THE EFFECT OF POTASSIUM FERTILIZATION ON CEREAL CROPS GROWN ON CALCAREOUS MANITOBA SOILS

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ABSTRACT

Field experiments were conducted on calcareous soils with exchangeable potassium levels which ranged from 30 to 414 ppm to determine the effect ot potassium fertilization on cereal growth. Barley plant matter samplings at 14, 21 and 28 days from seeding, and fifth leaf stage of growth indicated that the application of potassium fertilizer generally increased yield, potassium uptake and potassium concentration during early growth on all soils. Wheat and oat plant matter samplings at 21 and 28 days, and fifth leaf stage of growth indicated that potassium fertilizer generally increased yield, potassium uptake and potassium concentration during the early growth on soils with exchangeable potassium levels of 126 ppm or less. Generally, potassium concentration in the barley and oat plants at the early stages was correlated to final yields.

Final barley grain yields showed responses to one or more of the potassium treatments on 9 of the 10 soils studied; no responses occurred on the soil with 68 ppm exchangeable potassium. These responses although usually statistically non-significant were substantial, 2 bushels or more per acre. While wheat and oats showed some substantial, 3 bushels or more per acre, responses to potassium fertilization on soils with exchangeable potassium levels as high as 414 ppm, no consistant and uniform pattern of response was evident at exchangeable potassium levels greater than 84 ppm. On soils which had 84 ppm or less of exchangeable potassium, wheat showed statistically significant responses to potassium fertilization on all but one soil, there was no response on the soil which had 68 ppm exchangeable K, and oats showed both sig-

nificant and substantial, 5 bushels or more per acre, responses on all such soils. With barley, potassium fertilization generally increased potassium uptake on soils with 414 ppm or less of exchangeable potassium and, with wheat, on soils with 102 ppm or less of exchangeable potassium. This was of interest because potassium uptake at harvest was found to correlate significantly with final grain and total yields.

For the three cereals, potassium and nitrogen uptake at final harvest were found to be significantly correlated. The exchangeable Ca/K and Ca+Mg/K ratios in the soil at seeding were significantly negatively correlated to potassium uptake by wheat, barley, and oats; to barley grain yields, to barley total yields, and to wheat grain yields, at final harvest.

A greenhouse experiment indicated that barley yields were increased significantly with potassium fertilization on soils with 64 ppm or less of exchangeable potassium regardless of whether the soils were acidic or alkaline, calcareous or non-calcareous. However, no substantial barley yield increases were realized on soils with 107 ppm or more of exchangeable potassium. Potassium uptake and potassium concentration in the plant matter were increased with potassium fertilization. Yield was most strongly correlated with the potassium extracted by 1.0N ammonium acetate as compared with 0.01M$CaCl_2$ and distilled water.

Results of a greenhouse experiment indicated that barley plants were more prone to damage from below freezing temperatures on soils low in exchangeable potassium, 67 ppm, than on soils high in exchangeable potassium, 210 ppm. The damage to the plants was reduced when the potassium concentration in the plant matter was increased with potassium fertilization.

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I INTRODUCTION

Potassium is an essential plant nutrient. Although it remains in an ionic state within the plant, not entering any chemical combinations, it is thought to be associated (24) with the synthesis of simple sugars and starches, the translocation of carbohydrates, the reduction of nitrates, the snythesis of proteins, and cell division. Because potassium is an essential nutrient, and large areas of Manitoba are low in available potassium (34), the possibility of increasing crop yields with potassium fertilization is theoretically viable.

In 1965, field trials showed substantial barley yield responses to potassium fertilization on three calcareous soils with relatively high exchangeable potassium levels (18). However, on a fourth trial, also conducted on a soil relatively high in exchangeable potassium, but acidic, barley did not respond to potassium fertilization. In 1966, potassium fertilization (44) increased wheat and barley yields, 4 bushels or more, per acre, on calcareous soils with relatively high exchangeable potassium levels though only a slight wheat yield response to potassium fertilization, 0.5 bushels, was observed on an acidic soil also having a relatively high exchangeable potassium level. Although these responses were not statistically significant, they did suggest that a profitable response could be obtained by applying potassium fertilizer to cereal crops grown on calcareous soils for which present soil tests recommendations do not advise potassium application.

Therefore, in 1967 and 1968 field trials were undertaken to study the effect of potassium fertilization on cereal yields. Calcareous soils with both low and high levels of exchangeable potassium were used. The results of these experiments were to be related to existing soil test recommendations with the objective of confirming or improving existing soil test recommendations for the growth of wheat, oats and barley. A greenhouse experiment was also conducted to measure the effect of potassium fertilization on barley yields and potassium uptake. The soils used in this experiment varied in levels of exchangeable potassium, pH and percent $CaCO_3$. A second greenhouse experiment was conducted to determine the effectiveness of potassium fertilization in reducing frost damage to barley seedlings.

II LITERATURE REVIEW

Successful plant growth requires a balance of chemical, physical, biological and meteorological conditions. Working with crop fertility, it is very difficult to isolate any one of these factors because they all interact. This should be constantly kept in mind while evaluating the effect of potassium on plant growth as set out in the following literature review. Indeed, partly because of the difficulty of isolating any one factor, the literature dealing with the effect of potassium on crop or soil fertility is very controversial. Unlike the other plant nutrients, (nitrogen, phosphorous, and secondary elements), little is definitely known about the function of potassium in plants.

A. THE ROLE OF POTASSIUM IN PLANT GROWTH

It is known that potassium is required for plant growth and that it exists in ionic form not entering any chemical combination within the plant. According to Lawton and Cook (24), the plant processes which are affected by potassium are:

1. synthesis of simple sugars and starches
2. translocation of carbohydrates
3. reduction of nitrates and synthesis of proteins
4. normal cell division

They also suggest that potassium affects the turgor of plant cells, the formation of oils, the process of photosynthesis and the formation of organic acids. Kernan (23) suggests that potassium is largely responsible for neutralizing the chloride and phosphate ions in the plant cells. Potassium may also neutralize the physiologically important organic acids, act as an activator of various enzymes, promote the growth of young meristems, and play a part in adjusting stomatal movement (13).

B. NATURE OF POTASSIUM IN THE SOIL

In mineral soils the potassium content is usually between 0.2 and 3.3 percent (38). This soil potassium can be classified into one of three main groups: non-exchangeable potassium, exchangeable potassium, and water soluble potassium. It is catagorized into one of these groups by the specific extracting agents used and the extracting procedure followed.

Most soil potassium exists as non-exchangeable potassium as an elemental component of minerals such as feldspar, mica, leucite, illite, vermiculite and glauconite (38). This non-exchangeable potassium group also includes potassium that is very strongly adsorbed to the soil colloids (38). Potassium which is less firmly adsorbed to the soil colloids and which can undergo exchange reactions with other cations in the soil solution is called exchangeable potassium. Potassium existing in soil solution is known as water soluble potassium (38). It results from the dissolution of potash fertilizers and the freeing of exchangeable potassium ions from the soil colloids by hydrogen ions from water or carbonic acid (38). Of the three potassium groups in the soil it is the smallest.

An equilibrium exists between the three forms of potassium in the soil. This equilibrium can be represented by the following equation:

non-exchangeable K ⟷ exchangeable K ⟷ water soluble K

This is a dynamic equilibrium; it is always changing in the soil. These changes are brought about mainly by the uptake of potassium for plant growth, by the addition of potassium fertilizers, and by the dilution and concentration of potassium in soil solution caused by changes in soil moisture.

Garman (14) proposed an equilibrium which he claims would allow for a more exact interpretation of potassium behavior in the soil. The proposed equilibirum is:

exchangeable K

water soluble K ⟷ adsorbed K ⟷ structural K

non-exchangeable K

According to Garman the fraction of potassium in the soil that is usually referred to as non-exchangeable can include both strongly adsorbed and structural potassium. (His definition of structural potassium is that fraction of potassium which is bound in the structure of minerals and which is not readily replaceable by other cations in most extracting solutions. Adsorbed potassium is that fraction of potassium which is held electrostatically on the surface of colloidal material and which is more readily replaceable by other cations than is structural potassium.) Thus, Garman reasons that structural potassium and strongly adsorbed potassium should not be in the same category because of the difference in the ease with which the two forms are replaced.

C. AVAILABILITY AND THE MEASURE OF AVAILABILITY OF SOIL POTASSIUM TO PLANTS

Water soluble potassium and the exchangeable potassium which can be readily displaced from colloids by other cations, such as the ammonium ion, are considered to be available for plant growth. When water soluble and exchangeable potassium are too limited to supply the plant's demand for potassium the plant can make use of non-exchangeable potassium to a small degree (30, 45). Furthermore, the non-exchangeable potassium serves as a natural reservoir regenerating exchangeable and water soluble potassium levels when their concentration is reduced. The non-exchangeable potassium is liberated into the exchangeable forms through the outlined equilibrium (38).

Most chemical analyses used to determine the potassium available to plants are designed to measure the amount of exchangeable potassium in the soil. Exchangeable potassium is measured because it supplies the soil solution with potassium which, in turn, the plant can absorb, and because it can supply potassium directly to the plant through contact exchange (23, 45). But; because the equilibrium between the three forms of soil potassium is very dynamic, it is difficult to measure exchangeable potassium. Another difficulty is that the cation used to displace the potassium from the colloidal material may not always be displacing an amount of potassium comparable to that which the plant is able to remove from the soil. Furthermore, different plant species vary in their ability to remove potassium from the soil and hence the amount of exchangeable potassium in the soil is not an absolute standard for predicting the potassium available to all species of plants.

Another problem is using exchangeable potassium as a measure of the amount of potassium available to plants is that the amount of exchangeable potassium increases with air drying (17, 21, 27). Lueks _et al._ (27) working with Iowa soils concluded that exchangeable potassium values determined after air drying may not be as reliable in predicting potassium supplying abilities as determinations done on moist soils. But Jones _et al._ (21) working with Ohio soils, found that the increase in exchangeable potassium associated with air drying was non-significant for the interpretation of soil tests.

Nelson (30) in summarizing his work, states that for heterogenous soils determining the amount of exchangeable potassium in the soil provides the best measurement for predicting potassium uptake by plants. However he mentions that this might not hold for soils homogenous in the amounts and kinds of potassium bearing minerals present. For one homogenous group the determination of exchangeable potassium may be satisfactory for predicting uptake, whereas for some other homogenous group another chemical method such as strong acid extraction might be equally good or better.

D. PLANT ACCUMULATION OF POTASSIUM

Kernan (23) points out that no one knows whether the accumulation of potassium in plants is an active or a passive process. If it is an active process, it would require a carrier transport across the cell membrane as well as metabolic energy to work against the electrochemical gradient of the cell membrane (23). If it is a passive force, then cations may be drawn across the cell membrane by the movement of other ions (23). Kernan (23) also states that some evidence seems to indicate that potassium movement into the plant cells and root system is passive. This passive process may be either a mass flow of water or a transmembrane potential generated by the active transport process of other ions into the cell.

Many theories have been proposed to explain how plant roots obtain cations from the soil. One theory proposes the absorption of potassium from the soil solution (45). The plant roots not only absorb the potassium ions in solution which result from soluble potassium salts and potassium ions liberated from the colloids by the equilibrium process, but they can also absorb potassium which they themselves are responsible for liberating from the colloids into the soil solution. This liberation of potassium adsorbed to the colloids is achieved by respiratory carbon dioxide which reacts with water to form carbonic acid. In turn the carbonic acid reacts with the soil particles and thus releases potassium ions into the soil solution (45). If the potassium concentration in the soil solution is not maintained at an adequate level for the process of absorption then another mechanism must be operating to supply the demand. This may be direct contact between the root hairs and the clay particles (23, 45). When this contact occurs, there may be an exchange of hydrogen ions for potassium ions between the root hairs and the clay particles without either ion entering into the solution phase.

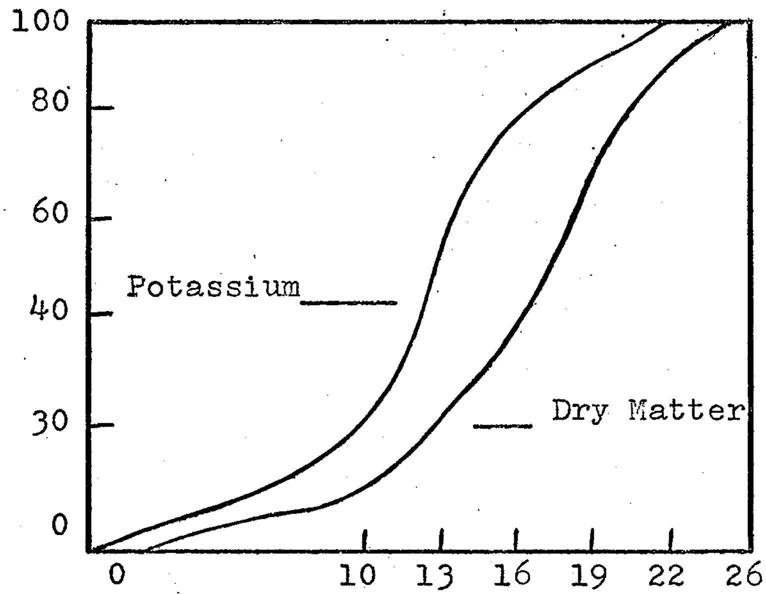
E. POTASSIUM UPTAKE AND YIELD

Dement *et al*. (9) placed potassium deficient oat and corn plants grown in sand cultures for fifteen to seventeen days, in contact with soils having different levels of potassium fertilizer for periods of one to fourteen days. Although differences in potassium uptake were evident among the different potassium fertilizer treatments after only three days of growth, no differences in yield were observed for the first week of growth. These findings illustrate that uptake and yield responses to potassium fertilization may not occur simultaneously in the growth cycle of plants.

Bartholomew and Janssen; as reported by Boswell and Parks (7), state that plants take up potassium throughout the growing period and that a deficiency at any time can affect growth. Russell (36) reports that the work of Richardson and Tumble shows that barley takes up potassium "rapidly when the plant is small, as measured by the amount of dry matter present, but the rate of uptake falls when the plant is making its dry matter rapidly"[1]. The following diagram illustrates their point:

1. E. Walter Russell, *Soil Conditions and Plant Growth* (London: Longmans, Green and Co. Ltd., 1961), p. 27.

Uptake of Nutrient and Production
of Dry Matter in Barley



Period of Growth in Weeks

Deleano; as Russel states, says that the amount of potassium in the aerial parts of the plant decreases at the end of the growing season. Since this potassium is not present in the roots he suggests that it is excreted back into the soil. Williams (45) found that the potassium content of plant tops reflected the concentration of potassium in the medium. That is; as the concentration of potassium increased in the medium, the concentration of potassium in the tops also increased. Interestingly, at the lower concentrations of potassium Williams (45) noted that more plant growth was produced per unit of potassium absorbed.

Luxury consumption of potassium will not occur unless the potassium level available to the plant is high (19). Lawton and Cook (24) cite Loehwing as mentioning that potassium absorption is in excess of plant needs during early growth but the excessive potassium is usually redistributed during later stages of growth.

Application of potassium fertilizer increases the concentration of potassium in the plant but the increase is mainly in the vegetative parts of the plant. The potassium concentration of the grain remains relatively unchanged despite different potassium treatments. Small grain crops and corn contain about three times as much potassium in the straw as in the seed (24).

F. OPTIMUM POTASSIUM LEVELS FOR PLANT GROWTH

Asher and Ozanne (3), working with fourteen species of plants grown on Hoagland type nutrient cultures, observed that root and top growth both reached a maximum at approximately the same potassium concentration. The potassium concentrations they used were 1.2, 7.7, 23.7, 94.6, and 1016 μ-molar. At a 1.2 μ-molar concentration, yields were greatly reduced and symptoms of severe potassium deficiency were evident. At 7.7 μ-molar concentration deficiency symptoms were not evident on most plants but yields were still substantially reduced. Under conditions of potassium deficiency top growth was more reduced than root growth. In their study they observed that most species achieved maximum growth at potassium concentrations between 24 and 95 micro-molar.

According to Asher and Ozanne, these concentrations might easily occur in the root environment of soil-grown plants. Asher and Ozanne further observed that maximum yield was obtained when the potassium concentration ranged from 112 to 197 μ-moles per gram of tops and from 54 to 126 μ-moles per gram of roots.

According to Lawton and Cook (24) the potassium requirement for the following per acre yields of wheat, oats, and barley are:

wheat	(30 bu)	-	25-30 pounds of potassium
oats	(50 bu)	-	30-40 pounds of potassium
barley	(40 bu)	-	30-40 pounds of potassium

In these cereals (24) the percent potassium in the grain can range from 0.3 to 0.5 and in the straw the percent potassium can range from 0.5 to 1.5.

Bray, as mentioned by Allaway and Pierre (2), state that 140 pounds of exchangeable potassium per acre in the surface six and two-thirds inches will give good crop growth on the corn belt soils of Iowa and Wisconsin. Soils in the range of 90-140 pounds of potassium would probably respond favorably to potassium and those below 90 pounds would show a good response. Allaway and Pierre further report that Volk and Truog suggested that 165 pounds of exchangeable potassium per acre is needed for proper plant growth, whereas according to Murphy a 120 pounds will usually support good crop growth on Oklahoma soils although occasional responses to potassium fertilization may occur on soils with up to 200 pounds of exchangeable potassium per acre. Albrecht (1) suggested that when the exchangeable potassium supply is less than 100 pounds per acre there is cause for concern about plant growth.

G. SOIL PROPERTIES IN RELATION TO POTASSIUM UPTAKE

Jaworski and Barker (20) did an experiment in which they used multiple linear regression analyses to see how soil properties affect uptake of potassium by plants. These properties were:

1. exchangeable potassium
2. exchange capacity
3. percent potassium saturation
4. exchangeable calcium and magnesium
5. percent organic matter
6. percent clay
7. pH
8. potassium supplying power
9. interaction between some of these variables and exchangeable potassium

They found that exchangeable potassium accounted for 65 percent of the variation in potassium uptake; that is, the coefficient of determination was 0.65. When exchange capacity, percent organic matter, exchangeable calcium, and potassium supplying power were included the coefficient of determination increased to 0.82. From prediction equations, it was possible to forecast that the uptake of potassium would increase when exchangeable potassium increases, when exchange capacity decreases, when organic matter increases, when exchangeable calcium increases, and when the potassium supplying power increases.

H. RELATIONSHIP BETWEEN POTASSIUM AND OTHER NUTRIENTS:

1. Phosphorous and Nitrogen

Soofi and Fuehring (40) observed that when available potassium was lacking, yield responses to nitrogen and phosphorous were negative. On the other hand, excessive potassium fertilization reduced uptake of other nutrients and upset crop growth.

