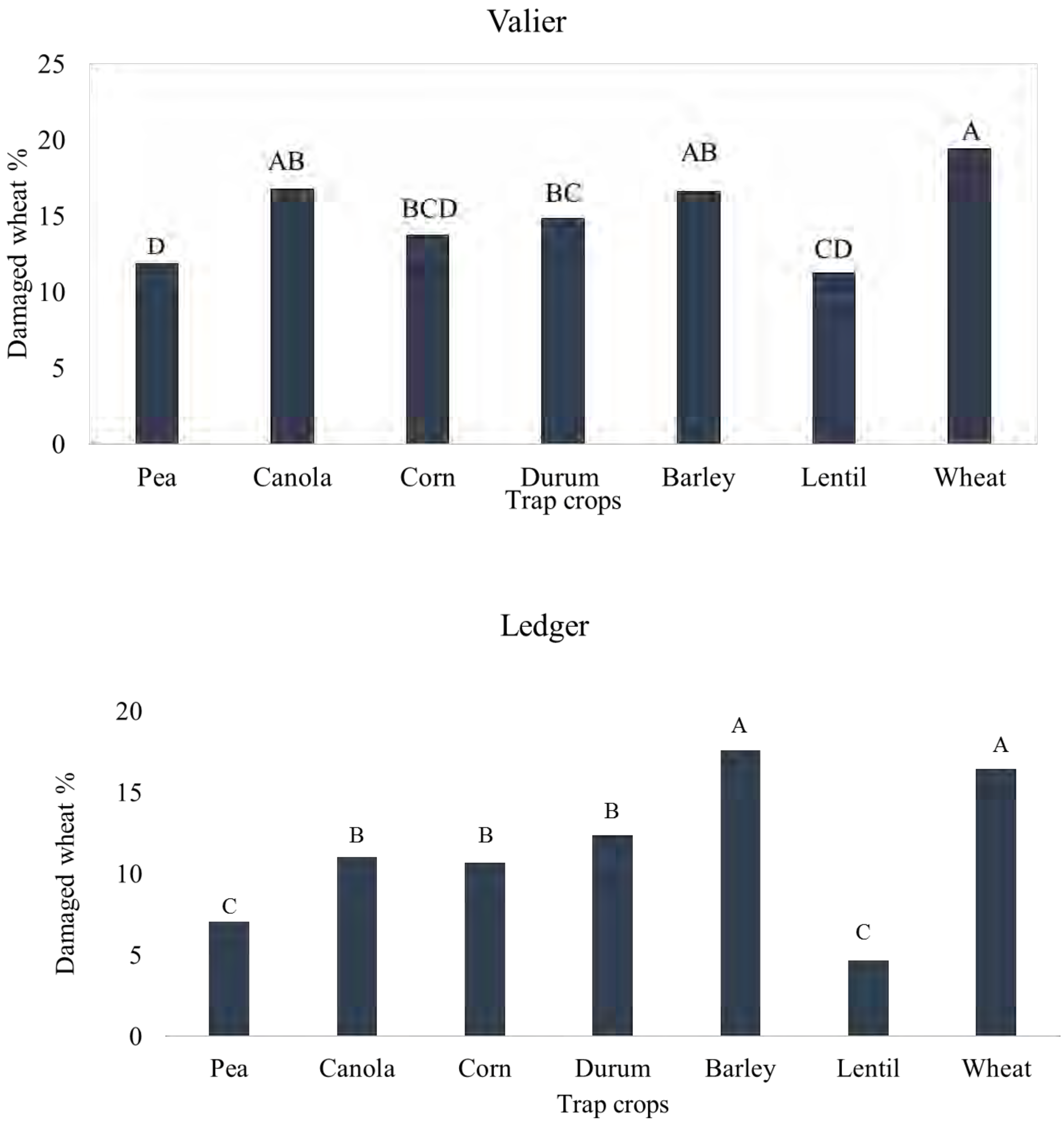
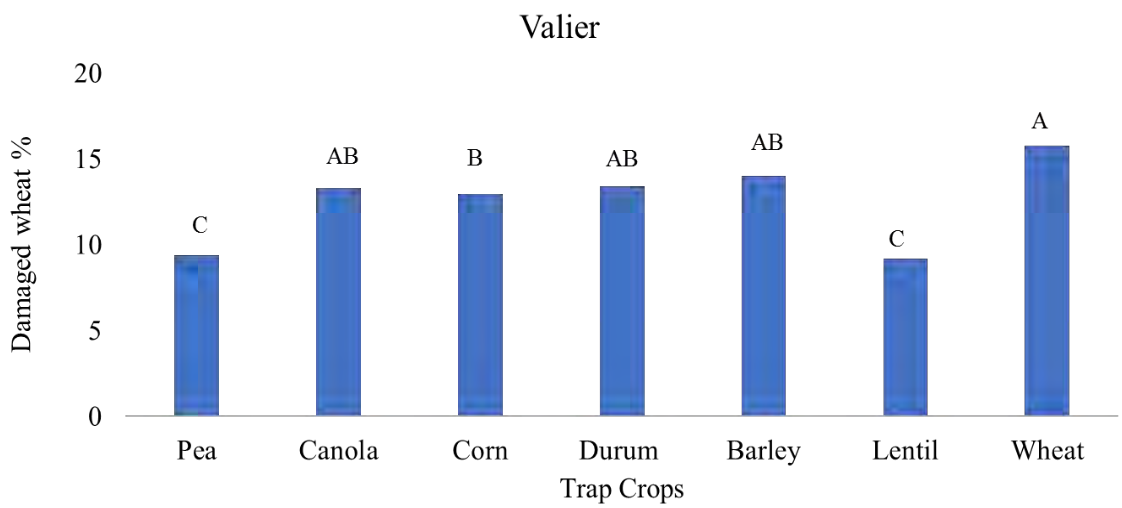


Fig. 1. Effect of trap crops on wheat plants damaged (%) by wireworms in Valier and Ledger locations in 2015. Different letters above bars indicated significant differences by two way ANOVA, Tukey HSD α=0.05.

Figure. 2.



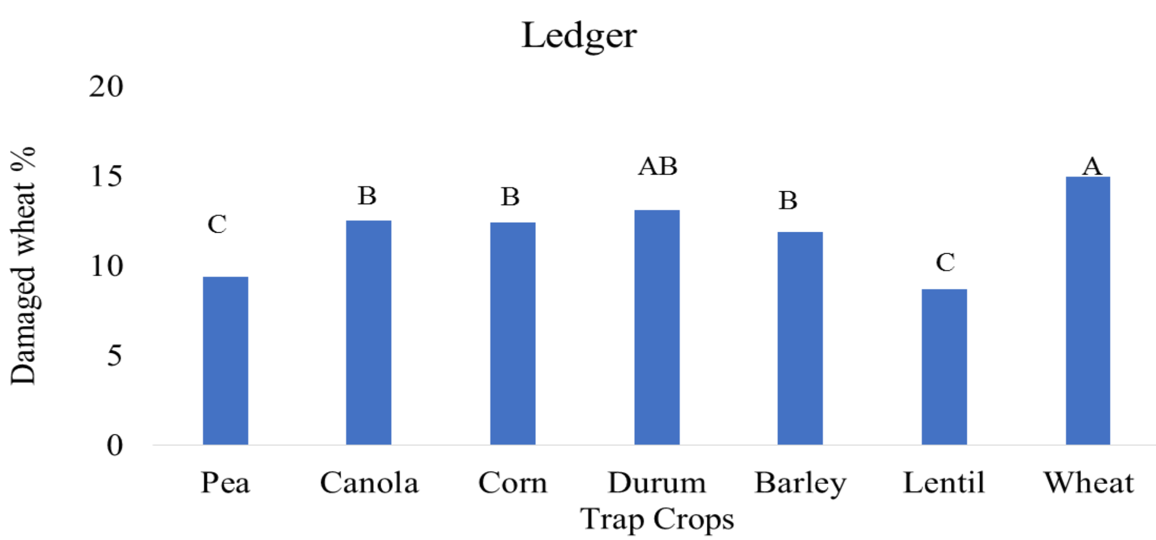


Fig. 2. Effect of trap crops on wheat plants damaged (%) by wireworms in Valier and Ledger locations in 2016. Different letters above bars indicated significant differences by two way ANOVA, Tukey HSD α=0.05.

Figure. 3.

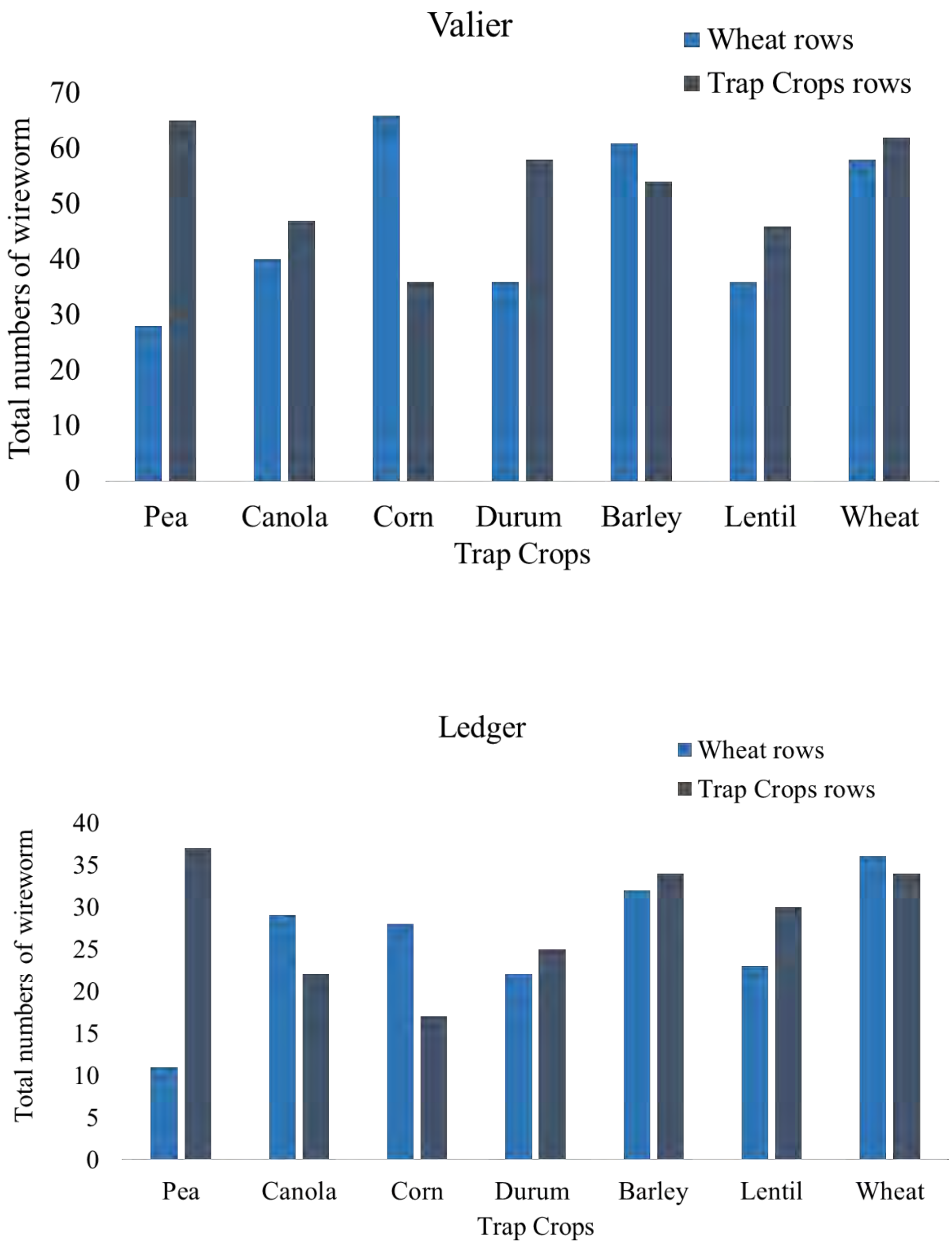
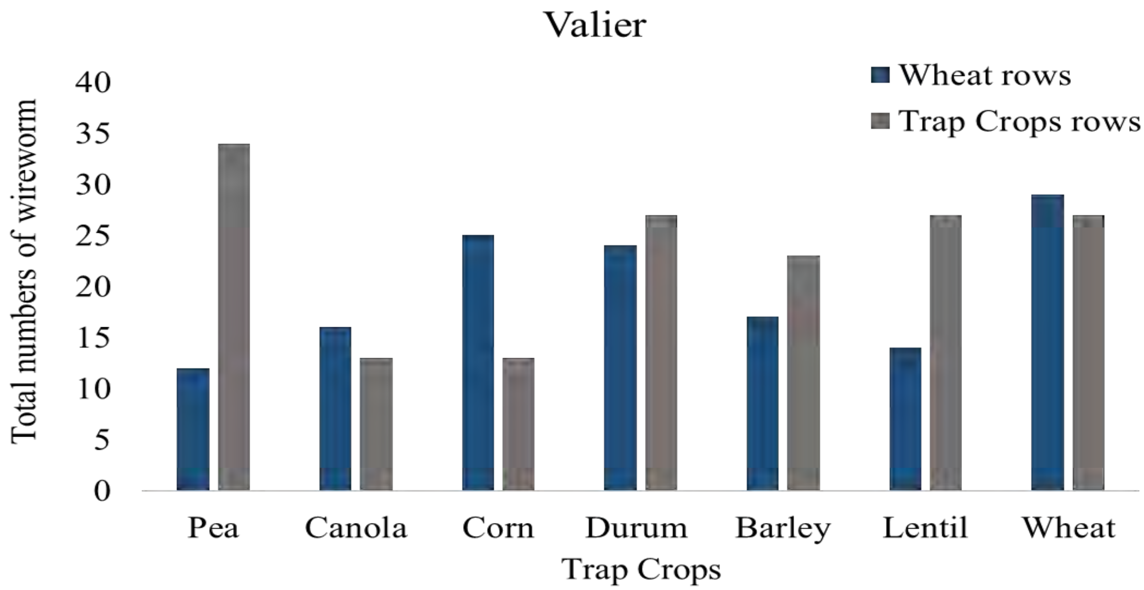


Fig. 3. Total number of wireworms collected from wheat rows and trap crops rows during soil sampling in Valier and Ledger locations in 2015.

Figure. 4.



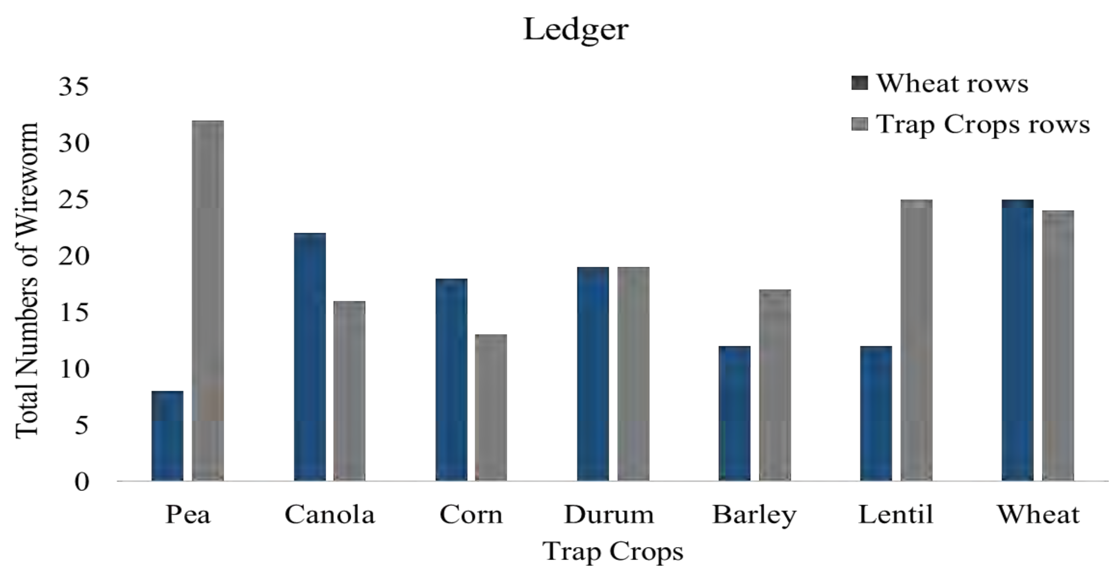


Fig. 4. Total number of wireworms collected from wheat rows and trap crops rows during soil sampling in Valier and Ledger locations in 2016.

Figure. 5.

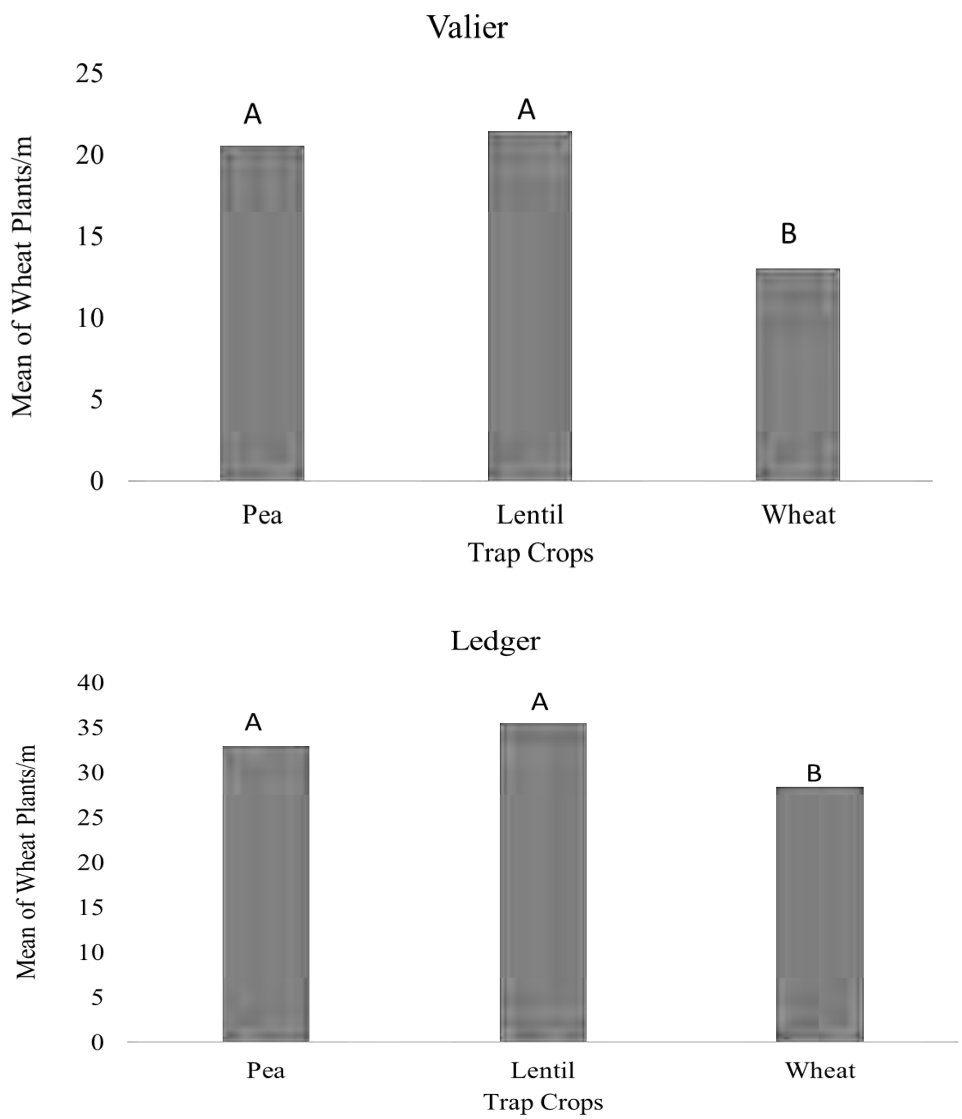
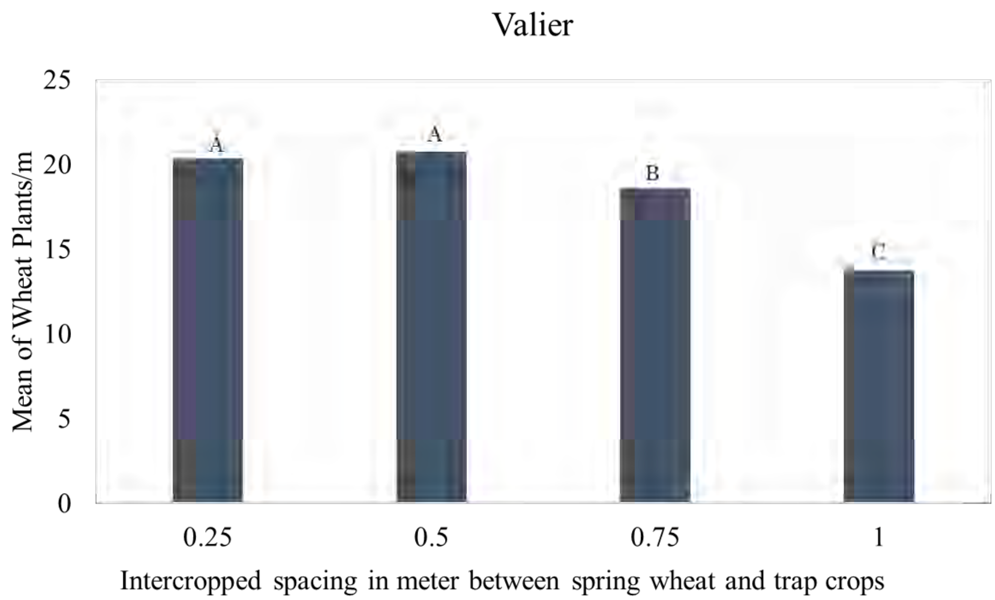


Fig. 5. Mean number of wheat plants/m when intercropped with different trap crops at spacing level of 0.25, 0.5, 0.75 and 1 m between wheat and different trap crops. Different letters over bars represent significant differences according to three way ANOVA, Tukey HSD $\alpha = 0.05$.

Figure. 6.



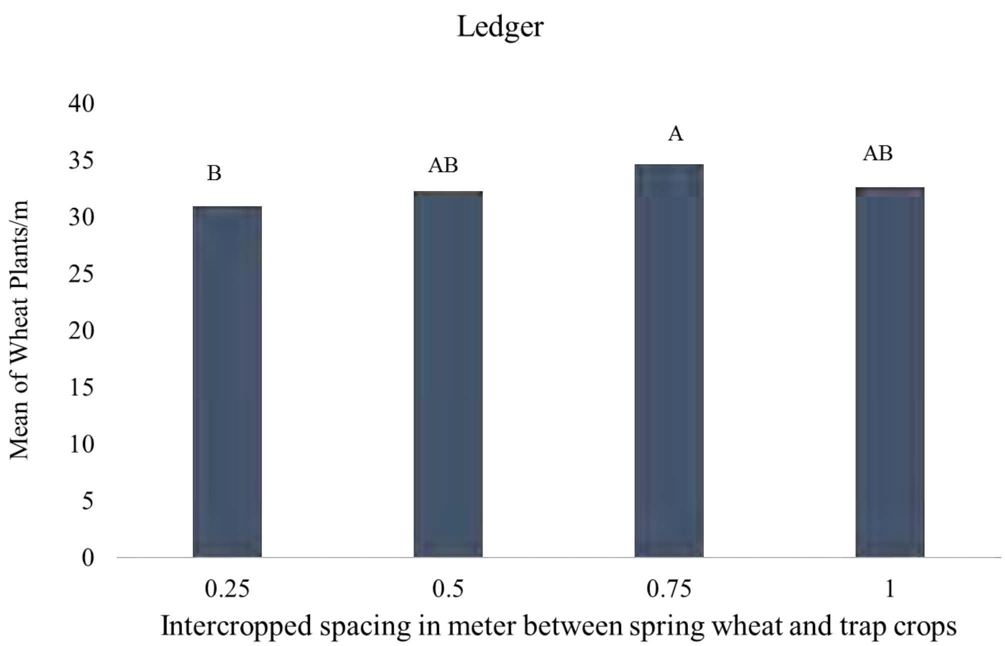


Fig. 6. Mean number of wheat plants/m, when spring wheat is intercropped with pea, lentil and wheat at spacing levels of 0.25, 0.5, 0.75 and 1 m. Different letters over bars represent significant differences according to three way ANOVA, Tukey HSD $\alpha = 0.05$.

Monitoring of Wheat Midge and the Associated Parasitoid *Macroglenes penetrans* in Spring Wheat Fields

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Aim of the Study

The aims of this study were: 1) to determine the wheat midge population in the Golden Triangle area of Montana and 2) to monitor the status of parasitoid *M. penetrans* in the Golden Triangle area of Montana

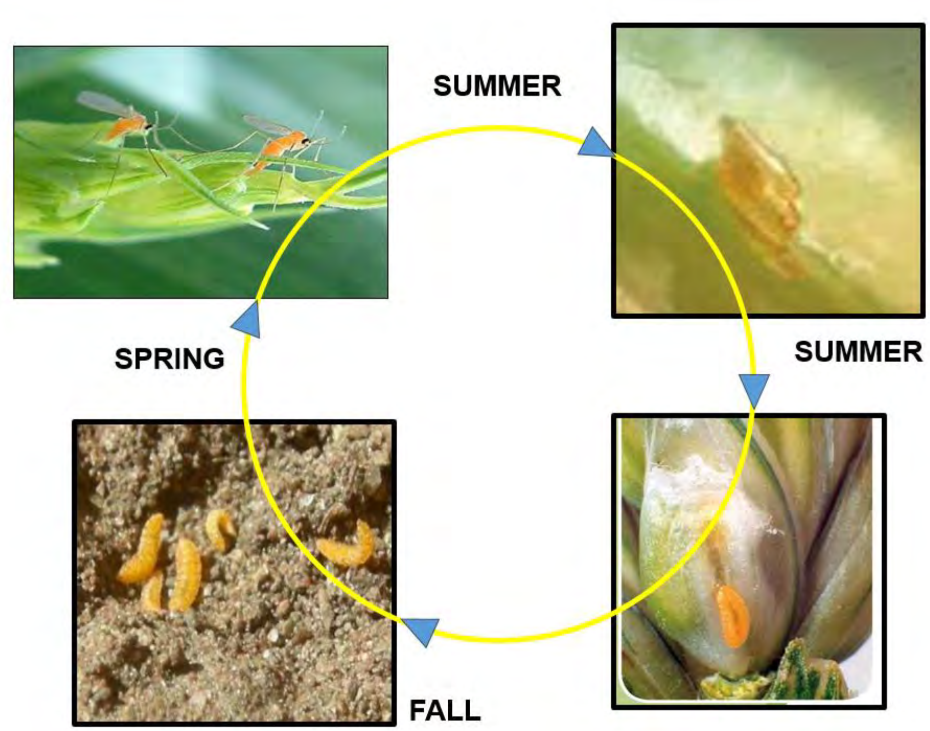

Fig. Life cycle of wheat midge

Materials and Methods

Wheat midge populations

WTARC installed 14 pheromone traps (Fig 1) in spring wheat fields at different locations such as in Valier, WTARC, Ledger, Cutbank, Devon, Choteau and Knees in the Golden Triangle area of Montana. Traps were set out from June 3-10, 2016. Pheromone traps were monitored every day from Monday to Friday in Valier, WTARC and Ledger areas, while at an average of 10 day intervals in Cutbank, Devon, Choteau and Knees areas. Trap monitoring work was wrapped up in the last week of July.

