PRELIMINARY ASSESSMENT OF AVAILABLE SOIL P IN ALBERTA: STATUS AND TRENDS

by
Paolo Manunta[1], Len Kryzanowski[2] and Doug Keyes[3]

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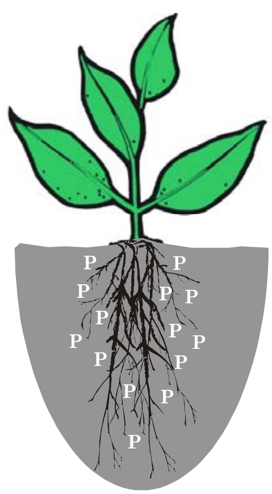
Conservation and Development Branch
Soil Quality Program
Alberta Agriculture, Food and Rural Development (AAFRD)



[1] Alberta Agriculture, Food and Rural Development, C & D Branch, Edmonton, Alberta.
[2] Alberta Agriculture, Food and Rural Development, Agronomy Unit, Edmonton, Alberta.
[3] Norwest Labs, Edmonton, Alberta.

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EXECUTIVE SUMMARY

Change in soil available phosphorus (P) in Alberta was determined by comparing results for agricultural soils submitted by farmers for routine analysis over two time periods (1963-67 vs. 1993-97). On dryland (non-irrigated) with annual crops, P increased in 15 (24%), decreased in 27 (44%) and did not change in 20 (32%) ecodistricts. Most of the statistically significant increases occurred in southern Alberta. For dryland with perennial crops, P increased in seven (18%), decreased in nine (22%) and did not change in 24 (60%) ecodistricts. For irrigated crops in southern Alberta (nine ecodistricts), there was a statistically significant increase in P for annual crops in four ecodistricts, and for perennial crops in one ecodistrict, with no changes detected in the other ecodistricts.

It appears that available soil P did not increase consistently from the 1960's to the 1990's despite increased fertilizer application rates during the 1950's, 1960's and 1970's, which were generally maintained into the 1980's and 1990's. One possible explanation is that relatively higher nitrogen rates, with concomitant increases in crop yields, has resulted in increased uptake of soil and fertilizer P. Another possibility is the changes in application technology, such as banding, to increase the efficiency of uptake of applied P.

These advancements have generally been applied more extensively to annual than to perennial cropping systems, which may explain why there was overall less of a decrease and more of a no-change in P for perennial crops.

Although there are some ecodistricts with a high proportion of fields with excess or optimum soil P for crop production, most soils in Alberta are deficient or marginal in soil P. For the 1993-97 time period 46 out of 62 (74%) ecodistricts for the dryland annual and 35 out of 40 (87%) for the dryland perennial crops had a soil P concentration equal or lower than 25 ppm. Soil P levels and soil testing is required to develop a nutrient management plan to encourage optimum economic crop production.

Descriptive statistics included in this report should be used to gain a more comprehensive characterization of the ecodistrict in terms of soil available P. Particularly, the range, skewness and kurtosis of the data tabulated in the appendices provide details in regards to the number of extreme values relative to the mean.

ACKNOWLEDGEMENTS

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1.0 INTRODUCTION

In recent years there has been increased attention to agricultural practices associated with the application and movement of soil phosphorus. The use of fertilizer has increased almost every year since 1945 (Goettel, 1987). Phosphorus fertilizer is added to the soil to provide an adequate supply of this essential nutrient to the crop. Phosphorus is essential for plant life and it ensures a series of functions ranging from the primary mechanisms for energy transfer to the transfer of genetic traits (Wallingford, 1978). Phosphorus is removed from the soil by plant uptake, erosion and runoff. In addition, different crops remove different amounts of P from the soil. Because agricultural practices across the prairie region have been changing over time, it is timely to assess how the use of fertilizer is reflected to the amount of available P found in soil.

The first objective of this project was to produce a preliminary assessment of soil phosphorus levels through ecodistrict estimates, and to determine the changes that have occurred over time. The second objective was to analyze the changes in terms of geographical distribution and identify areas in Alberta in which P amendments could result in a positive crop response. In particular, our analysis should be used as a basis for future research, while attempting to quantify crop response to P in particular areas of Alberta. It is suggested that the outcomes of this work could be used as a basis for:

a) crop modelling exercise to integrate soil, climate and management used to generate a first general assessment of the potential crop response;
b) further sampling in those ecodistricts that might have excessive P levels;
c) for specific areas and based upon more soil testing, to develop nutrient management plans which encourage optimum economic crop production.

2.0 MATERIALS AND METHODS

Although we recognize the importance and complexity of the different P forms found in the soil, the discussion focuses on the form of soil P that is readily available for plant uptake and extractable using common tests employed by laboratories in Alberta. Because of the amount of available data measured from producer-supplied samples and the scale of interest (ecodistrict level), an interactive GIS database was developed. This system provides an effective way to store and analyze large amounts of spatial and tabular data needed for the analysis (Schreier *et al.*, 1999). Fig. 2.1 displays ecoregions and ecodistricts of Alberta.

2.1 Available data

The original data set provided by the Agronomy Unit and the Soil and Crop Diagnostic Centre[4] of Alberta Agriculture Food and Rural Development (AAFRD), includes more than 150,000 records, and the data set provided by the Norwest Labs contains about 130,000. Soil phosphorus, nitrogen, potassium and sulfur are the measured nutrient elements. Soil pH is available in both databases, and percentage of organic matter is only available in the database supplied by the Northwest Labs. Original data sets were constructed by digitizing the results of the analysis performed on farmers supplied samples. The samples were brought to the laboratories for the purpose of measuring the soil fertility level and obtaining the fertilizer recommendation. In most cases, each record includes the name of the crop that was previously grown together with legal land location and depth of the sampling. During the extraction of the

[4] Formerly called Agricultural Soils and Animal Nutrition Lab (ASANL), and Agricultural Soils and Feed Testing Lab (ASFTL).

data for our analysis we selected the readings at depth of 0-15 cm and constructed two cropping classes, annuals and perennials. In order to construct these two crop classes, we identified and excluded the records with missing information regarding the cultivated crop, as well as crop types such as horticultural, trees and shrubs.

Crops such as wheat, barley and canola were grouped in the annual crop class, fallow is also part of this group. Grassland, alfalfa and clover are typical examples of the crops included in the perennial's group. Figure 2.2 shows the distribution of the sampling locations across Alberta. Only the locations on agricultural land were subsequently selected for the production of the mean P values at the ecodistrict level. In some cases the measuring protocol used by Norwest Labs had a maximum threshold value of 60 ppm, meaning that no effort was made to measure above this concentration. This approach was motivated by the agronomic use of the results; farmers were usually interested in knowing the range of P in the soil at which the crop would generally respond to P amendment (e.g., about 25-30 ppm). In many other instances, however, no specific maximum value was adopted during the measuring procedure. During our analysis, we investigated the extent to which the maximum threshold of 60 ppm occurred within each ecodistrict. In some ecodistricts only 2-5% of the observations would have values equal to 60 ppm signifying that a maximum threshold was indeed adopted. In some other and fewer cases however, the number of samples that could have tested higher than 60 ppm was between 13-21% of the total data points collected in the ecodistricts. Data provided by the Soil and Crop Diagnostic Centre of Alberta Agriculture Food and Rural Development (AAFRD) had a higher maximum threshold value than the one adopted by Norwest Labs, values as high as 100 ppm were found in the original data set.

2.2 Reconciling of the P test methods

We selected two five-year time periods 1963-67 and 1993-97 for comparison. Data recorded over the 1963-67 time period were obtained using the Miller and Axley method (Miller and Axley, 1956), while the data recorded during the 1993-97 time period were obtained using the Norwest modified Kelowna method (Ashworth and Mrazek, 1989). In order to reconcile the discrepancy in the measuring protocol we performed a simple regression analysis (SAS, 1990) using the data collected by McKenzie *et al.* (1995). In this study soil available P was measured for the same soil sample using a series of different extraction methods (McKenzie *et al.*, 1995). For our analysis we selected the measurements obtained using the Miller and Axley and the Norwest modified Kelowna methods. Because of the pH effect upon availability and extractability of P the data were stratified by three pH classes, acidic (<6.0), neutral (≥ 6.0 and < 7.5) and alkaline (>7.5). The intercept, slope and R^2 listed in Table 2.2 were used to adjust the measurements obtained using the Miller and Axley method to the Norwest modified Kelowna method. Student's *t* test was used to evaluate the difference between the ecodistrict means (SAS, 1990). Displaying of this analysis, and of the calculated mean P concentration per ecodistrict, was achieved using ArcView GIS 3.2 (ESRI, 1996).

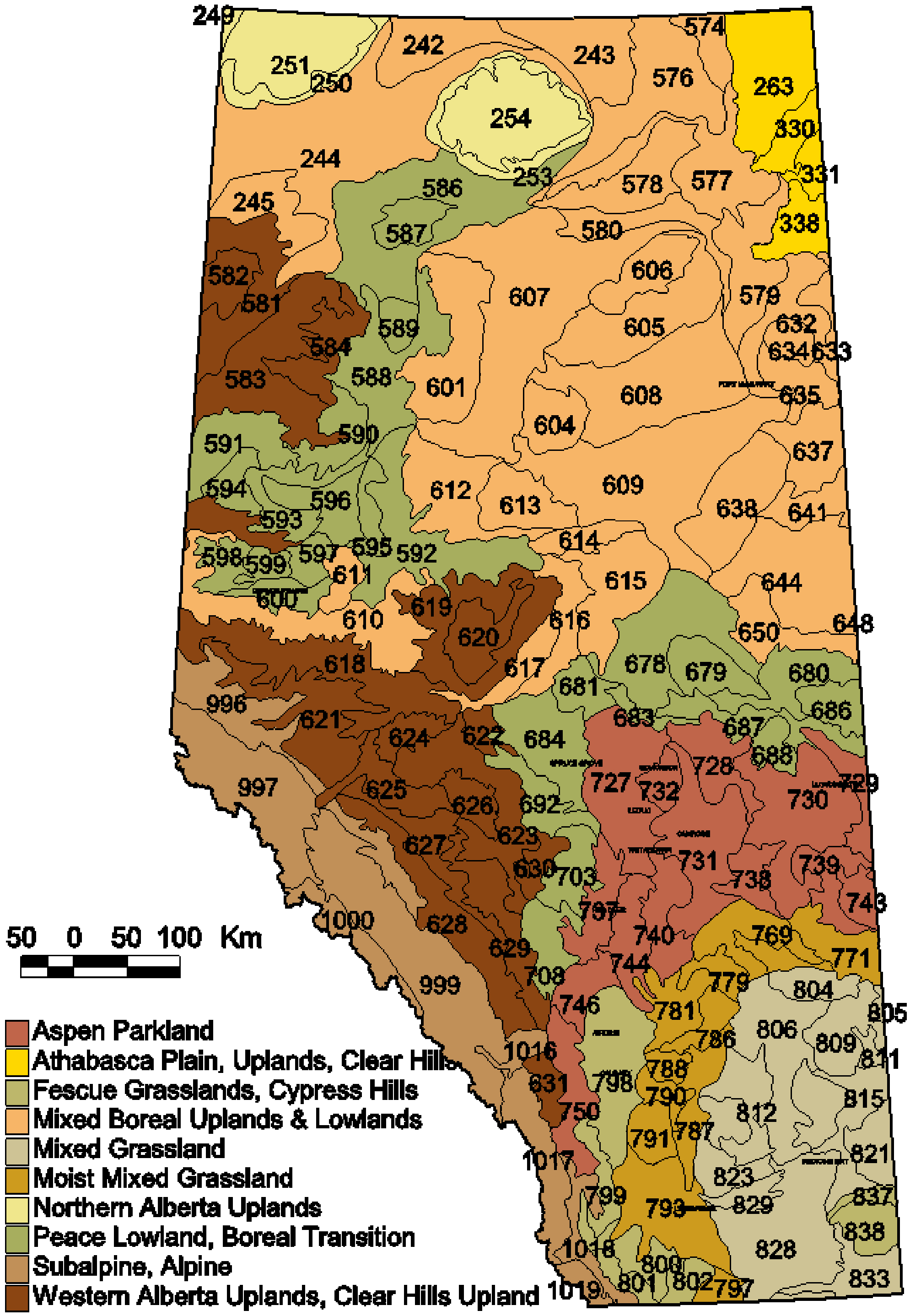

Fig. 2.1 Ecoregions over ecodistricts.

Fig. 2.2 Sampling locations across Alberta.

Table 2.2. Parameters of the regression analysis used to adjust the Miller and Axley method to the Norwest modified Kelowna method (original data from McKenzie *et al.*, 1995).

	pH<6.0	pH (≥ 6.0 and < 7.5)	pH >7.5
INTERCEPT	2.42	1.79	0.88
SLOPE	0.81	0.96	4.87
R^2	0.88	0.89	0.66
N	81	169	18

3.0 RESULTS

3.1 Descriptive statistics

In this analysis, we report some summary statistics that should facilitate the characterization of the data at the ecodistrict level. Each table in the attached appendix contains the number of observations used to calculate the mean representative value, and the tabulated minimum and maximum values to further characterize the information given by the range. Spreading of the values around the mean is described by the standard deviation (s). A measure of the shape of the data set is captured by the coefficient of skewness (Skew), in particular the symmetry of the data is described by the sign. A positive sign of the skewness indicates a long tail of high values to the right making the median less than the mean. If the data have a tail of values to the left, then the coefficient of skewness is negative, making the median greater than the mean. If the skewness is close to zero, this indicates that the histogram is probably symmetric and the median is close to the mean. Another parameter that describes the shape of the data is the coefficient of variation (CV), which is the ratio of the standard deviation to the mean multiplied by 100. The coefficient of variation can be used to quickly identify some potential problems. In particular, a coefficient of variation greater than 100 is due to the presence of some high values in the sample that may have an effect on the final estimates of the mean. Finally, the kurtosis (Kurt) quantifies the peakedness or flatness of the distribution as compared to the normal distribution. A positive value indicates a relatively peaked distribution and a negative value a relatively flat one. Large values of skewness and kurtosis, however, should be carefully considered since they may indicate that statistical methods based on normality assumptions may be inappropriate.

Measured values were used to compute the mean value for the ecodistrict and the descriptive statistics regarding the spread and shape of the data. The analysis of the soil available P was grouped in two time periods (1963-67 and 1993-97) and changes that occurred over time were also considered. In an attempt to characterize and explain the findings of soil P, the soil pH and organic matter content were also analyzed for the 1993-97 time period. Soil pH is an important parameter to be considered since it relates to the availability and extractability of soil P. Soil organic matter content was also considered since it is an important state variable that connects to the total soil P cycle (Gressel and McColl, 1997).

The following paragraphs give details in regards to the soil available P mean for dryland annual and perennial crops, irrigated annual and perennials.

3.1.1 Soil P for dryland annual crops

Descriptive statistics at the ecodistrict level for the 1963-67 and for the 1993-97 time periods are tabulated in Appendices 3.1.1 and 3.1.5. A comparison of the two time periods show that the coefficient of variation is generally higher in the 1963-67 time period indicating higher occurrence of high values in the soil available P concentration. The ranges of values are also higher in the data set collected during 1963-67, but this is due to a higher maximum value. Standard deviation is also higher in the set of measurements collected in the 60's. The skewness of the older data set is higher than the one of the data set collected in the 90's, but the histogram of the latter is probably more symmetric than the former, and it is characterized by a median closer to the mean. A similar trend is also detected with the kurtosis the two data sets.

Student's *t* test ($p>0.05$) was used to identify statistically significant trends in soil available P that occurred over time. Soil available P for dryland annual crops did not change in 20 ecodistricts, increased in 15, and decreased in 27 (Table 3.1.1).

Table 3.1.1. Summary table of the changes in available soil phosphorus in the 0-0.15 m soil profile for dryland annual crops (1963-67 vs. 1993-97).

ECO	Δ in [P]	Significance	ECO	Δ in [P]	Significance	ECO	Δ in [P]	Significance
590	-7	*	688	-3	*	786	18	*
591	-11	*	692	-2		787	12	*
593	-2	*	703	-3		788	21	*
594	-4		727	-2	*	790	-5	
596	-7	*	728	-2	*	791	23	*
597	-5	*	729	-1		793	6	*
598	-5	*	730	-2	*	798	10	*
599	5	*	731	1		799	10	
600	-14		732	-14	*	800	15	*
610	-5	*	737	1		804	-3	
615	-27	*	738	-2	*	806	-4	
618	-3		739	-4	*	809	-17	*
631	13	*	740	2	*	811	1	
678	-8	*	743	-1		812	-9	
679	-3		744	5	*	818	7	
680	-2	*	746	-4	*	821	-26	*
681	-1		750	10	*	823	10	*
683	-10	*	769	-2	*	828	5	*
684	-13	*	771	-6	*	837	-12	*
686	-10	*	777	5		838	-13	*
687	-1		779	3	*			

ECO= ecodistrict number, Δ in [P]= change in [P] in ppm, significance= significant difference of the means, 1963-67 vs. 1993-97 (Student's *t* test; $p>0.05$).

3.1.2 Soil P for irrigated annual crops

Summary statistics for the observations collected in nine ecodistricts during the 1963-67 and the 1993-97 time period are tabulated in Appendices 3.1.2 and 3.1.6. As in the case of dryland annual crops the coefficient of variation is generally higher in the 1963-67 time period, indicating more frequent occurrence of high values in the soil available P concentration. Likewise, the ranges of values are also higher in the data set collected during 1963-67, reflecting higher maximum values. Slightly higher standard deviation is found in the set of measurements collected in the 60’s. Skewness of the older data set is greater than the one of the data set collected in the 90's. Therefore, the histogram of the latter is probably more symmetric than the former one. Kurtosis of the data set collected in the 90’s has a relatively high number of negative values representing a probable flat distribution of the observed values. Kurtosis of the data collected in the 60’s is always positive indicating a probable peaked distribution compared to normal.

Increase in soil available P from the 60’s to the 90’s tested statistically significant in three ecodistricts and remained unchanged in the other six (Table 3.1.2).

Table 3.1.2. Summary table of the changes in available soil phosphorus in the 0-0.15 m soil profile for irrigated annual crops (1963-67 vs. 1993-97).

ECO	Δ in [P]	Significance	ECO	Δ in [P]	Significance	ECO	Δ in [P]	Significance
788	45	*	812	5		821	-8	
793	32	*	815	45		823	9	*
798	24	*	818	21		828	6	

ECO= ecodistrict number, Δ in [P]= change in [P] in ppm, significance= significant difference of the means, 1963-67 vs. 1993-97 (Student’s *t* test; $p>0.05$).

3.1.3 Soil P for dryland perennial crops

Appendices 3.1.3 and 3.1.7 contain the summary statistics of soil available P for dryland perennial crops for the 1963-67 and for the 1993-97 time periods. As in the previous cases, the coefficient of variation is generally higher in the 1963-67 time period indicating more frequent occurrence of high values in the soil available P concentration. The ranges of values are also higher in the data set collected during 1963-67 reflecting higher maximum values. Standard deviation and skewness for the data of the 60’s are also higher than the ones of the 90’s data indicating that 60’s data set might have more variability in the observed values. Variability of the measured values is also corroborated by the higher CV found in the older data set. Kurtosis is also higher for the data collected in the 60’s, indicating that the distribution of the data is relatively more peaked.

Soil available P from the 60’s compared to the 90’s remained unchanged in 24, increased in seven, and decreased in nine ecodistricts (Table 3.1.3).

Table 3.1.3. Summary table of the changes in available soil phosphorus in the 0-0.15 m soil profile for dryland perennial crops (1963-67 vs. 1993-97).

ECO	Δ in [P]	Significance	ECO	Δ in [P]	Significance	ECO	Δ in [P]	Significance
590	6	*	681	1		739	0	
591	-14	*	683	-7		740	3	
593	-3		684	-5	*	744	0	
594	-3		687	-9	*	746	-37	
597	-5		688	-5		750	6	*
598	-1		703	3		769	-2	
599	8	*	727	-4	*	771	-5	*
600	-18		728	-2		793	-7	
610	-3	*	729	6	*	798	1	
615	-29	*	730	3	*	799	-5	
631	16	*	731	1		812	7	
678	-11	*	732	-10	*	828	-4	
679	-1		737	1				
680	1		738	9	*			

ECO= ecodistrict number, Δ in [P]= change in [P] in ppm, significance= significant difference of the means, 1963-67 vs. 1993-97 (Student's *t* test; $p>0.05$).

3.1.4 Soil P for irrigated perennial crops

Summary statistics of the soil available P for irrigated perennial crops (seven ecodistricts) for the 1963-67 and for the 1993-97 time periods are tabulated in Appendices 3.1.4 and 3.1.8, respectively. Coefficient of variation is generally higher for the 1963-67 time period, indicating frequent occurrence of high values in the soil available P concentration. The ranges of values are also higher in the data set collected during 1963-67, reflecting higher maximum values. The same trend is observed for the standard deviation, which is generally higher in the 60's data set. Insight with regards of the shape of the histogram can be gained by examining the skewness of the data. For the 1963-67 time period all the ecodistricts have a positive skewness signifying that the data set is composed by some high values positioned on the right portion of the histogram. Data collected during the 1993-97 time period have few skewness values close to zero, indicating symmetry of the histogram. Nevertheless, this data set contains some negative values probably due to some low numbers on the left portion of the histogram. Finally, the data set collected in the 60's has some relatively higher kurtosis values than the 90's data set, signifying a more peaked distribution of the data.

Increase in soil available P between the 1963-67 and 1993-97 time period was statistically significant in only one ecodistrict. Non-significant changes were detected in all the other ecodistricts (Table 3.1.4).

Table 3.1.4. Summary table of the changes in available soil phosphorus in the 0-0.15 m soil profile for irrigated perennial crops (1963-67 vs. 1993-97).

ECO	Δ in [P]	Significance	ECO	Δ in [P]	Significance	ECO	Δ in [P]	Significance
793	3		815	14		828	8	
798	26	*	818	0				
812	-4		823	13				

ECO= ecodistrict number, Δ in [P]= change in [P] in ppm, significance= significant difference of the means, 1963-67 vs. 1993-97 (Student's *t* test; $p>0.05$).

3.1.5 Soil pH for dryland annual crops

Further characterization of the current soil available P was considered by analyzing the soil pH values per ecodistrict with particular emphasis on how soil pH affects availability and extractability of soil P.

Plant uptake of P is largely in the form of orthophosphate ions ($H_2PO_4^-$ and HPO_4^{2-}). Each form is present in the soil in different amounts depending on the soil pH level. At pH of 7.2 the amount of the two orthophosphates is about equal, below pH 7.2 primary orthophosphate ($H_2PO_4^-$) accounts for the majority of P available to plants. With pH above 7.2 the majority of P is in the form of secondary orthophosphate (HPO_4^{2-}). Uptake of this ion by plants is slower than for the primary orthophosphate ion (Mulla and Schepers, 1997).