Washko (43), working with bromegrass, found a slight rise in the nitrogen concentration of the tissue with increasing amounts of potassium supplied in solution up to 40 ppm. Beyond 40 ppm of potassium in solution, the material harvested at two months showed a decrease in its nitrogen concentration whereas the material harvested at three months showed an increase in nitrogen concentration. It was also noted that increasing the concentration of the solution decreased the phosphorous concentration within the plants. Gillingham (15) conducted an experiment with rye seedlings on Vancouver Island soils to see what influence nitrogen and phosphorous have on the absorption of exchangeable potassium and observed that the application of nitrogen and phosphorous; either singly or in combination, increased the amount of exchangeable potassium recovered by the rye seedlings. Lawton and Cook (24) mention that the use of nitrogen or phosphorous may intensify or even produce potassium deficiency symptoms if the supply of available potassium is low. In most cases this was due to increased growth with a resultant dilution of potassium.

Hamilton (16) reports that Kiertz *et al*. depressed the phosphorous concentration in a soil solution by the use of potassium chloride. He further reports that Fehr and Wesemael found that at pH7 the phosphorous concentration of a soil solution was lower in the presence of potassium chloride and potassium nitrate than in the presence of potassium sulfate. McGeorge and Beazele, also as reported by Hamilton, found the solubility of rock and soil phosphate decreased in the presence of potassium chloride and potassium sulfate. Hamilton observed that grain yields reached a maximum with monocalcium phosphate, ammonium sulfate, and potassium chloride whereas straw yields reached a maximum with monocalcium phosphate, ammonium sulfate, and potassium sulfate.

2. Calcium and Magnesium

Bailey (4), working with corn on Manitoba soils, found that a calcium to potassium ratio in the plant of between 0.10 and 0.15, (expressed in percent), gave the best yields. Stanford et al. (41) report Hoagland and Martin as having found that a high calcium and magnesium to potassium ratio within the plants had a decidedly inhibiting effect on the growth of barley and tomatoes.

Ion antagonism or competition may account for the repressive effect of lime on potassium absorption or the inverse calcium potassium relationship (31). Peach and Bradfield (31) attribute decreased absorption of potassium to calcium-potassium interactions initiated by the addition of lime to acid soils. The fact that plants absorb more potassium from sandy soils low in exchangeable potassium than from heavier soils higher in calcium and exchangeable potassium is also attributed to the high calcium to potassium ratio in the soil solution (31).

Pierre and Bower (32) state that it may be possible that poor uptake and yield on high lime soils are caused by high concentrations of calcium depressing both the uptake of potassium and the amount of exchangeable potassium that goes into solution. However, York et al. (46), working with artificially created calcareous soils and alfalfa, found no evidence that calcium ions in the presence of free calcium carbonate inhibited potassium absorption by the plants.

A few workers (2, 8, 41) have noted that corn grown on high lime soils in Iowa and Wisconsin exhibited poor growth and deficiency symptoms. Some of these soils had as much as 140 to 200 pounds of exchangeable potassium per acre. With the addition of potassium fertilizer corn yields on these soils were increased substantially. The workers concluded that the poor corn growth was due to the plants' failure to absorb adequate amounts of potassium because of an unfavourable balance of cations both within the plant and in the soil. Stanford _et al_. (41) claim that a calcium and magnesium to potassium ratio above 5, (expressed in meq per plant), indicates an unfavourable balance between the calcium, magnesium and potassium within the plant. Indeed, only ratios of less than 3.5 are suggestive of a state of favourable balance. When contrasted with the unproductive fields, the potassium content of the plants grown on productive fields was higher but their calcium and magnesium content was lower (41). One of the effects of potassium fertilization was to reduce the amount of calcium and magnesium within the plant (41). Evidently the increased uptake of potassium resulting from fertilization adjusted the proportions of calcium, magnesium, and potassium so that a favourable cation balance was attained. Thus, Allaway and Pierre (2) conclude that a higher level of exchangeable potassium is necessary for high lime soils than for normal soils. Allaway and Pierre (2) also point out that a few of the productive soils they worked with had a high calcium carbonate content. Therefore, they concluded that calcium carbonate is not the controlling factor in determining the productivity of the two types of soils. Russell (37) states that heavy potassium fertilization is required on the chalk soils of southern and eastern England owing to the high levels of calcium in such soils.

I. POTASSIUM IN RELATION TO FROST DAMAGE

Potassium may have yet another interesting effect on plant growth. Some workers have noted that potassium seems to reduce frost damage in many types of plants. Meyer *et al.* (28) report that frost damage to plants is of two types; intercellular freezing and intracellular freezing. Crystallization of water within the intercellular spaces produces intercellular freezing. This occurs most commonly when higher plants are frozen. Water moves toward the ice crystals from bordering cells and also from more distant cells by passage through intervening cells. Crystallization occurring very rapidly within the cells rather than within the intercellular spaces produces intracellular freezing. In the case of intracellular freezing ice may form in the cytoplasm, or in the vacuole, or in both, or it may even form between the cell wall and the protoplasm. Intracellular freezing causes damage because of the lacerating effect of ice on the cytoplasm. Intercellular freezing may damage the plant in two ways. It may dehydrate the protoplasm and so disorganize it. Or it may be that the ice crystals in the intercellular spaces cause mechanical deformation of the protoplasm. Meyer *et al.* (28) mention the possibility of plant damage when frozen plants are thawed.

Such damage can be caused by mechanical distortions of the protoplasm as a result of rapid re-entry of water into the cells from the intercellular spaces.

Meyer et al. (28) state that the basis for frost resistance lies in the properties of the protoplasm. An increased permeability of the protoplasmic membrane to water and other polar compounds, a decreased structural viscosity of the cytoplasm, and a reduced liability to coagulation in case of dehydration of certain layers of cytoplasm, are some of the changes in protoplasmic properties which relate to the hardening of plant tissue. All of these may contribute to increased frost resistance. Other less important features associated with frost resistance are: low cell-water content, relatively high sugar content within the cells, and a relatively high osmotic pressure within the cells. These factors reduce the amount of cell shrinkage with freezing and hence decrease the deformations of the protoplasm.

There are many factors to be considered when looking at frost damage. According to Levitt (26) frost damage depends upon:

1. rate of freezing
2. rate of thawing
3. length of time frozen
4. number of times frozen
5. post thawing treatment

Jung and Smith (22), in summarizing their work with alfalfa, say that the percent plant survival after exposure to freezing temperatures increased as the level of elemental potassium added increased, until a level of 200 pounds per acre was reached. Beyond the 200 pound level the percent survival decreased. In this experiment the level of elemental phosphorous was held constant at 80 pounds per acre. They also found that the percent survival after freezing was constant when both potassium and phosphorous were added provided the ratio of the two elements was 5 of potassium to 2 of phosphorous.

Baumann, according to Levitt (25), noted that potatoes supplied with potassium were uninjured at temperatures slightly below freezing while unfertilized potatoes were damaged. He felt this was due to poorer transportation of carbohydrates in potassium-deficient plants. Apparently the carbohydrates can be respired with production of heat which protects the plants. Levitt (25) mentions that Wilhelm attributes the favourable effect of potassium on plants exposed to freezing temperatures to an increase in cell sap concentration which promotes an increased cellular resistance to dehydration. Levitt further reports other workers have noted that potassium and phosphorous work in combination to promote frost resistance. Yasuda, again as reported by Levitt, claims potassium deficiency inhibits the formation of sugar in barley plants and so reduces their hardiness. Again according to Levitt, Arland claims that potassium deficiency leads to decreased frost resistance because of a high transpiration rate. Black (6) states that higher levels of potassium within the plant can not depress the freezing point sufficiently to affect the freezing of the plant very much. He claims that potassium-sufficient plants have a higher soluable carbohydrate content. Plants which are relatively high in carbohydrates tend to be cold resistant. Black also states that potassium-sufficient alfalfa plants suffer less from winter kill than potassium-deficient plants. Stoklasa, as reported by Lawton and Cook (24), mentions that potassium helps maintain proper turgor in plant cells and it is this property which is important in increasing the resistance of plants to the dehydrating effects of frost.

Thus, in sketching a conclusion, it is clearly evident that potassium is required for plant growth although its functions are not definitely known. Potassium exists in the soil in an equilibrium between non-exchangeable potassium, exchangeable potassium, and water soluble potassium. The amount of potassium within the plant is related to the amount of available potassium within the soil. To contribute in the most beneficial way to plant growth potassium must be balanced with other required nutrients. And; finally, in addition to its contributions to plant growth, by some mechanism potassium seems to help prevent frost damage.

III 1967 FIELD EXPERIMENT

In 1967 a field experiment was conducted to determine the effect of potassium fertilization on cereal growth and yield. Results from 1965 and 1966 field experiments influenced the decision to undertake the 1967 experiment. The 1965 and 1966 results (18, 44) had indicated a wheat and barley response to potassium fertilization on soils having an exchangeable potassium level considered adequate for cereal growth. Although the responses reported were not statistically significant, .05 level, they did suggest a profitable response could be obtained by applying potassium fertilizer to soils for which present soil test recommendations do not advise potassium application.

The 1965 results, by Hedlin and Soper (18), showed a barley yield response to potassium fertilization on three calcareous soils with relatively high exchangeable potassium levels. However, on a fourth field trial conducted on an acidic soil, also with a relatively high exchangeable potassium level, the barley did not respond to potassium. In 1966, Webber and Soper (44) reported similar results with wheat and barley. Potassium fertilization increased wheat and barley yields, 4 bushels plus, on calcareous soils with relatively high exchangeable potassium levels. But, only a slight wheat yield increase, 0.5 bushels, was observed on an acidic soil also having a relatively high exchangeable potassium level.

A. OBJECTIVES:

1. To determine the effect of potassium fertilization on yields and potassium uptake of cereals grown on calcareous soils with various exchangeable potassium levels. Furthermore, to relate the results of the experiment to existing soil test recommendations with the objective of confirming or improving present potassium recommendations for the growth of wheat, oats and barley on calcareous soils.

2. To study the effect of potassium fertilization on potassium concentration, potassium uptake, and yield of plant matter, at early stages of cereal growth on soils with various levels of exchangeable potassium.

3. To determine the effect of the exchangeable Ca/K ratio of the soil at seeding on cereal yields and potassium uptake by cereals.

4. To ascertain if there is a relationship between nitrogen and potassium uptake by cereals.

B. MATERIALS AND METHODS:

Soils: Five field trials were located on calcareous soils. The exchangeable potassium level of these soils varied from 48 to 341 ppm. Two Almasippi soils, one located south of Plumas (12) and one south of Gladstone (11), two Gladstone soils (11), both located south of Gladstone, and one Marquette soil (10), located north of Stonewall, were used. Table 1 lists some of the characteristics

Table 1

Characteristics of the Soils Used in the 1967 Field Experiment

	Depth (in)					
Co-operator		Peters	Arthur	Freeborn	Foxon	Ewanek
Soil Association		Almasippi	Almasippi	Gladstone	Gladstone	Marquette
K (ppm)	0 - 6	48	68	94	211	341
	6 - 12	32	29	58	76	205
Ca (meq/100g)	0 - 6	13.9	26.8	26.2	32.8	33.4
Ca/K Ratio(1)	0 - 6	116	155	109	61	38
Mg (meq/100g)	0 - 6	4.4	7.0	6.1	4.5	7.8
Ca+Mg/K Ratio(2)	0 - 6	153	195	134	69	47
Conductivity (mmhos/cm)	0 - 6	0.5	0.5	0.5	0.6	0.5
pH	0 - 6	8.1	7.6	7.7	7.4	7.6
Texture		L.F.S.	L.F.S.	V.F.S.C.L.	C.L.	C.
$CaCO_3$ (with HCl)	0 - 6	low	high	very high	very high	medium
	6 - 12	low	very high	very high	very high	high
P (ppm)	0 - 6	2.7	10.0	7.2	6.0	5.4
($NaHCO_3$ extractable)	6 - 12	1.4	1.3	2.1	1.0	1.0

Ca, Mg and K --- ammonium acetate extractable

(1) $\text{Ca/K Ratio} = \frac{\text{meq Ca/100g of soil}}{\text{meq K/100g of soil}}$

(2) $\text{Ca+Mg/K Ratio} = \frac{\text{meq Ca+Mg/100g of soil}}{\text{meq K/100g of soil}}$

of the soils.

Experimental Design: The trials consisted of six replicates and were in a randomized block design. Table 3 lists the treatments and crops grown.

Procedure: The trials were planted in the third week of May. The seed, and any fertilizer added with the seed, was drilled in with a six row self-propelled seeder of the V-belt design. Each individual plot was 6 rows in width, 42 inches, and thirty feet in length.

All treatments except 1, 6, and 11 received the equivalent of 90 pounds of nitrogen and 30 pounds of P_2O_5 per acre. The nitrogen was broadcast over the soil surface in the form of NH_4NO_3 (33.5-0-0). The phosphorous, applied as $NH_4H_2PO_4$ (11-48-0), was drilled in with the seed.

Treatments 3, 4, 8, 9, 13, and 14 received potassium in the form of KCl drilled in with the seed. On treatments 5, 10, 15, and 16, KCl was broadcast over the soil surface.

Manitou wheat was grown on treatments 1 to 5, Rodney oats on treatments 6 to 10, and Conquest barley on treatments 11 to 16.

Approximately three weeks after seeding a frost occurred in the area of the Foxon, Freeborn, and Arthur trials causing damage to the plants of those three trials. It was apparent that the damage to the barley plants was more severe on the plots that had not received potassium fertilizer than on those that had. Moreover, the damage to the barley plants was least severe on the plots which had received the highest rates of potassium. Therefore, in order to determine whether or not the potassium content of the barley plants differed according to the treatment which had been applied, a three foot portion from the two central rows of each frost-damaged plot was harvested. The harvested material was air-dried and weighed. Then the plant matter from each individual treatment of the six replicates was bulked, ground in a Wiley mill and analyzed for potassium content. As no pattern for the damage suffered by the wheat and oats could be distinguished among the various treatments they were not sampled.

At about the fifth leaf stage of growth a 10-foot portion from each of two central rows was harvested in each plot of the Arthur, Freeborn, and Foxon trials. On the Peters trial only the wheat plots were sampled because of wild oat infestation in the barley and oat plots. The Ewanek trial was not sampled at all because a lack of moisture had resulted in variable germination and hence the plant matter was not at a uniform stage of growth. The harvested material was air-dried and weighed. The plant matter from each individual treatment of the six replicates was bulked, ground in a Wiley mill, and analyzed for potassium content.

When the plants were mature, a 10-foot portion from each of the two central rows was harvested in every plot of the five trials. The harvested material was dried, weighed, and threshed. After threshing, the grain from each individual treatment of the six replicates was weighed, bulked, ground in a Wiley mill and analyzed for potassium and nitrogen content. The straw was handled in a similar fashion.

C. RESULTS AND DISCUSSION:

Results of the barley sampling on the Arthur, Freeborn, and Foxon trials at twenty-one days of growth (table 2) indicated a yield and potassium uptake response where nitrogen and phosphorous fertilizer had been applied. Where potassium fertizer had also been applied a further yield and potassium uptake response was evident; the largest response being to the 15 pound K_2O treatment. On two trials, the Arthur and Freeborn, the 15 pound K_2O treatment also produced the greatest percent potassium in the barley plants. However, on the Foxon trial, the application of potassium fertilizer failed to increase the potassium concentration in the barley plants. These findings were of interest because the percent potassium in the barley plants at twenty-one days of growth was significantly correlated, .05 level, with final barley yields, r=0.87. Hence the data from the first twenty-one days of growth suggests that 15 pounds of K_2O per acre, KCl drilled in with the seed, may enhance growth, potassium uptake and the concentration of potassium within the barley plants during early stages of growth, as well as increasing final yields. However, application rates greater than 15 pounds of K_2O per acre were of no further benefit in the first stages of growth.

The results of the barley sampling at the fifth leaf stage of growth (table 3), on the Arthur, Freeborn, and Foxon trials indicated that nitrogen and phosphorous fertilizer increased potassium uptake and yield; but gave no conclusive indication that potassium fertilization had further increased yields at this stage of

Table 2

Yield, Potassium Uptake and the Percent Potassium in the Barley Plant Matter at 21 Days of Growth (1967)

	Yield (lb/ac)			Potassium Uptake (lb/ac)			Percent Potassium		
Co-operator	Arthur	Freeborn	Foxon	Arthur	Freeborn	Foxon	Arthur	Freeborn	Foxon
Treatment									
$N - P_2O_5 - K_2O^{(1)}$									
11. 0 - 0 - 0	66.3	86.4	91.4	1.97	3.16	3.79	2.97	3.46	4.15
12. 90 - 30 - 0	118.8	110.6	125.2	3.10	4.18	5.95	2.61	3.78	4.75
13. 90 - 30 - 15D	156.8	123.8	133.9	5.17	5.37	6.32	3.30	4.34	4.72
14. 90 - 30 - 30D	125.7	101.0	121.1	4.14	4.32	5.66	3.29	4.28	4.67
15. 90 - 30 - 60B	151.3	118.4	129.8	4.16	4.49	6.05	2.75	3.79	4.66
16. 90 - 30 - 100B	125.7	104.7	122.0	3.24	3.78	5.90	2.58	3.61	4.84

D - KCl drilled in with the seed

B - KCl broadcast on the soil surface

(1) - nutrients in pounds per acre

Table 3

Yield, Potassium Uptake and Percent Potassium in the Plant Matter Sampled at the Fifth Leaf Stage of Growth (1967)

Co-operator		Yield (cwt/ac)				Potassium Uptake (lb/ac)				Percent Potassium			
		Peters	Arthur	Freeborn	Foxon	Peters	Arthur	Freeborn	Foxon	Peters	Arthur	Freeborn	Foxon
Wheat													
	Treatment $N - P_2O_5 - K_2O$ (1)												
1.	0 - 0 - 0	2.5	3.6	6.7	7.8	6.5	11.4	25.7	27.1	2.60	3.16	3.84	3.47
2.	90 - 30 - 0	3.7	4.4	10.6	12.0	8.7	12.0	42.2	46.3	2.35	2.72	3.98	3.62
3.	90 - 30 - 15D	5.2	5.5	10.9	11.4	14.5	14.4	42.7	41.4	2.79	2.61	3.92	3.63
4.	90 - 30 - 30D	5.8	5.5	10.1	11.6	18.6	19.0	42.1	41.6	3.20	3.46	4.17	3.59
5.	90 - 30 - 100B	4.2	5.2	11.0	12.0	13.4	16.8	42.4	43.0	3.20	3.24	3.85	3.58
	L.S.D. (.05)	1.1	NS	NS	NS								
Oats													
6.	0 - 0 - 0		2.2	4.1	4.5		6.8	15.6	20.5		3.10	3.80	4.55
7.	90 - 30 - 0		3.1	6.5	8.4		8.3	26.0	37.4		2.67	4.00	4.45
8.	90 - 30 - 15D		3.6	6.1	9.1		12.3	24.6	40.6		3.41	4.04	4.46
9.	90 - 30 - 30D		4.5	6.3	8.8		16.9	28.5	40.2		3.75	4.52	4.57
10.	90 - 30 - 100B		4.0	6.6	9.6		14.5	28.1	42.9		3.62	4.25	4.47
	L.S.D. (.05)		0.9	NS	NS								
Barley													
11.	0 - 0 - 0		2.1	10.1	7.3		6.3	36.8	27.9		2.99	3.64	3.82
12.	90 - 30 - 0		5.9	17.8	15.3		17.2	63.9	59.5		2.91	3.59	3.89
13.	90 - 30 - 15D		6.6	18.7	14.9		21.6	73.9	58.6		3.27	3.95	3.93
14.	90 - 30 - 30D		5.5	16.1	13.6		18.5	66.5	57.1		3.36	4.13	4.20
15.	90 - 30 - 60B		6.3	16.2	15.5		17.1	60.1	63.1		2.71	3.71	4.07
16.	90 - 30 - 100B		4.7	17.7	17.3		16.2	68.1	71.1		3.44	3.85	4.11
	L.S.D. (.05)		NS	NS	NS								

D - KCl drilled in with the seed

B - KCl broadcast on the soil surface

(1) - nutrients in pounds per acre

growth. However, in most cases, potassium uptake did increase with potassium fertilization. The potassium concentration in the barley plants also increased with all but one potassium treatment on one trial, treatment 15 on the Arthur trial. A significant, .05 level, although low, correlation coefficient, r=0.69, was calculated between the potassium concentration in the barley plants at the fifth leaf stage of growth and final barley yields. Overall, treatment 14 was considered optimum with regard to the percent potassium in the barley plants at the fifth leaf stage of growth.

