Renewable Energy Crop Sequences for Northeastern Colorado Dryland Production
Final Report

A. Project overview

Dryland crop production is of major importance in Colorado. Dryland farms occupy 5,000,000 acres and represent 74% of total crop land and 60% total sales. Winter wheat produced in combination with summer fallow (WF) has historically been the predominant dryland cropping system in Colorado. However, the wheat-fallow system is economically and environmentally fragile. Economically, the WF system is fragile due to the lack of diversification and the large amount of fallow land not in production annually. Environmentally, the WF systems are vulnerable to wind erosion and loss of soil organic matter in a typical summer fallow system. Research over the last 15 years has shown strong economic advantage to producers who reduce the frequency of fallow by intensifying dryland crop rotation. For example, a winter wheat-corn-summer fallow (WCF) or winter wheat-proso millet-summer fallow (WMF) are more intensive rotations that produce consistently higher yields on the same amount of precipitation and in turn increase net returns to the producer. These systems are also more environmentally sustainable due to reduced potential for soil erosion and loss of soil organic matter, when managed as a reduced or no-till system. Production of summer crops like corn and millet in rotation with winter wheat has increased in Colorado by about 500,000 acres since 1986. Assuming that summer crops are grown in a 3 year rotation, there are about 1,500,000 acres under more intensive cropping systems compared to 75,000 in 1986. While the intensification of dryland crop rotations has increased in Colorado, a major challenge for producers is diversifying the crop rotation. Currently, there is a very short list of potential crop choices for dryland production in Colorado (wheat, corn, millet, with lesser amounts of sunflower and sorghum). The national priority in renewable energy production has the potential to create options for new crops, markets, and value added products for dryland farms in Colorado. The overarching objective of this project is to assess the environmental and ecological sustainability of dryland cropping systems that are diversified with bioenergy crops, including oilseeds and biomass crops.

The Krupinsky (et al. 2006) method was be used to evaluate 6 crops (camelina, winter wheat, corn, proso millet, forage millet, forage sorghum,) and fallow planted parallel to one another in year one, the same set of 6 crops was planted perpendicular to the original crops in the second year to evaluate cropping sequence effects. Grain/biomass yield, residue silhouette area, and crop water use were measured. Grain yield was measured by mechanically harvesting each crop with a small plot combine. Biomass yield was measured using a small plot forage harvester. Residue silhouette area was determined in each experimental unit by measuring stem height and diameter on three feet of row (Nielsen 1998). Crop water use was measured using the neutron scatter technique by placing neutron access tubes to a depth of five feet in each experimental unit (Cole 1969). Measurements were be made twice during the growing season (pre-plant and post-harvest. The experimental design used was a randomized strip block design with four replications. Each crop was planted in a 30 X 210 ft. block. All data collected will be subjected to traditional analysis of variance and means separation procedures.

B. Key Findings

Based on these data most crops followed corn consistently better than other crops, with the exception of forage sorghum. In this case the corn residue that remained post–harvest remained relatively weed free and was more stable which provided a better environment for the following crop to germinate and establish. This residue which had an average height of 18 in. and a diameter of 1.25 in.

was able to capture fall and winter precipitation more efficiently due to inhibiting wind effects. Planting arrangement for 2009 and 2010 are presented in Figure 1. Weed management consisted of an application of glyphosate applied prior to each crop planting and residual herbicides in corn consisted of metolachlor. The corn variety was glyphosate tolerant and was sprayed at the 12 leaf stage with a combination of glyphosate and carfentrazone. Pendimthalin (H20) was applied to the camelina prior to emergence. No other herbicides were applied to camelina during the growing season. All other crops received an application of carfentrazone during the growing season to eliminate broad-leaf weeds.

2009:

On April 23 Camelina was planted on 7.5 in spacing at approximately 4lbs of seed per acre. The soil moisture readings taken at this time showed that due to the rainfall received the previous fall we had a 4 ft. profile at near field capacity. Camelina yields were suppressed due to weed pressure. Camelina yields averaged 725 lbs. per acre. Based on the price offered for camelina seed for oil the net returns to the producer would have been 3.65$/acre. On May 29 Corn was planted on 30 in spacing at a rate of 18,000 seeds/acre. Soil moisture readings at that time also showed a 4 ft. profile just slightly less than field capacity, due to poor emergence of the first planting of corn it was replanted on June 23. The second planting of corn produced and average yield of 53 bu/acre. Due to the delayed maturity and excessively cool temperatures the test weight of the corn crop was suppressed. Net returns for the corn were 93.89 $/acre. Proso millet was planted on June 23 at a rate of approximately 25 lbs. per acre. The soil moisture at this time showed a full profile to 4 ft. Forage millet at a rate of 20 lbs. per acre and forage sorghum at a rate of 10 lbs. per acre was both planted on June 24 into a full soil profile. Above average rainfall during the growing season both produced an opportunity for optimum growth of the crops but also allowed for extended weed emergence and competition. Proso millet yields were also suppressed by weed pressure and cool temperatures. The average yield produced by the proso millet plots was 14 bu/acre. Based on this yield the net returns to the producer would have been 1.48 $/acre. The forage millet yield averaged just under 4 tons/acre (3.796 tons/acre), and produced net returns of 121.46 $/acre. Forage sorghum was highly variable between plots but averaged over 4.5 tons/acre (4.766 tons/acre), which provided net returns to the producer of 198.74 $/acre. In both the forage millet and sorghum had the biomass been sold as a biofuel feedstock net returns to the producer would have been 68.39 and 39.14 $/acre respectively. This would indicate that producing these crops would be more profitable when sold as a livestock feed. Post-harvest soil moisture samples showed that due to the above average rainfall during growing season soil moisture remained near field capacity at the end of the season. Wheat was planted on September 15 into a 6 ft. profile of moisture. The planting arrangement is illustrated in Figure 1. Yield and economic data for all crops in 2009 is presented in Table 1. All crops were planted into existing wheat residue.

2010:

The same planting arrangement was used in 2010, however, crops were planted perpendicular to the 2009 planting arrangement. Camelina was planted on April 27 but due to environmental conditions adequate stands could not be obtained, therefore camelina was abandoned in 2010. Corn was planted on May 26 into the existing residue from the previous crops at a seeding rate of 18,000 seeds/acre. Corn yields were highly variable and ranged from 23 to 77 bu/acre. Corn followed by corn produced the highest yields (77 bu/acre) and corn following camelina produced the lowest yield (23 bu/acre). The corn followed by corn provided net returns to the producer of 367.65 $/acre while the corn following camelina provided 16.90 $/acre. Soil moisture data showed that corn was utilizing moisture at the 4 ft. depth an indication good root growth and development. Corn yield and economics are presented in Table 3, and soil moisture data is presented in Table 4. Forage millet and forage sorghum were planted on June 21 at a rate of 20 and 10 lbs/acre respectively. Forage yields were

suppressed due to lack of continued moisture during the growing season. Yields for forage millet ranged from 2.23 to 2.57 tons/acre. Forage millet following corn produced the highest yields (2.57tons/acre) and following camelina yields were again the lowest (2.23tons/acre). The net returns following corn were 23.3 $/acre and following camelina were 3.90 $/acre. If sold as a biofuel feedstock the net returns greatly reduced following corn it would have been 121.90 acre and following camelina it would have been 131.90 $/acre. Yield and economic data for forage millet is presented in Table 5 and soil moisture data is presented in Table 6. Soil moisture readings showed that forage millet was extracting from a depth of 4 ft. Forage sorghum yields were highly variable as was the trend for all crops. Yields ranged from 2.73 tons/acre following camelina to 2.07 tons/acre following forage sorghum. Net returns for forage sorghum ranged from 33.57 $/acre following forage sorghum to 19.77$/acre following camelina. If biomass from forage sorghum were sold for biofuel production net returns ranged from 139.90 to 116.90 $/acre. Yield and economic data is presented in Table 7 and soil moisture data is in Table 8. Proso millet was planted on June 18 at a rate of 25 lbs/acre. Proso millet yields ranged from 448.55 to 1524.65 lbs/acre with following corn providing the highest yields (1524.65 lb/acre) and camelina producing only 448.55 lbs/acre. Net returns following corn and camelina were 182.96 and 53.83 $/acre respectively. Yield and economic data for proso millet is presented in Table 9 and soil moisture data is presented in Table 10. Moisture readings showed again that proso millet was capable of extracting water from the 4 ft. depth. Wheat planted in 2009 yielded 30 bu/acre and provided 78.70 $/acre in net returns. Yield and economic data are presented in Table 10 and soil moisture data is presented in Table 11. There were no statistical differences between any treatments in any crop mostly due to high degree of variability of the data collected. There for there are no statistical comparisons presented in this report. Residue data (not presented) showed that based on height and diameter corn produced the best residue to catch snow post-harvest. Fallow produced the most abundant residue due to weed pressure. Camelina residue proved to be stable residue but due to height and diameter provided above average but was not sufficient to compete with corn. Proso millet, forage millet and forage sorghum provided the least amount of residue due to harvest height needed to maximize yield. Weather data for 2009 and 2010 are presented in table 12 and 13 respectively.

