The University of Manitoba

RELATIONSHIP BETWEEN FARM YIELDS AND YIELDS PREDICTED ON THE BASIS OF SOIL AND FERTILIZER NITROGEN AND WATER DEFICIT

by

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ABSTRACT

Quadratic and logarithmic equations were used to predict yields of wheat, barley and oats. Combinations of three variables were tested in the equations: 1) soil nitrate nitrogen content and fertilizer nitrogen applied, 2) soil nitrate nitrogen content, fertilizer nitrogen applied, and water deficit on August 13th, and 3) soil nitrate nitrogen content, fertilizer nitrogen applied, and water deficit on July 16th. The equations were derived from experimental small plot data. Crop yield data was collected from the records of the Manitoba Provincial Soil Testing Laboratory for the period 1967 to 1970. Farm yields were compared to yields predicted by the six equations. Crop yield data from farms was analysed in three ways: 1) by grouping all data, 1967 to 1970, 2) by years, 1967, 1968, 1969 and 1970, and 3) by agronomic soil groups.

Large variations in wheat yields occurred from year to year. In general, yields predicted by equations which included a water deficit factor accounted for these variations. The predictability of the equations was best when water deficit was calculated for August 13th.

Large variations in wheat yields were also found between the agronomic soil groups. Farm wheat yields were most closely related to yields predicted from equations which included water deficit on fine textured lacustrine soils, medium textured till soils with a high water deficit, well drained coarse textured soils, and imperfectly drained coarse textured soils with a high water deficit. Conversely, farm wheat yields were most closely related to yields predicted from equations which included only soil nitrate nitrogen and fertilizer nitrogen on medium textured till soils with a low to medium water deficit and imperfectly drained coarse textured soils with a medium water deficit. Wheat yields from moderately fine textured lacustrine soils were equally well related to yields predicted by all equations. Wheat yields from medium to medium coarse textured lacustrine soils and from complex soils were not closely related to yields predicted from any of the equations.

The water deficit factor in the barley equations resulted in highest yields being predicted when the water deficit level was highest. This was contrary to what normally was expected.

Except for barley yields on medium textured till soils with a low water deficit and oat yields on moderately fine textured lacustrine soils, farm yields of barley and oats were not closely related to yields predicted from equations which included soil nitrate nitrogen and fertilizer nitrogen variables only. Farm yields of barley and oats were, on the average, 10 to 12 bu./ac. and 15 to 17 bu./ac. lower, respectively, than the average predicted yields.

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INTRODUCTION

Response of wheat, barley, and oats to nitrogen fertilizer has been well established in previous fertility studies. Highly significant correlations have been shown between barley yields from small plots and those predicted from the level of soil nitrate nitrogen (NO_3-N) and fertilizer nitrogen present at seeding time (Soper *et al.*, 1971). This was the basis on which the Manitoba Provincial Soil Testing Laboratory (M.P.S.T.L.) initiated the Target Yield program for making fertilizer recommendations. These recommendations were based on the assumption that crop yields throughout Manitoba were similar when nitrogen supply was constant and climate and management were favourable.

Yield prediction equations were developed from small plot data. Farmers, however, often do not attain yields equivalent to predicted yields. When the Target Yield fertilizer recommendation program was introduced, the M.P.S.T.L. had sufficient farm yield records to permit a comparison of farm yields and predicted yields. Yield prediction equations used, to date, did not include a measurement of climate. Since water deficit values had been calculated for weather stations throughout Manitoba, a water deficit factor was introduced into yield prediction equations to determine if the relationship between predicted and actual farm yields could be improved.

This study was initiated to determine if farm yields of wheat, oats, and barley could be predicted accurately from soil NO_3-N, fertilizer N, and water deficit.

LITERATURE REVIEW

A. Nitrogen

Nitrogen is an essential element for plant growth. A 35 bu./ac. crop of wheat requires 1.9 pounds of nitrogen† per bushel of grain. Non-fallowed crop land, however, is generally low in available nitrogen, thus fertilizers are frequently added to supplement the soil nitrogen. Many authors (Young *et al.*, 1967; Peterson and Attoe, 1965) showed that available soil nitrogen strongly influenced yields of wheat, barley, rye and corn. Experimental results of Herron *et al.* (1968) showed a significant correlation (r = 0.91) between corn yields and residual soil nitrogen. They found yields increased from 55 to 120 bu./ac. as more residual nitrate nitrogen was present in a 180 cm. profile. Soper and Huang (1963) found barley response to nitrogen fertilizer to be quite variable. When 60 lb./ac. of N was applied on several plots, yield increased from 0.5 to 16.3 bu./ac. over the non-fertilized plots. Variations in crop response to nitrogen fertilizer were attributed to differences in the amounts of available nitrogen present in the soil profile at seeding time. In general, the greatest

† Unpublished data. P.I. Fehr. University of Manitoba. 1972.

increase in barley yield was obtained with the addition of 60 lb./ac. of N and 40 lb./ac. of P_2O_5. Alkier (1972) also showed significant wheat yield increases with the additions of N at 60 lb./ac. on nitrogen deficient soils in Manitoba.

To determine nitrogen requirements of crops an accurate measurement of available soil nitrogen at seeding time is required. Many authors indicated crop response to nitrogen fertilizer was closely related to readily extractable mineral nitrogen found in the soil profile (Nuttal *et al.*, 1971; Young *et al.*, 1967; Peterson and Attoe, 1965; Synghal *et al.*, 1959). Soper and Huang (1963) found that readily extractable NO_3-N when measured to four feet showed the best correlation (r = 0.95) with yield response to fertilizer nitrogen. Recently, Soper *et al.* (1971) stated:

> "In Manitoba it was found that the amount of nitrate nitrogen in the soil profile was a very good test for predicting cereal response to nitrogen, and subsequently it has been used as a soil test for available nitrogen in this province since 1963."

In the past two decades many investigators have concentrated on correlating crop yields and crop yield increases to many factors, such as nitrogen, which affect plant growth (Young *et al.*, 1967; Keeney and Bremner, 1966; Gasser and Williams, 1963; Synghal *et al.*, 1959; Cook *et al.*, 1957). The most common parameters studied in recent literature were nitrogen, water and management factors (Nuttal *et al.*, 1971; Soper, 1971; Geist *et al.*, 1970; Voss *et al.*, 1970). Soper *et al.* (1971) found that a measure of soil nitrate nitrogen was required to determine the quantity of fertilizer N required for a particular barley yield. Initially they determined total nitrogen in the above ground portion of the plant by the Kjeldahl method and soil NO_3-N using Harper's modified phenoldisulfonic acid method (Harper, 1924). The best r^2 value (0.84) indicated a significant relationship between nitrogen uptake by the barley plant and soil NO_3-N to a depth of 24 inches at seeding time. The average recovery of added NH_4NO_3 fertilizer was 52 percent. An equation was derived to determine the amount of NH_4NO_3 fertilizer required to produce a predetermined yield. By re-arranging this equation a yield was predicted from the soil NO_3-N content at seeding time and the level of applied NH_4NO_3 fertilizer. A simple correlation was determined between the predicted yields and yields used to derive the prediction equation. The best correlation ($r^2 = 0.69$) was found when yield was expressed as a logarithmetic function of soil NO_3-N (expressed in a linear manner) plus 0.52 x fertilizer nitrogen applied. This method of yield prediction involved a determination of nitrogen uptake from soil and fertilizer nitrogen with a subsequent determination of yield from nitrogen uptake. Fehr[†] determined that the intermediate step of predicting nitrogen uptake was not necessary. He found similar correlation values when yield was predicted directly from

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† Unpublished data. P. I. Fehr. University of Manitoba. 1972.

soil and fertilizer supplies. Soper (1971) also found that tests for nitrogen were useful in estimating yield increases of rapeseed.

In northeastern Saskatchewan barley yields were not highly correlated with soil tests for NH_4-N and NO_3-N (Nuttall *et al.*, 1971). However, a significent correlation (r^2 = 0.74) was found between the logarithm of the yield increase and soil test values for NO_3-N. When comparing soil nitrogen, determined as NO_3-N and NH_4-N plus NO_3-N, R^2 values of 0.63 and 0.64, respectively, were obtained when these soil test values were correlated with yield increases of barley. There appears to be little advantage in determining NH_4-N as a soil test.

Yield prediction equations have been derived using other parameters in addition to available inorganic soil nitrogen and fertilizer nitrogen supply. Geist *et al.* (1970) predicted yields of Moravian barley using mineral and fertilizer nitrogen. In 1966 and 1967 the R^2 values were 0.61 and 0.34, respectively. By using a measure of organic nitrogen plus mineral and fertilizer nitrogen the R^2 values increased to 0.65 and 0.41, respectively. Young *et al.* (1967) found a positive correlation between organic matter and yield response of spring wheat grown mainly on fine textured chernozemic soils.

A general yield equation for corn was determined by Voss *et al.* (1970). The following parameters were studied:

(a) applied fertility

(b) applied fertility plus stand and barrenness covariates

(c) indigenous fertility

(d) management factors

(e) relative photosynthesis index

The r^2 values in relation to corn yields were 0.04, 0.33, 0.16, 0.19, and 0.46, respectively. Correlations of various combinations of these parameters, a+c, b+c+d, a+c+d+e, and b+c+d+e interactions resulted in R^2 values of 0.20, 0.67, 0.76, and 0.80, respectively. The most important single parameter in relation to corn yield was relative photosynthesis index. This was an evaluation of soil moisture stress based on estimated daily relative turgidity of corn plants. The management factors are an index of seeding date, grassy weed infestation, plant population, and plant cropping history. The R^2 values indicate a measure of the relative photosynthesis index plus management factors included with soil and fertilizer nitrogen account for a large amount of the variation in corn yields.

B. Moisture

Soil moisture stress can reduce wheat yields considerably (Hutcheon and Paul, 1966). Young *et al.* (1967) found as soil moisture at seeding increased yield response to nitrogen fertilizer increased. They found soil moisture at seeding was a better indicator of yield response to nitrogen than measuring precipitation during the growing season. Baier *et al.* (1964) also studied the influence of stored available soil moisture on wheat yields. They found yields increased until moisture levels reached four inches, after which they remained relatively constant. As levels of stored available moisture increased, more applied nitrogen was required to produce maximum yield increases. Dubetz (1961) also found greater nitrogen fertilizer requirements with increasing stored available soil moisture. Luebs and Laag (1969) conducted a barley experiment on a sandy loam soil near Moreno, California. Under the water availability of a simulated growing season (irrigation) they found a 550 Kg/ha (21 per cent) increase in yield of barley with the addition of 45 kg/ha of nitrogen. However, 90 kg/ha resulted in a 1,470 kg/ha (68 per cent) reduction in barley yield compared to the check. The yield reduction was attributed to greater soil moisture stress. The authors suggested the yield of barley with 45 kg/ha of nitrogen applied would have been reduced with a longer period of soil moisture stress.

The time during the growing season that moisture stress occurred influenced the severity of wheat yield reduction (Lehane and Staple, 1962). Day and Intalap (1970) controlled soil moisture stress on spring wheat by irrigation. They found yield reduction to be greatest at jointing, then at flowering, and least at dough stages. The plants were allowed to visibly wilt at these stages for each particular treatment. Soil moisture content was maintained at an optimum level for the rest of the growing season. Robins and Domingo (1962) also studied the effect of soil moisture stress on yield. Irrigated spring wheat yield reductions occurred with high soil moisture stress and were most severe during or after heading.

Results showed a definite relationship between soil texture and yields of crops grown at various soil moisture levels (Lehane and Staple, 1965; 1962). Paul and Myers (1971) conducted greenhouse studies of wheat under which two Black Chernozemic soils were subjected to soil moisture stresses of 0.3 - 1 atm., 0.3 - 4 atm., and 0.3 - 10 atm. Yields of wheat grown on loam soils significantly decreased with increasing moisture stress. Yields of wheat grown on clay soils significantly increased as soil moisture stress increased from 0.3 - 1 atm. to 0.3 - 4 atm. Yields at 0.3 - 10 atm. were similar to the 0.3 - 4 atm. soil moisture regime. The clay soils were adversely affected by low soil moisture stress. Campbell *et al.* (1960) studied wheat grown on a clay loam soil at low soil moisture stress. They found yields increased from 11.5 to 26.7 g/pot by improving the soil aeration. Lehane and Staple (1965; 1962) found fine textured soils were more resistant than coarse textured soils to increasing soil moisture stress.

Wheat yield is closely related to evapotranspiration (Voss *et al.*, 1970; Lehane and Staple, 1965). DeJong and Rennie (1969) found wheat yields decreased on Brown soils when water use was low. This trend was not evident on Dark Brown and Black soils. The authors attributed the yield decrease to a higher potential evapotranspiration on the Brown soils. Baier and Robertson (1965) suggested a measurement of potential evapotranspiration was a good method of indexing climate. They developed a technique of estimating latent evaporation from meteorological data. Latent evaporation was converted to potential evapotranspiration by a simple multiplication factor)Baier and Robertson, 1967). This measure of potential evapotranspiration plus rainfall data was used to estimate irrigation water requirements of crops. The factors considered in this determination were long-term average sunshine duration, vapour pressure deficit, and wind velocity. Daily measurements of maximum and minimum temperature as well as precipitation were also required.

C. Temperature

Characteristic ranges in temperature exist in which plants will grow and reproduce. Variations in temperature within this range, however, may have significant effects on plant yields. In greenhouse experiments, Partridge (1971) found wheat yields decreased when temperatures increased from 15°C to 21°C. Salisbury and Ross (1969) found similar plant yield reduction with high temperature. They suggested this was a result of increased respiration rates relative to photosynthesis rates. Sosulski *et al.* (1963) found temperatures of 18°C and 24°C did not affect wheat yields at low soil moisture stress and low fertility. However, with 225 kg/ha of applied N, wheat yields decreased with increasing temperature.

METHODS

This study was conducted using farm yield data collected from the records of the Manitoba Provincial Soil Tesing Laboratory (M.P.S.T.L.). Wheat, barley, and oat yields were studied for the years 1967, 1968, 1969 and 1970. These farm yields were compared to yields predicted by crop response equations. A paired *t* test was used to determine if predicted yields were significantly different from actual yields obtained by the farmers. Yield prediction equations were derived from experimental small plot data. The factors considered to influence yield were soil NO_3-N and fertilizer nitrogen. Measurements of soil NO_3-N content, applied nitrogen fertilizer, and crop yield were required for each farm field. In addition, water deficit factors had to be calculated. A major portion of the analysis was computerized.

A. Farm Data Collection

Farm fields are normally soil tested in late fall or early spring. To aid in the fertilizer recommendation the farmer is required to complete an information sheet provided by the M.P.S.T.L. for each field sampled (Appendix A1). The sheet provides information for the coming crop as well as the previous crop grown, yields obtained, and the amount of fertilizer applied. Information considered in the data collection was (Appendix 1A):

(1) Section A. - Field and Soil Data

- (a) laboratory number
- (b) client number
- (c) field number
- (d) legal description
- (e) crop to be grown - 1st, 2nd, and 3rd choice
- (f) topography and drainage
- (g) area sampled
- (h) month sampled
- (i) soil type
- (j) number of depths sampled

(2) Section B. - Cropping History of Past Year

- (a) crop year
- (b) crop grown or fallow
- (c) crop seeded on fallow or breaking or other
- (d) yield per acre
- (e) crop damage
- (f) cause of damage
- (g) nutrients applied - N, P_2O_5, and K_2O
- (h) fertilizer applied according to previous soil test
- (i) use of manure

Each soil sample was analysed for nitrogen, phosphorus, pH, lime carbonate, salinity, and soil texture. The M.P.S.T.L. stored these results on computer tape, listed by laboratory number. For this study, the results of the soil analysis were examined and this data was recorded along with the data from the information sheets.