Figure1. A) Spring wheat growers (Cory Crawford and Tex Crawford) and a summer intern (Connie Miller) monitoring wheat midge adults on a pheromone trap at Valier and B) Wheat midge parasitoid *Macroglenes penetrans* adult

Parasitoid *Macroglenes penetrans*

Monitoring of *M. penetrans* adult (Fig 1) were performed in two steps: 1) determine the presence or absence of parasitoid adults in spring wheat fields where traps were established (only monitored at Valier, WTARC and Ledger areas) and, 2) monitor the *M. penetrans* adult activity at two locations throughout pest activity periods. Sweep net method was used to sample the parasitoids from each field (80 sweeps per sampling time) and the parasitoid adults were confirmed under a stereomicroscope. As a first step, parasitoid adults were monitored at 3-4 days intervals in all the traps established sites until its presence or absence was determined. First activity was initiated on June 20, 2016. As a second step, two spring wheat fields at Valier were selected to monitor the parasitoids activity throughout wheat midge activity periods. This is an area where almost all spring wheat growers spray insecticides to control wheat midge. This second activity began June 20 and completed on July 15, 2016.

Table 1. Total cumulative midge count observed in Valier, WTARC and Ledger areas of Montana

Field Sites	GPS Coordinates	Total Cumulative Midge Count/Trap
WTARC Dry 16	Lat:48.31044, Lng:-111.92539	306
WTARC- Irrigated 16	Lat:48.30388, Lng:-111.92513	407
Cory Crowford-Dryland	Lat:48.30206, Lng:-112.1435	2397

Jodi Hobel-Dryland	Lat:48.35183, Lng:-112.21256	820
Wayne Dean (1)	Lat:48.40994, Lng:-112.187	1391
Wayne Dean (2)	Lat:48.40925, Lng:-112.23311	190
Deb Meuli	Lat:48.26217, Lng:-111.63458	185
Ramsay Offerdahl-16	Lat:48.14403, Lng:-111.60119	133

Results

Wheat midge populations

Total cumulative midge count observed in our trap established locations were shown in Table 1. In 2016, wheat midge populations were checked in seven counties (Liberty, Toole, Teton, Chouteau, Glacier, Cascade and Pondera) at the Golden Triangle area of Montana. The total number of wheat midge pheromone traps installed in wheat fields were 58. Among the seven counties, the highest wheat midge populations were observed in Pondera County in contrast to no presence of wheat midge in Cascade County (Fig 1). The second highest wheat midge populations were noticed at Liberty County followed by Toole, Glacier, Teton and Chouteau Counties (Fig 1). In comparisons of this year data with previous years (2014 and 2015), wheat midge populations were further sharply increased in Pondera and Liberty Counties, remained steady in Teton, Glacier and Chouteau Counties and declined in Toole County (Fig 1).

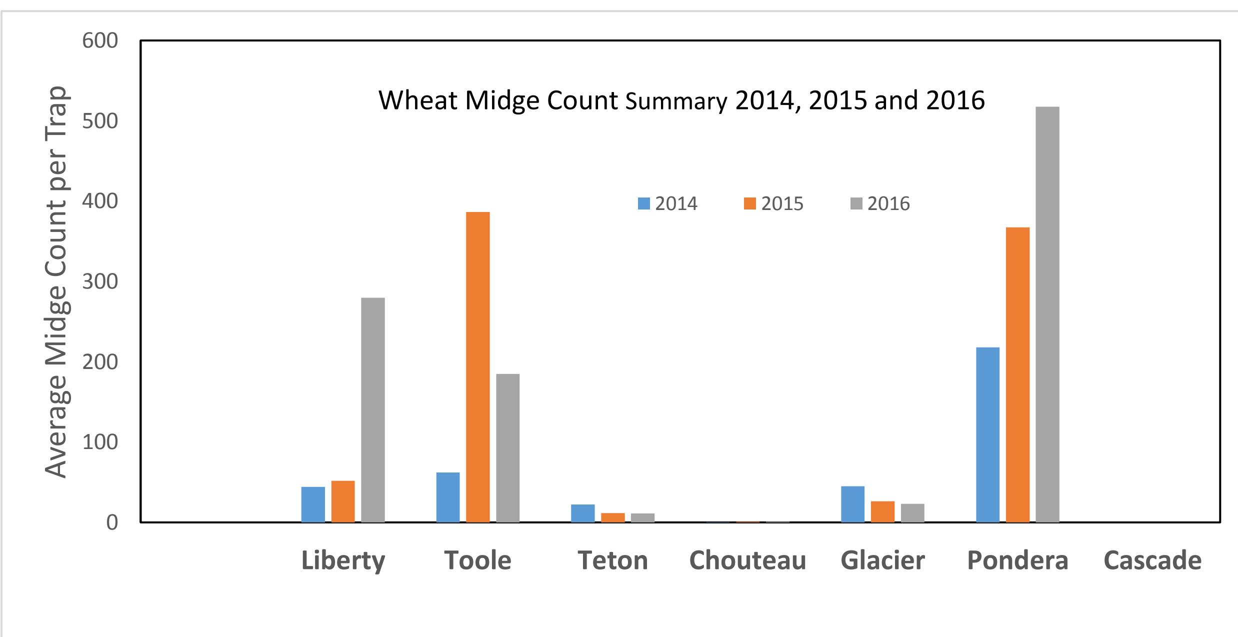

Fig1. Wheat midge population trends at the Golden Triangle area of Montana from 2014-2016

Parasitoid *Macroglenes penetrans*

Parasitoid adults were monitored in 8 field locations at the Golden Triangle area of Montana (see Table 2). Among the 8 locations, parasitoids were found in Valier (4 locations) and WTARC (2 locations) areas while no parasitoids were recorded in other two locations (Table 2).

Table 2.Monitoring of *Macroglenes penetrans* at field sites in Pondera County

Field sites	Parasitoid numbers observed (80 sweep/field) at different dates (Jun-Jul, 2016)								
	20-Jun	23-Jun	27-Jun	30-Jun	1-Jul	5-Jul	8-Jul	11-Jul	15-Jul
WTARC Dry 16	0	0	0	1	NA	NA	NA	NA	NA
WTARC- Irrigated 16	0	0	0	0	3	NA	NA	NA	NA
Cory Crowford-Dryland	0	0	2	NA	5	10	3	0	0
Jodi Hobel-Dryland	0	0	0	NA	1	9	4	0	0
Wayne Dean (1)	0	0	0	1	NA	NA	NA	NA	NA
Wayne Dean (2)	0	0	0	0	2	NA	NA	NA	NA
Deb Meuli	0	0	0	0	0	0	0	0	0
Ramsay Offerdahl-16	0	0	0	0	0	0	0	0	0

NA: Data not recorded

Acknowledgements

This work was supported by Montana Wheat and Barley Committee. We would like to thank Connie Miller for assistance with field work.

Introduction of two Biocontrol Agents *Euxestonotus error* and *Platygaster tuberosula* for the Management of Wheat Midge Population in Montana

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Aim of the Study

The aims of this study were: 1) to develop rearing methods for *Euxestonotus error* and *Platygaster tuberosula* under WTARC laboratory conditions and 2) to release the *E. error* and *P. tuberosula* at wheat midges infested fields in the Golden Triangle area of Montana

Material and Methods

The release process of parasitoids were illustrated in Fig 1.

Collection and storage of parasitoids

Prior to collection of parasitoids, a federal import permit (Permit#P526-141217-033) for *Euxestonotus error* and *Platygaster tuberosula* (Hymenoptera: Platygastridae) was issued on March 10, 2015 by USDA- Animal and Plant Health Inspection Service. In July 2015, approximately 20,000 wheat heads were collected from spring wheat fields of Langenburg, Saskatchewan (Canada) where *E. error* and *P. tuberosula* had been released in 1993 and 1994 and are now known to establish in this region. Immediately after the collections, parasitoids were transported to Western Triangle Agriculture Research Center, Montana State University, where the wheat heads were spread out in an even layer and left at room temperature (19–22°C) to dry for approximately 2 weeks in the laboratory. A small-sample de-awning machine was used to gently thresh dried heads. Midge larvae were separated from the seeds and the chaff with an air cleaner (Fig.1). Approximately 1500 larvae were harvested in this manner from 20,000 infested wheat heads. Harvested larvae were then placed in a soil-less mixture of vermiculite and sphagnum and stored at 2–4°C.

Fig 1. Whole release process of parasitoids

Literature review for rearing of parasitoids

Florent Affolter (1990) reported that emergence of *E. error* and *P. tuberosula* can occur within 4-5 weeks under laboratory conditions at 22ºC. Although it has not been clearly stated whether the incubation of parasitoids began from egg or larval stage, we speculated that the rearing of parasitoids had been done from the larval stages. This study further indicated that puparium can be formed after 18 days of incubation and the pupal stage could last for 12 ± 1.5 days (n=9) and 21 ±2 days (n=7) respectively for male and female. We are therefore motivated to use 22ºC as an incubation temperature for parasitoids and expected to see emergence in 4-5 weeks.

Regarding to the emergence of wheat midges, Thompson and Reddy (2016) reported that emergence of wheat midge adults may occur from June 16 to June 30 at the Golden Triangle area of Montana. The study further showed that 10% of wheat midge adults will be emerged by June 23 followed by 50% on June 26 and 90% on June 30. Although there might be a possibility of variation in emergence dates of wheat midge, the highest midge emergence could appear in last week of June.

Protocol development for morphological characteristic of *E. error* and *P. tuberosula*

The protocol to determine the morphological characteristic of *E. error* and *P. tuberosula* was developed with the great assistance of Peeter Neerup Buhl, a taxonomist working within the field of platygastridae. The criteria to identify the two parasitoid species are highlighted in Fig 2.

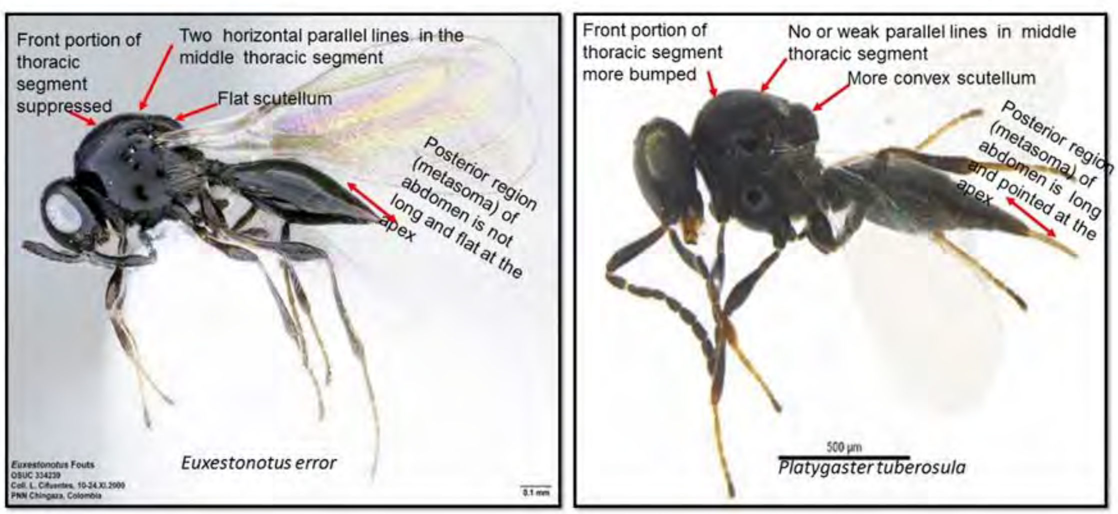

Fig 2. Morphological characteristic of parastioids

Taking out parasitoids larvae from the refrigerator

After a protocol was developed for rearing of parasitoids, the soil mixtures containing the parasitoid larvae were taken out of the insect refrigerator on June 3rd, 2016. The parasitoid larvae were placed in plastic round deli containers. However, the containers were first filled with garden soil and afterward the larvae were placed in the top layer of the soil. These containers were sprayed (hand sprayer) with distilled water (3-4 ml) to moisten the soil. When the parasitoids were expected to emerge (3 weeks after incubation), all these containers were taken out from the growth chamber and placed in insect cages where they were further sprayed with distilled water at 1-2 days intervals. In each insect cage, about 5-7 plastic containers were placed and the emergence of parasitoids were observed every day. After 1-2 days of parasitoid emergence in an insect cage, they were taken out with the help of an aspirator and kept in Petri dishes (1 parasitoid per Petri dish). These Petri dishes were then kept in a cooler growth chamber (10°C) for 2 hours and subsequently, the parasitoid species were identified under a stereomicroscope.

Selection of wheat midge infested fields for parasitoids release

Two highly infested wheat midge fields were selected during the third week of June, 2016 in Valier, Montana and it was based on midge trap count data. Immediately after the fields' selection, sweep netting activity (1-2 times before the parasitoids release) was performed to assess whether there were presence of *E. error* and *P. tuberosula* prior to their release at field sites. Selected field growers were further asked not to spray insecticide or inform us of their insecticide spray timing. As a result, we could better plan for release dates of the parasitoids.

Parasitoids release

The parasitoids species were identified under a stereomicroscope and released in wheat midge infested fields on different dates.

Results

Rearing of *Euxestonotus error* and *Platygaster tuberosula*

The parasitoids *E. error* and *P. tuberosula* were successfully reared under WTARC laboratory conditions. However, the number of parasitoids emerged was found extremely low as compared to the number parasitoids cultured (Fig 3) and, only 13 % of parasitoids adults were emerged from the cultured parasitoid larvae. It is suspected that many of parasitoids larvae could have died when they were stored at 2–4°C for 5-6 months.

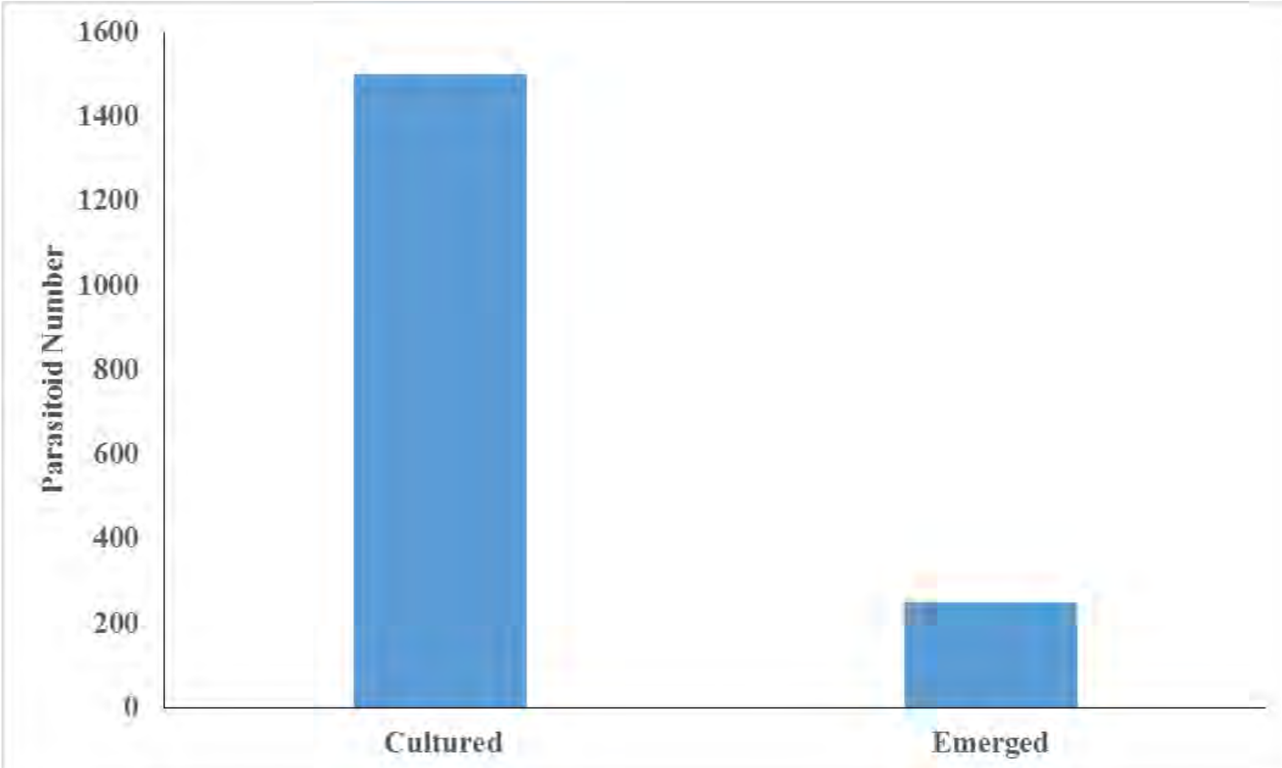

Fig 3. Parasitoids rearing history

Pre-release survey of *Euxestonotus error* and *Platygaster tuberosula*

This pre-release survey clearly depicted no presence of *E. error* and *P. tuberosula* at our selected field locations (Table 1) and it therefore allowed us to release these two parasitoids at our study sites.

Table 1. The information regarding to pre-releases of parasitoids

Pre-release Survey Dates	Grower Names	Location	Sweeps per Field	Status of Parasitoids
June 28, 2016	Cory Crawford	Valier MT	100	Not found
July 4, 2016	Jody Hobel	Valier MT	100	Not found
July 6, 2016	Jody Hobel	Valier MT	100	Not found

Release of *Euxestonotus error* and *Platygaster tuberosula*

Parasitoids *P. tuberosula* and *E. error* were released on several dates at two field locations from June 29 to July 14, 2016 since there was no consistency on emergence pattern of both parasitoids under our WTARC lab condition (Table 2). 136 parasitoids were released at Cory Crawford's field from June 29 to July 8 and 65 parasitoids were released at Jody Hobel's field from July 10-14

(Table 2). Altogether 211 parasitoids were released and 50 parasitoids escaped from the cages during the release process.

Table 2. The number of parasitoids released on different dates on two spring wheat fields

			Number of Parasitoids Released		
Release Dates	Grower name	Location	*Platygaster tuberosula*	*Euxestonotus error*	Person Involved in Releases
June 29, 2016	Cory Crawford	Valier MT	15	10	CM, CC, GS
July 1, 2016	Cory Crawford	Valier MT	20	25	CM & GS
July 5, 2016	Cory Crawford	Valier MT	25	16	CM & GS
July 8, 2016	Cory Crawford	Valier MT	11	14	CM & GS
July 10, 2016	Jody Hobel	Valier MT	15	10	CM & GS
July 12, 2016	Jody Hobel	Valier MT	11	15	CM & GS
July 14, 2016	Jody Hobel	Valier MT	10	4	CM & GS
Total			107	94	

(CM= Connie, Miller, CC= Cory Crawford and GS= Govinda Shrestha)

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We would like to thank Connie Miller for assistance with field work. This work was supported by Montana Wheat and Barley Committee. This material is also based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, Multistate Project W3185, The Working Group Biological Control of Pest Management Systems of Plants under Accession # 231844.

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Field Evaluation of Bio-pesticides Against Wheat Midge, *Sitodiplosis mosellana*

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Aim of the Study

The aim of this study was to examine the commercially available bio-pesticides against wheat midge management.

Materials and methods

Spring wheat fields

The experiments were conducted at three field locations: East Valier (N 48º 30.206 W112 º14.350), North Valier (N 48º 35.192 W112 º 21.169) and East Conrad (N 48º 14. 403 W111º 60.119), in the Golden Triangle area of Montana, United States, during summer of 2016. This area is situated in an important cereal growing region in Montana. Three field locations were selected based on the high level of infestations caused by *S. mosellana* in previous years (https://pestweb.montana.edu/Owbm/Home). A randomized complete block design with four replicates was used, with 8 × 4 m treatment plots separated from other plots by 1 m buffer zones to avoid any overlap of treatment effects. The trials were conducted in a spring wheat field with the cv. "Duclair".

Monitoring of wheat midge adults flights using a pheromone trap

To select the best date for application of bio-pesticide products, *S. mosellana* adults (male) flights were monitored using pheromone traps, as a method described by Gries et al. (2000). Wheat midge populations were monitored using delta traps baited with pheromone lures ((2S, 7S)-nonadiyl dibutyrate) (Great Lakes IPM, Inc., Vestaburg, MI), with sticky card inserts (Scentry®) at experimental fields. Delta traps were painted green to reduce non-target insect catch and positioned at the height of the wheat canopy (Thompson and Reddy, 2016). At each experimental field, a single trap was placed 20 m inside from the field edge, and the trap height was adjusted weekly to match the height of the wheat canopy. The trap was set on June 10 at each experimental location and monitored almost every day from Monday to Friday and continued until wheat plants crossed the susceptible stages.

Bio-pesticide products treatment application

Commercial formulations of five bio-pesticide products were used for the study. Mycotrol ESO® (*Beauveria bassiana* GHA) and Xpectro OD® (*Beauveria bassiana* GHA + pyrethrin) were obtained from Lam International (Butte, MT), entomopathogenic nematode *Steinernema feltiae* from Sierra Biological Inc. (Pioneer, CA), jasmonic acid from Sigma-Aldrich (St. Louis MO) and, PyGanic EC® 1.4 (pyrethrin) from McLaughlin Gormley King (Minneapolis, MN). The established concentrations of these products in the study were based on the product dose recommendation from company or the studies that have shown effective control against several insect pest species (Table 1).

Table 1. Materials and application rates of bio-pesticides used for the field studies against wheat midge *Sitodiplosis mosellana*.

Treatment	Chemical name	Dose	Amount of Product to Add/Gallon (3.785 L) water
T1	Untreated control (water)	-	-
T2	PyGanic EC® (Pyrethrins)	4.167 ml/L	15.7728 ml
T3	Mycotrol ESO® (*Beauveria bassiana* GHA)	2.50 ml/L	9.46 ml
T4	Xpectro® OD (*B. bassiana* GHA + Pyrethrins)	2.5 ml/L	9.4625 ml
T5	Barricade and *Steinernema feltiae*	Barricade 1 % w/v and x 300,000/m2 nematode	37.5 ml (g) + 17.098 g
T6	Jasmonic acid	1 mg/L	3.785 mg
T7	Lorsban (Positive Control)	4. 00 ml/L	12.385 ml

All bio-pesticide products were mixed with normal tap water, however: for jasmonic acid product, it was first dissolved in acetone and then mixed with water (Wakeil et al. 2010) and; for entomopathogenic nematode product, 1 % polymer gel was added further in mixture of entomopathogenic nematode and tap water (Antwi and Reddy 2016). Two controls were included in the study: 1) water served as a negative control and, 2) Lorsban worked as a positive control/reference chemical, since this chemical has been widely used by spring wheat growers in Montana to control wheat midges (Thompson and Reddy 2016; Stougaard et al. 2014).

All bio-pesticide product treatments including controls were applied on the same date at all field experimental trail locations. However, at East Conrad location, the wheat midge adults population was found extremely low based on pheromone trap data and the spring wheat plants were also found to cross wheat midges' susceptible stages. This field location was, therefore, decided to discard for bio-pesticide treatment applications. The treatments were sprayed using a SOLO backpack sprayer (SOLO, Newport News, VA), delivering the volume of 408 L mixture/ha. The plots were sprayed at 29th June, 2016, when the wheat plants were at midge susceptible stage (early boot) and the peak emergence of wheat midge adults was occurring. Furthermore, scouting was performed to determine wheat midge threshold level for treatment. The spraying activity was performed between 7- 9 pm as adult's activity seems to be high in the fields.

Wheat midge larvae in white traps

White traps were used to assess the wheat midge larval population in the treatment plots and the method was adapted from El-Wakeil et al. (2010). The traps, made of plastic dishes (diameter = 12.5 cm; height = 6.5 cm), were placed on the soil surface among wheat plants in each plot. Each trap was partly filled with tap water (100-150 ml) and 3-4 drops of soap detergent. Four days after treatment, two traps were placed in each treatment plot. Samples were collected from traps every week, immediately brought to lab and the presence of midge larvae in each sample was identified under a binocular or stereomicroscope.

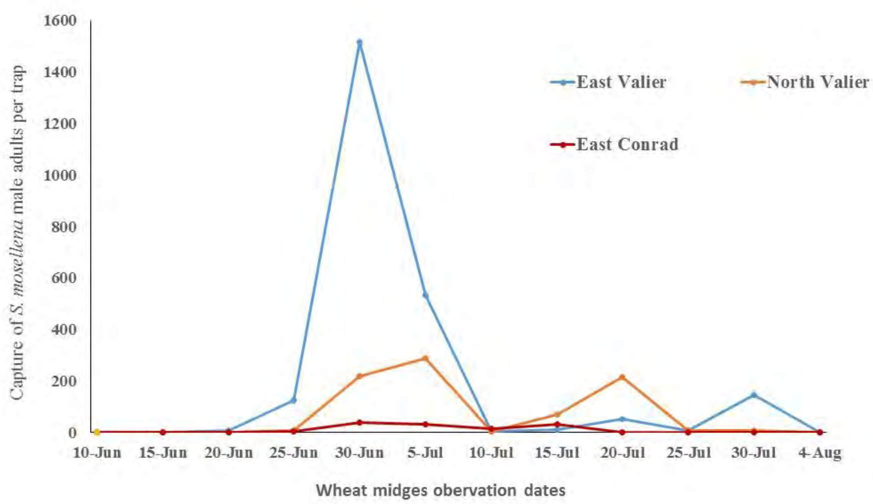

Figure 1. Wheat midge populations at three study locations

Midge-damaged wheat kernels

Wheat midge-damaged kernels in the biologically based or control treatment plots were assessed when the wheat kernels were about ready to harvest. Ten wheat ears were randomly sampled from each treatment plot, placed in a brown paper bag, transported immediately to the laboratory and dried at room temperature for 7 days. Wheat ears were subsequently threshed individually by hand to obtain the total number of wheat kernels and midge-damaged kernels per wheat ear. The midge-damaged kernels were characterized based on the criteria (such as shriveled, cracked or deformed kernels) reported by Kondel and Ganehiarchchi (2008) and Stougaard et al. (2014).