iii. Economical Sustainability

Based on the economic data presented in the tables below cropping systems which included bio-energy crops would only produce a net return to the producer of 197.79 $/A. This calculation is based on following the 2010 rotation listed (fallow, corn, forage millet, forage sorghum, proso millet, wheat). Camelina was omitted due to lack of stand establishment, but based on the 2009 data this would have lowered the net returns. This infers that over a 6 year rotation a producer would return to his operation less than $200.00. These data would indicate that economical sustainability could not be obtained based on current commodity prices and cost of production. These data do not include any land payments which would lower the net returns further.

iv. Ecological Sustainability

Based solely on crop production and net returns sold to traditional markets in most cases these rotations indicated that they are environmentally sustainable. With few exceptions these rotations produced adequate yields which show that each of the crops was able to follow the previous crop without detrimental effects. Proso millet data (Table 9) indicates that this crop follows all previous crops in this study with no negative effects on yield.

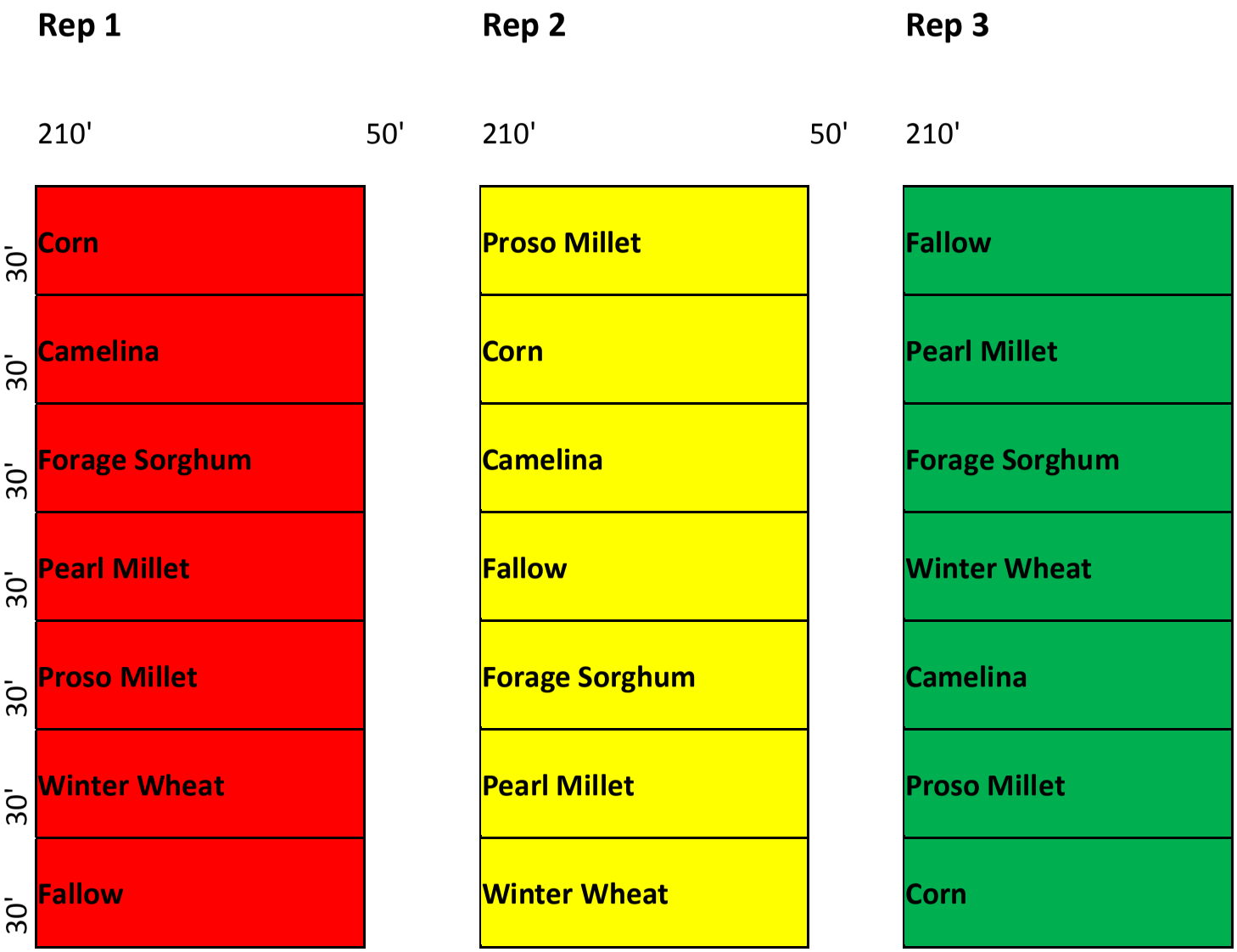
C. Next Steps.

