Long-Term Yield Patterns of Sugarbeet in Minnesota and Eastern North Dakota

L. G. Campbell

USDA-ARS, Northern Crop Science Laboratory, Fargo, ND 58105-5677

ABSTRACT

This study examined long-term sugarbeet *(Beta vulgaris* L.) root yield patterns in Minnesota and Eastern North Dakota. Regional sugarbeet yields have increased at an average rate of 0.5 Mg ha^{-1} yr^{-1} since the late 1950's and since the mid 1970's the sugarbeet acreage in this region has increased from 30% to 40% of the total US acreage. Counties in the southern part of the region had more variability in yields and a higher average yield than northern counties. A wide range of county yields within most years indicated that environmental conditions were seldom uniform across the region. Distinct production areas within the region were not identified and similarities between counties were directly proportional to the distance between the counties. It was concluded that only a few widely spaced locations and a few years are required to adequately sample the environmental variation within the region. Years and locations often can be substituted for each other in a field testing program.

Additional Key Words: *Beta vulgaris* L., environmental variation, year X location interactions, adaptation, root yield.

Understanding the environmental variation within a production region is beneficial in the establishment of agronomic research programs and in the interpretation of research results by producers. Allard and Bradshaw (1964) divided environmental variation into two classes, predictable and unpredictable. The predictable category included general climatic features, soil type, and agronomic practices common to a region. They believed that production data for a specific crop were probably the best indicator of this variation. Numerous attempts to characterize environmental variation have utilized data from cultivar performance trials. These generally have emphasized the magnitude and pattern of cultivar X environment interactions and the characterization of cultivar performance. Miller et al. (1959) demonstrated how variance components could be utilized to improve the efficiency of cultivar testing programs. Horner and Frey (1957) grouped test sites so that intraregional cultivar X location interactions were minimized. Correlations between yields at test sites were used by Guitard (1960) to determine regions of adaptation for cultivars and Hamblin et al. (1980) identified optimum testing sites based on correlations of cultivar performance in a locality with performance over a large area. Others have used cluster analysis to delineate areas within a production region (Abou-El-Fittouh et al., 1969; Ghaderi et al., 1980; Campbell and Lafever, 1977).

Most analyses have been based on small samples of cultivars, and locations, and a few consecutive years. It has been noted that this may not be a truly random sample of environmental conditions (Allard and Bradshaw, 1964). Hamblin et al. (1980) and Campbell and LaFever (1980) demonstrated that the set of years included in a sample may influence relative performance among sets of locations. Although county yield estimates included in official crop reports often provide an extensive amount of data, they are seldom examined in detail by agronomists as indicators of environmental variability. An analysis of long-term spring wheat *(Triticum aestivum* L.) yields in North Dakota described the yield patterns of individual counties and provided a logical basis for subdividing the state into production areas (Campbell, 1987).

This study uses long-term county yields to characterize yield patterns and variability within a major sugarbeet production area. The results provide insight for evaluating the efficiency of agronomic testing programs and for making recommendations based upon field tests or empirical observations. Annual root yield estimates from 19 counties in Minnesota and eastern North Dakota and 18 years were included.

MATERIALS AND METHODS

Most analyses were based upon sugarbeet root yields in Minnesota and Eastern North Dakota counties from 1975 to 1992. Data were obtained from Crop and Livestock Reporting Service annual reports (Minnesota Crop and Livestock Reporting Service, 1993; North Dakota Crop and Livestock Reporting Service, 1993; and previous annual summaries). The contribution of regional sugarbeet production to total US production was based upon data from USDA reports (U.S.D.A. Economic Research Service, 1993 and previous reports).