For the dryland annual crops the pH mean values, with some summary statistics, are reported in Appendix 3.1.9. Coefficients of variation are low indicating a low variability in the measured data set. The relatively contained spread of the measurements is also indicated by the low standard deviations. Minimum and maximum values of the observations produce a range that is usually close to two or three pH units. Skewness is usually close to zero indicating a probable symmetry of the histogram characterized by the median positioned close to the mean. Kurtosis values are mostly negative pointing out that these data may have a relative flat distribution as compared to the normal distribution.

3.1.6 Soil pH for irrigated annual crops

Appendix 3.1.10 reports mean soil pH values with the summary statistics for the irrigated annual crops. The spread of the data is similar to that of the dryland annual crops. Skewness values tend to be negative but always close to zero. Therefore, a relative symmetry of the histogram is expected. Kurtosis is also negative in most ecodistricts indicating a relatively more flat distribution than the normal.

3.1.7 Soil pH for dryland perennial crops

In Appendix 3.1.11 the mean soil pH values are listed together with the relative summary statistics. In terms of spread, these data have some similarity with the other pH measurements previously discussed. Skewness values tend to be low and usually positive indicating some degree of symmetry in the histogram. Kurtosis values are also relatively low with about an equal occurrence of negative and positive values.

3.1.8 Soil pH for irrigated perennial crops

Soil pH statistics for the irrigated perennial crops is characterized by a low spreading of the data. This is confirmed by low standard deviation and by a small coefficient of variation that never exceeds 11%, and the values of the range also being small (Appendix 3.1.12). Skewness of the data is usually around zero, with Kurtosis values that tend to be negative indicating some degree of flatness in the distribution of the observations.

3.1.9 Soil OM for dryland annual crops

Ecodistrict estimates of soil organic matter for dryland crops are tabulated on Appendix 3.1.13. An interpretation of the descriptive statistics reveals that the coefficient of variation is more than 100 on a few occasions. High maximum values in the data set caused the range to reach some high values (e.g., about 38). Standard deviation is usually around two. Skewness of the data is usually small, with positive values indicating the presence of some high numbers on the right of the mean. In some cases, the distribution of the data with respect to normal is probably highly peaked due to some positive kurtosis values.

3.1.10 Soil OM for irrigated annual crops

For the irrigated annual crops, the soil organic matter content has a coefficient of variation that is below 25 in most ecodistricts, and exceeds 100 only in one ecodistrict (Appendix 3.1.14). Standard deviation is usually below 0.5, and values of the range are usually small and only in one occasion equal to 21. Skewness of the data is usually small indicating some degree of symmetry in the histogram of the data. Kurtosis values are usually negative indicating that the distribution of the data may be more flat than the normal distribution.

3.1.11 Soil OM for dryland perennial crops

Descriptive statistics of the soil organic matter content for dryland perennial crops is summarized in Appendix 3.1.15. High values of the coefficient of variation are rare, and usually corresponding to high values associated with a relatively higher standard deviation. High range values (e.g., about 30) are usually associated with the high maximum value in the observations. Skewness is usually close to one or zero indicating some degree of symmetry. High skewness values reflect the presence of a high value in the set of measurements. Kurtosis ranges from negative to high positive values indicating some degree of flatness in the distribution in the first case, and some probable extremely peaked distribution in the second case.

3.1.12 Soil OM for irrigated perennial crops

Irrigated perennial crops have a fairly low coefficient of variation that is partially reflected in the low standard deviation (Appendix 3.1.16). Values of the range are also small and paralleled by low maximum values. Skewness is around zero for the majority of the ecodistricts indicating some symmetry of the histogram. Kurtosis is mainly negative representing a distribution flatter than the normal.

3.2 Spatial distribution

The results of the statistical analysis discussed in the previous sections were used to create a series of interactive GIS (Geographical Information System) databases. This approach provides an effective way to store and analyze large amounts of spatial and tabular data needed for the spatial analysis (Schreier *et al.*, 1999). A series of maps has been produced for each time period (1963-67 and 1993-97), and each cropping scenario (dryland annual and perennial; irrigated annual and perennial). Displaying of the mean available P for the ecodistrict was achieved by generating four classes while taking into account the natural breaks occurring in the data sets. Changes in soil available P that occurred from the 60's to the 90's were displayed in a different set of maps which synthesized the absolute change in soil available P, and the statistical significance of the changes. Student's *t* test was used to examine the statistical significance of two means from uneven sample size.

In the attempt to produce a more comprehensive analysis we produced a series of maps that summarized the mean soil pH and organic matter for the 1993-97 time period. Soil pH was regarded as an important parameter for the discussion since it ties with the plant uptake of P. Plants uptake phosphorus largely in the form of orthophosphate ions ($H_2PO_4^-$ and HPO_4^{2-}). Each form is present in the soil in different amounts depending on the pH level. At pH of 7.2 the amount of the two orthophosphates is about equal, below 7.2 $H_2PO_4^-$ accounts for the majority of the orthophosphates available to plants. With pH above 7.2 the majority of the orthophosphates are in the form of HPO_4^{2-}, uptake of the latter by plant is slower than for the $H_2PO_4^-$ orthophosphate ion (Tisdale *et al.,* 1993). Organic matter found in the soil has a net effect on the total phosphorus in the soil because of the potential role in releasing or immobilizing it. Presence of organic compounds due to the decomposition of organic residues seems to increase the availability of P (Tisdale *et al.*, 1993). Major processes for availability of P from organic matter are: a) formation of organophosphate compounds available for plant assimilation; b) anion replacement of $H_2PO_4^-$ on adsorption soil sites.

3.2.1 Mapping of the dryland annual crops scenario

In Figure 3.1 the mean available soil P is shown for each ecodistrict during the 1963-67 time period and for the dryland annual crops. The majority of the ecodistricts (i.e., 27) have a soil P concentration of 20-25 ppm, 19 ecodistricts 26-34 ppm, 13 ecodistricts 11-19 ppm and only three ecodistricts 35-45 ppm. For the 1993-97 time period 25 ecodistricts have a soil P level of 20-25 ppm, 20 ecodistricts 12-19 ppm, 12 ecodistricts 26-34 ppm, and five ecodistricts 35-47 ppm (Fig. 3.2). A comparison of the two time periods (1963-67 vs. 1993-97) indicates that soil available P for dryland annual crops did not change in 20 ecodistricts, increased in 15, and decreased in 27. The majority of the ecodistricts with the highest statistically significant increase in soil P are located in the southern part of Alberta (Fig. 3.3).

An attempt was also made to relate our mapping of soil P to physical patterns of the landforms. The changes in soil P that occurred with time were overlaid with the ecoregions compiled by the Ecological Stratification Working Group (1995). Compilation of ecoregions took into account distinctive large order landforms or groups of the latter, or in some cases smaller regional landforms and combined with macro or mesoclimates, vegetation, soil and water patterns. The largest clustering of the increase in soil P is located in the Moist Mixed Grassland and extends northward in the Aspen Parkland, eastward in the Mixed Grassland and westward in the Fescue Grasslands (Fig.3.13). These spatial patterns overlay a series of different soil groups such as the Brown, Dark Brown and Black Chernozemics.

However, our results do not show a strong spatial correlation that is consistently explainable by physical patterns of the landforms grouped in the ecoregions. This leads to the possibility that changes in soil P were largely due to anthropogenic activities. Mapping of the soil pH for the 1993-97 time period shows that the majority of the ecodistricts have a mean pH level below or equal to 7.1 while the higher values (equal or greater than 7.2) are clustered in the southern part of the province (Fig. 3.15). Potential availability of HPO_4^- orthophosphate ion for plant uptake is therefore dominant in most parts of the province. The southern part of Alberta is characterized by a potential higher availability of the HPO_4^{2-} orthophosphate ion which is taken up by plants at a relatively slower rate. This situation could play an important role in terms of available P for plant uptake and therefore to the amount of soil P residing in the soil. As previously indicated, another soil property that could play a role in the availability of soil P is the fraction of soil organic matter. The majority of the ecodistricts with lowest values of organic matter (2.1 – 3.8 %) are found in the southern part of Alberta (Fig. 3.19).

3.2.2 Mapping of the irrigated annual crops scenario

Ecodistricts with irrigated annual crops are located in the southern part of Alberta, for this analysis we were able to use a total of nine ecodistricts. For the 1963-67 time period, five ecodistricts had a P level within the 34-40 ppm range, two ecodistricts with 26-28 ppm, one ecodistrict with 29-33 ppm, and one ecodistrict with 41-57 ppm (Fig 3.4). During the later period (1993-97) three ecodistricts had a P level within the 30-38 ppm range, three ecodistricts 58-82 ppm, two ecodistricts 39-50 ppm, and one ecodistrict 51-57 ppm (Fig. 3.5). Changes that occurred over time (1963-67 vs. 1993-97) were non-significant for six ecodistricts while the other three ecodistricts had an increase that was statistically significant (Fig. 3.6). The significant increase in P level was actually in the 11-32 ppm range for two ecodistricts and in the 1-10 ppm range for the other ecodistrict. Mean soil pH level is mainly in the range above or equal to 7.2 (Fig. 3.16) creating the conditions for the orthophosphate to be mainly available in the form of HPO_4^{2-} ions which is the form that is taken up at a slower rate by plants. Most ecodistricts have a mean soil organic matter level between 2.5 and 2.8% (Fig. 3.20).

3.2.3 Mapping of the dryland perennial crops scenario

Dryland perennials are cultivated in ecodistricts that are distributed across the agricultural areas of Alberta. For the 1963-67 time period, 17 ecodistricts had mean available P values within the 16-21 ppm range, 11 ecodistricts with 22-32 ppm, eight ecodistricts with 11-15 ppm and four ecodistricts with 33-47 ppm (Fig. 3.7). Analysis of the 1993-97 data resulted in 20 ecodistricts in the 16-21 ppm range, nine ecodistricts with 11-15 ppm, eight ecodistricts with 22-28 ppm, and three ecodistricts with 29-40 ppm (Fig. 3.8). Soil available P for dryland perennial crops did not change in 24 ecodistricts, increased in seven and decreased in nine (Fig. 3.9). Increase in P levels that were statistically significant are not clustered around a specific regional area and the available soil P in these ecodistricts increased by about 2-16 ppm. Ecodistricts with unchanged levels in soil P are found over a wide range of ecoregions spanning from the Mixed and Moist Mixed Grasslands to the Boreal Transition (Fig. 3.14). As for the dryland annual crops, the soil pH level is below or equal to 7.1 in the majority of the ecodistricts; higher pH values are clustered in the southern part of the province (Fig. 3.17). If we extrapolate these findings to the availability of orthophosphate ions, we can speculate that plant uptake of orthophosphate could happen at a higher rate for the majority of ecodistricts. Ecodistricts with the lowest mean organic matter (2.3 – 4.4%) are scattered across the province, while ecodistricts with highest organic matter levels (6.8-10.1%) are found in the central-western part of Alberta (Fig. 3.21).

3.2.4 Mapping of the irrigated perennial crops scenario

As in the case of the irrigated annual crops the irrigated perennials are found in the ecodistricts located in the southern part of Alberta. The 1963-67 data set is composed of three ecodistricts with a P level in the 32-40 ppm range, two ecodistricts with 23-26 ppm, one ecodistrict with 27-31 ppm, and one ecodistrict with 41-46 ppm (Fig. 3.10). During the 1993-97 time period two ecodistricts had a P level of 27-40 ppm, two ecodistricts 41-49 ppm, two ecodistricts 50-53 ppm, and one ecodistrict 26 ppm (Fig. 3.11). A statistically significant increase in P level was observed in only one ecodistrict with an increment of 27 ppm (Fig. 3.12). As in the case of irrigated annual crops the soil pH level is equal to or above 7.3 creating the conditions for orthophosphate availability in the HPO_4^{2-} ion form which is taken up by plants at relative slower rate (Fig. 3.18). Soil organic matter ranges between 2.0 and 5.1%, with four out of nine ecodistricts having a mean soil organic matter content of 2-2.5%.

4.0 DISCUSSION

Comparison of the two time periods (1963-67 vs. 1993-97) highlighted a relatively higher level of variability in the older data set. Descriptive statistics were used to characterize the available P data. Analysis of spread and shape of the observations indicates that more extreme values are found in the data collected in the 1963-67 time period. The methodology is based on the use of two different data sets constructed by two different entities. Therefore, the results of the descriptive statistics could be used to analyze some of the potential or intrinsic problems of our approach. In some cases, the measuring protocol of available P used by Norwest Labs had a preset maximum threshold value of 60 ppm meaning that no effort was made to measure above this preset concentration. Norwest's approach is justifiable whenever the analysis of the results is used to formulate fertilizer recommendations, but it does not offer any details regarding sites with excessive amounts of available P. During our analysis we investigated up to which extent the maximum threshold of 60 ppm occurred in the data. Usually, only 2-5% of the observations collected within an ecodistrict would have values equal to 60 ppm indicating that a maximum threshold was indeed adopted. In some other and fewer ecodistricts the number of observations that could have tested higher than 60 ppm is about 13-21% of the total data points in the ecodistricts. On the other hand, the data provided by the Soil and Crop Diagnostic Centre of the Alberta Agriculture Food and Rural Development (AAFRD) had a higher maximum threshold value than the one used by the Norwest Labs; values as high as 100 ppm were found in the original data set. Our analysis is based on voluntary sampling, meaning that the samples were brought in by farmers and were not collected according to a statistical design for the whole province. Therefore, we cannot determine the exact causes for the higher spreading in the data collected in the 60's.

Despite these uncertainties, the two existing databases allowed the implementation on an analysis based upon a large number of observations, and in fact carries the intrinsic advantage of more uniform spatial coverage across the province. Descriptive statistics in the Appendices could be used to determine the level of confidence we should apply while interpreting the mean soil P for the ecodistrict. Each ecodistrict we analyzed has a line of descriptive statistics that includes information about the shape and spread of the observations. This preliminary assessment of soil P in Alberta could also be used as a base for further investigations. For example, an ecodistrict that in the 60's had a pronounced skewness value, which subsequently dropped in the 90's could indicate that over time the occurrence of extreme values, higher or lower than the mean has dropped. However, in order to substantiate this assumption more sampling may be needed;

therefore if a newly designed sampling protocol produces data with a low skewness this may indicate that the mean and mode are close together. Therefore, the low occurrence of extreme values would corroborate our initial assumption and could perhaps be used as an analog in other ecodistricts.

Alternatively, we could speculate that whenever the maximum value for the ecodistrict is found to be equal to 60 ppm for the 90's data, chances are that some soil samples might test higher in available P. Therefore, some more sampling within the ecodistrict might be useful in determining the occurrence of areas with a soil P value well above the typical agronomic level (e.g., about 25-30 ppm).

Since a relatively small portion of observations (e.g., 2-5 % and 13-21% depending on the ecodistrict) reached the preset value of 60 ppm imposed in some cases by Norwest Labs, we can retain a good level of confidence in our estimates of soil P mean. Descriptive statistics in Appendices 3.1.1 through 3.1.8 could be used to identify those ecodistricts in which the maximum value is equal to 60 ppm suggesting that some spots within the ecodistricts have soil P values that exceed 60 ppm. This information becomes useful when designing a field sampling program, which has the objective of identifying areas with excessive amounts of P in the soil. For the 1993-97 time period, 27 out 62 ecodistricts for the dryland annual, 15 out of 40 for the dryland perennial, one out nine ecodistricts for the irrigated annual, and none for the irrigated perennials has data in which the maximum observed value equals 60 ppm.

4.1 Temporal and spatial patterns

One of our objectives was first to investigate some of the changes in soil P that took place over time and secondly to analyze the changes in terms of geographical distribution across the province. A comparison of the two time periods (1963-67 vs. 1993-97) indicates that soil available P for dryland annual crops did not change in 20 ecodistricts, increased in 15, and decreased in 27 (Fig. 3.3). The majority of the significant increase in soil P occurred in the southern part of Alberta (Fig. 3.3). Plant available soil P for dryland perennial crops did not change in 24 ecodistricts, increased in seven, and decreased in nine, the unchanged levels in soil P are found across the province (Fig. 3.9).

Irrigated crops are mainly found in southern Alberta. Over time, increases in soil available P for the irrigated annual crops tested statistically significant in three ecodistricts and remained unchanged in the other six (Fig. 3.6). During the same time period, irrigated perennial crops had an increase in soil available P that was statistically significant only in one ecodistrict. Non-significant changes were detected in all the other ecodistricts (Fig. 3.12).

Historically, the use of commercial fertilizer in both the U.S. and Canada increased during the 1950's, 1960's and 1970's primarily by higher application rates. An analysis of the data provided by Agriculture and Agri-Food Canada (Korol and Rattray, 1999) reveals that the phosphate sales in Alberta have increased at a lower rate than nitrogen sales. In particular, phosphate sales doubled from 1968 to 1998 while nitrogen sales increased five times over the same period. These data represent the volume sold by retailers within Alberta and do not include inter-provincial purchases of fertilizers. Therefore, these figures may not correspond exactly to the whole consumption (Korol and Rattray, 1999). In the attempt to link the changes in plant available soil P and the trend in fertilizer sales, a more a complex data analysis should be carried out.

Although a number of cooccurring factors should be considered, it is possible that higher use of N fertilizer results in a higher biomass per m^2. Therefore, if the amount of applied P fertilizer is not proportionally increased, the net uptake of P per volume of soil increases because of the higher amount biomass. This may result in a decrease in plant available soil P.

An increase in yields for the annual crops, from the 60's to the 90's is captured in Fig. 4.1. An increase in perennial yields is also found, but yield data for the late 90's are characterized by a decreasing trend. Annual crop values were obtained by averaging the yields of wheat, oats, barley, rye, canola and flax; perennials include only tame hay. Therefore, these data should be considered as only indicative for Alberta since they do not consider all the annual and perennial crops used in the analysis of soil P.

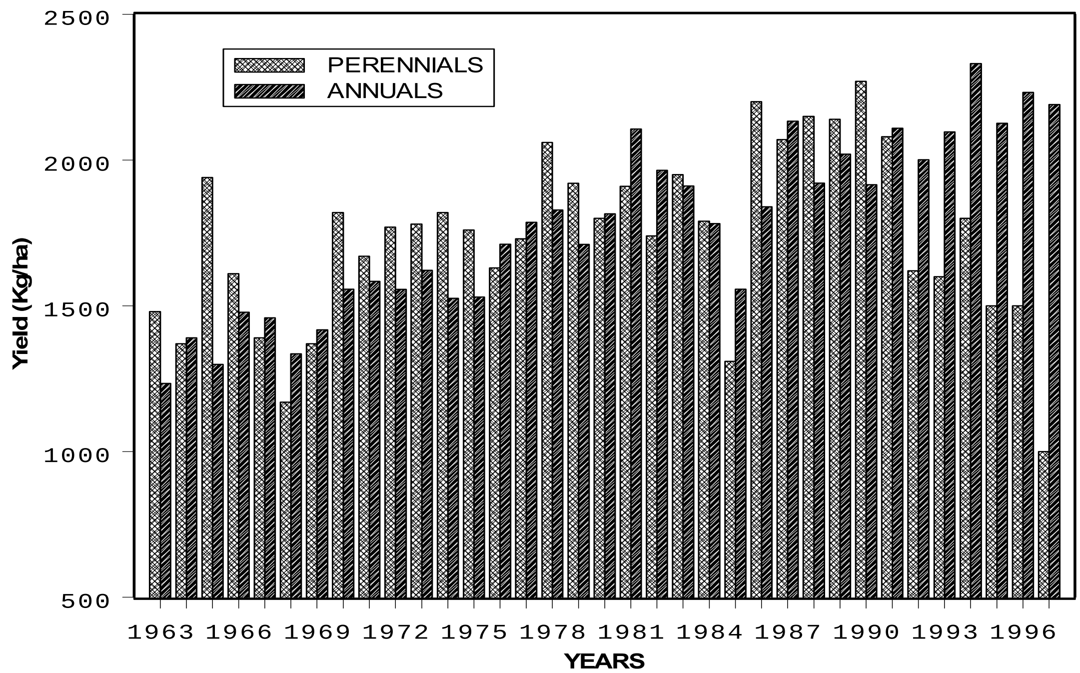

Fig. 4.1. Provincial yield averages grouped by annual and perennial crop classes. Original source of the data: Agriculture Division, Statistics Canada.

At first the changes that took place over time were more numerous on those soils cultivated with annual crops than on those cultivated with perennials. One of the possible reasons for having the soils cultivated with perennial crops being less affected by changes in soil P over time could be related to changes in management practices. Although a specific investigation is needed, we can hypothesize that changes in the technology that could affect the rational use of fertilizer had been more widely adopted in the production of annual crops. Phosphate ions tend to react with soils and become less mobile via sorption, precipitation and chelation. In acid soil, iron and aluminum tend to immobilize phosphate, whereas, in alkaline soil calcium does the immobilization. Fertilizer banded applications could trigger a more economical use of P by placing the fertilizer closer to the roots. Traditionally, the phosphorus fertilizer has been applied in-rows for cereal crops and top dressed for forage crops (Robertson, 1982). During the 80's the success in deep banding of nitrogen fertilizer stimulated the introduction of new application techniques for phosphorus. Good response obtained with banded or seed placed application of P fertilizer to annual crops has been the triggering factor in changing fertilizer practices toward a more economical use of P.

Although application of P fertilizer can improve dry matter yields and extend the growing season of perennials (Mahli, 1993), application of phosphorus fertilizers is still mainly restricted to top-dressing. Banded application below the surface of established perennial stands could cause serious damage to the roots, and therefore impair P uptake.

Major technological advancements in the way P fertilizer are applied to perennial crops have not been reported. Therefore, we could speculate that the lack of major changes in technology could be the cause for the higher number of ecodistricts that show no changes in the soil P level over time.

In an attempt to link the changes of soil P to land physical properties we found that the largest clustering of the increase in soil P occurred in the Moist Mixed Grassland extending northward in the Aspen Parkland, eastward in the Mixed Grassland and westward in the Fescue Grasslands (Fig.3.13). These spatial patterns overlay with a series of different soil groups such as the Brown, Dark Brown and Black Chernozemics. Increase in P levels that were statistically significant are not clustered around a specific regional area, with the available soil P in these ecodistricts having increased by about 2-16 ppm. For the dryland perennial crops we identified ecodistricts with a non-significant change in soil P over a wide range of ecoregions, spanning from the Mixed and Moist Mixed Grasslands to the Boreal Transition (Fig. 3.14). However, our findings did not reveal a strong spatial correlation that is consistently explainable by physical patterns of the landforms (i.e., ecoregions), leading to the possibility that changes in soil P were largely due to anthropogenic activities.