Results of the wheat sampling at the fifth leaf stage of growth (table 3) on the Peters, Arthur, Freeborn, and Foxon trials indicated that nitrogen and phosphorous fertilizer increased potassium uptake and yield. With the application of potassium fertilizer as well, yield and potassium uptake were further increased on soils with exchangeable potassium levels of 68 ppm or less. But, the application of potassium on soils having higher exchangeable potassium levels produced no yield, potassium uptake, or percent potassium, response in the wheat plant matter at the fifth leaf stage of growth. On the Peters and Arthur trials the 15 pound K_2O treatment produced the best yield increase per unit of fertilizer, increasing yields by 150 and 110 pounds respectively. The increase on the Peters trial was statistically significant, .05 level, although the increase on the Arthur trial was not. Results from the Peters and Arthur trials also indicated that potassium fertilization increased potassium concentration in the wheat plants at the fifth leaf stage of growth. However, the correlation coefficient, r=0.49, between the potassium concentration at this stage of growth and final wheat yields was non-significant at the .05 level.

Results of the oat sampling at the fifth leaf stage of growth on the Arthur, Freeborn and Foxon trials (table 3) indicated that nitrogen and phosphorous fertilizer increased potassium uptake and yield. On the Arthur trial, application of potassium as well produced a further response; the 15 pound K_2O treatment producing a substantial increase while the 30 and 100 pound K_2O treatments produced significant increases. This suggests the likelihood of an oat response to potassium fertilization at the fifth leaf stage of growth on soils of lower exchangeable potassium levels, 68 ppm or less. However, the results from the other two trials, the Foxon and Freeborn, which were higher in exchangeable potassium, showed no conclusive evidence for an oat yield response to potassium fertilization at the fifth leaf stage of growth. Similarly, the uptake of potassium and the concentration of potassium in the oat plant were substantially increased by potassium fertilization on the Arthur trial but not on the Freeborn and Foxon trials. A significant, .05 level, relationship, r=0.90, was observed between the percent potassium in the oat plant at this stage of growth and the final oat yields.

The potassium recommendation for cereals on the soils of the Peters and Arthur trials was 15 pounds of K_2O per acre (42) and the recommended method of application was to drill the potassium in with the seed. Therefore, on these soils, a wheat, oat, and barley response to potassium fertilizer was expected. On the Peters trial, there was a significant, .05 level, grain and total

Grain and Total Yields of Wheat, Oats and Barley
at Final Harvest (1967)

	Co-operator	Grain Yield (bu/ac) Peters	Arthur	Freeborn	Foxon	Ewanek	Total Yield (cwt/ac) Peters	Arthur	Freeborn	Foxon	Ewanek
	Wheat										
	Treatment $N - P_2O_5 - K_2O$ (1)										
1.	0 - 0 - 0	15.6	15.7	25.1	21.9	15.3	23.3	21.6	40.3	27.5	18.0
2.	90 - 30 - 0	22.9	21.5	32.3	33.6	36.2	37.4	26.9	42.5	46.2	49.0
3.	90 - 30 - 15D	34.4	22.9	29.3	31.4	25.3	49.3	31.0	39.0	42.9	37.8
4.	90 - 30 - 30D	31.8	22.2	30.0	28.7	24.7	48.0	31.6	39.0	39.1	36.2
5.	90 - 30 - 100B	29.4	22.1	29.5	29.2	29.8	44.7	32.5	43.2	39.9	40.4
	L.S.D. (.05)	6.9	NS	NS	NS	6.6	9.7	NS	NS	5.6	6.7
	Oats										
6.	0 - 0 - 0	22.3	14.1 (2)	45.1	49.8	37.4	20.8	11.3 (2)	32.6	33.0	27.1
7.	90 - 30 - 0	54.7	13.4	49.2	68.8	52.2	44.8	14.1	34.3	45.1	43.7
8.	90 - 30 - 15D	67.5	18.7	54.2	67.4	62.8	51.0	16.1	36.1	43.0	39.8
9.	90 - 30 - 30D	62.5	19.2	56.6	69.2	57.6	49.9	18.1	37.5	44.5	45.8
10.	90 - 30 - 100B	59.5	19.1	62.8	66.5	71.6	48.1	16.8	41.5	42.4	53.2
	L.S.D. (.05)	NS	4.8	10.1	NS	NS	NS	NS	6.9	NS	NS
	Barley										
11.	0 - 0 - 0	26.8	19.2	38.0	36.7	27.3	31.4	19.2	32.3	33.5	31.9
12.	90 - 30 - 0	42.4	40.1	41.6	53.2	64.9	53.8	29.4	39.5	50.1	60.0
13.	90 - 30 - 15D	47.7	40.4	44.6	51.0	64.2	56.7	37.5	41.8	47.7	57.8
14.	90 - 30 - 30D	43.3	34.9	43.9	48.3	63.4	56.3	33.3	41.3	45.0	58.7
15.	90 - 30 - 60B	43.9	37.5	42.2	55.3	68.9	55.8	34.1	40.2	51.9	62.2
16.	90 - 30 - 100B	34.5	36.7	39.0	56.9	64.2	52.6	33.8	39.5	55.2	61.9
	L.S.D. (.05)	NS	NS	NS	4.4	NS	NS	7.3	NS	4.3	NS

D - KCl drilled in with the seed

B - KCl broadcast on the soil surface

(1) - nutrients in pounds per acre

(2) - oat yields were small, probably due to low precipitation during growing season

yield response by wheat and a substantial but non-significant, .05 level, response by oats and barley to the recommended treatment (table 4). Furthermore, an overall comparison of the yields produced by the various potassium treatments revealed that the 15 pound K_2O treatment was optimum for cereals on this soil. On the Arthur trial, only oat grain showed a significant response, .05 level, to potassium fertilization; the optimum treatment being 15 pounds of K_2O. Wheat and barley results indicated no grain yield response to the application of potassium. However, 15 pounds of K_2O did increase total wheat and barley yields. The barley total yield increase was significant at the .05 level. Therefore, the results of these two trials support, though not conclusively, the present potassium recommendations for the two exchangeable potassium levels represented by these soils.

The soil test recommendation (42) for the Freeborn trial did not advise application of potassium for wheat, oats, and barley. But, as this soil had an exchangeable potassium level of 94 ppm, only 9 ppm above the present critical potassium level for cereal growth, it was doubtful whether or not the cereal grains would show a response to potassium. The yield results (table 4), both grain and total, revealed that wheat did not respond to potassium fertilization on this soil, and, in fact, wheat yields were reduced by potassium application, treatments 3, 4, and 5. Oats on the other hand, showed a favorable response to all potassium treatments. The 15 pound K_2O treatment increased oat grain yields significantly and the 30 pound K_2O treatment increased oat grain and total yields significantly, .05 level. Barley too showed a response to the 15 pound K_2O treatment although it was not significant at the .05 level, a 3 bushel increase in barley grain yield and a 230 pound increase in total barley yield. However, the barley yields produced by the 30, 60, and 100 pound K_2O treatments were lower than those produced by the 15 pound K_2O treatment. Therefore, although these results support the present potassium recommendations for wheat they also suggest that oat, and possibly barley yields, could be increased by potassium fertilization even on soils with an exchangeable potassium level as high as 94 ppm.

The exchangeable potassium levels of the soils of the Ewanek and Foxon trials was rated as very high and therefore the soil test recommendation (42) did not advise the application of potassium for cereal growth. Hence, on these two trials, a wheat, oat, or barley response to potassium fertilization was not expected. The grain and total yield results for wheat (table 4) bore out these expectations as potassium fertilization reduced yields on both trials. The reduction on the Ewanek trial was significant at an .05 level. On the Foxon trial potassium fertilization either did not alter oat grain and total yields, treatment 9, or else decreased them, treatments 8 and 10. But, on the Ewanek trial, oat yields were substantially, although non-significantly, increased by potassium fertilization; treatment 10 illustrated a 19.4 bushel per acre increase. Barley grown on the Foxon trial showed an increased response in grain and total yields to broadcast potassium treatments 15 and 16. And, on the Ewanek trial, treatment 15 produced increased barley grain and total barley yields although the increase was not significant at an .05 level. On the other potassium treatments of these two trials barley yields were reduced. Therefore, these results support the recommendation for wheat, but suggest that oats and barley might respond to high broadcast application of potassium, 60 and 100 pounds of K_2O per acre, even on soils with very high levels of exchangeable potassium.

In 1967, Ridley (35) and Bailey (5) reported similarly inconclusive barley results from their Manitoba field trials. Ridley's trials were located on soils which had an exchangeable potassium level considered sufficient for barley growth and his data indicated no barley response to potassium fertilization. On the other hand, Bailey, whose trials were also located on soils which were considered to have an adequate level of exchangeable potassium for barley growth, reported a good barley yield response to potassium fertilization, particularly on the 150 and 200 pound K_2O per acre broadcast treatments.

Total potassium uptake by wheat (table 5) increased on the Peters and Arthur trials with potassium application. On the Freeborn trial, only the 100 pound K_2O application resulted in an increased potassium uptake. On the Foxon and Ewanek trials, potassium application decreased uptake by wheat. With oats, potassium application consistently increased total potassium uptake on the Peters, Arthur, Freeborn, and Ewanek trials although the 15 pound K_2O treatment produced only a small uptake response on the Freeborn trial and decreased uptake on the Ewanek trial. On the Foxon trial the 15 and 30 pound K_2O treatments produced small potassium uptake responses although the high rate of application, 100 pounds of K_2O per acre, reduced uptake.

Table 5

Potassium Uptake by Wheat, Oats and Barley at Final Harvest (1967)

Co-operator		Crop	Potassium Uptake (lb/ac) Peters	Arthur	Freeborn	Foxon	Ewanek
	Treatment $N - P_2O_5 - K_2O$(1)						
1.	0 - 0 - 0	Wheat	14.6	15.2	33.2	24.5	15.6
2.	90 - 30 - 0	Wheat	22.0	17.6	33.6	43.8	46.0
3.	90 - 30 - 15D	Wheat	32.6	21.8	33.3	41.1	40.1
4.	90 - 30 - 30D	Wheat	34.8	25.0	33.3	38.7	40.5
5.	90 - 30 - 100B	Wheat	39.6	28.4	40.4	38.6	41.1
6.	0 - 0 - 0	Oats	11.6	8.4	27.6	48.1	31.2
7.	90 - 30 - 0	Oats	18.2	7.8	27.3	65.7	68.5
8.	90 - 30 - 15D	Oats	26.7	14.6	28.4	66.5	54.6
9.	90 - 30 - 30D	Oats	29.9	15.0	33.8	67.6	76.2
10.	90 - 30 - 100B	Oats	41.3	16.8	36.4	64.5	82.9
11.	0 - 0 - 0	Barley	22.4	14.9	29.9	48.4	38.5
12.	90 - 30 - 0	Barley	29.6	14.6	32.1	68.3	79.7
13.	90 - 30 - 15D	Barley	35.5	21.2	34.8	70.8	81.8
14.	90 - 30 - 30D	Barley	41.6	19.6	35.2	64.6	87.7
15.	90 - 30 - 60B	Barley	42.1	19.1	39.8	77.9	93.8
16.	90 - 30 - 100B	Barley	46.5	26.0	36.8	90.3	102.4

D - KCl drilled in with the seed

B - KCl broadcast on the soil surface

(1) - nutrients in pounds per acre

With barley, potassium application increased potassium uptake on all trials except treatment 14 on the Freeborn plot. Maximum uptake was achieved with the 100 pound K_2O treatment on all trials except the Freeborn which achieved maximum uptake in response to the 60 pound treatment.

Thus, increased potassium uptake in response to potassium fertilization can be expected from oats and barley grown on soils having an exchangeable potassium level of up to 341 ppm. Wheat, however, will probably not respond to potassium fertilization on soils with an available potassium level greater than 94 ppm. A possible explanation for the differing uptake response between wheat and the other two cereals may be that the uptake of potassium per unit weight for wheat was less than for oats and barley. The uptake of potassium per pound of wheat produced was 0.0087 pounds, whereas for oats it was 0.0110 per pound of oats produced, and for barley 0.0108 pounds per pound of barley produced.

Significant linear correlations, .05 level, were observed between the amount of potassium taken up by wheat, oats and barley and the grain yields at harvest (figures 1, 2, and 3). The correlation coefficients were 0.71, 0.71, and 0.91 respectively. Similarily, significant linear correlations were observed between the amount of potassium taken up by these three cereals and their total yields. The correlation coefficients calculated for these relationships were 0.71 (wheat), 0.66 (oats), and 0.78 (barley). Nelson (29) has reported that the uptake of potassium increases as barley and wheat yields increase. Thus, the 1967 data indicates that to a

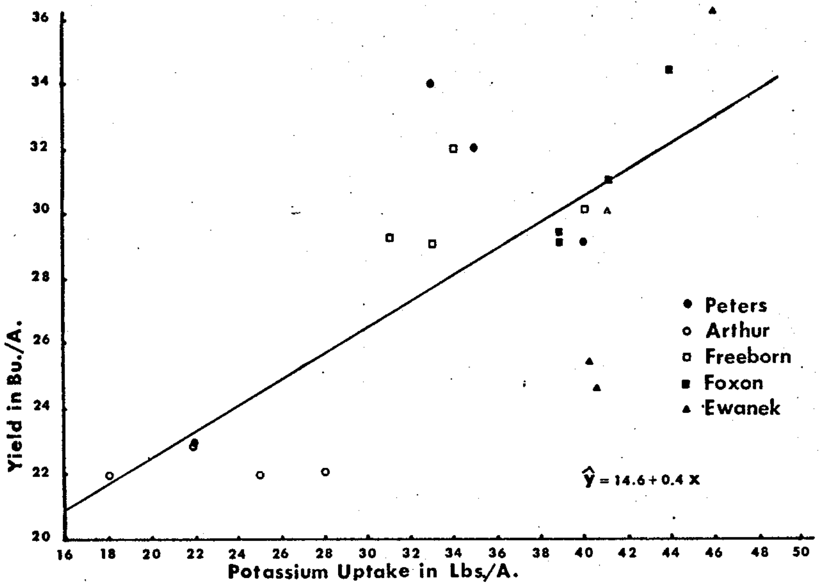


Figure 1 Potassium Uptake by Wheat Versus Wheat Yields at Final Harvest 1967

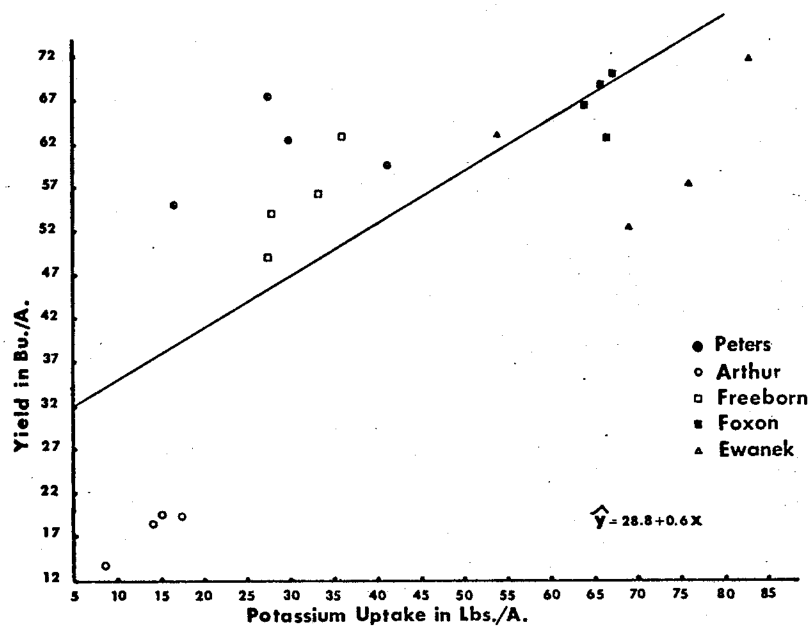


Figure 2 Potassium Uptake by Oats Versus Oat Yields at Final Harvest 1967

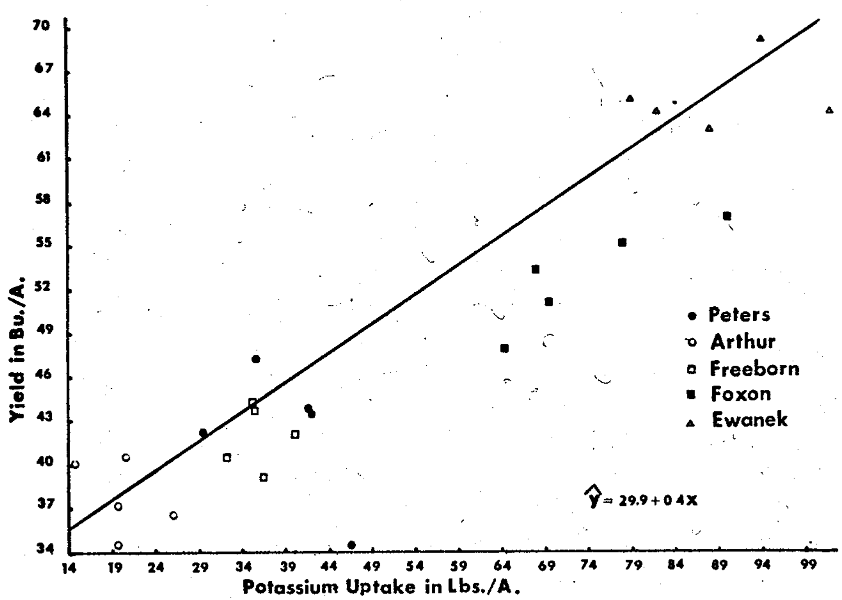


Figure 3 Potassium Uptake by Barley Versus Barley Yields at Final Harvest 1967

large extent uptake of potassium by cerals is a function of cereal yield.

