CONFERENCIA 2
ALTERNATIVE CROP ROTATIONS IN THE SEMI-ARID CENTRAL GREAT PLAINS REGION HOW MUCH FALLOW? EVALUATING THE ECONIMICS

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The traditional crop production system in the semi-arid Central Great Plains Region (CGPR) of the U.S.A. is winter wheat (*Triticum aestivum* L.)-summer fallow (WF) or one crop every two years. This system is not a long-term sustainable dryland system. It is conducive to soil degradation and provides minimal returns on investment in the CGPR. Recently utilizing no-till and more intensive cropping, we have shown several alternative rotations as superior to WF. Our objectives here are to evaluate several of these alternative rotations for economic yield, changes in soil quality, and economic returns. The economics returns to land labor and capital of 7 alternative rotation sequences (established in 1991) is compared and we report some of the effects of rotation intensity on changes in soil organic matter, soil aggregate stability. Specifically we evaluate how far we can push the system to eliminate fallow. Grain yields were measured in each rotation over an 11-year period starting 4 years after rotation establishment (1994-2004). The grain yield data was used to develop rules of thumb regarding long term average yields as affected by rotation sequence and then an economic analysis of net returns to land labor and capital was generated for the 7 rotations. That analysis indicated the most favorable sequences were wheat-millet (*Panicum miliacium* L.)-fallow (WMF) wheat-corn (*Zea mays* L.)-millet-fallow (WCMF) and wheat-millet (WM). The poorest performance was measured with WF and WCM. With respect to soil quality enhancement the best rotations were the continuously cropped WCM followed by WCMF and WCF and the poorest were with WF.

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Abstract

The traditional crop production system in the semi-arid Central Great Plains Region (CGPR) of the U.S.A. is winter wheat (*Triticum aestivum* L.)-summer fallow (WF) or one crop every two years. This system is not a long-term sustainable dryland system. It is conducive to soil degradation and provides minimal returns on investment in the CGPR. Recently, utilizing no-till and more intensive cropping, we have shown several alternative rotations as superior to WF. Our objectives here are to evaluate several of these alternative rotations for economic yield, changes in soil quality, and economic returns. The economics returns to land labor and capital of 7 alternative rotation sequences (established in 1991) is compared and we report some of the effects of rotation intensity on changes in soil organic matter, soil aggregate stability. Specifically we evaluate how far we can push the system to eliminate fallow. Grain yields were measured in each rotation over an 11-year period starting 4 years after rotation establishment (1994-2004). The grain yield data was used to develop rules of thumb regarding long term average yields as affected by rotation sequence and then an economic analysis of net returns to land labor and capital was generated for the 7 rotations. That analysis indicated the most favorable sequences were wheat-millet (*Panicum miliacium* L.)-fallow (WMF) wheat-corn (*Zea mays* L.)-millet-fallow (WCMF) and wheat-millet (WM). The poorest performance was measured with WF and WCM. With respect to soil quality enhancement the best rotations were the continuously cropped WCM followed by WCMF and WCF and the poorest were with WF.

Materials and Methods

The experiment was established in 1990 with the first crop harvested in 1991at the USDA-ARS Central Great Plains Research Station in Akron, Colorado. Detailed descriptions of the experiment can be found in Anderson et al.1999 and in Nielsen et al. 2002. Akron is at 1420 m above sea level (40° 09 'N, 103° 09 W). The mean annual temperature is 9.2°C but ranges between –40°C to 43°C. The long-term annual precipitation for the location is 420-mm but ranges between 240 and 670-mm. Most of the annual precipitation (82%) comes in the spring and summer. Winter precipitation is less than 18% of the total precipitation. Evaporative demand is between 6 and 8 times the amount of precipitation. These climatic conditions help to explain how dry and difficult it is to farm in the CGPR. The first two replications of the experiment are established in a Weld silt-loam soil (fine smectic, mesic, Aridic, Argiustolls) the last replication grades into a Norca-Colby Complex (fine, silty, mixed mesic Aridic Argiustolls-fine, silty, mixed (calcareous) mesic Ustic Torrriorthents). The experiment includes 16 fixed crop rotations for which only 7 will be emphasized here. The 7 selected are those that over the years have been consistent performers economically some of which have soil enhancing benefits. All crop phases in a given rotation appear each year and all rotation sequences and phases are replicated three times. All crops are planted no-till into previous years stubble except in the WF plots that are managed with conventional sweep tillage (WF-ct). Weeds in no-till fallow and between crops are controlled with standard herbicide rates and practices. This includes pre-plant applications of atrazine for corn followed by in crop applications for late season broadleaf control with 2,4-D and dicamba. Glyphosate or paraquat is used to control weeds just prior to planting or during fallow periods. Crops are fertilized using regional university soil fertility recommendations based on soil tests. Grain and biomass yield is measured in each plot. To evaluate rotation sequence effects on yields and economics, we considered it more correct to complete one cycle of the four-year rotations before making comparisons among the treatments. And so, here we evaluate data collected in 1994 through 2004. All comparisons of the rotation yields are compared back to WF-nt. We felt that WF-nt was a fairer comparison than WF-ct which has always yielded less than WF-nt. Yield comparisons are made with the rotations: wheat-corn-millet-fallow (WCMF), wheat-corn-fallow (WCF), wheat-millet-fallow (WMF), wheat-corn-sunflower (*Helianthus annuus* L.)-fallow (WCSF), wheat-sunflower-fallow (WSF), wheat-corn-millet (WCM), wheat-millet (WM), WF-nt and WF-ct. For the economic analysis 7 rotations are evaluated these are: wheat-corn-millet-fallow (WCMF), wheat-corn-fallow (WCF), wheat-millet-fallow (WMF), wheat-corn-millet (WCM), wheat-millet (WM), WF-nt and WF-ct. Production costs were tallied and 5 year and 10 year average commodity prices are used to calculate net returns from the long term average yields. All calculations were based on a 65 ha sized farm (160 acre farm). Periodic soil sampling of the surface 0-10 cm of the soil has been done to monitor changes in soil quality parameters in these plots these include soil organic matter (SOM) and particulate organic Matter (POM) and aggregate stability.