To calculate a predicted yield on a particular farm, field data on soil NO_3-N and fertilizer nitrogen applied were required. Farm crop yield was also required to compare to yields predicted for the farm field. Because the data was not available from one year's soil test record, the farmer must have soil tested for two consecutive years. The first year provided soil NO_3-N at seeding time and the second year provided crop yield and the amount of fertilizer applied. The farmer's code number and the legal description located the two successive years' soil samples on the same quarter section, however, there was no direct method of determining if the soil samples came from the same field. Thus, the data available was compared using the following criteria to choose fields which had been soil sampled for two successive years:

(1) wheat, barley, or oats must have been grown

(2) no manure applied

(3) the field must have been fertilized according to M.P.S.T.L. recommendations

(4) soil sampled to 24 inches

(5) the farm operator must have been the same

(6) the legal description must have been the same

(7) electrical conductivity of a 1-1 soil water solution had to be below 4 mmhos.

For some farms there were two or more fields on one quarter section which fulfilled the first seven criteria. The decision to include or reject data from these fields for analysis was based on the following criteria:

(1) crop grown was similar to the crop for which a recommendation was requested

(2) field number was similar

(3) topography and drainage were similar

(4) texture was similar

(5) soil type was similar

Approximately forty-four thousand fields were sampled by farmers and the samples tested by the M.P.S.T.L. from 1966 to 1970. Much of the data obtained, however, was not utilized for this study because fields were not fertilized according to soil test recommendations or wheat, oats, or barley were not grown. In total 716 fields of wheat, 266 fields of oats, and 401 fields of barley were selected for the data analysis.

B. Yield Prediction Equations

Farm yields were compared to yields predicted by crop response equations. The yield prediction equations were derived from experimental small plot data†. These experiments

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†Unpublished data. Ridley A. O., Racz G. J., Soper R. J. University of Manitoba. 1962-1970.

tested crop response to increments of fertilizer nitrogen over a range of soil NO_3-N levels. Other nutrients required for plant growth were added or were present in adequate amounts. Therefore, yield was initially predicted from soil NO_3-N in the spring to a depth of 24 inches and the amount of fertilizer nitrogen applied to the crop. Soper *et al.* (1971) had predicted barley yields using these parameters and found a highly significant correlation between predicted and experimental small plot yields. All crop response equations derived were logarithmic or quadratic.

Yield prediction equations were developed for wheat and barley directly from small plot data for these crops. However, small plot experiments conducted had not included oats, therefore, prediction equations for this crop had to be made by interpolation. It was assumed that yields of barley and oats were equivalent when expressed in pounds per acre of grain. Thus, barley equations were used to predict oat yields. The barley equations, however, predicted yields in bushels per acre, therefore, the barley yield in bushels per acre had to be converted to an oat equivalent in bushels per acre. This was accomplished as follows:

Bushel weight conversion factor =

$$\frac{\text{48 lb. of grain per bushel of barley}}{\text{34 lb. of grain per bushel of oats}} = 1.41$$

Thus:

(Barley Yield; bu./ac.)(1.41) = Oat Yield; bu./ac.)

Soils are generally sampled in fall or early spring, however, some soils may be sampled just prior to seeding in May. It was assumed mineralization began in May, therefore, these soil samples would show higher nitrate levels compared to the fall or early spring samples. To correct for mineralization in the spring, 8 lb./ac. NO_3-N[†] was added to the soil test values for sampling dates prior to May 1st.

A water deficit factor was included as a third variable in the yield prediction equations to account for some aspects of climatic variation in Manitoba. To calculate water deficit, potential evapotranspiration had to be determined first. This was calculated on a daily basis using the following formula developed by Baier and Robertson (1967; 1965):

$$E = -\ 0.296 - 0.00315\ T_{max} + 0.00317\ (T_{max} - T_{min}) + 0.000165\ Q$$

where:

E = potential evapotranspiration (in./day)

T_{max} = maximum temperature (°F)

T_{min} = minimum temperature (°F)

Q = solar radiation at the top of the atmosphere (cal.-cm.$^{-2}$-day^{-1})

[†]Unpublished data. M.P.S.T.L. University of Manitoba. 1970.

Soil water deficit is a calculated value[†] of inches of water necessary to add by irrigation to maintain soil water content at an optimum level, providing actual and potential evapotranspiration are approximately equal. The general soil water balance equation was:

$$\text{inches of readily available water on April 30th} + \text{precipitation on May 1st} - \text{potential evapotranspiration on May 1st} = \text{inches of available water on May 1st}$$

For this study available water was determined daily by adding precipitation and subtracting potential evapotranspiration from the previous day's water deficit. Calculations were made beginning on May 1st when it was assumed there was four inches of readily available water in the soil. Daily measurements of maximum and minimum temperature were required to calculate potential evapotranspiration. Temperature and precipitation records were obtained from weather stations throughout Manitoba. Therefore, available soil water values were calculated for each of these weather stations. The calculation continued from May 1st to May 2nd in the following manner:

$$\text{inches of available water on May 1st} + \text{precipitation on May 2nd} - \text{potential evapotranspiration on May 2nd} = \text{inches of available water on May 2nd}$$

Water deficit was then defined as available soil water

[†]Unpublished data. C.F. Shaykewich. University of Manitoba. 1971.

multiplied by minus one. Water deficit calculations are made daily. For this study the calculations were continued to July 16th and to August 13th.

Each small plot yield and farm yield required a water deficit value for July 16th and August 13th for the year the crop was grown. For each small plot, water deficit values were calculated from the records of the weather station closest to the plot site. For the farm yields, water deficit values chosen were those calculated from records of weather stations located on similar soil associations and as close to the field as possible.

Yield prediction equations were developed for barley by determining nitrogen uptake from soil nitrate nitrogen and fertilizer nitrogen. A highly significant correlation was found between nitrogen uptake and barley yields (Soper *et al.*, 1971). They predicted yield in two steps. Initially, nitrogen uptake was predicted from NO_3-N and fertilizer N, and secondly, yield was predicted from nitrogen uptake. In the experiment nitrogen uptake by the above ground portion of the plant was obtained by sampling grain and straw at harvest time and determining total N by the Kjeldal method. They also found that only 52 per cent of the fertilizer nitrogen applied to barley was taken up by the plant.

When this study was initiated in 1970 the same form of prediction equations for barley and wheat (Table I, Equations [2] and [1], respectively) were in use by the

TABLE I Yield and Nitrogen Uptake Prediction Equations for Wheat and Barley.

Equation Number	Regression Equation	n	R^2	r^2
1.	$WY = 23.3 \, Log_{10}(22.8 + 0.98x_1 + 0.52x_2) - 62.4$			
2.	$BY = 33.6 \, Log_{10}(22.8 + 0.98x_1 + 0.52x_2) - 88.3$			
3.	$WY = 11.4 + 0.543x_1 - 0.00239x_1^2 + 0.532x_2 - 0.00148x_2^2 + 0.000512x_1x_2$	53	0.65	
4.	$BY = 18.2 + 1.01x_1 - 0.00632x_1^2 + 0.504x_2 - 0.00130x_2^2 - 0.00144x_1x_2$	180	0.69	
5.	$WY^+ = 50.1 \, Log_{10}(12.6 + 1.67x_1 - 0.00826x_1^2 + 0.568x_2) - 56.1$			
6.	$BY^* = 75.7 \, Log_{10}(12.6 + 1.67x_1 - 0.00826x_1^2 + 0.541x_2) - 82.5$			
7.	$BY^* = 75.7 \, Log_{10}(5.58 + 1.97x_1 - 0.0117x_1^2 + 0.711x_2 - 0.00112x_2^2 - 0.00273x_1x_2 - 82.5$			
	Note: $WY^+ = 50.1 \, Log_{10}(Z) - 56.1$	53		0.87
	$BY^* = 75.7 \, Log_{10}(Z) - 82.5$	180		0.83
	$V = 12.58 + 1.67x_1 - 0.00826x_1^2$	89		0.78
	$N = 5.58 + 1.97x_1 - 0.0117x_1^2 + 0.711x_2 - 0.00112x_2^2 - 0.00237x_1x_2$	180		0.84
	$Z = V + 0.568x_2$ (wheat) or $0.541x_2$ (barley)			

WY = wheat yield in bu./ac.
BY = barley yield in bu./ac.
x_1 = soil NO_3-N to 2 ft. (lb./ac.)
x_2 = fertilizer nitrogen applied (lb./ac.)
Z = nitrogen uptake by plant from fertilizer N
V = nitrogen uptake by plant from NO_3-N
N = nitrogen uptake by plant from NO_3-N and fertilizer N

M.P.S.T.L.; therefore these equations were used to predict yields for the preliminary analysis of 1969 farm yields. By 1971, when 1967, 1968, and 1970 farm yields were collected, the yield prediction equations developed by the M.P.S.T.L. had been updated. These new equations were based on a larger sample of experimental small plot data (180 barley and 53 wheat observations). The mathematical models used for the yield and nitrogen uptake prediction equations were:

(1) Yield predicted from nitrogen uptake expressed in a logarithmic manner. Nitrogen uptake was predicted from soil NO_3-N expressed in a quadratic manner and fertilizer nitrogen expressed in a linear manner. (Table I, Equations [5] and [6] for wheat and barley, respectively). For barley yields, nitrogen uptake was also predicted from soil NO_3-N and fertilizer N expressed in a quadratic form with interactions between the independent variables (Table I, Equation [7]).

(2) Yield was predicted from soil NO_3-N and fertilizer nitrogen expressed in a quadratic manner with interaction between the independent variables (Table I, Equations [3] and [4] for wheat and barley, respectively).

A study of all the farm data was conducted with these equations. Upon completion of this study the water deficit factor was considered in an attempt to improve the level of predictability. Water deficit values were determined for the 1971 experimental small plot data. One weather station, at Gimli, was not considered to be representative of plot sites because the station was located close to Lake Winnipeg. Therefore, 20 barley and 2 wheat observations had to be excluded from the small plot data. Six new equations for wheat and six new equations for barley were derived. Three quadratic equations predicted yield and three quadratic equations predicted nitrogen uptake from the following independent variables (Tables II and III, for wheat and barley, respectively):

(1) soil NO_3-N and fertilizer N

(2) soil NO_3-N, fertilizer N, and water deficit on August 13th.

(3) soil NO_3-N, fertilizer N, and water deficit on July 16th.

To predict yield from nitrogen uptake, the logarithmic equations from the previous study were used. This final set of equations predict wheat and barley yields from the same equation models. Therefore, to describe the mathematical model and the variables used in predicting wheat or barley yields, the following abbreviations were used for the six respective equations: Q2V, Q3VA, Q3VJ, L2V, L3VA, L3VJ where Q represents quadratic; L represents logarithmic; 2V represents 2 variables; 3V represents 3 variables; A

TABLE II Yield and Nitrogen Uptake Prediction Equations for Wheat

Equation Indentification	Regression Equation	n	R^2	r^2
Q2V	$Y = 11.5 + 0.614x_1 - 0.00301x_1^2 + 0.325x_2 - 0.00122x_2^2 - 0.000190x_1x_2$	51	0.66	
Q3VA	$Y = 7.12 + 0.902x_1 - 0.00618x_1^2 + 0.412x_2 - 0.00160x_2^2 - 0.598x_3 + 0.0740x_3^2$ $- 0.00393x_1x_2 + 0.0430x_1x_3 + 0.0116x_2x_3$	51	0.70	
Q3VJ	$Y = 9.23 + 0.775x_1 - 0.00550x_1^2 + 0.393x_2 - 0.00166x_2^2 - 0.917x_4 + 0.0309x_4^2$ $- 0.00210x_1x_2 + 0.0432x_1x_4 + 0.0175x_2x_4$			
L2V	$Y = 50.1 \text{ Log}_{10} (Z_1) - 56.2$			
L3VA	$Y = 50.1 \text{ Log}_{10} (Z_2) - 56.2$			
L3VJ	$Y = 50.1 \text{ Log}_{10} (Z_3) - 56.2$			
	NOTE: $Y = 50.1 \text{ Log}_{10}(Z) - 56.2$	53		0.87
	$z_1 = 19.6 + 0.975x_1 - 0.00235x_1^2 + 0.510x_2 - 0.00070x_2^2 + 0.00537x_1x_2$	51	0.74	
	$z_2 = 12.2 + 1.55x_1 - 0.00872x_1^2 + 0.797x_2 - 0.00215x_1^2 - 1.190x_3 + 0.00585x_3^2$ $- 0.00347x_1x_2 + 0.0877x_1x_3 + 0.0326x_2x_3$	51	0.80	
	$z_3 = 11.8 + 1.305x_1 - 0.00706x_1^2 + 0.644x_2 - 0.00166x_2^2 - 0.806x_4$ $+ 0.498x_4^2 + 0.00216x_1x_2 + 0.0568x_1x_4 + 0.0399x_2x_4$	51	0.79	

Y = yield wheat (bu./ac.)

x_1 = NO_3-N (lb./ac.) to 2 ft.

x_2 = fertilizer N applied (lb./ac.)

x_3 = water deficit on August 13th (inches)

x_4 = water deficit on July 16th (inches)

z = measured nitrogen uptake by the plant

z_1, z_2, z_3 = predicted nitrogen uptake by the plant

TABLE III Yield and Nitrogen Uptake Prediction Equations for Barley.

Equation Identification	Regression Equation	n	R^2	r^2
Q2V	$Y = 19.4 + 0.986x_1 - 0.00578x_1^2 + 0.502x_2 - 0.00128x_2^2 - 0.00173x_1x_3$	160	0.69	
Q3VA	$Y = 18.5 + 0.902x_1 - 0.00485x_1^2 + 0.502x_2 - 0.00120x_2^2 - 0.541x_3 + 0.189x_3^2 - 0.00161x_1x_2 - 0.0118x_1x_3 + 0.00649x_2x_3$	160	0.71	
Q3VJ	$Y = 16.0 + 1.004x_1 - 0.00619x_1^2 + 0.485x_2 - 0.00117x_2^2 - 0.588x_4 + 0.534x_4^2 - 0.00155x_1x_2 + 0.00812x_1x_4 + 0.00943x_2x_4$	160	0.73	
L2V	$Y = 75.7 \text{ Log}_{10}(Z_1) - 82.5$			
L3VA	$Y = 75.7 \text{ Log}_{10}(Z_2) - 82.5$			
L3V3	$Y = 75.7 \text{ Log}_{10}(Z_3) - 82.5$			
	Note: $Y = 75.7 \text{ Log}_{10}(Z) - 82.5$	180		0.83
	$Z_1 = 6.35 + 1.95x_1 - 0.0115x_1^2 + 0.733x_2 - 0.00122x_2^2 - 0.00276x_1x_2$	160	0.85	
	$Z_2 = 3.27 + 1.91x_1 - 0.0109x_1^2 + 0.739x_2 - 0.00119x_2^2 - 0.393x_3 + 0.161x_3^2 - 0.00266x_1x_2 + 0.00256x_1x_3 + 0.00573x_2x_3$	160	0.86	
	$Z_3 = -0.092 + 2.01x_1 - 0.0129x_1^2 + 0.705x_2 - 0.00105x_2^2 - 1.26x_4 + 0.947x_4^2 - 0.00238x_1x_2 + 0.0271x_1x_4 + 0.0137x_2x_4$	160	0.89	

Y = yield barley (bu./ac.)

x_1 = NO_3-N (lb./ac.) to 2 ft.

x_2 = fertilizer N applied (lb./ac.)

x_3 = water deficit on August 13th (inches)

x_4 = water deficit on July 16th (inches)

z = measured uptake by the plant

z_1, z_2, z_3 = predicted nitrogen uptake by the plant represents August 13th water deficit; and J represents July 16th water deficit.