Parasitoid *Macroglenes penetrans* population

This study was performed to determine whether the bio-pesticides or Lorsban treatment had a significant impact on parasitoid populations as it has recently stated the presence of *M. penetrans* in the Golden Triangle area of Montana (Reddy and Thompson 2016). To obtain parasitoid population estimate, sweep net method was used. Sweeping was conducted with a standard sweep net, and 20 sweeps were made per treatment plot.

Yield and quality of wheat kernels

Hege 140 plot combine was used to thresh the wheat grains from treatment plots. The precautions were used to avoid the borders and any overlap of treatment effects on wheat yield and quality. Each plot was trimmed from edges, plot length was measured and the wheat grain threshing was done only from the center of each plot. Wheat grains were cleaned with a seed processor (Almaco, Nevada, IA) and weighed on a scale to determine yield and test weight. The protein and moisture content of seed was determined with NIR grain analyzer IM 9500 (Perten Instruments, Springfield, IL).

Statistical analysis

One-way analysis of variance (ANOVA) was performed to test the bio-pesticide treatments had significant abilities to protect kernels from wheat midge damages and, to improve yield and qualities (test weight, protein percentages and moisture percentages) of spring wheat in comparison with two controls; water and Lorsban treatment at each trial location. A normal quantile-quantile plot was performed to confirm normality of data and equality of the variance. No transformation of data was required to achieve normal distribution. Tukey's post hoc test was used for multiple comparisons among the treatment means. Similarly, for the sweep net data set, one way analysis of variance (ANOVA) was performed to examine the effect of treatments on total population of parasitoid *M. penetrans* adults at each trail location.

The water traps data was found to be non-normally distributed even after the log transformation, and the non-parametric one-way analysis of variance (Kruskal-Wallis test), was consequently used to examine effect of treatments on wheat midge larvae per sampling time across the treatments on each sampling date. A Mann-Whitney U-test was used as a post hoc test for multiple comparisons between the means followed by a Bonferroni correction.

Results

Wheat midge adult activities based on pheromone trap catch

In all three field sites, the flight activities of wheat midge adults began in about the same time, June 15-21 of the year 2016 (Fig 1). Within the two weeks, adult activity accelerated sharply at East Valier, gradually at North Valier and presented very low at East Conrad (Fig 1). The economic threshold levels of wheat midge adults' activity that warranted the application of control measures in relation to susceptible stages of spring wheat were only found at the East Valier and North Valier locations, while it was not observed in the East Conrad location (Fig 1). The cumulative number of adult midges observed in East Valier, North Valier and East Conrad were: 2397, 855 and 121 respectively.

Larval populations

Irrespective of treatments or trial locations, no wheat midge larvae were caught in water traps until the first three sampling dates with exception of few larvae (0.25-0.50) caught in Lorsban and entomopathogenic nematode treatments at the East Valier location but without significant differences (Table 2). However, at fourth and fifth sampling dates, wheat midge larvae were found in all treatment plots at both trial locations. The significant differences in midge larvae were recorded between treatment plots at fourth (χ^2 = 23.42; df =6; P < 0.001, Kruskal-Wallis test) and fifth sampling (χ^2 = 18.43; df =6; P < 0.01, Kruskal-Wallis test) dates in the East Valier location while only at fourth sampling (χ^2 = 22.82; df =6; P < 0.001, Kruskal-Wallis test) date in the North Valier location.

Table 2. Effect of bio-pesticides on wheat midge larval populations (two traps/plot)

Treatments	**Wheat midge larvae (Mean ± SE)**				
	Jul-7	**Jul-14**	**Jul-21**	**Jul-28**	**Aug-5**
North Valier					
Water control	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	5.50 ± 0.65a	1.25 ± 0.48a
Steinernema feltiae	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	1.00 ± 0.41b	0.75 ± 0.25a
Jasmonic acid	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.25 ± 0.48bc	0.75 ± 0.25a
Beauveria bassiana GHA	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	4.75 ± 0.63a	1.25 ± 0.48a
Beauveria bassiana GHA + pyrethrin	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	1.75 ± 0.25b	0.75 ± 0.25a
Pyrethrin	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	4.50 ± 0.29a	2.25 ± 0.48a
Lorsban control	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.50 ± 0.29bc	0.50 ± 0.50a
P value	*NS*	*NS*	*NS*	0.001	*NS*
East Valier					
Water control	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	8.25 ± 0.63a	4.25 ± 0.48a
Steinernema feltiae	0.00 ± 0.00	0.00 ± 0.00	0.50 ± 0.29	2.50 ± 0.28b	1.25 ± 0.62ab
Jasmonic acid	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	2.50 ± 0.29b	0.75 ± 0.25b
Beauveria bassiana GHA	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	7.50 ± 1.19a	2.50 ± 0.65ab
Beauveria bassiana GHA + pyrethrin	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	4.25 ± 0.48ab	2.25 ± 0.48ab
Pyrethrin	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	4.75 ± 0.65a	3.50 ± 0.29a
Lorsban control	0.00 ± 0.00	0.00 ± 0.00	0.25 ± 0.25	1.75 ± 0.62b	0.75 ± 0.48b
P value	*NS*	*NS*	*NS*	0.001	0.01

Mean values within columns bearing the same letter within each location are not significantly different (Mann Whitney-U test, P > 0.05).

Kernel damage

Regardless of treatments, higher kernels damage percentages inflicted by wheat midges was observed at East Valier as compared to North Valier (Fig 2) and this result was further supported by number of wheat midge adults caught on pheromone traps in study sites (Fig 1). Kernel damage percentages recorded in bio-pesticide treatment plots including the water and Lorsban varies from 20-48 % and 11-23 % at East Valier and North Valier respectively (Fig 2). However, bio-pesticide treatments had found significant impact on wheat midge kernel damage at both field sites: East Valier (df = 6, 258; F = 11.7; P < 0.001) and North Valier (df = 6, 267; F = 7.40; P < 0.001).

Among the biopesticide treatment plots, interestingly, the significantly lower kernel damage percentages were observed when wheat plots were treated with jasmonic acid, entomopathogenic nematode or Xpectro over water control plots at both field sites. In contrary, other two biopesticides treatments: pyrethrin and *Beauveria bassiana* had not protected the wheat kernels from wheat midge damages and the kernel damage levels were similar to water treated plots.

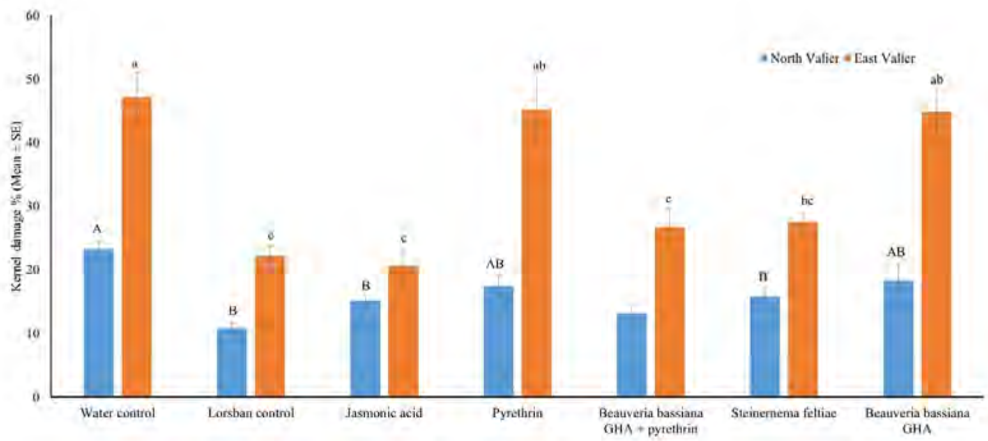

Fig 2. Wheat kernel damage percentages inflicted by wheat midges in bio-pesticide treatments. Bars bearing the same uppercase and lower case letters are not significantly different (Tukey test, $P > 0.05$).

Yield

To assess the impact of bio-pesticide treatments on wheat grain yield, the obtained yield data of each bio-pesticide treatment plot was compared with yields from the untreated (water control) and Lorsban treatments (positive control) plots. The result clearly depicted that bio-pesticide treatments had a significant impact on wheat grain yield at both field sites: East Valier (df = 6, 21; $F = 8.03$; $P < 0.001$) and North Valier (df = 6, 21; $F = 11.27$; $P < 0.001$). Grain yield at the East Valier site was significantly higher for treatments with the entomopathogenic nematode or jasmonic acid as compared to the treatment with water control (Fig 3). The yield of these two biopesticide treatments were also similar to treatment with Lorsban control, with no significant difference (Fig 3). In contrast, *B. bassiana* (Mycotrol) or *B. bassiana* in conjunction with pyrethrin (Xpectro) treatments had not improved the wheat grain yield as compared with yield obtained from Lorsban control treatment (Fig 3), while there was no significant difference in grain yield between the pyrethrin or Lorsban treatment groups (Fig 3). Similarly, at the North Valier site, significantly improved yield production was also observed with entomopathogenic nematode, jasmonic acid or *B. bassiana* in conjunction with pyrethrin treatments over the untreated control. In contrast, *B. bassiana* (Mycotrol) or pyrethrin treatments had not impact on wheat grain yield (Fig 3).

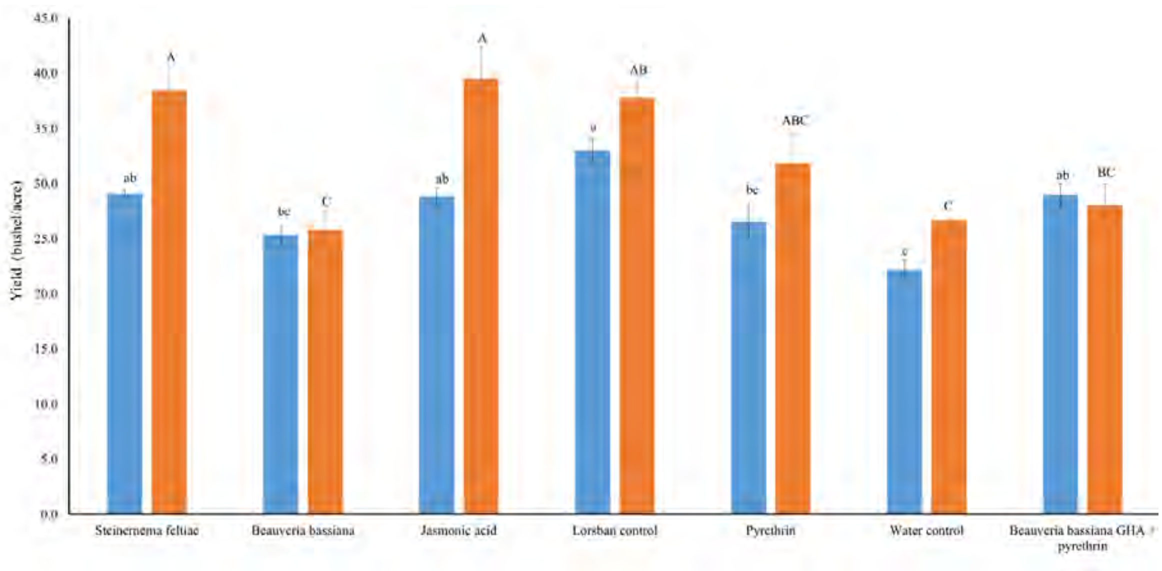

Fig 3. Yield of spring wheat treated with bio-pesticides. Bars bearing the same uppercase and lower case letters are not significantly different (Tukey test, P > 0.05).

Quality

Test weight, protein content % and moisture % were measured as a part of wheat kernel quality to determine whether the biopesticide treatments had an effect on these parameters compared with the untreated (water control) and Lorsban (positive control) treatments. Test weight across the treatments varies from 58 to 62 (lbs/bushel) and from 59 to 62 (lbs/bushel) at East Valier and North Valier respectively (Table 3). Treatments had a significant impact in test weight at East Valier (F = 8.96; df = 6, 21; P < 0.001) while no significant differences at North Valier (F = 2.26, df = 6, 21; P = >0.05). With respect to other quality parameters, treatments had not shown any impact on protein or moisture percentages at both field sites: East Valier (protein: F = 0.52; df = 6, 20; P = 0.79 and moisture: F = 0.95; df = 6, 20; P = 0.49) and North Valier (protein: F = 0.74; df = 6, 20; P = 0.62 and moisture: F = 0.60; df = 6, 20; P = 0.73). The overall average protein and moisture percentages were: 16-17 and 10-11 respectively, irrespective of treatments and field sites (Table 3).

Table 3. Quality of spring wheat treated with bio-pesticides

Treatments	**Quality parameters (Mean ± SE)**		
	Test weight (bushel/acre)	**Protein %**	**Moisture %**
North Valier			
Water control	59.06 ± 1.13a	16.72 ± 0.22a	10.25 ± 0.01a
Steinernema feltiae	61.98 ± 0.56a	17.09 ± 0.28a	10.32 ± 0.03a
Jasmonic acid	61.59 ± 0.46a	17.05 ± 0.26a	10.27 ± 0.04a
Beauveria bassiana GHA	60.49 ± 0.50a	17.09 ± 0.28a	10.26 ± 0.03a

Beauveria bassiana GHA + pyrethrin	61.35 ± 0.41a	16.72 ± 0.32a	10.25 ± 0.04a
Pyrethrin	61.20 ± 0.51a	16.90 ± 0.27a	10.30 ± 0.03a
Lorsban control	61.18 ± 0.35a	16.95 ± 0.16a	10.26 ± 0.03a
East Valier			
Water control	57.98 ± 0.31c	16.61 ± 0.13a	10.57 ± 0.02a
Steinernema feltiae	61.25 ± 0.51ab	16.36 ± 0.48a	10.61 ± 0.03a
Jasmonic acid	61.75 ± 0.17ab	16.52 ± 0.37a	10.53 ± 0.04a
Beauveria bassiana GHA	56.66 ± 1.03bc	16.75 ± 0.64a	10.49 ± 0.05a
Beauveria bassiana GHA + pyrethrin	58.28 ± 0.70 bc	17.23 ± 0.15a	10.51 ± 0.03a
Pyrethrin	59.00 ± 0.89 abc	17.10 ± 0.46a	10.50 ± 0.03a
Lorsban control	61.50± 0.67ab	17.45 ± 0.27a	10.50 ± 0.02a

Mean values within columns bearing the same letter within each location are not significantly different (Tukey test, P > 0.05).

Parasitoid population

Regardless of locations, bio-pesticide or Lorsban treatments had no significant impact on examine on total population of parasitoid *M. penetrans* adults (P > 0.05). The total mean number of parasitoid adults per treatment plot recorded at two locations; North Valier and East Valier ranged from 1.25 – 3.00 and 1.00 – 4.00 respectively.

Acknowledgements

This work was supported by Montana Wheat and Barley Committee. This material is also based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, Multistate Project W3185, # The Working Group Biological Control of Pest Management Systems of Plants under Accession # 231844. We would like to thank cooperator growers (Cory Crowford and Jody Hobel) for allowing their fields for the study.

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Development of Pheromone based Monitoring and Mass Trapping for Pea Leaf Weevil in Pulse Crops

Principle Investigator: Gadi V.P. Reddy
Project Personnel: Debra Miller, Kendall Franks and Govinda Shrestha

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Aim of the Study

The aims of this study was to develop pheromone baited traps which will help in monitoring and mass trapping the pea leaf weevil population in the Golden Triangle areas of Montana.

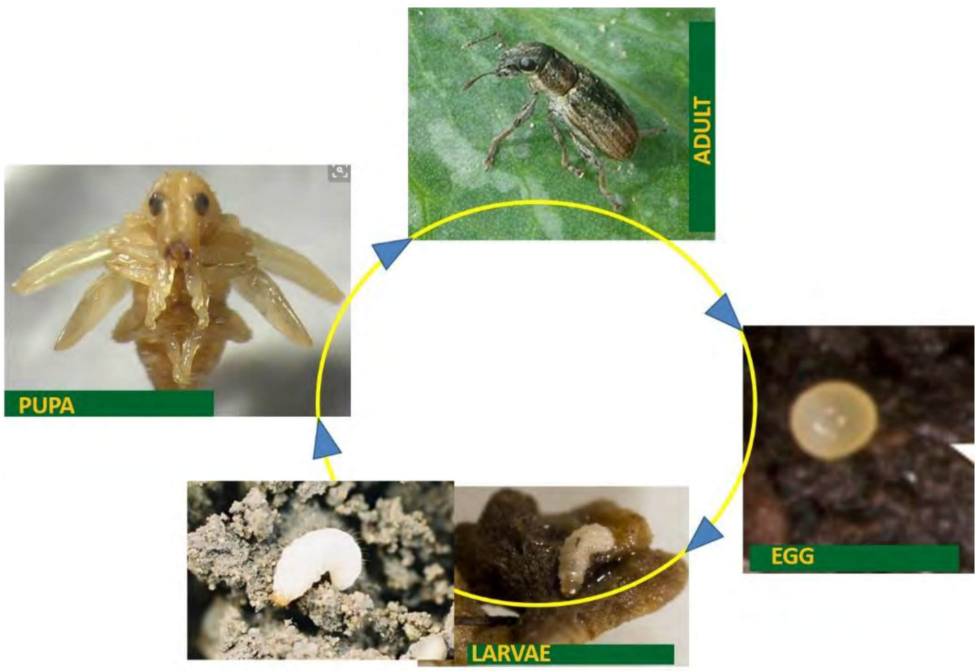

Fig. Pea leaf weevil life cycle

Materials Methods

Experiments were carried out at four locations: Conrad, Valier, Ledger and Chester in the Golden Triangle areas of Montana. Trap design were shown in figure-1. The rubber septa with pheromone lures were used. Traps without pheromone lures were used as controls. Tests were replicated three times at each site to yield 12 replications. Pheromone lures were loaded with 4-methyl-3, 5-heptanedione as described in Blight et al. (1984). These lures were obtained from Chem Tica Internacional S.A. (San José, Costa Rica).

Effect of trap design

In the first experiment, four different types of traps (pitfall, delta, ground and ramp traps) were placed at borders in the field. Overall, 96 traps were used (4 trap designs, each with and without lures × 3 replications × 4 sites). Each week, the trapped adult weevils were removed, counted and their numbers recorded. We interchanged trap positions weekly at each location to avoid positional effects on trap catch. The study was conducted from May-August 2016.

Effect of pheromone lure

In the second experiment, the effectiveness of pheromone lures with rubber septa or bubble septa were evaluate on the trap catches of pea leaf weevil adults. Trap without lures served as controls. At each site, three traps of each lure type were set up and their positions rotated weekly. Tests were replicated three times at each site to yield 9 replications. The overall study consisted 36 traps (2 lure type, trap without lures×3 replications×4 sites). The experiment was conducted from May–August 2016.

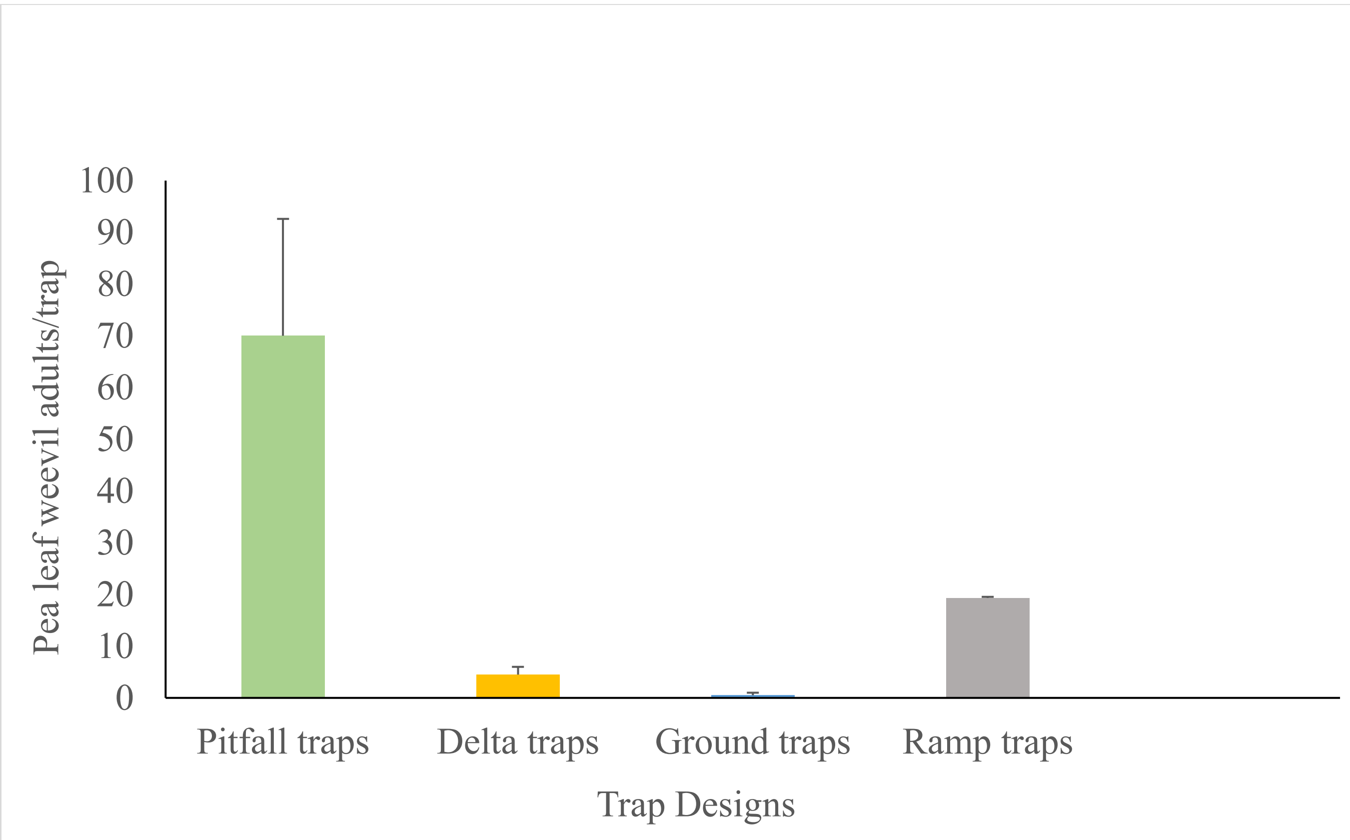

Figure 2. Mean (±SE) number of pea leaf weevils caught by different trap designs

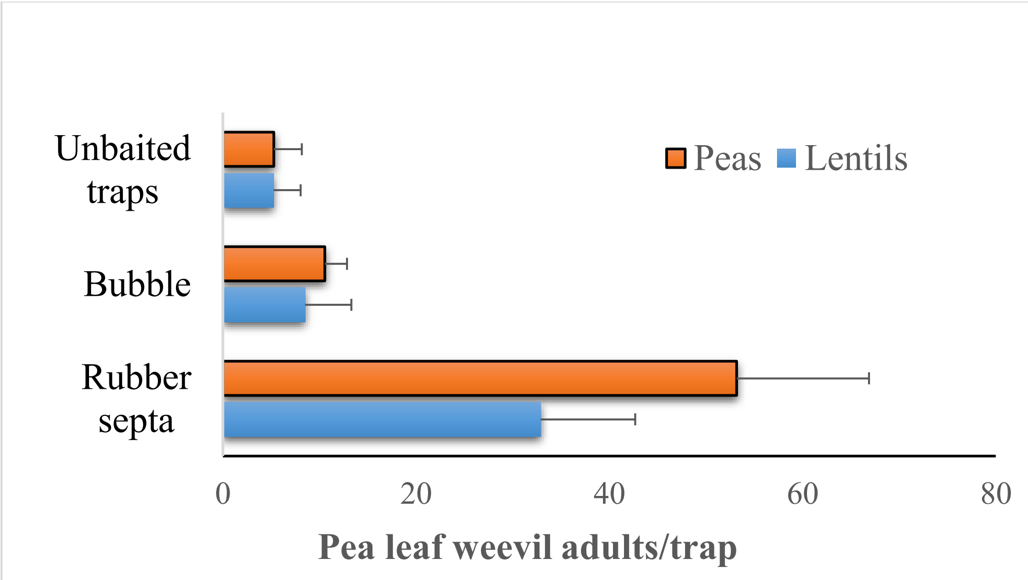

Figure 3. Mean (±SE) number of pea leaf weevils caught in pitfall traps baited with different lures.

Results

Effect of trap design

Among the trap tested, pitfall traps caught higher number of weevils than other traps tested. This was followed by ramp, delta and ground traps.

Effect of lure type

The pitfall traps baited with pheromone impregnated rubber septa caught higher number of catches than the bubble septa and trap without pheromone septa.

Conclusions

The results indicated that the trap and lure type affect the response of pea leaf weevil to pheromone-baited traps. In particular, the pitfall traps with rubber septa lures gave the highest catches of pea leaf weevil. These results are useful and should be taken into consideration when monitoring and management strategies are developed.

Acknowledgements

This work was funded by the Montana Specialty Crop Block Grant Award#15SCBGPMT0005. Kendall stipend was funded by MAES summer Interns Program and WTARC Entomology/Insect Ecology at WTARC, Conrad.

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Laboratory Evaluation of Bio-pesticides against Pea Leaf Weevil *Sitona lineatus* (L.) (Coleoptera: Curculionidae) Adults

Principle Investigator: Gadi V.P. Reddy

Project Personnel: Govinda Shrestha and Debra Miller

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Aim of the Study

The aim of the study was to evaluate commercially available bio-pesticides (such as Spinosad (*Saccharopolyspora spinosa*), PyGanic EC® (Pyrethrins), Mycotrol ESO® (*Beauveria bassiana* GHA), Xpulse® OD (*B. bassiana* GHA + Cold pressed Neem extract) and Xpectro® OD *B. bassiana* GHA + Pyrethrin) against pea leaf weevil adults *Sitona lineatus*, which consequently help on reducing of synthetic insecticides toward this pest.