4.2 Soil available P levels and potential crop response to fertilizer

Assessment of soil available P has been the objective of previous studies. For example the Potash & Phosphate Institute (PPI) produced a report on soil samples across the United States and part of Canada, and indicated that 65% of the soil samples collected in Alberta tested medium or lower in soil P level (PPI, 1998). Soil testing medium and low in soil P are those in which an additional P amendment generally results in a crop yield response. In our investigation, we probably used a higher number of observations and refined our analysis at a more detailed spatial scale (i.e., ecodistrict). Our conclusions are similar to those released by PPI. For the 1993-97 time period 46 out of 62 ecodistricts for the dryland annual, and 35 out of 40 for the dryland perennial crops had a soil P concentration equal or lower than 25 ppm. We found that one out of nine ecodistricts for irrigated annual crops, and one out of eight for the irrigated perennial crops, have a mean soil P value between 25 and 30 ppm.

This macro scale scenario for Alberta corroborates with previous findings (PPI, 1998) but with improved precision and more refined spatial scale. Our findings, however, cannot be used to directly infer future yields as a function of increased fertilization rates in those ecodistricts with soil P value between 25 and 30 ppm. Instead, a more detailed analysis with the objective of verifying the potential for crop response at the field level should be implemented. For example we suggest that the current analysis could be combined with a crop modelling exercise to include the potential effects of soil type and climate that are found in particular ecodistricts. Although model simulations provide results that resemble and not necessarily reproduce exactly the full field conditions, this approach may provide preliminary information before the actual implementation of field trials. Other investigators used this approach to evaluate the general crop response to change in boundary conditions such as climate (Izaurralde *et al*., 1999; Phillips *et al*., 1996). Similarly a preliminary regional assessment of the potential increase in crop productivity as a result of more P application could be obtained through the use of similar models. However, our work is meant to support regional assessments and not to replace detailed field-testing procedures used to formulate recommendations that apply at a more detailed scale (e.g., single field). Regardless, our analysis shows that currently there are large areas of Alberta that have low to moderate soil P levels and soil testing is required to develop a nutrient management plan to encourage optimum economic crop production.

5.0 SUMMARY AND CONCLUSIONS

Over the 30-year period the mean soil P for the majority of the ecodistricts remained unchanged or decreased. During the 1993-97 time period the majority of the ecodistricts had a mean soil P value between 25 and 30 ppm. Although our results support the fact that on average much of the agricultural soils in Alberta could benefit from P amendment, we recommend that fertilizer management strategies should be examined on a farm by farm basis. An increase in P fertilization may result in higher crop production, but over use of P amendment can be an environmental hazard. Therefore, if the objective is to maximize crop production while controlling P loss from the soil, then the extra P amendment should be considered together with the landscape and climatic characteristics that would have an impact on the P loss. Accepting that strategy, it becomes even more crucial if an extra supply of P is available due to animal production, and therefore the necessity for recycling of this other form of P becomes more of a priority.

In order to produce a comparison between the data collected in the 60's and the data collected in the 90's a regression analysis was performed using the data set of McKenzie *et al.* (1995). A good correlation between the Norwest soil test method and the Miller and Axley method was found for neutral and acid soils, but as the soil pH increased the correlation worsens, similar conclusions were reached by Ashworth and Mrazek (1989). Calculated intercept and slope values were used to adjust the measurements obtained using the Miller and Axley method to the Norwest modified Kelowna method. However, some of the significant changes that occurred over time in the Southern part of Alberta are found on alkaline soils, and although we accounted for the differences of the two soil tests through a regression analysis some caution should be used in drawing conclusions. Therefore, it is possible that some of the increase in soil P that we see from the 60's into the 90's could be in part due to the Miller and Axley unsuitability to extract plant available P in alkaline soils. Ashworth and Mrazek (1989) indicated that the poor correlation found in soils with free lime is presumably due to the sulfuric acid in the Miller and Axley solution being the cause for the extract pH to rise from < 2 to > 6 in some cases. The extract of the other test is well buffered at about pH 4.5.

Because the measuring procedure used in the 60's was different from the one used in the 90's, an historical comparison of soil organic matter content was difficult to implement. Therefore, the observations collected in the 90's were used to map the current scenario across the province. Lowest soil organic matter content (2-5 %), is found in Southern Alberta, whereas the rest of the Province ranges between 6 and 10% depending on crop type and water supply. Soil organic matter was considered because it is a potential source or sink for P, however the rate at which P is released is a function of organic matter decomposition rates. Phosphorus released from organic matter decomposition may be an important fraction of the total soil P. However, reliable estimates could be obtained with a more comprehensive analysis. It is suggested that an attempt to quantify the mineralization rate of P should include incubation experiments as well as considerations of the major factors having an impact on the decomposition rate (e.g., soil pH, soil moisture). However, a previous finding indicates that the mineralization of P is particularly important in natural ecosystems (Polglase *et al*., 1992) or becomes an important source of plant available P in unfertilized soils (Gressel and McColl 1997).

Finally, it was our objective to provide the reader with descriptive statistics to be used for a more comprehensive characterization of the ecodistrict in terms of soil available P. In particular, the range, skewness and kurtosis of the data, tabulated in the appendices provide details to the number of extreme values relative to the mean.

6.0 REFERENCES

Ashworth, J. and Mrazek, K., 1989. The acetic-fluorite test for available phosphorus and potassium. *Proceedings of the 26th Annual Alberta Soil Science Workshop*, Feb. 21st-22nd, 1989, pp. 178-182.

Daniel, T.C., Carton, O.T., and Magette, W.L., 1997. Nutrient management planning. In: *Phosphorus Loss from Soil to Water*, Tunney, H., Carton, O.T., Brookes, P.C., and A.E., Johnston, Eds. CAB International, New York, USA, pp. 297-310.

Ecological Stratification Working Group, 1995. *A National Ecological Framework for Canada*. 125 pp..

ESRI Inc. 1996. Using ArcView GIS. ESRI Inc. Redlands, CA USA.

Goettel, A.W. 1987. Crop nutrient removal and additions in Alberta. *Proceedings of the 24th Alberta Soil Science Workshop,* Feb. 17th-18th, 1987, pp. 219-232.

Gressel N., and McColl J.G., 1997. Phosphorus mineralization and organic matter decomposition: a critical review. In: *Driven by nature*, Cardish, G. and K.E., Giller, Eds. CAB International, London, UK, pp. 297-308.

Izaurralde, R.C., Rosenberg, N.J., Brown, R.A., Legler, D.M., Tiscareño Lòpez, M., and Srinivasan, R., 1999. Modeled effects of moderate and strong 'Los Niños' on crop productivity in North America. *Agricultural and Forest Meteorology* 94: 259-268.

Korol, M., and Rattray, G., 1999. *Canadian fertilizer consumption, shipment and trade 1997/1998.* Agriculture and Agri-Food Canada, (Internet site: http://www.agr.ca).

Mahli, S.S., Harapiak, J.T., Kryzanowski, L.M. and Ukrainetz, H., 1993. Fertilizer management of forage crops in western Canada. *The Proceeding of Western Canada Agronomy Workshop*, July 7th-9th, 1993.

McKenzie, R.H., Kryzanowski, L., Cannon, K., Solberg, E., Penney, D., Coy, G., Heaney, D., Harapiak, J. and Flore, N., 1995. *Field evaluation of laboratory tests for soil phosphorus.* Alberta Agricultural Research Institute, Project No. 90 M230. 36 pp. & XI Appendixes.

Miller, J.R. and Axley, J.H. 1956. Correlation of chemical soil tests for available phosphorus with crop response, including a proposed method. *Soil Science* 82: 117-127.

Mullar, D.J., and Schepers J.S., 1997. Key processes and properties for site-specific soil and crop management. In: *The state of site-specific management for agriculture*, ASA-CSSA-SSSA, Madison, WI, USA, pp. 1-18.

Phillips, D.L., Lee, J.J., and Dodson, R.F., 1996. Sensitivity of the US corn belt to climate change and elevated CO_2: I. Corn and soybean yields. *Agricultural systems* 52: 481-502.

Polglase, P.J., Comerford, N.B. and Jokela, E.J., 1992. Mineralization of nitrogen and phosphorus from soil organic matter in southern pine plantation. *Soil Science Society of America* 56: 921-927.

PPI/PPIC/FAR, 1998. *Soil test levels in North America, summary update.* PPI/PPIC/FAR Technical Bulletin 1998-3.

Robertson, J.A., 1982. *Fertilizer placement. Alberta Agriculture*, Agdex 542-5.

SAS Institute Inc. 1990. *SAS user's guide: Statistics, Version 6 Edition.* Cary, NC USA SAS Institute Inc..

Schreier, H., Brown, S., Lavkulich, L.M., Shah, P.B., 1999. Phosphorus dynamics and soil P-fertility constraints in Nepal. *Soil Science* 164 (5): 341-350.

Tisdale, S. L., Nelson, W.L., Beaton, J.D., and Havlin, J.L., 1993. *Soil fertility and fertilizers*. Macmillan, New York, USA, pp.176-229.

Wallingford, W. 1978. Phosphorus functions in plants. In: *Phosphorus for agriculture, a situation analysis.* Potash/Phosphate Institute. 160 pp..

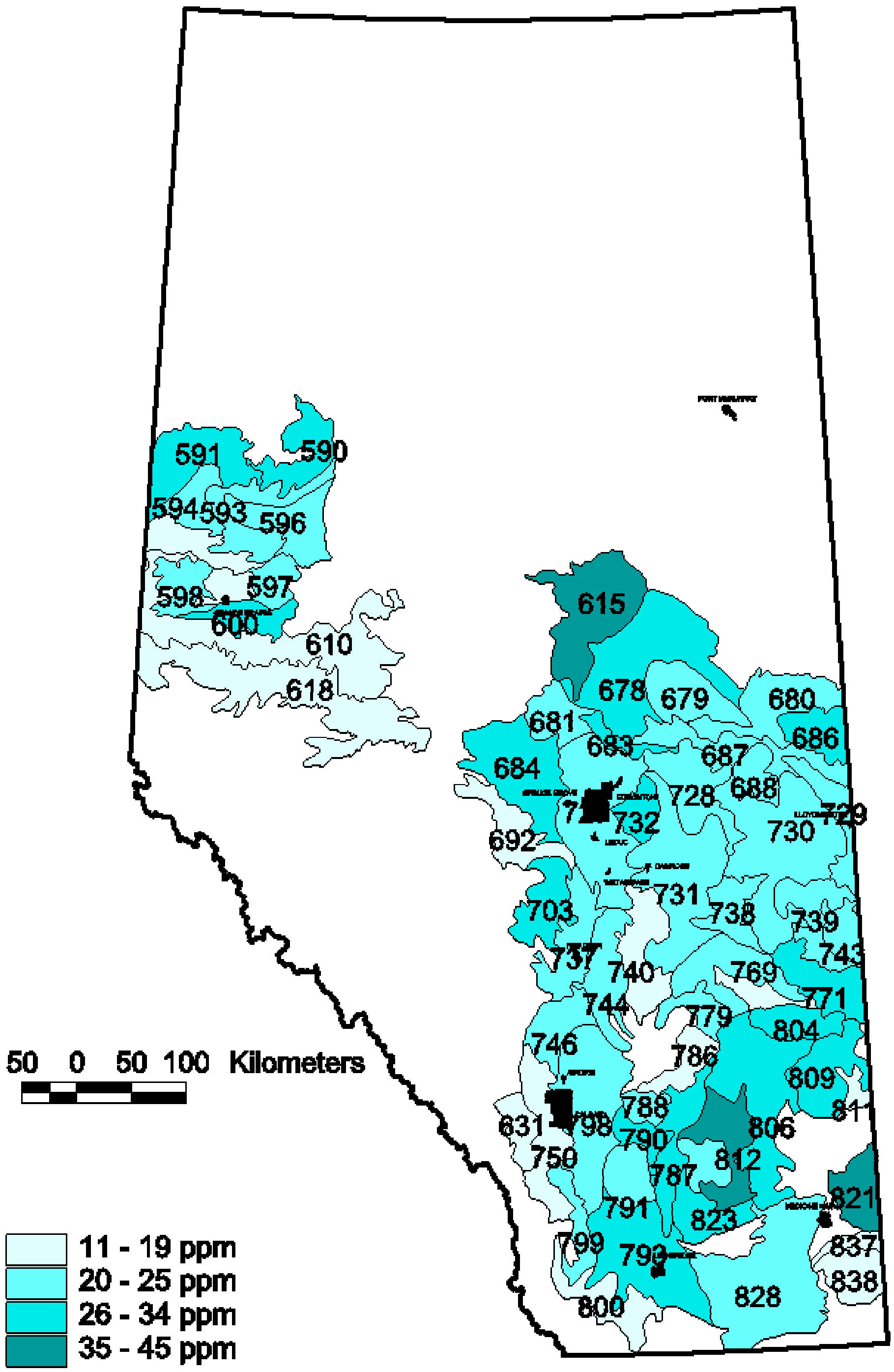

Fig. 3.1. Available P for dryland annual crops from 1963 to 1967.

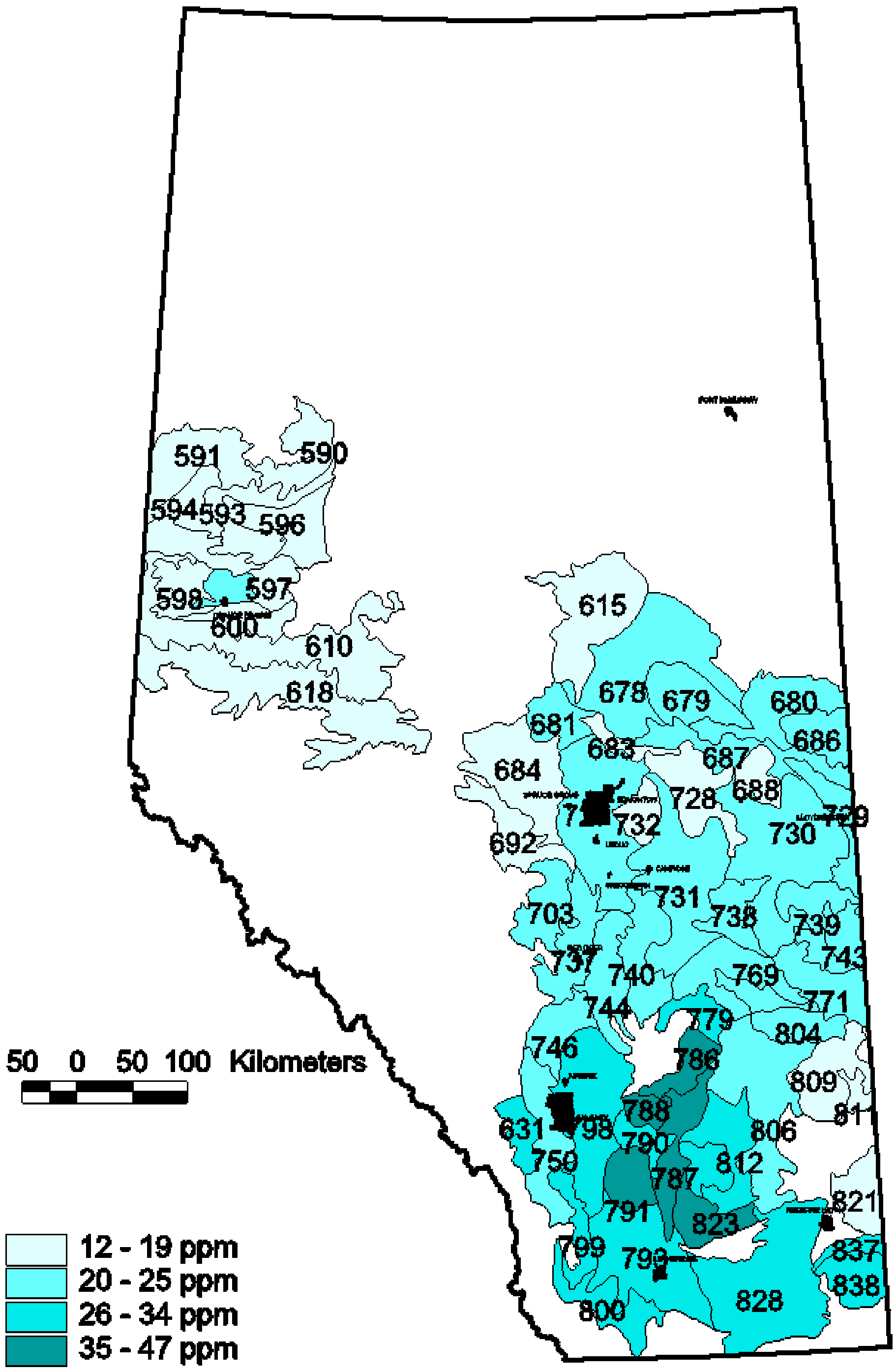

Fig. 3.2. Available P for dryland annual crops from 1993 to 1997.

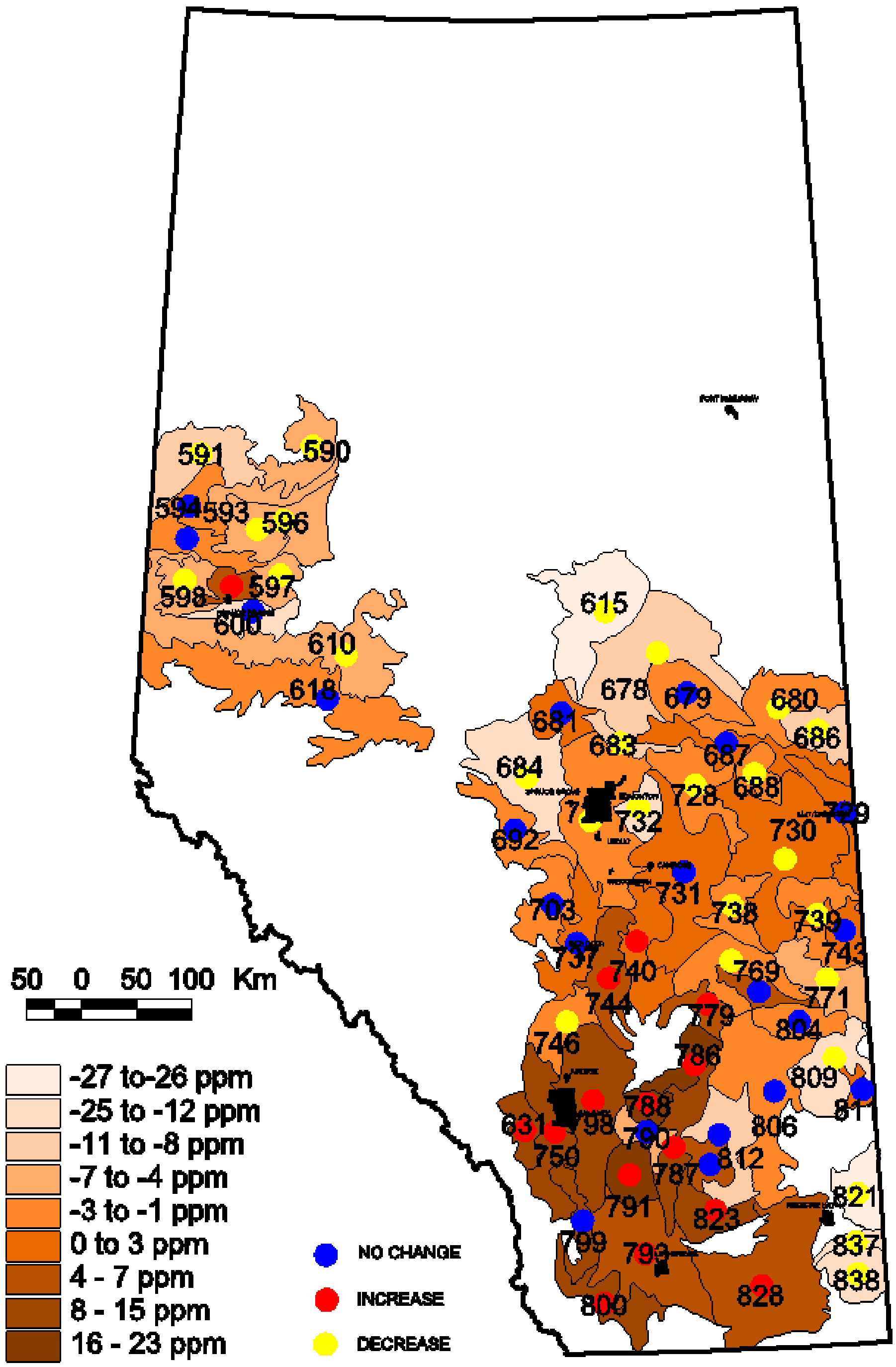

Fig. 3.3. Changes in available P for dryland annual crops (1963-67 vs. 1993-97).