C. Analysis of Farm Data

Procedures for analysis of wheat, barley, and oat yield data were similar. The data for each farm yield included the crop grown, its yield, the soil NO_3-N level at seeding time, the amount of fertilizer N applied, and the water deficit values on July 16th and August 13th. The yield prediction equations discussed in the previous section were used to predict yields for each farm field. These predicted yields were compared to the actual crop yield. A paired t test was used to determine the relationship between actual and predicted yields. A large t value indicated predicted yields were significantly different from actual yields. When t values were low the equations accurately predicted farm yields, and as the t value approached zero the accuracy increased. Dispersion of differences between actual and predicted yields was measured by the standard deviation of the difference. For example, a standard deviation of 8 bu./ac. indicated that difference between actual and predicted yields was within plus or minus 8 bu./ac. of the mean difference sixty-seven per cent of the time.

Farm data was grouped in three general ways, and the accuracy of the prediction of farm yields by each equation was determined for each group. The three groups were:

(1) all the farm data, 1967 to 1970, inclusive

(2) farm data grouped by years, 1967, 1968, 1969, and 1970, respectively

(3) agronomic soil groups

Groups (1) and (2) were representative of the manner in which fertilizer recommendations are presently made in Manitoba; that is, one fertilizer recommendation for all fields in Manitoba with equivalent nutrient status. However, crop yields across Manitoba may vary in any one given year with factors such as regional climatic variation, soil texture, and internal and external drainage differences. In an attempt to improve the accuracy of predictions, yields from soils of similar characteristics were grouped together giving several "agronomic groups". Agronomic soil groups were established by interpretation of profile characteristics. Description of the soil associations were found in Manitoba Soil Survey reports (Ehrlich *et al.*, 1959; Ehrlich *et al.*, 1958; Ehrlich *et al.*, 1957; Ehrlich *et al.*, 1956; Ehrlich *et al.*, 1953; Ellis and Shafer, 1943; Ellis and Shafer, 1940). The agronomic soil groups were:

(1) Moderately well to well drained medium textured Black till soils found above the escarpment

consisting of:

(a) Waskada and Oxbow associations located in southwestern Manitoba

(b) Newdale association located in west-central Manitoba

(c) Manitou, Darlingford, and Snowflake association located in south-central Manitoba

(2) Black water worked till soils above the escarpment consisting of:

(a) Heaslip complex. These soils are located in southwestern Manitoba.

(3) Black lacustrine and outwash soils above the escarpment consisting of:

(a) Souris association. This association includes imperfectly to poorly drained coarse textured soils of southwestern Manitoba which have a high water table in the spring.

(b) Stockton, Miniota, and Marringhurst associations. These associations include well drained coarse textured soils of central and west-central Manitoba.

(c) Carrol, Glenboro, Wellwood and Holland associations. These associations include well drained medium to medium coarse textured soils of central and south-central Manitoba.

(4) Black lacustrine and outwash soils below the escarpment consisting of:

(a) Altona and Almasippi soil associations. These associations include imperfectly drained coarse textured soils with a high water table in the spring. They are located below the eastern edge of the escarpment in the Manitoba lowlands.

(b) Portage, Sperling, Oakville, Gladstone, Riverdale, and Firdale soil associations. These soil associations include well to imperfectly drained medium textured soils found in the Manitoba lowlands.

(c) Red River, Gretna, Marquette, Morden, Fort Garry, Emerson, Semple, Myrtle, Morris, Peguis, Rathwell, and Westbourne soil associations and the Horndean complex soil. These soils are imperfectly to poorly drained fine textured soils found in the Manitoba lowlands.

(d) Dauphin and Edwards soil associations. These soil associations include imperfect to poorly drained fine textured soils found in northwestern Manitoba.

RESULTS AND DISCUSSION

Equations derived to calculate the amount of fertilizer nitrogen necessary to add to crops to achieve "target yields" were based on experimental data from small plots. When the target yield program was implemented by the M.P.S.T.L., sufficient farm data was available for the previous several years to determine if the yields farmers had achieved could have been predicted by the target yield equations. The reasons for selecting years 1966 to 1970 were:

(1) before 1966, data recorded by the M.P.S.T.L. was not in a form that could be used for this study.

(2) data after 1970 was not used because this study had begun prior to it being available.

(3) a large sample of farm data was available for this period.

A. Relationship Between Actual Farm and Predicted Yields of Wheat

1. Preliminary analysis of 1969 farm yield data

A study of the 1969 farm wheat data indicated that some farm yields were significantly reduced due to factors such as hail, drought, excessive wetness, disease, etc. The assessment of damage was made by the farmer and indicated on the crop record sheets submitted with the soil samples. When data from fields which had incurred moderate or severe crop damage were removed the relationship between actual farm wheat yields and those predicted (Table I, equation [1]) was improved. Paired t values decreased from 7.73 to 5.41 (Table IV). Both these t values were high and indicated actual and predicted yields were significantly different. The logarithmic equation was therefore, not adequately predicting the farm yields. However, because a lower t value was obtained when yield data from crops which had been moderately to severely damaged were removed from the sample, these wheat yields were subsequently removed from the farm data set for all further analysis. Although this may introduce some bias the literature (Fehr, 1971) indicated that good predictions or target yields can be expected only with favourable climate and management. Removing this data was consistent with the

TABLE IV. Effect of Moderately and Severely Damaged Wheat Crops on the Relationship Between Actual and Predicted Yields

Farm Data Included in the Analysis for the 1969 Crop Year	No. of Farm Yields	Mean Yield (bu./ac.) Actual	Mean Yield (bu./ac.) Predicted	Paired *t* Value
A) All yield data	100	32.0	39.1	7.73*
B) Wheat yields with moderately and severely damaged crops removed	81	34.2	39.0	5.41*
C) Max. pred. yield set at:				
.55 bu./ac.	81	34.2	39.0	5.41*
.50 bu./ac.	79	34.2	38.6	5.41*
.45 bu./ac.	74	33.9	38.1	4.77*
.40 bu./ac.	49	33.5	36.2	2.37*

* Significantly different at p=0.05.

manner in which the small plot data was selected, i.e. small plot data was not included in formulating prediction equations if plots had been moderately or severely damaged.

Wheat yields greater than 50 bu./ac. were predicted when the nitrogen supply was high. However, fifty bushels of wheat per acre is seldom achieved. To determine the effect of the high predicted yields on the accuracy of farm yield prediction, an upper predicted yield limit was set at 55, 50, 45, and 40 bu./ac. Farm data was removed when predicted yields were higher than the limit for the respective analysis. The *t* values decreased from 5.41 to 2.37, respectively. This indicated that not all nitrogen was being utilized for yield as the prediction equation suggested. Alkier (1972) showed that any nitrogen applied in addition to that required for yield, increased protein content. This should be measured by the yield prediction equations, however, it was found that some farm field levels of soil NO_3-N or fertilizer nitrogen were considerably higher than the nitrogen levels in small plots. Therefore, the yield prediction equations were only considered valid for the range of nitrogen levels covered by the small plot data. Thus the nitrogen levels for the farm fields must have been within the range covered by the small plot data before the field was included in all further analysis. This criteria was used because arbitrarily limiting maximum predicted yields was not considered reasonable.

2. Relationship of farm yields to yield predicted from equations which included soil NO_3-N and Fertilizer N

Yield prediction equations were recalculated, using new data as it became available (Table I, equation [3] and [5]). These updated equations showed that farm wheat yields i.e. from all fields, 1967 to 1970, inclusive, differed significantly from predicted yield (Table V and VI). Both a logarithmic and quadratic equation were used to predict yields. While predicted yields were distributed above and below actual yields, most frequently they were above the actual yields. On the average predicted yields were 5 to 6 bu./ac. higher than actual yields. The standard deviation of the difference between actual and predicted yields was approximately 7 to 8 bu./ac. This is a relatively high standard deviation and may be due in part to the manner in which farmers reported yields. Often yields are reported to the closest 5 bu./ac. increment, for example 30, 35, or 40 bu./ac. of wheat, while the equations predict yields to the closest bushel.

Crop yields vary from year to year; therefore, farm yields were grouped by years, 1967 to 1970, respectively, and compared to yields predicted by quadratic and logarithmic equations. Mean predicted yields for each

TABLE V Relationship Between Farm Wheat Yields and Yields Predicted from a Quadratic Equation[1]

Data Group	No. of Farm Yields	Mean Yield (bu./ac.)		Paired t Value	Standard Deviation of the Difference (bu./ac.)	Number of Predicted Yields	
		Actual	Predicted			Above Actual	Below Actual
All Fields 1967-1970	716	33.5	38.8	17.7*	8.0	532	184
1967	312	31.5	38.5	16.7*	7.4	259	53
1968	265	36.9	39.4	5.37*	7.6	163	102
1969	80	34.1	37.7	4.14*	7.9	57	23
1970	59	28.3	39.2	11.2*	7.5	53	6

[1] Equation [3] (Table I)
*Significantly different at $p=0.05$.

TABLE VI Relationship Between Farm Wheat Yields and Yields Predicted from a Logarithmic Equation[1]

Data Group	No. of Farm Yields	Mean Yield (bu./ac.)		Paired t Value	Standard Deviation of the Difference (bu./ac.)	Number of Predicted Yields	
		Actual	Predicted			Above Actual	Below Actual
All Fields 1967-1970	716	33.5	40.0	22.3*	7.8	561	155
1967	312	31.5	40.0	21.1*	7.1	267	45
1968	265	36.9	40.5	7.68*	7.5	177	88
1969	80	34.1	38.8	5.58*	7.6	62	18
1970	59	28.3	40.1	12.7*	7.1	55	4

[1]Equation [5] (Table I)
*Significantly different at $p=0.05$.

year varied from 38 to 40 bu./ac. while farm yields varied on the average from 28.3 bu./ac. in 1970 to 36.9 bu./ac. in 1968. In 1968 and 1969 farm yields were generally much higher than in 1967 and 1970; however, even when farm yields were the highest they were not adequately described by yield prediction equations. The quadratic equation (Table I, equation [3]) predicted yields which were more closely related to farm yields than the logarithmic equation (Table I, equation [5]). The high yearly variation in farm yield may be due to seasonal variation in climate. Yield prediction equations which considered only NO_3-N and fertilizer N as variables did not account for this variation. Thus in an attempt to partially measure climatic variations, a water deficit factor was introduced into the yield prediction equations.

3. Effect of a water deficit variable on the accuracy of farm yield prediction

A new set of yield prediction equations (Table II) were derived in order to include a variable which partially described climate. This variable was a water deficit factor. In the first calculations water deficit on August 13th was chosen because it approximated the end of crop growth. Literature suggested that wheat yield reductions because of soil moisture stress were greatest when the plant growth stage was from jointing, to heading, and after heading (Day and Intalap, 1970; Robins and Domingo, 1962). A second water deficit date, July 16th, was chosen to approximate the heading stage of wheat growth.

The addition of a water deficit factor improved the R values for the quadratic yield prediction and nitrogen uptake prediction equations (Table II). To assess the effect of the water deficit factor, predicted yields were calculated with decreasing water deficit at various levels of soil NO_3-N plus fertilizer nitrogen (Tables VII and VIII). Except at low nitrogen levels, the equations which included a water deficit factor predicted yields which increased with decreasing water deficit. This indicated that unfavourable temperature and precipitation could be limiting wheat yields. Also, as nitrogen levels increased there was greater yield response to decreasing water deficit. This was consistent with the literature where Bauer *et al.* (1964) showed that as stored available soil moisture increased, more applied nitrogen was required to produce maximum yield. At low nitrogen levels where no yield increase was predicted; lack of nitrogen was assumed to be the factor limiting wheat yields. One other trend was noted; at high water deficit levels there was little or no yield response to the higher nitrogen levels. The August water deficit equations even predicted a yield reduction when soil NO_3-N was increased from 30 to

TABLE VII Wheat Yields in Bushels per Acre Predicted by the Q3VA, Q3VJ, and Q2V Equations at Various Nitrogen and Water Deficit Levels.

Equation	Soil NO_3-N - Fertilizer N / Water Deficit (inches)	10-0	10-20	10-40	10-60	10-80	30-0	30-20	30-40	30-60	60-0	60-20	60-40
	7	25	30	33	35	36	30	33	34	35	27	28	27
	5	24	29	33	35	36	30	34	36	37	30	31	31
	3	23	29	33	36	37	31	35	38	39	34	35	36
Q3VA	1	23	29	34	37	39	33	37	40	42	38	40	41
	-1	24	30	35	39	42	35	40	43	46	43	45	47
	-3	25	32	37	42	45	38	43	47	50	48	51	53
	4	24	29	32	35	36	29	33	36	37	29	32	33
	2	23	29	33	36	38	30	35	39	41	33	36	39
Q3VJ	0	23	29	34	38	40	32	37	42	44	37	41	44
	-2	23	30	36	40	43	34	40	45	48	41	46	50
	-4	23	31	38	43	46	36	43	48	52	46	52	56
Q2V	Check	22	28	33	37	40	31	37	42	45	40	46	50

TABLE VIII Wheat Yields in Bushels per Acre Predicted by the L3VA, L3VJ and L2V Equations at Various Nitrogen and Water Deficit Levels

Equation	Water Deficit (inches) \ Soil NO_3-N - Fertilizer N	10-0	10-20	10-40	10-60	10-80	30-0	30-20	30-40	30-60	60-0	60-20	60-40
L3VA	7	22	27	30	33	34	27	30	33	34	26	29	31
	5	23	28	32	34	36	29	32	35	37	31	33	35
	3	23	29	33	36	38	31	35	37	39	34	37	39
	1	24	30	35	38	40	32	36	39	42	37	40	42
	-1	25	31	36	39	41	34	38	41	44	40	43	45
	-3	25	32	37	40	43	36	40	43	45	43	45	48
L3VJ	4	20	25	29	32	35	27	32	35	38	31	35	39
	2	21	27	31	35	37	29	34	37	40	34	38	41
	0	22	29	33	37	39	31	36	39	42	36	41	44
	-2	23	24	35	37	42	32	37	41	44	38	43	46
	-4	24	31	37	40	43	34	39	43	46	40	45	48
L2V	Check	22	28	33	37	40	30	35	39	43	38	43	46

60 lb./ac. A similiar trend was found by Luebs and Laag (1970). In a simulated grassland experiment with equivalent rainfall they found barley yields when compared to the check increased with 45kg/ha fertilizer N and decreased with 90 kg/ha fertilizer N. They suggested higher levels of nitrogen increased plant proliferation, thus increasing transpiration. This has the effect of increasing soil water stress and subsequently decreasing yield.

Yields predicted by the Q3VA and Q3VJ equations were similar at low soil NO_3-N levels; however, as soil NO_3-N increased to 60 lb./ac. the Q3VJ equation predicted slightly higher yields than the Q3VA equation.

The logarithmic equations which included a water deficit predicted yields similar to the quadratic equations which included a water deficit. Two slight differences however were noted: (i) predicted yields increased slightly with decreasing water deficit at low nitrogen levels and (ii) predicted yields at high nitrogen levels and low water deficit were lower with the logarithmic than with the quadratic equations at both periods of moisture deficit.

Water deficit as a variable in the yield prediction equations resulted in large yield variations at constant nitrogen levels. Several problems associated with the water deficit factor must be considered when it is used in a prediction equation. These include:

(1) Data for calculating water deficit values were obtained from weather stations located as close as possible to the experimental small plot sites. The amount of precipitation, however, can vary considerably over short distances, therefore, the water deficit at the plot site may differ from the water deficit at the weather station. An accurate measure of water deficit could be obtained by recording temperature and precipitation at the experimental plot sites, but this was not done.

(2) The large amount of experimental plot yield data required to cover all possible combinations of low to high soil NO_3-N, fertilizer N, and water deficits are not available and this presents a major problem. These combinations must be considered in order to develop a good yield prediction equation.

(3) Potential evapotranspiration is calculated and used in the yield prediction equations. This introduces a possible error which could be overcome if actual evapotranspiration could be measured.

(4) It is assumed that four inches of water is readily available on May 1st. The amount actually available may vary between years and with soil characteristics such as texture.