The uptake data also indicates that potassium uptake by wheat and barley varies with the level of available potassium in the soil. Significant correlation coefficients, .05 level, were observed between the level of available potassium and potassium uptake by wheat, r=0.88, and the level of available potassium and uptake by barley, r=0.94. However, no significant relationship, .05 level, was observed between the level of available potassium and potassium uptake by oats, r=0.61.

The addition of nitrogen and phosphorous to the equivalent of 90 pounds of N and 30 pounds of P_2O_5 per acre resulted in rather large increases in grain and total yield for all three cereals on all trials with only one exception; oat grain yields on the Arthur trial were reduced by the application of nitrogen and phosphorous (table 4). Likewise, the application of nitrogen and phosphorous resulted in increased potassium uptake by cereals on the Peters, Foxon, and Ewanek trials (table 5). The increases on the Foxon and Ewanek trials were large. Probably this increased potassium uptake was due to increased cereal growth in response to the nitrogen and phosphorous fertilization. But, on the Arthur and Freeborn trials, potassium uptake by cereals was either reduced, unaffected, or increased only slightly, where nitrogen and phosphorous fertilizers had been applied.

To determine the degree of relationship between nitrogen and potassium uptake, linear correlation values were calculated for the uptake of the two nutrients by the three cereals at final harvest. The uptake of the two nutrients was observed to be significantly correlated, .05 level; r=0.72 for wheat, 0.72 for oats, and 0.90 for barley. Since potassium uptake was significantly correlated with cereal yields and nitrogen uptake was significantly correlated with potassium uptake, one can postulate that if nitrogen was a limiting factor then a response to potassium fertilization might not materialize. If so, this would be especially true of soils already high in available potassium because there might not be sufficient additional nitrogen to bring about a response in growth if potassium were added.

Results which indicate that calcium and magnesium affect potassium uptake and therefore the growth of plants have been reported. Workers (30, 31) noted that corn grown on high lime soils in Iowa and Wisconsin exhibited poor growth and potassium deficiency symptoms, although the soils had 140 to 200 pounds of exchangeable potassium per acre. Their conclusion was that the poor corn growth was due to the plants' failure to absorb adequate amounts of potassium because of an unfavorable balance of cations both within the plant and the soil. Potassium fertilization increased potassium uptake thereby adjusting the proportion of Ca, Mg, and K in the plant so that a more favorable cation balance was attained. Other workers (32, 38, 42) have reported similar observations and conclusions.

To ascertain whether the Ca/K and Ca+Mg/K ratios in the soil had affected potassium uptake and cereal yields on the trials of this experiment, linear correlation values were calculated (table 7). With wheat, significant negative linear correlation coefficients,

Table 6

Nitrogen Uptake by Wheat, Oats and Barley at Final Harvest (1967)

Co-operator	Crop	Nitrogen Uptake (lb/ac) Peters	Arthur	Freeborn	Foxon	Ewanek
Treatment $N - P_2O_5 - K_2O^{(1)}$						
1. 0 - 0 - 0	Wheat	29.3	33.2	53.8	42.6	24.8
2. 90 - 30 - 0	Wheat	49.5	48.6	66.9	75.8	74.7
3. 90 - 30 - 15D	Wheat	69.8	52.3	62.9	73.7	53.9
4. 90 - 30 - 30D	Wheat	65.6	52.5	64.8	66.7	53.3
5. 90 - 30 - 100B	Wheat	59.5	53.3	64.5	68.4	63.5
6. 0 - 0 - 0	Oats	23.8	19.4	42.2	45.7	27.0
7. 90 - 30 - 0	Oats	53.1	25.7	47.6	66.2	52.2
8. 90 - 30 - 15D	Oats	59.8	40.1	50.6	63.7	52.3
9. 90 - 30 - 30D	Oats	60.7	31.7	51.7	65.8	52.2
10. 90 - 30 - 100B	Oats	56.9	29.3	55.7	61.6	65.5
11. 0 - 0 - 0	Barley	38.1	31.9	50.2	45.8	29.9
12. 90 - 30 - 0	Barley	73.1	51.6	62.8	77.5	83.6
13. 90 - 30 - 15D	Barley	74.2	61.9	66.8	76.5	79.0
14. 90 - 30 - 30D	Barley	69.0	51.8	65.5	74.6	80.0
15. 90 - 30 - 60B	Barley	65.7	51.3	60.2	83.4	87.1
16. 90 - 30 - 100B	Barley	61.0	55.4	60.5	86.1	80.9

D - KCl drilled in with the seed

B - KCl broadcast on the soil surface

(1) - nutrients in pounds per acre

.05 level, were observed between the Ca/K ratio and grain yields; r=-0.89, the Ca+Mg/K ratio and grain yields; r=-0.91, and the Ca+Mg/K ratio and total yields; r=-0.95. These correlation results suggest that the Ca/K and Ca+Mg/K ratios in the soil do have some bearing on wheat growth, apparently the lower the ratios, the higher the yields. The correlation results for oats also suggested that the Ca/K and Ca+Mg/K ratio in the soil affect yields and potassium uptake. Significant negative linear correlation coefficients, .05 level, were calculated between the Ca/K ratio and potassium uptake by oats; r=-0.99, the Ca+Mg/K ratio and total oat yield; r=-0.96, and the Ca+Mg/K ratio and potassium uptake by oats; r=-0.99. Similarly, correlation results strongly indicate that barley growth is affected by the Ca/K and Ca+Mg/K ratios in the soil, because significant negative correlation coefficients were calculated between the Ca/K ratio and grain yields; r=-0.93, total yield; r=-0.99, and potassium uptake; r=-0.92, and, between the Ca+Mg/K ratio and grain yield; r=-0.92, total yield; r=-0.98, and potassium uptake; r=-0.99.

Table 7

Linear Correlation Values (r) between Ca/K, Ca+Mg/K Ratios in the Soil at Planting Time and Grain Yields, Total Yields and Potassium Uptake by the Cereals at Final Harvest. (1967)

			Wheat	n(2)	r(3)
Ca/K	ratio	vs.	grain yield	3	-0.89(1)
Ca/K	ratio	vs.	total yield	2	-0.95
Ca/K	ratio	vs.	potassium uptake	2	-0.90
Ca+Mg/K	ratio	vs.	grain yield	3	-0.91(1)
Ca+Mg/K	ratio	vs.	total yield	2	-0.95(1)
Ca+Mg/K	ratio	vs.	potassium uptake	2	-0.90
			Oats		
Ca/K	ratio	vs.	grain yield	3	-0.75
Ca/K	ratio	vs.	total yield	2	-0.95
Ca/K	ratio	vs.	potassium uptake	2	-0.99
Ca+Mg/K	ratio	vs.	grain yield	3	-0.74
Ca+Mg/K	ratio	vs.	total yield	2	-0.96(1)
Ca+Mg/K	ratio	vs.	potassium uptake	2	-0.99(1)
			Barley		
Ca/K	ratio	vs.	grain yield	3	-0.93(1)
Ca/K	ratio	vs.	total yield	3	-0.99(1)
Ca/K	ratio	vs.	potassium uptake	2	-0.99(1)
Ca+Mg/K	ratio	vs.	grain yield	3	-0.92(1)
Ca+Mg/K	ratio	vs.	total yield	3	-0.98(1)
Ca+Mg/K	ratio	vs.	potassium uptake	2	-0.99(1)

(1) significant correlation at the .05 level.

(2) Peters' trial not included where n=2 (n is the number of degrees of freedom).

(3) r values are for 90-30-0 treatment.

IV 1968 FIELD EXPERIMENT

In 1968 a field experiment similar to the 1967 field experiment was conducted to supplement the 1967 results. More explicitly, the experiment was conducted to determine if comparable results could be obtained within the seasonal variations of two growing years. Hence, this experiment was also conducted on calcareous soils which ranged from very low to very high in exchangeable potassium.

A. OBJECTIVES:

1. To determine the effect of potassium fertilization on yields and potassium uptake of cereals grown on calcareous soils with various exchangeable potassium levels. Furthermore, to relate the results of the experiment to existing soil test recommendations with the objective of confirming or improving present potassium recommendations for the growth of wheat, oats and barley on calcareous soils.

2. To study the effect of potassium fertilization on potassium concentration, potassium uptake, and yield of plant matter, at early stages of cereal growth on soils with various levels of exchangeable potassium.

3. To determine the effect of the exchangeable Ca/K ratio of the soil at seeding on cereal yields and potassium uptake by cereals.

4. To ascertain if there is a relationship between nitrogen and potassium uptake by cereals.

B. MATERIALS AND METHODS:

Soils: Five field trials were located on calcareous soils. The exchangeable potassium level of these soils varied from 30 to 414 ppm. Three Plum Ridge soils (33), located north-east of Teulon, one Pine Ridge soil (10), located south of Vita, and one Marquette soil (10), located north of Stonewall, were used. Table 8 lists some of the characteristics of the soils.

Experimental Design: The trials consisted of six replicates and were in a randomized block design. Table 10 lists the treatments and crops grown.

Procedure: The trials were planted in the third week of May. The seed, and any fertilizer added with the seed, was drilled in with a six row self-propelled seeder of the V-belt design. Each individual plot was 6 rows in width (42 inches) and thirty feet in length.

All treatments received the equivalent of 90 pounds of nitrogen and 30 pounds of P_2O_5 per acre. The nitrogen was broadcast over the soil surface in the form of NH_4NO_3 (33.5-0-0). The phosphorous, applied as $NH_4H_2PO_4$ (11-48-0), was drilled in with the seed.

Treatments 2, 3, 6, 7, 10, 11, 12, and 14 received potassium in the form of KCl drilled in with the seed. On treatments 4, 8, 13, and 15, KCl was broadcast over the soil surface.

Manitou wheat was grown in treatments 1 to 4, Rodney oats

Table 8

Characteristics of the Soils Used in the 1968
Field Experiment

Co-operator	Depth (in)	Eliuk	Kiel	Persoage north[1]	Persoage east[1]	Ewanek
Soil Association		Pine Ridge	Plum Ridge	Plum Ridge	Plum Ridge	Marquette
K (ppm)	0 - 6	30	83	102	126	414
Ca (meq/100g)	0 - 6	21.8	19.5	24.3	24.5	28.4
Ca/K Ratio [2]	0 - 6	284	92	93	76	27
Mg (meq/100g)	0 - 6	5.5	4.4	3.9	5.2	5.7
Ca+Mg/K Ratio [3]	0 - 6	355	113	108	91	32
Conductivity (mmhos/cm)	0 - 6	0.6	0.2	0.3	0.3	0.4
pH	0 - 6	8.0	8.3	8.2	8.3	7.8
Texture		F.S.L.	V.F.S.C.L.	V.F.S.C.L.	V.F.S.C.L.	C.
Percent $CaCO_3$	0 - 6	6.8	11.3	11.2	10.3	7.7
	6 - 12	14.5	23.6	24.0	18.6	20.4
P (ppm)	0 - 6	3.9	4.1	4.8	10.2	7.4
($NaHCO_3$ extractable)	6 - 12	7.1	0.9	0.9	1.5	2.0

Ca, Mg and K --- ammonium acetate extractable

(1) Location of test on co-operator's land

(2) $$\text{Ca/K Ratio} = \frac{\text{meq Ca/100g of soil}}{\text{meq K/100g of soil}}$$

(3) $$\text{Ca+Mg/K Ratio} = \frac{\text{meq Ca+Mg/100g of soil}}{\text{meq K/100g of soil}}$$

Table 9

Yield, Potassium Uptake and the Percent Potassium in the Barley Plant Matter Sampled at 14 Days of Growth (1968)

	Co-operator	Yield (lb/ac)					Potassium Uptake (lb/ac)					Percent Potassium				
		Eliuk	Kiel	Persoage north(2)	Persoage east(2)	Ewanek	Eliuk	Kiel	Persoage north(2)	Persoage east(2)	Ewanek	Eliuk	Kiel	Persoage north(2)	Persoage east(2)	Ewanek
	Treatment $N - P_2O_5 - K_2O$ (1)															
9.	90 - 30 - 0	18.7	37.5	27.4	72.2	44.3	0.1	1.0	0.9	2.8	2.2	0.6	2.7	3.3	3.9	4.9
10.	90 - 30 - 15D	34.7	41.1	34.7	78.1	53.5	0.6	1.7	1.6	3.1	3.2	1.6	4.2	4.5	4.0	6.0
11.	90 - 30 - 30D	41.1	43.9	32.0	64.0	54.8	0.8	2.0	1.7	3.6	2.7	2.0	4.6	5.4	5.6	4.9
12.	90 - 30 - 60D	38.4	55.3	30.2	53.9	41.1	1.0	3.0	1.7	3.0	2.6	2.5	5.4	5.7	5.6	6.2
13.	90 - 30 - 60B	29.7	48.0	39.3	73.6	38.8	0.4	1.4	1.3	2.6	2.0	1.3	3.0	3.3	3.5	5.1
14.	90 - 30 - 100D	43.9	47.5	20.6	41.1	34.7	1.1	2.7	1.2	2.6	2.2	2.6	5.7	5.6	5.1	6.2
15.	90 - 30 - 100B	33.8	41.6	38.8	67.6	37.9	0.5	1.3	1.6	2.7	2.1	1.5	3.1	4.2	4.0	5.4

D - KCl drilled in with the seed

B - KCl broadcast on the soil surface

(1) - nutrients in pounds per acre

(2) - location of test on co-operator's land

in treatments 5 to 8, and Conquest barley in treatments 9 to 15.

During the early part of the growing season samples were taken as follows; at 14 days of growth a three foot portion from each of the two central rows of each barley plot of the 5 trials was harvested. At 21 and 28 days of growth all three cereals were sampled, a three foot portion being harvested from each of the two central rows of each plot of the five trials. The harvested plant material from each individual treatment of the six replicates was bulked. The bulked material was then air dried, weighed, ground in a Wiley mill and analyzed for potassium content.

When the plants were mature, a 10 foot portion from each of the two central rows was harvested in every plot of the five trials. The harvested material was dried, weighed, and threshed. After threshing, the grain from each individual treatment of the six replicates was weighed, bulked, ground in a Wiley mill and analyzed for potassium and nitrogen content. The straw was handled in a similar fashion.

C. RESULTS AND DISCUSSION:

Results of the barley sampling at 14 days of growth (table 9), indicated that the application of potassium fertilizer to soils having an exchangeable potassium level of 102 ppm or less enhanced growth, potassium uptake, and the concentration of potassium in the barley plants. On the Eliuk trial, every potassium treatment increased growth considerably; the 100 pound K_2O drilled in treatment produced maximum yield, potassium uptake, and concentration of potassium in the plant. Every potassium treatment increased growth on the

Kiel trial also, with the 60 pound K_2O drilled in treatment showing the largest yield and potassium uptake responses and the 100 pound K_2O drilled in treatment showing the largest concentration of potassium in the plant matter. Every treatment but one, the 100 pound K_2O drilled in treatment, increased yields on the Persoage north trial, the largest response being to the 100 pound K_2O broadcast treatment. Also on the Persoage north trial, potassium uptake, and, in all but one case, the potassium concentration in the plant matter, was increased with potassium fertilization. (The 60 pound K_2O broadcast treatment did not alter the potassium concentration in the plants). On the Persoage east and Ewanek trials, exchangeable potassium levels of 126 and 414 ppm respectively, the 15 pound K_2O treatment produced an increase in barley plant matter yield. However, the other potassium treatments, except treatment 13 on the Persoage east trial and treatment 11 on the Ewanek trial, resulted in decreased plant matter yields at 14 days of growth. Potassium uptake and the percent potassium in the barley plant matter either increased or remained unaltered when potassium fertilizer was applied to these two trials. Overall, the potassium concentration in the barley plants at 14 days of growth was significantly correlated, .05 level, with the final barley yields, r=0.50, although the correlation coefficient was small.