Counties were clustered with the average linkage option of the SAS cluster procedure (SAS Institute, 1988). County rankings within each year and Spearman's Rank Correlations among pairs of counties provided insight into location similarities. Rank correlations between all pairs of counties were regressed on the distance between the two counties. Distance between counties was the length of a straight line between the centers of the two counties on a map, converted to km. The above analyses were based upon annual yield estimates for 19 counties (Fig. 1) in which sugarbeets were produced continuously during the 18-year period. Individual county yields were regressed on the annual regional mean yields in a manner analogous to that used to describe cultivar stability (Eberhart and Russell, 1966). Regression coefficients near one and a relatively large coefficient of determination indicate a close correspondence between annual changes in a county's yield and annual changes in the regional average. Regression coefficients less than one are characteristic of counties in which the year-to-year yield fluctuation is less than the fluctuation in regional yield. Counties with regression coefficients greater than one frequently have annual yields substantially lower and/or higher than the annual regional average. The yearly average yields were regressed on years to measure long-term changes in productivity. The stability measurements and long-term productivity regression analysis were based upon all available data from 1958 to 1992. Because county and yearly averages were to be regarded as measures of productivity they were unweighted (for acreage) means and thus may differ from those reported elsewhere.

RESULTS AND DISCUSSION

Average root yields for individual environments ranged from 13.6 Mg ha^{-1} in Swift County in 1976 to 52.4 Mg ha^{-1} in Kandiyohi County in 1987. County means (Table 1) for the 18-year period (1975 to 1992) ranged from 34.1 Mg ha^{-1} for Kittson County to 41.2 Mg ha^{-1} for Kandiyohi and Renville Counties. The lowest yearly average root yield,

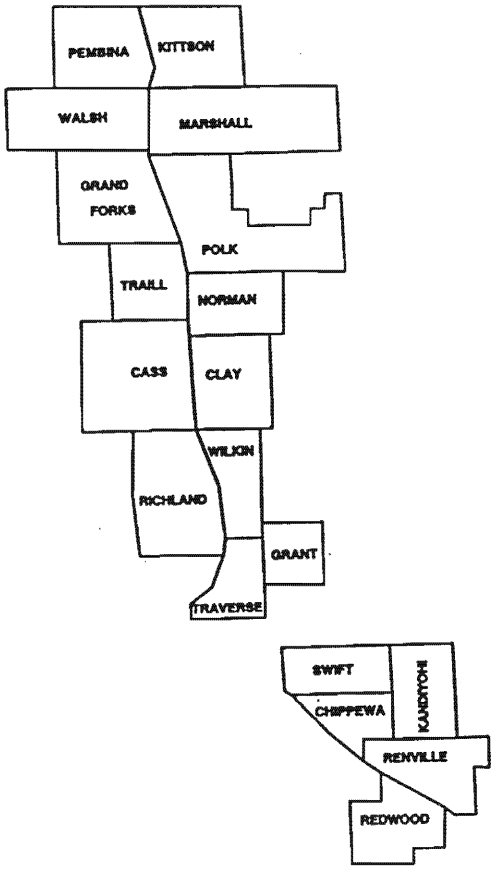

Figure 1. Principal sugarbeet producing counties in Minnesota and Eastern North Dakota, 1975 - 1992.

25.7 Mg ha^{-1}, was in 1976 and the highest, 44.2 Mg ha^{-4}, in 1987 (Table 2). Root yields for the region have increased from approximately 25 Mg ha^{-1} in the late 1950's to 40 Mg ha^{-1} in the early 1990's at an average rate of 0.5 Mg ha^{-1} yr^{-1} (Fig. 2). Although considerable annual variation occurred (r^2 = 0.64), this increase appeared to be linear over the 36-year period and not attributable to major breakthroughs. From 1975 to 1992, the proportion of the US sugarbeet crop (tons of sugarbeets) produced in this region increased from less than one-fourth to one third (Fig. 3); primarily, this was

Table 1. Summary of sugarbeet yield and stability statistics for 19 Minnesota and Eastern North Dakota Counties 1975-1992.