Although the problems are numerous, the water deficit factor does attempt to relate precipitation and potential evapotranspiration thus partially accounting for climatic variations. It is, at present, the only method of measuring climatic variables in a way which will permit their recognition in a yield prediction equation.

Prior to the analysis of the farm yield data with the water deficit equations it was necessary to understand the effect the water deficit factor had on predicted yields. Yields predicted by the Q3VA, Q3VJ, L3VA, L3VJ, Q2V, and L2V were compared to the farm wheat yields of 1967 to 1970, inclusive. An excellent relationship was found between the actual wheat yields and yields predicted by the Q3VA and L3VA equations (Table IX). For both equations the mean predicted yield was 34.6 bu./ac. compared to a mean actual yield of 34.7 bu./ac. The t values of 0.05 and -0.11, respectively, were very low and showed farm yields were accurately predicted over the four years. The standard deviation of the difference between actual and predicted yields was 9.9 and 8.7 bu./ac., respectively (Appendix A3). This large variation would appear to present a major problem in attempting to accurately describe farm yields with yield prediction equations. The other four equations, Q3VJ, L3VJ, L2V, and Q2V had t values of 3.49, 6.28, 9.08, and 12.1, respectively. Although t values indicated actual and predicted yields were significantly different, they also showed the July water deficit equations predicted yields more closely related to actual yields than

TABLE IX Effect of the Water Deficit Factor on the Accuracy of Farm Wheat Yield Prediction

			Regression Equation										Regression Equation			
			Q2V		L2V		Q3VA		L3VA				Q3VJ		L3VJ	
Data Group	No. of Farm Yields	$\bar{x}$ Actual bu./ac.	t Value	$\bar{x}$ Pred. bu./ac.	t Value	$\bar{x}$ Pred. bu./ac.	t Value	$\bar{x}$ Pred. bu./ac.	t Value	$\bar{x}$ Pred. bu./ac.	No. of Farm Yields	$\bar{x}$ Actual bu./ac.	t Value	$\bar{x}$ Pred. bu./ac.	t Value	$\bar{x}$ Pred. bu./ac
All Years 1967-1970	396	34.7	12.1*	39.5	9.08*	38.3	-0.05	34.6	-0.11	34.6	438	34.2	3.49*	35.8	6.28*	36.7
1967	96	32.2	9.83*	39.0	8.06*	37.7	-0.96	31.1	-1.57	30.7	122	32.0	1.69	33.4	4.99*	35.3
1968	206	37.1	5.62*	40.1	3.23*	38.8	-1.45	36.1	-1.60	36.2	206	37.1	0.13	37.2	1.21	37.8
1969	63	33.7	4.46*	38.3	3.49*	37.1	2.75*	36.4	2.84*	36.4	63	33.7	3.71*	37.4	2.67*	36.3
1970	30	28.0	7.85*	39.9	7.31*	38.5	3.43*	32.2	3.92*	32.7	46	28.2	4.64*	33.8	7.06*	35.6

* Significantly different at $p=0.05$.

the two equations which did not include a water deficit factor. When yield was predicted from soil NO_3-N and fertilizer N only, the average yield was 3.6 to 4.8 bu./ac. greater than the mean farm yields. The results indicated that the prediction equations which included a water deficit measured in August accurately predicted farm yields and these equations would be best suited to making farm fertilizer recommendations. Generally farmers did not grow as high wheat yields as the nitrogen fertility levels suggested they could. It would appear that adverse temperature and precipitation began to limit wheat yield response to nitrogen.

Considerable yearly variation in farm yields was noted in the previous farm yield analysis. To determine if yield prediction equations which included a water deficit, better explained the yearly variation in farm yields, the data was analysed by years. Analysis of the data indicated that this occurred. For example, comparing the Q2V and Q3VA equations, the mean predicted yields in bu./ac. were 39.0 and 31.1 in 1967, 40.1 and 36.1 in 1968, 38.3 and 36.4 in 1969, and 39.9 and 32.2 in 1970. Comparing these to the mean actual yields of 32.2, 37.1, 33.7, and 28.0 bu./ac. from 1967 to 1970, respectively, the mean predicted yields for the Q3VA equation follow the mean farm yields closely. In contrast, for the Q2V equation, the greatest variation in mean predicted yield between any two years was 1.8 bu./ac., from 40.1 bu./ac. in 1968 to 38.3 bu./ac. in 1969. The *t* values showed farm yields were accurately predicted by the Q3VA, L3VA, and Q3VJ equations in 1967 and 1968; however, in 1969 and 1970 predicted yields were generally higher than the actual yields. This suggested the water deficit factor accounts for a large portion, but not all of the yearly variation in farm yields. It was likely yield reductions could be attributed to factors such as weed control, seeding date, ponding of water, or others, including management in general. Although these three equations predicted yields which were significantly different than farm yields in 1969 and 1970, their *t* values showed they predicted farm yields more accurately than the other equations. The fourth water deficit equation L3VJ, predicted more constant yields from year to year; however, it did account for some of the yearly variation. The L2V and Q2V equations did not account for any yearly variation in farm yields. Comparing these two equations there is a definite trend for the L2V equation to predict yields lower and therefore closer to farm yields.

Data showed that the addition of the water deficit factor improved the accuracy of farm yield predictions. In general, better predictions were made when water deficit was calculated on August 13th. Good management is required to achieve a target yield but this factor was not measured.

4. Effect of Agronomic Soil Groups on the Efficiency of Farm Yield Prediction Equations

Sufficient experimental data were not available to calculate yield prediction equations for all soil types when the Target Yield Program was put into effect. Therefore, all data were pooled and prediction equations were derived which were assumed to be valid for Manitoba in general. Because of the large quantity of farm data, it was possible to arrange the farm data according to soil characteristics into "agronomic groups" and examine the equations and data to determine if some equations were more suited to predicting yields on certain soil types.

The analysis of farm data arranged by agronomic soil groups showed farm yields were more accurately predicted in some areas when the water deficit factor was included in the yield prediction equations while in other areas it was not. Farm yields were compared to yields predicted by the L2V, Q2V, L3VA, Q3VA, L3VJ, and Q3VJ equations. Occasionally, the number of farm observations within an agronomic soil group varied. Some farm data were omitted because the calculated water deficit for the farm fields were not within the range of the water deficit values for small plots. For the following analysis of each agronomic soil group the results are shown in Table X, while the prediction equations used are shown in Table II.

TABLE X Effect of Agronomic Soil Groups on the Accuracy of Farm Wheat Yield Prediction

			Regression Equation										Regression Equation			
			Q2V		L2V		Q3VA		L3VA				Q3VJ		L3VJ	
Soil Grouping	No. of Farm Yields	$\bar{x}$ Actual bu./ac.	t Value	$\bar{x}$ Pred. bu./ac.	t Value	$\bar{x}$ Pred. bu./ac.	t Value	$\bar{x}$ Pred. bu./ac.	t Value	$\bar{x}$ Pred. bu./ac.	No. of Farm Yields	$\bar{x}$ Pred. bu./ac.	t Value	$\bar{x}$ Pred. bu./ac.	t Value	$\bar{x}$ Pred. bu./ac.
1a. Waskada	33	33.8	4.53*	39.7	3.63*	38.4	-1.136	31.4	-1.18	32.1	40	32.9	-0.37	32.3	1.97	35.2
b. Newdale	20	37.6	1.61	40.7	0.79	39.2	-2.75*	32.5	-2.34*	33.8	20	37.6	-2.64*	32.4	-1.23	35.6
c. Manitou	29	36.4	3.31*	40.5	2.00	39.0	5.88*	44.0	3.96*	41.0	29	36.4	6.93*	44.6	4.81	41.9
2a. Heaslip	21	30.5	8.84*	41.9	7.86*	40.0	3.59*	35.1	4.57*	35.8	22	30.1	5.42*	36.3	6.40*	37.2
3a. Souris[1]	11	30.7	4.17*	39.5	3.77*	38.1	0.19	31.2	-2.79*	25.2	8	32.5	-0.88	30.3	2.05*	36.2
b. Stockton	15	31.5	2.66*	36.3	2.48*	34.1	1.33	33.5	1.88	34.1	15	31.5	1.53	33.8	1.66	34.0
c. Carrol	39	33.8	4.53*	40.2	3.68*	39.0	4.53*	41.0	3.77*	39.3	39	33.8	5.06*	41.9	4.44*	40.3
4a. Altona	80	39.0	1.00	39.8	-0.42	38.6	-4.22*	35.1	-3.57*	35.9	111	36.6	-3.02*	34.1	-0.93	35.9
b. Portage	16	36.4	1.06	38.9	0.563	37.6	-1.28	32.8	-1.22	33.5	19	35.7	-0.96	33.5	-0.48	34.7
c. Red River	137	32.8	9.63*	38.9	7.89*	37.7	-0.90	32.0	-1.11	31.9	133	32.6	3.65*	35.8	5.60*	36.3
c. Dauphin	10	29.9	4.15*	38.1	3.15*	36.7	0.62	31.7	0.05	29.7	-	-	-	-	-	-

* Significantly different at p=0.05.
[1] Farm water deficit on August 13th did not fall within small plot data range.

Throughout the discussion the water deficits calculated for soils within an agronomic soil group were referred to as low, medium, and high. Water deficit values from the four years were averaged, and if they were below one inch the soils within the group were considered to have a low water deficit, if they were between one and six inches the water deficit was medium, and above six inches, was high. The results of the analysis of farm yields in each agronomic soil group were:

(1) Till soils above the escarpment consisting of:

(a) Waskada loam to clay loam and Oxbow loam to clay loam

High water deficit values were calculated from weather stations within these soil associations. Farm wheat yields were not significantly different from yields predicted by equations including a water deficit variables. These equations predicted yields which averaged 31.4 to 35.2 bu./ac. compared to a mean actual yield of approximately 33.5 bu./ac. Farm yields were most accurately predicted by the Q3VJ, L3VA, and Q3VA equations. The L2V and Q2V equations had mean predicted yields approximately 5 bu./ac.

higher than the mean actual yields and the *t* values indicated the actual and predicted yields were significantly different.

The addition of the water deficit as a variable in the yield prediction equations was effective in improving the accuracy of farm yield prediction. Since the water deficit calculated for these soils was high, lower predicted yields resulted. Because the water deficit factor was mainly based on daily precipitation and temperature, it appeared these factors were limiting farm yields compared to those predicted from nitrogen status only. The 25 to 40 year average precipitation (Figure 1) and water deficit (Figure 2) show four weather stations at Deloraine, Pierson, Waskada and Boissevain which are located on Waskada or Oxbow soil associations. Precipitation tended to be relatively constant throughout Manitoba.
A comparison of the long term precipitation and water deficit maps showed that potential evqpotranspiration was a larger factor in the variation in water deficit throughout Manitoba because of small variations in precipitation between weather stations.

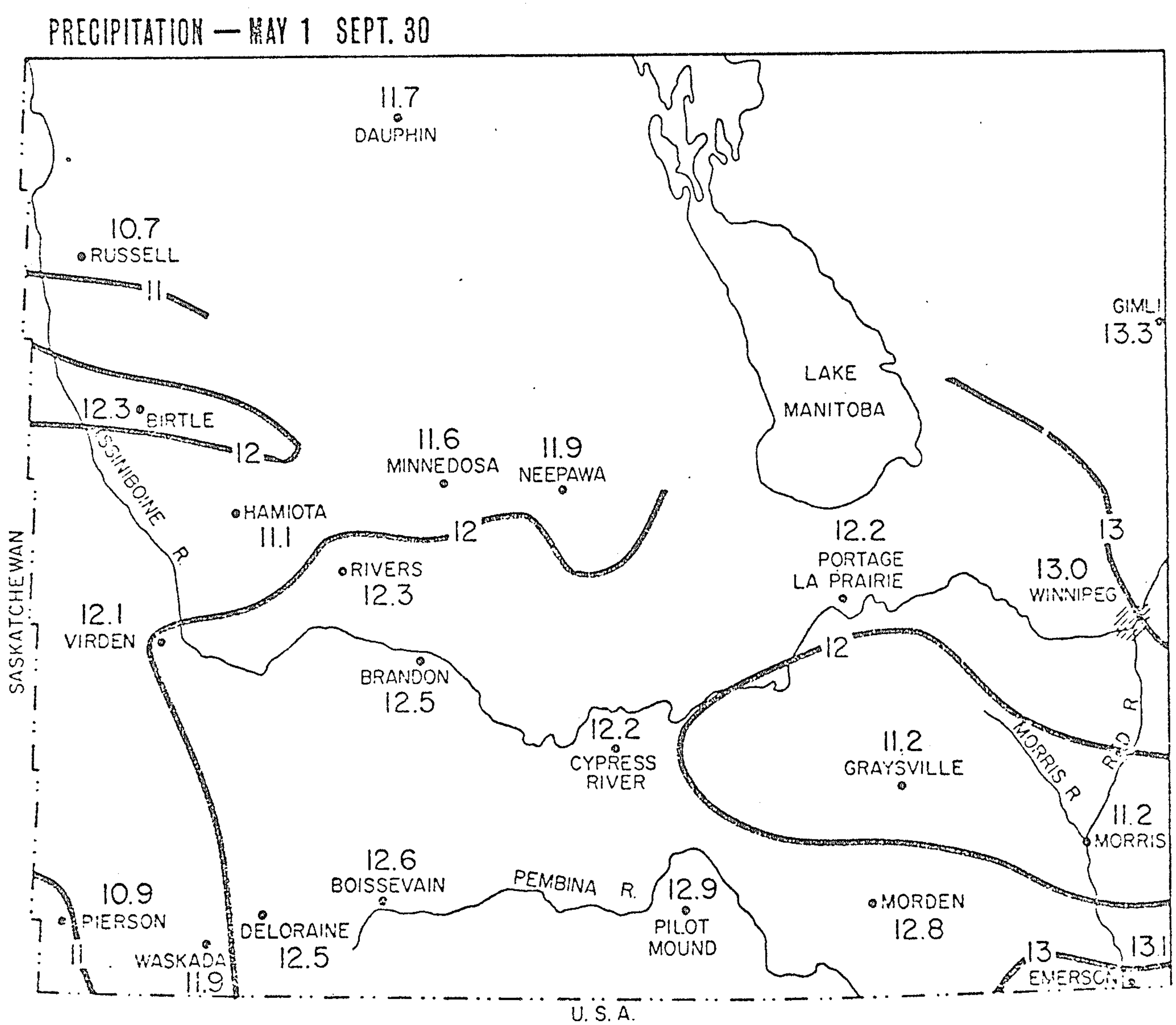

Figure 1. Long term average precipitation for southern Manitoba. (from C.F. Shaykewich)