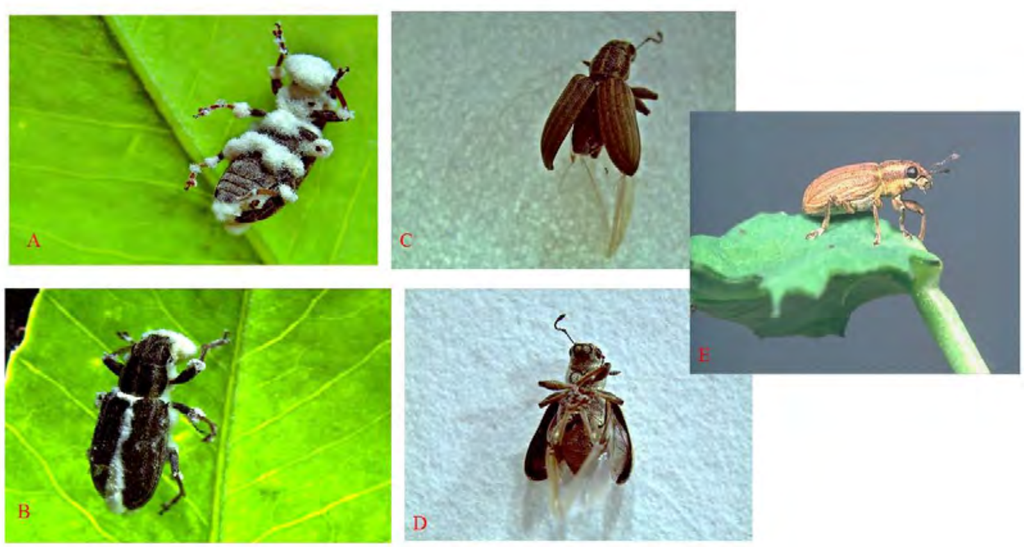

Figure 1. Pea leaf weevil adult killed by *Beauveria bassiana* GHA or *B. bassiana* GHA with Pyrethrins- dorsal (A) and frontal (B) views; pea leaf weevil adult killed by Spinosad (*Saccharopolyspora spinosa*)- frontal(C) and dorsal (D) views; uninfected/live pea leaf weevil adult (E).

Material and Methods

Insects

Sitona lineatus adults were collected during spring and fall of 2016 from various host plants (e.g. peas, lentils and alfalfa) at several locations in the Golden Triangle area of Montana. During the spring season, pheromone traps baited with lures 4-methyl-3, 5-heptanedione (ChemTica Internacional, Costa Rica) were installed on the soil surface in pea and lentil fields to catch *S.*

lineatus adults. This pheromone has been known to attract both male and female of this pest (Nielsen and Jensen 1993). Adults caught in pheromone traps were collected once a week, placed in plastic deli cups (diameter = 12 cm and height = 8 cm) and transported immediately to the laboratory. Approximately 50 *S. lineatus* adults were placed inside a deli cup, reared with alfalfa foliage (5-6 stems) and maintained in a climate cabinet at 12 ^{o}C for 2-3 days, until enough adults were obtained to initiate bioassay experiments. In the fall season, *S. lineatus* adults were collected from alfalfa fields using sweep nets as the adults were found highly aggregated in alfalfa fields (Shrestha, Personal Observation). These collected adults were kept in plastic ziploc® bags with alfalfa foliage and transported immediately to laboratory. *S. lineatus* adults were reared under a laboratory condition in a similar method described above for spring season collected adults.

Table 1 Materials and application rates of bio-pesticides used for the laboratory bioassays against *Sitona lineatus* adults.

Treatment	Chemical name	Trade name	Concentrations (ml/L)
T1	Untreated control (water)	-	-
T2	Spinosad (*Saccharopolyspora spinosa*)	Entrust® WP	0.00091, 0.0091, 0.0455, 0.091, and 0.182
T3	*Beauveria bassiana* GHA	Mycotrol ESO®	0.072, 0.36, 0.72, and 1.44
T4	*B. bassiana* GHA + Pyrethrin	Xpectro® OD	0.25, 1.25, 2.5, and 5.0
T5	*B. bassiana* GHA + Cold pressed Neem extract	Xpulse® OD	0.072, 0.36, 0.72 and 1.44
T6	Pyrethrins	PyGanic EC®	0.072, 0.72, 1.44 and 2.88

Bio-pesticide products

Five bio-pesticide products of commercial formulations were used for the study (Table 1). Mycotrol ESO® (*Beauveria bassiana* GHA), Xpectro OD® (*Beauveria bassiana* GHA + pyrethrins) and Xpulse OD® (*Beauveria bassiana* GHA + azadirachtin) were obtained from Lam International (Butte, MT), Entrust WP® (spinosad 80%) from Dow Agro Sciences (Indianapolis, IN) and, PyGanic EC® 1.4 (pyrethrin) from McLaughlin Gormley King (Minneapolis, MN). Stock solutions were prepared for each product prior each experiment by dissolving the product materials in tap water and lower concentrations were prepared by serial dilutions with tap water. The concentrations tested were 0.1, 0.5, 1.0 and 2.0 fold lowest label rate (Table 1).

Laboratory bioassay

Prior to performing experiments, the bioassay methods such as immersion and spray (bottle and perfume sprayer) were preliminarily assessed to select the most appropriate one for testing the efficacy of bio-pesticide products against *S. lineatus* adults. Among these bioassay methods, the perfume sprayer was selected for experiments as other methods resulted higher mortalities of *S. lineatus* adults (~ 80%) both in treatments and control groups after 48 h.

Similar sized of pea leaf weevil adults (length = 5-5.5 mm) were placed in groups of 7 adult individuals in a Petri dish lined with a filter paper (diameter = 9 cm). Placement of the weevils was accomplished with the help of a fine camel paint brush. The Petri dishes were then maintained in a cold climate cabinet (5 ºC) for 1 h to reduce the adults' activity. The adult individuals of each group were then placed in the center of Petri dish. They were then topically treated with 1 ml of bio-pesticide product materials. Controls were treated with 1.0 ml of tap water. After the spray applications, a fresh alfalfa stem about 5 cm long with 9-12 leaves, was placed close to the treated adult individuals inside a Petri dish as a source of feeding materials. Feeding materials were replaced within 2-3 day intervals. Dishes were incubated in a climate cabinet at 22 ºC ± 1 ºC, 16:8 L: D and 75% RH. The bioassay experiment was performed in two seasons- spring and fall. The numbers of replicates (one replicate equals one Petri dish) per treatment were 8 and 5, respectively, in the spring and fall experimental run. However, in the fall season, only bio-pesticide products that were effective in spring experimental run were tested.

Starting one day after the treatment, pea leaf weevil adults' mortality was checked daily for 9 days. *S. lineatus* adults have a specific characteristic since they act like dead weevils with minimum disturbance (Shrestha, Personal Observation) and are known as "dead play" insects (Jackson and Macdougall 1920). By gentle prodding with a camel paint brush the individual adult mortality was determined. Any adults that lacked any movement were considered to be dead. Dead weevils, particularly from insect pathogenic fungi or mixture with other product, were removed and placed on moist filter paper in a Petri dish to check for sporulation.

Statistical analysis

The statistical analysis part of this study (such as calculations of LC_{50} and LT_{50}) is underway. The raw results (Mean ± Standard Error) of this study were only presented for the interim.

Results

Mortality of spring population of pea leaf weevil adults

Five bio-pesticide products were evaluated against adults of pea leaf weevil. Overall, this study showed that all tested bio-pesticide products have abilities to cause mortalities on pea leaf weevil adults (Table 2). However, the difference in pea leaf weevil adult mortalities were observed across products or at their concentration levels. Among the five tested products, Spinosad (Entrust WP®) seems to be most effective product (Fig 1), Mycotrol ESO® and Xpectro OD® as moderately effective (Fig 1) and the Xpulse OD® and PyGanic EC® as less effective products. The total mean mortality of pea leaf weevil adults caused by bio-pesticide products ranged from 16 to 100% for Spinosad product, 9 to 64% for Mycotrol ESO® product, 9 to 63% for Xpectro OD®, 7 to 36% for Xpulse OD® and 5 to 21% for Pyganic EC® (Table 2).

Table 2. Total mean percentage mortality of spring population of pea leaf weevil adults treated with different concentrations of bio-pesticides. Mean percentage of mortality (± SE) 9 days post inoculation.

Treatments	Concentrations					
	2 X	1 X	0.5 X	0.1 X	0.01 X	0.00
Entrust WP®	100 ± 0.00	100 ± 0.00	64.29 ± 4.68	39.29± 0.57	16.07 ± 4.21	
Xpectro OD®	62.50 ± 5.10	33.93 ± 6.03	23.21± 3.76	8.93 ± 2.61		
Mycotrol ESO®	64.29 ± 4.23	41.07± 5.68	14.29± 3.82	8.93± 2.61		
Xpulse OD®	35.71 ± 5.40	25.00 ± 3.57	10.71± 3.57	7.143± 2.70		
PyGanic EC®	21.43 ± 3.82	14.29 ± 3.82	7.143 ± 3.82	5.357 ± 2.61		
Untreated (water)						4. 76 ± 2.61

Mortality of fall population of pea leaf weevil adults

Three bio-pesticide products were only evaluated against fall population of pea leaf weevil adults since Spinosad (Entrust WP®), Mycotrol ESO® and Xpectro OD® were found effective against spring population of pea leaf weevil adults. The similar results were also found for fall population of pea leaf weevil adults (Table 3) but with slightly lower mortalities (from 8-10%) for Mycotrol ESO® and Xpectro OD® bio-pesticide treatments.

Table 3. Total mean percentage mortality of fall population of pea leaf weevil adults treated with different concentrations of bio-pesticides. Mean percentage of mortality (± SE) 9 days post inoculation.

Treatments	Concentrations					
	2 X	1 X	0.5 X	0.1 X	0.01 X	0.00
Entrust WP®	100 ± 0.00	100 ± 0.00	62.85 ± 4.52	42.86± 3.57	22.85 ± 2.77	
Xpectro OD®	57.14 ± 4.51	25.71 ± 5.34	11.42± 5.34	5.71 ± 3.50		
Mycotrol ESO®	51.43 ± 5.71	28.57± 4.52	20.00± 3.49	14.29± 4.51		
Untreated (Water)						2.85 ± 2.85

Acknowledgements

We would like to thank Connie Miller for assistance with field work. This material is based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, Multistate Project S-1052, and the Working Group on Improving Microbial Control of Arthropod Pests Covering Research in Montana under Accession # 232056.

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New pest in Montana-Pea weevil: Determining Weevil Population Distribution, Abundance, and Pea Damage Assessments

Principle Investigator: Dr. Gadi V.P. Reddy

Project personnel: Ramadevi L. Gadi, Govinda Shrestha

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Aim of the Study

The aim of this study is to survey for determining the pea weevil, *Bruchus pisorum* (Coleoptera: Chrysomelidae) population distribution, abundance and pea damage assessment for Montana.

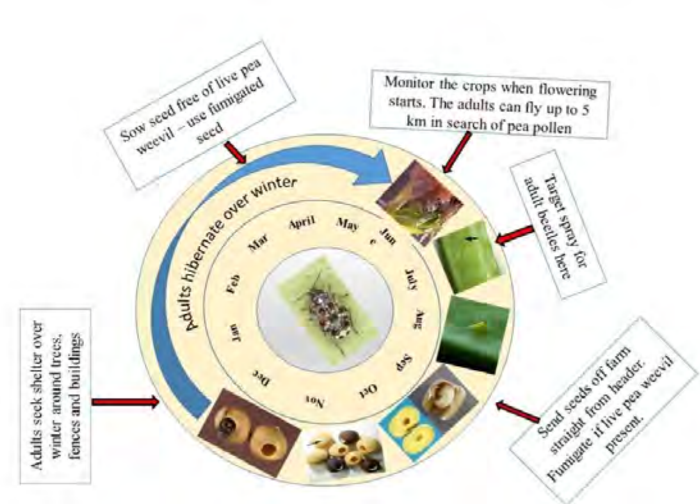

Fig. Pea weevil life cycle and their management strategy

Materials and Methods (Proposed)

Survey of pea weevil

Twenty pea field sites and six grain elevators (Chinook/Harlem, Choteau, Conrad South, Tiber/Rudyard, Fort Benton and Havre) will be selected in Hi-Line and North Central areas of Montana for the survey of pea weevil. A sample of 2,000 seeds from the plots and elevators will be collected every two weeks from May 2017 to May 2018. Also, 100 sweep nets in each field will be carried out before to the blooming stage during spring. The samples will be analyzed in the laboratory for damage and different life stages of the pea weevil.

Assessment of damage distribution and abundance

The number of peas with exit holes and immature stages (egg, larvae, pupae and adult) will be counted from the samples from different locations in the laboratory. Damage levels will be assessed based on the scoring system. 0=no damage; 1= slight damage (less than 5%); 2= moderate damage (5-20%); 3= heavy damage (more than 20%).

Relationship between damage and weevil numbers

The intention is to identify a relationship (correlation) between damage levels and weevil numbers. Pearson's correlation analysis - determine, whether or not, there is a significant correlation between damage levels and weevil number for both sampling periods, and in all damage categories. Data will also include damage levels on different pea varieties, grown at different locations.

Mass rearing of pea weevil in the laboratory

The immature stages of the pea weevil will be collected from the field and grain bins. Mass reared in the laboratory to help in conducting further studies.

Results

Currently, there is no any results for this study, except a newsletter published in *Trader dispatch* (see below). The full article will be found on this following link- http://agresearch.montana.edu/wtarc/fielddays-pdf/2016TradersDispatch5.pdf

Trader's Dispatch

Watch out for a new pest in Montana - pea weevil

A new pea pest in Montana, pea weevil, has been confirmed by researchers at WTARC in Conrad from samples submitted from the Highline area. Damage was first noticed in 2014 and follow-up samples were sent to the lab at the Western Triangle Agricultural Research Center for analysis. The peas were gently crushed and the extracted adults were positively identified as pea weevils. This insect is not to be confused with the wide spread pest in peas with a similar name, the pea leaf weevil.

The pea weevil is one of the most damaging insects on peas in the Pacific Northwest of US. This pest damage comprises the direct loss of seed contents consumed by the insect, decreased germination capacity and diminished market value. The seed damage in that region ranges from 42-82%. However, pea weevil is a very new pest in Montana. Pea weevil feeds only on green peas in which the larva devours the inner content of the seed. The adult is gray or brownish gray, marked with black and white spots, and is about 1/5 inch long. Females attach their eggs to the outsides of green pea pods. They lay about 100 eggs, either singly, or in batches of up to 12 eggs. Inside the pods, the larvae develop in the growing seeds and pupate inside the pea seeds. Feeding results in large, stout exit holes with a diameter of 2.5 mm. Pupation typically occurs as much as one month after harvest. Pupae develop while the grain is being stored. After pupation, adults chew an exit hole through the seed coat. Adults emerge starting in mid-December and overwinter with the stored peas and in the field. Adults fly to hibernation sites at the end of summer or at beginning of fall (e.g. under loose shingles, cracks in buildings, under loose bark, debris under trees, alfalfa/other perennial legumes crops). They remain in hibernation throughout winter until late spring or early summer emerging and migrating to pea fields to mate and lay eggs. The typical lifecycle of the pea weevil takes 4-5 months to complete. There is only one generation per year.

The economic impact from this pest includes damage to seed and loss of seed contents along with loss of germination rates. The damage is reflected through discounts at the elevator which is passed on to the grower.

Thresholds and management recommendations have been developed for this pest at other areas and that information is available at, http://agresearch.montana.edu/wtarc/producerinfo/index.html

Now that pea weevils have been reported in Montana, the next step is to identify the areas infested and assess the extent of the damage in order to implement the necessary control methods. Management strategies can then be optimized to prevent further spread to other areas.

The USA Dry Pea & Lentil Council and American Pulse Association has funded a survey to determine the weevil population distribution, abundance and pea damage assessment for Montana. The MSU WTARC is conducting a survey this fall and are asking help from Montana pea growers and pea handlers. Pl
two pounds of suspected pea
VP Reddy, Western Triangle

Shelby Rd., P. O. Box 656, Conrad, MT 59425. For more information or asistance with sample pickup contact Gadi V.P. Reddy at 278-7707; 406-450-0375, reddy@montana.edu or Govinda Shrestha, govinda.shrestha@montana.edu, 406-450-3052.

Fig. Article published in Trader dispatch

Acknowledgement

This project is funded by "The USA Dry Pea & Lentil Council and American Pulse Association".

Effect of Bio-pesticides against Canola Flea Beetle, *Phyllotreta cruciferae*

Principle Investigator: Gadi V.P. Reddy

Project personnel: Frank Antwi, John H. Miller and Julie Prewett

Western Triangle Agricultural Research Center, Montana State University, 9546 Old Shelby Rd.,

P.O. Box 656, Conrad, MT 59425

Aim of the Study

The aim of this study was to compare the effect of bio-pesticides and traditional insecticides against canola flea beetle, *Phyllotreta cruciferae*.

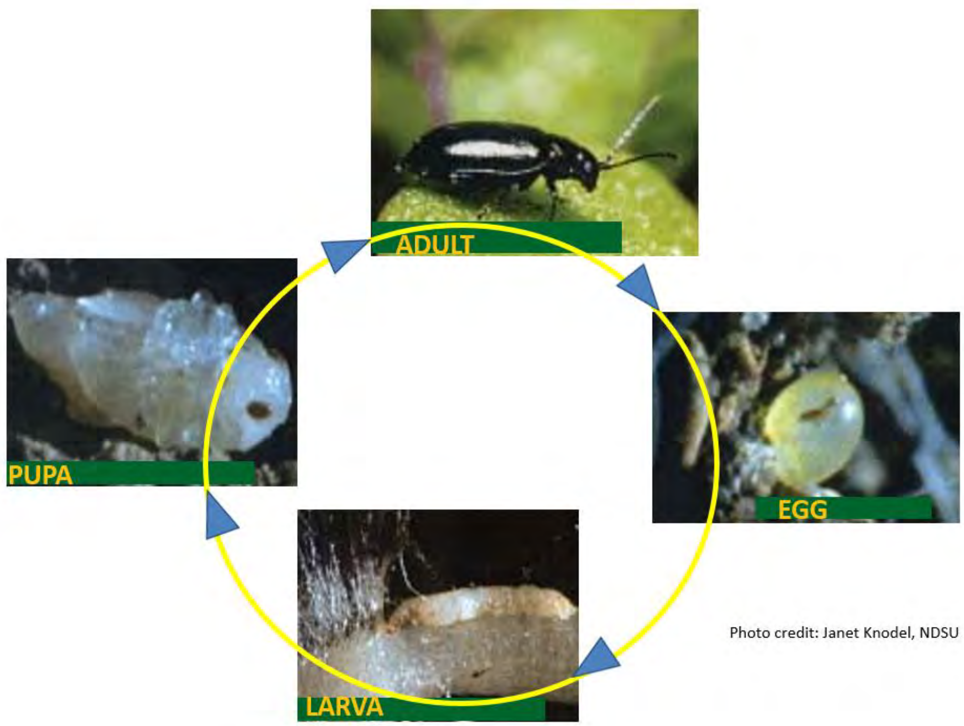

Fig. Life cycle of canola flea beetle

Materials and Methods

Study sites

Field studies were conducted at two locations: Western Triangle Agricultural Research Center (WTARC) (48º 18.627'N, 111º 55.402' W) in Conrad, and Sweet Grass (48º 57.831'N, 111º 40.801' W) Montana, USA. Seeding on experimental plots were done on 12 April, 2016 at WTARC, and on 13 April, 2016 at Sweet Grass. Canola seeds Hy-Class® (WindField Solutions, LLC) were used for both locations, and were seeded at a rate of 12 seeds per 30 cm using a four-row plot drill with a row spacing of 30 cm. The herbicide RT3® (a.i. glyphosate) at a rate of 2.5 L/ha was applied before seeding. At the time of seeding fertilizers at an N, P, K and S ratio of 134.5, 25.2, 61.6, and 22.4 kg/ha and N, P, K ratio of 12.3, 25.2, and 0 kg/ha were applied. The field trials were conducted under dryland (i.e., non-irrigated) conditions.

Treatments

The treatments used are as presented in Table 1. These were Water, Gaucho® (imidacloprid), Entrust® (spinosad), Steinernema-System® (*Steinernema feltiae*) + Barricade® (Barricade polymer 1%), Aza-Direct® (azadirachtin), Pyganic1.4® EC (pyrethrins), Grandevo® SC (*Chromobacterium subtsugae*), and Venerate® XC (Heat Killed *Burkholderia sp. srain A396*) as seed treatment and foliar application.

Plot design and data collection

The design for the field trial was a Randomized Complete Block Design (RCBD). The plot sizes used were 3.6 m × 1.2 m, and a buffer zone of 1.2 m was set up between each plot to avoid cross contamination of spray drift. Treatments were replicated 4 times at each location. A SOLO backpack sprayer (SOLO, Newport News, VA) calibrated at 816.89 L/ha was used for treatment application, after flea beetles arrival in plots and when air temperatures were (14 - 20 ºC), and canola was in the cotyledon or one to two-leaf stage. Plots sprayed with water served as control. Each plot was rated for *P. cruciferae* feeding injury along one 3.6-m section of row, by sampling 10 plants at 0.3 m intervals before treatment applications (PT). The injury measurements of *Phyllotreta cruciferae* were made by visual classification into the EPPO damage categories as 1= no damage; 2 = up to 2% leaf area eaten; 3 = 3 - 10% leaf area eaten; 4 = 10 - 25% leaf area eaten; and 5 = >25% leaf area eaten (EPPO, 2004). The visual injury ratings were converted into percent leaf area injury with (OEPP/EPPO, 2004), where 1 = 0%; 2 = 2%; 3 = 5%; 4 = 10%; and 5 = 25% leaf area injury. Post-application ratings for *P. cruciferae* injury at 7 and 14 d after application of foliar insecticides (7 and 14 DPT) was used to determine treatment efficacy duration. Treatment effects were evaluated by comparing feeding injury and yield from plots

Plots were swathed on 5 August, 2016 and harvesting was done on 16 August, 2016 at WTARC. At Sweet Grass the plots were straight combined on 1 September, 2016 when 50% of canola seeds were dark in color. The canola crop was harvested at 30% seed moisture, stored and air dried for 7 days until the seeds were at 8-10% moisture. The seeds were then cleaned and weighed to determine the seed yield per plot (as kilograms per hectare) for each experimental unit between August and October, 2016.

Data analysis

Data were analyzed using multivariate analyses of covariance (SAS Institute, 2015). This was done to account for and eliminate effects of pre-foliar treatment ratings on change in *P. cruciferae* feeding injury across dates after treatments. Least square means (LSMEANs) was run following ANOVA (SAS Institute, 2015). PROC GLM procedure (PROC GLM, SAS Institute 2015) was used in determining the main and interaction effects of location by treatment on *P. cruciferae* feeding injury ratings and yields.

Results

Leaf area feeding injury due to flea *Phyllotreta cruciferae* were generally lower for the chemical seed treatment Gaucho across the locations (Table 2). Leaf area feeding injury at pre-treatment (PT) ranged from 1.7 to 6.1% at WTARC (Table 2). At 7 days post treatment (7 DPT) Gaucho treatment resulted in a significantly lower leaf area injury of 5.4% (Table 2). The leaf area injury for the rest of the treatments were not significant when compared to the water control (Table 2). Except Gaucho, and Entrust which had lower leaf feeding injury of 7.6 and 8.6, respectively, none of the treatments had feeding injuries which were significant when compared to the water control (Table 2).

At Sweet Grass leaf area feeding injury by *Phyllotreta cruciferae* varied from 3.1 to 6.3% at PT (Table 2). At 7 DPT in Sweet Grass the trend in feeding injuries were similar to that of WTARC (Table 2). Gaucho was the only treatment that resulted in a significantly lower feeding injury of 6.6% at Sweet Grass (Table 2). Gaucho treatment resulted in a significantly leaf feeding area of 8.0% in Sweet Grass at 14 DPT (Table 2). Except Grandevo at 14 DPT, leaf area feeding injury for all the treatments were significant when compared to the water control in Sweet Grass (Table 2).

The yield ($F = 12.36$; $df = 17,95$; $P < 0.0001$) and location ($F = 165.99$; $df = 1,95$; $P < 0.0001$) effects were significant. However, treatment ($F = 1.69$; $df = 8, 95$; $P = 0.1131$), and location × treatment ($F = 0.80$; $df = 8,95$; $P = 0.6006$) effects were not significant.

Gaucho treatment resulted in a higher yield of 937.3 kg/ha at WTARC ((Table 3). However, none of the treatments had yield which were significant when compared to the water control (Table 3). Entrust (863.0 kg/ha) and Scanmask + Barricade (817.2 kg/ha) were the treatments that had a greater seed yield after Gaucho (Table 3). At Sweet Grass seed yield among the treatments were not significant (Table 3).

Seed test weight were not significant among the treatments at WTARC (Table 4). Seed test weight for Grandevo was higher (60.8 lb/bushel) at Sweet Grass (Table 4). However, except Grandevo test weight among the treatments were not significant when compared to the water control (Table 4).

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Acknowledgements

This work was supported by Montana Wheat and Barley Committee. This material is also based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, Multistate Project W3185, The Working Group Biological Control of Pest Management Systems of Plants under Accession # 231844.

Table 1. Materials and rates of application in each treatment

Treatment	Active Ingredient	Concentration	Amount/3.785 L water	Source
Water	water	Same volume as in mix	-	-
Gaucho	imidacloprid	190 ml/45 kg seed	-	Bayer Crop Science
Entrust	spinosad	0.091 ml/L of water	0.34352 ml	Dow AgroSciences
Steinernema-System + Barricade	*Steinernema feltiae* + Barricade polymer (1%)	300000/m^2 + 1% Barricade	17.098g (*S. feltiae*) + 37.85 ml (g) (Barricade)	Biobest USA Inc. Romulus, MI and Barricade International http://firegel.com
Aza-Direct	azadirachtin	1.43 ml/L (473 ml/acre)	5.42 ml	Gowan Company
Pyganic1.4 EC	pyrethrins	1.45 ml/L (473 ml/acre)	5.50 ml	McLaughlin Gormley King Co., Inc. Minneapolis, MN
Grandevo SC In-Furrow application	*Chromobacterium subtsugae*	1.36 kg/acre (3lbs/acre)	-	Marrone Bio Innovations Inc., Davis CA
Venerate XC (Seed treatment)	Heat Killed *Burkholderia sp. srain A396*	0.41 ml/2.9 g seed (384.46 ml/acre)	-	Marrone Bio Innovations Inc., Davis CA
Venerate XC (Foliar application)	Heat Killed *Burkholderia sp. srain A396*	11.45 ml/L (3784 ml/acre)	43.33 ml	Marrone Bio Innovations Inc., Davis CA

Table 2. Crucifer flea beetle leaf area feeding injury to seedling canola treated with reduced risk insecticides in Montana

	WTARC			Sweet Grass		
Treatment	PT[a]	7 DPT[b]	14 DPT[c]	PT[a]	7 DPT[b]	14 DPT[c]
	………………………………….….……...…..Leaf area injury (%)……………………………………					
Water	4.1	12.6 b	16.0 bc	5.6	13.1 b	21.3 f
Gaucho 600	1.7	5.4 a	7.6 a	3.1	6.6 a	8.0 a
Entrust	4.3	10.5 b	8.5 a	4.8	11.5 b	14.5 bc
Steinernema-System + Barricade	6.1	12.8 b	19.1 c	4.9	12.5 b	11.8 b
Aza-Direct	5.0	12.0 b	16.4 bc	5.1	12.9 b	16.3 cde
PyGanic1.4 EC	3.9	11.9 b	15.3 bc	4.2	12.6 b	16.0 cd
Grandevo	4.6	10.8 b	14.1 bc	6.3	11.1 b	19.0 ef
Venerate XC (Seed treatment)	3.9	11.4 b	14.1 bc	5.8	13.0 b	17.4 de
Venerate XC (Foliar application)	4.3	11.1 b	12.6 ab	5.5	13.4 b	16.0 cd

[a], PT, pre foliar application.

