POTASSIUM AS A LIMITING NUTRIENT FOR MAXIMUM PRODUCTION OF WHEAT IN MANITOBA

By

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ABSTRACT

Field and lysimeter experiments were conducted to determine methods of placement and the level of potassium needed for maximum production of wheat. In field experiments large amounts of K were broadcast in the first year and K was banded with the seed each year. The field experiments were conducted for three years at three sites with low, medium and medium to high levels of available K and the results presented are for two years. Lysimeter experiment was conducted for one year in the soil low in K. The influence of K and moisture regimes on wheat yields and water use efficiency was also studied in a growth chamber experiment.

In field experiments sampling to determine plant dry matter yield and plant tissue nutrient concentration was done at the early tillering, the boot, the heading and the milk stages of growth. Total plant dry matter and grain yields were also determined at maturity.

On the K deficient site, vegetative plant yield, at various stages of growth in both years, increased with increasing amounts of broadcast K. In the first year of this study, however, maximum grain yield was obtained when 100 Kg/ha of broadcast K was applied while in the second year 400 Kg K/ha was required for maximum grain yield. In both years, shoot percent K and K uptake at all the sampled stages of growth increased as the levels of applied K increased. Shoot percent N did not change appreciably

as broadcast K increased. However, N uptake showed an increasing trend with increasing broadcast K levels. In the first year of the study, the highest protein content of the grain was obtained when 100 Kg K/ha was broadcasted while in the second year, up to 400 Kg K/ha was required for maximum grain protein.

In terms of plant dry matter and grain yield, 33 Kg K/ha banded with the seed was as effective as 100 or 200 Kg/ha of broadcast K in the first year and 400 Kg K/ha in the second year. It was also observed that grain yields from plots which received banded plus broadcast K were not influenced by increasing levels of broadcast K. Shoot percent K and K uptake at various stages of growth, from plots which received banded K, increased with increasing rates of broadcast K. Nitrogen concentration in the shoots and N uptake remained almost constant across the levels of broadcast K. However, banded K alone was not enough for maximum grain protein content.

On two of the sites with medium to high levels of available K, there was no response in wheat yields to K in both years. In 1982, however, slight depressions in plant dry matter yields at the early stages of growth were observed when K was banded in plots which had received various levels of broadcast K. Throughout the sampled stages of growth percent K in the shoots and K uptake were not influenced by added K. Similarly shoot N, N uptake and protein content of grains were not influenced by added K.

A lysimeter study showed that maximum production of plant dry matter and K uptake could be obtained with the application of

100 Kg K/ha. However, maximum grain yield required addition of 200 Kg K/ha. Total N uptake and grain protein were increased by application of 100 Kg K/ha but no further increase was observed when the level of applied K increased to 200 Kg K/ha.

Depth of K mixing (0-7.5 cm versus 0-15 cm) in the field and lysimeter experiments, on the average, had no effect on yield and nutrient uptake. The lysimeter study, however, showed that the yields declined when either 100 or 200 Kg K/ha was mixed with 0-30 cm layer of soil as compared to the yield obtained when 0-7.5, 0-15 and 15-30 cm layers of soil were mixed with the same rates of K.

A growth chamber study with the K deficient soil showed no significant yield response to applied K but K uptake increased with increasing levels of added K. Increasing levels of added K also led to increasing N uptake and protein content of wheat grain. High moisture regime resulted in significantly higher yields compared to low moisture regime. It was, however, observed that water use efficiency was neither influenced by K nor by moisture treatments. Analysis of soil samples taken at the end of the experiment indicated that this soil has a capacity for fixing a considerable amount of K.

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Chapter 1

INTRODUCTION

Soils vary greatly in their ability to support crop growth. Climate and management also affect the ability of a soil to produce. However, under a given climate and specific management program, a given soil has its unique maximum yield potential for a given crop and a given fertility level. Quite often soils lack sufficient quantities of one or more plant nutrients which means that maximum yield is unattainable unless sufficient levels of these nutrients are applied.

For a long time it has been known that for normal plant growth and yield, potassium like other nutrients must be supplied in sufficient levels either from the soil or by fertilizer K application. Most Manitoba soils contain sufficient available potassium and the only soils likely to contain insufficient potassium are the coarse-textured soils (sands to sandy loams) and the organic soils. However, with increasing use of high yielding varieties of crops as well as the increasing use of high levels of nitrogen and phosphorus, in pursuit of maximum yields, responses to applied K are becoming more common in many soils which have been considered medium to high in available K.