Results of the barley sampling at 21 days of growth (table 10) indicated that in most cases the application of potassium fertilizer increased yields, potassium uptake, and the potassium concentration in the barley plants. On the Eliuk trial, every potassium treatment considerably increased growth, potassium uptake,

Table 10

Yield, Potassium Uptake and the Percent Potassium in the Plant Matter Sampled at 21 Days of Growth (1968)

Co-operator	Yield (lb/ac) Eliuk	Kiel	Persoage north(2)	Persoage east(2)	Ewanek	Potassium Uptake (lb/ac) Eliuk	Kiel	Persoage north(2)	Persoage east(2)	Ewanek	Percent Potassium Eliuk	Kiel	Persoage north(2)	Persoage east(2)	Ewanek
Wheat															
Treatment $N - P_2O_5 - K_2O$(1)															
1. 90 - 30 - 0	37.5	107.9	62.2	54.8	123.4	0.2	4.3	2.5	2.0	7.1	0.5	4.0	4.0	3.7	5.8
2. 90 - 30 - 15D	114.3	118.4	65.4	53.5	110.6	3.9	5.9	3.1	2.5	6.3	3.4	5.0	4.7	4.6	5.7
3. 90 - 30 - 30D	129.8	128.4	53.0	65.4	112.0	4.7	6.4	2.3	2.9	6.4	3.6	5.0	4.3	4.5	5.7
4. 90 - 30 - 100B	115.2	112.0	60.3	59.4	122.9	4.4	4.8	2.5	2.6	7.0	3.8	4.3	4.2	4.3	5.7
Oats															
5. 90 - 30 - 0	30.6	67.2	50.3	43.4	83.6	0.2	2.4	2.1	2.0	5.0	0.7	3.5	4.1	4.5	6.0
6. 90 - 30 - 15D	69.9	59.0	55.3	40.2	81.3	2.0	3.1	2.9	2.2	5.2	2.9	5.3	5.3	5.4	6.4
7. 90 - 30 - 30D	64.0	63.1	55.8	39.3	75.9	2.3	3.5	3.2	2.3	4.9	3.6	5.5	5.8	5.8	6.4
8. 90 - 30 - 100B	69.5	71.3	64.0	54.8	85.5	2.6	2.9	2.8	2.4	5.3	3.7	4.0	4.3	4.3	6.2
Barley															
9. 90 - 30 - 0	33.4	143.0	82.3	160.9	134.4	0.2	6.2	3.1	6.3	7.5	0.6	4.3	3.8	3.9	5.6
10. 90 - 30 - 15D	147.2	186.5	117.0	205.7	147.6	3.2	10.1	5.5	8.6	9.0	2.2	5.4	4.7	4.2	6.1
11. 90 - 30 - 30D	163.1	155.4	111.1	242.2	124.8	6.0	6.8	5.3	11.1	7.5	3.7	4.4	4.8	4.6	6.0
12. 90 - 30 - 60D	164.1	152.6	108.8	216.2	116.1	8.2	9.0	5.4	8.7	7.2	5.0	5.9	5.0	4.0	6.2
13. 90 - 30 - 60B	144.0	170.5	124.8	215.2	147.6	3.5	7.8	4.6	8.4	8.9	2.4	4.6	3.7	3.9	6.0
14. 90 - 30 - 100D	133.9	134.4	82.7	147.2	114.3	6.2	7.9	4.5	7.8	7.2	4.6	5.9	5.4	5.3	6.3
15. 90 - 30 - 100B	136.6	137.6	110.1	173.7	145.3	4.2	6.1	5.0	7.5	7.8	3.1	4.4	4.5	4.3	5.4

D - KCl drilled in with the seed
B - KCl broadcast on the soil surface
(1) - nutrient in pounds per acre
(2) - location of test on co-operator's land

and potassium concentration in the barley plants, the maximum growth, potassium uptake, and potassium concentration, being produced by the 60 pound K_2O drilled in treatment. However, at this stage, the 30 pound K_2O treatment was optimum with regard to yield. On the Kiel trial, all treatments increased growth with the exception of the 100 pound K_2O drilled in and broadcast treatments, which reduced growth. The 15 pound K_2O treatment produced maximum yield. Potassium uptake by barley grown on the Kiel trial was increased with every potassium treatment except the 100 pound K_2O broadcast treatment which did not alter uptake. Potassium concentration in the barley plant matter increased with the 15 pound, the 60 pound and the 100 pound drilled in treatments; the other potassium treatments did not alter potassium concentration. On the Persoage east and Persoage north trials potassium fertilization increased both potassium uptake and yield. (There was one exception, the 100 pound K_2O drilled in treatment did not alter yield). Maximum yield on the Persoage north trial was obtained with the 60 pound K_2O broadcast treatment; on the Persoage east trial maximum yield was obtained with the 30 pound K_2O treatment. For these two trials the potassium concentration was either increased or not altered when potassium fertilizer was applied. On the Ewanek trial, the 15 pound, the 60 pound, and the 100 pound K_2O broadcast treatments increased yield with the 15 pound K_2O treatment being optimum. The other three treatments reduced yield. However, potassium fertilization did increase potassium concentration (except for the 100 pound broadcast treatment which did not alter potassium concentration) and potassium uptake. Final barley yields were not found to correlate significantly, .05 level, with percent potassium in the barley plants at 21 days of growth, r=0.23.

Results of the wheat sampling at 21 days of growth (table 10) indicated that potassium fertilization increased yields, potassium uptake, and the concentration of potassium in the plants on soils with an exchangeable potassium level of 83 ppm or less. On the Kiel and Eliuk trials every potassium treatment produced a response in yield, potassium uptake, and potassium concentration in the plant matter; the 30 pound K_2O treatment being optimum with regard to yield on these two trials. On the other three trials potassium fertilization produced fewer positive responses in yield, uptake, and concentration. Only three treatments produced a response in yield on these three trials, the 15 pound K_2O treatment on the Persoage north trial, and the 30 and 100 pound K_2O treatments on the Persoage east trial. The other potassium treatments, except the 100 pound K_2O treatment on the Ewanek trial which did not alter yield, reduced yield at this stage of growth. On the Persoage east trial potassium uptake increased with every potassium treatment. On the Persoage north trial the 15 pound K_2O treatment increased uptake while the 30 and 100 pound K_2O treatments did not alter potassium uptake. On the Ewanek trial, potassium uptake decreased with the 15 and 30 pound K_2O treatments, and was not altered by the 100 pound K_2O treatment. On the two Persoage trials potassium concentration increased with the application of potassium fertilizer, while, on the Ewanek trial, potassium concentration was not altered with the application of potassium fertilizer. Overall, no significant correlation coefficient, .05 level, was observed between potassium concentration in the wheat plant at this stage of growth and final wheat yields, r=0.32.

Results of the oat sampling at 21 days of growth (table 10) indicated that potassium fertilization had a more consistently positive effect on uptake and concentration than on yield. On the Eliuk and Persoage north trials every potassium treatment produced a yield response. But; on the Kiel, Persoage east, and Ewanek trials, only the 100 pound K_2O treatment increased oat yield; the other potassium treatments reduced yields at this stage of growth. Potassium fertilization increased potassium uptake on every trial, the only exception being the 30 pound K_2O treatment on the Ewanek trial. Potassium fertilization also increased potassium concentration in the plant matter on all trials, with one exception, the 100 pound K_2O treatment on the Persoage east trial. However, the correlation coefficient, r=0.41, between potassium concentration at this stage of growth and final yields was non-significant at the .05 level.

Results of the barley sampling at 28 days of growth (table 11) indicated that in most cases potassium fertilization produced increased yields, potassium uptake, and potassium concentration in the plant matter. On the Eliuk and Ewanek trials, every potassium treatment increased yield. Yields were also increased with all but two potassium treatments on the Kiel trial; treatments 11 and 15 reduced yields. Similarly, on the Persoage north trial yields were increased with all but two potassium treatments; treatments 13 and 14 reduced yields. On the Persoage east trial three potassium treatments; the 15, the 30, and the 60 pound K_2O broadcast treatments, increased yields. However, the 60 pound K_2O drilled in and the 100 pound K_2O drilled in treatments reduced yields, while the 100 pound K_2O broadcast treatment did not alter yields. Potassium uptake

Table 11

Yield, Potassium Uptake and the Percent Potassium in the Plant Matter Sampled at 28 Days of Growth (1968)

Co-operator	Yield (lb/ac)					Potassium Uptake (lb/ac)					Percent Potassium				
	Eliuk	Kiel	Persoage north(2)	Persoage east(2)	Ewanek	Eliuk	Kiel	Persoage north(2)	Persoage east(2)	Ewanek	Eliuk	Kiel	Persoage north(2)	Persoage east(2)	Ewanek
Wheat															
Treatment $N - P_2O_5 - K_2O$(1)															
1. 90 - 30 - 0	59.9	314.4	147.2	160.4	240.4	0.6	13.8	5.3	6.6	12.0	1.0	4.4	3.6	4.1	5.0
2. 90 - 30 - 15D	290.7	266.9	188.3	221.2	267.3	7.6	12.8	8.1	9.7	14.7	2.6	4.8	4.3	4.4	5.5
3. 90 - 30 - 30D	363.3	287.9	169.1	160.4	222.1	12.7	14.4	7.3	8.0	12.0	3.5	5.0	4.3	5.0	5.4
4. 90 - 30 - 100B	265.1	289.3	194.2	179.6	272.8	10.9	13.9	8.4	8.1	14.2	4.1	4.8	4.3	4.5	5.2
Oats															
5. 90 - 30 - 0	92.3	134.4	197.0	132.1	220.3	0.7	5.5	6.9	5.9	12.1	0.8	4.1	3.5	4.5	5.5
6. 90 - 30 - 15D	230.3	152.2	188.7	139.4	185.5	5.1	7.8	9.3	7.5	10.9	2.2	5.1	4.9	5.4	5.9
7. 90 - 30 - 30D	174.6	139.8	217.1	194.7	185.5	5.4	7.6	10.6	10.9	10.9	3.1	5.4	4.9	5.6	5.9
8. 90 - 30 - 100B	215.2	142.6	249.1	159.5	218.0	8.2	7.1	11.7	8.5	12.9	3.8	5.0	4.7	5.3	5.9
Barley															
9. 90 - 30 - 0	62.2	527.4	339.6	519.2	287.9	0.4	21.1	12.6	17.1	13.5	0.7	4.0	3.7	3.3	4.7
10. 90 - 30 - 15D	446.0	627.5	380.7	591.8	351.0	8.0	27.0	17.1	23.1	17.6	1.8	4.3	4.5	3.9	5.0
11. 90 - 30 - 30D	393.9	466.6	353.7	566.7	354.6	12.2	23.3	16.3	27.2	18.1	3.1	5.0	4.6	4.8	5.1
12. 90 - 30 - 60D	539.3	660.4	365.6	503.2	299.3	22.7	36.3	18.7	25.7	16.2	4.2	5.5	5.1	5.1	5.4
13. 90 - 30 - 60B	415.0	611.0	202.9	570.8	330.1	14.5	24.7	8.1	23.4	16.5	3.5	4.0	4.0	4.1	5.0
14. 90 - 30 - 100D	420.0	554.8	254.1	446.5	312.1	22.3	30.5	13.0	22.8	16.9	5.3	5.5	5.1	5.1	5.4
15. 90 - 30 - 100B	461.1	473.9	351.0	516.4	337.3	18.4	21.3	15.1	23.8	17.5	4.0	4.5	4.3	4.6	5.2

D - KCl drilled in with the seed
B - KCl broadcast on the soil surface
(1) - nutrients in pounds per acre
(2) - location of test on co-operator's land

responded to potassium treatments on all five trials, as did the potassium concentration in the plant matter. The only exception was the 60 pound K_2O broadcast treatment on the Kiel trial which did not affect the potassium concentration in the plant matter. Moreover, a significant, .05 level, correlation coefficient, r=0.77, was observed between the potassium concentration in the barley plants at 28 days of growth and final barley yields.

The results of the wheat sampling at 28 days of growth (table 11) indicated somewhat erratic yield responses to potassium fertilization, although uptake and concentration responses were quite consistently positive. On the Eliuk trial potassium fertilization produced a yield response. However, on the Kiel trial, potassium fertilization reduced wheat yields at this stage of growth. On the other three trials potassium fertilization increased wheat yields, except for the 30 pound K_2O treatment which, on the Persoage east trial, did not alter yield and, on the Ewanek trial, reduced yield. Potassium uptake was increased by the application of potassium fertilizer on all five trials with only three exceptions. These were the 15 pound K_2O treatment on the Kiel trial which reduced uptake; the 100 pound K_2O treatment on the Kiel trial which did not affect uptake, and, the 30 pound K_2O treatment on the Ewanek trial which did not affect uptake. Furthermore, potassium fertilization increased potassium concentration in the plant matter on all five trials. However, no significant, .05 level, correlation coefficient, r=0.38, was observed between the potassium concentration at 28 days of growth and final wheat yields.

The results of the oat sampling at 28 days (table 11) indicated that potassium fertilization increased yields on soils with an exchangeable potassium level of 126 ppm or less. The only exception was the 15 pound K_2O treatment on the Persoage north trial which reduced oat yields. On the Ewanek trial which had an exchangeable potassium level of 414 ppm, yields were consistently reduced by the application of potassium fertilizer. Potassium uptake also increased when potassium fertilizer was applied to soils with an exchangeable potassium level of 126 ppm or less. Interestingly, on the Ewanek trial, potassium uptake was reduced with the 15 and 30 pound K_2O treatments but slightly increased with the 100 pound K_2O treatment. The potassium concentration in the plant matter increased on all five trials with the application of potassium fertilizer. A significant, .05 level, correlation coefficient, r=0.62, was observed between potassium concentration at 28 days and final oat yields.

The potassium recommendation for cereals (43) on the soil of the Eliuk trial was 30 pounds of K_2O per acre, and on the soil of Kiel trial 15 pounds of K_2O per acre. The recommended method of application was to drill the potassium in with the seed. Therefore, on these soils, a wheat, oat, and barley grain response to potassium fertilizer was expected.

On the Eliuk trial, there was a significant, .05 level, grain and total yield response by wheat, oats, and barley (table 12) to every potassium treatment. But, an overall comparison of the yields produced by the various treatments revealed that the recommended rate of 30 pounds of K_2O per acre was not sufficient to produce maximum cereal yields on a soil with such a low exchangeable potassium level. On this trial the largest cereal yields were realized with the 100 pound K_2O treatment. It should also be noted that barley

Table 12

Grain and Total Yields of Wheat, Oats and Barley
at Final Harvest (1968)

	Grain Yield (bu/ac)					Total Yield (cwt/ac)				
Co-operator	Eliuk	Kiel	Persoage north(2)	Persoage east(2)	Ewanek	Eliuk	Kiel	Persoage north(2)	Persoage east(2)	Ewanek
Wheat										
Treatment $N - P_2O_5 - K_2O$ (1)										
1. 90 - 30 - 0	5.0	52.1	31.3	37.3	25.0	23.3	85.5	49.9	66.9	47.2
2. 90 - 30 - 15D	33.7	59.0	30.9	39.2	26.0	61.8	100.5	52.2	68.3	46.9
3. 90 - 30 - 30D	40.7	60.0	33.9	35.0	29.4	71.5	92.4	55.6	61.6	50.4
4. 90 - 30 - 100B	44.4	59.5	32.5	38.9	30.7	70.6	95.2	54.2	70.9	51.6
L.S.D. (.05)	3.7	5.2	NS	NS	3.6	15.9	NS	NS	NS	NS
Oats										
5. 90 - 30 - 0	22.3	106.1	71.3	100.3	72.1	31.9	83.7	65.4	73.3	52.9
6. 90 - 30 - 15D	52.4	104.9	69.5	97.8	72.6	62.5	79.4	67.8	72.7	52.6
7. 90 - 30 - 30D	75.1	104.4	68.4	107.3	71.5	76.5	82.1	61.7	79.4	52.5
8. 90 - 30 - 100B	84.3	111.6	72.6	97.4	80.0	83.8	85.1	66.3	73.8	54.2
L.S.D. (.05)	18.2	NS	NS	NS	NS	17.4	NS	NS	NS	NS
Barley										
9. 90 - 30 - 0	2.4	75.1	58.9	59.9	62.1	6.0	82.5	62.9	71.9	52.6
10. 90 - 30 - 15D	43.8	71.6	53.1	63.8	68.1	49.4	74.6	59.5	70.5	56.3
11. 90 - 30 - 30D	56.9	77.7	62.2	62.8	68.8	59.6	82.2	69.8	71.4	58.9
12. 90 - 30 - 60D	62.7	79.1	63.5	58.6	65.6	65.9	94.7	74.4	66.6	55.8
13. 90 - 30 - 60B	57.9	76.7	64.8	66.6	69.4	70.5	84.9	68.5	77.8	57.9
14. 90 - 30 - 100D	65.4	80.2	68.8	57.8	71.1	68.9	95.3	78.6	67.7	58.3
15. 90 - 30 - 100B	59.2	77.4	53.3	69.0	70.8	63.9	88.7	65.0	78.3	59.7
L.S.D. (.05)	7.2	NS	NS	NS	NS	9.5	12.2	NS	NS	NS

D - KCl drilled in with the seed
B - KCl broadcast on the soil surface
(1) - nutrients in pounds per acre
(2) - location of test on co-operator's land

grain yields of the drilled in potassium treatments surpassed the yields of the broadcast treatments.

On the Kiel trial, a significant, .05 level, wheat grain and a non-significant, .05 level, wheat total yield response was observed with every potassium treatment, the optimum treatment with regard to wheat yield being 15 pounds of K_2O per acre. With oats, only the 100 pound K_2O per acre treatment increased grain and total yields, a non-significant increase at the .05 level. The 15 and 30 pound K_2O treatments reduced both oat grain and total yields. Two treatments on the Kiel trial, 60 and 100 pounds of K_2O drilled in, produced a substantial, although non-significant, .05 level, barley grain response; 4.0 and 5.0 bushels respectively. These two drilled in treatments also increased barley total yields significantly, .05 level. The 60 and 100 pound K_2O broadcast treatments, and the 30 pound K_2O drilled in treatment also realized non-significant, .05 level, barley grain responses. But, the 15 pound K_2O treatment reduced barley grain yield.

Hence, these results support present potassium recommendations for the growth of wheat on a soil having an exchangeable potassium level as represented by the Kiel trial. However, the results from the Eliuk trial and the oat and barley results from the Kiel trial suggest that the rate of potassium fertilization presently recommended for the growth of these cereals be increased on soils with exchangeable potassium levels as represented by these two trials.

The soil test recommendation (43) for the two Persoage trials did not advise the application of potassium fertilizer for wheat, oats, and barley. Because these soils had exchangeable potassium levels of 102 and 126 ppm it was doubtful whether or not cereals would respond to potassium fertilization. However, small, 2.6 bushels or less, non-significant, .05 level, wheat grain responses were observed with the 30 and 100 pound K_2O treatments on the Persoage north trial, and with the 15 and 100 pound K_2O treatments on the Persoage east trial. Substantial but non-significant, .05 level, total wheat yield increases were observed with all treatments except the 30 pound K_2O treatment on the east trial. But, on these two trials, only one treatment increased oat grain and total oat yields substantially, non-significantly at an .05 level, the 30 pound K_2O treatment on the Persoage east trial. The other potassium treatments either had little effect or reduced oat yields. On the other hand, on the Persoage north trial, every potassium treatment but two, the 15 pound and 100 pound K_2O broadcast treatments, increased barley grain yields, non-significantly at an .05 level. Maximum barley grain yield on the Persoage north trial was observed with the 100 pound K_2O drilled in treatment which produced a 9.9 bushel response. Total barley yields also showed a response, non-significant at an .05 level, to every potassium treatment except the 15 pound K_2O treatment which reduced yields. On the Persoage east trial, every potassium treatment but two, 60 and 100 pounds of K_2O drilled in, increased barley grain yields. The 100 pound K_2O broadcast treatment produced the maximum response on the Persoage east trial, 9.1 bushels. However, only two potassium treatments increased the total barley yield on the Persoage east trial, the 60 and 100 pound K_2O broadcast treatments. Therefore, although these results support the present recommendations for oats, they also suggest that barley yields, and to a smaller degree, wheat yields, could be increased on soils having exchangeable potassium levels as represented by these two trials.