County	Yield					Stability	
	Mean	Standard deviation	Low	High	Range	Regression coefficient	Coefficient of determination
	Mg ha^{-1}					b	r^2
Cass	34.7	5.4	23.7	45.0	21.3	0.75*	0.64
Kittson	34.1	4.5	23.1	41.7	18.6	0.78*	0.62
Marshall	34.4	5.0	25.8	42.3	16.5	0.82*	0.69
Clay	36.8	4.5	26.2	44.1	17.9	0.95	0.88
Norman	38.9	4.7	28.9	47.0	18.1	1.00	0.90
Grand Forks	37.1	5.3	29.3	47.0	17.7	0.93	0.76
Trail	36.6	5.6	25.1	45.2	20.1	0.98	0.80
Pembina	37.6	4.4	29.6	45.2	15.6	0.95	0.68
Walsh	37.4	5.6	27.6	46.6	19.0	0.94	0.72
Polk	36.2	6.1	25.3	45.0	19.7	0.83	0.64
Chippewa	40.8	7.9	19.7	52.2	32.5	1.14	0.72
Kandiyohi	41.2	6.4	26.4	52.4	26.0	1.23	0.70
Renville	41.2	7.3	27.1	52.2	25.1	1.14	0.70
Grant	38.5	7.9	18.1	50.2	32.1	1.39*	0.73
Richland	36.0	6.0	21.7	44.8	23.1	1.05	0.79
Wilkin	37.3	6.5	19.0	46.6	27.6	1.19*	0.85
Traverse	35.2	7.5	18.6	48.2	29.6	1.26	0.73
Swift	40.0	7.8	13.7	44.6	30.9	0.96	0.60
Redwood	36.0	8.6	19.5	52.0	32.5	1.07	0.66
Mean	37.4	6.2	23.6	47.0	23.4	—	—

* Indicates regression coefficient is significantly different from 1 at the 0.05 level.

Table 2. Summary of annual sugarbeet root yield means for 19 Minnesota and Eastern North Dakota Counties, 1975 - 1992.

Year	Yield				
	Mean	Standard deviation	Low	High	Range
	Mg ha^{-1}				
1987	44.2	4.2	38.1	52.4	14.3
1992	42.3	5.7	32.0	50.4	18.4
1982	41.6	5.7	33.2	52.0	18.8
1985	41.1	5.4	33.8	52.2	18.4
1978	41.2	3.9	31.4	47.0	15.6
1977	40.6	3.6	36.3	50.2	13.9
1991	39.1	3.6	31.8	43.4	11.6
1983	39.0	5.0	29.8	47.5	17.7
1981	37.6	5.5	27.8	46.6	18.8
1989	37.4	5.2	27.1	49.0	21.9
1984	36.7	2.8	32.0	41.0	9.0
1986	36.4	4.1	27.3	42.1	14.8
1990	34.9	5.4	25.3	44.8	19.5
1979	34.1	2.5	27.8	37.2	9.4
1980	32.6	4.6	26.2	43.2	17.0
1988	32.6	5.4	23.1	43.2	20.1
1975	31.5	3.7	26.9	39.4	12.5
1976	25.7	6.6	13.7	36.5	22.8
Mean	37.3	4.6	29.1	45.5	16.4

because acreage increased from about 30% to 40% of the US sugarbeet acreage. The root yield increases over time were not unique to the region so probably had a minor effect on the relative standing of the region. The construction of three sugar factories and a major addition to an older factory during the mid 1970's facilitated the increase in prominence of the region. Also, in some other regions factories were closed during this period. Since 1975 US sugarbeet acreage has ranged from 425,250 ha in 1983 to 615,600 ha in 1975, with an average of 506,250 and no apparent trends in acres of sugarbeets produced.

County mean yields (Table 1) were highest in the Southern Minnesota Counties (Chippewa, Kandiyohi, Renville, Grant) and lowest in the Northern Red River Valley (Kittson, Marshall, Pembina).