[b], 7 DPT, days after foliar application.

[c], 14 DPT, days after foliar application.

WTARC: Hypothesis of no overall treatment effect (F=4.46; df =16, 938; P < 0.0001)

WTARC: Hypothesis of no overall pre-treatment leaf area effect (F = 2.10; df =2, 469; P = 0.1238)

Sweetgrass: Hypothesis of no overall treatment effect (F = 10.87; df =16, 938; P < 0.0001)

Sweetgrass: Hypothesis of no overall pre-treatment leaf area effect (F = 3.76; df =2, 469; P = 0.0240)

Table 3. Canola seed yield after treatment of seedlings with reduced risk insecticides in Montana

	……………..…...…..…Location……………..	
Treatment	WTARC[a]	Sweet Grass
	………………......Yield (kg/ha)….................	
Water	668.4 abcd	1363.4 a
Gaucho 600	937.3 a	1592.5 a
Entrust	863.0 ab	1473.5 a
Steinernema-System + Barricade	817.2 ab	1546.4 a
Aza-Direct	494.8 cd	1658.0 a
PyGanic1.4 EC	420.5 d	1309.3 a
Grandevo	772.5 abc	1526.0 a
Venerate XC (Seed treatment)	697.6 abcd	1551.7 a
Venerate XC (Foliar application)	589.8 bcd	1417.0 a

[a], WTARC, Western Triangle Agricultural Research Center.

Table 4. Canola seed test weight after treatment of seedlings with reduced risk insecticides in Montana

	……….………..…Location……….……..	
Treatment	WTARC[a]	Sweet Grass
	………….......Yield (lb/bushel)….................	
Water	51.7 a	59.2 b
Gaucho 600	53.0 a	59.4 b
Entrust	52.7 a	59.2 b
Steinernema-System + Barricade	51.4 a	59.9 ab
Aza-Direct	50.1 a	59.8 ab
PyGanic1.4 EC	51.1 a	59.5 b
Grandevo	51.2 a	60.8 a
Venerate XC (Seed treatment)	53.1 a	59.4 b
Venerate XC (Foliar application)	51.3 a	59.0 b

[a], WTARC, Western Triangle Agricultural Research Center.

Determining Efficacy of *Bacillus thuringiensis galleriae* STS-502 (BeetleGone ®) Against the Larvae of Alfalfa Weevil *Hypera postica* Gyllenhal under Montana Conditions

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Aim of the Study

The aims of this study were: 1) to evaluate the efficacy of *Bacillus thuringiensis* galleriae STS-502 (BeetleGone ®) against the larvae of alfalfa weevil *Hypera postica* Gyllenhal under Montana Conditions and 2) to determine the impact of *B. thuringiensis* on parasitization rate of *Bathyplectes* spp. against *H. postica* larvae.

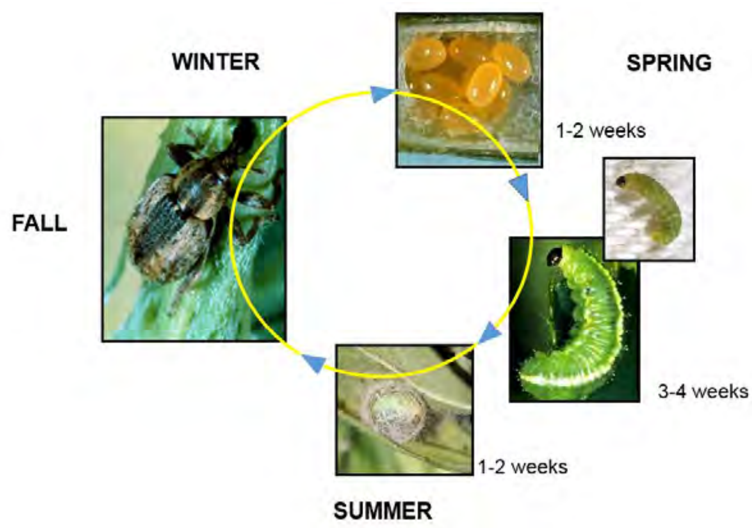

Fig. Life cycle of alfalfa weevil

Materials and Methods

Alfalfa fields

The research reported here was conducted in 2016. Two commercial alfalfa fields with a moderate to heavy history of *H. postica* infestations were selected in Valier and Conrad locations, in the Golden Triangle area of Montana, United States. Before selecting two fields for experiments, five fields (one and four fields in Valier and Conrad respectively) were checked during first week of June 2016, to determine whether which alfalfa field had moderate or high infestation level of alfalfa weevil for imposing treatments. Two persons were walked inside each alfalfa field, starting from 5 m away from the field edges. Each person collected six stems and a stem was collected at a distance of 5 m away from another collection point. All collected stems were kept in Ziploc bags and brought immediately to lab for the assessment of number of larvae per stem.

A randomized complete block design with four replicates was used, with 6 × 6 m treatment plots separated from other plots by 3 m buffer zones to avoid any overlap of treatment effects. Plots were positioned at least 6 m from field edge Furthermore, treatment plots were demarcated by using 1 m tall marking red painted wooden sticks.

BeetleGone ® Ag Phyllom Bioproducts application

A commercial formulation of BeetleGone® Ag Phyllom bioproduct *B. thuringiensis galleriae STS-502* was used for the study. Two concentrations of this product was used at the rates of 907.19 grams (low dose) and 1814. 27 grams (high dose) per 4046.86 m^2 in 94635.3 ml. NuFilm 17 (236.588 ml/4046.86 m^2) was further added in each dose rate to enhance the activity of product, considered here as a surfactant. A product material was first mixed with water, then surfactant was added, and the final suspension was well agitated before spray application. NuFilm 17 with water was considered as a control treatment. The treatments were applied using a CO2 pressure sprayer, delivering the volume of 102.206 L/ 4046.86 m^2 and two-man 3.66 m boom with nozzles spaced 0.46 m apart. Furthermore, each plot was sprayed in two swaths and the sprayer was calibrated for ground speed of 20 m in 6 seconds at 35 psi. The spraying activity was performed between 6- 8 am.

Sampling

Alfalfa weevil larvae population

Hypera postica larvae were sampled from BeetleGone or control treatment plots to determine whether *B. thuringiensis* application had an impact on alfalfa weevil populations.The times of sampling were 2 day before treatment and 3 or 7 days post application. Ten samples, consisting of 3 stems from each sample were collected from each plot and the sampling was performed along an N-shaped transect beginning 1-5 m into the plot. The stems were grabbed at their base and cut off, placing the stems, inverted, into a labeled 6 L plastic bag. The collected 30 stems were placed into one bag, closed and kept in picnic cooler. The samples were returned to lab and dislodged the larvae from foliage by vigorous shaking in a plastic bucket. The larvae were collected, sorted by age class-‘young’ (L1-L2) and ‘old’ (L3-L4) and counted.

Parasitization rate of *Bathyplectes* spp.

The parasitism of *Bathyplectes* spp. against *H. postica* larvae were determined in experimental plots by rearing of alfalfa weevil larvae that were collected at 7 days post application by stem cut or sweep net method. Sweeping was conducted with a standard sweep net (180^o arc), and 20 sweeps were made per each treatment plot. The sweeping was performed along an N-shaped transect beginning 1-5 m into the plot as a similar method described above for alfalfa stem sampling. The collected larvae from each treatment plot were kept in a plastic ziploc® bag with alfalfa foliage and transported immediately to laboratory. In the lab, *H. postica* larvae from each treatment were treatment were transferred into a large paper bag with a paper towel in the bottom. Fresh alfalfa foliage (usually 1 -2 healthy stems) was placed in each bag, top of the bag was folded multiple times and secured with a large binder clip. Fresh foliage was added every other day as needed and dried out foliage was left in a bag in order to avoid risk of losing insects. All bags were kept at room/lab temperature for 14 days at which time most insects had pupated/emerged.

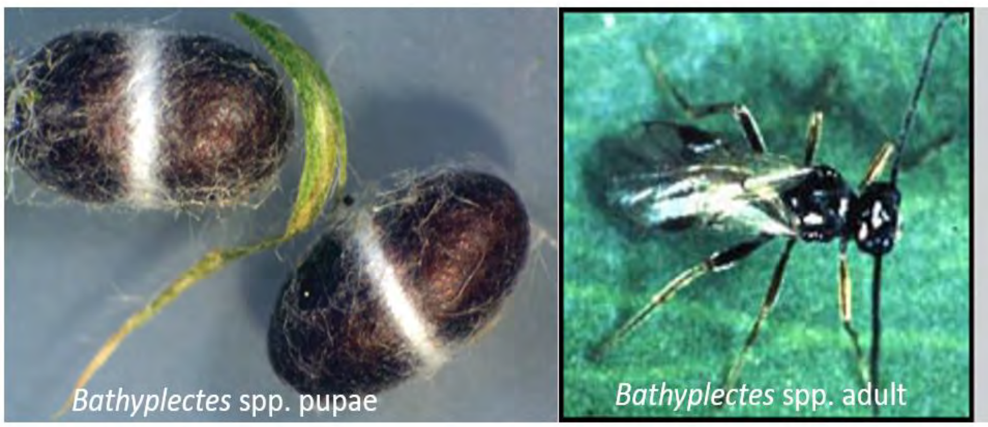

Fig 1. Alfalfa weevil parasitoid

Data analysis

The data were analyzed in R 2.15.1 (R Development Core Team, 2012). For all data, a test with a normal quantile-quantile plot was performed to confirm normality of the data and equality of variance. Where appropriate, Tukey contrast pairwise multiple comparisons were used to test for significant differences in means (Hothorn et al., 2008). Furthermore, the data were subjected to angular transformation prior to statistical analysis.

Alfalfa weevil population

The percentage reduction of alfalfa weevil population was calculated relative to the initial larval population (assessed 2 days before spraying) as follows:
Alfalfa weevil density reduction (AWDR) (%)

$$= \frac{\mathrm{AWDR}st0 - \mathrm{AWDR}st1}{\mathrm{AWDR}st0} \times 100;$$

Where $\mathrm{AWDR}_s t_0$ represents the number of alfalfa weevil larvae recorded at each treatment plot before the BeetleGone® application and $\mathrm{AWDR}_s t_1$ is the number of alfalfa weevil larvae recorded at each treatment plot in each sampling time (3 days or 7 days after BeetleGone® or NuFilm 17 treatments).

The overall data were fitted to a linear mixed model with sampling time interval, BeetleGone® treatment dose and alfalfa weevil populations per replicate as fixed effects (categorical variables converted to factors), the variation in alfalfa weevil populations (1|Unit) as random effect and the mean alfalfa weevil populations per treatment as response variable using the function “lmer”. The mean alfalfa weevil population per treatment was calculated using the “Summaryby” work package (doBy). The model was then simplified with stepwise removal of factors having no effect. The Kenward-Roger test was run using the function “KRmodcomp” to compare the models (Halekoh and Højsgaard, 2012).

For the subset data, One-Way Analysis of Variance (ANOVA) was carried out to determine the effect on alfalfa weevil population across treatment levels at each sampling time.

Parasitism level

One way-ANOVA was performed to evaluate whether the spray of BeetleGone® has an effect on parasitism level of *Bathyplectes* spp. on alfalfa weevil population. The parasitism percentage was calculated as (Numbers of parasitoids pupae formed / Total number of alfalfa weevil larvae reared from collected treatment plots) × 100.

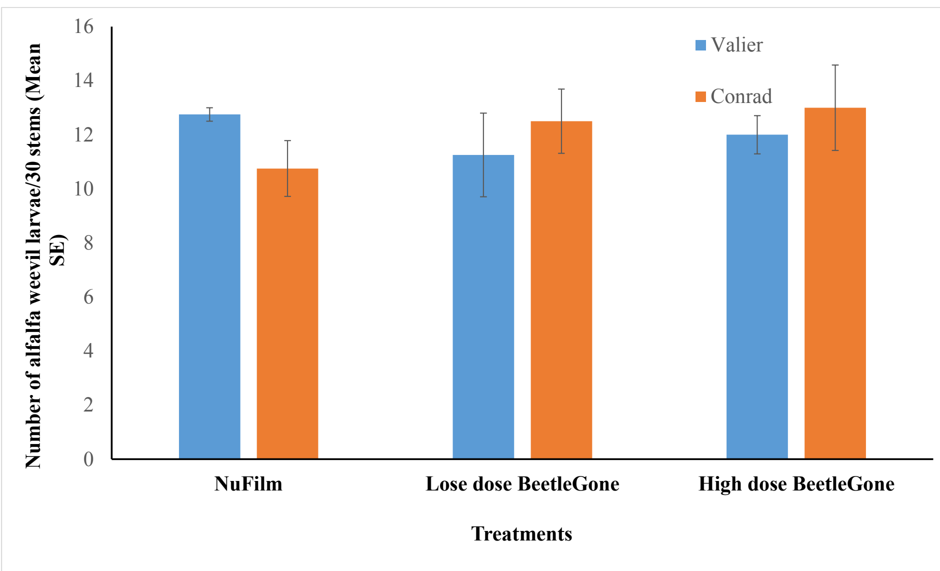

Figure 2. Mean numbers (± SE) of alfalfa weevil larvae recorded 2 days before treatments

Results

Alfalfa weevil population

The mean number (± SE) of alfalfa weevil larvae per 30 alfalfa stems, as quantified 2 days before the BeetleGone® or NuFilm 17 spray on alfalfa plants at two locations; Valier and Conrad ranged from 11.25 -12.75 and 10.75-13.00, respectively across treatment plots (Figure 2). Overall, this field experiment clearly demonstrated significant main effects on alfalfa weevil population for both treatment levels (Valier: $F = 13.19$; df = 2, 18; $P < P < 0.0001$; Conrad: $F = 15.20$; df = 2, 18;

P < 0.0001) and sampling times (Valier: F = 6.09; df = 1, 18; P < 0.05; Conrad: F = 5.66; df = 1, 18; P < 0.05). However, no significant interaction effects between the treatments and sampling times was found (Valier: F = 0.1; df = 2, 18; P > 0.05; Conrad: F = 0. 06; df = 2, 18; P > 0.05).

Table 1. Cumulative percentage reduction (mean ± SE) of alfalfa weevil larval population on alfalfa plants after BeetleGone® or Nu-Film (Control) application.

Location	Sampling times	Treatments		
		NuFilm 17(Control)	**Low dose BeetleGone®**	**High dose BeetleGone®**
Valier	3 DAT	1.92 ± 1.92b	10.99 ± 6.88b	33.17 ± 2.07a
	7 DAT	9.16 ± 3.68b	26.80 ± 10.90b	55.06 ± 8.29a
Conrad	3 DAT	5.77 ± 5.77b	24.90 ±5.07b	38.27 ± 5.96a
	7 DAT	14.16 ± 8.37b	39.57 ± 5.17a	59.49 ± 10.90a

Different letters within a row indicate significant differences between treatments (Tukey test, p<, p< 0.05).

Across the treatment levels, the significant difference on alfalfa weevil population was found at 3 days (Valier: F = 5.32; df = 2, 9; P <0.05; Conrad: F = 6.78; df = 2, 9; P <0.05) or 7 days (Valier: F = 8.93; df = 2, 9; P <0.01; Conrad: F = 9.98; df = 2, 9; P <0.01) after the BeetleGone® spray. The percentage reduction of alfalfa weevil larval populations over the BeetleGone® treatments including the control (NuFilm 17), was found dose-dependent with the highest reduction percentage recorded with highest concentration at both sampling times (Table 1). In Valier location, mean levels of alfalfa weevil larval population in alfalfa plots treated with high dose of BeetleGone® ranged from 33-55 %, 11 to 27 % for low dose of BeetleGone® and 2 to 9 % for NuFilm 17 (3 days or 7 days after treatments, respectively; Table 1). Similarly, in Conrad location, average levels of alfalfa weevil larval population in alfalfa plots treated with high dose of BeetleGone® varied from 38-59 %, 25 to 40 % for low dose of BeetleGone® and 6 to 15 % for NuFilm 17 (3 days or 7 days after treatments, correspondingly; Table 1).

Parasitism level

Alfalfa weevil larval parasitoids *Bathyplectes* spp. have been found in alfalfa fields at both research locations. Irrespective of sampling methods or locations, the results showed that there were a tendency of higher parasitism of *Bathyplectes* spp. on alfalfa weevil population when alfalfa plots were treated with NuFilm 17 as compared with BeetleGone® treated alfalfa plots (Table 2). However, only a significantly lower percentage of *Bathyplectes* spp. parasitism was found when alfalfa larvae were collected from alfalfa fields treated with high dose of BeetleGone® through stem cut at Valier location ($F = 5.35$; $df = 2,9$; $P = 0.02$). In other cases, no significant differences were found on parasitism levels between alfalfa fields treated with NuFilm 17, lower or higher doses of BeetleGone® at both Conrad (stem cut: $F = 3.02$; $df = 2, 9$; $P = 0.09$ and sweep netting: $F = 0.87$; $df = 2, 9$; $P = 0.45$) and Valier (sweep net: $F = 2.20$; $df = 2, 9$; $P = 0.17$) locations. The mean parasitism level at Valier and Conrad research locations varies from 5- 26 % and 17-36 % respectively (Table 2).

Table 2. Parasitism percentage (mean ± SE) of *Bathyplectes* spp. on alfalfa weevil population 7 days after BeetleGone® or NuFilm 17(Control) applications

Location	**Sampling Methods**	**Treatments**		
		NuFilm 17 (Control)	**Low dose BeetleGone®**	**High dose BeetleGone®**
Valier	Stem cut	19.30 ± 1.68a	15.82 ± 2.17a	5.00 ± 5. 00b
	Sweep net	25.77 ± 3.05a	18. 24 ± 2.41a	24.06 ± 2.84a
Conrad	Stem cut	36.25 ± 5.54a	22.38 ±4.03a	17.50 ± 6.85a
	Sweep net	26.79 ± 5.28a	20.19 ± 2.53a	21.28 ± 3.62a

Different letters within a row indicate significant differences between treatments (Tukey test, $p< 0.05$).

Acknowledgements

We would like to thank Connie Miller for assistance with field work. This material is based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, Multistate Project S-1052, and the Working Group on Improving Microbial Control of Arthropod Pests Covering Research in Montana under Accession # 232056.

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Joint Toxicity and Risk of Bifenthrin and Zeta-cypermethrin to a Non-target Insect

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Aim of the Study

The purpose of this paper was to test the (1) hypotheses of independent, uncorrelated and similar (additive) joint actions, (2) assess whether the interaction was synergistic, antagonistic, or additive, and (3) determine the risks of bifenthrin and zeta-cypermethrin mixture using *T. molitor* as a surrogate species.

Materials and Methods

Insects

Tenebrio molitor (mealworm larvae) third instars were purchased from Petco (Petco Company, Joliet, IL). *T. molitor* was chosen because of ease of handling and rearing, and immature life stage. A sample of 100 *T. molitor* were weighed to obtain the average weight per larva (mean wet weight = 134.9 mg; SD = 30.1 mg).

Bioassay

The bioassay experiments were conducted between June 30 and July 12, 2015 in a laboratory at Western Triangle Agricultural Research Center, Conrad, Montana. The prevailing laboratory conditions were 25 ºC ± 1 temperature, 66 ± 5% relative humidity, and 16:8 h light: dark photoperiod. Ten grams (10 g) of potting mix soil (Scotts Miracle-Gro Company, Marysville, OH) was placed in 2.25 oz. (66.55 ml) Gelatin shot glasses (NorthWest Enterprises, Elk Grove Village, IL 60007). Two *T. molitor* third instar larvae were placed in each cup and 1 ml of tap water was sprayed with a 473 ml capacity plant and garden atomizer sprayer (Sprayco, Livonia, MI) on each soil in the cups. A small slice of potato (1 cm^3) was placed in the cup as a food source. Hero (a.i. zeta-cypermethrin 3.75% and bifenthrin 11.25%; Mustang Max (a.i. zeta-cypermethrin 9.15%), Brigade 2EC (a.i. bifenthrin 25.1%) from FMC Corporation, Philadelphia, PA were used as treatments. A stock solution (10X) of the insecticidal treatment was prepared out of which serial dilutions were made (0, 0.25X, 0.50X, 1X, 2X field fold). One ml of each dilution was sprayed on the soil, food source, and on the larvae of the surrogate organism (*T. molitor*). The lids of the cups were perforated and the perforated lids were used to cover the cups. The covered cups were then placed in trays on a wheel shelve in the laboratory. Counting for insect mortalities were recorded for 3 days. Insect that did not move when prodded with forceps were considered dead.

Data analysis

Abbott method (Abbott 1925) was used to account for control or natural mortalities. Water was used as the control. The data were analyzed with SAS. The LC_{50} values were determined with PROC PROBIT. Mortalities were regressed on concentrations using PROC REG. Graphs of percentage mortality against $\log_{10}$ concentration were plotted with Sigma Plot. Risk Quotients (RQ) were determined by integrating estimated environmental concentration (EEC) and the toxic endpoint LC_{50} to characterize the risk. The Risk Quotient values were then compared with an RQ Level of Concern (LOC) of ≥ 0.5 for terrestrial animals used by USEPA.

Independent and Similar actions

Equivalent concentrations of z-cypermethrin and bifenthrin were obtained by multiplying the total active concentration in Hero EC by 3.75 and 11.25% for z-cypermethrin and bifenthrin, respectively. The hypothesis of independent action was determined using the equation below:

$P = P_1 + P_2 - P_1P_2$ ………………………………………………………………….. (1)

Where amounts of the two constituents of the mixture resulted in kills of proportions P_1, P_2 respectively of the tested organism (Bliss 1934). These proportions were then multiplied by 100 to obtain the expected percentage of mortalities for independent action in Table 5. For similar action the equivalent concentrations of zeta-cypermethrin and bifenthrin were substituted in the regression equations for Hero EC treatment in Table 3 for the respective percentage mortalities. These were then summed up to obtain the expected percentage mortalities for similar action in Table 5. Based on the observed and expected percentage mortalities Chi Square Analysis was done to test the hypotheses of independent and similar actions for the constituents of the mixture Hero EC (Bliss 1934).

A chi-square (χ^2) test was used to determine synergistic, additive, or antagonistic interactions between Brigade (bifenthrin) and Mustang Max (zeta-cypermethrin) in the treatments. Abbott method [30] was used to correct for control mortalities. The expected additive proportional percentage mortality Me for the zeta-cypermethrin - bifenthrin mixture was determined as Me = Mz + Mb (1 - Mz), where Mz and Mb are the observed proportional percentage mortality by zeta-cypermethrin (Mustang Max) and Brigade (bifenthrin) alone, respectively. A χ^2 test determined as ($\chi^2 = (Mzb - Me)^2/Me$) whereby Mzb = the observed percentage mortality for the zeta-cypermethrin - bifenthrin mixture was compared with the χ^2 table value for 4 df. A non-additive effect between two actives was suspected when the calculated χ^2 value exceeded the table value (Finney 1964). A significant interaction was considered as synergistic when the difference Mzb - Me had a positive value. When the difference Mzb - Me had a negative value, a significant interaction was considered antagonistic.

Results

Time-concentration-mortality response

The mortality responses of *T. molitor* with time is represented in Table 2, and Fig. 1. Mortality responses ranged from 0 to 80% at day 1 for all treatments (Hero, Mustang Max and Brigade) across the concentrations (Table 2, Fig. 1). At day 2, mortalities were 0 to 86.2% for Hero, 0 to 57.7% for Mustang Max, and 0 to 45.1% for Brigade across the concentrations (Table 2, Fig. 1). Across the concentrations at day 3 percentage mortalities ranged from 0 to 46.2% for Hero, 0 to 94.7% for Mustang Max, and 0 to 100% for Brigade (Table 2, Fig. 1).

Mortality and concentration relationships

The relationships between *T. molitor* mortalities and log concentrations are as shown in Table 3 and Fig. 1 for days 1 to 3. The regression models were significant (Table 3). The regression models explained 66.3 to 85.29%, 28.0 to 72.63%, 35.27 to 92.77% of the total response variation for *T. molitor*, at days 1 to 3 for the treatments Hero, Mustang Max, and Brigade, respectively (Table 3). The standard deviation of *T. molitor* sensitivity to the treatments varied from 0.21 - 0.28%, 0.23 - 1.02%, and 0.21 - 0.69% at days 1 to 3 on treatment with Hero, Mustang Max, and Brigade, respectively (Table 3). For a unit change in concentration, mortalities of *T. molitor* varied from 3.59 to 4.78%, 0.98 to 4.34%, and 1.45 to 4.71% at days 1 to 3 for Hero, Mustang Max, and Brigade, respectively (Table 3).

Lethal concentrations and risk quotients

The lethal concentrations, relative potencies, and risk quotients on treatment of *T. molitor* larvae with Hero, Mustang Maxx, and Brigade insecticides are presented in Table 4. The lethal concentrations generally decreased with time for Hero and Mustang Maxx, and increased for Brigade at days 1 to 3 (Table 4). The lethal concentrations at days 1 to 3 were for Hero (0.0000102 - 1.11371 g a.i./L), for Mustang Maxx (0.01117 - 0.01207 g a.i./L), and for Brigade (8.84121×10^{-7} – 0.0001239 g a.i./L) (Table 4).

Except at day 3 for Hero, none of the treatments exceeded the relative potency of Brigade insecticide (Table 4). The relative potencies were for Hero ($7.94 \times 10^{-7} – 1.21 \times 10^{1}$), for Mustang Maxx ($7.32 \times 10^{-5}$ - 1.11×10^{-2}), and for Brigade (1.00) (Table 4).
Also, except at days 1 and 2 for Hero, risk quotients (RQs) were exceedingly high (> 1) for the treatments (Table 4). The risk quotients were for Hero (0.13 - 13747.35), for Mustang Maxx (2.16 - 2.97), and for Brigade (7.35×10^{2} - 1.63×10^{2}) (Table 4).