The exchangeable potassium level of the soil of the Ewanek trial was rated as very high and the soil test recommendation (43) did not advise the application of potassium for cereal growth. Therefore, on this soil a cereal response to potassium fertilizer was not expected. However, wheat and barley did respond to potassium fertilization. The 30 and 100 pound K_2O treatments produced a significant, .05 level, response in wheat grain yields. These two treatments also increased, non-significantly at an .05 level, total wheat yields. Barley grain and total barley yields also showed a response to every potassium treatment. The maximum barley yield was achieved with the 100 pound K_2O drilled in treatment, a 9.0 bushel response. However, only one treatment increased oat grain and total oat yields; the 100 pound K_2O treatment which produced a 7.9 bushel response. The other two treatments did not affect oat grain and total oat yields. These results suggest that wheat and barley might respond to potassium fertilization on soils with very high levels of exchangeable potassium. Additionally, they also suggest the possibility that oats might respond to high applications of potassium on soils with high levels of exchangeable potassium.

Total potassium uptake by wheat (table 13) increased on the Eliuk, Kiel, and Persoage north trials with the application of potassium fertilizer. On the other two trials, the Ewanek and the Persoage east, total uptake of potassium decreased with potassium fertilization, except for the 100 pound K_2O treatment on the Persoage

Table 13

Potassium Uptake by Wheat, Oats and Barley at Final Harvest (1968)

Co-operator	Crop	Potassium Uptake (lb/ac)				
		Eliuk	Kiel	Persoage north(2)	Persoage east(2)	Ewanek
Treatment						
$N - P_2O_5 - K_2O$(1)						
1. 90 - 30 - 0	Wheat	12.2	58.6	26.2	46.9	36.8
2. 90 - 30 - 15D	Wheat	15.8	75.3	28.9	42.9	33.1
3. 90 - 30 - 30D	Wheat	20.0	73.6	35.3	43.8	39.1
4. 90 - 30 - 100B	Wheat	34.2	84.5	34.6	59.0	35.5
5. 90 - 30 - 0	Oats	9.5	76.1	42.9	54.8	60.1
6. 90 - 30 - 15D	Oats	13.0	79.5	45.5	61.1	63.1
7. 90 - 30 - 30D	Oats	19.1	85.6	39.6	65.7	60.1
8. 90 - 30 - 100B	Oats	25.7	94.5	46.2	62.0	55.4
9. 90 - 30 - 0	Barley	2.8	79.6	47.0	50.0	49.4
10. 90 - 30 - 15D	Barley	13.8	70.9	49.1	51.8	58.9
11. 90 - 30 - 30D	Barley	21.5	90.3	55.8	52.1	63.5
12. 90 - 30 - 60D	Barley	35.0	125.0	68.8	54.1	66.7
13. 90 - 30 - 60B	Barley	33.4	106.2	53.5	65.1	69.7
14. 90 - 30 - 100D	Barley	53.8	136.8	78.9	59.9	68.7
15. 90 - 30 - 100B	Barley	46.6	120.8	70.1	81.5	70.8

D - KCl drilled in with the seed

B - KCl broadcast on the soil surface

(1) - nutrients in pounds per acre

(2) - location of test on co-operator's land

east trial and 30 pound K_2O treatment on the Ewanek trial which increased uptake.

Total potassium uptake by oats (table 13) increased on the Eliuk, Kiel, and Persoage trials with potassium fertilization. The only exception was a decrease in uptake with the 30 pound K_2O treatment on the Persoage north trial. On the Ewanek trial only the 15 pound K_2O treatment produced a small increase in potassium uptake.

Summing up these results; an increased potassium uptake in response to potassium fertilization can be expected for barley grown on soils with an exchangeable potassium level of 414 ppm or less. Potassium uptake by oats can be expected to increase when soils having an exchangeable potassium level of 126 ppm or less are fertilized with potassium. Probably, potassium uptake by wheat will respond to potassium fertilization on soils with an exchangeable potassium level of 102 ppm or less. In a general summary of potassium uptake data, it should also be noted that the uptake of potassium per pound of wheat produced was 0.0066 pounds whereas for oats it was 0.0077 pounds per pound of oats produced, and for barley 0.0092 pounds per pound of barley produced.

Significant linear correlation coefficients, .05 level, were calculated between the amount of potassium taken up by wheat, oats, and barley and grain yields at harvest, figures 4, 5, and 6. The correlation coefficients were 0.86, 0.75 and 0.85 respectively. When the 1967 and 1968 data was combined, significant linear correlation coefficients, .05 level, were also calculated between potassium uptake and grain yields of wheat, oats and barley at final harvest;

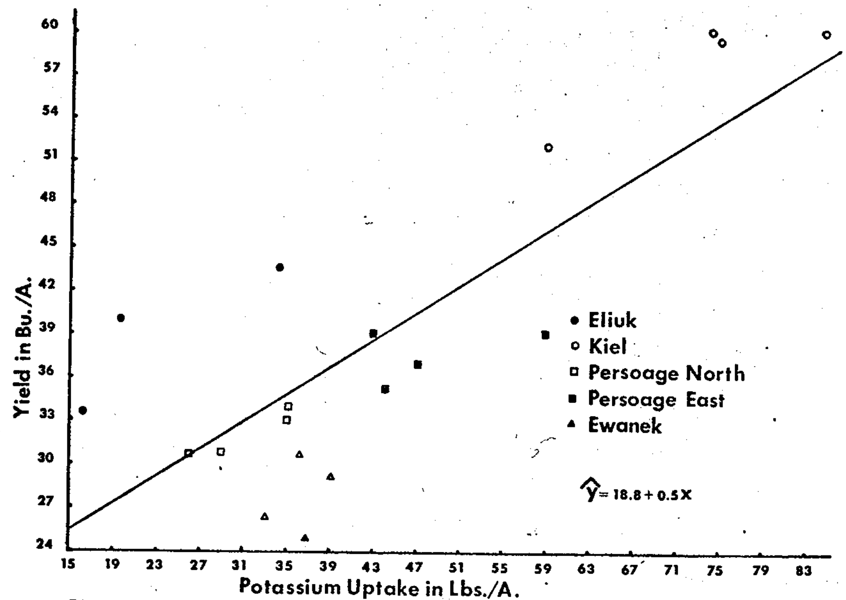


Figure 4 Potassium Uptake by Wheat Versus Wheat Yields at Final Harvest 1968

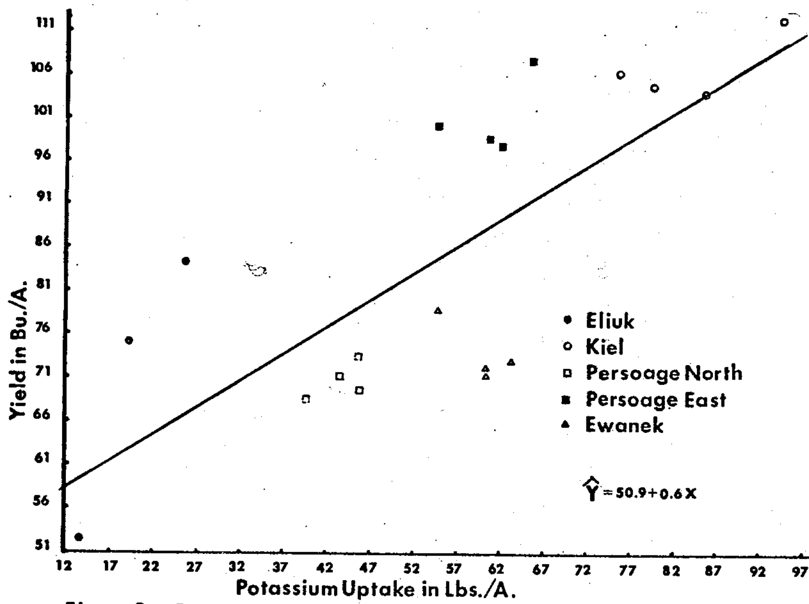


Figure 5 Potassium Uptake by Oats Versus Oat Yields at Final Harvest 1968

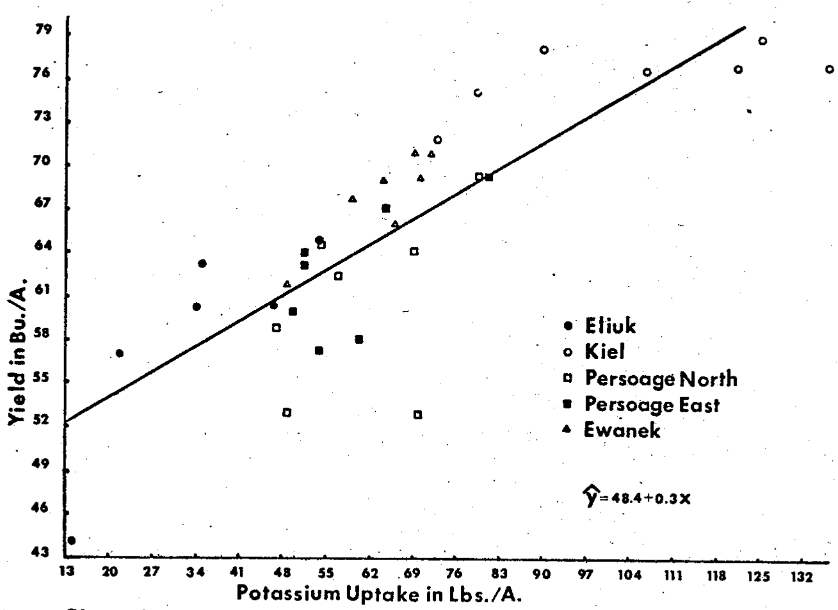


Figure 6 Potassium Uptake by Barley Versus Barley Yields at Final Harvest 1968

r=0.81, 0.73 and 0.79 respectively. Significant linear correlation coefficients, .05 level, were calculated between the amount of potassium taken up by wheat and barley and the total yields in the 1968 data. The correlation coefficients were 0.89 and 0.78 respectively. However, no significant correlation coefficient, .05 level, was observed between potassium uptake and oat total yield, r=0.28. But, when the 1967 and 1968 data was combined significant linear correlation coefficients, .05 level, were calculated between potassium uptake and total yields of the three cereals at final harvest, r=0.75 for wheat, 0.56 for oats and 0.74 for barley. No significant relationship, .05 level, was observed between potassium uptake (1968 data) by wheat, oats and barley and the level of exchangeable potassium in the soil; r=0.16, 0.40 and 0.22 respectively.

A comparison of the drilled in and broadcast methods of application is interesting (table 12). For example, on the Eliuk and Kiel trials the 60 pound K_2O drilled in treatment produced more barley grain than the 60 pound broadcast treatment, whereas on the two Persoage trials and the Ewanek trial it produced less barley grain. However, in a comparison of the two methods of application for 100 pound K_2O treatments, the drilled in treatment out yielded the broadcast treatment on the Kiel, Eliuk, and Persoage north trials. On the Persoage east trial, the 100 pound K_2O broadcast treatment out yielded the drilled in treatment, but; on the Ewanek trial, no distinct difference in barley grain yield was observed between the two methods of application. However, with both the 60 and 100 pound K_2O applications, the differences in yield between the broadcast and drilled in treatments, although fairly large, were non-significant at an .05 level on the Eliuk, Kiel, and Persoage trials. These results suggest that drilling in high rates of potassium fertilizer with the seed on soils with low exchangeable potassium levels, 102 ppm or less, is a more favourable method of application than broadcasting the fertilizer on the soil surface with regard to barley grain yields. On soils of higher exchangeable potassium levels broadcasting high rates of potassium fertilizer will probably result in greater barley grain yields than drilling the fertilizer in with the seed.

To determine the degree of relationship between nitrogen and potassium uptake, linear correlation values were calculated for the uptake of the two nutrients by the three cereals. The uptake of the two nutrients was observed to be significantly correlated, .05 level, for wheat; r=0.78, and barley; r=0.70. However, nitrogen and potassium uptake by oats was not observed to be significantly, .05 level, correlated, r=0.22. But when the 1967 and 1968 data was combined and linear correlation coefficients were calculated between nitrogen and potassium uptake, significant relationships, .05 level, were observed for wheat; r=0.75, oats; r=0.52, and barley; r=0.75.

To ascertain whether the Ca/K and Ca+Mg/K ratios in the soil had affected potassium uptake and cereal yields on the trials of this experiment, linear correlation values were calculated (table 15). Only one significant, .05 level, correlation value was observed, the relationship between the Ca+Mg/K ratio in the soil and barley grain yields, r=-0.92. The correlation values for the other relationships, Ca/K and Ca+Mg/K ratios versus potassium uptake, grain yield, and total yield, proved to be non-significant, .05 level, for the three

Table 14

Nitrogen Uptake by Wheat, Oats and Barley at Final Harvest (1968)

Co-operator	Crop	Nitrogen Uptake (lb/ac)				
		Eliuk	Kiel	Persoage north[(2)]	Persoage east[(2)]	Ewanek
Treatment $N - P_2O_5 - K_2O$[(1)]						
1. 90 - 30 - 0	Wheat	42.0	108.6	56.6	80.3	52.3
2. 90 - 30 - 15D	Wheat	81.9	125.2	55.6	77.3	50.1
3. 90 - 30 - 30D	Wheat	92.7	120.1	62.0	70.6	56.6
4. 90 - 30 - 100B	Wheat	98.0	117.9	56.1	75.4	59.3
5. 90 - 30 - 0	Oats	48.6	100.3	56.3	72.2	60.4
6. 90 - 30 - 15D	Oats	78.6	92.7	56.1	73.3	60.1
7. 90 - 30 - 30D	Oats	95.4	95.5	51.9	79.4	58.4
8. 90 - 30 - 100B	Oats	96.7	94.5	58.6	69.6	66.0
9. 90 - 30 - 0	Barley	14.6	125.6	75.4	80.2	69.6
10. 90 - 30 - 15D	Barley	81.8	113.8	64.8	77.4	76.7
11. 90 - 30 - 30D	Barley	89.1	122.6	71.8	77.2	77.0
12. 90 - 30 - 60D	Barley	96.3	138.8	73.7	70.5	73.8
13. 90 - 30 - 60B	Barley	87.1	129.8	75.0	80.7	74.1
14. 90 - 30 - 100B	Barley	101.3	141.6	81.9	66.0	75.8
15. 90 - 30 - 100D	Barley	91.7	126.7	69.6	83.0	103.5

D - KCl drilled in with the seed

B - KCl broadcast on the soil surface

(1) - nutrients in pounds per acre

(2) - location of test on co-operator's land

crops, the exception being as mentioned above between the Ca+Mg/K ratio and barley grain yield. However, the number of degrees of freedom for these relationships in this experiment was small (table 15). When linear correlation coefficients were calculated for the 1967 and 1968 combined data (table 15) most of these relationships were significant, .05 level. With wheat, significant, .05 level, negative linear correlation coefficients were observed between the Ca/K ratio in the soil and grain yield; r=-0.70, between Ca/K ratio and potassium uptake; r=-0.73, between Ca+Mg/K ratio and grain yield; r=-0.70, and between Ca+Mg/K ratio and potassium uptake; r=-0.73. For oats, significant, .05 level, negative linear correlation coefficients were calculated between the Ca/K ratio in the soil and potassium uptake; r=-0.79, and between the Ca+Mg/K ratio in the soil and potassium uptake; r=-0.80. Similarly, significant, .05 level, negative correlation coefficients were calculated between the Ca/K ratio in the soil and barley grain yield; r=-0.86, barley total yields, r=-0.76, and potassium uptake by barley; r=-0.80, and between Ca+Mg/K ratio in the soil and barley grain yield; r=-0.87, total barley grain yield; r=-0.77, and potassium uptake by barley; r=-0.80.

Table 15

Linear Correlation Values (r) between Ca/K, Ca+Mg/K Ratios in the Soil at Planting Time and Grain Yields, Total Yields and Potassium Uptake by the Cereals at Final Harvest for 1968 and for 1967 and 1968 Combined Data

				- 1968 -		- 1967 and 1968 -	
wheat				n	r[2]	n[3]	r[2]
Ca/K	ratio	vs.	grain yield	3	-0.68	8	-0.70[1]
Ca/K	ratio	vs.	total yield	3	-0.55	7	-0.55
Ca/K	ratio	vs.	potassium uptake	3	-0.68	7	-0.73[1]
Ca+Mg/K	ratio	vs.	grain yield	3	-0.68	8	-0.70[1]
Ca+Mg/K	ratio	vs.	total yield	3	-0.55	7	-0.55
Ca+Mg/K	ratio	vs.	potassium uptake	3	-0.67	7	-0.73[1]
oats							
Ca/K	ratio	vs.	grain yield	3	-0.79	8	-0.61
Ca/K	ratio	vs.	total yield	3	-0.67	7	-0.44
Ca/K	ratio	vs.	potassium uptake	3	-0.85	7	-0.79[1]
Ca+Mg/K	ratio	vs.	grain yield	3	-0.79	8	-0.62
Ca+Mg/K	ratio	vs.	total yield	3	-0.68	7	-0.45
Ca+Mg/K	ratio	vs.	potassium uptake	3	-0.85	7	-0.80[1]
barley							
Ca/K	ratio	vs.	grain yield	3	-0.32	8	-0.86[1]
Ca/K	ratio	vs.	total yield	3	-0.82	8	-0.76[1]
Ca/K	ratio	vs.	potassium uptake	3	-0.78	7	-0.80[1]
Ca+Mg/K	ratio	vs.	grain yield	3	-0.92[1]	8	-0.87[1]
Ca+Mg/K	ratio	vs.	total yield	3	-0.82	8	-0.77[1]
Ca+Mg/K	ratio	vs.	potassium uptake	3	-0.79	7	-0.80[1]

(1) significant correlation at the .05 level
(2) r values are for the 90-30-0 treatment
(3) Peters' trial not included where n = 7

V GREENHOUSE EXPERIMENT I

In the summer of 1967 a greenhouse experiment was conducted. Primarily, the purpose of this experiment was to provide further data and information to supplement the information obtained from the field experiments.

A. MATERIALS AND METHODS:

Soils: Twenty-three soils were studied in this experiment. These soils were selected primarily for their range in available potassium content and secondly for their range in percent $CaCO_3$ equivalent, and pH. The samples were obtained from the plow layer of cultivated Manitoba soils. Soil Analysis (table 16) indicated that the available potassium content ranged from 20 to 454 ppm; the percent $CaCO_3$ equivalent ranged from 0.08 to 31.66, and the pH from 5.9 to 7.7.

Experimental Design: There were two treatments for each soil. Treatment A did not receive potassium fertilizer while treatment B received potassium fertilizer, KCl, to the equivalent of 60 pounds of K_2O per acre (weight basis). Each treatment was replicated four times with every soil and the data was analyzed statistically using the randomized block design.