Results and Discussion

Wheat yields are significantly affected by rotation sequence (Table 1). Corn and millet yields (in general) are not affected by rotation sequence (Table 2). Because winter wheat is very dependant upon stored soil water that accumulates during the 14 month summer fallow period we see a large yield enhancement for wheat in rotations that have summer fallow. The summer crops corn and millet have only a short (9-10 month) winter fallow period before they are planted. Also corn and millet yields tend to be more dependant upon precipitation amounts received during the summer months. They are particularly sensitive to precipitation received during the critical flowering period in July and August. These differences in how winter wheat and the summer crops are impacted by summer versus winter fallow may partially explain the importance of rotation sequence on wheat as compared to corn and millet. The greatest wheat yields are measured in WCF and WCMF. In 1994, through 1998 (the first 5 years of the 11 years presented here) and in 2002 and 2003 the rotations WCMF and WCF had a positive effect on wheat yields (relative to WF-nt). In 1999, 2000 and 2001 these same rotations reduced wheat yields (Table 1). The key point is that in WCF and WCMF, wheat comes after fallow and so soil moisture storage should be similar to WF-nt. We evaluated in-season-precipitation and precipitation received during fallow and found no reasonable or consistent relationship between wheat yield increases in WCF/WCMF that could be explained by precipitation timing or amounts received. It seems plausible that WCF/WCMF may have stored more soil moisture than the other rotations with fallow but why the effect happens the first five years and for a total of 7 of the 11 years, and not in other years is not clear. Further analysis of pre-plant available stored water in these rotations may explain the effect. In any case, these rotations appear to significantly increase wheat yields above that measured in WF-nt and that effect happens 64% of the time. Other rotations (WSF, WCSF, WM, WCM) always reduce wheat yields. With these 4 rotations, the effect has been shown (in earlier work) as the result of less stored soil water. Sunflowers are efficient at extracting soil water to levels that are lower than other crops and continuous cropping doesn't allow any soil water recharge. For WCF and WCMF we suspect that the measured wheat yield advantage is a sort of a "rotation effect". Perhaps being out of wheat for 2 or 3 years (a long break in weed, insect and disease cycles for winter wheat) is helping wheat do well in WCF and WCMF. There is evidence that corn serves as a better host for mycorrhizal infection then the other crops grown in these rotations. One could speculate that corn might increase mycorrhizae inoculum levels in the soil. The increased inoculum could benefit the subsequent wheat crop via more complete mycorrhizal infection. At this point we really do not know what the cause for better wheat yields in these rotations with corn.

We used the 1994 to 2004 average yields to develop the following grain yield performance "Rules of thumb". These are:

- Millet after corn (with or with out fallow in the rotation) averages 1910 kg ha^{-1} (34 bu/acre).
- Millet after wheat (with or without fallow in the rotation) averages 2190 kg ha^{-1} (39 bu/acre).

- Corn after wheat with fallow in the rotation averages 2950 kg ha^{-1} (47 bu/acre).
- Corn in continuous rotations averages 2570 kg ha^{-1} (41 bu/acre).

- Wheat after fallow with corn in the rotation averages 3030 kg ha^{-1} (45 bu/acre).
- Wheat after fallow with just millet averages 2760 kg ha^{-1} (41 bu/acre).
- Wheat in continuous rotations after millet averages 1550 kg ha^{-1} (23 bu/acre).