Joint action and interaction

The joint action or toxicity of the insecticide mixture Hero (zeta-cypermethrin + bifenthrin) at various time points and concentrations are shown in Table 5. The interaction between Brigade (bifenthrin) and Mustang Maxx (zeta-cypermethrin) against *T. molitor* at various concentration and at days 1 to 3 are presented in Table 6.

The expected or predicted mortalities were always less than the observed mortalities for both independent and similar action hypotheses tested (Table 5, Fig. 1). The observed mortalities ranged from 56.7 - 80%, 27.6 - 86.2%, and 33.3 - 46.2% at days 1 to 3 (Table 5, Fig. 1). For independent action, expected mortalities ranged from 12.56 - 20.44%, 10.42 -16.46%, and 10.72 - 17.45% at days 1 to 3 (Table 5, Fig. 1). For similar action, expected mortalities varied from 12.96 - 21.60%, 10.70 - 17.19%, and 11.01 - 18.28% at days 1 to 3 (Table 5, Fig. 1). The calculated χ^2 values at days 1 to 3 were always greater than the Table value ($\chi^2_{0.050,\, df = 4} = 9.488$), for both independent and similar actions (Table 5). Therefore, the hypotheses of independent and similar actions were rejected (Table 5). Except at day 2 for Mustang Max, and Brigade at 1X and 2X, across the concentrations (0.25X to 2X) at days 1 to 3 for the treatments (Hero, Mustang Maxx, and Brigade) the interactions were antagonistic (Table 6).

Acknowledgement

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Table 1. Insecticide treatments and concentrations used.

Treatments	Insecticide concentration[a]				
	0X	0.25X	0.5X	1X	2X
Hero EC[b]	0	0.09076	0.18152	0.36304	0.72608
Mustang Max[c]	0	0.0726075	0.145215	0.29043	0.58086
Brigade 2EC[d]	0	0.06807	0.13614	0.27228	0.54456

[a] Insecticide concentration: 0X, control (water); 0.25X, 0.5X, 1X, and 2X the lowest field application rate.

[b] Hero: 0X = water; 0.25X = 0.09076 ml/L (0.013614 g a.i./L); 0.5X = 0.18152 ml/L (0.027228 g a. i./L); 1X = 0.36304 ml/L (0.054456 g a.i./L); 2X = 0.72608 ml/L (0.108912 g a.i./L).

[c] Mustang Maxx: : 0X = water; 0.25X = 0.0726075 ml/L (0.0066425 g a.i./L); 0.5X = 0.145215 ml/L (0.013285 g a. i./L); 1X = 0.29043 ml/L (0.02657434 g a.i./L); 2X = 0.58086 ml/L (0.0531487 g a.i./L).

[d] Brigade 2EC: : 0X = water; 0.25X = 0.06807 ml/L (0.0170856 g a.i./L); 0.5X = 0.13614 ml/L (0.03417115 g a.i./L); 1X = 0.27228 ml/L (0.06834228 g a.i./L); 2X = 0.54456 ml/L (0.1366846 g a.i./L).

Table 2. Time-concentration-mortality response of *Tenebrio molitor* larvae to Hero, Mustang, and Brigade insecticides.

Treatments	DAT[a]	Insecticide concentration[b]				
		0X	0.25X	0.5X	1X	2X
		% Mortality[c]				
Hero EC	1	0	80	66.7	56.7	71.7
Mustang Maxx	1	0	80	66.7	56.7	71.7
Brigade 2EC	1	0	76.7	65	71.7	80
Water[d]	1	0	0	0	0	0
Hero EC	2	0	27.6	51.7	75.9	86.2
Mustang Maxx	2	0	40.4	43.3	32.7	57.7
Brigade 2EC	2	0	38.2	45.1	43.1	32.4
Water	2	0	0	0	0	0
Hero EC	3	0	35.9	46.2	33.3	43.6
Mustang Maxx	3	0	91.2	93.0	93.0	94.7
Brigade 2EC	3	0	76.3	100	76.3	96.6
Water	3	0	0	0	0	0

[a] DAT, Days after treatment.

[b] Insecticide concentration: 1X the lowest label application rate equals Hero, 0.36304 ml/L; Mustang Maxx, 0.29043 ml/L; Brigade 2 EC, 0.27228 ml/L.

[c] Mortalities were adjusted for using the Abbot method (Abbott 1925).

[d] Water, control.

Table 3. Relationship between mortality and log concentrations of Hero, Mustang and Brigade insecticides to mealworm larvae

Treatment	Day	Regression model[a]	SD[b]	F	R^2	P
Hero EC	1	Y = 21.08 + 4.78X	0.21	162.29	0.8529	<.0001
	2	Y = 16.32 + 3.59X	0.28	55.09	0.6630	<.0001
	3	Y = 17.79 + 4.02X	0.25	76.97	0.7333	<.0001
Mustang Maxx	1	Y = 17.55 + 4.34X	0.23	74.29	0.7263	<.0001
	2	Y = 5.27 + 1.22X	0.82	29.77	0.3392	<.0001
	3	Y = 4.46 + 0.98X	1.02	22.55	0.2800	<.0001
Brigade 2EC	1	Y = 6.41 + 1.45X	0.69	15.26	0.3527	0.0005
	2	Y = 20.88 + 4.71X	0.21	359.12	0.9277	<.0001
	3	Y = 9.23 + 2.09X	0.48	39.15	0.5426	<.0001

[a] Regression model: Y = Mortality (%); X = Concentration (g a.i./L).

[b] SD = Standard deviation of sensitivity to the treatments

Table 4. Lethal concentrations, relative potencies, and risk quotients for *Tenebrio molitor* larvae on treatment with Hero, Mustang Max, and Brigade insecticides

Treatment	Day	LC_{50} (g a.i./L)	C. I. (95%)	$P > \chi^2$	Relative Toxicity (LC_{50};s/LC_{50};T)[a]	Risk quotient (EEC/ LC_{50})[b]
Hero EC[c]	1	1.11371	ND[d]	0.0428	7.94E-07	0.13
Hero EC	2	1.11371	ND	0.0428	5.02E-07	0.13
Hero EC	3	0.0000102	ND	0.1758	1.21E+01	13747.35
Mustang Max[e]	1	0.01207	0.00921- 0.01497	0.7793	7.32E-05	2.75
Mustang Max	2	0.01535	ND	0.0122	3.64E-05	2.16
Mustang Max	3	0.01117	ND	0.2583	1.11E-02	2.97
Brigade 2EC[f]	1	8.84121E-7	ND	0.5674	1.00E+00	1.03E+05
Brigade 2EC	2	5.59056E-7	ND	0.9718	1.00E+00	1.63E+05
Brigade 2EC	3	0.0001239	ND	<.0001	1.00E+00	7.35E+02

[a] Ratios of the lethal concentrations (LC_{50}) of standard insecticide Brigade 2EC) to the treatments at 50% mortality for days 1 to 3.

[b] EEC = maximum commercial field rate

[c] Hero EC maximum commercial field rate = 0.93483 ml/L (10.3 fl. oz/acre) (0.140223 g a.i./L).

[d] ND, no data as confidence interval could not be determined by statistical analysis.

[e] Mustang Max maximum commercial field rate = 0.36304 ml/L (4 fl. oz/acre) (0.0332183 g a.i./L).

[f] Brigade 2EC maximum commercial field rate = 0.36304 ml/L (4 fl. oz/acre) (0.0911225 g a.i./L).

[g] 8.84121E-7 = 8.84121×10^{-7}

Table 5. Joint action of Hero (zeta-cypermethrin + bifenthrin) insecticide to *Tenebrio molitor* larvae at three time points and four concentration levels

					Independent Action			Similar Action		
Concentration[a]	Concentration[b]	Concentration[c]	Day	Observed Mortality (%)	Expected Mortality (%)	$(O-E)^2/E$[d]	χ^2	Expected Mortality (%)	$(O-E)^2/E$	χ^2
0.013614	0.000510525	0.001531575	1	80	12.56	362.28	9.488	12.96	346.68	9.488
0.027228	0.00102105	0.00306315	1	66.7	15.23	174.01		15.84	163.30	
0.054456	0.0020421	0.0061263	1	56.7	17.86	84.51		18.72	77.07	
0.108912	0.0040842	0.0122526	1	71.1	20.44	125.53		21.60	113.48	
0.013614	0.000510525	0.001531575	2	27.6	10.42	28.30	9.488	10.70	26.68	9.488
0.027228	0.00102105	0.00306315	2	51.7	12.46	123.58		12.87	117.20	
0.054456	0.0020421	0.0061263	2	75.9	14.47	260.72		15.03	246.51	
0.108912	0.0040842	0.0122526	2	86.2	16.46	295.43		17.19	276.95	
0.013614	0.000510525	0.001531575	3	35.9	10.72	59.16	9.488	11.01	56.24	9.488
0.027228	0.00102105	0.00306315	3	46.2	12.99	84.87		13.44	79.91	
0.054456	0.0020421	0.0061263	3	33.3	15.24	21.41		15.86	19.19	
0.108912	0.0040842	0.0122526	3	43.6	17.45	39.17		18.28	35.07	

[a] Hero EC concentration: 0.013614 g a.i./L = 0.25X; 0.027228 g a.i./L = 0.5X; 0.054456 g a.i./L = 1X; 0.108912 g a.i./L = 2X.

[b] Concentration: equivalent zeta-cypermethrin (g a.i./L; 3.75%).

[c] Concentration: equivalent bifenthrin (g a.i./L; 11.25%).

[d] (Observed % Mortality – Expected % Mortality)^2/Expected % Mortality.

Table 6. Interaction between Brigade (bifenthrin) and zeta-cypermethrin (Mustang Max) against *Tenebrio molitor* larvae at three time points and four concentration levels

		Concentration[a]											
		……0.25X……						……0.5X……					
Treatment	Day	Mz[b]	Mb[c]	Me[d]	Mzb[e]	Mzb – Me[f]	(Mzb-Me)^2/Me	Mz[b]	Mb[c]	Me[d]	Mzb[e]	Mzb – Me[f]	(Mzb-Me)^2/Me
Hero EC[b]	1	0.8	0.767	0.953	0.8	-0.153	0.025	0.667	0.065	0.689	0.667	-0.217	0.068
Mustang Max[c]	1	0.8	0.767	0.953	0.8	-0.153	0.025	0.667	0.065	0.689	0.667	-0.217	0.068
Brigade 2EC[d]	1	0.8	0.767	0.953	0.8	-0.153	0.025	0.65	0.065	0.67275	0.667	-0.006	4.915E-05
		……1X……						……2X……					
Hero EC[b]	1	0.567	0.717	0.878	0.567	-0.311	0.110	0.717	0.8	0.9434	0.717	-0.226	0.054
Mustang Max[c]	1	0.567	0.717	0.878	0.567	-0.311	0.110	0.717	0.8	0.9434	0.717	-0.226	0.054
Brigade 2EC[d]	1	0.717	0.717	0.92	0.567	-0.353	0.135	0.8	0.8	0.96	0.717	-0.243	0.062
		……0.25X……						……0.5X……					
Hero EC[b]	2	0.276	0.382	0.552	0.276	-0.277	0.138	0.517	0.451	0.734	0.517	-0.218	0.065
Mustang Maxx[c]	2	0.404	0.382	0.631	0.404	-0.228	0.082	0.433	0.451	0.689	0.517	-0.172	0.043
Brigade 2EC[d]	2	0.382	0.382	0.618	0.382	-0.236	0.090	0.451	0.451	0.699	0.517	-0.182	0.047
		……1X……						……2X……					
Hero EC[b]	2	0.759	0.431	0.863	0.759	-0.104	0.013	0.862	0.324	0.907	0.862	-0.045	0.907
Mustang Max[c]	2	0.327	0.431	0.617	0.759	0.014	0.0003	0.577	0.324	0.714	0.862	0.148	0.714
Brigade 2EC[d]	2	0.431	0.431	0.676	0.759	0.083	0.010	0.324	0.324	0.543	0.862	0.319	0.543

		……0.25X……						……0.5X……					
Hero EC[b]	3	0.359	0.763	0.848	0.359	-0.489	0.282	0.462	1	0.462	0.462	0	0
Mustang Max[c]	3	0.0912	0.763	0.785	0.091	-0.693	0.613	0.93	1	0.93	0.462	-0.468	0.236
Brigade 2EC[d]	3	0.763	0.763	0.943	0.763	-0.181	0.035	1	1	1	0.462	-0.538	0.289
		……1X……						……2X……					
Hero EC[b]	3	0.333	0.763	0.842	0.333	-0.509	0.308	0.436	0.966	0.981	0.436	-0.545	0.303
Mustang Maxx[c]	3	0.93	0.763	0.983	0.333	-0.650	0.430	0.947	0.966	0.998	0.436	-0.562	0.317
Brigade 2EC[d]	3	0.763	0.763	0.944	0.333	-0.611	0.395	0.966	0.966	0.999	0.436	-0.563	0.317

[a] Insecticide concentration: 0.25X, 0.5X, 1X, and 2X the lowest field application rate.

[b] Observed proportional percentage mortality caused by Mustang Maxx (zeta-cypermethrin) alone.

[c] Observed proportional percentage mortality caused by Brigade (bifenthrin) alone.

[d] Expected additive proportional mortality for Hero (zeta-cypermethrin - bifenthrin) mixture.

[e] Observed proportional mortality for Hero (zeta-cypermethrin - bifenthrin) mixture.

[f] Interaction between treatments: Antagonistic (Mzb - Me = a negative value), Non-additive effect (synergistic or antagonistic; $\chi > 3.841$), (Synergistic (Mzb - Me = a positive value).

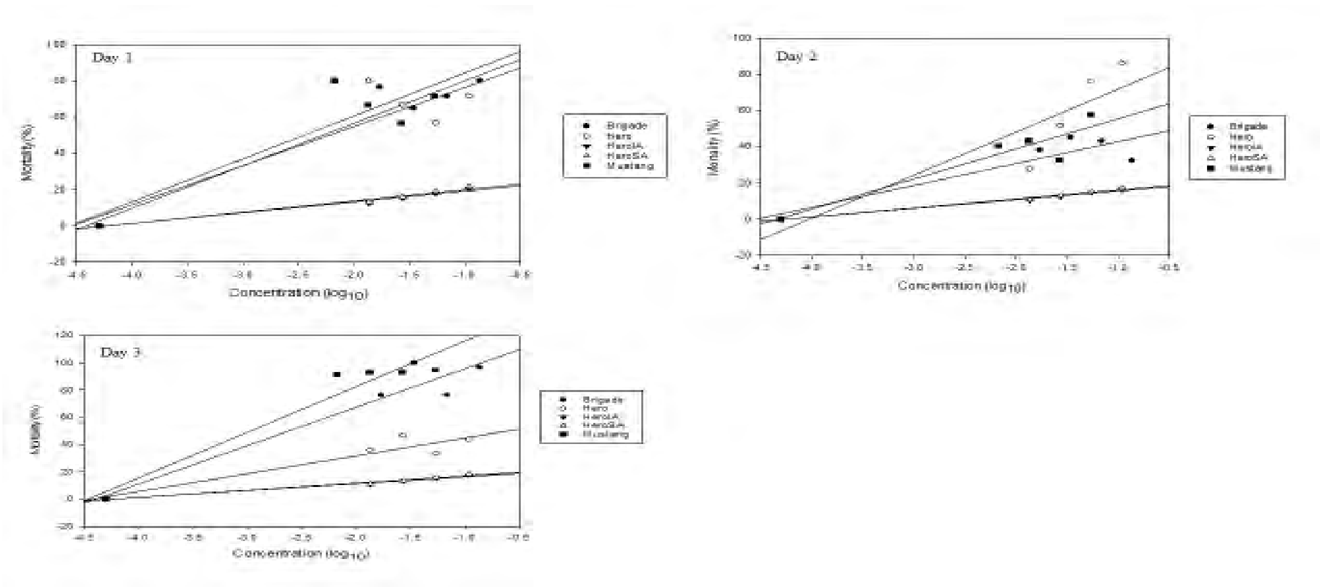

Fig. 1. Pecentage mortality of third instar larvae of *Tenebrio molitor* on treatment with different concentrations of insecticides: Hero EC (bifenthrin + zeta-cypermethrin); Brigade 2EC (bifenthrin); Mustang Maxx (zeta-cypermethrin); independent action predictions for Hero HeroIA; similar action predictions for Hero (HeroSA).

Analysis of the Spatio-Temporal Distribution of Major Insect Fauna of Alfalfa by Using Geostatistical and Spatial Analysis by Distance Indices: Implications for Pest Management

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Aim of the Study

The aims of this study were: 1) to determine the spatio-temporal distribution of major insect fauna of alfalfa crops in the Golden Triangle area of Montana and 2) to assess the destructive and beneficial insects of alfalfa crops in the Golden Triangle area of Montana.

Material and Methods

Study sites

The research stated here was carried out in 2016 field season. Commercial alfalfa fields were selected from Ledger (two fields), Bullhead (one field), Conrad (one field), and Valier (one field), the areas in Pondera County. These sites are located in the Golden Triangle region of Montana.

Sampling

The sampling of major insect fauna of alfalfa field was conducted in an area of each field (45 × 45 m) about 5 m away from the field edges. The insects sampled for this study were alfalfa weevils (*Hypera postica*), lygus bugs (*Lygus* spp.), alfalfa weevil parasitoids (*Bathyplectes* spp.), aphid parasitoids (*Aphidius* spp.), damsel bugs (*Nabis* spp.) and coccinellids/ lady beetles, (*Coccinella* spp.). The sampling area contained 81 sampling points distributed at every 5-m distance in a square gird (i.e. 9 sampling points across X-coordinates and 9 sampling points across Y-coordinates) demarcated by using 1 m tall marking red painted wooden sticks. Sweep net sampling was used in which sweeping was conducted using a standard sweep net (180^{o} arc), and 20 sweeps (five sweeps per direction) were made per sampling point. The collected insects were kept in plastic ziploc® bags and transported immediately to laboratory. The insect samples were either processed immediately or frozen for insect identification and counting under a microscope/naked eye at a later time. Four samplings were carried out: two samplings were performed before and two samplings after the first alfalfa cutting. After second sampling (before first cutting), wooden sticks were removed from study sites and were replaced with plastic ear tags. Prior to the start of the third sampling, plastic ear tags were removed and wooden sticks were relocated in the study sites. The sampling was conducted at 10 day intervals: first sampling from June 1-3; second sampling from June 16-17; third sampling from July 27-29; and fourth sampling from August 5-8, 2016.

Data analysis

Two major statistical analysis (Geostatistics (semivariogram) and Spatial Analysis by Distance Indices (SADIE)) are underway. The preliminary results (Mean ± Standard Error) of this study were presented for the interim.

Results

Pests

Alfalfa weevils

Alfalfa weevil larvae were present throughout the season (i.e., in all 4 samplings) in all sites. However, especially before the first cutting, higher variation of weevil larval population was observed in study sites. Among the five study sites, higher infestation levels of alfalfa weevil larvae were observed at the Bullhead and Valier study sites, moderate infestation level at Conrad study site and very low infestation level at Ledger study sites (Table 1). However, after first cutting, very low infestation of alfalfa weevil larvae were noticed in all study sites and the mean number of alfalfa weevil larvae were 2-3 per 20 sweeps. With respect to alfalfa weevil adults, they were found only at first or last two sampling in all field sites but no presence recorded at second sampling (Table 1). The mean number of alfalfa weevil adults caught in 20 sweeps was relatively low, with mean value varied from 0.30- 0.70 (Table 1).

Lygus bugs

Lygus bugs (*Lygus* spp.) were observed throughout sampling period irrespective of study sites (Table 1). Similar levels of lygus bug infestation were seen in all study sites (Table 1). However, infestation level was very low with mean value ranged from 0.20 – 2.00 and, it thereby indicating no threat to alfalfa crop.

Natural enemies

Parasitoids

Two parastioid species were recorded from all study sites: 1) alfalfa weevil parasitoids *Bathyplectes* spp. and 2) aphid parastioids *Aphidiu*s spp. (Table 2). Overall, higher number of aphid parasitoids were observed in all study sites as compared to alfalfa weevil parastioids. Although very low number of alfalfa weevil parastioid adults were found in study sites, there was a tendency to find more parasitoids before the first alfalfa cutting rather than after first cutting (Table 2).

Table 1. Mean (± SE) number of larvae and adults of *Hypera postica* and *Lygus* spp. recorded per 20 sweeps in alfalfa fields in Pondera County, MT, 2016

Field Location	**Sampling Dates**	***Hypera postica* Larvae**	***Hypera postica* Adults**	***Lygus* spp.**
Conrad	1	2.04 ± 0.13	0.73 ± 0.09	1.21 ± 0.15

	2	7.61 ± 0.44	0.00 ± 0.00	1.80 ± 0.20
	3	2.77 ± 0.23	0.37 ± 0.06	0.60 ± 0.09
	4	3.16 ± 0.25	0.67 ± 0.11	0.90 ± 0.12
Valier	1	8.74 ± 0.51	0.48 ± 0.11	1.60 ± 0.18
	2	17.40 ± 0.88	0.01 ± 0.01	1.42 ± 0.16
	3	2.09 ± 0.18	0.22 ± 0.05	1.40 ± 0.14
	4	2.91 ± 0.26	0.40 ± 0.07	2.21 ± 0.21
Ledger	1	1.36 ± 0.16	0.10 ± 0.04	1.30 ± 0.14
	2	2.58 ± 0.19	0.00 ± 0.00	2.52 ± 0.22
	3	2.03 ± 0.20	0.27 ± 0.05	0.80 ± 0.12
	4	2.84 ± 0.25	0.48 ± 0.08	0.60 ± 0.11
Bullhead Road	1	9.10 ± 0.60	0.10 ± 0.10	1.50 ± 0.10
	2	14.40 ± 0.65	0.00 ± 0.00	0.60 ± 0.10
	3	3.70 ± 0.20	0.40 ± 0.10	1.30 ± 0.10
	4	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Ledger	1	2.80 ± 0.40	0.10 ± 0.00	0.20 ± 0.10
	2	3.80 ± 0.20	0.00 ± 0.00	2.30 ± 0.20
	3	2.70 ± 0.30	0.30 ± 0.10	0.70 ± 0.10
	4	3.60 ± 0.30	0.50 ± 0.10	1.30 ± 0.10

Table 2. Mean (± SE) number of *Bathyplectes* spp. adults and, *Aphidius* spp. adults and mummies recorded per 20 sweeps in alfalfa fields in Pondera County, MT, 2016

Field Location	**Sampling Dates**	***Bathyplectes* spp. Adults**	***Aphidius* spp. Adults and Mummies**
Conrad	1	0.40 ± 0.07	1.30 ± 0.14
	2	0.01 ± 0.01	0.48 ± 0.07
	3	0.00 ± 0.00	0.35 ± 0.06
	4	0.00 ± 0.00	2.44 ± 0.24
Valier	1	1.43 ± 0.60	0.80 ± 0.10
	2	0.02 ± 0.02	0.17 ± 0.07
	3	0.12 ± 0.04	1.44 ± 0.14
	4	0.00 ± 0.00	0.16 ± 0.04
Ledger	1	0.47 ± 0.09	0.94 ± 0.13
	2	0.01 ± 0.01	0.48 ± 0.07
	3	0.14 ± 0.05	4.00 ± 0.40
	4	0.09 ± 0.05	1.05 ± 0.15
Bullhead Road	1	0.90 ± 0.20	1.50 ± 0.20
	2	0.00 ± 0.00	0.00 ± 0.00
	3	0.00 ± 0.00	2.00 ± 0.20
	4	0.00 ± 0.00	0.00 ± 0.00
Ledger	1	0.05 ± 0.03	1.14 ± 0.11
	2	0.01 ± 0.01	0.35 ± 0.07
	3	0.0 ± 0.00	1.10 ± 0.20
	4	0.00 ± 0.00	0.30 ± 0.10

Predators

Two predators were recorded from all study sites: 1) damsel bugs (*Nabis* spp.) which prey on aphids and alfalfa weevil larvae, and 2) coccinellids (*Coccinella* spp.) that prey mostly on aphids but also on alfalfa weevil larvae. Nearly similar level of damsel bugs population were seen in all study sites with relatively high population after first cutting (Table 3). Similar trend was also recorded for coccinellids (Table 3).

Table 3. Mean (± SE) number of *Nabis* spp. adults and, *Coccinella* spp. adults and larvae recorded per 20 sweeps in alfalfa fields in Pondera County, MT, 2016.

Field Location	**Sampling Dates**	***Nabis* spp. Adults**	***Coccinella* spp. Adults and Larvae**
Conrad	1	0.22 ± 0.04	1.40 ± 0.10
	2	0.20 ± 0.04	1.12 ± 0.13
	3	0.41 ± 0.06	0.59 ± 0.08
	4	1.11 ± 0.12	2.38 ± 0.20
Valier	1	0.57 ± 0.08	1.09 ± 0.12
	2	0.14 ± 0.04	1.58 ± 0.15
	3	1.48 ± 0.14	1.05 ± 0.14
	4	2.00 ± 0.16	3.88 ± 0.23
Ledger	1	0.42 ± 0.07	1.00 ± 0.11
	2	0.19 ± 0.04	0.75 ± 0.10
	3	0.83 ± 0.12	0.83 ± 0.14
	4	0.79 ± 0.10	5.26 ± 0.36
Bullhead Road	1	0.19 ± 0.04	0.97 ± 0.11
	2	0.16 ± 0.04	0.73 ± 0.09
	3	1.06 ± 0.09	0.60 ± 0.08
	4	-	-
Ledger	1	0.23 ± 0.04	0.63 ± 0.08
	2	0.11 ± 0.03	0.67 ± 0.10
	3	0.65 ± 0.09	0.56 ± 0.08
	4	1.46 ± 0.12	4.01 ± 0.27

Acknowledgements

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MONTANA STATE UNIVERSITY
College of AGRICULTURE & MONTANA AGRICULTURAL EXPERIMENT STATION

Agronomy and Soil Nutrient Management Program

WESTERN TRIANGLE AGRICULTURAL CENTER
AGRONOMY AND NUTRIENT MANAGEMENT PROGRAM
PROGRAM HEAD: Dr Roger Ondoua

2016 ANNUAL REPORT

From the spring through fall 2015, the Agronomy and Nutrient Management Program conducted nine experiments in the fields of agronomy, cropping systems, soil fertility and salinity, and nutrient management.

STUDY 1: Sustainable Cropping Systems for Dual-Purpose Biennial Winter Canola.