Based on the data collected from this study, this project (providing funding sources can be located) will be expanded to include more potential crops such as canola, and sunflower. The limited time for this study has given more questions than answers to issues that arise from cropping systems and intensive rotations. More emphasis will be placed on soil moisture consumption and recharge throughout the year not just with in the growing season. Weed management issues arising due to limitations on chemistries available that do not incur injury on a subsequent crop is another area of study that will be expanded upon. Soil quality measurements would also be beneficial to explore within these rotations to determine the effects on increases in soil organic matter increases as well as soil structure improvements due to increased biological activity in the soil.

Other steps to be taken in addition to the ones mentioned are to re-analyze the data based on a crop compared to itself in all systems and rotations. This is to determine the effects of sequencing upon each crop. Publications planned from this research include factsheets, and presentations at upcoming meetings and field days.

D. Notable Successes

The most notable success from this study was the proof that intensive rotations are environmentally and economically feasible. Other studies have shown an environmental benefit to intensive rotations, some have been done in other areas. CSU and USDA research has shown benefits across the state. This study took a more in depth look at the economics in attempt to address the effects of the entire rotation on net returns to producers.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Pearl Millet
Winter Wheat
Fallow
Pearl Millet
Forage Sorghum
Winter Wheat
Camelina
Proso Millet
Corn

Figure 1.

Table 1. Yield and Economics for 2009.

		yield	yield	yield	COST OF PRODUCTION	price/unit	RETURN	PRICE FOR BIOMASS	RETURN FOR BIOFUEL
		bu/ac	lb/ac	T-US					
1	Fallow	0	0	0		0	0		
2	Corn	53.333	0	0	185.94	5.25	93.89		
3	Forage Millet	0	0	3.797	182.30	80	121.46	30	-68.39
4	Forage Sorghum	0	0	4.763	182.30	80	198.74	30	-34.41
5	Proso Millet	13.82	0	0	134.15	9.6	-1.48		
6	Camelina	0	725	0	134.15	0.18	-3.65		
7	Wheat	0	0	0		0	0		

Table 3. Corn Yield and Economics.

Character Rated					
Rating Data Type		yield	COST	PRICE	RETURN
Rating Unit		YIELD	COST	PRICE	INCNET
Trt	Treatment	BU	DOLLAR	DOLLAR	DOLLAR
No.	Name				
1	corn after fallow	52	185.94	7.22	187.45
2	corn after camelina	23	185.94	7.22	-16.90
3	corn after corn	77	185.94	7.22	367.65
4	fallow	0	0	0	0
5	corn after forage millet	48	185.94	7.22	163.29
6	corn after forage sorghum	60	185.94	7.22	244.97
7	corn after proso millet	51	185.94	7.22	181.27

Table 4. Corn Moisture Data.

Character Rated		begin moist	begin moist	begin moist	begin moist	end moist	end moist	end moist	end moist
Rating Data Type		MOICON	MOICON	MOICON	MOICON	MOICON	MOICON	MOICON	MOICON
Rating Unit		percent	Percent	percent	percent	percent	percent	percent	percent
Trt	Treatment	4ft	3ft	2ft	1ft	4ft	3ft	2ft	1ft
No.	Name								
1	corn after fallow	17.31	17.62	15.81	10.79	13.26	15.52	18.84	10.54
2	corn after camelina	16.93	18.31	19.18	7.50	12.38	12.31	16.24	8.20
3	corn after corn	14.23	22.08	25.07	9.68	11.65	13.61	17.98	8.91
4	fallow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	corn after forage millet	11.27	8.92	13.77	9.51	16.72	17.22	20.30	10.50
6	corn after forage sorghum	19.14	15.60	15.96	10.79	8.70	11.24	13.33	9.75
7	corn after proso millet	16.26	17.14	20.11	8.67	11.82	13.23	17.52	8.50

Table 5. Forage Millet Yield and Economics.