Procedure: The soils were air-dried, mixed, and sieved to remove roots and plant residue. A representative sample of each soil was taken for chemical analysis. Two kilo-grams of soil were placed in one-gallon glazed porcelain crocks. Ten ppm phosphorous, as

Table 16

Characteristics of Soils Used in Greenhouse Experiment

Soil Association		ppm K NH_4OAC extractable	ppm K $CaCl_2$ extractable	ppm K H_2O extractable	pH	$CaCO_3$ equivalent %	Texture
Pelan	I	20	15	15	7.4	9.91	L.S.
Almasippi	II	30	25	25	7.1	0.18	L.S.
Pelan	III	31	24	27	7.4	1.30	L.S.
Pelan	IV	34	53	19	7.0	0.55	S.L.
Stockton	V	36	40	31	5.9	0.24	F.S.L.
Almasippi	VI	42	40	31	7.4	0.54	L.S.
Almasippi	VII	47	45	23	6.4	0.08	L.S.
Gladstone	VIII	51	37	20	7.4	6.72	F.S.L.
Foster[1]	IX	55	37	34	7.4	0.74	L.S.
Pine Ridge	X	60	58	38	7.3	1.82	L.S.
Almasippi	XI	64	36	17	7.3	0.45	L.S.
Pine Ridge	XII	101	57	41	7.4	6.62	L.F.S.
Lakeland	XIII	102	57	30	7.7	31.66	Si.C.L.
Lakeland	XIV	107	71	33	7.4	20.81	Si.C.L.
Almasippi	XV	109	71	47	7.5	1.25	V.F.S.L.
Holland	XVI	122	92	39	7.4	0.61	V.F.S.L.
Foster[1]	XVII	135	97	81	7.4	2.31	L.S.
Stockton	XVIII	150	124	70	6.8	0.27	F.S.L.
Holland	XIX	162	115	48	6.4	0.29	V.F.S.L.
Emerson	XX	204	85	31	7.6	16.11	Si.L.
Rathwell	XXI	300	220	78	7.2	0.77	C.L.
Emerson	XXII	420	232	51	7.5	1.86	Si.L.
Osborne	XXIII	454	258	105	7.6	1.47	C.

(1) - name of farmer from whom soil was obtained

$NH_4H_2PO_4$, was added in dilute solution as a band 1.5 inches below the soil surface. In treatment B, five pellets of KCl, each weighing approximately 20 mgms, were placed equidistant from each other across the diameter of the crocks. Two rows of Parkland barley seed, consisting of four seeds in each row, were sown; one row on either side of the KCl pellets. Both the seed and the KCl pellets were about a half an inch below the soil surface. Five days after emergence the seedlings were thinned to four plants per crock. Distilled water was used for watering. The plants received sixteen hours of light per day. The crocks of each of the four replicates were randomly arranged on the greenhouse bench and their position on the bench was rotated once every week. After emergence all the pots received three surface applications of nitrogen. Five days after emergence 40 ppm nitrogen was applied as $(NH_4)_2SO_4$ dissolved in distilled water. The two other applications, each supplying 30 ppm nitrogen, NH_4NO_3 dissolved in distilled water, were applied fifteen days and thirty days after emergence. Fifty-six days after seeding the above ground portion of the plants was harvested. The harvested plant material was air dried, weighed and ground in a Wiley mill. Then the ammonium acetate extractable potassium in these harvested plant samples was measured.

B. RESULTS AND DISCUSSION:

The application of potassium fertilizer is recommended for barley growth on Manitoba soils with 84 ppm or less of available potassium (42). Soils I to XI (table 16) were in this range. The yield and percent potassium in plant matter data (table 17) from these soils, if applied to field conditions, definitely support recommendations for the application of potassium fertilizer. Significant barley plant matter increases to potassium fertilization, .05 level for four soils and .01 level for six soils, were recorded for ten of the eleven soils and a substantial increase was recorded for the eleventh soil, Almasippi II. The percent potassium in plant matter grown on these soils was also increased by the application of potassium fertilizers, significantly for eight soils, .05 level for four soils and .01 level for four soils, and substantially for two soils. Furthermore, potassium fertilization increased yield and percent potassium in the barley plants on both acidic and alkaline soils and on both calcareous and non-calcareous soils.

The available potassium level of soils XII to XXIII ranged from 101 to 454 ppm (table 16). The application of potassium fertilizer for barley growth would not be recommended for soils with these levels of available potassium (42). However, the application of potassium fertilizer to these twelve soils resulted in two significant yield increases, Holland XVI significant at the .05 level and Emerson XX significant at the .01 level, as well as one significant increase, .05 level, in the percent potassium in the barley matter, Almasippi XV. Substantial but not significant yield increases were realized on the Pine Ridge XII, Lakeland XIII, and Emerson XXII soils. Although barley yields did increase on the other seven soils with potassium fertilization, these increases were not substantial. Therefore, in the main, if the yield data were applied to field condi-

Table 17

Yield, Potassium Concentration, and Potassium Uptake by the Plant Matter in the Greenhouse Experiment

Soil Association		Yield of check in grams	Yield of 60 lb/ac treatment in grams	Percent K in plant matter of check treatment	Percent K in plant matter of 60 lb/ac treatment	K uptake in check treatment (grams)	K uptake in 60 lb/ac treatment (grams)	Difference in yield between check and 60 lb/ac treatment (grams)
Pelan	I	1.25	2.63**	1.43	2.29**	0.02	0.06	1.38
Almasippi	II	2.40	3.66	1.69	2.38	0.04	0.09	1.26
Pelan	III	1.60	2.98**	1.30	2.16*	0.02	0.06	1.38
Pelan	IV	1.97	3.30**	1.99	2.60**	0.04	0.09	1.33
Stockton	V	1.85	2.53*	2.92	3.59*	0.05	0.09	1.33
Almasippi	VI	2.50	3.91**	2.44	2.78**	0.06	0.09	0.68
Almasippi	VII	2.57	3.71**	2.75	2.91	0.07	0.11	1.41
Gladstone	VIII	2.99	3.62*	1.25	1.99**	0.04	0.11	1.14
Foster(1)	IX	1.83	3.36**	2.24	2.67*	0.04	0.07	0.63
Pine Ridge	X	2.95	3.56*	2.74	3.24	0.08	0.09	1.53
Almasippi	XI	2.65	4.33**	1.87	2.18*	0.05	0.12	0.61
Pine Ridge	XII	4.25	5.53	2.36	2.80	0.10	0.09	1.68
Lakeland	XIII	4.54	5.36	1.94	2.41	0.09	0.15	1.28
Lakeland	XIV	4.43	4.53	3.31	3.47	0.15	0.13	0.82
Almasippi	XV	4.25	4.47	2.49	2.90*	0.11	0.16	0.10
Holland	XVI	4.11	4.91*	3.52	3.53	0.14	0.13	0.22
Foster(1)	XVII	5.17	5.74	3.58	3.79	0.19	0.17	0.80
Stockton	XVIII	4.21	4.62	3.84	3.91	0.16	0.22	0.57
Holland	XIX	4.76	5.17	3.45	3.46	0.16	0.17	0.41
Emerson	XX	4.68	5.47**	3.45	3.87	0.16	0.18	0.41
Rathwell	XXI	5.38	5.52	4.70	4.72	0.25	0.21	0.79
Emerson	XXII	6.64	7.59	3.74	3.78	0.25	0.27	0.14
Osborne	XXIII	6.38	6.47	4.73	4.66	0.30	0.29	0.95
							0.30	0.09

(1) - name of farmer from whom soil was obtained

* - significant at .05 level

** - significant at .01 level

tions it supports present potassium recommendations because for seven of the twelve soils potassium fertilization resulted in only non-substantial barley yield increases. However, the possibility exists that if higher rates of potassium fertilization than those studied in this experiment were used the increases might have been substantial. Bailey (5) working with barley on Manitoba soils having 101 and 115 ppm of available potassium, reported significant yield increases to rates as high as 150 and 200 pounds of K_2O per acre. The yield data from five of the twelve soils did suggest that a barley response to potassium fertilization can occur on soils having relatively high levels of available potassium.

The yield of barley was significantly correlated, .05 level, with both potassium uptake and the percent potassium in the plant matter, r=0.94 and 0.86 respectively. As the yield increased, both potassium uptake (figure 7) and percent potassium in the plant matter increased correspondingly. It should be noted that although yield, potassium uptake, and percent potassium increased when KCl was added to the soil (table 17), the greatest increase was in relation to increasing amounts of available potassium in the soil.

Yield (figure 8), potassium uptake (figure 9), and percent potassium in the barley plants were significantly correlated, .05 level, with the ammonium acetate extractable potassium levels of the soils, r=0.96, 0.97, and 0.79 respectively. Barley yield increased rapidly with increasing levels of available potassium until a level of approximately 190 ppm was reached. Beyond 190 ppm the yield increased very gradually with increased amounts of available potassium. Potassium uptake also increased rapidly as the avail-

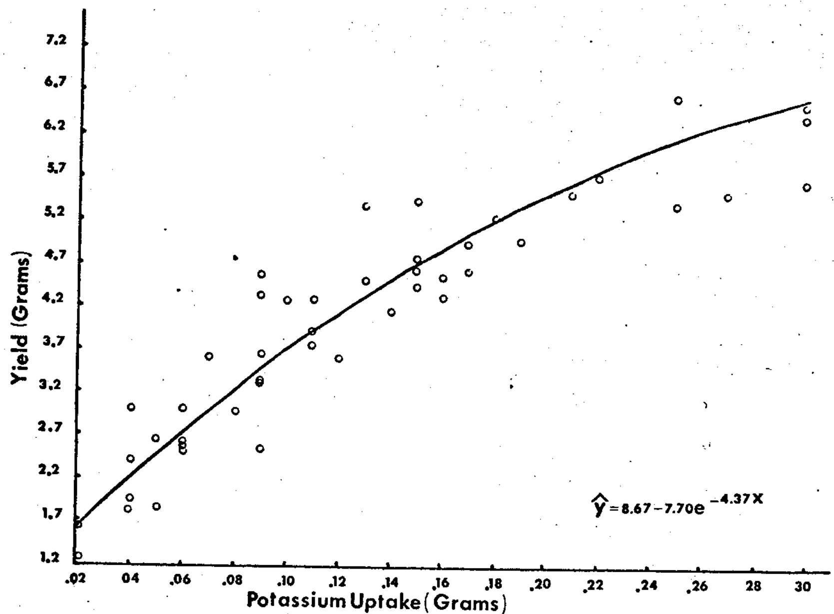


Figure 7 Potassium Uptake by Barley Versus Barley Yield

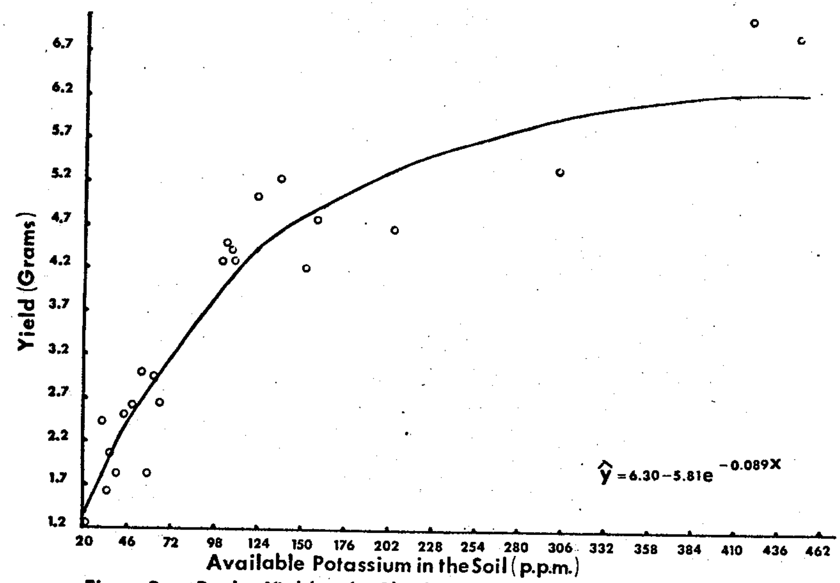


Figure 8 Barley Yield in the Check Treatment Versus the Available Potassium in the Soil (NH_4OAc Extractable)

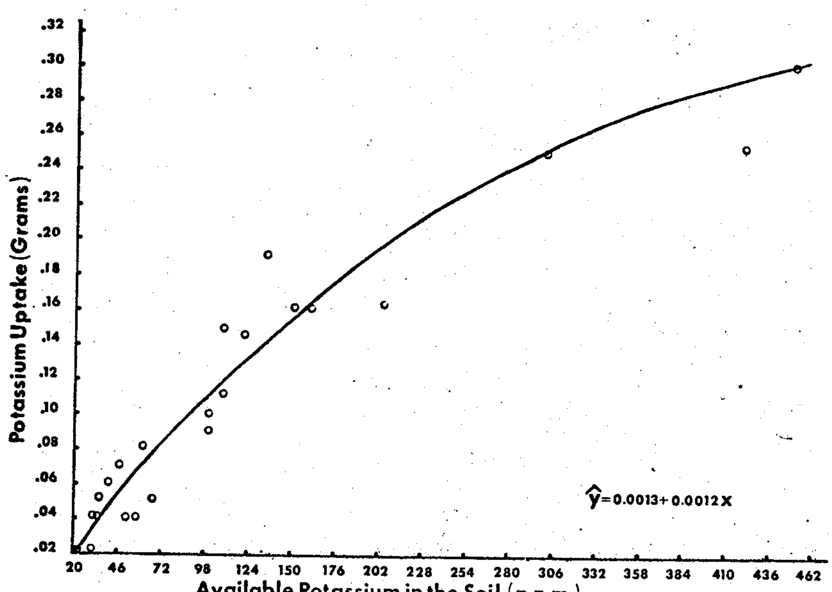


Figure 9 Potassium Uptake by Barley in the Check Treatment Versus Available Potassium in the Soil (NH_4OAc Extractable)

able potassium of the soil increased, with the sharpest increase occurring up to a level of about 220 ppm. These two curves, figures 8 and 9, and figure 7, illustrate that yield increases with uptake, and suggest that the desirable minimum level of available potassium for barley growth is in the range of 190 to 220 ppm. These two curves also indicate that on soils below this range of available potassium barley should respond favorably to potassium fertilization.

In this experiment three extracting agents were compared as to their ability to measure available potassium in the soil. Table 18 presents the correlation values between yield and available potassium in the soil as measured by these three extracting solutions. Yield was most strongly correlated with the potassium extracted by 1.0N ammonium acetate solution; r=0.96, as compared with 0.01 M $CaCl_2$; r=0.88, and distilled water; r=0.75. Thus, the r values indicate that 1.0 N ammonium acetate is the most reliable of the three extracting agents for relating available potassium levels in the soil to barley yields.

Table 18

Values for Correlation (r) between Yield and Available Potassium in the Soil as Measured by Three Extracting Solutions

	Extracting Solution	(r) value
(1)	1.0 N Ammonium Acetate + 250 ppm $LiNO_3$	0.96
(2)	0.01 M $CaCl_2$ + 250 ppm $LiNO_3$	0.88
(3)	Distilled water + 250 ppm $LiNO_3$	0.75

VI GREENHOUSE EXPERIMENT II

A field inspection of the 1967 trials, approximately 20 days after seeding revealed that a frost had occurred the previous night in the area of the Arthur, Freeborn and Foxon trials. Upon inspecting these three trials, it was observed that the frost damage was not as extensive to the barley plants that received potassium chloride as to those that did not. As a result of the field observation, an experiment was conducted in the greenhouse to determine whether the addition of potassium to a soil reduced frost damage to barley and, if so, whether or not the reduction varies with the initial potassium status of the soil.

A. MATERIALS AND METHODS:

Soils: Two soils were used in this study, one from the Almasippi association (11) and one from the Gladstone association (11). The Almasippi soil was low in available potassium while the Gladstone soil was high in available potassium. Both soils were calcareous.

Table 19 lists some of the characteristics of the soils used.

Experimental Design: To determine whether the potassium or the chloride was responsible for reducing damage to barley which had been exposed to below freezing temperatures, two soils with different levels of exchangeable potassium (table 19) were used and both soils were treated with another chloride salt (NaCl) as well as KCl. The other criteria for using sodium chloride was to see if compar-

Table 19

Some Characteristics of the Soils Used in the Greenhouse Frost Experiment

Co-operator	Peters	Foxon
Soil	Almasippi	Gladstone
ppm exchangeable K	67	210
ppm NO_3 - N	1.39	2.37
ppm P ($NaHCO_3$ extractable)	6.16	2.34
pH	8.1	7.4
Texture	L.F.S.	C.L.
$CaCO_3$ content (with HCl)	low	very high

able observations could be produced by Na and K when the plants were exposed to below freezing temperatures. The amounts of Na and K added to the soil in the different treatments were equivalent as shown below:

Treatment number	Treatment
1.	15 ppm potassium
2.	15 ppm sodium
3.	100 ppm potassium
4.	100 ppm sodium
5.	0 ppm sodium and 0 ppm potassium

However the amount of chloride applied was varied by the fact that for the same weights of Na and K applied, more chloride was applied with the Na than with the K.

Each soil received the above five treatments and every treatment was replicated four times on each of the two soils used.

Procedure: The soils were obtained in August. Only the surface six inches were used. The soils were air dried, mixed, and sieved to remove plant residue and pebbles. Representative samples were submitted for chemical analysis. Two kilograms of soil were placed in glazed-porcelain gallon crocks. 10 ppm phosphorous as $NH_4H_2PO_4$ in dilute solution was banded an inch and a half below the seed. The sodium, as NaCl in dilute solution, and potassium, as KCl in dilute solution, treatments were similarly banded. On January 31, eight seeds of the barley variety Conquest were planted. After germination the seedling stand was thinned to four plants per pot. The moisture levels were maintained at field capacity with distilled water. Seventy ppm nitrogen was added in two installments; forty ppm as $(NH_4)_2SO_4$ in dilute solution four days after emergence, and thirty ppm as NH_4NO_3 in dilute solution fifteen days after emergence. The plants were exposed to fourteen hours of light per day. The plants were frost hardened by exposure to temperatures of approximately 37 degrees Fahrenheit at the following rate: a two hour exposure on February 18th, a four hour exposure on February 19th, and a six hour exposure on February 20th. On February 21st the plants were exposed to two hours of below freezing temperature. During the exposure the temperature fluctuated between 26 and 29 degrees Fahrenheit. Immediately following their frost exposure the plants were kept at a room temperature of approximately 45 - 50 degrees Fahrenheit for three hours. This was to prevent damage to the plants from a too rapid exposure to room temperatures. After being exposed to the interim temperature for three hours, the plants were exposed to room temperature and examined. The examination consisted of a visual comparison of the damage to the plants in the different treatments. The plants were harvested on February 23rd. They were then air-dried, ground in a Wiley mill and analyzed for their potassium and sodium contents.