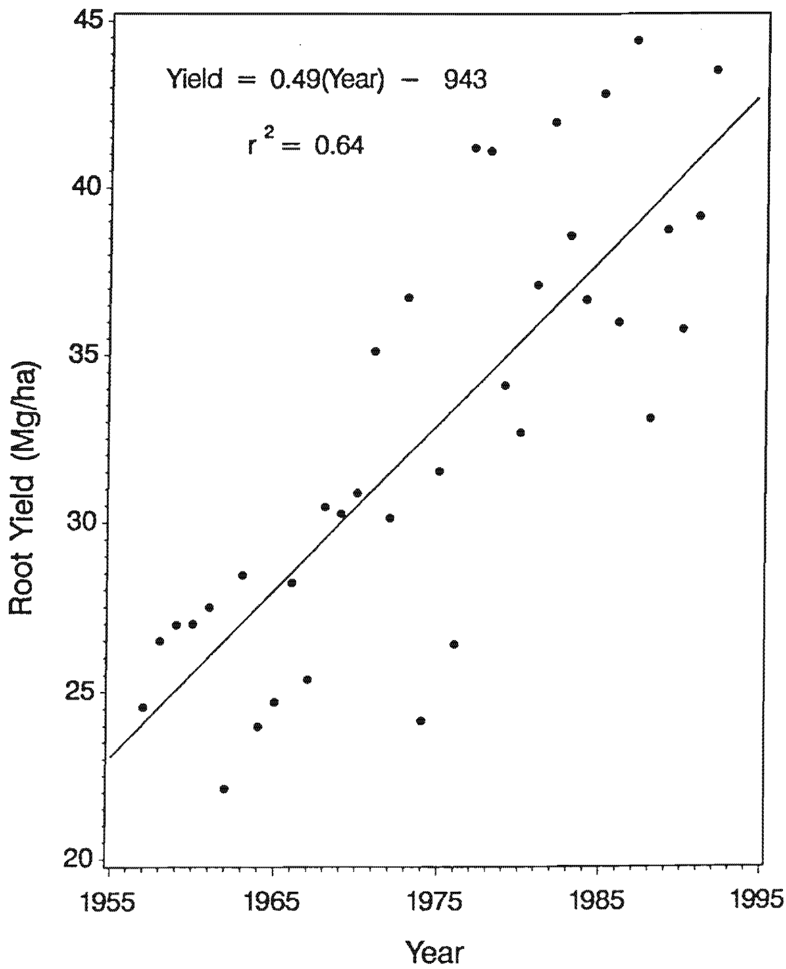

Figure 2. Average sugarbeet root yields for Minnesota and Eastern North Dakota, 1957 - 1992.

Cluster analysis (not shown) divided the region into a Northern and a Southern area but provided little additional information. Richland and Wilkin Counties, both in the Southern Red River Valley, appeared more similar to counties to their south than to nearby counties to the north. This grouping was consistent with a cluster analysis based upon spring wheat yields in which Richland County was not grouped with other eastern North Dakota (Red River Valley) counties (Campbell, 1987). Because of the lack of well defined county groupings in the cluster

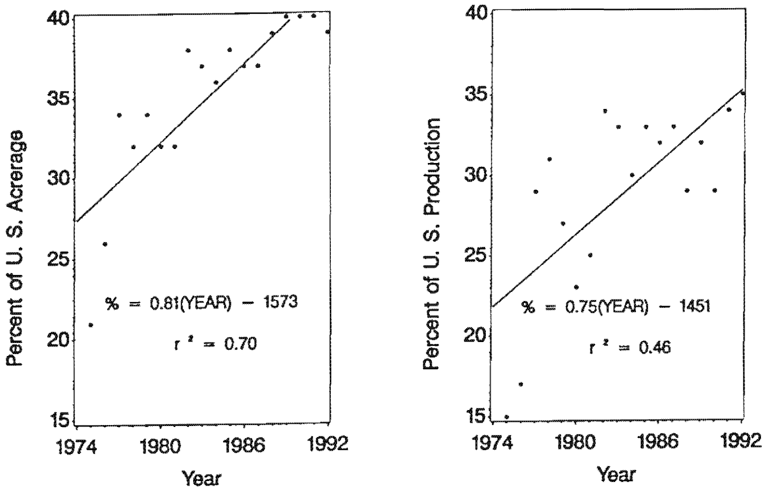

Figure 3. Regional sugarbeet acreage and production expressed as a percent of United States total, 1975 - 1992.

analysis, rank correlations among all pairs of counties provided a better indicator of yield patterns within the region (Table 3). A general decrease in Spearman's rank correlation coefficients as distance between counties increased (coefficients decrease as one moves to the right of or up from the diagonal in Table 3) indicated that location differences were due to gradual changes and the absence of discernible areas within the region. A similar pattern was observed in commercial sugarbeet hybrid performance trial results from five locations in the Red River Valley (Campbell and Kern, 1982).