Character Rated		yield	Cost	price	return	PRICE	RETURN
Rating Data Type		YIELD	COST	PRICE	INCNET	PRICE	INCNET
Rating Unit		T-US	DOLLAR	DOLLAR	DOLLAR	DOLLAR	DOLLAR
Trt	Treatment					FOR BIOFUEL	FOR BIOFUEL
No.	Name						
1	Forage Milllet after fallow	2.23	198.90	80	-20.23	30	-131.90
2	Forage Millet after camelina	2.23	198.90	80	-20.23	30	-131.90
3	Forage Millet after corn	2.57	198.90	80	6.43	30	-121.90
4	Fallow	0	0	0	0	0	0
5	Forage Millet after forage millet	2.53	198.90	80	3.77	30	-122.90
6	Forage Millet after forage sorghum	2.5	198.90	80	1.10	30	-123.90
7	Forage Millet after proso millet	2.5	198.90	80	1.10	30	-123.90

Table 6. Forage millet Moisture Data.

Character Rated		begin moist	begin moist	begin moist	begin moist	end moist	end moist	end moist	end moist
Rating Data Type		MOICON	MOICON	MOICON	MOICON	MOICON	MOICON	MOICON	MOICON
Rating Unit		percent	percent	percent	percent	percent	percent	percent	percent
Trt	Treatment	4ft	3ft	2ft	1ft	4ft	3ft	2ft	1ft
No.	Name								
1	Forage Milllet after fallow	17.37	16.23	15.99	9.57	9.78	9.49	11.44	9.24
2	Forage Millet after camelina	15.77	13.73	17.03	5.70	10.03	11.02	12.97	9.82
3	Forage Millet after corn	15.99	19.29	24.67	10.25	9.73	12.01	13.55	9.84
4	Fallow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Forage Millet after forage millet	11.62	14.30	16.53	9.57	9.78	9.86	11.32	10.46
6	Forage Millet after forage sorghum	16.46	18.03	17.15	10.49	8.52	9.63	10.79	10.16
7	Forage Millet after proso millet	19.71	21.67	22.05	9.86	9.31	9.74	11.16	8.45

Table 7. Forage Sorghum Yield and Economics.

Character Rated			cost	PRICE	return	PRICE	RETURN
Rating Data Type		YIELD	COST	PRICE	INCNET	PRICE	INCNET
Rating Unit		T-US	DOLLAR	DOLLAR	DOLLAR	DOLLAR	DOLLAR
Trt-Eval Interval						FOR BIOFUEL	FOR BIOFUEL
Trt	Treatment						
No.	Name						
1	Forage Sorghum after Fallow	2.7	198.90	80	17.10	30	-117.90
2	Forage Sorghum after camelina	2.73	198.90	80	19.77	30	-116.90
3	Forage Sorghum after corn	2.57	198.90	80	6.43	30	-121.90
4	Fallow	0	0	0	0	0	0
5	Forage Sorghum after forage millet	2.6	198.90	80	9.10	30	-120.90
6	Forage Sorghum after forage sorghum	2.07	198.90	80	-33.57	30	-136.90
7	Forage Sorghum after proso millet	2.27	198.90	80	-17.57	30	-130.90

Table 8. Forage Sorghum Soil Moisture Data.

Character Rated		begin moist	begin moist	begin moist	begin moist	end moist	end moist	end moist	end moist
Rating Data Type		MOICON	MOICON	MOICON	MOICON	MOICON	MOICON	MOICON	MOICON
Rating Unit		percent	percent	percent	percent	percent	percent	percent	percent
Trt-Eval Interval		4ft	3ft	2ft	1ft	4ft	3ft	2ft	1ft
Trt	Treatment								
No.	Name								
1	Forage Sorghum after Fallow	13.04	13.51	15.47	9.52	12.47	12.35	13.32	10.10
2	Forage Sorghum after camelina	15.67	19.69	18.46	9.87	12.08	10.63	10.82	10.50
3	Forage Sorghum after corn	17.66	15.95	15.51	10.02	10.30	10.39	11.06	10.57
4	Fallow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Forage Sorghum after forage millet	17.92	14.81	17.73	7.07	12.39	13.48	12.19	9.62
6	Forage Sorghum after forage sorghum	15.57	19.74	21.41	7.75	11.48	11.81	11.54	10.22
7	Forage Sorghum after proso millet	17.07	19.55	24.84	11.22	12.33	12.55	11.84	9.28

Table 9. Proso Millet Yields and Economics.