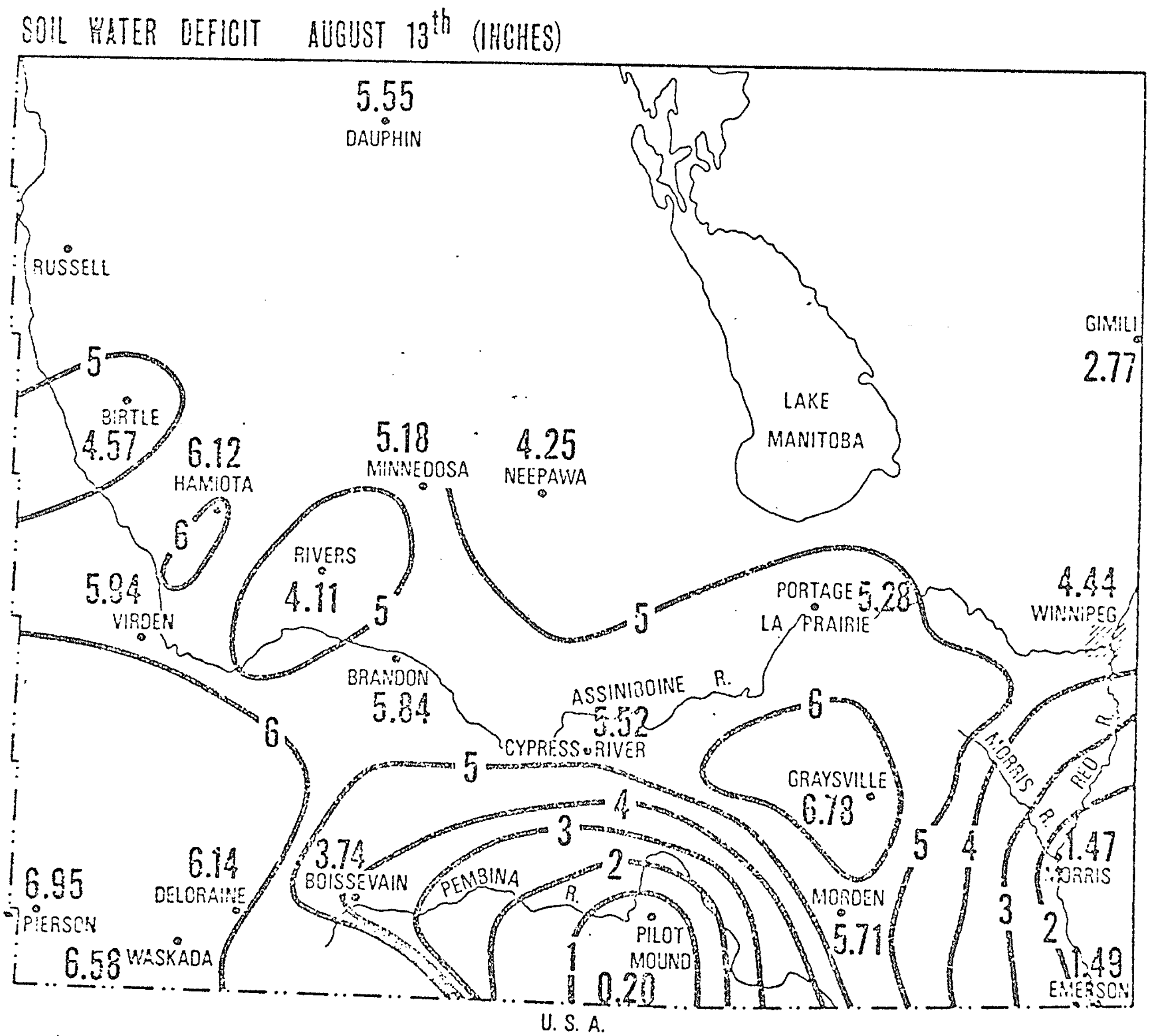

Figure 2. Long term average August 13th soil water deficit for southern Manitoba. (from C.F. Shaykewich)

Possibly for these soils, high potential evapotranspiration was the major reason for lower farm yields. The higher water deficit trend and lower farm yields would support the previous soil classification system whereby these soils were delineated as Dark Brown Steppe-Black Earth transition soils. This zonal classification, based on climate and vegetation, indicated these were the most arid soils in Manitoba.

Factors, other than temperature and precipitation, may be responsible for the lower farm yields. These soils, especially in the rolling and undulating areas, are characterized by eroded knolls which would not be included in a representative soil sample. Probably the knolls would have a lower nutrient status and therefore, would not be expected to yield as high as the more humid parts of the field. These soils also have many shallow potholes and saline areas which, in many cases, the farmer seeds with the field. However, they may not yield as high as other areas of the field. These knolls, potholes, and saline areas, although they probably constitute a small acreage in the field, may lower the bushel per acre yield. Farm management, including such factors as seeding date and weed control may also affect farm yields, however, this was not measured. Considering these factors it was difficult to determine the amount, if any, of yield reduction which was due to unfavourable temperature and precipitation. The small plot experiments, on which the prediction equations are based, were located in central and east-central Manitoba. No experiments were conducted on the Waskada or Oxbow soil associations. Until sufficient experiments have been conducted on these soils the results indicate that fertilizer recommendations would be improved in this area by including water deficit was a variable in the yield prediction equations.

(b) Newdale clay loam

Medium water deficit values were calculated for these soils. Farm yields were not significantly different from yields predicted by the L2V, Q2V, and L3VJ equations. The mean predicted yields for the L2V and Q2V were 39.2 and 40.7 bu./ac., respectively, compared to a mean actual yield of 37.6 bu./ac. The L2V equation, with a t value of 0.79, most accurately predicted farm yields in this agronomic soil group. The mean predicted yield of 35.6 bu./ac. for the L3VJ equation was slightly lower than the mean actual yield. The Q3VA, L3VA, and Q3VJ equations predicted yields which were considerably lower than farm yields and therefore did not accurately predict yields. In comparison these three equations were the most accurate in predicting farm yields in the Waskada soil group. It was suggested the actual evapotranspiration was closer to the potential evapotranspiration in the Waskada area, therefore, the equations including a water deficit more accurately predicted farm yields. Conversely, in the Newdale area the actual evapotranspiration was likely considerably lower than the potential evapotranspiration, therefore, farm yields were higher than yields predicted by these equations.

Results of this analysis suggested fertilizer recommendations can be made for the Newdale soils on the basis of soil NO_3-N and fertilizer N variables only, or by a logarithmic model equation which includes a water deficit variable.

(c) Manitou clay loam, Darlingford clay loam, and Snowflake clay loam

The water deficit values calculated for these soils were very low. All equations, except the L2V, predicted yields which were significantly different than actual yields In the previous two soil groups the L2V and Q2V equations predicted yields which were on the average higher than yields predicted from equations which include a water deficit variable. However, in this area, where a low water deficit was calculated mean predicted yields were lower when the equations included soil NO_3-N and fertilizer N variables only. The three agronomic soil groups, Waskada, Newdale, and Manitou had water deficits rated high, medium and low respectively. The mean predicted yields were approximately 32, 33 and 43 bu./ac. respectively compared to mean actual yields of 33.5, 37.6, and 36.4 bu./ac., respectively. Farm yields would appear to rise, then become constant as the water deficit decreases. However, the equations did not measure this accurately. This may be due to inadequate small plot data on soils with a high NO_3-N content.

(2) Complex soils above the escarpment consisting of:

(a) Heaslip

Wheat yields for these soils were significantly different than yields predicted from all equations. The August 13th water deficit equations, however, predicted yields closest to farm yields. These equations had a mean predicted yield of approximately 35.5 bu./ac. compared to a mean actual yield of 30.5 bu./ac. A mean predicted yield of 35.5 bu./ac. was much closer to the farm yield than 40.0 and 41.9 bu./ac. for the L2V and Q2V equations, respectively. Heaslip soils are a water worked till and have a gravelly layer 0 to 24 inches below the surface. This restricts root penetration and moisture flow and causes a possible change in moisture use by crops. These soils are found in an area adjacent to the Waskada-Oxbow soils which indicates the medium water deficit calculated for these soils may have been too low.

(3) Lacustrine and outwash soils above the escarpment consisting of:

(a) Souris sand to loam

Yield data from farms in this agronomic

group were limited. Only 11 farm yields were selected. The water deficit values calculated for these soils were bery high. Even though the data sample was small it indicated that a measure of water deficit was required in order to predict farm yield. This was consistant with the results of the Waskada-Oxbow soil group which occurs in an adjacent area.

(b) Stockton loamy sand to sandy loam, Miniota sandy loam, and Marringhurst sandy loam

Wheat yields from these soils, which had a medium water deficit, were not significantly different from yield predicted by the Q3VA, L3VA, Q3VJ, and L3VJ equations. The mean actual yield of 31.5 bu./ac. was generally 2.0 to 2.6 bu./ac. lower than the mean predicted yields. However, for equations, Q2V and L2V, the mean actual yield was 4 to 5 bu./ac. lower than the mean predicted yields. Due to the inherent lower water holding capacity of well drained sandy soils it was not surprising that wheat yields in these areas were lower and were more accurately predicted when a measure of water deficit was included in the yield prediction equations.

(c) Carrol clay loam, Holland very fine sandy loam to clay loam, Glenboro very fine sandy loam to clay loam, and Wellwood clay loam

A low to medium water deficit was determined for these medium textured soils. Yields predicted by the six equations averaged from 39.0 to 41.9 bu./ac. When compared to actual yields which averaged 33.8 bu./ac., the predicted yields were significantly higher. No explanations are offered which would account for the large difference between actual and predicted yields. The L2V equation showed the lowest *t* value when actual and predicted yields were compared.

(4) Lacustrine and outwash soils below the escarpment consisting of:

(a) Altona sandy loam to loam, Almasippi loamy sand

Data indicated that farm yields on these soils were greater than those predicted by equations including a water deficit factor. A medium water deficit was calculated for these coarse textured soils. The high yields may be due to a relatively high water table resulting from an impervious clay layer below the sands. This would modify the actual water deficit because water deficit, as calculated and used for this study, was based only on surface variables, rainfall, temperature and solar radiation. One hundred and eleven and 80 farm fields were included in the analysis with the equations which included the July and August water deficit factors, respectively. Thirty-one fields were not included in the analysis with the equations which included an August water deficit because these water deficits had increased beyond that calculated for the small plot sites. Excluding the 31 field yield data resulted in an increase in mean farm yield of 2.4 bu./ac. The fields which were removed likely incurred yield reductions due to unfavourable temperature and precipitation. Therefore July 16th may be too early to measure water deficit.

Farm yields, which averaged 39 bu./ac. from 80 observations, were not significantly different than yields predicted by the Q2V and L2V equations. The mean predicted yields were 39.8 and 38.6 bu./ac., respectively. The equations which included the August water deficit factor predicted yields significantly different from the actual yields - on the average predicted yields were too low. For the L3VJ equation, when the mean actual yield dropped to 36.6 bu./ac. for 111 fields, predicted yields were closely related to farm yields. However, yields predicted from the Q3VJ equation were significantly different from actual yields. If farm fertilizer recommendations were to be made for the potential yields indicated by these equations, the L2V,Q2V, and L3VJ equations would give the best results.

(b) Portage very fine sandy loam to silty clay, Riverdale silty clay, Sperling loam, Oakville silty clay loam to clay loam, Gladstone sandy loam to silty clay, and Firdale loamy sand to clay loam

These soils had a medium (one to six inches) water deficit. The t values indicated actual wheat yields were not significantly different than yields predicted from all six equations. Compared to mean actual yield of approximately 36 bu./ac., mean predicted yields for the L2V and Q2V equations were slightly higher, and for the Q3VJ, L3VJ, Q3VA, and L3VA were lower.

(c) Red River clay, Gretna clay, Marquette clay to clay loam, Morden loam to clay, Fort Garry clay, Emerson silty loam to silty clay, Semple clay loam to clay, Myrtle loam to clay, Morris clay, Peguis clay, Rathwell clay loam to clay, Westbourne clay, and Horndean clay.

Wheat yields in these imperfect to poorly drained clay soils were not significantly different from yields predicted by the Q3VA and L3VA equations. Mean predicted yields of 32.0 and 31.9 bu./ac., respectively, were very close to the mean actual yield of 32.8 bu./ac. The July water deficit equations predicted yields which averaged approximately 36 bu./ac. while the mean predicted yields from the L2V and Q2V equations were higher at 37.7 and 38.9 bu./ac., respectively.

The clay textured soils of the Red River Valley have a medium calculated water deficit. This, combined with the high water retention capacity of clay soils,suggested farm yields should be high and would be accurately predicted from NO_3 -N and fertilizer N only.

However, farm yields were best described with the August water deficit factor included in the yield prediction equations. Throughout the analysis for the other agronomic soil groups the August water deficit equations have predicted, on the average, yields from 31 to 36 bu./ac. The L2V and Q2V equations had mean predicted yields from 36 to 41 bu./ac. Farm yields on these clay soils were approximately equal to those predicted by the equations including a water deficit. Farm yields were lower than yields predicted from the equations including NO_3-N and fertilizer N variables only. This is consistent with the work of Paul and Meyer (1970) who have shown that wheat yields on clay soils were significantly lower with low compared to medium soil moisture stress. Campbell *et al.* (1969) increased wheat yields significantly by improving soil aeration in clay loam soils with a low soil moisture stress. Reduced yields on these clay soils may be due more often to excess water resulting in poor soil aeration than higher actual or potential evapotranspiration. However, the August water deficit equations predicted yields which were not significantly different than the actual yields; therefore, if fertilizer recommendations were made for these soils by the use of the yield prediction equations studied the Q3VA or the L3VA equation would best describe farm yields.

(d) Dauphin clay, Edwards silty loam to silty clay

The number of observations for these soils was low, thus the accuracy of yield prediction was low. In addition, the August water deficit values for these farm fields was outside the water deficit range of the experimental small plot data. The analysis, however, showed farm yields in the area were not significantly different from yields predicted by the Q3VA and L3VA equations. The L2V and Q2V equations predicted yields which averaged 7 to 8 bu./ac. higher than the mean actual yields. Indications were the inclusion of the August 13th water deficit in the yield prediction equations improved the relationship between actual and predicted yields.

Small plot wheat experiments, on which the yield prediction equations were based, were conducted on six soil associations, Almasippi, Altona, Manitou, Newdale, Red River, and Wellwood. The first four associations made up approximately 70 per cent of the total observations. It is significant that farm yields on these soils were accurately predicted by equations, including soil NO_3-N and fertilizer N variable only. With the exception of Red River, the agronomic soil groups where the water deficit factor was required in the equations in order to accurately predict farm yields had no soil associations where small plot experiments had been conducted. This would indicate yield potentials under "favourable climate" were accurately measured by small plot experiments. By growing crops "favourable climate" was reflected in the yields produced; thus a climatic factor, i.e. water deficit, was not required. However, the water deficit factor improved considerably, the accuracy of farm yield prediction when attempting to extrapolate small plot yields to many areas of Manitoba.

B. Relationship Between Actual Farm and Predicted Yields of Barley and Oats

Farm yields of barley and oats were compared to predicted yields using the procedure as outlined for wheat. Farm yields that had sustained moderate or severe crop damage were removed from the data set. The equations used for the barley and oat study were derived from small plot barley data. It was assumed that oats and barley yields were similar when expressed in lb./ac. The equations predicted barley yields in bu./ac.; therefore, when the equations were used to predict oat yields, the barley yields predicted were multiplied by the bushel weight conversion factor of 1.41 giving an oat yield in bu./ac. For example, given a farm yield with 30 lb./ac. soil NO_3-N, 30 lb./ac. fertilizer N added and a yield of 69 bu./ac. oats, a yield would be predicted in the following manner:

(1) Use the quadratic barley yield prediction equation (Table I, equation [4])

(2) Barley yield predicted = 56 bu./ac.

(3) Assume barley yield (lb./ac.) = oat yield (lb./ac.)

(4) To convert barley yield in bu./ac. to oat yield in bu./ac. use the ratio of their bushel weights $\frac{48 \text{ lb./bu.}}{34 \text{ lb./bu.}} = 1.41$. Therefore the predicted oat yield = 56 x 1.41 = 79 bu./ac.

(5) Thus the farmer achieved 69 bu./ac. compared to a 79 bu./ac. predicted yield.

For the following results and discussion of oats and barley the yield prediction equations were adjusted for oats.

Barley and oat farm yields were compared to yields predicted by a quadratic and two logarithmic equations (Table I, equations [4], [6], and [7]). The logarithmic equations were similar except fertilizer nitrogen was expressed in a linear manner in equation [6] and in a quadratic manner in equation [7]. The yields predicted from equation [6] and [7] were very similar, therefore, the term "logarithmic equations" in the following results and discussion refers to the results of both equations. The results of the comparison of actual and predicted yields are shown in Tables XI and XII for barley and oats, respectively.