With the above in mind, a three-year field experiment was started in 1982 to study how limiting K is for maximum yield of wheat at three locations having low, medium and high levels of available K. High levels of fertilizer K were applied at all the three locations in order to allow a study of residual effect of K on plant yield. Apart from the direct effect of K on yield, the manner in which the former was applied was also investigated.

Adjacent to the large field experiment in the K deficient soil at Haywood, a lysimeter experiment was also set up to provide more information on the influence of K on plant dry matter and grain yield. On a further attempt to study the effect of potassium on yield and yield components of wheat as well as the influence of potassium on water use efficiency, a growth chamber experiment using Haywood soil was set up. The growth chamber experiment also made the study of the fate of potassium possible.

In the three experiments, the effect of potassium on percent protein in wheat grains was also investigated.

Chapter 2

LITERATURE REVIEW

A balance of chemical, physical, biological and meteorological factors is a prime requirement for successful plant growth in the field. Apart from the fact that all these factors interact, they are also known to vary from place to place and from time to time during the growing period of plants. It is therefore difficult to make a comprehensive study of the influence of a single factor on plant growth, not only because of the difficulties encountered in isolating it, but also those involved in holding others at an optimal constant level. This should therefore be constantly kept in mind while evaluating the effect of potassium on plant growth as set out in the literature review below.

A. The Role of Potassium in Plant Growth

A salient feature of potassium is the high rate at which it is taken up by plants. Of all the soil nutrients taken up by the plant, the uptake of potassium is only second to that of nitrogen. Though it is not a constituent of any organic compounds, potassium is known to enhance a number of physiological processes in the plant such as photosynthesis (Smid and Peaslee, 1976), translocation of assimilates (Mengel and Haeder, 1977), regulation of water regime of the plant (Baker and Weatherly, 1969), and protein synthesis (Mengel et al., 1981). Kernan (1966) suggested that potassium is also responsible for neutralizing chloride and phosphate ions as well as physiologically important organic acids. The role of potassium as an activator of enzymes has also been pointed out by Hawker et al., (1979).

B. Potassium Availability in the Soil

The amount of potassium-bearing minerals in a soil is a good indicator of the potential source of potassium to plants. These minerals however play only an indirect role in terms of the ability of the soil to supply potassium to plant roots (Mengel and Kirkby, 1980). Three K fractions in the soil have been established using different extraction techniques. These are soil solution potassium, potassium adsorbed to clay minerals or humus, and potassium present in secondary minerals. According to Scheffer and Schoehtschabel (1967), a dynamic equilibrium exists between these fractions. This equilibrium can be represented by the following equation:

$$\text{Non-exchangeable K} \rightleftharpoons \text{Exchangeable K} \rightleftharpoons \text{Water soluble K}$$

Soluble and exchangeable forms of potassium in the soil appear to be readily available to plants. When the levels of these forms of K are reduced by cropping however, some of the non-exchangeable potassium may be released and become available to plants (Reitemeier et al., 1951). Tabatabai and Hanway (1969) have also shown that interlayer (non-exchangeable) K may contribute to a considerable extent in supplying K for plant uptake.

The work of Newman (1969) supports the above view. In studies on the release of potassium by mica, he has reported that the potassium concentration in equilibrium with interlayer K decreases as the interlayer potassium is depleted. The process of interlayer K release is not yet completely understood. Jackson and During (1979) have demonstrated for New Zealand topsoils of widely differing clay mineralogy that pretreatment of the soils with ca^{++} (as acetate) results in an expansion of clay mineral and an increase in potassium desorption. Potassium desorption is also often associated with the oxidation of Fe^{2+} to Fe^{3+} (Farmer and Wilson, 1970). From the foregoing, it appears that interlayer K release is an exchange process associated with diffusion in which potassium is replaced by other cation species.

In most cases exchangeable potassium is regarded as a satisfactory measure of K availability status of soils. This fraction however, comprises both solution K and K adsorbed by varying strengths to adsorption sites. According to Nemeth et al., (1970) soils with the same values for exchangeable K may thus differ considerably in K concentrations in soil solution, because more selectively bound K is equilibrated with relatively low K concentration and vice versa.