Regression coefficients below one and the low mean yields for Kittson, Marshall, and Cass Counties indicated that root yields in these counties were consistently low relative to the regional average (Table 1). This pattern was also apparent in county rankings for individual years (Table 4). With few exceptions, these three counties had relatively low root yields. All counties with regression coefficients greater than one were in the southern half of the region. Only Grant and Wilkin Counties had regression coefficients significantly greater than one. The relative yield (rank) of these two counties was not consistent from year to year (Table 4). The lowest yields recorded in these counties were below the lowest yields in the extreme northern counties and the highest yields exceeded those of the northern counties when conditions were favorable (Table 1). The relatively high average root yields in the southern counties compensated, in part, for the

Table 3. Spearman's rank correlations for root yield of sugarbeet in 19 counties of Minnesota and North Dakota, 1975 to 1992.

	Kittson	Marshall	Pembina	Walsh	Gr.Forks	Polk	Norman	Trail	Cass	Clay	Wilkin	Richland	Traverse	Grant	Swift	Chippewa	Kandiyohi	Renville	Redwood
										r									
Kittson†		0.72	0.81	0.76	0.49	0.50	0.67	0.44	0.48	0.66	0.34	0.33	0.22	0.12	-0.17	-0.02	-0.14	0.08	0.20
Marshall	**		0.76	0.95	0.86	0.76	0.80	0.65	0.71	0.75	0.52	0.52	0.35	0.36	-0.06	0.14	-0.03	0.06	0.12
Pembina	**	**		0.84	0.65	0.70	0.72	0.54	0.48	0.98	0.27	0.17	0.07	0.18	-0.27	-0.07	-0.14	0.12	0.05
Walsh	**	**	**		0.85	0.85	0.87	0.71	0.68	0.78	0.49	0.44	0.29	0.28	-0.11	0.11	-0.02	0.11	0.14
Gr.Forks	*	**	**	**		0.74	0.83	0.78	0.72	0.83	0.62	0.60	0.40	0.45	0.11	0.32	0.27	0.26	0.33
Polk	*	**	**	**	**		0.84	0.85	0.63	0.71	0.48	0.35	0.29	0.29	-0.02	0.22	0.19	0.31	0.18
Norman	**	**	**	**	**	**		0.84	0.64	0.82	0.75	0.57	0.56	0.58	0.22	0.47	0.38	0.50	0.53
Trail	*	**	*	**	**	**	**		0.76	0.77	0.61	0.51	0.44	0.40	0.10	0.29	0.33	0.47	0.51
Cass	*	**	*	**	**	**	**	**		0.84	0.55	0.75	0.54	0.36	0.05	0.20	0.06	0.20	0.40
Clay	**	**	**	**	**	**	**	**	**		0.71	0.72	0.60	0.51	0.16	0.38	0.28	0.49	0.56
Wilkin	—	*	—	*	**	*	**	**	*	**		0.83	0.92	0.81	0.71	0.84	0.68	0.69	0.82
Richland	—	*	—	—	**	—	*	*	**	**	**		0.87	0.59	0.50	0.65	0.50	0.46	0.68
Traverse	—	—	—	—	—	—	*	*	*	**	**	**		0.82	0.77	0.87	0.64	0.68	0.81
Grant	—	—	—	—	—	—	*	—	—	*	**	**	**		0.69	0.83	0.60	0.73	0.68
Swift	—	—	—	—	—	—	—	—	—	—	**	*	**	**		0.90	0.76	0.59	0.63
Chippewa	—	—	—	—	—	—	*	—	—	—	**	**	**	**	**		0.86	0.77	0.74
Kandiyohi	—	—	—	—	—	—	—	—	—	—	**	*	**	**	**	**		0.82	0.75
Renville	—	—	—	—	—	—	*	*	—	*	**	*	**	**	**	**	**		0.82
Redwood	—	—	—	—	—	—	*	*	—	*	**	**	**	**	**	**	**	**	

*,** Indicates significance at the 0.05 and 0.01 levels, respectively.

† Counties are listed from north to south.

Table 4. County ranks for sugarbeet root yield within years for 19 Minnesota and Eastern North Dakota Coiunties, 1975 - 1992 (Counties are listed in order of county average yield and years in order of year average yield).