From these rules we generated economic returns from the rotation data. The rotations that produced the greatest returns to land labor and capital in this analysis were WM, WMF and WCMF (Table 2). Rotations that were less favorable were WF-ct, WF-nt, WCF and WCM. It was interesting to see that a continuous crop rotation ended up in both the favorable and unfavorable economic categories.

Using the "rules of thumb" listed above, we developed a theoretical rotation of wheat-millet-corn-millet-fallow (WMCMF, 4 crops in 5 years). Using this theoretical rotation we calculated net returns of $6670 based on the last 10-year average prices for a 65 ha (160 acre) farm. Net returns were $10297 based on the last 5-year average prices for corn and wheat and millet. These net return values are within $60 of the returns calculated for the WM rotation. The big advantage would be in the greater diversity with the WMCMF sequence compared to the WM rotation. The risk is spread over more enterprises than just wheat or millet.

Table 1. Wheat yield percentage increase/decrease as influenced by rotation sequence (1994-2001) in 9 rotations at USDA-ARS-CGPRS, Akron, Colorado relative to wheat fallow no-till (WF-nt).

Rotation	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	11 year average
WCMF	*+8*	*+18*	*+11*	*+3*	*+40*	-3	-11	-6	+9	+8	-25	*+5*
WCF	-6	*+19*	*+3*	*+13*	*+24*	-3	*+2*	-7	-3	+8	-15	*+4*
WMF	-8	*+1*	*+7*	-2	-2	-9	-7	-11	-8	+11	-5	-3
WCSF	-6	*+28*	*+2*	-15	-37	-12	-54	-28	-4	-6	-25	-21
WSF	-21	-6	-37	-23	-40	-45	-29	-32	-27	-5	+18	-22
WCM	-22	-18	-66	-40	-56	-64	-47	-45	-60	-1	-97	-47
WM	-51	-34	-66	-512	-46	-68	-49	-37	-71	-1	-85	-51
WF-nt	---	---	---	---	----	----	----	----	----	----	----	----
WF-ct	-13	-17	-26	-38	-4	-25	-28	-11	-19	-12	-60	-23
P>F	0.008	0.004	0.001	0.001	0.002	0.001	0.001	0.002	0.002	0.002	0.002	0.0001

We also measured improvements in soil organic carbon, and aggregate stability in the surface 10 cm of the soils in these plots. The best rotations for improving or maintaining soil quality are WCM>WCMF> WCF> WFnt>WFct. The greater total biomass production with greater cropping intensity combined with no tillage is suspected as being the explanation for improvements in measured soil quality parameters. Statistically significant increases in aggregate stability and increases in SOM and POM have been measured with increasing cropping intensity in these plots. We have also documented statistically significant increases in the plant availability of P, Zn, Cu and Fe in these plots with an increase in cropping intensity. These increases in availability are linked to reductions in soil pH that are the result of continued soil-surface applications of ammoniacal fertilizer in these no-till managed plots.

Conclusions

Increasing rotation intensity from 1 crop in 2 years to 2 crops in three years or to three crops in four years enhances economic returns for farmers in the CGPR. Not all rotations that are best for the soil are necessarily best for the farmers return on investment. For example WCM is a good rotation for the soil but performs poorly when we consider economic returns. Wheat is highly responsive to stored moisture during the long summer fallow period. And the greatest wheat yields are in rotations that have summer fallow. However, the long fallow period is expensive to manage and the increased cost of managing summer fallow reduces overall economic returns in WFnt and WFct. The greatest economic returns are found with WM, WMF and with WCMF.

Table 2. Ten-year average yields (1994-2004) and net returns for corn, millet and wheat in seven ACR rotations at Akron, Colorado. Commodity prices used in the calculations are the last 5-year averages (2003-2008) of: April corn at $3.42/bu; January wheat at $5.52/bu wheat and November millet at $4.32/bu. Values in parenthesis are the returns based on the 10 year average prices of $3.72 January wheat, $2.59 April corn and $3.36 November millet (1994-2004).

Rotation	Corn	Proso millet	Wheat	$ U.S. Returns 65 ha farm
	------- kg/ha -------			$/farm
WCMF	3012	1905	2960	9513 (6210)
WCF	2887		3090	8837 (4960)
WMF		2186	2757	10303 (6650)
WCM	2573	1906	1547	8173 (5133)
WM		2130	1480	10356 (6840)
WF-no-till			2892	8544 (5540)
WF-ct (sweeps)			2018	4180 (2650)
P>F	0.54	0.35	0.0001***	

*** P>F This indicates statistical significance. Values smaller than 0.05 are considered statistically significant.

References cited

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Resúmenes

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