ESTIMATING THE EFFECT OF MANAGEMENT ON LANDSCAPE YIELDS

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For the last half century, summerfallow has been required and extensively used for adequate soil moisture accumulation and weed control in the Brown and Dark Brown soil zones of Saskatchewan. In recent years, soil conservation practices such as minimum tillage and chemical summerfallow have been emphasized (Lindwall and Dubetz 1983). Alternatives to conventional summerfallow such as extended rotations and stubble management for snow water capture have been suggested and are under evaluation in various parts of the province (Campbell et al. 1983). Little is known about the performance of these systems on individual soil associations or on different slope positions within the landscape. A major goal of the Innovative Acres Program, initiated in 1981, was to evaluate the performance of cropping systems on various soil mapping units. This information would help to form recommendations regarding different management systems for individual mapped soils and help to attain maximum productivity and minimum soil degradation on these soils. The objectives of the study reported in this manuscript were to interpret the production and water data obtained for the Weyburn Association and to translate these yields to whole landscapes, or map units of the Weyburn Association.

METHODS

Using yield and moisture data from two farms located on Weyburn soils of the Dark Brown soil zone (Stoney Beach and Semans, Saskatchewan), linear regression equations were derived for yield as a function of total available soil moisture (TAW) (growing season precipitation plus available soil moisture at seeding) for upper, mid and lower slope positions for four "simulated" management systems. These systems included standing stubble (ST), fall cultivated stubble (FC), chemical summerfallow (CMF), and conventional summerfallow (SMF). It was assumed that a relatively high and uniform fertility level had been maintained at both locations and no differences in WUE were to be expected at different slope positions due to fertility. This assumption unfortunately was incorrect, as production levels at the Stoney Beach location were low due to nitrogen limitations. One linear regression equation was formed by grouping all slope positions together. The calculated WUE for this equation was 75.5 kg ha^{-1} cm^{-1}.

Moisture conservation efficiencies (CE), or the percentage of precipitation conserved as soil moisture, were estimated for the upper, mid and lower slope positions under these different management systems. The estimated CE's for each portion of the non-cropped period are shown in Table 1.

Stored available moisture at seeding (AMS) was calculated as:

$$AMS = CE_j * PREC_j \qquad [1]$$

where: CE_j = conservation efficiency of period j and $PREC_j$ = precipitation (cm) of period j.

Precipitation data for the Saskatoon area was gathered from records compiled by the Saskatchewan Research Council. Growing season precipitation (GSP) was calculated as that falling between May 15 and August 15; all other dates were combined to provide fall, winter and spring precipitation for the years 1970 to 1985 inclusive (Table 2).

The amount of total plant available soil moisture (TAW) was calculated as:

$$TAW = AMS + GSP \qquad [2]$$

Table 1. Estimated conservation efficiencies[1] (%) for upper, mid and lower slope positions for different management systems.

Management	Slope position		
	Upper	Mid	Lower
1st winter			
Standing stubble	30	35	50
Fall cultivated stubble	20	30	45
Summer			
Conventional summerfallow	5	10	10
Chemical summerfallow	10	10	10
2nd winter			
Conventional summerfallow	15	15	25
Chemical summerfallow	20	20	30

[1]Percentage of precipitation stored as moisture in the soil

Table 2. Growing season and fall, winter and spring precipitation, 1970-1985, Saskatoon.

Year	Growing season precipitation (cm)	Fall, winter and spring precipitation (cm)[1]
1970	21.41	27.11
1971	24.84	16.94
1972	14.66	19.88
1973	14.73	16.15
1974	24.92	28.01
1975	20.17	17.56
1976	18.18	18.03
1977	14.04	16.9
1978	14.58	17.16
1979	14.34	27.73
1980	12.26	15.42
1981	12.71	18.33
1982	24.94	13.82
1983	21.1	26.74
1984	10.05	16.09
1985	19.45	30.96
Ave.	17.65	20.43

[1]Fall, winter and spring precipitation is that which precedes the growing season, e.g. the value cited for 1970 is that which fell between the 1969 and 1970 growing seasons (15 Aug-15 May)

where AMS = estimated stored available moisture at seeding (cm) and GSP = Saskatoon growing season precipitation (cm).