County	Year																	
	1987	1992	1982	1985	1978	1977	1991	1983	1981	1989	1984	1986	1990	1979	1980	1988	1975	1976
	Rank																	
Kandiyohi	1.0	3.0	4.0	2.0	7.0	12.5	12.0	3.5	13.5	2.0	2.0	14.0	4.0	8.0	2.0	1.0	1.0	9.0
Renville	2.0	3.0	2.0	3.5	6.0	2.0	18.0	3.5	13.5	1.0	3.0	11.5	5.0	16.0	1.0	2.0	4.0	8.0
Chipewa	3.0	5.5	3.0	1.0	13.0	4.0	8.0	1.0	16.5	4.0	1.0	13.0	2.5	5.5	4.0	3.0	2.0	14.0
Norman	5.0	12.5	6.0	10.0	1.0	8.0	9.5	9.0	4.0	10.0	5.0	7.0	8.0	1.0	7.0	5.0	14.0	5.0
Grant	6.0	3.0	8.0	7.0	17.0	1.0	6.0	2.0	12.0	6.0	11.5	15.0	1.0	18.0	6.0	8.5	10.0	18.0
Pembina	10.5	18.0	14.0	18.0	9.0	5.0	2.5	12.0	2.0	14.0	9.0	9.0	16.0	5.5	3.0	11.0	6.0	1.0
Walsh	12.0	17.0	10.0	15.0	5.0	9.0	1.0	7.0	1.0	14.0	6.5	4.5	18.0	7.0	11.5	15.0	5.0	3.0
Wilkin	13.0	7.0	5.0	8.0	14.5	7.0	6.0	11.0	11.0	9.0	6.5	11.5	6.0	15.0	13.5	7.0	8.5	16.0
Grand Forks	4.0	12.5	16.0	13.5	9.0	18.0	2.5	6.0	5.5	16.5	8.0	2.0	13.0	17.0	11.5	6.0	12.5	7.0
Clay	8.5	14.5	12.5	12.0	9.0	10.0	9.5	14.0	9.0	11.0	13.0	4.5	11.0	11.0	5.0	13.0	12.5	10.0
Trail	7.0	10.0	12.5	13.5	2.0	14.0	16.0	13.0	3.0	16.5	11.5	6.0	14.0	3.0	16.0	4.0	15.5	11.0
Polk	8.5	14.5	9.0	11.0	3.5	11.0	17.0	5.0	5.5	19.0	10.0	3.0	19.0	4.0	13.5	14.0	7.0	6.0
Redwood	10.5	1.0	1.0	9.0	11.0	6.0	19.0	19.0	16.5	3.0	17.0	17.5	9.0	19.0	10.0	8.5	19.0	15.0
Richland	16.0	9.0	17.0	5.0	12.0	12.5	6.0	15.0	15.0	8.0	4.0	8.0	10.0	9.5	19.0	12.0	11.0	13.0
Swift	15.0	8.0	7.0	6.0	19.0	19.0	13.0	8.0	19.0	5.0	18.0	19.0	2.5	2.0	9.0	10.0	3.0	19.0
Traverse	14.0	5.5	11.0	3.5	18.0	3.0	15.0	16.0	18.0	7.0	15.5	17.5	7.0	13.0	18.0	16.0	8.5	17.0
Cass	17.0	11.0	18.0	17.0	3.5	15.5	14.0	18.0	10.0	14.0	14.0	1.0	12.0	9.5	15.0	17.0	17.0	12.0
Marshall	18.0	16.0	19.0	16.0	14.5	17.0	4.0	10.0	8.0	18.0	15.5	10.0	17.0	13.0	17.0	18.0	18.0	4.0
Kittson	19.0	19.0	15.0	19.0	16.0	15.5	11.0	17.0	7.0	12.0	19.0	16.0	15.0	13.0	8.0	19.0	15.5	2.0

wide range of yields characteristic of these counties. Kandiyohi, Renville, and Chippewa Counties were frequently among the top yielding counties in the region (Table 4). This may be a response to a growing season that is approximately 40 days longer in the southern part of the region than in the extreme northern counties. The southern areas are also warmer (about 2.5°C in July) and receive 10 cm more summer rainfall on the average (USDA, 1941). Centrally located counties had regression coefficients near one (average stability) and root yields near the regional average (Table 1). This would be expected in a region where changes in environmental conditions are gradual and distinct production areas cannot be identified.