Character Rated		YIELD	cost	PRICE	RETURN
Rating Data Type		YIELD	COST	PRICE	INCNET
Rating Unit		Lb/ac	DOLLAR	DOLLAR	DOLLAR
Trt	Treatment				
No.	Name				
1	proso millet after fallow	931.89	135	12	111.83
2	proso millet after camelina	448.55	135	12	53.83
3	proso millet after corn	1524.65	135	12	182.96
4	Fallow	0.00	0	0	0.00
5	proso millet after forage millet	662.52	135	12	79.5
6	proso millet after forage sorghum	1453.70	135	12	174.44
7	proso millet after proso millet	879.63	135	12	105.56

Table 10. Proso Millet Soil Moisture Data.

Character Rated		begin moist	begin moist	begin moist	begin moist	end moist	end moist	end moist	end moist
Rating Data Type		CONMOI	CONMOI	CONMOI	CONMOI	CONMOI	CONMOI	CONMOI	CONMOI
Rating Unit		percent	percent	percent	Percent	percent	percent	percent	percent
		4ft	3ft	2ft	1ft	4ft	3ft	2ft	1ft
Trt	Treatment								
No.	Name								
1	proso millet after fallow	16.27	18.34	18.63	8.97	16.00	20.05	21.94	12.61
2	prpso millet after camelina	15.09	18.91	22.78	9.90	16.38	19.38	23.35	15.10
3	proso millet after corn	16.52	15.18	17.16	6.17	12.89	17.08	20.33	14.58
4	Fallow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	proso millet after forage millet	18.08	15.66	15.36	9.96	16.79	20.32	23.04	16.42
6	proso millet after forage sorghum	13.21	17.05	18.71	10.01	15.82	20.15	24.19	11.86
7	proso millet after fallow	17.75	18.11	20.77	10.45	15.72	18.86	24.69	15.70

Table 11. Wheat Yield and Economics.

Character Rated		yield	cost	PRICE	RETURN
Rating Data Type		YIELD	COST	PRICE	INCRET
Rating Unit		bu/ac	DOLLAR	DOLLAR	DOLLAR
Trt	Treatment				
No.	Name				
1	Wheat	30	195.03	9.18	78.7

Table 11. Wheat Soil Moisture Data.

Character Rated		Begin moist	Begin moist	Begin moist	Begin moist	End moist	End moist	End moist	End moist
Rating Data Type		CONMOI	CONMOI	CONMOI	CONMOI	CONMOI	CONMOI	CONMOI	CONMOI
Rating Unit		percent	percent	percent	percent	percent	percent	percent	percent
Trt-Eval Interval		4ft	3ft	2ft	1ft	4ft	3ft	2ft	1ft
Trt	Treatment								
No.	Name								
1	Wheat	12.84	11.38	13.10	8.12	26.09	27.03	6.34	6.42

Table 12. 2009 Weather Data.

Monthly mean maximum temperature (F).

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
45.5	49.8	55	58	70.6	77.7	85.4	84.3	75.3	52.2	55	33.4

Monthly mean minimum temperature (F).

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
16.2	18.7	21.2	31.8	73.8	51.6	57.1	54	46.7	29.7	26.2	9.6

Total monthly precipitation (in.).

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.06	0.23	0.36	2.15	1.47	4.34	2.54	3.55	1.84	1.57	0.22	0.01

2009 Total precipitation (in.).

18.34

Table 13. 2010 Weather Data.

Monthly mean maximum temperature (F).

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
41.4	39.3	52.9	62.2	68	83	88.4	88.7	83.2	68.9	50.3	46.5

Monthly mean minimum temperature (F).

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
17.3	15.2	26.9	32.1	38.7	54.3	58.4	58.1	47.6	37.8	21.5	16.3

Total monthly precipitation (in.).

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.01	0.26	0.78	1.75	1.7	2.34	1.87	1.7	0.17	0.67	0.64	0

2010 Total precipitation (in.).

11.59