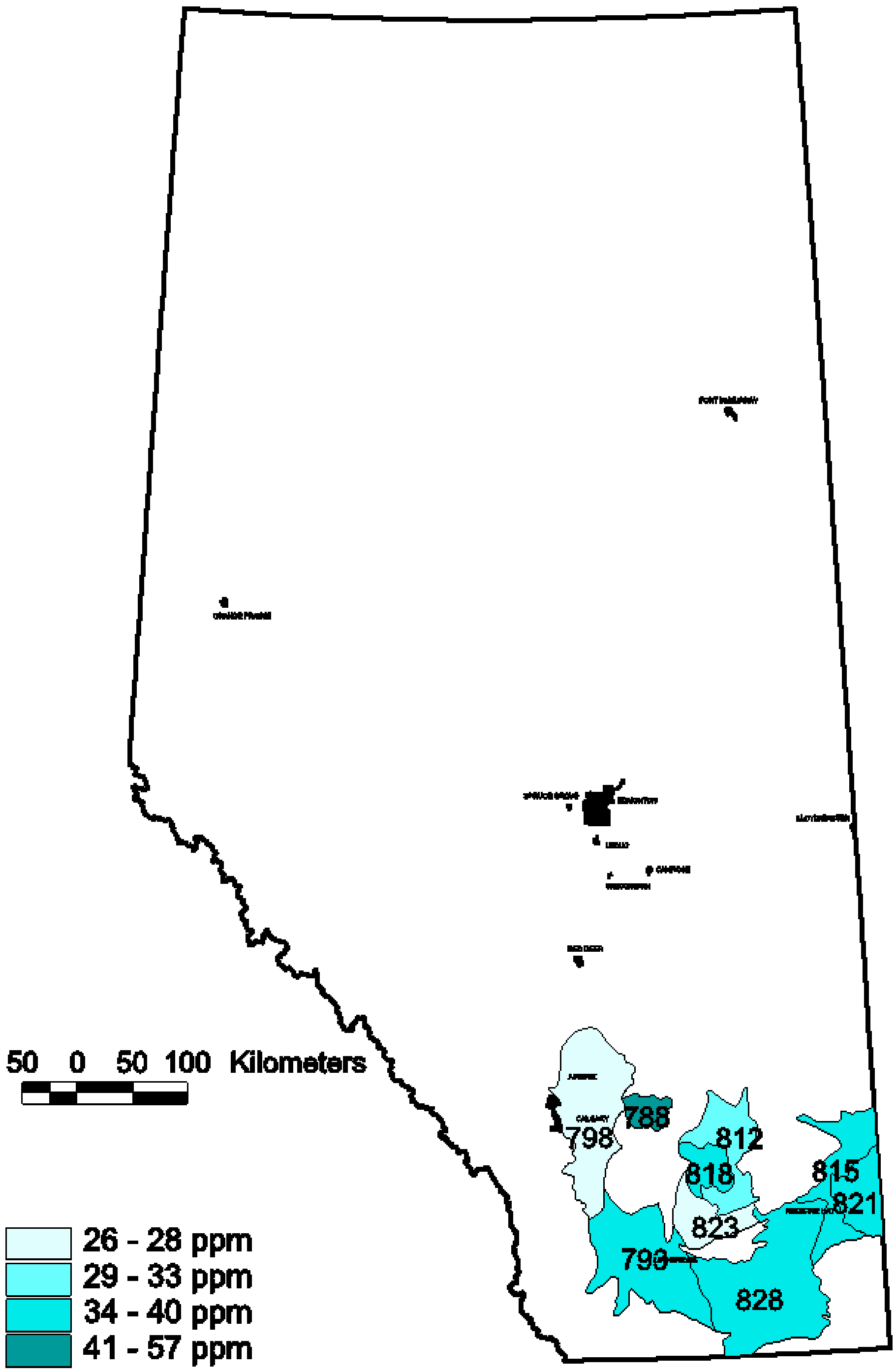

Fig. 3.4. Available P for irrigated annual crops from 1963 to 1967.

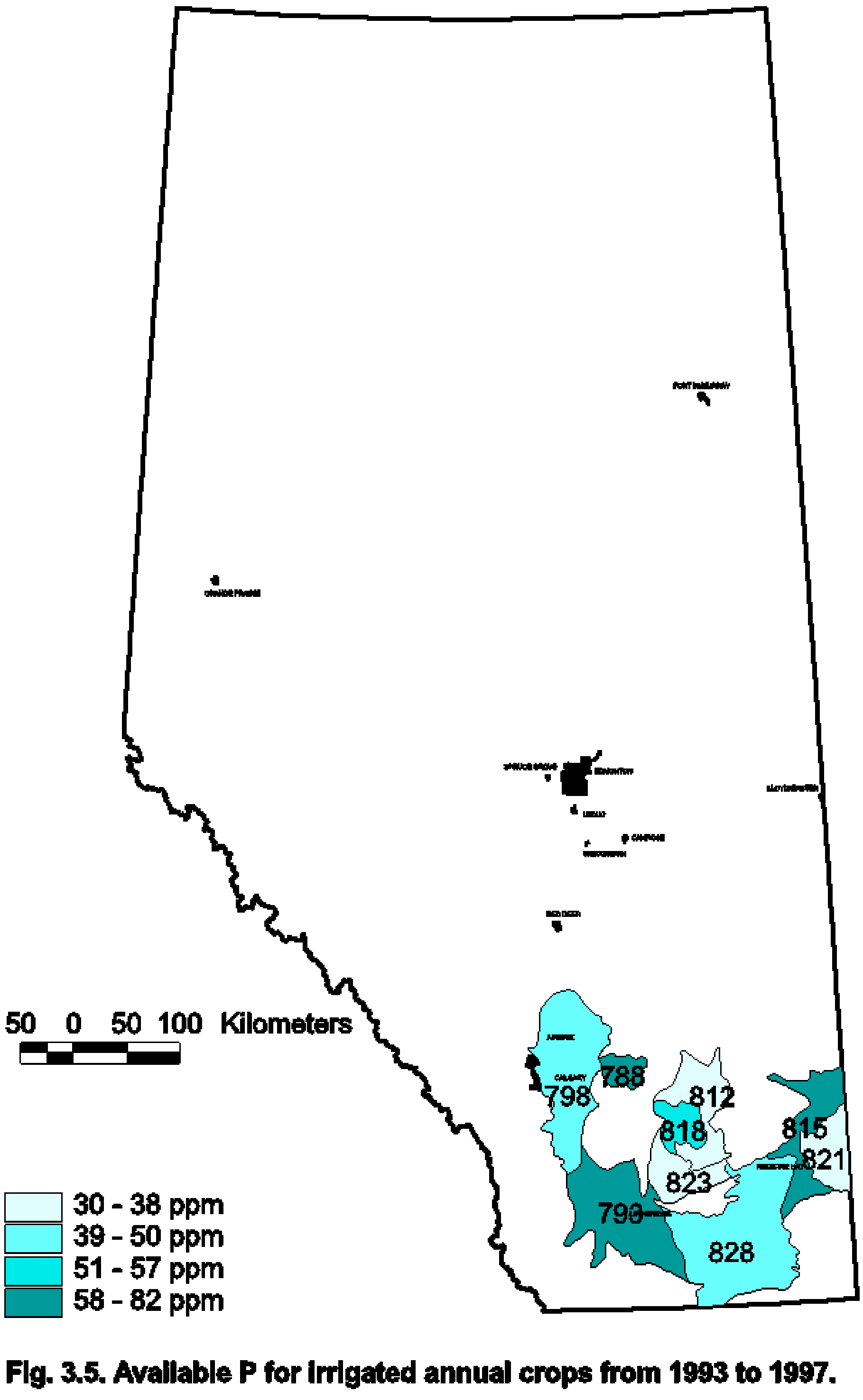

Fig. 3.5. Available P for irrigated annual crops from 1993 to 1997.

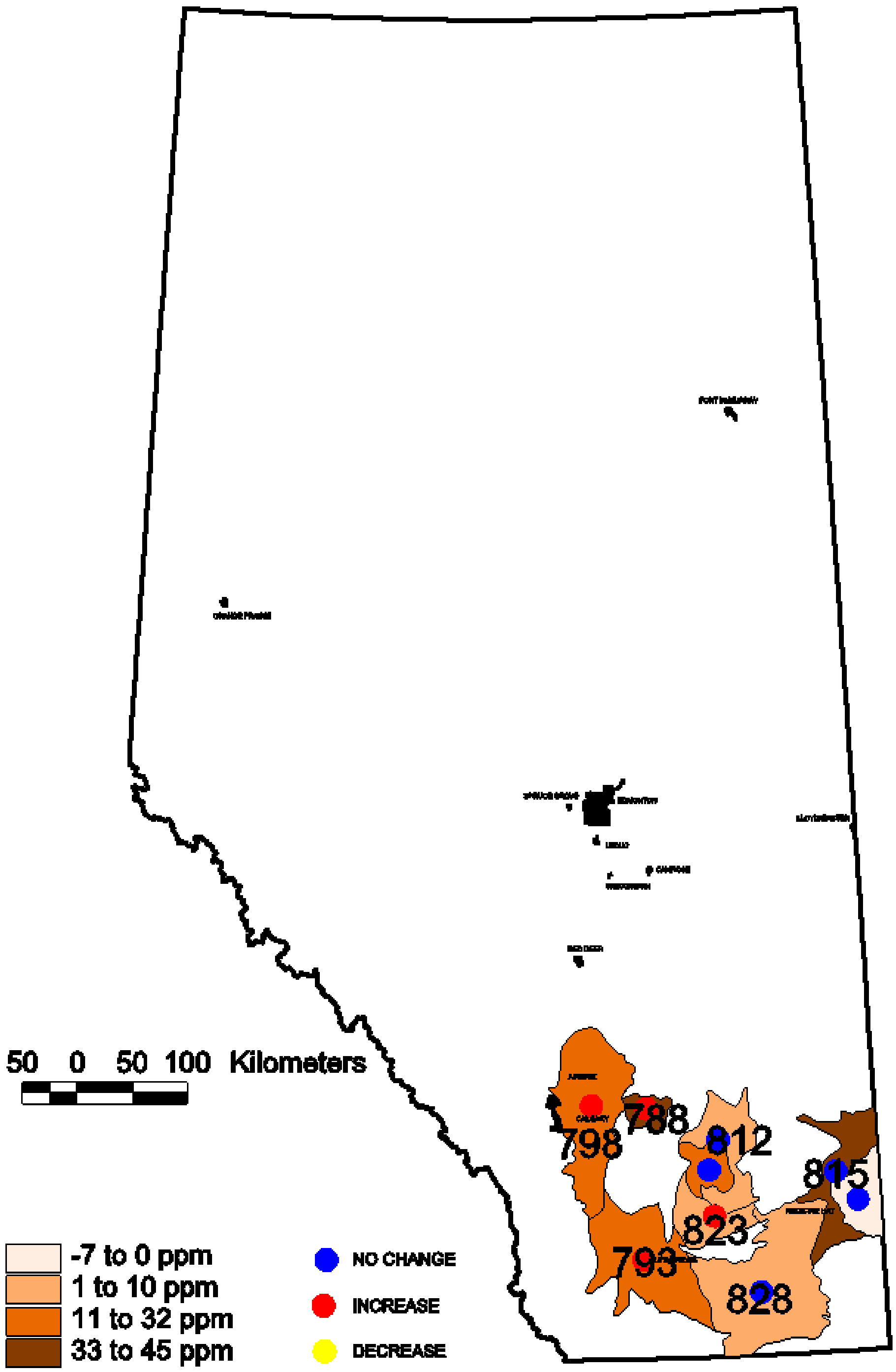

Fig. 3.6. Changes in available P for irrigated annual crops (1963-67 vs. 1993-97).

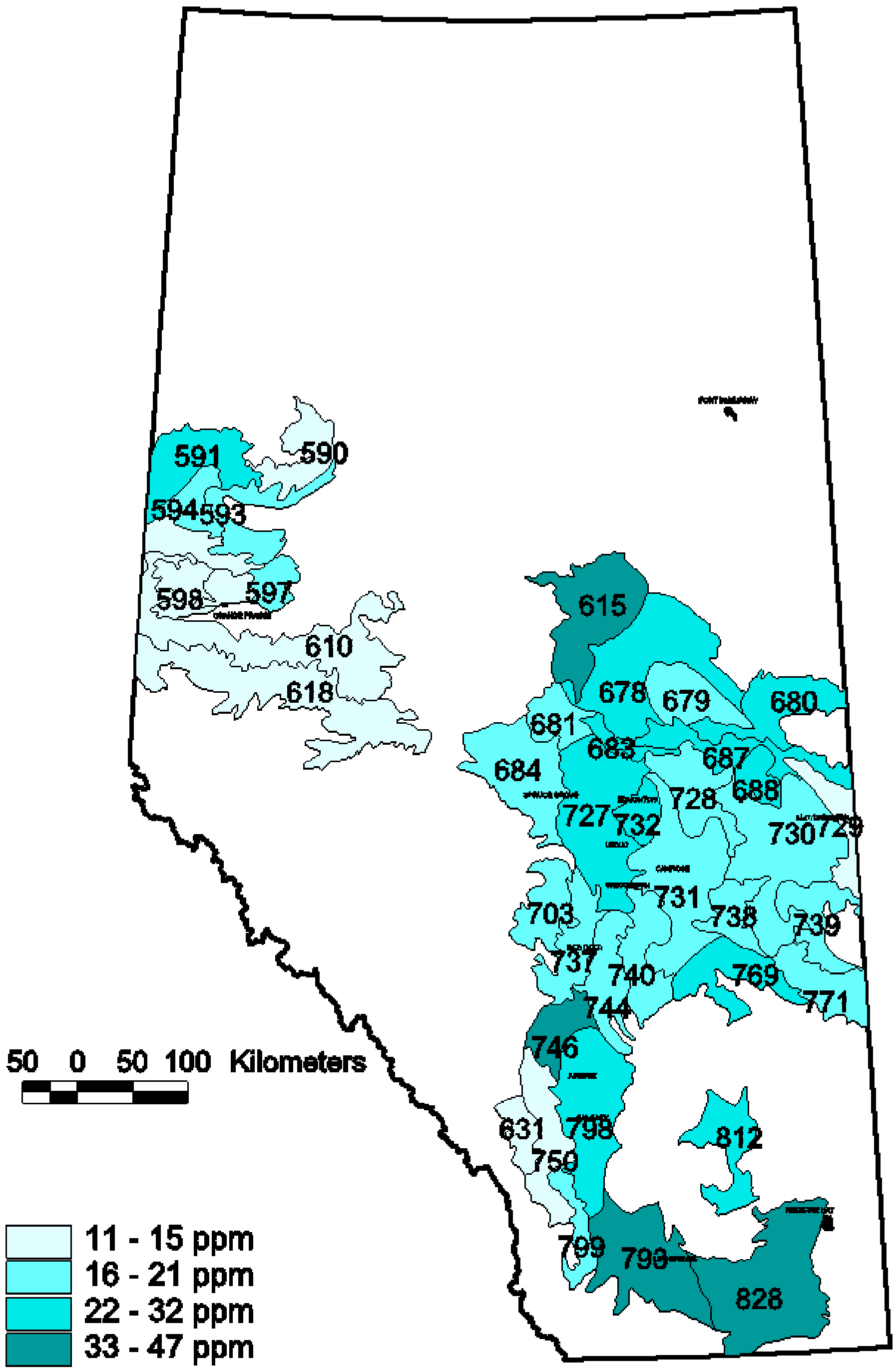

Fig. 3.7. Available P for dryland perennial crops from 1963 to 1967.

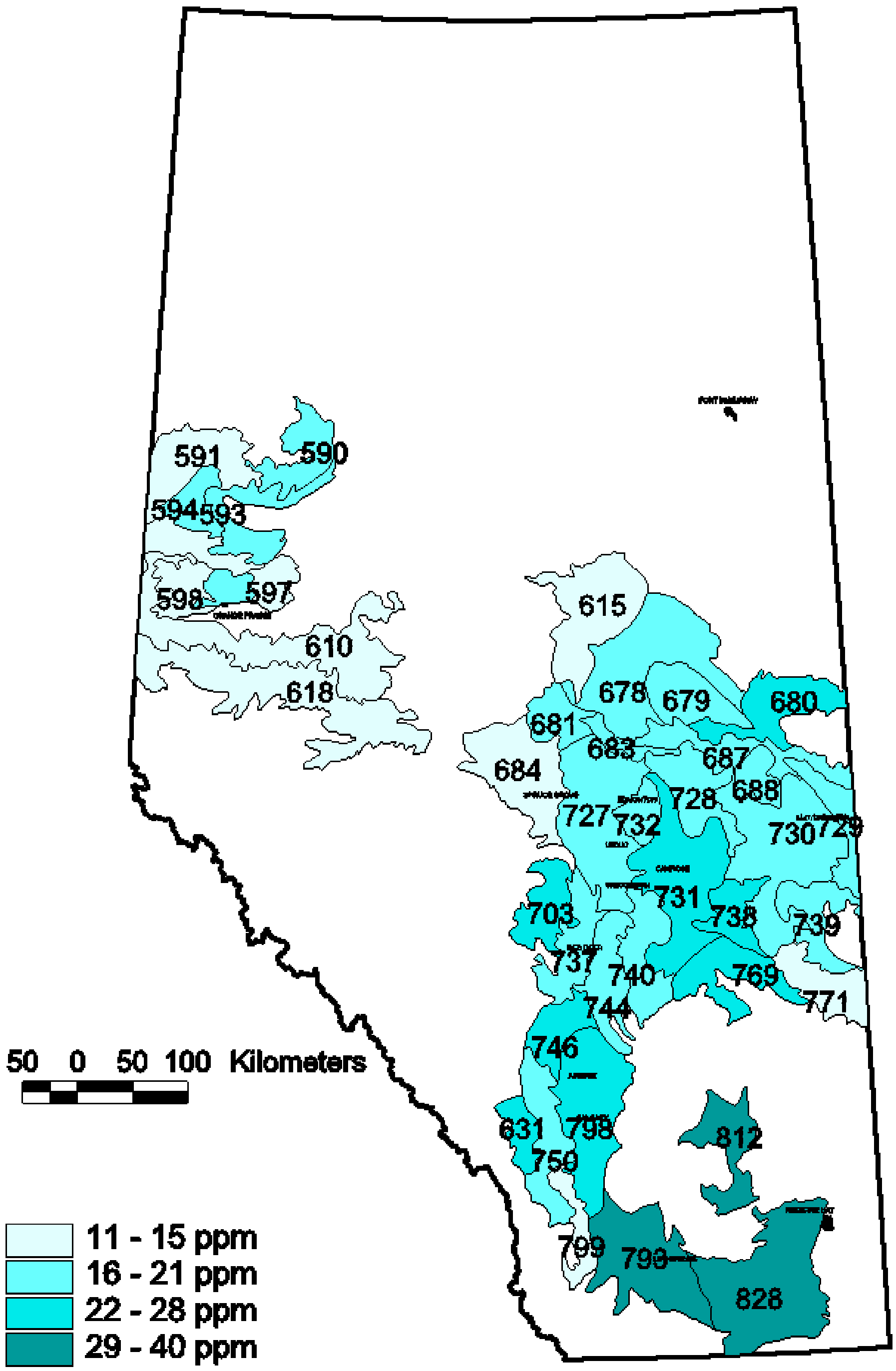

Fig.3.8. Available P for dryland perennial crops from 1993 to 1997.

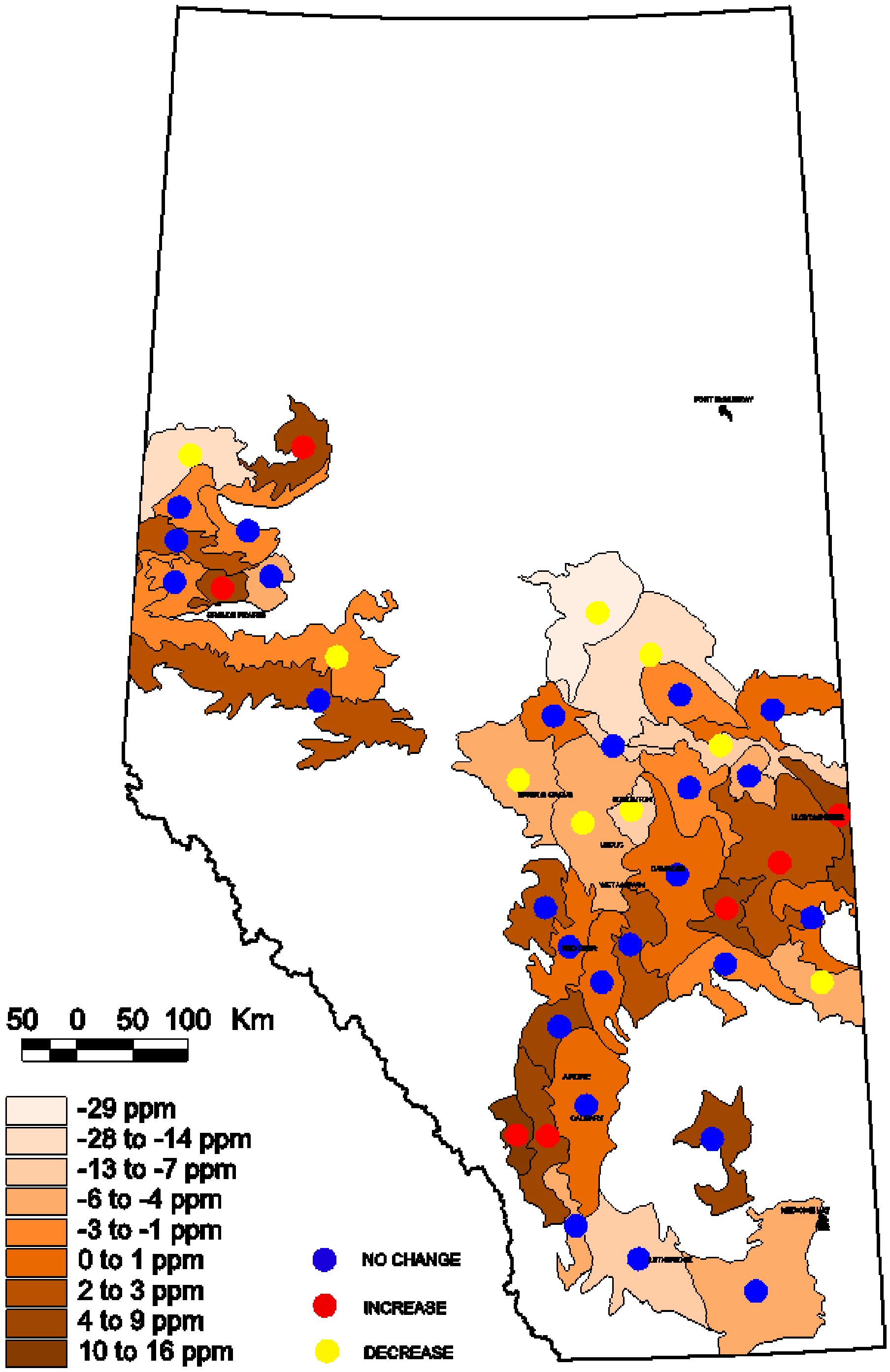

Fig. 3.9. Changes in available P for dryland perennial crops (1963 -67 vs. 1993-97).