SPONSOR: NIFA/WSARE

Principal Investigator: Dr Roger Ondoua, Western Triangle Agricultural Research Center.
Research Assistant: Phillip Hammermeister, Western Triangle Agricultural Research Center.
Farmer Cooperators: Steve Keil (Conrad, MT); Paul Kronebusch (Vallier, MT)

1.1. Objectives: Evaluate the effects of N and S Fertilization Strategies; Rotation Type; and Purpose Type on winter canola:

1.2. Methods:

The experiment was set up at the Northern Agricultural Research Center in Havres in Summer, 2015 under the irrigation system. The experimental design was a split-split-plot factorial with the rotation type as the main factor, the type of purpose as the subplot factor, and the N and S fertilization strategies as the sub-sub-plot factor. Biennial winter canola HyCLASS® 115W was seeded on August 31, 2015. On September 14, 2015, "forage and grain" plots were grazed by 20 bulls.

1.2.1. N and S fertilization strategies:

1) Control
2) 200 lb N/ac (manure)
3) 200 lb N/ac (compost)
4) 100 lb N + 40 lb S/ ac (inorganic)
5) 200 lb N + 40 lb S/ ac (inorganic)
6) 300 lb N + 40 lb S/ ac (inorganic)
7) 200 lb N/ac (manure + compost)

1.2.2. Type of rotation (Figure 1):

1) Fresh pea-winter canola
2) Fallow-winter canola

1.2.3. Type of purpose (Figure 2)

1) Forage + Grain
2) Grain only

***Figure 1**. Organic amendment of the Conrad field. From left to right and top to bottom, green manure incorporation; cow manure spreading and incorporation; compost spreading and layout of the field.*

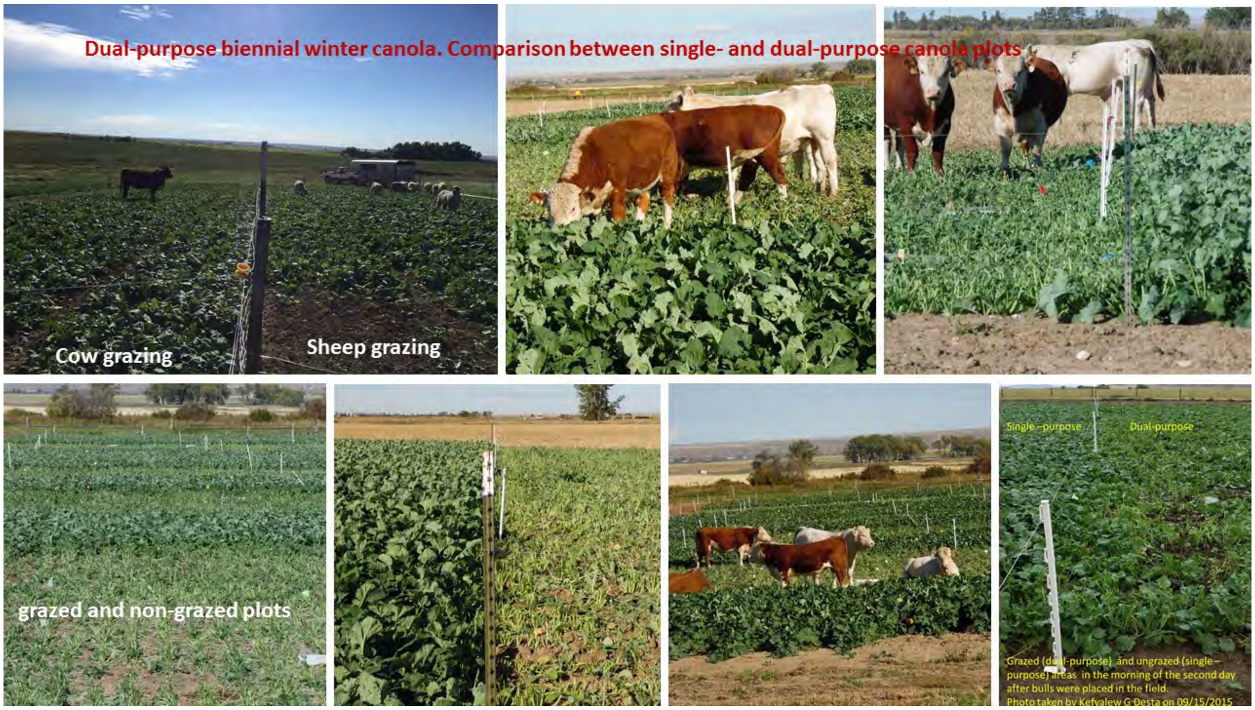

***Figure 2**. Cows and sheep grazing canola experimental plots*

1.3. Results

1.3.1. Effect of fertilization strategies on canola grain and forage yields, and plant density

There were significant differences between the various N and S fertilization strategies. The highest grain yields, irrespective of the purpose or rotation types, were obtained when canola was fertilized at the rate of 200 pounds of nitrogen per acre supplied by cow manure (Treatment 2), and 300 pounds of nitrogen and 40 pound of sulfur per acre supplied by urea and ammonium sulfate (Treatment 6) (**Figure 3**)

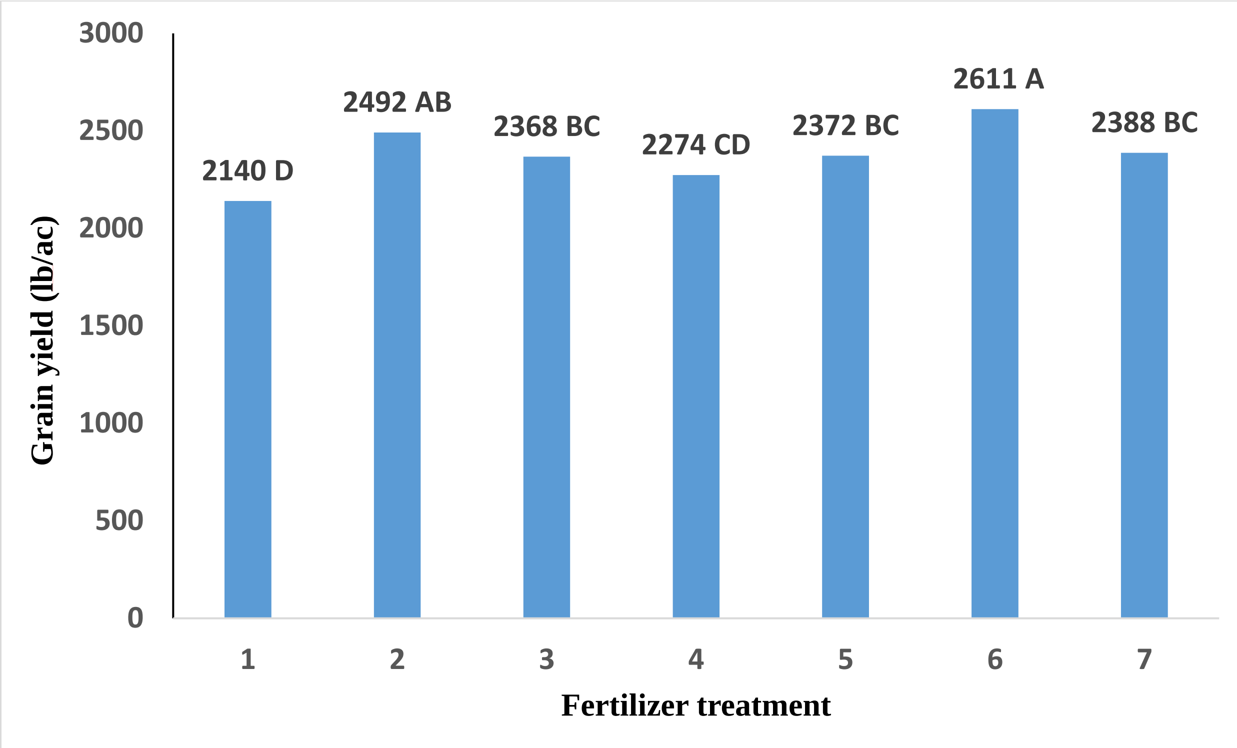

Figure 3. *Grain yield response of biennial winter canola to N and S sources and rates. Treatments:* ***1*** *= control;* ***2*** *= 200 lbs N/ac by cow manure;* ***3*** *= 200 lbs N/ac by compost (municipal wastes);* ***4*** *= 100 lbs N/ac + 40 lbs S/ac by urea and ammonium sulfate;* ***5*** *= 200 lbs N/ac + 40 lbs S/ac by urea and ammonium sulfate;* ***6*** *= 300 lbs N/ac + 40 lbs S/ac by urea and ammonium sulfate;* ***7*** *= 200 lbs N/ac by cow manure + compost. Treatments followed by the same letter are not statistically different at α = 5%.*

Fertilizer treatments affected canola forage yield and plant density. Organic amendments and moderate amount of inorganic fertilizers (100 lb N/ac) produced the highest hay yields and plant density, whereas higher amounts of mineral nitrogen (200 and 300 lb N/ac) resulted in lower plant density (**Figure 4**)

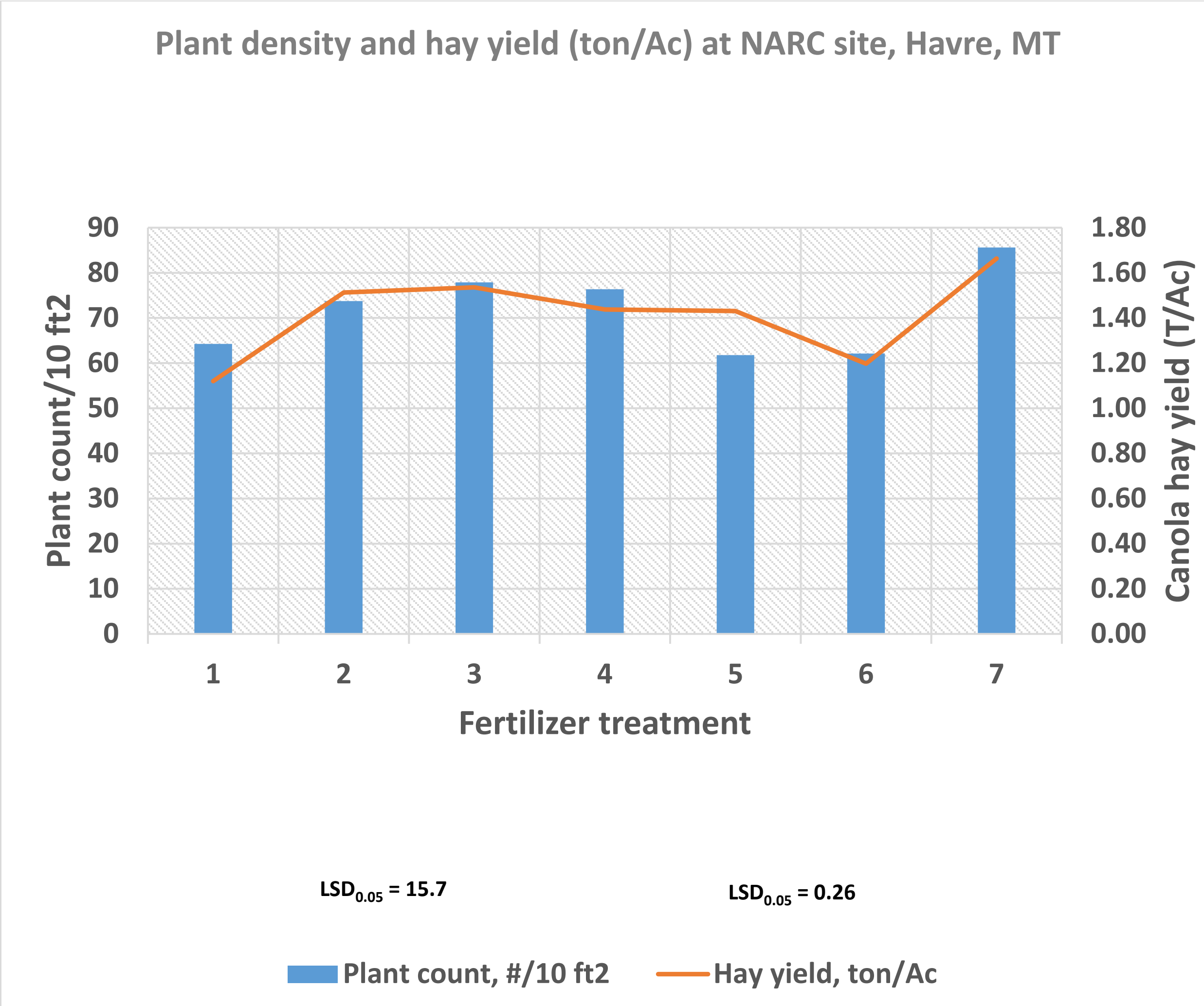

Figure 4*. Forage yield response of biennial winter canola to N and S sources and rates. Treatments:* ***1*** *= control;* ***2*** *= 200 lbs N/ac by cow manure;* ***3*** *= 200 lbs N/ac by compost (municipal wastes);* ***4*** *= 100 lbs N/ac + 40 lbs S/ac by urea and ammonium sulfate;* ***5*** *= 200 lbs N/ac + 40 lbs S/ac by urea and ammonium sulfate;* ***6*** *= 300 lbs N/ac + 40 lbs S/ac by urea and ammonium sulfate;* ***7*** *= 200 lbs N/ac by cow manure + compost.*

1.3.2. Effect of grazing on winter canola grain yield, tiller number, and plant height.

Grazing canola in the fall significantly increased grain yield by nearly 500 pounds per acre (**Figure 5**), tiller number by 4 tillers/m^2(**Figure 6**), and the average plant height by 4 inches (**Figure 7**).

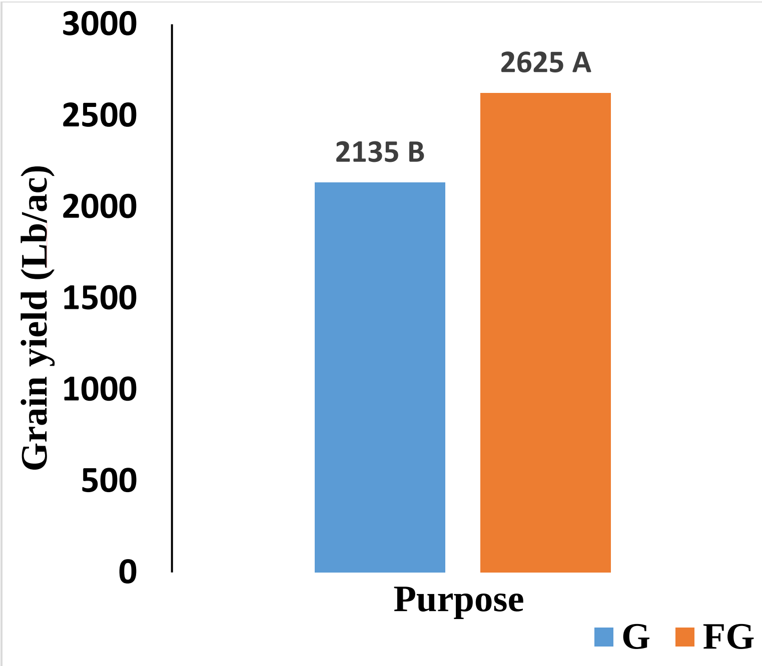

Figure 5. *Grain yield response of biennial winter canola to fall grazing. G = Grain only; FG = Forage + Grain. FG plots are those grazed in the fall 2015 by bulls, then harvested in the summer 2016 for the canola grain. Treatments topped by different letters are statistically different at α = 5%.*

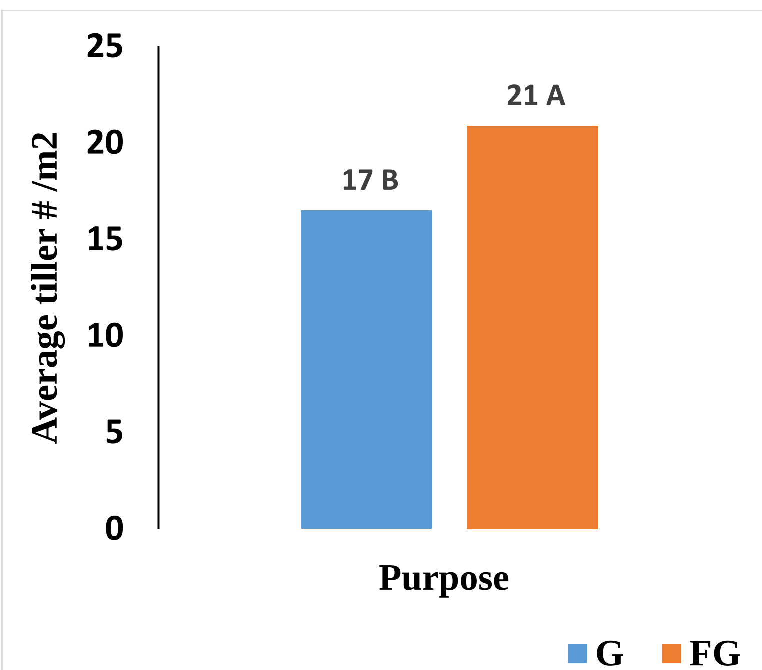

Figure 6. *Tillering response of biennial winter canola to fall grazing. G = Grain only; FG = Forage + Grain. FG plots are those grazed in the fall 2015 by bulls, then harvested in the summer*

2016 for the canola grain. Treatments topped by different letters are statistically different at α = 5%.

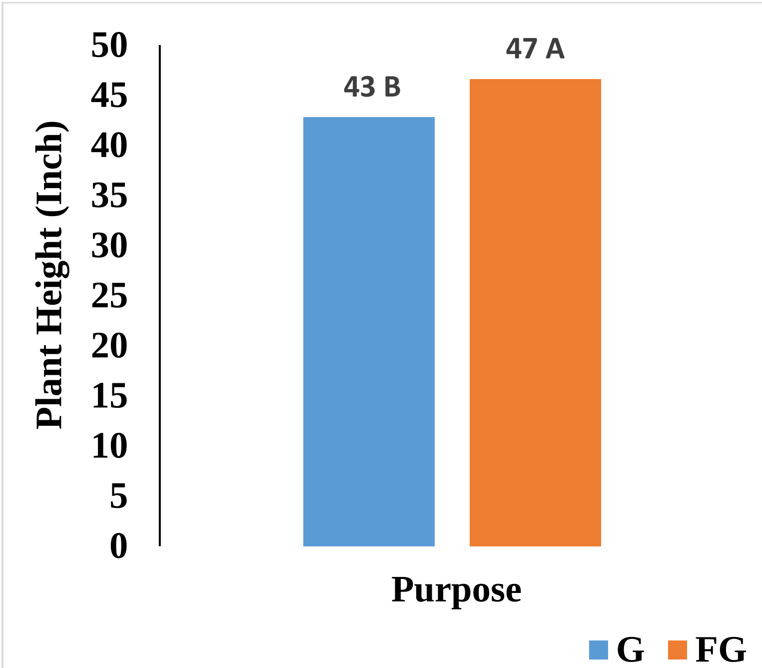

Figure 7. *Plant height response of biennial winter canola to fall grazing. G = Grain only; FG = Forage + Grain. FG plots are those grazed in the fall 2015 by bulls, then harvested in the summer 2016 for the canola grain. Treatments topped by different letters are statistically different at α = 5%.*

STUDY 2: Effect of soil water storage on total grain and protein yields of pea-whiter wheat, lentil-winter wheat, and barley-winter wheat rotations.

SPONSOR: MONTAN WHEAT AND BARLEY COMMITTEE

Principal Investigator: Dr Roger Ondoua, Western Triangle Agricultural Research Center.
Research Assistant: Phillip Hammermeister, Western Triangle Agricultural Research Center.

2.1. Objectives:

- To determine grain and protein yield responses of pea-winter wheat, lentil-winter wheat, and barley-winter wheat sequences to soil moisture content.
- To determine the relationships between grain and protein yields of pea-winter wheat, lentil-winter wheat, and barley-winter wheat sequences and the independent variables soil moisture, in-season precipitations, and evapotranspiration.

- To determine the relationships between grain and protein yields of pea-winter wheat, lentil-winter wheat, and barley-winter wheat sequences and the independent variables soil moisture, in-season precipitations, and evapotranspiration.

- To study the profitability of pea-winter wheat, lentil-winter wheat, barley-winter wheat, winter wheat-fallow, and continuous winter wheat crop sequences under different scenarios of soil moisture.

2.2.Methods:

At the Western Triangle Agricultural Research Center, a 400 x 100-feet field was fall-recharged using a gradient irrigation which created a soil moisture gradient along the field. Thus, five 55 x 100-feet blocks with average gravimetric soil moisture contents ranging from 15% (control-block with no supplemental recharge) to 22% were created through the 0-4 feet soil profile (**Figure 8**). The treatments, laid out in a randomized complete block design, consisted of five crop sequences: pea-winter wheat, lentil-winter wheat, barley-winter wheat, continuous winter wheat, and winter wheat-fallow. In September 2015, winter wheat plots were seeded after soil sampling at 0-4 feet soil depth. In April 2016, pea, lentil, and barley plots were seeded following soil sampling at 0-4 feet soil depth. All the plots were harvested in August 2016, and reseeded with winter wheat in October 2016.

2.3.Results:

Results of the first year of this research show that pea, lentil, barley and wheat grain yields were influenced by the five soil moisture regimes (Figure 9); and evapotranspiration over cropped plots was lower at the lowest soil moisture contents. In September 2016, winter wheat (WW)was seeded in plots previously cropped with pea, lentil, and barley. The FY 2017 funding shall allow the estimation of winter wheat's yields and the total yield of each rotation type (pea-WW, lentil-WW, barley-WW) as well. A multivariate analysis will be conducted in 2017 to evaluate the relationship between the total grain yield of the rotation and the soil water content in 2016, evapotranspiration, and in-season precipitations.

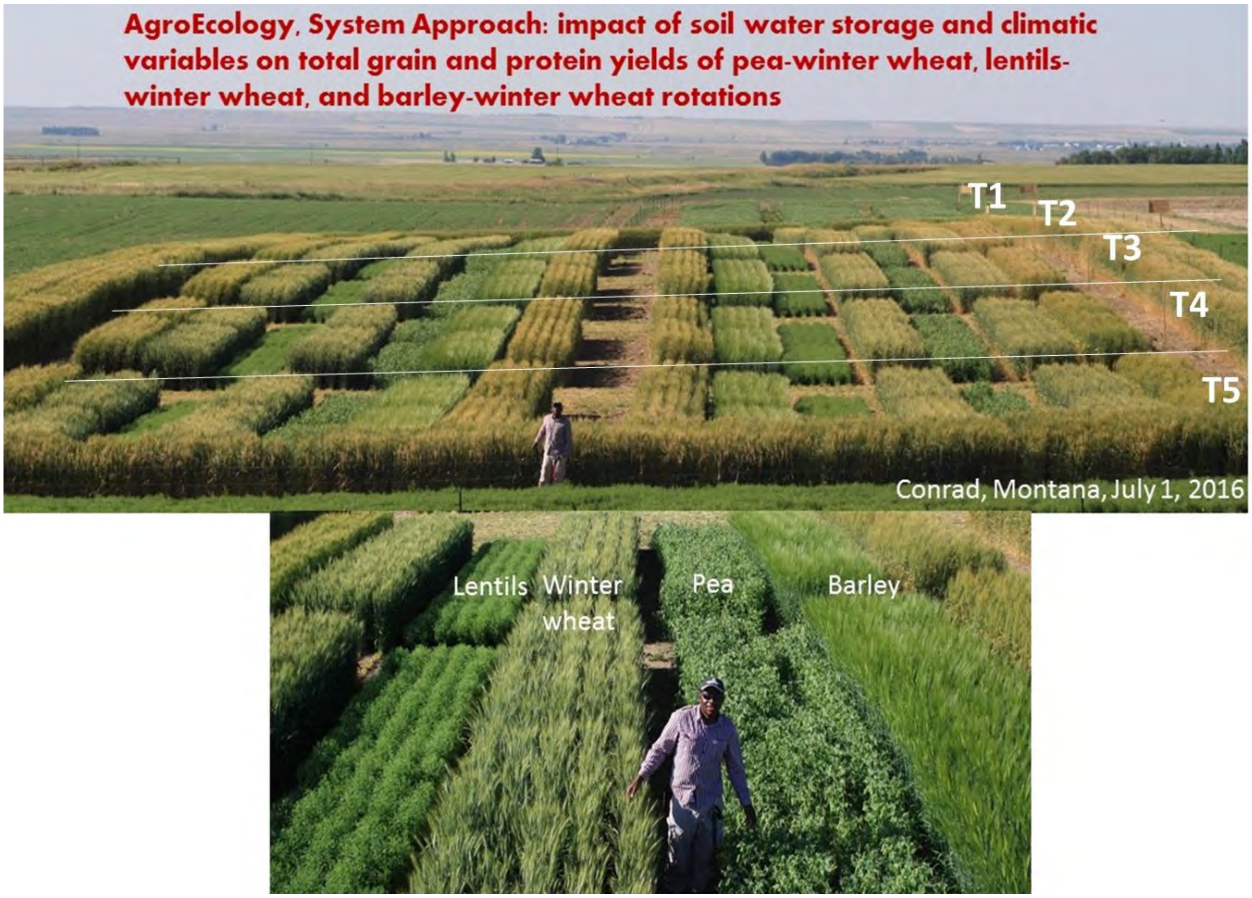

Figure 8. *Field strips (T_1, T_2, T_3, T_4, T_5) with different soil moisture contents created following a gradient irrigation method. T_2, through T5, received increasing amount of irrigation water. T_1 = control (No irrigation water)*

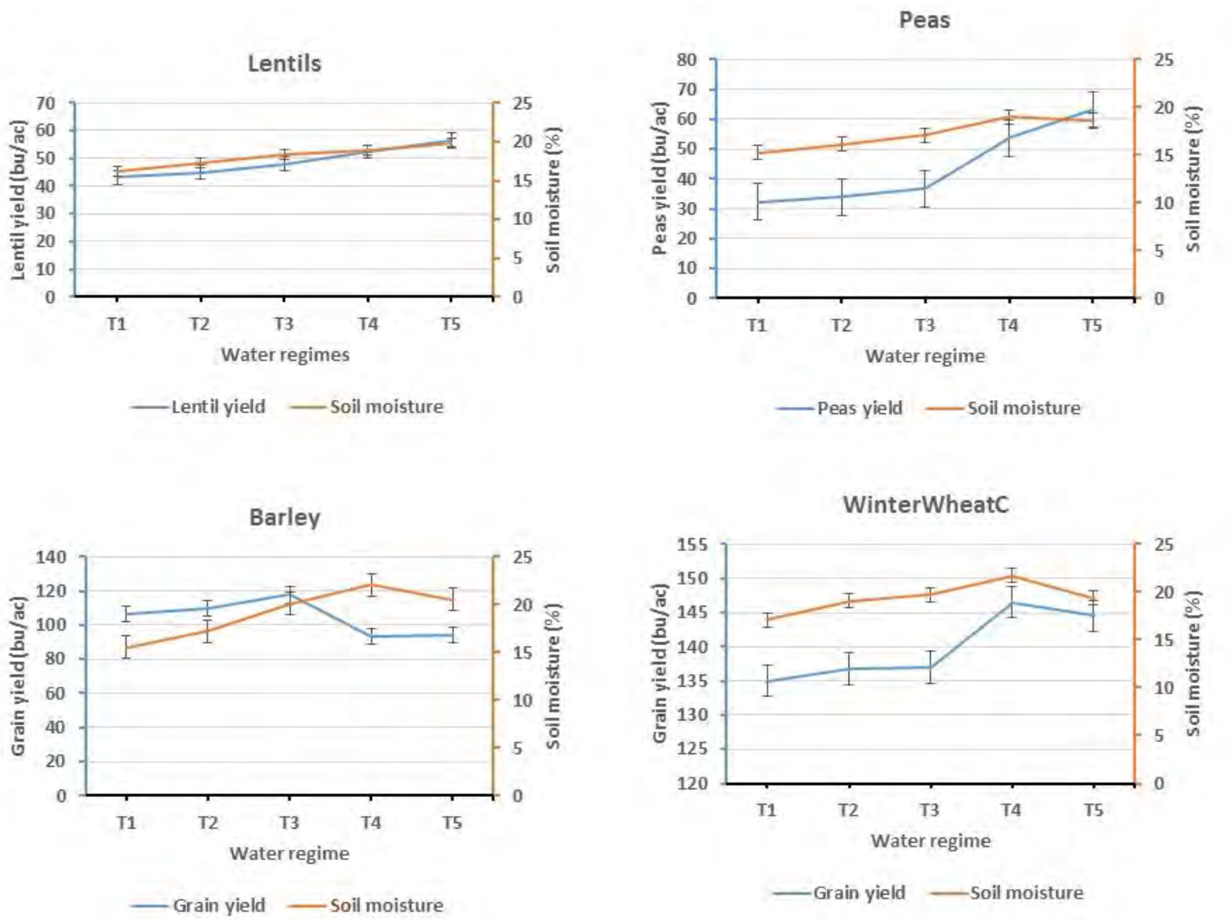

Figure 9. *Relationships between grain yields of pea, lentil, barley, and winter wheat and soil moisture content in the 0-4 ft soil profile.*

STUDY 3: Varietal Nitrogen and Water Use Efficiency Differences in two Montana Cropping Systems.