The wide range of county yields within individual years suggested that growing conditions were seldom uniform throughout the region (Table 2). In all but three years at least one county had yields of 40 Mg ha^{-1} or more. In 1987, the year with the highest average yield, all county yields were above the long-term regional average (37.3 Mg ha^{-1}). Only in 1976 and 1979, years with low average yields, were all counties below the long term regional average.

The range of yearly estimates for individual counties (Table 1) and of county yields for each year (Table 2) indicated large year X county interactions within the region. Nine of the 19 counties were the highest yielding county and all but three counties ranked at least third highest in at least one of the 18 years (Table 4). Thirteen counties were among the three lowest yielding counties in the region in at least one year. Relative county yield (county rank) did not appear related to the relative year average yield. Kandiyohi County produced the highest yield in 1987, a year with generally high yields and in 1975 and 1979, years with generally low yields. In 1986, Cass County ranked first and Kandiyohi County fourteenth; in contrast, in 1987, Kandiyohi County had the highest yield in the region and Cass County ranked seventeenth. While the year to year variation within a county may pose management problems for individual sugarbeet growers, the variation among counties within a year assures area sugar cooperatives a relatively consistent supply of sugarbeets.

Insights from an examination of long-term yield patterns can benefit researchers conducting cultivar yield trials or other agronomic studies. The wide range of county yields within a year and the magnitude of year X county interactions suggested that years and locations often may be substituted for each other in sampling production environments. This is especially true if the region were first divided into a northern and southern area or inferences were expected to apply to specific portions of the region. Because of the greater year-to-year variation in the southern counties, more test sites (or years) may be needed to evaluate hybrid performance or agronomic practices in the south than in the north. Recommendations for locating multiple test sites are made difficult by the absence of distinct areas within the region. Northern and southern counties differ but a demarcation between north and south is not apparent. Richland, Wilkin, and Traverse Counties are logical transitional counties. Whether these counties are more like the nearby northern counties or counties to the south depends upon the year; however, their yield pattern (range and stability), in general, resembles counties to their south.

Researchers frequently desire to sample the environmental diversity within an area with as few test sites as possible. The relatively high correlations between nearby counties is analogous to the correlated response for adjacent plots in a single agronomic study (van Es and van Es, 1993). The association between correlation coefficients and distance between counties apparent from Table 3 suggested that the regression of correlation coefficients on distance could provide guidance for establishing or evaluating agronomic research sites. Correlation coefficients between counties decreased an average of 0.10 for every 52 km between counties (r_s = 0.89 - 0.0019*km; r^2 = 0.71).

The maximum distance between counties was 512 km. Correlation coefficients between counties of 0.31, 0.40, and 0.57 were significant at the 10%, 5%, and 1% level, respectively. The distances associated with these values were 305, 258, and 170 km.

This suggests that, for locations closer than 170 km, treatment response patterns often will be correlated; whereas, locations separated by more than 300 km have a high probability of a non-significant correlation. These distances and the range of yields within years suggested that a reasonable sample of the region's environments, for most agronomic research, would require only a few widely spaced locations and a few (two or three) years of testing. A previous examination of sugarbeet hybrid performance trials indicated that testing more than three years at four locations per year provided little additional benefit in characterizing hybrid performance (Campbell and Kern, 1982).

Studies such as this identify general patterns within a region but may not apply to specific sites. Counties vary in size and degree of environmental heterogeneity. Also, political boundaries coincide with changes in environmental conditions only by chance. In most cases data from replicated field plots is more precise than the survey data used in this study. This deficiency is overshadowed by including more locations (counties) and years than would be feasible in a testing program. An examination of long-term yield patterns provides an indication of the environmental variation researchers are attempting to sample when conducting field trials. An increase in productivity is especially important when production costs increase faster than commodity prices. Both an increase in productivity and acreage have contributed to the economic viability of the sugar industry in the region.

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