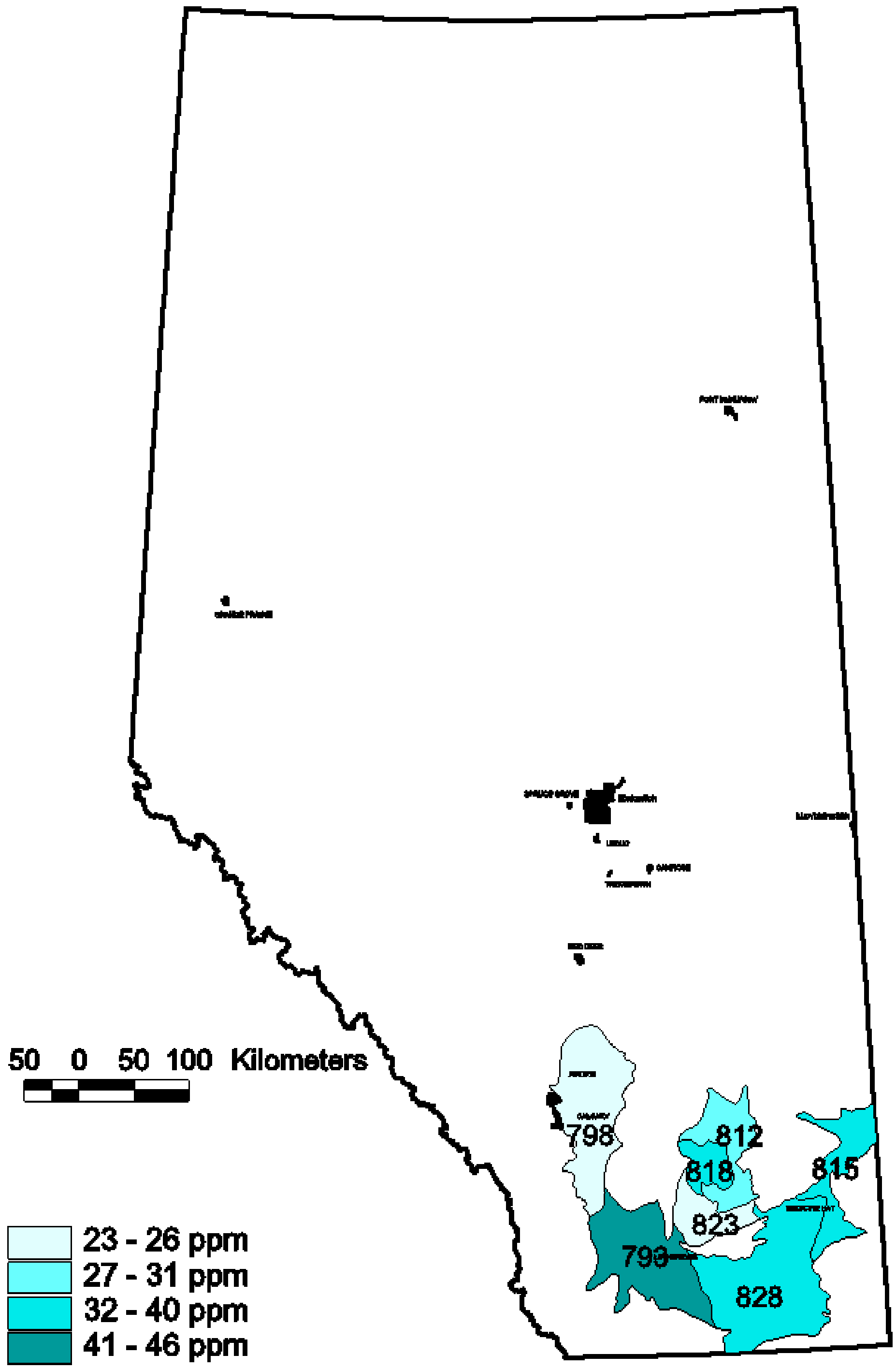

Fig. 3.10. Available P for irrigated perennial crops from 1963 to 1967.

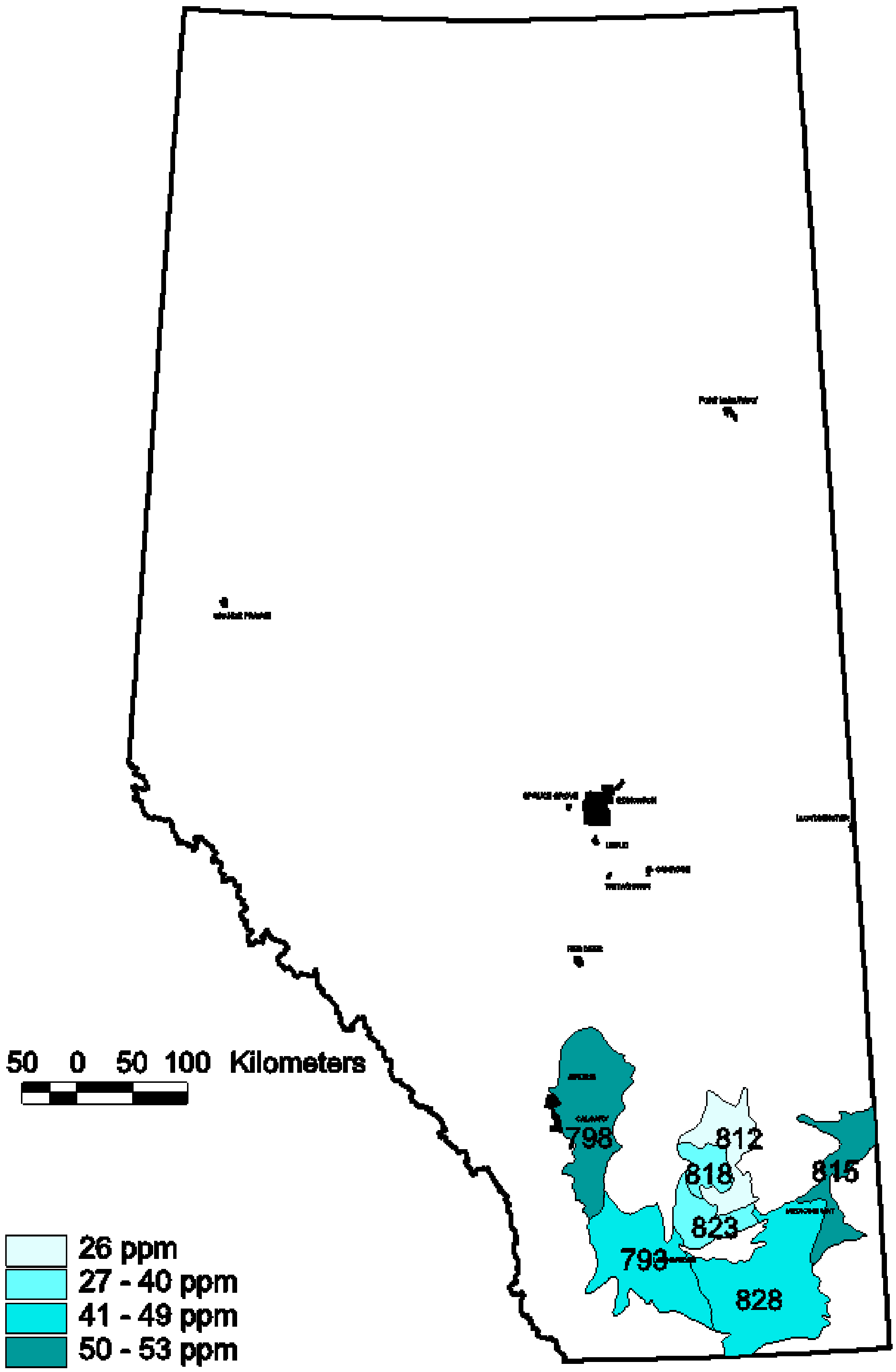

Fig. 3.11. Available P for irrigated perennial crops from 1993 to 1997.

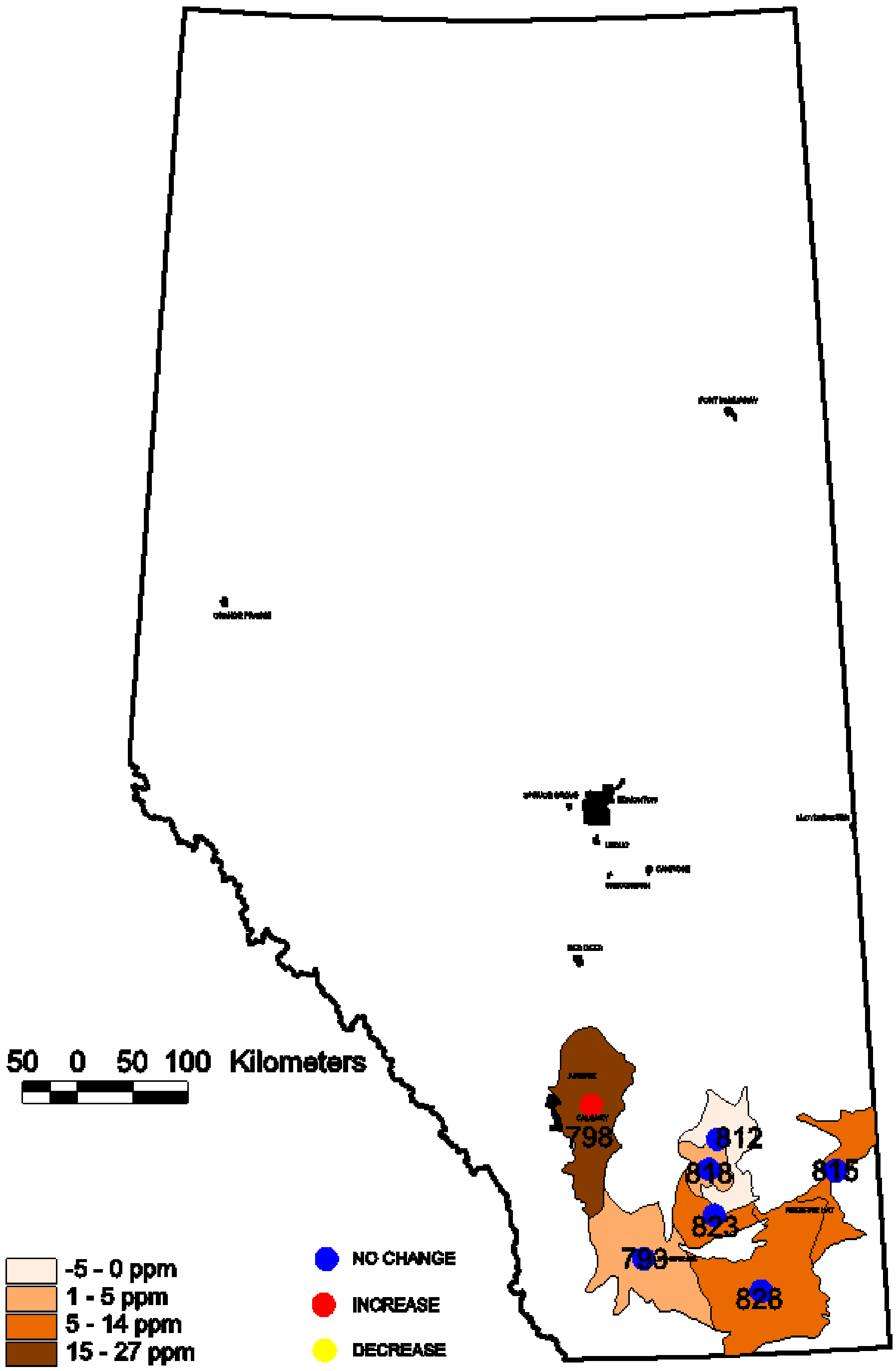

Fig. 3.12. Changes in available P for irrigated perennial crops (1963-67 vs. 1993-97).

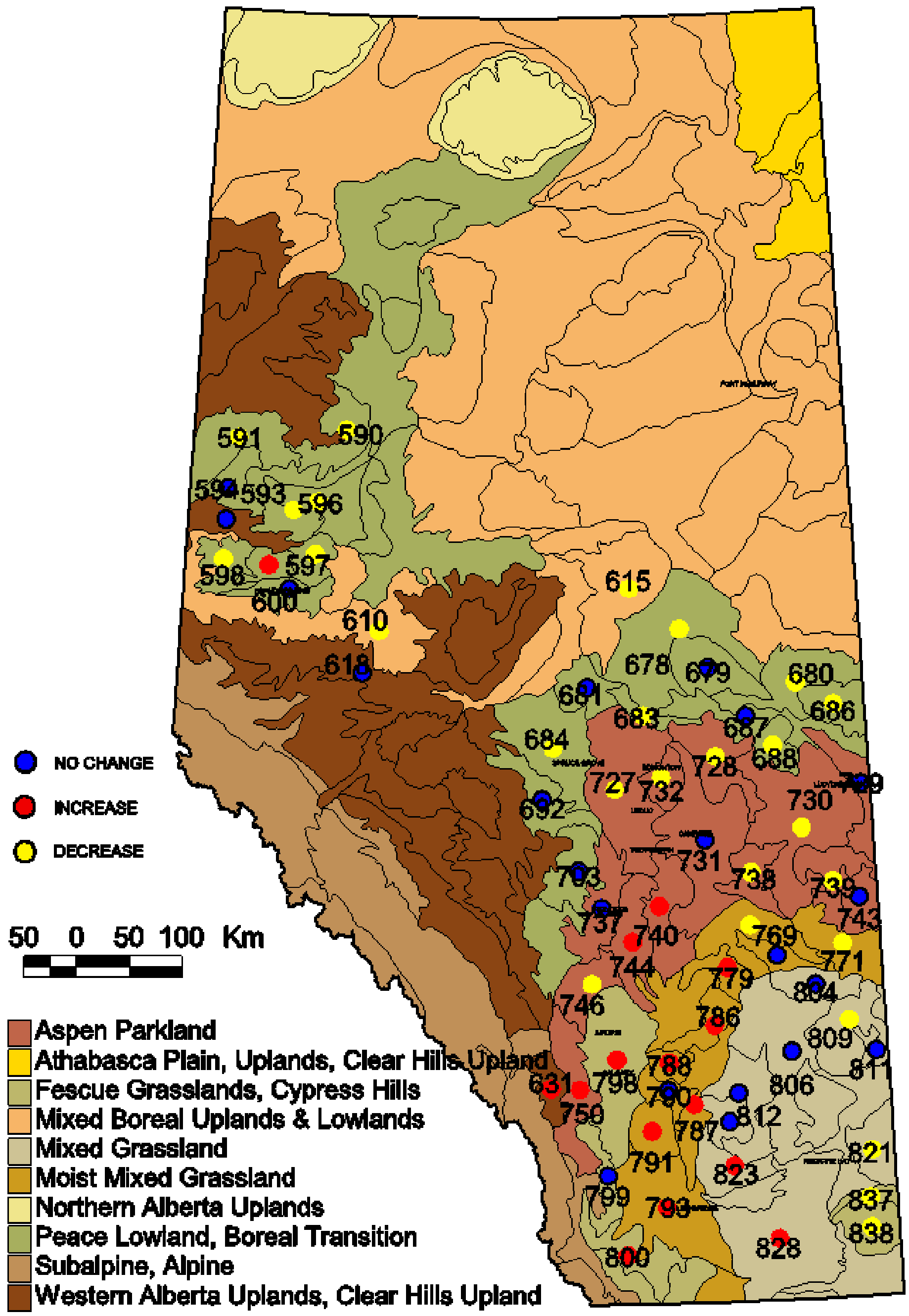

Fig. 3.13. Changes in available P for dryland annual crops (1963-67 vs. 1993-97), ecoregions over ecodistricts.

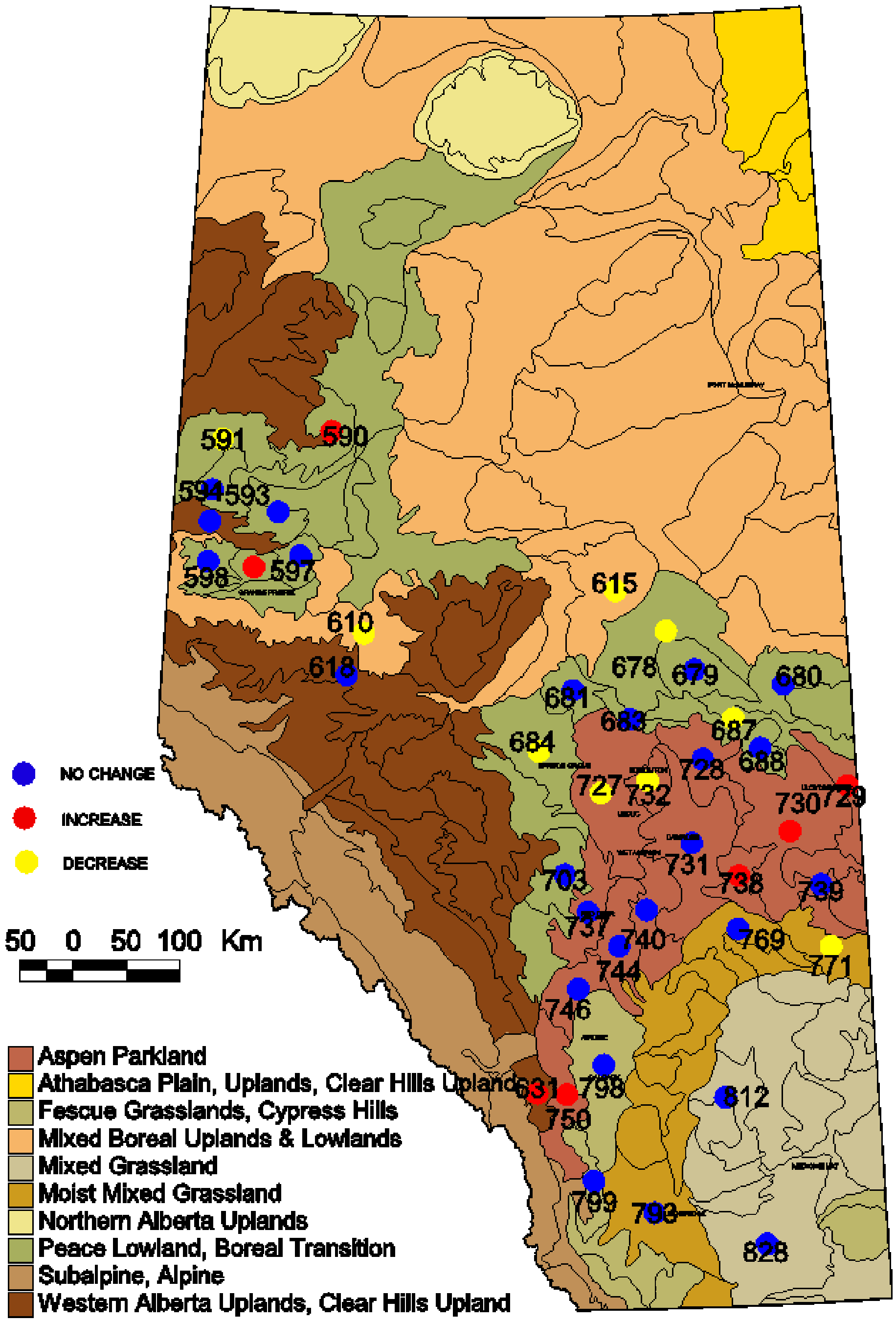

Fig. 3.14. Changes in available P for dryland perennial crops (1963-67 vs. 1993-97), ecoregions over ecodistricts.

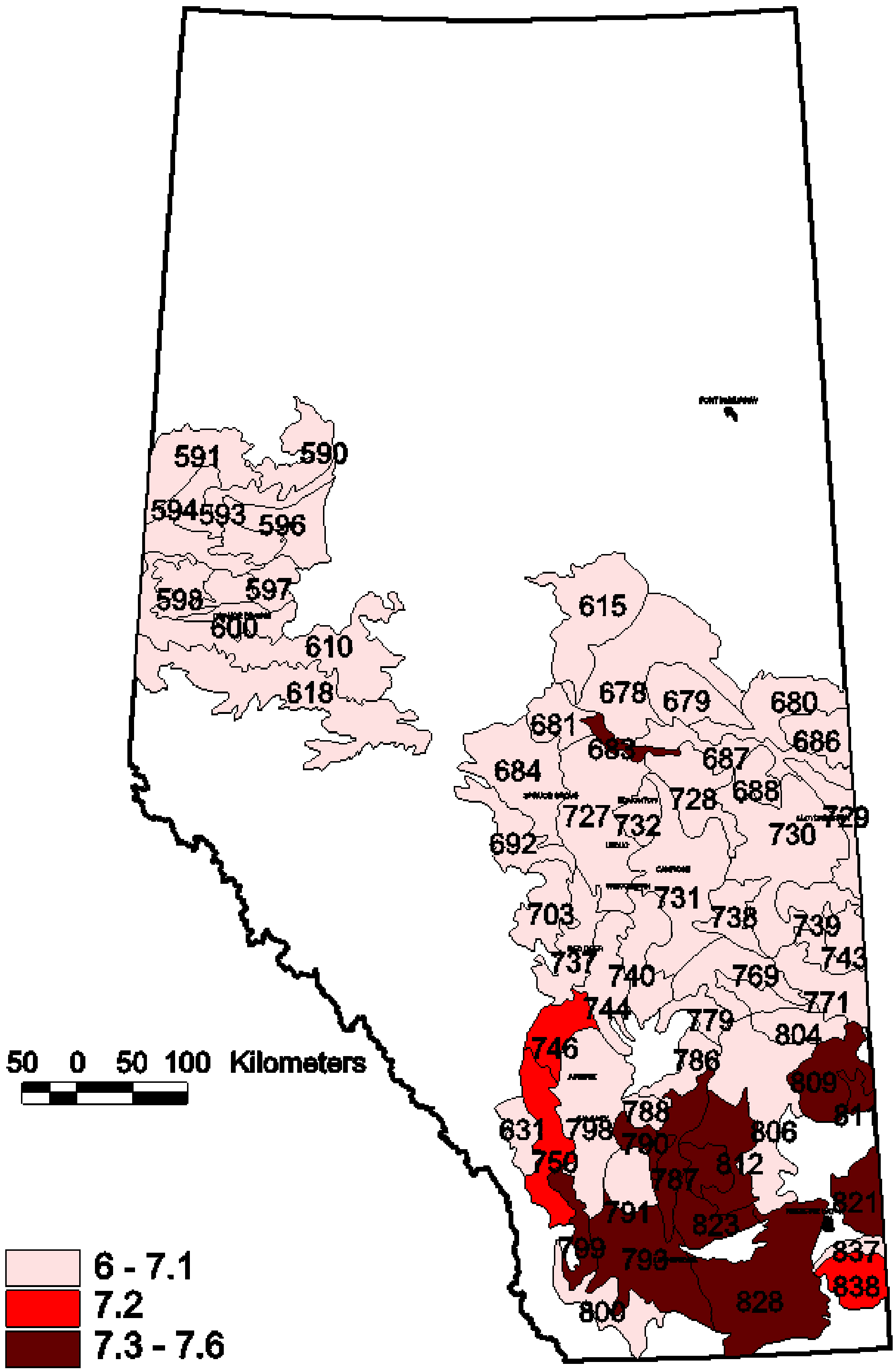

Fig. 3.15. Soil pH for dryland annual crops from 1993 to 1997.