SPONSOR: MONTAN WHEAT AND BARLEY COMMITTEE

Principal Investigator: Dr Roger Ondoua, Western Triangle Agricultural Research Center.
Research Assistant: Phillip Hammermeister, Western Triangle Agricultural Research Center.

3.1. Objective: this study aimed at evaluating both nitrogen and water use efficiencies of five varieties of spring wheat (Vida, Duclair, Corbin; WB 9668; and WB Gunnison) as related to two Montana cropping systems, Continuous Cropping, and Crop-Fallow.

Expected outcomes:

- Identification of the spring wheat variety with the greatest nitrogen and/or water use efficiency.

- Determination of total nitrogen loss to the environment.

- Determination of N, P, K removal rates.

3.2. Methods: the experiment was conducted in the spring 2016 at four sites of the Montana Western Triangle, Valier and Ledger. At each location, the experimental site included two adjacent fields, one of which was a spring wheat fallow, and the other a recently-cropped field (**Figure 10**). The experimental design was a split-split-plot in a randomized complete block design with four repetitions. The main plot factor was cropping system with two levels (Fallow-Crop, Continuous Cropping), the sub-plot factor was spring wheat variety with five levels, and the sub-sub-plot factor was nitrogen rate with four levels (0; 50; 100; and 150 lbs N/ac). Before seeding, thirty soil cores were sampled and then composited from each of the 16 blocks of each field. Succion lysimeters were placed at 4 feet-depth at the center of each plot, and each individual plot was soil and tissue-sampled at harvest.

***Figure 10**. Layout of the water and nitrogen use efficiency study in Valier and Ledger.*

3.3. Results

704 soil samples and 640 tissue samples were collected, processed, and shipped for analysis to a commercial laboratory. Tests results are not yet available.

STUDY 4: Evaluation of four seed coating compounds for the establishment of winter wheat in saline soils.

SPONSOR: P.I. Bioscience Limited

Principal Investigators: Dr Roger Ondoua, Assistant Professor, Agronomy and Nutrient Management, MAES/Western Triangle Agricultural Research Center (WTARC).

Collaborator: Phillip Hammermeister, Research Assistant, Western Triangle Agricultural Research Center;

Farmer Cooperator: Barry Wharram, Highwood, MT.

4.1. Objective: to test prototype seed coating compounds designed to enhance the establishment of winter wheat in saline soils.

4.2. Methods: four seed coating compounds from P.I. Bioscience Limited were applied to seed of Yellowstone winter wheat variety at the rate of 5 litres/ton seed (Figure 11) at the WTARC's seed laboratory. The trial was located around the Wharram saline seep in September 2015, in Highwood, Chouteau County of Montana (Figure 4). The experimental design was a split-split-plot in a randomized complete block design with four repetitions. The main factor was soil electrical conductivity (EC) with two levels (High and Low EC); the sub-plot factor was seeding rate with two levels (normal and late seeding dates); and the sub-sub-plot factor was seed coating compound with four levels (A, B, C, D) that included a control. Four high EC blocks, with EC values ranging from 5 to 15 mmhos/cm, were set up around the eye of the saline seep; while four low EC blocks, with values ranging from 0.3 to 1.18mmhos/cm, were set up further inland.

Figure 11. Chemically-coated and non-coated Yellowstone seeds

4.3 Results:

The analysis of variance of grain yield shows that there were no significant differences among treatments, which included a control (**Figure 12**). The average seedling emergence, tiller number, and grain yield of treated seeds were significantly lower (by 13, 6, and 59 units, respectively) in high salinity plots (EC 5 – 15 mmhos/cm) than in low salinity plots (EC 0.3 – 1.17 mmhos/cm) (**Figures 13, 14, 15**). Finally, when the grain yields from treated seeds were plotted against corresponding ECs, grain yields on average linearly decreased with increased electrical conductivity in the soil (**Figure 16**).

All these results suggest that the chemical treatment of winter wheat seeds did not improve their establishment in high salinity soils.

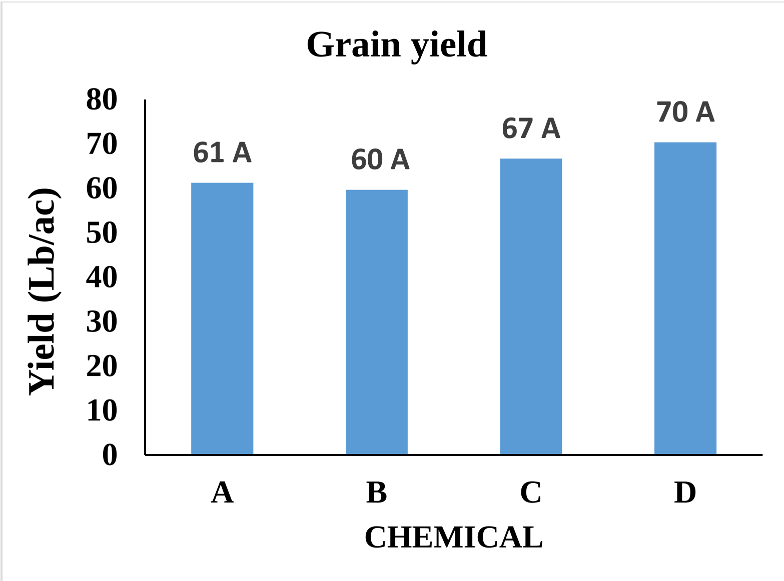

Figure 12. *Grain yield of winter wheat in relation to chemical treatment of seeds*

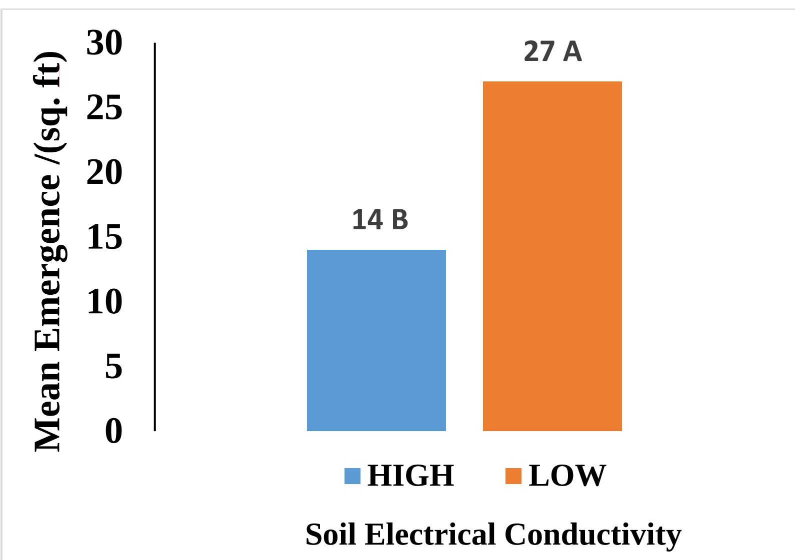

Figure 13. *Relationship between average seedling emergence of chemically treated seeds in relation to soil salinity (High: EC between 5 – 15 mmhos/cm; Low: Ec between 0.3 – 1.17 mmhos/cm)*

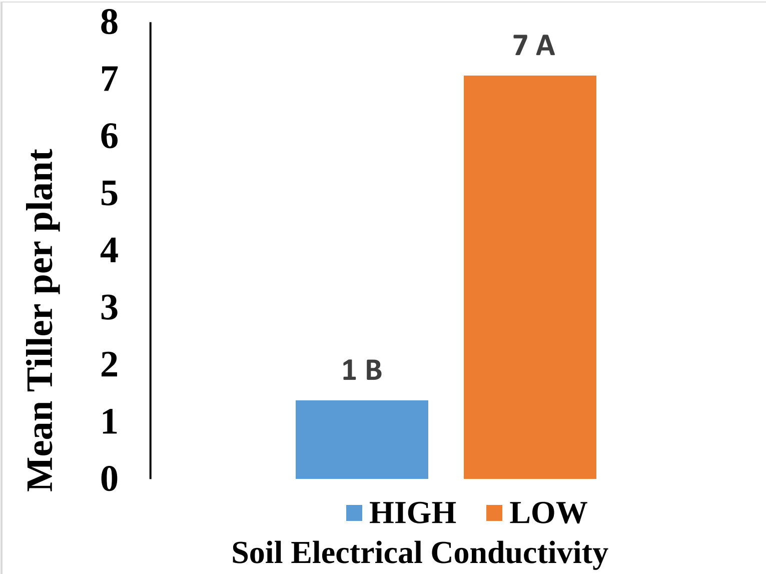

Figure 14. *Relationship between average tiller number of chemically treated seeds in relation to soil salinity (High: EC between 5 – 15 mmhos/cm; Low: Ec between 0.3 – 1.17 mmhos/cm)*

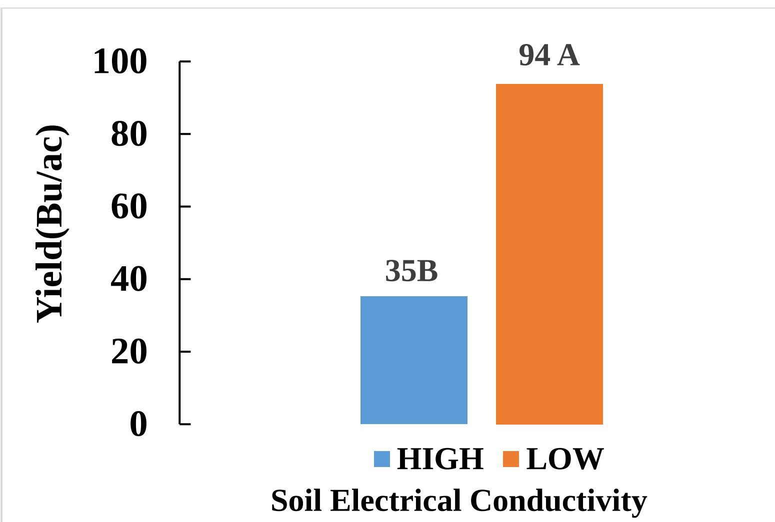

Figure 15. *Relationship between grain yield of chemically treated seeds in relation to soil salinity (High: EC between 5 – 15 mmhos/cm; Low: Ec between 0.3 – 1.17 mmhos/cm)*

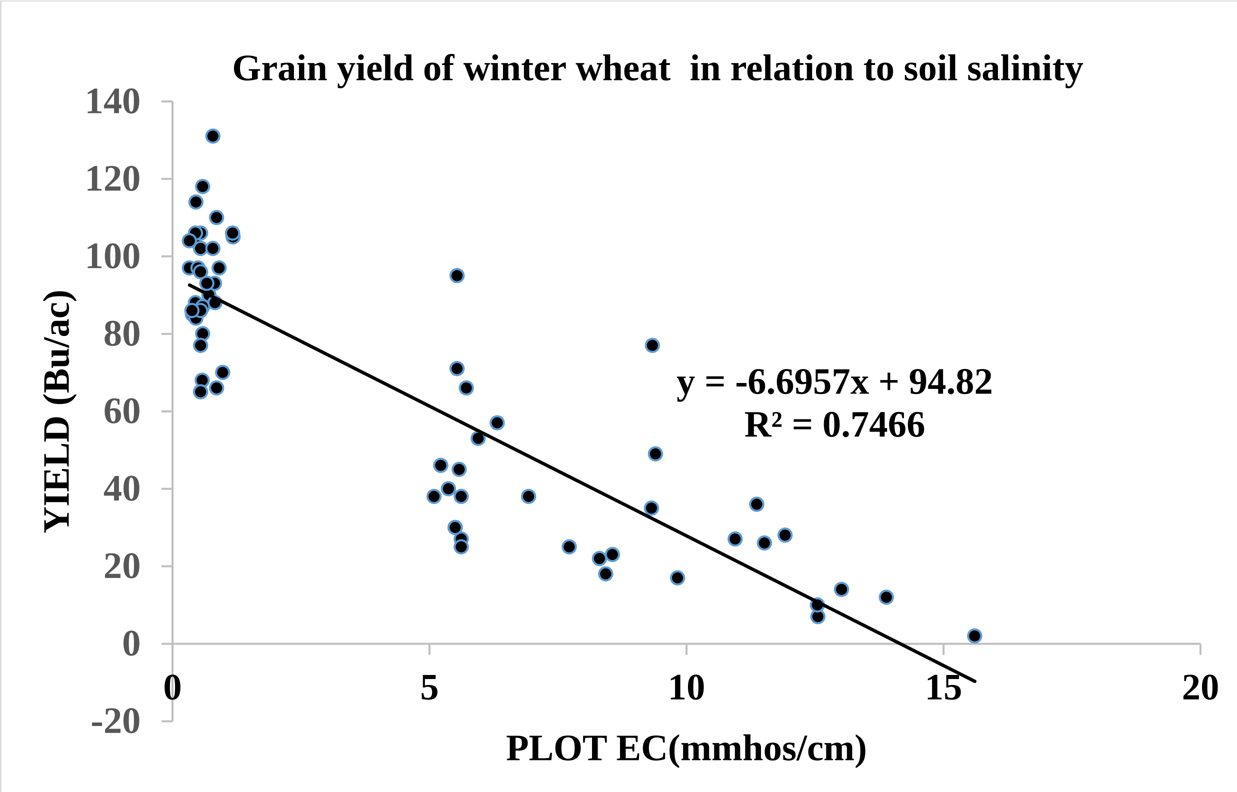

Figure 16. *Relationship between grain yield of chemically treated seeds and soil electrical conductivity (EC)*

STUDY 5: Pea Variety Trial

SPONSOR: Montana University System Research Initiative: 51040-MUSRI2015-02

Principal Investigator: Dr Roger Ondoua, Western Triangle Agricultural Research Center.
Research Assistant: Phillip Hammermeister, Western Triangle Agricultural Research Center.

Twenty-four yellow pea, and eighteen green pea varieties were evaluated in Conrad, at the Western Triangle Agricultural Research Center in 2016 for yield, test weight, plant height, and flowering date. For the yellow peas, the average yield was 4039 lb/ac and eleven varieties performed above this average (**Table 1**). Cultivar NETTE 2010 had the highest yield (5329 lb/ac). Regarding the green peas variety trial, the average yield in Conrad was 4003 lb/ac, 9 varieties performed above the average with cultivar PRO-131-6221 outperforming (5106 lb/ac) the set of tested green pea cultivars (**Table 2**).

***Table 1**. Performances of yellow pea varieties in 2016 at the Western Triangle Agricultural Research Center in Conrad*

Yellow pea variety/line	Grain Yield (lb/ac)	Test Weight (lb/bu)	Plant Height (cm)	Number of days to flowering*
AAC CARVER	2985	64.10	58	67
AAC LACOMBE	2984	62.78	52	68
AC EARLYSTAR	4852	64.03	57	65
ABARTH	3841	62.95	58	64
AGASSIZ	3863	60.33	50	65
BRIDGER	4223	61.35	47	64
CDC AMARILLO	3960	64.00	56	65
CDC SAFFRON	4367	61.05	57	66
CDC TREASURE	3434	63.55	74	64
DS ADMIRAL	3239	61.90	59	65
DELTA	3933	62.18	58	62
DURWOOD	3988	63.08	70	64
GUNNER	4606	65.20	55	66
HYLINE	3929	65.35	56	65
JET SET	3350	60.53	59	
KORANDO	4394	60.63	58	58
NAVARRO	4283	62.88	58	58
NETTE 2010	5329	64.93	63	60
PSO826MT460	4286			64

PSO826MT492		**61.33**	**56**	
PSO877MT632	**3330**	**63.60**	**50**	**65**
PRO 093-7410	**4758**	**64.05**	**54**	**61**
SALAMANCA	**4191**	**64.27**	**47**	**64**
SPIDER	**4666**	**62.83**	**57**	**66**
Mean	**4039**	**62.84**	**57**	**64**
P-Value	**0.0001**	**0.2640**	**<0.0001**	**<0.0001**
LSD (0.05)	**1072**	**Ns**	**5.1**	
CV (%)	**18.78**	**4.05**	**6.31**	

Table 2. *Performances of green pea varieties in 2016 at the Western Triangle Agricultural Research Center in Conrad*

Green pea variety/line	Grain Yield (lb/ac)	Test Weight (lb/bu)	Plant Height (cm)	Number of days to flowering*
ARAGON	**4939**	**64.20**	**48**	**64**
ARCADIA	**4838**	**64.35**	**41**	
BANNER	**3706**	**62.63**	**51**	**64**
CDC PATRICK	**2944**	**64.77**	**54**	
CDC RAEZER	**2764**	**64.55**	**68**	**64**
CRUISER	**2923**	**63.25**	**61**	**64**
GINNY	**3696**	**64.73**	**53**	**65**
GREENWOOD	**3863**	**64.35**	**53**	**66**
HAMPTON	**3923**	**63.88**	**54**	

LN 1123	4089	61.73	54	
MAJORET	2367	62.20	54	
PSO826MT190	4386	61.00	54	64
PSO877MT076	4231	62.17	52	64
PSO877MT499	4670	62.80	51	66
PRO 131-6221	5106	63.43	50	65
PRO 131-7123	4730	62.95	52	65
PRO 131-7125	4643	63.45	50	66
VIPER	3636	62.90	53	66
Mean	4003	63.38	53	65
P-value	0.0004	0.1608	<0.0001	<0.0001
LSD (0.05)	1173	Ns	3.6	
CV (%)	20.71	2.52	4.78	

STUDY 6: Chickpea Variety Trial

SPONSOR: Montana University System Research Initiative: 51040-MUSRI2015-02

Principal Investigator: Dr Roger Ondoua, Western Triangle Agricultural Research Center.
Research Assistant: Phillip Hammermeister, Western Triangle Agricultural Research Center.

Eight chickpea cultivars were evaluated in Conrad, at the Western Triangle Agricultural Research Center in 2016 for yield and test weight. The average yield was 3963 lb/ac and three varieties performed above this average (**Table 3**). Cultivar CDC Frontier had the highest yield (5463 lb/ac).

***Table 3**. Performances of chickpea varieties in 2016 at the Western Triangle Agricultural Research Center in Conrad*

Variety/lines	Grain Yield (lb/ac)	Test Weight (lb/bu)
BGC090017	4538	55.28
CDC Alma	3172	56.65
CDC Frontier	5463	57.23
CDC Leader	4741	56.40
CDC Orion	3662	52.20
Myles	3306	46.28
Sawyer	3611	57.05
Sierra	3215	57.18
Mean	3963	54.78
P-Value	<0.0001	0.0009
LSD (0.05)	754	4.70
CV (%)	13.45	5.84

STUDY 7: Lentil Variety Trial

SPONSOR: Montana University System Research Initiative: 51040-MUSRI2015-02

Principal Investigator: Dr Roger Ondoua, Western Triangle Agricultural Research Center.
Research Assistant: Phillip Hammermeister, Western Triangle Agricultural Research Center.

Eight lentil cultivars were evaluated in Conrad, at the Western Triangle Agricultural Research Center in 2016 for yield and test weight. The average yield was 2636 lb/ac and five varieties performed above this average (**Table 4**). Cultivar CDC Richlea had the highest yield (3288 lb/ac).

Table 4*. Performances of lentil varieties in 2016 at the Western Triangle Agricultural Research Center in Conrad*

Variety/lines	Grain Yield (lb/ac)	Test Weight (lb/bu)	Number of days to flowering
AVONDALE	2226	58.52	65
CDC RICHLEA	3288	57.63	63
CDC IMI-GREEN	1491	48.75	65
CDC IMVINCIBLE CL	3033	60.00	64
EAGLE	2310	57.40	64
CDC VICEROY	3059	61.25	66
CDC IMPALA CL	2986	61.20	63
CDC REDCOATS	2701	58.10	66
Mean	2636	57.86	64
P-Value	<0.0001	<0.0001	0.0048
LSD (0.05)0	550	3.01	3.5
CV (%)	14.20	3.63	3.71

STUDY 8: Durum Wheat Variety Trial

SPONSOR: Montana University System Research Initiative: 51040-MUSRI2015-02

Principal Investigator: Dr Roger Ondoua, Western Triangle Agricultural Research Center.
Research Assistant: Phillip Hammermeister, Western Triangle Agricultural Research Center.

Fourteen Durum wheat cultivars were evaluated in Conrad, at the Western Triangle Agricultural Research Center in 2016 for yield, test weight, height and flowering date. The average yield was 47 Bu/ac and six varieties performed above this average (**Table 4**). Cultivar MT101694 had the highest yield (60.5 Bu/ac).

Table 5*. Performances of Durum wheat varieties in 2016 at the Western Triangle Agricultural Research Center in Conrad*

Variety	Height (Inch)	Flowering Date (Day)	Test Weight (lb/Bu))	Yield (Bu/ac)
CARPIO	27.7 A	73.0 D	54.40 A	52.80 AB
TIOGA	27.7 A	71.0 F	45.93 AB	52.13 AB
DIVIDE	27.0 AB	72.0 D	43.75 AB	47.46 ABC
MT112434	26.3 ABC	76.0 B	49.33 AB	40.70 BC
MOUNTRAIL	26.3 ABC	70.0 G	28.90 C	32.26 C
JOPPA	25.7 ABC	71.0 F	42.46 AB	57.63 AB
MT101694	25.0 BCD	74.0 C	49.86 AB	60.53 A
MT112444	24.7 BCD	74.0 C	51.56 AB	45.53 ABC
ALKABO	24.7 BCD	73.0 D	46.90 AB	44.60 ABC
SILVER	24.7 BCD	71.0 F	44.56 AB	45.26 ABC
GRENORA	24.0 CDE	72.0 E	40.90 B	46.36 ABC

MT112463	**22.7 DEF**	**74.0 C**	**44.66 AB**	**40.80 BC**
MT101717	**22.0 EF**	**74.0 C**	**51.0 AB**	**54.20 AB**
MT112219	**21.7 F**	**79.0 A**	**54.53 A**	**44.33 ABC**
MEAN	**25.0**	**73.1**	**47.27**	**47.28**
P value	**<.0001**	**<.0001**	**0.0648**	**0.11**
LSD(0.05)	**2.04**	**2.04**	**2.05**	**2.04**
CV(%)	**5.19**	**0.62**	**13.40**	**20.95**

STUDY 9: Cool season Cover Crops Variety Trial

SPONSOR: Montana University System Research Initiative: 51040-MUSRI2015-02

Principal Investigator: Dr Roger Ondoua, Western Triangle Agricultural Research Center.
Research Assistant: Phillip Hammermeister, Western Triangle Agricultural Research Center.

Fourteen cover crops and cocktail of cover crops were evaluated in Conrad, at the Western Triangle Agricultural Research Center in 2016 for dry biomass yield at the onset of flowering.

Table 6*. Dry weights of cover crops and cocktails of cover crops in 2016 at the Western Triangle Agricultural Research Center in Conrad*

Variety	**Biomass (lb/ac, dwt)**
OTANA OAT	**5694 A**
BALDY SPINELESS SUNFLOWER	**3028.1 B**
MIX DIVERSITY EARLY	**2513.6 BC**
MIX COOL EARLY	**2273 BC**
HAIRY VETCH, COMMON	**2194.4 BC**
ARVIKA PEA	**2169.2 BC**
PURPLE TOP TURNIP	**2001.3 BC**

DKL30-42 CANOLA	**1915.2BC**
WB GUNNISON	**1627.2 BC**
TRITICALE, SPRING	**1611.6 BC**
MIX WARMEARLY	**1512.3 BC**
ALSIKE CLOVER, COMMON	**1171.7 C**
OMEGA FLAX	**1094 C**
GROUND HOG RADISH	**828.6 C**
MEAN	**2134.1**
P VALUVE	**<.0001**
LSD(0.05)	**2.03**
CV(%)	**44.89**

MIX DIVERSITY EARLY: *Ground Hog Radish; Purple Top Turnip; Spring Pea; FabaBean; Chickpea; Canola; Spineless Safflower; Oat; Sorghum;* **MIX COOL EARLY:** *Radish; Purple Top Turnip; Spring Pea; Canola; Spineless Safflower; Oat;* **MIX WARM EARLY***: Radish; Purple Top Turnip; Chickpea; FabaBean; Sunflower; Sorghum.*