From descriptions of the various Weyburn map units found in Saskatchewan (Saskatchewan Institute of Pedology, 1985) and discussion with soil surveyors, the relative distributions of upper, mid and lower landscape units and uncultivated areas for individual map units (W1 - W14) were estimated (Table 3). Weyburn 6 (W6) map units were not included in this study due to significant calcareous and saline meadow profiles. The slope position yields were then translated into yields per map unit area for each map unit.

Table 3. Distribution of landscape units for Weyburn map units (%).

Map unit	Landscape unit			Uncultivated
	Upper	Mid	Lower	
		Distribution		
W1, W3	10	60	30	
W2, W13, W14	30	40	15	15
W4, W8, W10	30	50	20	
W5	20	50	15	15
W7	20	40	10	30
W9	40	35	10	15
W11	20	50	20	10
W12	20	60	20	

All yields and production values for each map unit were calculated on a per unit area basis. That is, the uncultivated portions of some map units were fully considered when moisture and yield calculations were made for those map units.

Weyburn map unit yields for CMF and SMF were calculated for 1971 to 1985, while those of ST and FC were calculated for 1970 to 1985 inclusively. The different management systems could then be combined to simulate different cropping rotations and the relative performance of each cropping system on the different map units were evaluated.

A number of assumptions or conditions were associated with each management system; they are described in the following:

1) CMF - fallow period of 21 months
- weeds are controlled through the use of herbicides only
- good weed control is maintained throughout the period
- minimum or zero tillage system

2) SMF - fallow period of 21 months
- 4 or 5 tillage operations throughout fallow period required (Anderson, 1971)

3) ST - stubble left standing in fall
- fall application of herbicides provides good weed control

4) FC - stubble is incorporated in the fall; little residue left on surface

RESULTS

Table 4 shows simple statistics for the estimated AMS of each slope position for the 1970 to 1985 period for the four management systems. Stubble management was shown to conserve a mean 2 cm more moisture on the U slopes, and 1 cm more on the M and L slopes than did cultivated stubble management. CMF conserved a mean of 2 cm more on the U slope positions, and 1 cm more on the M and L slopes than did SMF. Table 4 shows that AMS increased from upper to lower slope positions, and mean AMS increased in the order FC < ST < SMF < CMF. Grevers et al. (1985) reported results from 12 site years in Saskatchewan, where zero tillage was compared with conventional tillage and found similar trends; soil water recharge increased in the order conventional till fall cultivated < conventional till stubble (tilled one

Table 4. Simple statistics for predicted available moisture at seeding for each slope position for four management systems, 1970-85.

Management	Slope position	Mean (cm)	Standard deviation (cm)	C.V. (%)
Conventional summerfallow (1971-85)	U	9.8	1.4	13.8
	M	11.7	1.7	14.5
	L	16.6	2.3	13.8
Chemical summerfallow (1971-85)	U	11.7	1.5	12.8
	M	12.7	1.7	13.3
	L	17.6	2.3	13.1
Standing stubble (1970-85)	U	6.1	1.7	27.3
	M	7.2	2.0	27.3
	L	10.2	2.8	27.3
Fall cultivated stubble (1970-85)	U	4.1	1.1	27.3
	M	6.1	1.7	27.3
	L	9.2	2.5	27.3

week prior to seeding) and conventional till < zero till.

Simple statistics for predicted yields on SMF, CMF, ST and FC management systems for the three slope positions during the period 1970 to 1985 are given in Table 5. Mean ST:SMF ratios for the U, M and L slope positions were 0.80, 0.78 and 0.74, respectively. The ST:SMF ratios for the three landscape units increased significantly, and became similar when a wet winter followed a dry winter. This occurred four times in the 16 year study period (1973-74, 1978-79, 1982-83 and 1984-85). The range of the average ST:SMF ratios were very similar to those reported by other workers (Austenson et al. 1970; Kirkland and Keys 1981; Campbell et al. 1983).