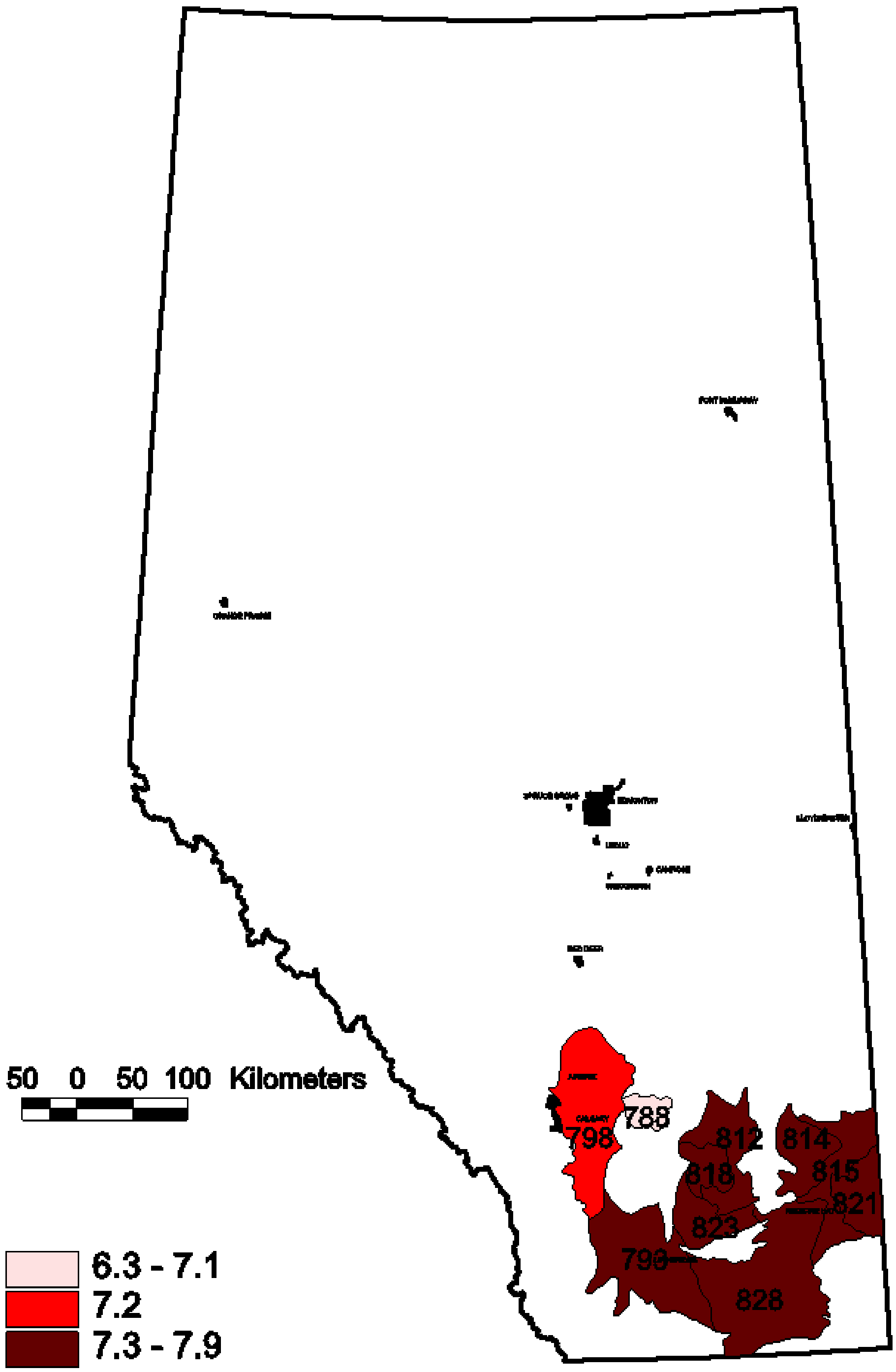

Fig. 3.16. Soil pH for irrigated annual crops from 1993 to 1997.

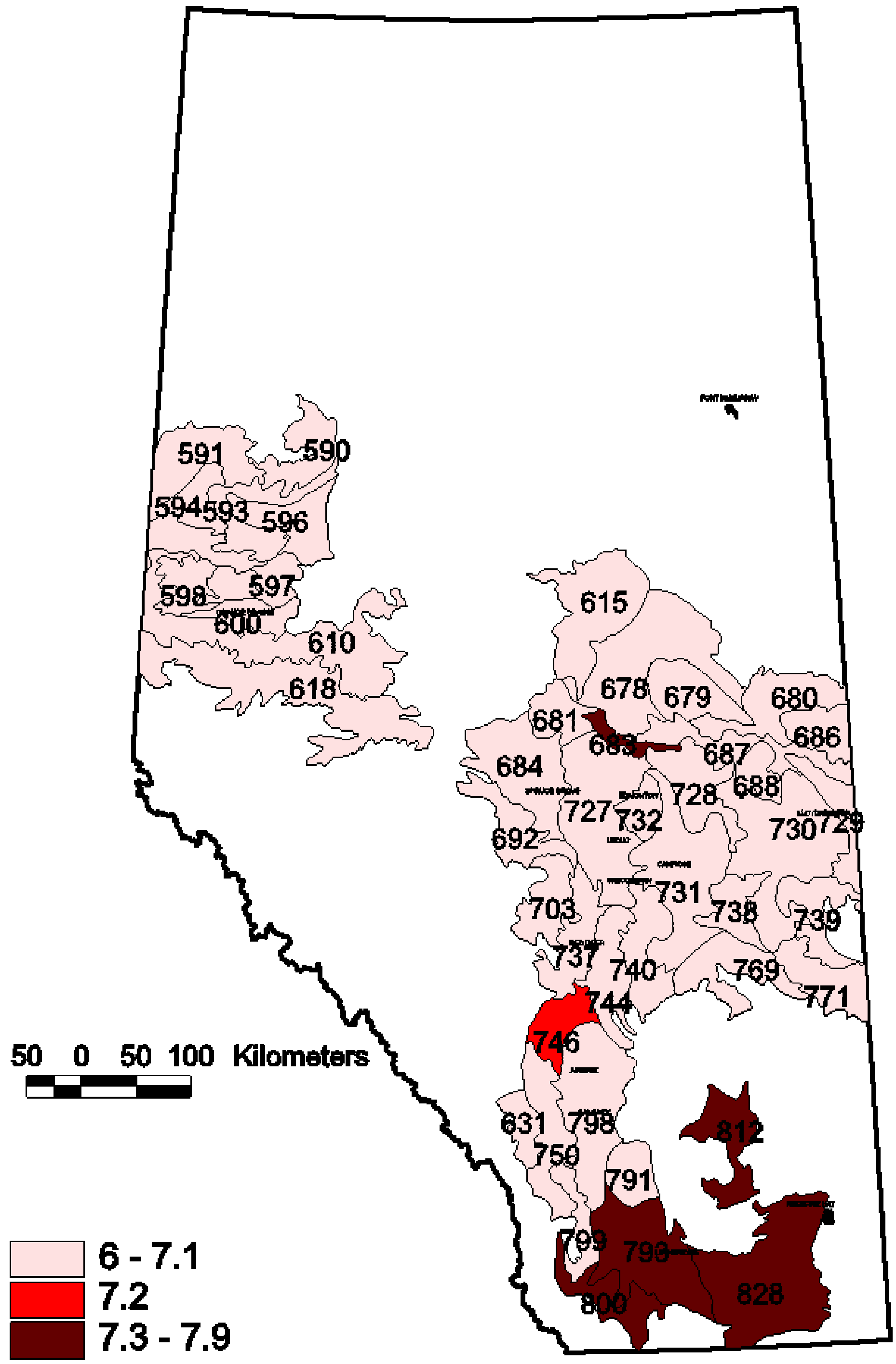

Fig. 3.17. Soil pH for dryland perennial crops from 1993 to 1997.

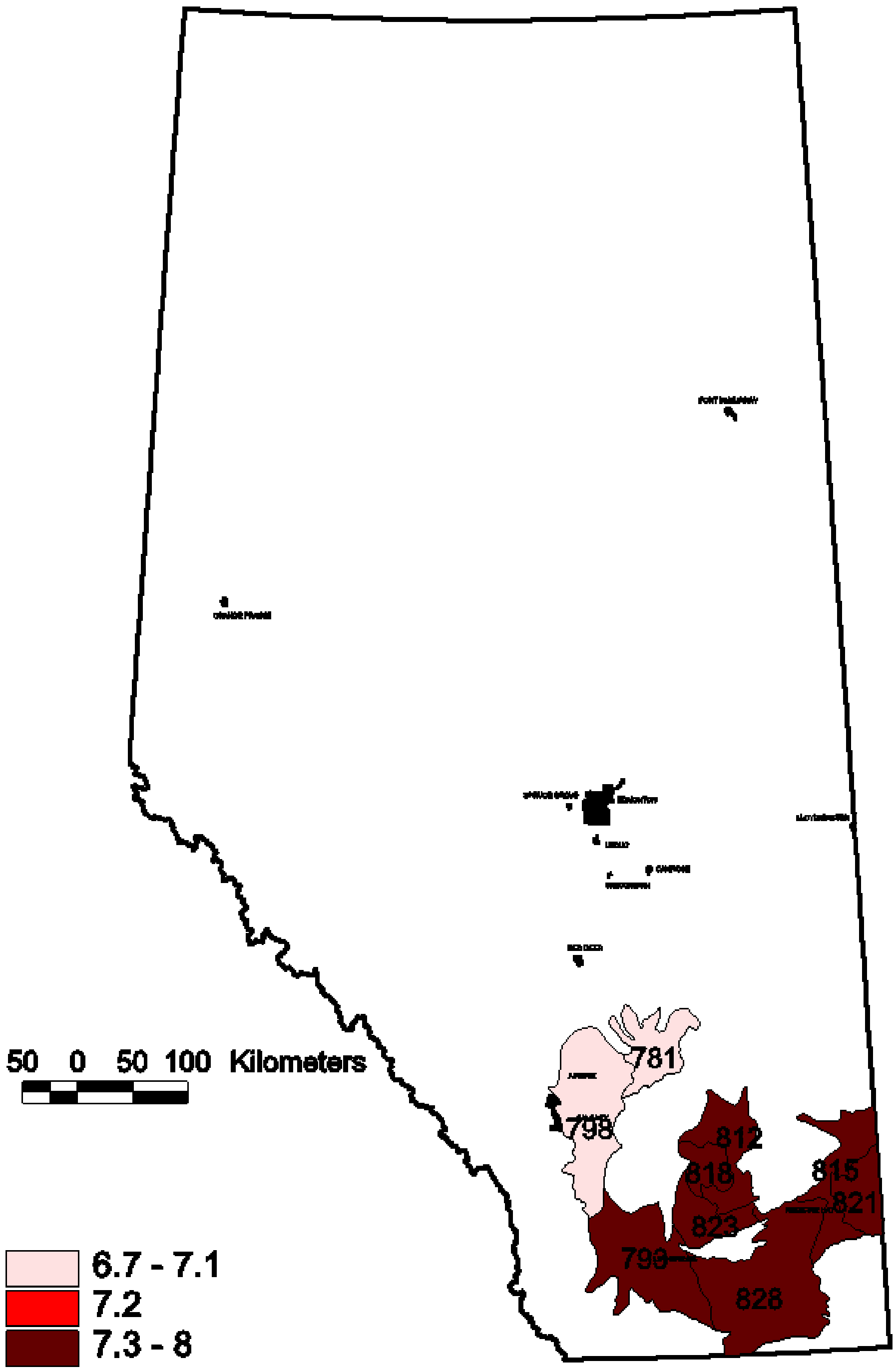

Fig. 3.18. Soil pH irrigated perennial crops from 1993 to 1997.

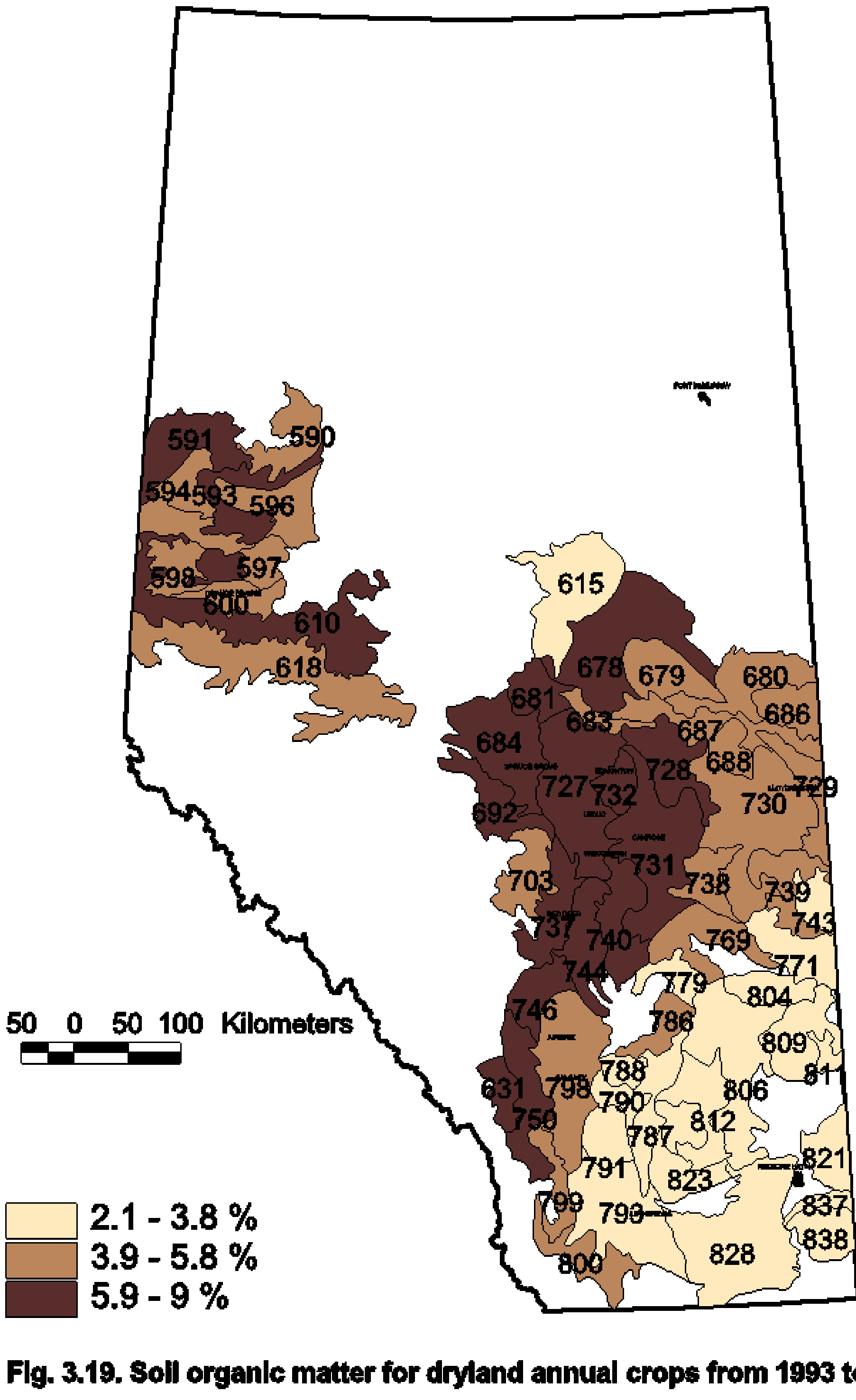

Fig. 3.19. Soil organic matter for dryland annual crops from 1993 to 1997.

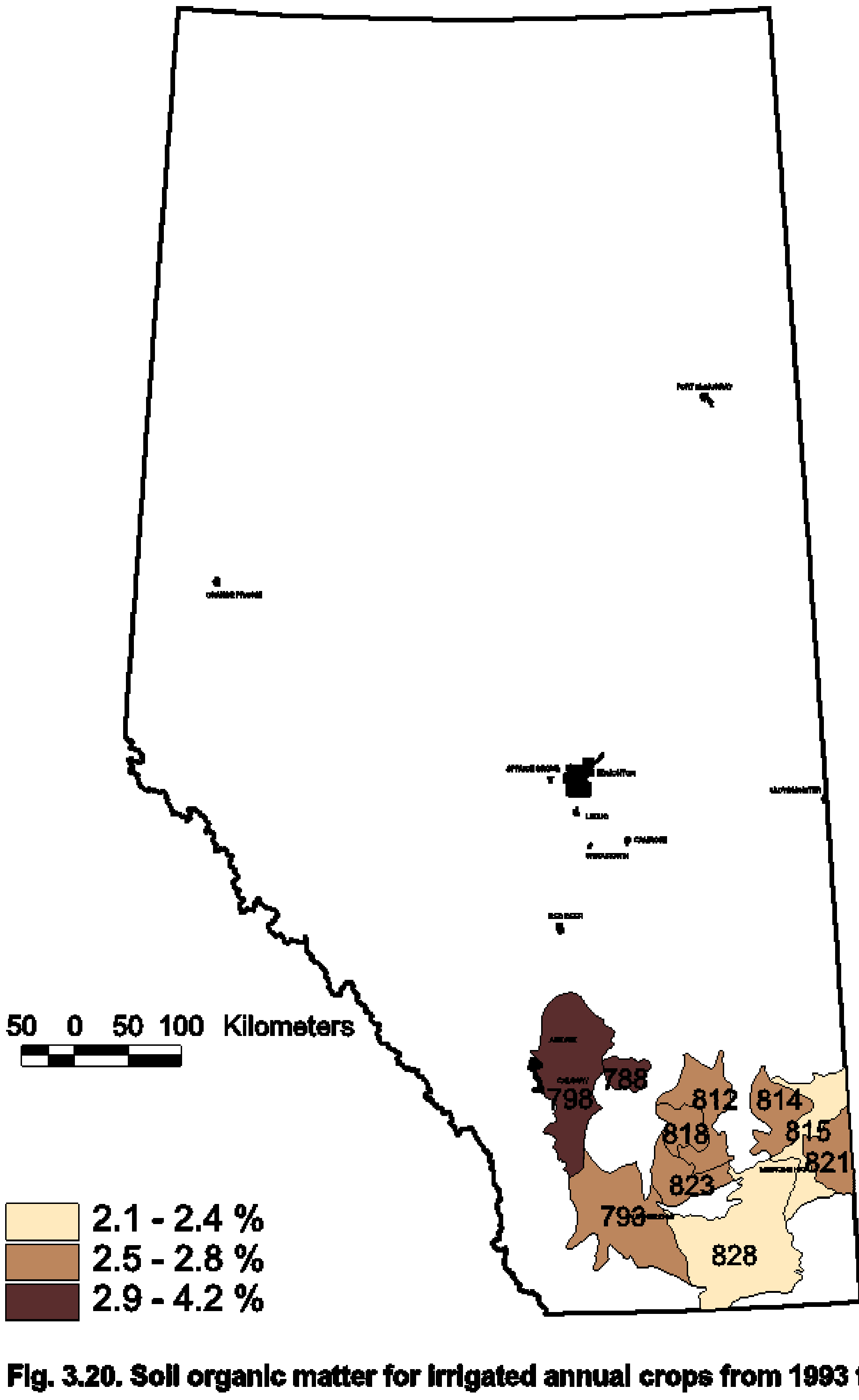

Fig. 3.20. Soil organic matter for irrigated annual crops from 1993 to 1997.

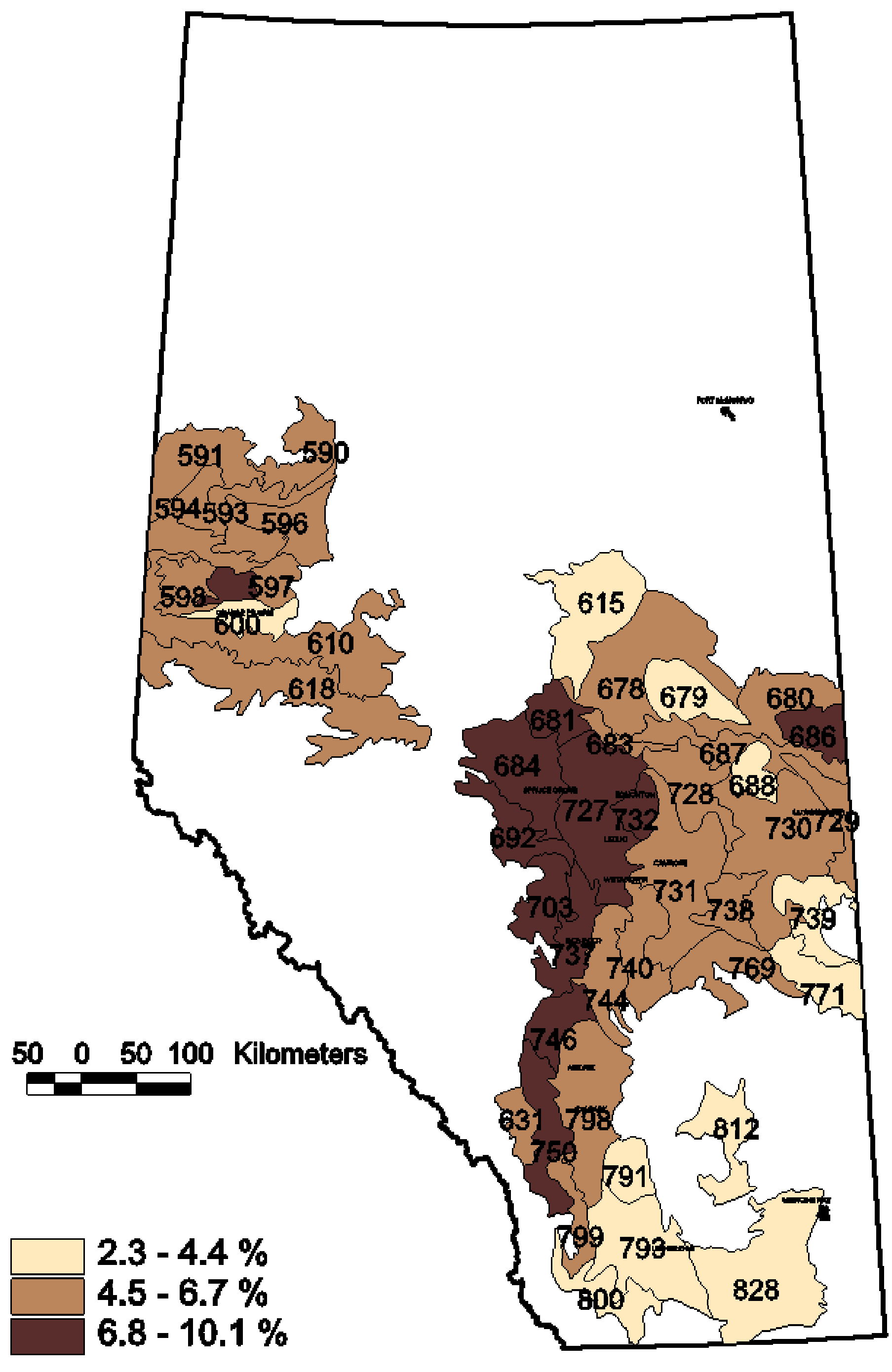

Fig. 3.21. Soil organic matter for dryland perennial crops from 1993 to 1997.