B. OBSERVATIONS:

I. Foxon Soil

- The plants grown on the Foxon soil, definitely withstood the below freezing temperatures better than those grown on the Peters soil.
- Only one sample, a check treatment, showed leaf damage and this was very slight.
- There was no visual damage to any of the other plants.

II. Peters Soil

- The plants were definitely damaged
- The order of damage from greatest to least was:

1. check
2. 15 ppm sodium
3. 100 ppm sodium
4. 15 ppm potassium
5. 100 ppm potassium

Photographs (figure 10) were taken after the plants were exposed to the frost. A discussion of these photographs follows:

Figure A: The plants in pot I showed less damage than those in pot II. Both pots contained Peters soil but pot I had a treatment of 100 ppm sodium whereas pot II was a check sample.

Figure B: The plants in pot V which received 15 ppm potassium were uninjured whereas the plants in pot II, a check sample, were injured. Both V and II contained Peters soil.

Figure C: The plants in pot III were injured slightly less than those in pot II. Pot III received 15 ppm sodium and pot II was a check treatment. Both II and III were grown on Peters soil.

Figure D: None of the plants in pot VI nor VII exhibited frost damage. Both were grown on the Foxon soil. However, VII received a 15 ppm potassium treatment while VI was a check sample.

Figure E: The plants in IV showed no damage while those in pot I did show damage. Both were grown on Peters soil, but, IV received a 100 ppm potassium treatment, whereas I received a 100 ppm sodium treatment.

Figure F: The plants in II showed noticeable damage; those in IV did not. Both were grown on Peters soil. However, pot IV received a 100 ppm potassium treatment whereas pot II was a check sample.

Figure G: There was very evident damage to the plants grown in pot II whereas there was no visible damage to those grown in pot VI. II was the check sample grown on Peters soils and VI was the check sample grown on the Foxon soil.

Barley Plants After Frost Exposure

figure A

figure B

figure C

figure D

figure E

figure F

figure G

C. RESULTS AND DISCUSSIONS:

The potassium and not the chloride appeared to be responsible for increasing the ability of barley to withstand below freezing temperatures. This was concluded from the fact that the plants that received KCl showed less damage from frost exposure than the ones that received NaCl. If the chloride was responsible for reducing damage, then the plants receiving NaCl should have withstood the exposure better than the ones that received KCl because more chloride was applied as NaCl than as KCl. Also, the fact that the plants on the Foxon soil suffered no damage further confirms that the potassium and not the chloride was responsible for the reduced damage to barley upon exposure. The Foxon soil, high in exchangeable potassium, resulted in a high concentration of potassium in the barley (table 20) and hence no difference was observed between the check treatment and the other treatments after exposure.

With increasing potassium percentages (table 20) within the plants, the barley grown on the Peters soil showed a noticeable decrease in frost damage after exposure. Thus, on the Peters soil, as the potassium treatment was increased, the percent potassium within the plants was also increased, and correspondingly, damage decreased. In the field, it was observed that the damage was not as extensive on barley plants that received potassium as on those that did not. Samples taken in the field showed that the percentage potassium in the plants increased with fertilization (table 2, 1967 data). The plants grown on the Foxon soil were not noticeably affected by the exposure to the below freezing temperature. The addition of sodium had less effect in reducing damage than did the addition of potassium. It is

Table 20

Percent Potassium Within the Plants
After Frost Exposure

Treatment	Peters Percentage K	Peters Percentage Na	Foxon Percentage K	Foxon Percentage Na
Check	4.60	1.21	6.63	0.24
15 ppm K	5.74	0.74	6.77	0.17
100 ppm K	7.20	0.49	7.31	0.16
15 ppm Na	4.39	1.38	6.51	0.32
100 ppm Na	4.07	1.93	6.32	0.76

not known whether or not the frost reduced yields because the experiment was not designed to study the effect of frost on yield.

Barley grown on soils low in exchangeable potassium such as the Peters soil will most probably suffer damage from below freezing temperatures sooner and more extensively than when grown on soils higher in exchangeable potassium such as the Foxon soil. This could be overcome to a large extent by use of potassium fertilizer, thereby bringing the potassium percentage in the plant to an adequate level whereby the plant could withstand a mild frost. A potassium percentage of 6.6 or better in the barley plant will most probably safeguard the plant from a light frost exposure. A figure of 6.6 was arrived at by the fact that the check on the Foxon soil in this experiment showed no damage.

Baumann (25) made similar observations with potatoes. He noted that potatoes supplied with potassium were uninjured at temperatures slightly below freezing while unfertilized potatoes were damaged. Jung and Smith (22) noted that the percent survival of alfalfa after exposure to freezing temperatures increased as the potassium was increased until a level of 200 pounds per acre was reached.

Therefore, the data seems to indicate that the addition of potassium lowers frost damage to plants grown on soils which are low in exchangeable potassium. The cause of the barley plants' increased ability to withstand frost exposure after potassium fertilization was not investigated.

VII ANAYLTICAL PROCEDURES

A. DETERMINATION OF EXCHANGEABLE POTASSIUM IN SOILS

10 gram samples of 2 mm air dried soil were used. For potassium extraction 100 ml of 1.0 N ammonium acetate adjusted to a pH of 7 and containing 250 ppm Li solution were used. The soil and solution were shaken for an hour on a vertical shaker and then filtered through #1 filter paper. The potassium determination was done on a Baird Atomic KY2 flame photometer. In Greenhouse Experiment I, 0.01M $CaCl_2$ plus 250 ppm Li solution and distilled water plus 250 ppm Li solution were also used as extracting agents.

B. DETERMINATION OF EXCHANGEABLE CALCIUM AND MAGNESIUM IN THE SOIL

(a) Procedures for exchangeable Ca+Mg

5 ml of 1.0 N ammonium acetate extract as described in A were placed in an Erlenmeyer flask and diluted to 50 ml with distilled water. 5 ml of monoethanolamine buffer solution (55 ml conc. HCl and 310 ml monoethanolamine diluted to 1 liter with distilled water), 30 mg KCN, and 30 mg hydroxylamine hydrochloride, were then added. The mixture was titrated with 0.01M EDTA solution using Eriochrome Black T as an indicator to determine the exchangeable Ca+Mg.

(b) Procedures for exchangeable Ca

5 ml of 1.0 N ammonium acetate extract as described in A were placed in an Erlenmeyer flask and diluted to 50 ml with distilled water. Approximately 1 ml of 6N NaOH and 4-5 drops of calcon indicator were added. The solution was titrated with 0.01M EDTA solution to determine the exchangeable calcium.

(c) Exchangeable Mg

The amount of exchangeable Mg in the sample was obtained by difference between the amount of exchangeable Ca+Mg and the amount of exchangeable Ca.

C. DETERMINATION OF POTASSIUM IN PLANT MATTER

The plant matter samples were air dried and were ground in a Wiley mill. 0.20 grams of plant matter were used in the determination. The extraction of potassium was done with 1.0 N ammonium acetate solution as described in A. The potassium determination was done on a Baird Atomic KY2 flame photometer.

D. DETERMINATION OF SODIUM IN PLANT MATTER

The procedure was the same as that described for the determination of potassium in plant matter except that the KY2 flame photometer was set to determine Na rather than K.

E. DETERMINATION OF TOTAL NITROGEN IN THE PLANT MATTER

The Kjeldahl-Gunning method was used to determine the total nitrogen in the plant matter. One gram of plant matter was digested with 25 ml of concentrated H_2SO_4. After digestion, the sample was cooled and 200 ml of water were added. To this, 25 ml of $Na_2S_2O_3$ solution were added to complete the reduction. Then 60 ml of 1-1 NaOH plus distilled water solution was added and the digested material was distilled into flasks containing 25 ml of 0.1N H_2SO_4 plus 50 ml of distilled water. After the distillation the excess H_2SO_4 was back titrated with 0.1N NaOH solution using methyl red as an indicator.

F. DETERMINATION OF THE pH AND CONDUCTIVITY OF THE SOILS

50 gram samples of 2 mm air dried soil were placed into 125 ml Erlenmeyer flasks. 50 ml of distilled water were added. The soil and water mixture was shaken for 30 minutes on a vertical shaker. The conductivity of the soil suspension was directly read using a Radiometer conductivity meter type CDM2d. The pH of the soil suspension was determined with a Beckman Zeromatic pH meter.

G. DETERMINATION OF NO_3-N IN THE SOIL

12.5 gram samples of 2 mm oven dried soil were weighed into shaking bottles. 50 ml of nitrate extracting solution (consisting of 2.5 g $CuSO_4 \cdot 5H_2O$ and 6 g Ag_2SO_4 diluted to 1 liter with distilled water) were added. The soil and solution were shaken for 10 minutes on a vertical shaker. 0.16 g of $Ca(OH)_2$ were added and the soil and solution were shaken for 5 minutes. 0.5 g of $MgCO_3$ were added and the soil and solution were shaken for an additional 15 minutes. The soil and solution were then filtered through #1 filter paper into dry flasks. 25 ml of the filtered solution were pipetted into a 50 ml beaker and evaporated to dryness on a hot plate. 2 ml of phenoldisulphonic acid (75 g phenol per 675 ml conc. sulfuric acid) were added to the 50 ml beaker and then the beaker was rotated until the dried residue was wet with acid. The wet residue was allowed to stand for 10 minutes and then it was diluted with 25 ml of distilled water. When the residue was dissolved, it was washed into 100 ml volumetric flasks. Then 1-1 NH_4OH plus distilled water solution was added to the dissolved residue in the flask until a permanent yellow colour developed. The yellow solution was made up to the 100 ml volume with distilled water and the colour intensity was read at a wavelength of 415 m μ using small Coleman cuvettes.

H. DETERMINATION OF PHOSPHOROUS IN THE SOIL (OLSEN'S $NaHCO_3$ METHOD)

5.0 gram samples of 2 mm air dried soil samples were placed in shaker bottles. 100 ml of 0.5 N $NaHCO_3$ extracting solution adjusted to pH 8.5 and a teaspoon of pretreated activated charcoal were added to the bottles. The soil and solution were shaken on a vertical shaker for 30 minutes and filtered through #1 filter paper. 50 ml of the filtered solution were transferred to a 100 ml volumetric flask. 5 ml of conc. HCl were added slowly. 20 ml of ammonium molybdate-HCl solution (15 g $(NH_4)_6Mo \cdot 4H_2O$ and 400 ml 10.0 N HCl diluted to 1 liter with distilled water) were added. Then 10 ml of $SnCl_2$ solution (0.4 g $SnCl_2 \cdot 2H_2O$ and 1 ml conc. HCl per 332 ml distilled water) were added to the flask. The flask was shaken and the solution was diluted to volume. The colour intensity was determined on a Spectronic 20 colorimeter at a wavelength of 60 m μ.

I. DETERMINATION OF THE PERCENT CALCIUM CARBONATE IN THE SOIL

A one gram soil sample was digested in 10% HCl for 10 minutes. The CO_2 evolved was sucked through a drying and adsorption train, then absorbed by Ascarite. The weight of CO_2 absorbed was determined and expressed as percent $CaCO_3$ equivalent.

VIII SUMMARY AND CONCLUSIONS

1965 and 1966 field results (18, 44) indicated a wheat and barley response to potassium fertilization on calcareous soils having an exchangeable potassium level considered adequate for cereal growth. However on acidic soils also having relatively high exchangeable potassium levels, wheat and barley did not respond to potassium fertilization. Although the responses on the calcareous soils were not statistically significant, they did suggest that a profitable response could be obtained by applying potassium fertilizer to cereal crops grown on calcareous soils for which present recommendations do not advise potassium application.

Therefore field experiments were conducted in 1967 and 1968 on calcareous soils with exchangeable potassium levels which ranged from 30 to 414 ppm to determine the effect of potassium fertilization on cereal growth. The results of these experiments were related to existing soil test recommendations with the objective of confirming or improving existing soil test recommendations for the growth of cereals. The effect of potassium fertilization on potassium concentration, potassium uptake and yield of plant matter at early stages of cereal growth was investigated. The effect of the exchangeable Ca/K and Ca+Mg/K ratio of the soil at seeding on yield and potassium uptake by cereals was also investigated. In a greenhouse experiment, the effect of potassium fertilization on barley grown on soils varying in levels of exchangeable potassium, pH and percent $CaCO_3$ was studied. In a correlation study, the exchangeable potassium levels as measured by three extracting agents were compared to determine which was most strongly correlated to barley yields. A second greenhouse experiment was conducted to study the effectiveness of potassium fertilization in reducing frost damage to barley seedlings.

Barley plant matter samplings in the field trials at 14, 21, and 28 days and fifth leaf stage of growth indicated that the application of potassium fertilizer generally increased yield, potassium uptake and potassium concentration in the plants during early growth on all soils. Wheat and oat plant matter samplings at 21 and 28 days and fifth leaf stage of growth indicated that potassium fertilization generally increased yield, potassium uptake and potassium concentration during the early growth on soils with an exchangeable potassium level of 126 ppm or less. Generally final oat and barley grain yields were significantly, .05 level, correlated to the potassium concentration at these early growth stages. For wheat, no significant correlation was evident. These results suggest that potassium concentration in early barley and oat growth might have bearing on final yields.

The potassium recommendation (42) does not advise the application of potassium fertilizer for cereal growth on soils having more than 84 ppm exchangeable potassium. Final barley grain yields showed responses to one or more of the potassium treatments on 9 of the 10 soils studied; no responses occurred on the soil with 68 ppm exchangeable potassium. These responses although usually statistically non-significant, .05 level, were substantial, 2 bushels or more per acre. Therefore, these results suggest that barley might respond to potassium fertilization on soils having exchangeable potassium levels greater than 84 ppm. Wheat showed significant, .05 level, responses to potassium fertilization on all soils which had 84 ppm or less exchangeable potassium but one; no response was evident on the soil which had 68 ppm exchangeable potassium. Oats showed both significant, .05 level, and substantial, 5 bushels or more per acre, responses on all soils which had 84 ppm or less exchangeable potassium. Both wheat and oats showed some substantial, 3 bushels or more per acre, responses to potassium fertilization on soils with exchangeable potassium levels as high as 414 ppm, but no consistant and uniform pattern of response was evident at these higher levels of exchangeable potassium. Therefore these results support the potassium recommendation which advises the application of potassium fertilizer for growth of wheat and oats on soils having 84 ppm or less of exchangeable potassium.

With barley, potassium fertilization generally increased potassium uptake on soils with 414 ppm or less of exchangeable potassium, with oats, on soils with 341 ppm or less of exchangeable potassium, and with wheat, on soils with 102 ppm or less of exchangeable potassium. This was of interest because potassium uptake by wheat, oats and barley at harvest was found to be significantly, .05 level, correlated with final grain and total yields.

For the three cereals potassium and nitrogen uptake at final harvest were found to be significantly, .05 level, correlated. Since potassium uptake was significantly correlated with cereal yields, and nitrogen uptake was significantly correlated with potassium uptake, one can postulate that if nitrogen was a limiting factor then a response to potassium fertilization might not materialize. If so, this would be especially true of soils already high in available potassium because there might not be sufficient additional nitrogen to bring about a response in growth if potassium fertilizer were added.

The exchangeable Ca/K and Ca+Mg/K ratios in the soil at seeding had bearing on the growth of these three cereals because these ratios were significantly, .05 level, negatively correlated to potassium uptake by wheat, oats and barley; to barley grain yield, to barley total yields and to wheat grain yields at final harvest. From these results one can postulate that if potassium fertilizer reduced the exchangeable Ca/K and Ca+Mg/K ratios in the soil, then yields of wheat and barley might increase with potassium fertilization.

In a greenhouse experiment, statistically significant, .05 level, barley yield increases to potassium fertilization were found on soils with 64 ppm or less of exchangeable potassium and substantial increases were realized on soils having 101 and 102 ppm exchangeable potassium. Potassium fertilization did not, with one exception, substantially increase barley yields on soils having higher levels of exchangeable potassium. The soils in this experiment varied in pH and percent $CaCO_3$ as well as levels of exchangeable potassium. In the main, these results, if applied to field conditions, support the potassium recommendation for the growth of barley although they do suggest that a substantial increase might be attained with potassium fertilization on soils having up to 102 ppm exchangeable potassium. In this greenhouse experiment also, potassium uptake and potassium concentration in the plant matter were found to increase with potassium fertilization. Potassium uptake and potassium concentration in the plant matter were significantly, .05 level, correlated to final barley yields.

In a comparison of three extracting agents; 1.0N ammonium acetate, 0.01M $CaCl_2$ and distilled water, barley yields in the greenhouse experiment were most strongly correlated to available potassium levels as indicated by ammonium acetate extraction. Therefore, if field yields do not relate well to exchangeable potassium as measured with ammonium acetate, other factors such as moisture, rooting depth, amount of exchangeable potassium in the sub soil, etc., may be operative.

A second greenhouse experiment indicated that barley seedlings grown on soils with high exchangeable potassium levels, 210 ppm, have greater frost resistance than those grown on soils with low levels of exchangeable potassium, 67 ppm. The damage to the plants was reduced when the potassium concentration in the plant matter was increased with potassium fertilization.

Overall these results support present potassium recommendations for the growth of wheat and oats. However, they indicate that barley might respond to potassium application on soils with higher levels of exchangeable potassium than present recommendations indicate.

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X APPENDIX

Nitrate Levels of the Soils Used in the 1967 and 1968 Field Experiments (p.p.m.)

1967

Co-operator	Peters	Arthur	Freeborn	Foxon	Ewanek
Depth (ins.)					
0 - 6	2.5	2.1	8.9	8.9	1.7
6 - 12	2.3	1.1	6.9	5.0	0.7
12 - 24	1.1	0.7	7.4	7.7	0.5
24 - 36	0.2	1.9	6.2	0.7	0.9
36 - 48	1.5	0.0	4.6	5.1	1.4

1968

Co-operator	Eliuk	Kiel	Persoage(1)	Persoage(2)	Ewanek
Depth (ins.)					
0 - 6	13.4	4.4	1.4	1.6	1.4
6 - 12	6.0	6.7	1.9	2.6	0.9
12 - 24	3.8	5.0	1.4	0.4	0.8
24 - 36	4.0	3.4	0.5	0.7	0.5
36 - 48	0.7	3.9	0.2	0.0	0.4

(1) Located on north-east side of farmer's land.

(2) Located on south-west side of farmer's land.