The CV's in Table 5 show that yield variability decreased from the upper to lower slope positions on each management system. Estimated yield variability was lower for both fallow systems (CMF and SMF) than for the

Table 5. Simple statistics for predicted yield for each slope position for four management systems, 1970-85.

Management	Slope position	Mean (kg/ha)	Standard deviation (kg/ha)	C.V. (%)
Conventional summerfallow (1971-85)	U	1297	392	30.2
	M	1438	398	27.7
	L	1812	420	23.2
Chemical summerfallow (1971-85)	U	1439	401	27.8
	M	1513	403	26.6
	L	1887	425	22.5
Standing stubble (1970-85)	U	1040	443	40.7
	M	1117	435	38.9
	L	1348	475	35.3
Fall cultivated stubble (1970-85)	U	886	401	45.3
	M	1040	423	40.7
	L	1271	461	36.3

recrop ST and FC systems. Standing stubble yields were approximately 17% higher than those under fall cultivated stubble on the upper slope positions.

The slope position yield data were used to calculate yields for the different Weyburn map units for the four management systems for the same 16 year study period, based on the percentages of upper, mid, lower and uncultivated areas within each map unit.

Mean available moisture at seeding for each Weyburn map unit under the four management systems is shown in Table 6. Generally SMF was found to have 8 to 11% less moisture at seeding than did CMF. Soil moisture reserves on ST were approximately 62% of SMF, and 56% of those for CMF. Map units which had been fall cultivated had approixmately half the available moisture of those that had been chemically fallowed, and 81 to 86% of those under stubble. Available moisture at seeding was highest for W1 and W3, and lowest for W9. This order essentially reflects the different percentages of lower slope

Table 6. Simple statistics for predicted available moisture at seeding of Weyburn map units under four management systems, 1970-1985.

	Map unit							
	W1, W3	W2, W13,W14	W4, W8,W10	W5	W7	W9	W11	W12
			Standing Stubble (1970-85)					
Mean (cm)	8.0	7.3	7.5	7.4	7.3	7.0	7.6	7.6
Std. Dev. (cm)	2.2	1.7	2.0	1.7	1.4	1.6	1.9	2.1
C.V. (%)	27.3	27.3	27.3	27.3	27.3	27.3	27.3	27.3
			Chemical Summerfallow (1971-85)					
Mean (cm)	14.0	13.2	13.4	13.3	13.1	12.8	13.6	13.5
Std. Dev. (cm)	1.9	1.5	1.8	1.5	1.2	1.4	1.6	1.8
C.V. (%)	13.2	13.1	13.1	13.1	13.1	13.0	13.1	13.1
			Conventional Summerfallow (1971-85)					
Mean (cm)	13.0	11.9	12.1	12.1	11.9	11.4	12.3	12.3
Std. Dev. (cm)	1.8	1.4	1.7	1.5	1.2	1.4	1.6	1.7
C.V. (%)	14.1	14.1	14.1	14.2	14.1	14.1	14.1	14.1
			Fall Cultivated Stubble (1970-85)					
Mean (cm)	6.8	6.0	6.1	6.2	6.0	5.5	6.3	6.3
Std. Dev. (cm)	1.9	1.4	1.7	1.4	1.1	1.3	1.6	1.7
C.V. (%)	27.3	27.3	27.3	27.3	27.3	27.3	27.3	27.3

positions within each map unit. Those map units with a small proportion of lower slope positions will provide the lowest mean available moisture at seeding. The range in AMS was approximately 1 cm for each management system.

Means, standard deviations, and CV's for all estimated Weyburn map unit yields per unit area are shown in Table 7. CMF and SMF map unit yields showed less variability than did ST or FC map unit yields. This has often been reported in the literature (Anderson 1971; Austenson et al. 1970; Austenson and Khatri 1972; Campbell et al. 1983), and is a major reason why farmers continue to practice summerfallow.

To assess the relative performance of different cropping rotations on

Table 7. Simple statistics for predicted Weyburn map unit yields per map unit area under four management systems, 1970-1985.