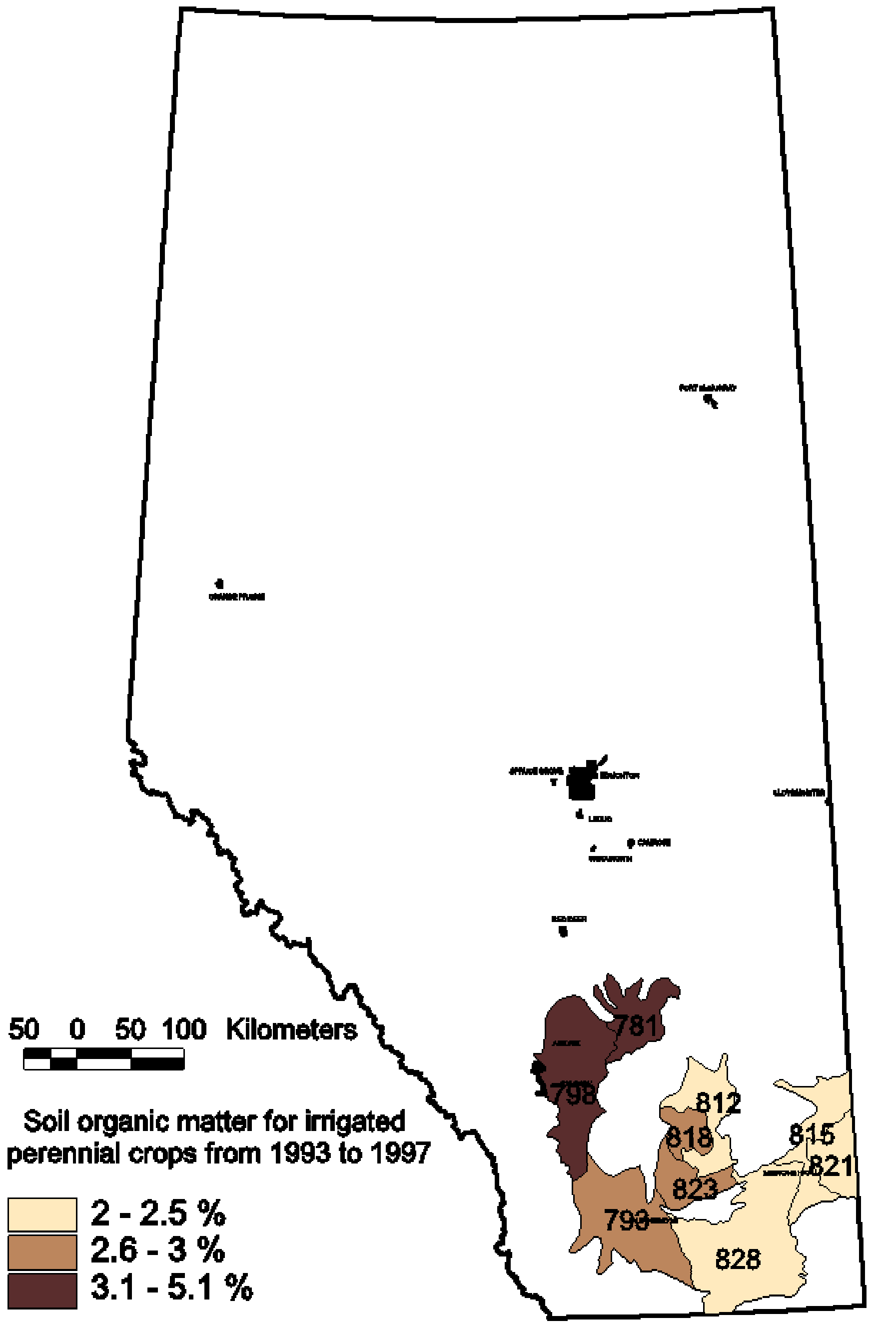

Fig.3.22. Soil organic matter for irrigated perennial crops from 1993 to 1997.

7.0 APPENDICES

Appendix 3.1.1. Summary statistics of the available soil phosphorus in the 0-0.15 m soil profile for dryland annual crops from 1963-67.

ECO	Obs	Mean	s	Skew	Kurt	CV	Max	Min	Range
590	105	26	12	1	1	45	64	7	57
591	265	27	22	4	25	79	181	3	178
593	642	24	18	9	120	73	303	5	298
593	644	26	34	12	183	131	586	5	581
594	39	21	11	1	3	52	59	8	51
596	21	25	12	1	2	49	60	8	52
597	148	20	21	8	76	107	233	6	227
598	290	20	29	12	173	146	444	6	438
599	187	15	7	2	8	47	55	7	48
600	18	32	35	3	6	110	142	6	136
610	147	17	10	3	18	57	89	6	83
615	279	44	45	4	23	104	396	4	392
618	82	19	14	5	36	75	125	6	119
631	15	13	6	2	3	47	28	8	20
678	1083	30	29	6	56	96	435	3	432
679	371	23	16	3	15	68	157	6	151
680	540	25	25	9	135	102	440	3	437
681	475	23	21	4	18	91	206	3	203
683	392	26	23	2	7	88	157	3	154
684	282	31	30	5	46	97	352	3	349
686	47	31	19	1	1	59	91	7	84
687	709	23	18	4	31	77	206	5	201
688	218	22	12	2	3	52	66	4	62
692	6	18	10	0	-2	55	31	6	25
703	161	28	27	4	21	94	225	3	222
727	4692	23	22	7	77	97	371	3	369
728	1325	20	16	10	180	79	371	3	368
729	580	21	16	7	82	77	245	5	240
730	1465	21	10	5	58	49	196	4	192
731	2532	23	15	16	443	64	483	4	480
730	1469	22	20	21	601	91	630	4	626
731	2536	23	19	19	531	83	625	4	621
732	56	32	20	1	2	61	105	8	97
737	829	22	28	8	81	127	425	3	422
738	321	23	11	4	35	45	128	8	120
739	214	24	17	4	15	72	126	7	119
740	568	19	14	6	51	73	176	3	173
743	98	23	7	0	1	30	46	6	40
744	880	20	16	6	65	82	249	3	246
746	469	25	31	5	37	123	357	3	354
750	274	12	7	3	10	59	55	3	52
769	396	24	11	6	60	46	147	3	144

771	149	27	36	9	93	135	415	6	409
777	8	16	6	0	-2	35	23	10	13
779	163	23	20	4	21	84	157	3	154
786	209	18	16	6	41	90	167	5	162
787	440	27	26	4	25	98	269	3	266
788	173	21	15	3	14	74	118	5	113
790	81	33	34	2	7	104	186	3	183
791	604	24	27	8	79	114	396	6	390
793	1412	26	28	4	31	108	352	3	349
798	2211	21	17	5	38	84	235	3	232
799	81	24	19	2	2	82	89	3	86
800	261	17	13	5	49	80	157	3	154
804	14	26	9	1	0	35	45	16	29
806	79	28	21	2	6	75	118	6	112
809	76	34	31	2	6	91	171	11	160
811	5	11	5	0	-3	45	16	6	10
812	69	38	33	2	2	86	147	7	140
818	8	24	13	1	2	53	50	8	42
821	51	45	38	1	0	85	147	8	139
823	48	27	27	3	13	99	162	5	157
828	522	23	21	3	12	93	152	3	149
837	49	18	8	1	2	48	45	6	39
838	17	17	6	1	2	37	33	10	23

ECO= ecodistrict number, Obs= number of observation within the Ecodistrict, Mean= mean [P], s= standard deviation, Skew= Skewness, Kurt= Kurtosis, CV= coefficient of variation, Max= maximum observed value, Min= minimum observed value, Range= range of the observed values.

Appendix 3.1.2 Summary statistics of the available soil phosphorus in the 0-0.15 m soil profile for irrigated annual crops from 1963-67.

ECO	Obs	Mean	s	Skew	Kurt	CV	Max	Min	Range
788	17	28	22	3	10	77	103	10	93
793	221	38	35	2	3	91	171	3	168
798	33	26	20	3	13	77	118	10	108
812	125	33	37	3	9	110	235	6	229
815	71	37	29	2	2	78	128	6	122
818	17	37	36	1	1	97	118	10	108
821	11	37	41	2	4	112	142	7	135
823	53	28	27	2	2	98	113	5	108
828	256	40	47	3	12	118	337	3	334

ECO= ecodistrict number, Obs= number of observation within the Ecodistrict, Mean= mean [P], s= standard deviation, Skew= Skewness, Kurt= Kurtosis, CV= coefficient of variation, Max= maximum observed value, Min= minimum observed value, Range= range of the observed values.

Appendix 3.1.3. Summary statistics of the available soil phosphorus in the 0-0.15 m soil profile for dryland perennial crops from 1963-67.

ECO	Obs	Mean	s	Skew	Kurt	CV	Max	Min	Range
590	11	14	5	0	-1	38	23	6	17
591	48	25	26	4	15	102	152	7	145
593	89	21	19	4	26	93	152	6	146
594	7	18	10	2	4	57	40	10	30
597	22	18	12	2	5	69	60	7	53
598	57	14	7	3	16	51	55	6	49
599	10	12	2	-1	1	18	15	7	8
610	41	14	5	1	0	36	29	7	22
615	84	40	34	3	12	84	220	5	215
618	15	12	6	1	0	45	23	4	19
631	24	11	5	2	2	48	25	7	18
678	227	31	30	3	12	98	235	4	231
679	52	19	18	2	6	94	88	3	85
680	66	23	19	2	3	80	93	6	87
681	78	17	11	3	9	66	74	6	68
683	20	24	17	1	2	72	74	7	67
684	34	21	14	2	7	70	79	6	73
687	57	27	31	4	26	115	218	3	215
688	18	24	8	0	-1	35	38	10	28
703	31	19	15	2	5	77	74	4	70
727	676	23	23	5	38	102	293	3	290
728	106	20	13	3	18	65	106	5	101
729	39	15	8	3	10	53	50	5	45
730	93	17	9	3	11	54	69	8	61
731	157	21	23	8	76	110	263	5	258
732	32	27	17	1	1	62	69	7	62
737	105	17	20	5	27	117	155	3	152
738	8	19	6	-1	-1	30	26	10	16
739	13	17	4	1	-1	26	26	12	14
740	35	17	13	3	9	76	69	6	63
744	54	20	15	2	3	79	69	6	63
746	20	19	15	1	0	80	50	5	45
750	214	12	8	3	12	70	64	3	61
769	15	30	46	4	14	156	196	11	185
771	11	19	7	0	-1	38	31	8	23
793	45	47	58	3	9	123	293	6	287
798	211	25	30	5	33	120	286	3	283
799	12	17	14	1	0	78	45	4	41
812	18	32	32	2	1	101	107	6	101
828	14	39	43	3	7	111	171	10	161

ECO= ecodistrict number, Obs= number of observation within the Ecodistrict, Mean= mean [P], s= standard deviation, Skew= Skewness, Kurt= Kurtosis, CV= coefficient of variation, Max= maximum observed value, Min= minimum observed value, Range= range of the observed values.

Appendix 3.1.4. Summary statistics of the available soil phosphorus in the 0-0.15 m soil profile for irrigated perennial crops from 1963-67.

ECO	Obs	Mean	s	Skew	Kurt	CV	Max	Min	Range
793	84	46	55	3	9	119	308	5	303
798	31	26	18	1	1	71	79	6	73
812	54	31	30	2	5	97	147	3	144
815	32	38	40	4	20	106	235	5	230
818	7	39	24	0	-2	62	69	8	61
823	14	23	31	4	13	134	128	6	122
828	95	40	39	2	4	97	181	6	175

ECO= ecodistrict number, Obs= number of observation within the Ecodistrict, Mean= mean [P], s= standard deviation, Skew= Skewness, Kurt= Kurtosis, CV= coefficient of variation, Max= maximum observed value, Min = minimum observed value, Range= range of the observed values.

Appendix 3.1.5. Summary statistics of the available soil phosphorus in the 0-0.15 m soil profile for dryland annual crops from 1993-97.

ECO	Obs	Mean	s	Skew	Kurt	CV	Max	Min	Range
590	474	19	12	1	2	62	60	2	58
591	347	16	9	2	6	54	60	2	58
593	1983	18	8	1	3	46	60	1	59
594	330	18	6	1	1	35	41	6	35
596	1349	18	9	2	5	52	60	3	57
597	264	14	6	1	1	45	38	3	35
598	1161	15	9	2	7	59	60	1	59
599	656	20	10	2	4	48	60	3	57
600	99	18	12	2	3	67	60	3	57
610	235	13	7	2	12	57	60	2	58
615	38	17	10	1	1	61	45	5	40
618	61	17	9	1	2	55	47	3	44
631	6	26	4	0	-3	15	29	22	7
678	1524	22	16	3	11	72	140	1	139
679	91	20	14	1	1	73	60	1	59
680	2519	22	13	1	1	59	60	2	58
681	975	22	16	1	0	71	60	1	59
683	340	16	8	2	5	52	60	3	57
684	1322	18	14	1	1	78	60	1	59
686	175	21	12	1	3	56	60	2	58
687	1717	22	13	2	5	58	110	3	107
688	493	19	11	1	2	58	60	2	58
692	318	16	13	2	4	79	60	2	58
703	442	25	15	1	0	60	60	3	57
727	7985	21	14	1	1	66	60	1	59
728	3332	18	13	8	128	72	250	1	249
729	1176	20	10	1	3	49	60	1	59
730	4623	20	10	2	4	49	76	1	75
731	4080	24	12	1	1	50	73	1	72
732	147	18	13	2	3	71	60	4	56
737	1289	23	15	1	0	65	70	1	69
738	1202	21	10	2	4	48	66	6	60
739	428	20	11	2	5	55	60	6	54
740	844	21	13	1	2	61	60	1	59
743	173	22	12	2	3	52	60	7	53
744	1097	25	20	4	27	80	200	1	199
746	601	21	15	1	1	71	60	1	59
750	89	21	15	1	1	69	62	2	60
769	708	22	11	2	3	48	70	3	67
771	624	20	10	2	4	49	60	4	56
777	86	21	13	1	1	61	60	4	56
779	100	27	12	0	-1	44	50	6	44
786	92	36	23	2	7	65	140	6	134
787	197	39	24	1	1	61	120	5	115

788	162	42	25	1	2	60	130	4	126
790	161	27	15	2	7	54	89	8	81
791	521	47	35	6	61	74	400	7	393
793	338	33	19	3	17	58	160	10	150
798	1708	31	21	2	9	66	190	2	188
799	9	34	15	0	-2	43	51	18	33
800	19	32	13	0	-2	40	51	11	40
804	57	23	10	2	4	43	60	8	52
806	29	24	6	-1	4	25	38	5	33
809	120	17	10	2	3	57	55	1	54
811	27	12	5	1	2	45	28	3	25
812	47	29	20	1	-1	70	67	5	62
818	16	31	17	1	0	55	63	11	52
821	23	19	6	1	2	29	32	11	21
823	14	37	9	0	-1	25	50	21	29
828	220	28	15	3	11	53	110	8	102
837	18	30	3	-1	-1	10	33	25	8
838	33	30	8	-1	0	26	40	8	32

ECO= ecodistrict number, Obs= number of observation within the Ecodistrict, Mean= mean [P], s= standard deviation, Skew= Skewness, Kurt= Kurtosis, CV= coefficient of variation, Max= maximum observed value, Min= minimum observed value, Range= range of the observed values.

Appendix 3.1.6. Summary statistics of the available soil phosphorus in the 0-0.15 m soil profile for irrigated annual crops from 1993-97.

ECO	Obs	Mean	s	Skew	Kurt	CV	Max	Min	Range
788	8	73	7	1	-2	10	81	66	15
793	198	70	58	2	3	83	280	12	268
798	9	50	8	1	-2	15	60	43	17
812	148	38	32	4	20	83	220	11	209
815	15	82	88	2	1	107	250	20	230
818	44	57	64	3	9	111	280	15	265
821	6	30	6	0	-3	20	35	24	11
823	51	37	10	0	-1	26	56	21	35
828	100	45	26	2	7	57	160	13	147

ECO= ecodistrict number, Obs= number of observation within the Ecodistrict, Mean= mean [P], s= standard deviation, Skew= Skewness, Kurt= Kurtosis, CV= coefficient of variation, Max= maximum observed value, Min= minimum observed value, Range= range of the observed values.

Appendix 3.1.7. Summary statistics of the available soil phosphorus in the 0-0.15 m soil profile for dryland perennial crops from 1993-97.

ECO	Obs	Mean	s	Skew	Kurt	CV	Max	Min	Range
590	94	21	12	1	1	59	60	3	57
591	51	12	5	0	-1	43	23	2	21
593	162	18	9	1	3	50	55	4	51
594	26	16	5	0	0	34	27	6	21
597	32	13	10	3	13	78	60	5	55
598	162	13	9	2	5	66	54	2	52
599	56	20	10	2	4	52	60	3	57
610	69	11	9	1	1	77	35	1	34
615	7	11	5	0	-2	45	17	5	12
618	11	14	8	1	0	55	29	5	24
631	21	26	13	1	0	51	52	14	38
678	209	20	15	1	1	73	60	2	58
679	14	18	14	1	1	75	49	3	46
680	235	24	15	1	0	64	60	3	57
681	226	19	14	1	1	74	60	2	58
683	42	17	13	1	1	76	50	3	47
684	462	15	14	2	3	89	60	1	59
687	165	18	13	1	2	68	60	1	59
688	30	19	14	2	4	73	60	5	55
703	270	23	17	1	0	76	60	1	59
727	1150	19	14	1	2	75	60	1	59
728	375	18	13	5	34	70	120	1	119
729	79	21	10	0	0	47	47	1	46
730	352	20	10	1	3	50	60	4	56
731	458	22	11	1	2	51	75	3	72
732	32	18	16	2	3	89	60	3	57
737	329	19	14	1	1	75	60	1	59
738	69	28	16	1	1	57	72	7	65
739	14	17	13	2	5	74	54	5	49
740	140	20	14	2	2	74	60	2	58
744	166	20	16	2	7	79	92	1	91
746	84	23	20	2	4	88	91	4	87
750	103	18	15	3	12	84	87	2	85
769	36	28	17	1	0	62	62	8	54
771	38	14	7	1	4	49	40	3	37
793	18	40	25	2	2	62	93	25	68
798	160	25	17	1	0	67	74	1	73
799	9	12	1	0	-2	11	14	11	3
812	12	39	39	1	-1	102	99	7	92
828	22	35	18	1	0	50	70	6	64

ECO= ecodistrict number, Obs= number of observation within the Ecodistrict, Mean= mean [P], s= standard deviation, Skew= Skewness, Kurt= Kurtosis, CV= coefficient of variation, Max= maximum observed value, Min= minimum observed value, Range= range of the observed values.

Appendix 3.1.8. Summary statistics of the available soil phosphorus in the 0-0.15 m soil profile for irrigated perennial crops from 1993-97.

ECO	Obs	Mean	s	Skew	Kurt	CV	Max	Min	Range
793	69	49	28	1	3	58	140	14	126
798	51	53	11	-1	1	21	69	25	44
812	61	26	13	2	3	50	66	15	51
815	9	52	59	1	-2	113	130	11	119
818	6	40	27	0	-3	68	64	15	49
823	21	36	8	-1	-1	23	46	22	24
828	58	49	28	0	-1	57	99	14	85

ECO= ecodistrict number, Obs= number of observation within the Ecodistrict, Mean= mean [P], s= standard deviation, Skew= Skewness, Kurt= Kurtosis, CV= coefficient of variation, Max= maximum observed value, Min = minimum observed value, Range= range of the observed values.

Appendix 3.1.9. Summary statistics of soil pH in the 0-0.15 m soil profile for dryland annual crops from 1993-97.

ECO	Obs	Mean	s	Skew	Kurt	CV	Max	Min	Range
590	474	6.4	0.5	-0.2	1.9	7.4	7.9	4.3	3.6
591	347	6.2	0.4	-0.1	1.2	6.2	7.3	4.5	2.8
593	1983	6.3	0.5	0.9	1.1	7.4	8.3	5.3	3
594	330	6.1	0.3	0.9	2.2	5.7	7.6	5.2	2.4
596	1349	7	0.5	0.1	-0.8	7.8	8.3	5.4	2.9
597	264	6.3	0.5	0.7	0.7	7.4	8	5.1	2.9
598	1161	6.2	0.4	0.7	1.4	6.5	8.1	5.2	2.9
599	656	6	0.4	0.8	1.7	6	7.6	5.2	2.4
600	99	6.8	0.6	0	-0.5	8.2	8.3	5.5	2.8
610	235	6.4	0.5	0.3	0.2	7.2	8	5.2	2.8
615	38	6.9	0.6	0.3	-0.4	8.1	8.1	6	2.1
618	61	6.3	0.7	0.7	0.2	10.8	8.1	5.2	2.9
631	6	6.9	0.1	0	-3.3	1.6	7	6.8	0.2
678	1524	7	0.6	-0.1	-0.2	8.2	8.6	4.3	4.3
679	91	6.6	0.4	0.6	0.6	6.5	7.9	5.6	2.3
680	2519	6.7	0.5	0.3	-0.1	6.9	8.4	5.3	3.1
681	975	7.1	0.5	-0.1	-0.5	7.5	8.4	5.5	2.9
683	335	7.4	0.5	-0.5	0	6.2	8.4	6	2.4
684	1322	6.6	0.6	0.2	0.6	8.4	8.3	3.9	4.4
686	175	6.7	0.4	0.5	0.6	6.1	8.1	5.7	2.4
687	1717	6.8	0.6	0.4	-0.4	8.3	8.5	5.3	3.2
688	493	6.6	0.4	0.2	0.8	6.1	8	5.3	2.7
692	318	6.3	0.5	0.8	0.9	7.8	8	5.1	2.9
703	442	6.4	0.4	1.1	2.3	6.7	8.3	5.4	2.9
727	7985	6.5	0.5	0.6	0.2	7.5	8.4	4.8	3.6
728	3332	6.7	0.5	0.3	-0.2	7.4	8.6	5.2	3.4
729	1176	6.5	0.5	0.7	0.4	7.1	8.2	5.5	2.7
730	4623	6.4	0.4	0.1	5.2	6.9	8.1	1	7.1
731	4080	6.2	0.4	0.7	1.1	6.8	8.3	4.9	3.4
732	147	6.5	0.5	-0.2	2.5	7	7.8	4.5	3.3
737	1289	6.7	0.5	0.3	-0.2	7.7	8.8	5.4	3.4
738	1202	6.2	0.4	1.1	1.8	7.3	8.5	5.3	3.2
739	428	6.5	0.4	0.6	0.4	6.3	8.2	5.3	2.9
740	844	6.3	0.4	0.6	0.8	6.7	8.2	5.1	3.1
743	173	6.7	0.5	-0.3	-0.5	8.1	7.8	5.2	2.6
744	1097	6.4	0.5	0.9	3	8	10.2	5	5.2
746	601	7.2	0.5	-0.2	-0.3	7.2	8.5	5.5	3
750	89	7.2	0.6	-0.3	-1.1	8.2	8.1	6	2.1
769	708	6.2	0.5	0.8	0.2	7.5	7.9	5	2.9
771	624	6.9	0.5	-0.2	-0.6	7.9	8.3	5.2	3.1
777	86	6.5	0.6	0.9	0.4	9.8	8.2	5.6	2.6
779	100	6.9	0.6	-0.4	-0.6	8.6	7.9	5.7	2.2
786	92	6.8	0.7	0	-1.1	10.8	8.2	5.4	2.8
787	197	7.5	0.5	-0.9	1	6.7	8.3	5.8	2.5

788	162	6.9	0.7	-0.4	-0.8	9.9	8.2	5.3	2.9
790	161	7.6	0.5	-1.2	1.1	6.7	8.2	6	2.2
791	521	6.7	0.7	-0.1	-0.8	9.9	8.2	5.4	2.8
793	338	7.5	0.5	-0.3	-0.2	6.9	8.6	6.1	2.5
798	1708	6.8	0.6	0	-0.7	8.7	8.2	5.4	2.8
799	9	7.3	0.2	-0.2	-1.4	2.7	7.6	7.1	0.5
800	19	6.9	0.7	0.3	-1.1	9.5	8	6.1	1.9
804	57	6.5	0.6	0.1	-1.1	9	7.5	5.5	2
806	29	7.1	0.4	-0.2	0.1	6.2	8	6.2	1.8
809	120	7.4	0.5	-0.9	1	6.8	8.3	5.9	2.4
811	27	7.5	0.4	-1	1.6	5.1	8.1	6.4	1.7
812	41	7.5	0.5	-1.7	3.7	7	8.3	5.8	2.5
818	16	7.4	0.4	-0.3	0.3	5.4	8.1	6.5	1.6
821	23	7.6	0.6	-1	0.3	7.9	8.2	6.2	2
823	14	7.6	0.4	-1.8	2.5	5	7.9	6.7	1.2
828	220	7.4	0.4	-0.4	0.6	5	8.2	6.2	2
837	18	6.9	0.8	0.3	-1.6	11.3	8.1	6.1	2

ECO= ecodistrict number, Obs= number of observation within the Ecodistrict, Mean = mean [P], s = standard deviation, Skew= Skewness, Kurt= Kurtosis, CV= coefficient of variation, Max= maximum observed value, Min = minimum observed value, Range = range of the observed values.