Farm yields of barley and oats from 1967 to 1970 were significantly different from yields predicted by the quadratic and the logarithmic equations. For barley the mean actual yield of 48.7 bu./ac. was 10 to 12 bu./ac. lower than predicted yields. Similarly for oats the mean actual yield of 67.0 bu./ac. was 15 to 17 bu./ac. lower than the predicted yields. For both crops the quadratic equations predicted slightly lower yields than the logarithmic equations. However, the analysis of farm yields of barley and oats showed the prediction equations used did not adequately predict farm yields.

Crop yields may vary from year to year, therefore, the farm data was examined by years and these yields were compared to yields predicted by the quadratic and logarithmic equations. Mean farm yields showed a large yearly variation compared to relatively constant mean predicted yields. This was consistent with the mean farm yields for wheat. For

TABLE XI Comparison of Farm Barley Yields to Yields Predicted by a Quadratic and two Logarithmic Equations[1]

Equation	Data Group	No. of Farm Yields	$\bar{x}$ Actual (bu./ac.)	$\bar{x}$ Predicted (bu./ac.)	Paired t Value	St. Dev. of the Difference (bu./ac.)	Number of Predicted Yields Above Actual	Below Actual
4	All Data 1967-1970	401	48.7	59.2	17.2*	12.2	72	329
	1967	108	42.8	58.8	15.5*	10.7	6	102
	1968	141	51.5	59.2	7.95*	11.6	35	106
	1969	65	55.8	59.5	2.45*	12.2	23	42
	1970	87	46.3	59.5	10.8*	11.4	8	79
6	All data 1967-1970	401	48.7	61.5	20.7*	12.4	59	342
	1967	108	42.8	61.6	17.6*	11.0	6	102
	1968	141	51.8	61.3	10.1*	11.7	27	114
	1969	65	55.8	60.7	3.35*	11.8	20	45
	1970	87	46.3	62.3	13.5*	11.1	6	81
7	All data 1967-1970	401	48.7	61.2	20.2*	12.3	61	340
	1967	108	42.8	61.5	17.9*	10.9	6	102
	1968	141	51.8	61.0	9.79*	11.5	27	114
	1969	65	55.8	60.3	3.08*	11.8	21	44
	1970	87	46.3	61.8	13.1*	11.0	7	80

*Significantly different at p=0.05.
[1] Equations [4], [6], [7] (Table 1)

TABLE XII Comparison of Farm Oat Yields to Yields Predicted by a Quadratic and Two Logarithmic Equations[1]

Equation	Data Group	No. of Farm Yields	$\bar{x}$ Actual (bu./ac.)	$\bar{x}$ Predicted (bu./ac.)	Paired t Value	St. Dev. of the Difference (bu./ac.)	Number of Predicted Yields Above Actual	Number of Predicted Yields Below Actual
	All data 1967-1970	266	67.0	81.8	14.0*	17.3	49	217
4	1967	84	57.2	81.9	14.9*	15.2	6	78
	1968	123	72.5	82.4	6.87*	-	30	93
	1969	46	72.9	80.3	3.24*	15.4	13	33
	1970	13	57.3	81.5	5.46*	16.0	0	13
	All data 1967-1970	266	67.0	84.6	16.3*	17.6	43	223
6	1967	84	57.2	85.0	16.4*	15.5	6	78
	1968	123	72.5	84.8	8.49*	16.1	25	98
	1969	46	72.9	82.7	4.45*	14.9	12	34
	1970	13	57.3	86.1	6.11*	17.0	0	13
	All data 1967-1970	266	67.0	84.4	16.3*	17.4	43	223
7	1967	84	57.2	85.1	16.5*	15.4	6	78
	1968	123	72.5	84.5	8.42*	15.9	25	98
	1969	46	72.9	82.5	4.38*	14.9	12	34
	1970	13	57.3	85.3	6.21*	16.2	0	13

*Significantly different at $p=0.05$.
[1]Equations [4], [6], and [7] (Table I) modified to predict oat yields.

barley, mean farm yields ranged from 42.8 bu./ac. in 1967 to 55.8 bu./ac. in 1969. The largest seasonal variation in oat yields also occurred in these years, from 57.2 bu./ac. in 1967 to 72.9 bu./ac. in 1969. Over the four year period mean predicted yields for barley and oats were relatively constant at approximately 60 and 83 bu./ac., respectively.

There were two major limitations with these equations. The first was their inability to accurately predict farm yields, especially when farm yields were low. The second was their inability to account for yearly variations in farm yields.

In an attempt to account for this yearly variation, which may have been caused by climate, the water deficit factor was introduced into yield prediction equations (Table XIII) and the data was analysed using the same procedures as were conducted with the farm wheat data.

Yields of barley predicted by equations including a water deficit factor and also by equations without the water deficit factor are shown in Table XIII. At 3, 0, and -3 and 1, -1, and -3 inch water deficit on August 13th and July 16th, respectively, the yields predicted by all equations were similar, irrespective of the water deficit factor. However, at all nitrogen levels the highest yields were predicted with the highest water deficit, which was unexpected. High water deficit measurements indicate potential evapotranspiration was high and/or precipitation

TABLE XIII Barley* Yields in Bushels per Acre Predicted by Several Equations at Various Nitrogen and Water Deficit Levels.

		NO$_3$-N - Fertilizer N (lb./ac.)					
Equation	Water Deficit (inches)	10-0	10-40	10-80	30-0	30-40	60-0
	9	48	62	73	62	75	76
	6	40	55	67	54	68	67
Q3VA	3	36	52	64	49	60	61
	0	35	52	65	47	63	58
	-3	38	55	69	49	66	59
	5	50	64	75	61	75	70
	3	40	55	67	52	66	61
Q3VJ	1	35	51	63	48	62	57
	-1	34	51	64	47	62	57
	3	38	55	69	51	67	61
Q2V		36	53	68	49	64	60
	9	49	61	68	61	69	69
	6	43	57	66	58	67	66
L3VA	3	39	55	64	55	65	64
	0	37	54	64	54	64	64
	-3	37	55	65	54	65	64
	5	54	64	70	64	71	69
	3	44	57	65	57	66	64
L3VJ	1	37	53	63	53	63	61
	-1	35	53	63	53	64	62
	3	40	57	66	57	67	65
L2V		38	55	64	55	65	64

*Note: oat yields = 1.41(barley yields)

was low, therefore, it is likely barley yield would be reduced. The equations, however, suggested the yields were increased under these conditions. No explanation was offered for the effect water deficit had on predicted yield for barley.

Farm data analyses are shown in the Appendix (A11 to A18). Normally as precipitation increases and potential evapotranspiration decreases, water deficit decreases. Barley yield would be expected to increase unless the soils became saturated. This would be consistent with wheat yield prediction equations which included the water deficit factor. For barley, yearly variations in farm yields, which were attributed to climate, were not improved with the inclusion of a water deficit factor. Further study is necessary to develop a water deficit value or other measures of climate to improve the barley yield prediction equations.

Farm yield data was examined when it was arranged in agronomic soil groups to determine if barley and oat yield within these areas could be predicted. Due to the limited number of farm yield data for these crops some soil groups had less than 10 farm yields and were therefore not included in this discussion.

With the exception of the quadratic equation on the Manitou soil group, the equations (Table I, Equations [4], [6], and [7]) did not adequately predict yields of barley (Table XIV). The Manitou soil group had a mean actual

TABLE XIV Effect of Agronomic Soil Groups on the Accuracy of Farm Yield Predictions for Barley and Oats[1]

Crop	Soil Grouping	No. of Farm Yields	$\bar{x}$ Actual bu./ac.	Regression Equation 4: $\bar{x}$ pred bu./ac.	4: paired t Value	4: St. Dev. of the Difference bu./ac.	Regression Equation 6: $\bar{x}$ pred bu./ac.	6: paired t Value	6: St. Dev. of the Difference bu./ac.	Regression Equation 7: $\bar{x}$ pred bu./ac.	7: paired t Value	7: St. Dev. of the Difference bu./ac.
barley	1a. Waskada	24	44.8	57.7	3.82*	16.5	61.2	4.89*	16.4	60.6	4.7*	16.5
	b. Newdale	37	47.8	58.9	5.82*	11.6	61.7	7.40*	11.5	61.3	7.13*	11.6
	c. Manitou	23	57.8	61.9	1.46	13.5	63.2	1.77*	14.6	62.8	1.66*	14.4
	3c. Carrol	26	49.0	57.7	3.76*	11.7	60.4	5.31*	10.9	59.9	4.99*	11.1
	4a. Altona	66	49.0	59.0	6.52*	12.6	60.4	7.85*	12.3	60.2	7.51*	12.2
	b. Portage	46	50.7	58.4	4.12*	12.6	60.1	5.24*	12.2	59.8	5.05*	12.3
	c. Red River	78	46.4	59.8	10.1*	11.8	61.9	11.5*	12.0	61.7	11.4*	11.9
oats	1a. Waskada	17	55.7	80.5	7.06*	14.5	83.5	7.48*	15.3	83.4	7.53*	15.1
	c. Manitou	12	76.7	87.0	2.12*	17.0	90.4	2.68*	17.8	90.0	2.61*	17.7
	3a. Souris	11	66.6	82.7	4.34*	12.3	86.7	5.60*	11.9	86.5	5.55*	11.86
	4a. Altona	80	70.8	81.7	6.47*	15.1	83.9	7.47*	15.7	83.8	7.51*	15.5
	b. Portage	14	76.1	79.6	0.64	20.6	83.0	1.30	19.9	83.0	1.29	20.0
	c. Red River	53	64.2	82.1	7.99*	16.3	85.1	9.26*	16.4	84.8	9.16*	16.4

* Significantly different at $p=0.05$.
[1] Oats yield (bu./ac.) = 1.41 (barley yield (bu./ac.))

yield of 57.8 bu./ac. compared to a mean predicted yield of 61.9 bu./ac. using the quadratic equation. The other soil groups had mean actual yields of approximately 45 to 50 bu./ac. which were 10 to 15 bu./ac. lower than their mean predicted yield.

Mean actual yields of oats reported by farmers varied considerably. Yields of oats ranged from 55.7 bu./ac. in the Waskada soil group to 76.7 bu./ac. in the Manitou soil group. With the exception of the Portage soil group, farm yields of oats were significantly different from yields predicted by the quadratic and logarithmic equations.

In general, the farm yields of barley and oats were considerably lower than the predicted yields. This may be due, in part, to yearly climatic variations and soil characteristics. However, experimental data from 1962 to 1970 indicated high yields were possible.

Wheat yields were relatively well described by the yield prediction equations. With a few exceptions this was not consistent for barley and oats. Therefore, in relation to the potential yield of the crop as suggested by their prediction equations, wheat yields were generally higher than yields of oats and barley. This was likely due to better management of wheat than barley and oats. In the past, wheat has been the most important crop grown by farmers. It most frequently was grown on fallowed land, and therefore had a preferential position in the crop sequence compared to barley and oats, which were often grown on stubble. This suggests that better management would improve barley and oats yields to a greater extent than wheat yields. However, yearly climatic variations must be measured by the yield prediction equations before farm yield for oats and barley can be predicted with consistency.

SUMMARY AND CONCLUSIONS

Small plot research had indicated that plant uptake of nitrogen and yields obtained were related to soil NO_3-N content and fertilizer N applied. The M.P.S.T.L. developed logarithmic and quadratic yield prediction equations using a measure of soil NO_3-N and fertilizer N applied. Sufficient farm yield data was available from the records of the M.P.S.T.L. to compare yields farmers obtained with predicted yields. However, it is generally recognized that many factors influence yield. One factor, i.e. climate, can be expressed as water deficit. Therefore, water deficit was introduced as a third variable in the yield prediction equations.

Farm yields of wheat, oats, and barley were not adequately predicted when soil NO_3-N and fertilizer N were the only variables included in the equations. Examination of data by years indicated that the mean actual yields were extremely variable compared to relatively constant mean predicted yields. Total nitrogen supply recommended for crops should have resulted in uniform yields, therefore, the variability in farm yields was presumed to be due to variations in climate. A water deficit factor was introduced as a third variable in the yield prediction equations as a measure of climate. Water deficit increased as potential evapotranspiration increased and precipitation decreased. Predicted yields and farm yields were expected to decrease with increasing water deficit. As the water deficit decreased predicted wheat yields increased. However, for barley the water deficit equations indicated that highest yields were predicted at the highest water deficit levels. Yields decreased until a medium water deficit was reached, then remained constant through the lower water deficit levels. No explanation is suggested for this trend. This yearly variation in farm yields of barley and oats was not explained.

Farm wheat yields, when examined as one data group, were accurately predicted by the equations which included a water deficit variable. However, when data were examined by years farm yields were accurately predicted in 1967 and 1968 but were generally lower than predicted yields in 1969 and 1970. For 1969 and 1970 the equations which included the water deficit variables predicted farm yields more accurately than equations which included soil NO_3-N and fertilizer N only. Thus, the water deficit factor should be a major consideration for inclusion in prediction equations.

Farm yield data were examined for agronomic soil groups and the accuracy of farm yield prediction equations was determined. The results for wheat showed that no single type of prediction equation was best for all soil groups. This suggests that fertilizer recommendations should be made using two types of prediction equations:

(1) Equations which include NO_3-N and fertilizer N variables. Agronomic groups which are best predicted by these equations are:

(a) Well drained, medium textured, till and lacustrine soils with a low to medium water deficit. These soils are located above the escarpment in central, west-central, and south-central Manitoba.

(b) Imperfectly drained coarse and medium textured, medium water deficit soils located below the escarpment in the Manitoba lowlands.

(2) Equations which include NO_3-N, fertilizer N, and water deficit variables. Agronomic groups which are best predicted by these equations are:

(a) Well drained, medium textured, high water deficit till soils; complex soils; and imperfectly drained, coarse-textured, high water deficit lacustrine soils located above the escarpment in south-western Manitoba.

(b) Well drained, coarse textured, medium water deficit outwash soils located above the escarpment in central and west-central Manitoba.

(c) Imperfect to poorly drained, fine textured medium water deficit lacustrine soils located below the escarpment in the Manitoba lowlands.

(d) Imperfectly to poorly drained, fine textured, medium water deficit lacustrine and alluvial soils of the northern portion of the agricultural area of Manitoba.

When examined by agronomic soil groups farm yields of barley and oats also showed considerable yield variation. With the exception of barley in the Manitou soil group and oats in the Portage soil group, farm yields were not adequately predicted using equations including soil NO_3-N and fertilizer N variables only.

The conclusions are:

(1) In general, the best types of equation for predicting yields of wheat were the quadratic and logarithmic equations which included a water deficit factor. However, logarithmic equations which did not include a water deficit

factor adequately predicted farm yields for areas other than southwestern Manitoba and fine textured soils of the Red River Valley. The logarithmic equation model which includes NO_3-N and fertilizer N variables only is the model used by the M.P.S.T.L.

(2) Farm yield variations occurred which could not be explained totally by soil NO_3-N and fertilizer N. Further study of the effect of climate, i.e., water deficit could account for yield variations.

(3) Yield prediction equations generally did not accurately describe farm yields of oats and barley. Furthermore, predicted yields were generally further from actual yields when a water deficit factor was included in the yield prediction equations.

(4) Farmers did not achieve yields of barley and oats that these yield prediction equations indicated. This may be due to better management on small plots than farmers provide for fields of barley and oats.

REFERENCES CITED

Alkier, A.C. 1972. The effect of nitrogen supply on the protein content of Neepawa wheat. M.Sc. Thesis, The University of Manitoba, Winnipeg.

Baier, W. and Robertson, G.W. 1965. Estimation of latent evaporation from simple weather observations. Can. J. Plant Sci. 45: 276-284.

Baier, W. and Robertson, G.W. 1967. Estimating supplemental irrigation water requirements from climatological data. Can. Agr. Eng. 9:46-50.

Bauer, A., Young, R.A., Ozbun, J.L. 1964. Effects of moisture and fertilizer on yields of spring wheat and barley. Agron. J. 57: 354-356.

Campbell, C.A., McBean, D.S., and Green, D.G. 1969. Influence of moisture stress, relative humidity, and oxygen diffusion rate on seed set and yield of wheat. Can. J. Plant Sci. 49: 29-37.