	Map unit							
	W1, W3	W2, W13,W14	W4, W8,W10	W5	W7	W9	W11	W12
			Standing Stubble (1970-85)					
Mean (kg/ha)	1178	961	1140	969	789	942	1036	1148
Std. Dev. (kg/ha)	445	372	439	373	306	369	397	440
C.V. (%)	37.8	38.7	38.5	38.5	38.7	39.1	38.3	38.3
			Chemical Summerfallow (1971-85)					
Mean (kg/ha)	1618	1320	1566	1328	1082	1294	1422	1573
Std. Dev. (kg/ha)	409	345	406	345	284	344	366	406
C.V. (%)	25.3	26.1	25.9	26.0	26.2	26.6	25.7	25.8
			Conventional Summerfallow (1971-85)					
Mean (kg/ha)	1536	1236	1471	1250	1016	1203	1341	1485
Std. Dev. (kg/ha)	404	339	400	340	279	337	361	401
C.V. (%)	26.3	27.4	27.2	27.2	27.5	28.0	26.9	27.0
			Fall Cultivated Stubble (1970-85)					
Mean (kg/ha)	1094	872	1040	889	720	845	951	1055
Std. Dev. (kg/ha)	431	358	423	360	295	354	383	425
C.V. (%)	39.4	41.0	40.1	40.6	40.9	41.8	40.3	40.3

each Weyburn map unit, five different rotations were simulated for this study. Three rotations (A, B and C) included CMF; two were set up as flexible cropping systems (based on a critical minimum level of available moisture at seeding of 6.5 cm), and one as an extended five year rotation (chemical fallow-W-W-W-W). Two regular rotations (D and E) included a F-W and a F-W-W rotation, respectively. The flexible rotation A had no limit on the number of CMF periods allowed. The second IF rotation (B) allowed a CMF period only once in three years; each 3-year period had to contain one ST yield. This procedure was followed for each map unit.

The total production per unit area (tonnes/ha) for each map unit under the five simulated rotations for the 16-year period is shown in Figure 1. As the number of cropped years increased, total production increased. The flexible rotation B was most successful in terms of total production on map units W1, W3 and W12, and was practically equal to that of rotation C for map units W4, W8 and W10. Adequate AMS (>6.5 cm) was often present during the 16 years, and infrequent CMF periods were required. The 5-year fixed rotation (C) was most favorable for map units W2, W13, W14, W5, W9 and W11 in terms of total production.