Appendix 3.1.10. Summary statistics of soil pH in the 0-0.15 m soil profile for irrigated annual crops from 1993-97.

ECO	Obs	Mean	S	Skew	Kurt	CV	Max	Min	Range
788	8	6.3	0.6	-0.5	-2.2	9.8	6.9	5.6	1.3
793	198	7.8	0.4	-1	1.4	4.9	8.4	6.4	2
798	9	7.2	0.2	0.7	-1.7	3.2	7.5	7	0.5
812	136	7.9	0.2	-0.8	0	2.8	8.2	7.3	0.9
814	6	7.9	0.1	0	-3.3	0.7	7.9	7.8	0.1
815	15	7.6	0.3	-1.4	0.5	4.3	7.9	7	0.9
818	44	7.6	0.2	-0.4	-1.2	2.9	7.9	7.2	0.7
821	6	7.7	0.2	0	-3.3	2.1	7.8	7.5	0.3
823	51	7.8	0.2	-0.7	-0.5	3	8.1	7.3	0.8
828	99	7.7	0.7	-8	74.1	9.5	8.2	1	7.2

ECO= ecodistrict number, Obs= number of observation within the Ecodistrict, Mean= mean [P], s= standard deviation, Skew= Skewness, Kurt= Kurtosis, CV= coefficient of variation, Max = maximum observed value, Min= minimum observed value, Range = range of the observed values.

Appendix 3.1.11. Summary statistics of soil pH in the 0-0.15 m soil profile for dryland perennial crops from 1993-97.

ECO	Obs	Mean	s	Skew	Kurt	CV	Max	Min	Range
590	94	6.5	0.4	0.9	2.0	6.1	8.0	5.7	2.3
591	51	6.3	0.5	0.9	2.5	7.2	8	5.5	2.5
593	162	6.4	0.5	1	1.3	7.3	7.9	5.3	2.6
594	26	6.1	0.5	1	1.3	8.4	7.5	5.4	2.1
596	116	6.9	0.6	0	-0.6	8	8.4	5.8	2.6
597	32	6.2	0.3	0.2	1.5	4.5	6.9	5.5	1.4
598	162	6.2	0.3	0.3	0.6	5.4	7.4	5.4	2
599	56	6.1	0.5	1.3	1.7	8	7.5	5.3	2.2
600	15	6.9	0.7	0.5	-0.1	10.7	8.2	5.6	2.6
610	69	6.4	0.5	0.2	0.3	7.2	7.7	5.3	2.4
615	7	6.5	0.5	-1.8	3.5	8.2	6.9	5.4	1.5
618	11	6.5	0.7	0.6	-0.2	10.3	7.7	5.5	2.2
631	21	6.2	0.3	-1.1	0.3	5	6.5	5.6	0.9
678	209	6.9	0.5	0.2	-0.9	7.9	8.1	5.7	2.4
679	14	6.8	0.4	0.4	0.2	6.5	7.7	6.1	1.6
680	235	6.8	0.5	0.6	0.5	7.2	8.7	5.8	2.9
681	226	7	0.6	-0.3	0.9	8.8	8.5	4.4	4.1
683	42	7.3	0.5	-0.6	-0.3	6.4	8.1	6.2	1.9
684	462	6.6	0.5	0.3	-0.3	8.2	8	5.3	2.7
686	11	6.5	0.5	0.5	-0.1	7.3	7.4	5.8	1.6
687	165	6.8	0.6	0.1	-0.2	8.2	8.2	5.3	2.9
688	30	6.7	0.3	1.3	1.7	5.1	7.7	6.2	1.5
692	187	6.4	0.5	0.8	2	7.9	8.3	5.2	3.1
703	270	6.5	0.4	0.7	0.8	6.6	8	5.6	2.4
727	1150	6.6	0.5	0.6	0.6	8	8.4	4.1	4.3
728	375	6.7	0.5	0.4	-0.2	7.6	8.5	5.5	3
729	79	6.5	0.5	0.7	0.5	6.9	8	5.7	2.3
730	352	6.3	0.4	1.2	2.9	6.7	8.3	5.4	2.9
731	458	6.2	0.4	0.4	1.5	6.9	7.8	4.4	3.4
732	32	6.5	0.4	1.5	6.5	6	8	5.7	2.3
737	329	6.7	0.5	0.7	1.2	7.8	9.1	5.6	3.5
738	69	6	0.5	1.7	3.1	8.9	8.1	5.4	2.7
739	14	6.5	0.3	0.3	-0.7	4.7	7	6	1
740	140	6.3	0.4	0.6	0.4	6	7.3	5.3	2
744	166	6.4	0.5	0.8	2	8	8.3	5.1	3.2
746	84	7.2	0.6	0.5	0.2	7.9	8.9	6.1	2.8
750	103	7.1	0.7	0.4	0.7	9.6	9.1	5.7	3.4
769	36	6.2	0.5	0.8	0.3	8	7.4	5.3	2.1
771	38	6.9	0.5	-0.2	-0.9	7.9	7.9	5.7	2.2
791	22	6.4	0.6	-0.2	-0.7	8.7	7.4	5.5	1.9
793	18	7.8	0.3	0.3	-1.1	3.6	8.2	7.4	0.8
798	160	6.8	0.6	-0.1	-0.6	8.2	8.1	5.6	2.5
799	9	6.1	0.3	0.8	-1.7	5.4	6.5	5.8	0.7
800	4	7.9	0.8	-2	4	9.5	8.3	6.8	1.5

812	12	7.4	0.6	-0.8	-0.9	8.1	8.1	6.5	1.6
828	22	7.3	0.4	-1.8	4.9	5	7.7	6.1	1.6

ECO= ecodistrict number, Obs= number of observation within the Ecodistrict, Mean= mean [P], s= standard deviation, Skew = Skewness, Kurt = Kurtosis, CV= coefficient of variation, Max= maximum observed value, Min = minimum observed value, Range = range of the observed values.

Appendix 3.1.12. Summary statistics of soil pH in the 0-0.15 m soil profile for irrigated perennial crops from 1993-97.

ECO	Obs	Mean	S	Skew	Kurt	CV	Max	Min	Range
781	8	6.7	0.2	0	-2.1	2.8	6.9	6.5	0.4
793	69	8	0.3	0	-1.3	3.8	8.5	7.6	0.9
798	51	6.8	0.7	0.4	-0.6	10.8	8.4	5.8	2.6
812	61	7.6	0.4	-1.7	3.1	5	8	6.4	1.6
815	9	7.6	0.3	0	-1.7	3.4	7.9	7.3	0.6
818	6	7.6	0	.	.	0	7.6	7.6	0
821	6	7.7	0.1	0	-3.3	0.7	7.7	7.6	0.1
823	21	7.7	0.2	-1.5	1.4	2.5	7.9	7.3	0.6
828	58	7.6	0.3	-0.3	-0.4	3.3	8.1	7.1	1

ECO= ecodistrict number, Obs= number of observation within the Ecodistrict, Mean= mean [P], s= standard deviation, Skew= Skewness, Kurt= Kurtosis, CV= coefficient of variation, Max= maximum observed value, Min= minimum observed value, Range= range of the observed values.

Appendix 3.1.13. Summary statistics of soil organic matter in the 0-0.15 m soil profile for dryland annual crops from 1993-97.

ECO	Obs	Mean	s	Skew	Kurt	CV	Max	Min	Range
590	165	5.0	2.2	6.0	52.1	44.8	26.5	2.1	24.4
591	96	6.1	2.0	1.4	2.8	32.0	13.7	3.3	10.4
593	827	6.0	1.8	1.7	13.7	29.5	24.1	2.2	21.9
594	193	4.5	1.2	1.2	2.0	27.6	9.1	1.8	7.3
596	543	4.8	1.4	2.8	23.3	28.8	19.3	2.1	17.2
597	137	4.6	2.0	2.3	11.2	43.9	17.5	1.6	15.9
598	277	5.7	1.5	1.3	4.5	26.9	14.5	2.9	11.6
599	276	7.1	1.3	-0.6	0.2	18.7	10.2	2.7	7.5
600	46	5.5	2.6	0.8	0.1	48.0	12.2	2.0	10.2
610	89	6.3	4.3	5.4	39.1	68.3	39.5	3.0	36.5
615	14	3.7	0.8	0.5	-0.6	21.3	5.2	2.7	2.5
618	41	5.4	2.4	3.7	17.8	43.7	17.7	3.0	14.7
631	6	6.3	0.2	0.0	-3.3	2.6	6.4	6.1	0.3
678	975	6.4	3.8	4.0	24.1	59.2	37.4	1.1	36.3
679	19	4.4	2.2	0.6	0.7	50.7	9.5	1.0	8.5
680	1218	5.6	2.6	2.3	12.7	46.9	28.5	1.0	27.5
681	728	5.6	2.7	4.5	41.3	48.0	39.8	1.6	38.2
683	234	5.3	2.8	3.7	19.6	53.1	24.2	1.0	23.2
684	1052	5.7	3.1	3.6	22.8	53.7	33.8	1.0	32.8
686	128	5.1	3.0	2.8	12.5	59.6	22.3	1.4	20.9
687	1133	5.6	2.1	1.7	12.0	37.5	26.0	1.2	24.8
688	391	4.6	1.6	0.5	-0.2	33.8	9.3	1.6	7.7
692	125	5.4	2.3	2.5	10.6	41.9	19.2	2.8	16.4
703	142	4.8	1.9	1.1	0.9	39.3	10.5	2.1	8.4
727	5778	7.7	2.6	2.4	22.0	34.0	38.4	1.0	37.4
728	1873	5.9	1.4	0.0	0.4	23.4	11.3	1.6	9.7
729	679	5.7	1.5	0.0	0.2	26.0	11.1	1.3	9.8
730	3258	5.3	1.5	1.2	10.2	28.2	25.3	1.0	24.3
731	1849	6.3	1.4	0.3	1.3	21.8	14.7	1.6	13.1
732	74	6.1	2.0	1.0	3.3	33.1	14.8	2.2	12.6
737	438	7.5	2.3	0.3	0.5	29.9	16.2	2.6	13.6
738	296	4.4	1.2	-0.1	0.4	27.1	8.7	1.1	7.6
739	350	4.6	1.4	0.4	0.2	30.9	9.9	1.8	8.1
740	425	6.2	1.7	0.2	-0.2	27.5	11.6	1.3	10.3
743	78	3.7	1.0	0.2	-0.1	27.9	6.4	1.5	4.9
744	662	5.9	1.5	0.4	0.9	24.6	13.9	1.9	12.0
746	328	9.0	2.1	-0.6	1.3	23.5	14.3	1.4	12.9
750	75	7.8	1.9	1.0	-0.1	24.5	12.6	5.5	7.1
769	103	4.2	1.0	0.4	1.0	22.6	7.2	1.9	5.3
771	84	3.1	0.9	-0.3	-0.4	27.4	4.9	1.0	3.9
779	84	3.7	1.0	0.8	0.1	27.5	6.5	2.2	4.3
786	56	4.1	1.5	3.8	20.8	37.1	12.8	2.3	10.5
787	148	3.2	0.7	0.3	0.6	21.4	5.5	1.7	3.8
788	157	3.3	0.8	0.4	0.0	24.9	5.4	1.3	4.1

790	149	3.5	1.1	1.1	1.6	31.1	7.3	2.0	5.3
791	399	3.6	0.9	0.6	-0.1	25.0	6.3	2.1	4.2
793	306	2.2	0.5	1.1	6.5	21.4	4.7	1.0	3.7
798	1381	5.3	1.5	0.8	1.2	28.4	13.2	2.0	11.2
799	3	4.4	0.0	.	.	0.0	4.4	4.4	0.0
800	16	5.4	2.1	1.6	2.2	38.4	10.5	3.4	7.1
804	19	3.8	1.0	0.6	0.3	26.2	5.9	2.0	3.9
806	26	2.3	0.3	1.1	2.0	11.4	3.0	1.9	1.1
809	80	2.3	0.8	1.3	2.7	35.4	5.0	1.0	4.0
811	13	3.7	1.0	-0.2	-0.5	26.1	5.3	1.9	3.4
812	5	2.6	0.7	1.4	1.2	27.6	3.7	2.1	1.6
818	11	2.7	0.4	-1.7	1.5	14.6	2.9	1.9	1.0
821	13	3.0	1.9	0.8	-1.4	62.1	5.8	1.5	4.3
823	5	3.6	1.6	1.1	-0.8	45.3	6.1	2.5	3.6
828	210	2.1	0.5	3.1	17.9	25.2	5.5	1.2	4.3
837	18	2.1	0.1	0.4	-1.6	6.0	2.3	2.0	0.3
838	32	2.3	0.9	4.0	19.0	39.4	6.8	1.6	5.2

ECO= ecodistrict number, Obs= number of observation within the Ecodistrict, Mean= mean [P], s= standard deviation, Skew= Skewness, Kurt= Kurtosis, CV= coefficient of variation, Max= maximum observed value, Min= minimum observed value, Range= range of the observed values.

Appendix 3.1.14. Summary statistics of soil organic matter in the 0-0.15 m soil profile for irrigated annual crops from 1993-97.

ECO	Obs	Mean	s	Skew	Kurt	CV	Max	Min	Range
788	8	3.6	0.7	1.4	0.0	19.8	4.8	3.2	1.6
793	168	2.8	0.4	0.4	0.1	14.7	3.9	2.0	1.9
798	9	4.2	0.5	-0.7	-1.7	10.9	4.6	3.6	1.0
812	127	2.8	3.0	6.1	37.1	106.7	22.0	1.4	20.6
814	6	2.6	0.1	0.0	-3.3	2.1	2.6	2.5	0.1
815	12	2.4	0.6	1.2	-0.4	24.6	3.3	1.9	1.4
818	44	2.8	0.3	0.2	-1.3	10.5	3.3	2.4	0.9
821	6	2.6	0.2	0.0	-3.3	6.4	2.7	2.4	0.3
823	51	2.5	0.4	0.7	1.2	17.8	3.6	1.7	1.9
828	100	2.1	0.4	0.2	-0.8	18.7	2.8	1.4	1.4

ECO= ecodistrict number, Obs= number of observation within the Ecodistrict, Mean= mean [P], s= standard deviation, Skew= Skewness, Kurt= Kurtosis, CV= coefficient of variation, Max= maximum observed value, Min= minimum observed value, Range = range of the observed values.

Appendix 3.1.15. Summary statistics of soil organic matter in the 0-0.15 m soil profile for dryland perennial crops from 1993-97.

ECO	Obs	Mean	s	Skew	Kurt	CV	Max	Min	Range
590	51	4.8	1.3	1.1	1.2	26.9	9.0	3.0	6.0
591	19	5.7	1.9	1.3	0.8	33.1	10.2	3.4	6.8
593	66	5.5	1.7	0.2	-0.7	30.3	8.8	2.1	6.7
594	12	4.7	1.6	0.5	-1.3	34.1	7.5	2.9	4.6
596	53	4.8	1.1	0.3	-0.6	23.5	7.3	2.9	4.4
597	24	5.2	2.1	0.3	-1.4	40.7	8.8	2.2	6.6
598	26	6.4	2.0	1.4	3.0	30.6	12.4	3.5	8.9
599	18	7.1	1.4	-0.1	-0.1	19.8	9.7	4.2	5.5
600	8	3.7	1.1	-0.4	-0.3	28.5	5.0	1.9	3.1
610	16	6.1	4.0	3.4	12.6	66.9	20.5	2.0	18.5
615	1	3.9	.	.	.	.	3.9	3.9	0.0
618	4	5.0	2.1	1.7	3.0	42.3	8.0	3.3	4.7
631	21	6.4	0.6	0.5	-1.4	9.9	7.3	5.7	1.6
678	88	6.1	2.8	1.5	2.3	46.3	15.4	2.1	13.3
679	1	3.4	.	.	.	.	3.4	3.4	0.0
680	114	5.4	2.6	1.7	4.0	47.5	16.3	1.7	14.6
681	142	6.4	4.3	4.4	25.9	67.1	35.3	2.0	33.3
683	27	5.3	2.7	0.8	-0.3	50.7	11.0	1.8	9.2
684	360	6.3	3.1	3.6	21.6	49.8	31.9	1.6	30.3
686	8	3.1	0.4	1.1	0.4	14.2	3.9	2.6	1.3
687	101	5.5	2.2	1.6	5.8	40.0	16.8	1.9	14.9
688	16	4.2	1.4	-0.5	0.1	33.5	6.3	1.0	5.3
692	92	5.8	2.2	1.0	0.9	38.3	13.2	2.1	11.1
703	90	7.5	6.0	2.1	4.0	79.9	29.9	2.7	27.2
727	721	7.6	2.9	2.6	16.9	38.3	32.2	1.3	30.9
728	204	6.1	1.5	0.6	2.8	23.9	13.1	2.3	10.8
729	44	5.7	1.3	-0.2	0.6	21.8	8.9	2.4	6.5
730	233	5.4	1.6	0.9	2.1	29.4	12.6	1.7	10.9
731	223	6.4	1.4	-0.1	0.2	21.0	9.6	1.6	8.0
732	21	5.5	1.8	0.2	-1.1	32.8	8.8	2.7	6.1
737	87	7.3	2.3	-0.1	-1.0	31.9	12.2	2.7	9.5
738	23	4.7	1.3	0.5	0.0	27.6	7.6	2.5	5.1
739	11	3.6	1.2	-0.3	-1.4	34.1	5.2	1.7	3.5
740	51	6.7	1.8	-0.3	-0.7	26.7	9.9	2.3	7.6
744	74	6.2	1.8	0.5	1.9	29.5	12.8	1.0	11.8
746	39	8.4	2.1	0.3	-0.7	25.1	12.8	5.0	7.8
750	95	8.0	2.5	1.3	1.6	30.6	17.3	5.5	11.8
769	10	5.6	0.5	-1.9	4.0	8.5	6.0	4.4	1.6
771	3	2.5	0.5	1.4	.	19.2	3.0	2.1	0.9
791	18	4.4	0.8	-0.2	-1.7	17.4	5.3	3.3	2.0
793	15	2.7	0.5	1.4	0.4	19.8	3.7	2.3	1.4
798	124	5.7	1.4	1.4	4.3	25.4	12.7	2.4	10.3
799	9	6.5	0.1	-0.9	-1.7	0.8	6.5	6.4	0.1
800	3	3.4	0.0	.	.	0.0	3.4	3.4	0.0

812	5	3.6	1.2	-0.9	-1.9	33.3	4.4	1.9	2.5
828	20	2.3	0.3	-0.5	-0.5	15.1	2.8	1.7	1.1

ECO= ecodistrict number, Obs= number of observation within the Ecodistrict, Mean= mean [P], s= standard deviation, Skew= Skewness, Kurt= Kurtosis, CV= coefficient of variation, Max= maximum observed value, Min= minimum observed value, Range= range of the observed values.

Appendix 3.1.16. Summary statistics of soil organic matter in the 0-0.15 m soil profile for irrigated perennial crops from 1993-97.

ECO	Obs	Mean	s	Skew	Kurt	CV	Max	Min	Range
781	8	5.1	0.5	0.8	-0.8	8.9	5.8	4.7	1.1
793	69	2.8	0.7	2.6	8.8	24.3	5.4	1.9	3.5
798	48	4.6	0.9	0.1	-1.2	20.5	6.2	3.2	3.0
812	61	2.5	0.4	0.6	-0.7	17.3	3.3	1.8	1.5
815	9	2.2	0.3	-0.8	-1.7	14.7	2.5	1.8	0.7
818	6	3.0	0.4	0.0	-3.3	13.0	3.3	2.6	0.7
821	6	2.0	0.1	0.0	-3.3	2.8	2.0	1.9	0.1
823	21	3.0	0.5	0.7	-1.2	15.8	3.7	2.5	1.2
828	58	2.2	0.5	0.1	-0.8	22.4	3.2	1.3	1.9

ECO= ecodistrict number, Obs= number of observation within the Ecodistrict, Mean= mean [P], s= standard deviation, Skew= Skewness, Kurt= Kurtosis, CV= coefficient of variation, Max= maximum observed value, Min= minimum observed value, Range= range of the observed values.