Cook, F.D., Warder, F.G., and Doughty, J.L. 1957. Relationship of nitrate accumulation to yield response of wheat in some Saskatchewan soils. Can. J. Soil Sci. 37: 84-88.

Day, A.D. and Intalap, S. 1970. Some effects of soil moisture stress on growth of wheat (*Triticum aestivum* L. em Thell.). Agron. J. 62: 27-29.

DeJong, E. and Rennie, D.A. 1969. Effect of soil profile type and fertilizer on moisture use by wheat grown on fallow or stubble land. Can. J. Soil Sci. 49: 189-198.

Dubetz, S. 1960. Effect of soil type, soil moisture, and nitrogen fertilizer on the growth of spring wheat. Can. J. Soil Sci. 41: 44-51.

Ehrlich, W.A., Poyser, E.A., and Pratt, L.E. 1957. Report of Reconnaissance Soil Survey of Carberry Map Sheet Area.

Ehrlich, W.A., Poyser, E.A., Pratt, L.E., and Ellis, J.H. 1953. Report of Reconnaissance Soil Survey of Winnipeg and Morris Map Sheet Areas.

Ehrlich, W.A., Pratt, L.E., and Leclaire, F.P. 1959. Report of Reconnaissance Soil Survey of Grandview Map Sheet Area.

Ehrlich, W.A., Pratt, L.E., and Poyser, E.A. 1956. Report of Reconnaissance Soil Survey of Rossburn and Virden Map Sheet Areas.

Ehrlich, W.A., Pratt, L.E., Poyser, E.A., and Leclaire, F.P. 1958. Report of Reconnaissance Soil Survey of West-Lake Map Sheet Area.

Ellis, J.H. and Shafer, W.H. 1940. Reconnaissance Soil Survey South Western Manitoba.

Ellis, J.H. and Shafer, W.H. 1943. Report of Reconnaissance Soil Survey of South Central Manitoba.

Fehr, P.I. 1971. Interpretation of your soil test recommendation. University of Manitoba, Provincial Soil Testing Laboratory.

Gasser, J.K.R. and Williams, R.J.B. 1963. Soil Nitrogen. VII. Correlations between measurements of nitrogen status of soils and nitrogen % and nitrogen content of crops. J. Sci. Fd. Agr. 14: 269-277.

Geist, J.M., Reuss, J.O., and Johnson, D.D. 1970. Prediction of nitrogen fertilizer requirements of field crops. II. Application of theoretical models to malting barley. Agron. J. 62: 358-390.

Harper, H.J. 1924. The accurate determination of nitrates in soils. Ind. Eng. Chem. 16: 180-183.

Herron, G.M., Terman, G.L., Drier, A.F., and Olson, R.A. 1968. Residual nitrate nitrogen in fertilized deep loess-derived soils. Agron. J. 60: 477-481.

Hutcheon, W.L. and Paul, E.A. 1966. Control of the protein content of Thatcher wheat by nitrogen fertilization and moisture stress. Can. J. Soil Sci. 46: 101-108.

Lehane, J.J. and Staple, W.J. 1962. Effects of soil moisture tensions on growth of wheat. Can. J. Soil Sci. 42: 180-188.

Lehane, J.J. and Staple, W.J. 1965. Influence of soil texture, depth of soil profile, and rainfall distribution on wheat yields in southwestern Saskatchewan. Can. J. Soil Sci. 45: 207-219.

Luebs, R.E. and Laag, A.E. 1969. Evapotranspiration and water stress of barley with increased nitrogen. Agron. J. 61: 921-924.

Nuttall, W.F., Zandstra, H.G., and Bowren, K.E. 1971. Exchangeable ammonium- and nitrate-nitrogen related to yields of Conquest barley grown as second or third crop after fallow in northeastern Saskatchewan. Can. J. Soil Sci. 51: 371-378.

Partridge, J.R.D. 1971. The effects of nitrogen, temperature, and moisture regime on the yield and protein content of Neepawa wheat. M.Sc. Thesis, The University of Manitoba, Winnipeg.

Paul, E.A. and Myers, R.J.K. 1971. Effect of soil moisture stress on uptake and recovery of tagged nitrogen by wheat. Can. J. Soil Sci. 51: 37-43.

Peterson, L.A. and Attoe, O.J. 1965. Importance of soil nitrogen in determination of need and recovery of fertilizer nitrogen. Agron. J. 57: 572-574.

Robins, J.S. and Domingo, C.E. 1962. Moisture and nitrogen effects on irrigated spring wheat. Agron. J. 54: 135-138.

Salisbury, F.B. and Ross, C. 1969. Plant Physiology. Wadsworth Publishing Co., Inc., Belmont, Calif. pp. 277-348.

Soper, R.J. 1971. Soil tests as a means of predicting response of rape to added N, P. and K. Agron. J. 63: 564-566.

Soper, R.J. and Huang, P.M. 1963. The effect of nitrate nitrogen in the soil profile on the response of barley to fertilizer nitrogen. Can. J. Soil Sci. 43: 350-358.

Soper, R.J., Racz, G.J., and Fehr, P.I. 1971. Nitrate nitrogen in the soil as a means of predicting the fertilizer nitrogen requirements of barley. Can. J. Soil Sci. 51: 45-49.

Sosulski, F.W., Lin, D.M., and Paul, E.A. 1966. Effect of moisture, temperature, and nitrogen on yield and protein quality of Thatcher wheat. Can. J. Plant Sci. 46: 583-588.

Synghal, K.N., Toogood, J.A., and Bentley, C.F. 1959. Assessing nitrogen requirements of some Alberta soils. Can. J. Soil Sci. 39: 120-128.

Voss, R.E., Hanway, J.J., and Fuller, W.A. 1970. Influence of soil, management, and climatic factors on the yield response by corn (*Zea mays* L.). Agron. J. 62: 736-740.

Young, R.A., Ozbun, J.L., Bauer, A., and Vasey, E.H. 1967. Yield response of spring wheat and barley to nitrogen fertilizer in relation to soil and climatic factors. Soil Sci. Soc. Am. Proc. 31: 407-410.

APPENDIX

Table A1(a) M.P.S.T.L. Information Sheet for Soil Samples.

CHECK (√) ANALYSIS REQUIRED:
- ( ) NITROGEN ONLY ($4.00 PER FIELD)
- ( ) COMPLETE - INCLUDES NITROGEN, PHOSPHORUS, POTASSIUM, PH, SALINITY AND LIME ($6.00 PER FIELD)

PROVINCIAL SOIL TESTING LABORATORY

c/o Department of Soil Science, University of Manitoba
Winnipeg 19, Manitoba
INFORMATION SHEET FOR FARM AND GARDEN SOILS

INSTRUCTIONS ON THE BACK

NAME: ______________ (print clearly) P.O. or R.R. ______________ (print clearly) TOWN or CITY ______________ (print clearly)

RECEIPT NO. ______

NOTE: THIS INFORMATION MUST BE SUPPLIED FOR EACH FIELD SAMPLED. READ SOIL TESTING BULLETIN BEFORE SAMPLING.

FOR LAB USE ONLY

LAB NO. ______ CLIENT NO. ______

SOIL TYPE NO. ______ N.D.S. ______

DISTRIBUTOR NO. ______

FIELD PLAN OF SAMPLED AREA

N / S / E / W

NW QT. - 1	NE QT. - 2
SW QT. - 4	SE QT. - 8

SECTION A - FIELD AND SOIL DATA

AGRIC. REP. AREA (SEE CODE)	FIELD NUMBER	QT. (SEE CODE)	SEC.	TWP.	RGE.	W. OR E. OF MERIDIAN	RIVER LOT? (IF YES, GIVE NUMBER)	CROP TO BE GROWN (SEE CODE)	TOPOGRAPHY (FLAT, ROLLING, ETC.) (CIRLCE A NUMBER)	DRAINAGE GOOD, FAIR, ETC. (CIRLCE A NUMBER)	NO. OF PLACES SAMPLED	SAMPLED AREA (ACRES)	MONTH OF SAMPLING (01 FOR JAN., ETC.)
						1 WEST	1 NO	1ST CHOICE	1 FLAT	1 EXCESSIVE			
						2 EAST	2 YES	2ND CHOICE	2 ROLLING	2 GOOD			
								3RD CHOICE	3 HILLY	3 FAIR			
										4 POOR			

CODES ARE LISTED ON BACK

RIVER LOT # ______

PARISH ______

SECTION B - CROPPING HISTORY OF PAST YEAR

CROP YEAR	CROP OR FALLOW PRACTICE (SEE CODE)	YIELD PER ACRE	DAMAGE (CIRCLE A NUMBER)	CAUSE OF DAMAGE (IF ANY) (CIRCLE A NUMBER OPPOSITE CAUSE)		NUTRIENTS APPLIED: NITROGEN LB. PER ACRE.	NUTRIENTS APPLIED: PHOSPHATE LB. PER ACRE	NUTRIENTS APPLIED: POTASH LB. PER ACRE	APPLIED ACCORDING TO PREVIOUS SOIL TEST RESULTS	MANURED (CIRCLE A NUMBER)
19		BU. OR	1 NONE	1 HAIL	4 EXCESS MOISTURE	(N)	(P_2O_5)	(K_2O)	1 NO	1 NO
		TONS OR	2 LIGHT	2 FROST	5 DISEASE				2 YES	2 IN FALL OF CROP YEAR
		CWT	3 MEDIUM	3 DROUGHT	6 OTHER					3 IN SPRING OF CROP YEAR
			4 SEVERE							

CODES ARE LISTED ON BACK

OR

KIND AND AMOUNT OF FERTILIZER USED:
(I.E. 11-48-0 AT 60 LBS. PER ACRE
PLUS 120 LBS. PER ACRE OF 33½-0-0)

____

____

WAS CROP LISTED IN SECTION B
SEEDED ON: - FALLOW OR BREAKING ☐
- OTHER ---------------------- ☐

TABLE A2 Comparison of Farm Wheat Yields to Yields Predicted by the Q2V and L2V Equations

Equation	Data Group	No. of Farm Yields	$\bar{x}$ Actual (bu./ac.)	$\bar{x}$ Predicted (bu./ac.)	Paired t Value	St. Dev. of the Difference (bu./ac.)	Predicted Actual: Above Actual	Predicted Actual: Below Actual
Q2V	All data 1967-1970	396	34.7	39.5	12.1*	8.0	285	111
	1967	96	32.2	39.0	9.82*	6.8	80	16
	1968	206	37.1	40.1	5.62*	7.7	131	75
	1969	63	33.7	38.3	4.46*	8.3	47	16
	1970	30	28.0	39.9	7.85*	8.3	26	4
L2V	All data 1967-1970	396	34.7	38.3	9.08*	7.9	264	132
	1967	96	32.2	37.7	8.06*	6.7	76	20
	1968	206	37.1	38.8	3.23*	7.6	119	87
	1969	63	33.7	37.1	3.49*	8.0	41	22
	1970	30	28.0	38.5	7.30*	7.9	27	3

*Significantly different at $p=0.05$.

TABLE A3 Comparison of Farm Wheat Yields to Yields Predicted by the Q3VA and L3VA Equations

Equation	Data Group	No. of Farm Yields	$\bar{x}$ Actual (bu./ac.)	$\bar{x}$ Predicted (bu./ac.)	Paired t Value	St. Dev. of the Difference (bu./ac.)	Predicted Actual: Above Actual	Predicted Actual: Below Actual
Q3VA	All data 1967-1970	396	34.7	34.6	-0.05	9.9	212	184
	1967	96	32.2	31.5	-0.96	10.7	57	39
	1968	206	37.1	36.1	-1.45	10.2	94	112
	1969	63	33.7	36.4	2.75*	8.0	39	24
	1970	30	28.0	32.2	3.43*	6.8	21	9
L3VA	All data 1967-1970	396	34.7	34.6	-0.11	8.7	208	188
	1967	96	32.2	30.7	-1.57	9.3	51	45
	1968	206	37.1	36.2	-1.60	8.5	95	111
	1969	63	33.7	36.4	2.84*	7.8	38	25
	1970	30	28.0	32.7	3.92*	6.6	23	7

*Significantly different at $p=0.05$.

TABLE A4 Comparison of Farm Wheat Yields to Yields Predicted by the Q3VJ and L3VJ Equations

Equation	Data Group	No. of Farm Yields	$\bar{x}$ Actual (bu./ac.)	$\bar{x}$ Predicted (bu./ac.)	Paired t Value	St. Dev. of the Difference (bu./ac.)	Predicted Actual Above Actual	Predicted Actual Below Actual
Q3VJ	All data 1967-1970	438	34.2	35.8	3.49*	9.5	265	173
	1967	122	32.0	33.4	1.69	9.5	82	40
	1968	206	37.1	37.2	0.13	9.8	106	100
	1969	64	33.7	37.4	3.71*	8.1	42	22
	1970	46	28.2	33.8	4.64*	8.2	35	11
L3VJ	All data 1967-1970	438	34.2	36.7	6.28*	8.0	278	162
	1967	122	32.0	35.3	4.99*	7.4	88	34
	1968	206	37.1	37.8	1.21	8.1	111	95
	1969	64	33.7	36.3	2.67*	7.9	39	25
	1970	46	28.2	35.6	7.06*	7.1	38	8

* Significantly different at $p=0.05$.

TABLE A5 Comparison of Farm Wheat Yields by Agronomic Soil Group to Yields Predicted by the Q2V Equation

Soil Grouping	No. of Farm Yields	$\bar{x}$ Actual (bu./ac.)	$\bar{x}$ Predicted (bu./ac.)	Paired t Value	St. Dev. of the Difference (bu./ac.)	Predicted Actual: Above Actual	Predicted Actual: Below Actual
1a. Waskada	33	33.8	39.7	4.53*	7.5	25	8
b. Newdale	20	37.8	40.7	1.61	8.2	12	8
c. Manitou	29	36.4	40.5	3.31*	6.7	19	10
2a. Heaslip	21	30.5	41.9	8.84*	5.9	20	1
3a. Souris	-	-	-	-	-	-	-
b. Stockton	15	31.5	36.6	2.66*	7.5	11	4
c. Carrol	39	33.8	40.2	4.53*	8.9	28	11
4a. Altona	80	39.0	39.8	1.00	7.6	46	34
b. Portage	16	36.4	38.9	1.06	9.2	9	7
c. Red River	137	32.8	38.9	9.63*	7.4	110	27
d. Dauphin	-	-	-	-	-	-	-

*Significantly different at $p=0.05$.
-All data excluded due to high farm water deficit on August 13th

TABLE A6 Comparison of Farm Wheat Yields by Agronomic Soil Group to Yields Predicted by the L2V Equation

Soil Grouping	No. of Farm Yields	$\bar{x}$ Actual (bu./ac.)	$\bar{x}$ Predicted (bu./ac.)	Paired t Value	St. Dev. of the Difference (bu./ac.)	Predicted Actual: Above Actual	Predicted Actual: Below Actual
1a. Waskada	33	33.8	38.4	3.63*	7.1	24	9
b. Newdale	20	37.8	39.2	0.79	8.5	11	9
c. Manitou	29	36.4	39.0	2.14*	6.6	17	12
2a. Heaslip	21	30.5	40.0	7.86*	5.6	20	1
3a. Souris	-	-	-	-	-	-	-
b. Stockton	15	31.5	35.8	2.48*	6.8	11	4
c. Carrol	39	33.8	39.0	3.68*	8.8	27	12
4a. Altona	80	39.0	8.0	-0.42	7.8	36	44
b. Portage	16	36.4	37.6	0.56	8.6	8	8
c. Red River	137	32.8	37.7	7.89*	7.3	106	31
d. Dauphin	-	-	-	-	-	-	-

*Significantly different at $p=0.05$.
-All data excluded due to high farm water deficit on August 13th.