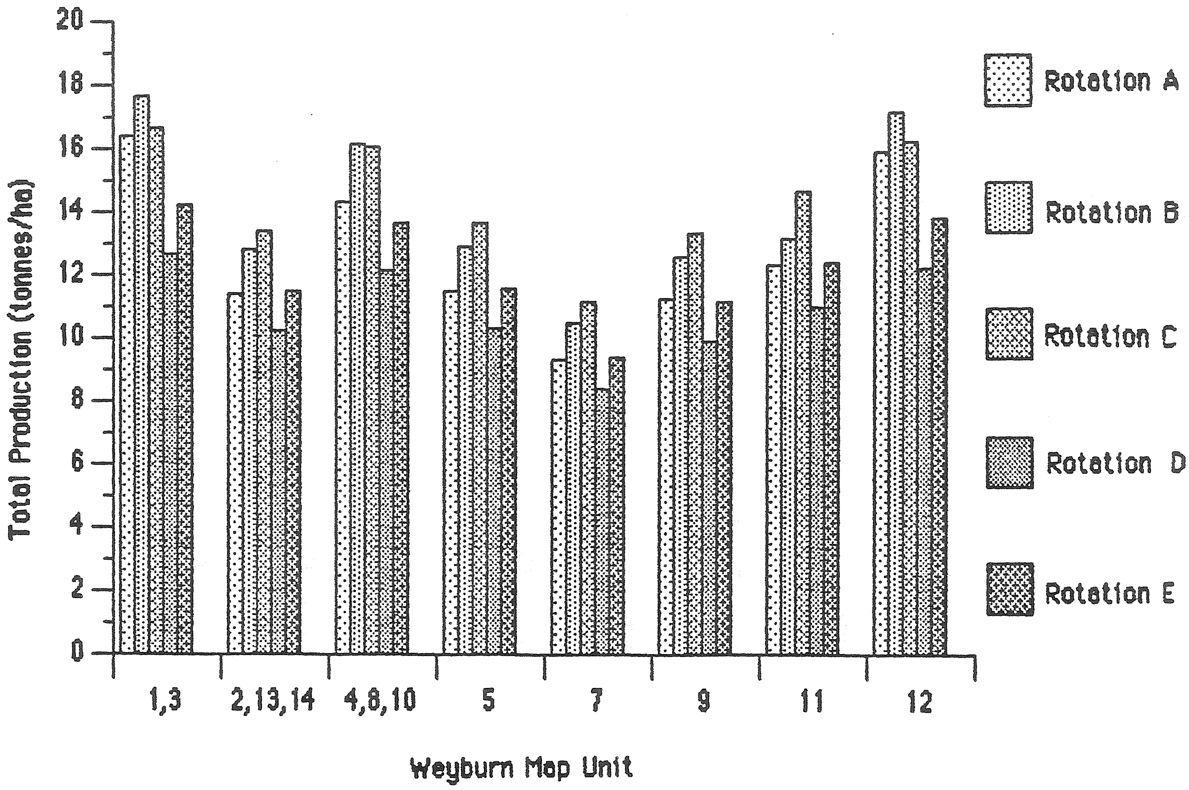

Figure 1. Total Weyburn map unit production per unit area for rotations during 1970-85 (tonnes/ha).

All average recrop yields on W7 were below the acceptable minimum yield, that is, less than 70% of average SMF yield, because of the high percentage of uncultivated land (30%) within this map unit. This indicated that a F-W rotation is the only feasible rotation for this map unit.

CONCLUSIONS

Even though the yields resulting from the simulated rotations were substantially lower than "real yield values", they showed distinct trends, and for some of the map units, indicated which rotations are most suitable for given map units.

The approach used in this study allowed for an evaluation of different cropping systems on different simulated map units, and thus related yields and productivity to both management and landscape. This approach could easily be used for mapping units of soil associations other than Weyburn to provide further information about the relative performance of different rotations on different landscapes. Recommendations for improved management systems for individual map units could be more easily determined.

REFERENCES

Anderson, C.H. 1971. Comparison of tillage and chemical summerfallow in a semiarid region. Can. J. Soil Sci. 51: 397-403.

Austenson, H.M. and Khatri, S.R. 1972. Relative yields of wheat, barley and oat cultivars on summerfallow and stubble land. Can. J. Plant Sci. 52: 659-666.

Austenson, H.M., Wenhardt, A. and White, W.J. 1970. Effect of summer-fallowing and rotation on yield of wheat, barley and flax. Can. J. Plant Sci. 50: 659-666.

Campbell, C.A., Read, D.W.L., Zentner, R.P., Leyshon, A.J. and Ferguson, W.S. 1983. First 12 years of a long-term crop rotation study in southwestern Saskatchewan - yields and quality of grain. Can. J. Plant Sci. 63: 91-108.

Grevers, M.C., Kirkland, J.A., de Jong, E. and Rennie, D.A. 1985. Soil water conservation under zero and conventional tillage farming systems on the prairies. International Soil Tillage Research Organization, 10th Conference, July 8-12, 1985. Univ. of Guelph, Guelph, Ontario. 18 p.

Kirkland, K.J. and Keys, C.H. 1981. The effect of snow trapping and cropping sequence on moisture conservation and utilization in west-central Saskatchewan. Can. J. Plant Sci. 61: 241-246.

Lindwall, C.W. and Dubetz, S. 1983. Conservation tillage. Proc. Second Annual Western Provincial Conference on Rationalization of Water and Soil Research and Management: Soil Erosion and Degradation. Saskatoon, Sask., Nov. 29-Dec. 1, 1983. pp. 121-129.