TABLE A7 Comparison of Farm Wheat Yields by Agronomic Soil Group to Yields Predicted by the Q3VA Equation

Soil Grouping	No. of Farm Yields	$\bar{x}$ Actual (bu./ac.)	$\bar{x}$ Predicted (bu./ac.)	Paired *t* Value	St. Dev. of the Difference (bu./ac.)	Predicted Actual: Above Actual	Predicted Actual: Below Actual
1a. Waskada	33	33.8	31.4	-1.36	10.4	11	22
b. Newdale	20	37.8	32.5	-2.75*	8.5	4	16
c. Manitou	29	36.4	44.0	5.89*	6.9	24	5
2a. Heaslip	21	30.5	35.1	3.59*	5.9	16	5
3a. Souris	-	-	-	-	-	-	-
b. Stockton	15	31.5	33.5	1.33	5.8	10	5
c. Carrol	39	33.8	41.0	4.53*	9.9	31	8
4a. Altona	80	39.0	35.1	-4.22*	8.3	26	54
b. Portage	16	36.4	32.8	-1.28	11.4	6	10
c. Red River	137	32.8	32.0	-0.90	10.0	79	58
c. Dauphin		-	-	-	-	-	-

*Significantly different at p=0.05.
-All data excluded due to high farm water deficit on August 13th.

TABLE A8 Comparison of Farm Wheat Yields by Agronomic Soil Group to Yields Predicted by the L3VA Equation

Soil Grouping	No. of Farm Yields	$\bar{x}$ Actual (bu./ac.)	$\bar{x}$ Predicted (bu./ac.)	Paired t Value	St. Dev. of the Difference (bu./ac.)	Predicted Actual: Above Actual	Predicted Actual: Below Actual
1a. Waskada	33	33.8	32.1	-1.18	8.7	12	21
b. Newdale	20	37.8	33.8	-2.34*	7.6	4	16
c. Manitou	24	36.4	41.0	3.96*	6.2	20	9
2a. Heaslip	21	30.5	35.8	4.57*	5.4	17	4
3a. Souris	-	-	-	-	-	-	-
b. Stockton	15	31.5	34.1	1.88	5.4	10	5
c. Carrol	39	33.8	39.3	3.77*	9.1	30	9
4a. Altona	80	39.0	35.9	3.57*	7.6	28	52
b. Portage	16	36.4	33.5	-1.22	9.7	6	10
c. Red River	137	32.8	31.9	-1.11	8.9	77	60
c. Dauphin	-	-	-	-	-	-	-

*Significantly different at $p=0.05$.
-All data excluded due to high farm water deficit on August 13th.

TABLE A9 Comparison of Farm Wheat Yields by Agronomic Soil Group to Yields Predicted by the Q3VJ Equation

Soil Grouping	No. of Farm Yields	$\bar{x}$ Actual (bu./ac.)	$\bar{x}$ Predicted (bu./ac.)	Paired t Value	St. Dev. of the Difference (bu./ac.)	Predicted Actual Above Actual	Predicted Actual Below Actual
1a. Waskada	40	32.9	32.3	0.37	9.8	18	22
b. Newdale	20	37.8	32.4	-2.64*	9.1	4	16
c. Manitou	29	36.4	44.6	6.93*	6.3	27	2
2a. Heaslip	22	31.0	36.3	5.43*	5.3	19	3
3a. Souris	8	32.5	30.3	-0.88	7.01	2	6
b. Stockton	15	31.5	33.8	1.53	6.0	11	4
c. Carrol	39	33.8	41.9	5.06*	10.0	32	7
4a. Altona	112	36.6	34.1	-3.02*	8.5	45	67
b. Portage	19	35.7	33.5	-0.955	10.1	8	11
c. Red River	137	32.8	35.6	3.65*	9.0	97	40
c. Dauphin	-	-	-	-	-	-	-

*Significantly different at $p=0.05$.

- All data excluded due to high farm water deficit on July 16th.

TABLE A10 Comparison of Farm Wheat Yields by Agronomic Soil Group to Yields Predicted by the L3VJ Equation

Soil Grouping	No. of Farm Yields	$\bar{x}$ Actual (bu./ac.)	$\bar{x}$ Predicted (bu./ac.)	Paired t Value	St. Dev. of the Difference (bu./ac.)	Predicted Actual: Above Actual	Predicted Actual: Below Actual
1a. Waskada	40	32.9	35.2	1.97	7.5	25	15
b. Newdale	20	37.8	35.6	-1.23	7.9	5	15
c. Manitou	29	36.4	41.9	4.81*	6.1	19	10
2a. Heaslip	22	30.1	37.2	6.40*	5.2	19	3
3a. Souris	8	32.5	36.2	2.05	5.1	6	2
b. Stockton	15	31.5	34.0	1.66	6.0	10	5
c. Carrol	39	33.8	40.3	4.44*	9.2	32	7
4a. Altona	112	36.6	35.9	-0.93	8.1	51	61
b. Portage	19	35.7	34.7	0.48	8.9	8	11
c. Red River	137	32.8	36.3	5.60*	7.3	104	33
c. Dauphin	-	-	-	-	-	-	-

*Significantly different at p=0.05.
-All data excluded due to high farm water deficit on July 16th.

TABLE A11 Comparison of Farm Barley Yields to Yields Predicted by the Q3VJ and L3VJ Equations

Equation	Data Group	No. of Farm Yields	$\bar{x}$ Actual (bu./ac.)	$\bar{x}$ Predicted (bu./ac.)	Paired t Value	St. Dev. of the Difference (bu./ac.)	Predicted Actual: Above Actual	Predicted Actual: Below Actual
Q3VJ	All data 1967-1969	217	50.5	60.6	11.3*	13.3	168	49
	1967	47	42.5	62.9	12.8*	10.9	45	2
	1968	116	51.3	60.7	8.40*	12.1	92	24
	1969	54	55.7	58.4	1.65	12.1	31	23
	1970	69	45.0	59.0	10.3*	11.3	61	8
L3VJ	All data 1967-1969	217	50.5	61.2	12.2*	12.9	172	45
	1967	47	42.5	63.2	13.8*	10.3	46	1
	1968	116	51.3	61.3	9.14*	11.9	93	23
	1969	54	55.7	58.9	2.09*	11.4	33	21
	1970	69	45.0	60.4	11.6*	11.0	63	6

*Significantly different at $p=0.05$.

TABLE A12 Comparison of Farm Barley Yields to Yields Predicted by the Q2V and L2V Equations

Equation	Data Group	No. of Farm Yields	$\bar{x}$ Actual (bu./ac.)	$\bar{x}$ Predicted (bu./ac.)	Paired t Value	St. Dev. of the Difference (bu./ac.)	Predicted Actual: Above Actual	Predicted Actual: Below Actual
Q2V	All data 1967-1970	305	48.9	60.2	15.8*	12.5	253	52
	1967	66	43.4	60.2	12.5*	10.9	62	4
	1968	116	51.3	60.1	7.89*	11.9	91	25
	1969	54	55.7	60.4	2.81*	12.2	35	19
	1970	69	45.0	60.3	11.1*	11.5	65	4
L2V	All data 1967-1970	305	48.9	61.2	17.2*	12.4	260	45
	1967	66	43.4	61.7	14.0*	10.7	63	3
	1968	116	51.3	61.0	8.85*	11.8	94	22
	1969	54	55.7	60.4	2.98*	11.7	38	16
	1970	69	45.0	61.6	12.2*	11.2	65	4

*Significantly different at $p=0.05$.

Table A13 Comparison of Farm Barley Yields to Yields Predicted by the Q3VA and L3Va Equations

Equation	Data Group	No. of Farm Yields	$\bar{x}$ Actual (bu./ac.)	$\bar{x}$ Predicted (bu./ac.)	Paired t Value	St. Dev. of the Difference (bu./ac.)	Predicted Actual Above Actual	Predicted Actual Below Actual
Q3VA	All data 1967-1970	305	48.9	61.0	15.5*	13.6	250	55
	1967	66	43.4	64.7	14.9*	11.6	64	2
	1968	116	51.3	59.3	7.42*	11.8	91	25
	1969	54	55.7	58.4	1.62*	12.1	31	23
	1970	69	45.0	62.3	11.9*	12.1	64	5
L3VA	All data 1967-1970	305	48.9	61.5	17.1*	12.9	254	51
	1967	66	43.4	63.7	15.4*	10.7	64	2
	1968	116	51.3	60.6	8.53*	11.8	92	24
	1969	54	55.7	59.4	2.33*	11.8	33	21
	1970	69	45.0	62.6	13.0*	11.2	65	4

*Significantly different at p=0.05.

TABLE A14 Comparison of Farm Oats Yields to Yields Predicted by the Q2V and L2V Equations

Equation	Data Group	No. of Farm Yields	$\bar{x}$ Actual (bu./ac.)	$\bar{x}$ Predicted (bu./ac.)	Paired t Value	St. Dev. of the Difference (bu./ac.)	Predicted Actual: Above Actual	Predicted Actual: Below Actual
Q2V	All data 1967-1970	207	68.6	83.2	13.1*	15.9	169	38
	1967	62	59.7	83.5	12.7*	14.8	56	6
	1968	100	73.1	83.8	7.66*	13.9	78	22
	1969	36	73.9	80.9	2.90*	14.6	26	10
	1970	9	59.4	83.2	3.87*	18.4	9	0
L2V	All data 1967-1970	207	68.6	84.7	14.5*	16.0	175	32
	1967	62	59.7	85.7	13.8*	14.9	56	6
	1968	100	73.1	84.9	8.55*	13.8	84	16
	1969	36	73.9	82.5	3.62*	14.3	26	10
	1970	9	59.4	85.0	4.39*	17.4	9	0

* Significantly different at $p=0.05$.

TABLE A15 Comparison Farm Oats Yields to Yields Predicted by the Q3VA and L3VA Equations

Equation	Data Group	No. of Farm Yields	$\bar{x}$ Actual (bu./ac.)	$\bar{x}$ Predicted (bu./ac.)	Paired t Value	St. Dev. of the Difference (bu./ac.)	Predicted Actual: Above Actual	Predicted Actual: Below Actual
Q3VA	All data 1967-1970	207	68.6	83.5	12.1*	17.7	167	40
	1967	62	59.7	87.8	14.7*	15.0	57	5
	1968	100	73.1	82.4	6.26*	14.7	76	24
	1969	36	73.9	78.5	1.90	14.6	25	11
	1970	9	59.4	85.8	4.58*	17.3	9	0
L3VA	All data 1967-1970	207	68.6	85.1	14.0*	16.8	171	36
	1967	62	59.7	88.2	15.1*	14.8	59	3
	1968	100	73.1	84.4	7.92*	14.2	78	22
	1969	36	73.9	81.3	3.10*	14.4	25	11
	1970	9	59.4	86.8	4.94*	16.6	9	0

* Significantly different at $p=0.05$

TABLE A16 Comparison of Farm Oat Yields to Yields Predicted by the Q3VJ and L3VJ Equations

Equation	Data Group	No. of Farm Yields	$\bar{x}$ Actual (bu./ac.)	$\bar{x}$ Predicted (bu./ac.)	Paired t Value	St. Dev. of the Difference (bu./ac.)	Predicted Actual: Above Actual	Predicted Actual: Below Actual
Q3VJ	All data 1967-1970	197	69.0	83.4	12.6*	17.5	161	36
	1967	56	60.2	88.0	14.0*	14.9	53	3
	1968	96	73.3	83.0	6.35*	14.9	75	21
	1969	36	73.9	77.8	1.65	14.5	24	12
	1970	9	59.4	81.9	4.04*	16.6	9	0
L3VJ	All data 1967-1970	197	69.0	84.7	12.9*	17.0	164	33
	1967	56	60.2	88.8	14.5*	14.5	53	3
	1968	96	73.3	84.2	7.32*	14.6	75	21
	1969	36	73.9	79.8	2.48*	14.4	27	9
	1970	9	59.4	84.2	4.64*	16.0	9	0

* Significantly different at $p=0.05$

TABLE A17 Effect of Agronomic Soil Groups[1] on the Accuracy of Farm Barley Yield Prediction

			Prediction Equation										Prediction Equation			
			Q2V		L2V		Q3VA		L3VA				Q3VJ		L3VJ	
Soil Grouping	No. of Farm Yields	$\bar{x}$ Actual bu./ac.	$\bar{x}$ Pred. bu./ac.	Paired t Value	$\bar{x}$ Pred. bu./ac.	Paired t Value	$\bar{x}$ Pred. bu./ac.	Paired t Value	$\bar{x}$ Pred. bu./ac.	Paired t Value	No. of Farm Yields	$\bar{x}$ Actual bu./ac.	$\bar{x}$ Pred. bu./ac.	Paired t Value	$\bar{x}$ Pred. bu./ac.	Paired t Value
1a. Waskada	16	49.4	58.5	2.24*	5.97	2.63*	60.2	2.47*	60.7	2.84*	-	-	-	-	-	-
b. Newdale	37	47.8	60.3	6.64*	61.6	7.32*	64.2	7.08*	63.2	7.57*	21	51.3	59.9	4.13*	60.8	4.59*
c. Manitou	23	57.8	62.9	1.78	61.3	1.77	63.1	1.84	62.5	1.54	23	57.8	66.0	2.93*	65.2	2.54*
3c. Carrol	22	50.0	59.3	3.64*	60.6	4.23*	59.1	3.61*	59.9	4.00*	23	50.0	61.3	4.36*	61.7	4.68*
4a. Altona	66	49.0	59.9	7.13*	60.6	7.78*	59.2	6.13*	60.3	7.31*	66	49.0	59.0	5.85*	59.7	6.63*
b. Portage	46	50.7	59.4	4.73*	60.2	5.29*	60.8	5.15*	61.0	5.64*	37	51.1	58.8	4.09*	59.6	4.72*
c. Red River	78	46.4	60.9	10.9*	62.0	11.7*	61.4	10.2*	62.4	11.5*	78	46.4	59.9	9.84*	61.2	10.9*

*Significantly different at $p=0.05$
[1]Only soil groups with 10 or more observations included
-Less than 10 observations

TABLE A18 Effect of Agronomic Soil Groups[1] on the Accuracy of Farm Oat[2] Yield Prediction

			Prediction Equation										Prediction Equation			
			Q2V		L2V		Q3VA		L3VA				Q3VJ		L3VJ	
Soil Grouping	No. of Farm Yields	$\bar{x}$ Actual bu./ac.	$\bar{x}$ Pred. bu./ac.	Paired Value	$\bar{x}$ Pred. bu./ac.	Paired Value	$\bar{x}$ Pred. bu./ac.	Paired Value	$\bar{x}$ Pred. bu./ac.	Paired Value	No. of Farm Yields	$\bar{x}$ Actual bu./ac.	$\bar{x}$ Pred. bu./ac.	Paired Value	$\bar{x}$ Pred. bu./ac.	Paired Value
1a. Waskada	10	62.5	81.1	4.60*	82.4	5.09*	81.6	4.91*	83.5	5.55*	-	-	-	-	-	-
c. Manitou	12	76.7	88.8	2.45*	90.3	2.67*	88.1	2.46*	89.4	2.51*	12	76.7	92.7	3.98*	93.1	3.67*
4a. Altona	80	70.8	82.9	7.17*	84.4	7.90*	82.5	6.06*	84.3	7.39*	90	69.8	83.1	6.85*	84.1	7.75*
b. Portage	14	76.1	80.9	0.89	83.4	1.37	81.5	0.90	84.1	1.43	10	82.0	81.0	-0.20	83.3	0.27
c. Red River	53	64.2	83.6	8.72*	85.3	9.43*	84.3	8.24*	85.9	9.26*	53	64.2	83.3	8.24*	85.0	9.05*

[1] Only soil groups with 10 or more observations included
[2] Oat yields (bu./ac.) = 1.41 (Barley yields (bu./ac.))
* Significantly different at $p=0.05$
\- Less than 10 observations