During and Duganzich (1979) have reported that K uptake of white clover was best reflected by K concentration of the soil solution. Exchangeable K alone correlated very poorly with uptake except in soils of very low K status. Recent experiments of Wanasura and De Delta (1981) have shown that the potassium of paddy soils extracted by electroultrafiltration (EUF) was positively correlated with the grain yield of rice, whereas no significant correlation with exchangeable K was obtained. According to Nemeth (1979) EUF-extractable K does reflect the potassium concentration of the soil solution. Barrow (1966) reported that the correlation between the potassium uptake of clover and the content of exchangeable potassium was improved if in addition to the exchangeable K, the K buffer capacity was also taken into account.

C. Methods of Fertilizer K Placement

Recommendations on placement of fertilizers for agronomic crops differ considerably depending on the crop and the nutrient in consideration. P and K are classified as immobile since they do not move readily in the soil as compared to nitrogen (Bray, 1954). Plant roots must therefore extend into the zone of P and K fertilizer before plants can use these elements. Placement methods include banded, broadcast and left on the surface, plowed down or disked into the soil (Ham et al., 1973).

Considerable information is available on the influence of fertilizer placement on corn (Zea mays L.) growth. Bates et al., (1965) reported that early growth and nutrient content were increased markedly by fertilizer applied with the seed even when accompanied by recommended amounts of band placed fertilizer (3.8 cm to the side and below the seed). Nelson and Randall (1968), in agreement with Bates et al., (1965) reported significant response in early growth and grain yield when banded treatments were supplemented with small amounts of fertilizer applied with the seed. Their study also indicated that small amounts of fertilizer applied with the seed would seem adequate for optimum corn yield provided additional amounts of P and K were broadcast previously.

Barber (1959) reported no differences in corn yields between row and broadcast K. In this study however, yield response to K was not large. Under these circumstances, it would be difficult to measure any yield differences due to placement. Plummel (1957) found that K banded for cereals in river clays was 3.65 times as effective as broadcast K, 1.00 and 1.60 times as effective for potatoes with low and high pH soils respectively. Welch et al., (1966) suggests that broadcast K may not be as efficient as banded K because of a difference in chemical and/or positional unavailability between the two placement methods. Broadcast application may result in potassium being placed in soil zones that are not permeated by plant roots. Potassium may also undergo changes with respect to availability when added to the soil. Mixing with the soil may enhance fixation more than does localized placements.

Parks and Walker (1969) observed that the effect of potassium placement on corn yield decreases as the soil potassium level increases. This was in agreement with the conclusions of Mederski and January (1962) that response advantages for row placement of potassium is decreased as the fertility of the soil increases. Ham et al., (1973) investigating the influence of fertilizer placement on yield response of soybeans reported yield increases of 746, 598, and 941 Kg/ha with band, seed placement and broadcast treatments respectively. When P and K levels were very high, no yield increases were obtained from any fertilizer placement.

The choice of the method of potassium placement depends on the objective the farmer has in mind. According to Welch et al., (1966) broadcast should be done when one wants to obtain a specified yield on low potassium soil; the potassium unabsorbed by plants may accummulate as residual. The above researchers also feel that the rate of fertilizer has a great influence on the choice of the method of application. At high rates of fertilizer application, germination and/or seedling injury may occur if the fertilizer is placed too close to the seed.

D. Residual Effect of Fertilizer Potassium

The residual effect of fertilizer commonly refers to the favorable response of crops to nutrients applied to the previous crops (Cook and Davis, 1957). In some cases the effect from the previously applied fertilizers may be of considerable benefit in a poor soil where the buildup of nutrient stock is required in order to attain a specified yield level. The residual effect may also be harmful in that soils may become acidic or an unfavorable nutrient balance may be established (Cook and Davis, 1957).

Accumulation of nutrients in the soil as a result of heavy fertilizer application is influenced to a great extent by the ability of a given soil to hold these nutrients against excessive plant removal and leaching losses. In a review of literature dealing with the residual effect of fertilizer, Nelson and Stanford (1958) presented evidence that potassium applied regularly accumulates in the soil in a form which is readily available to plants. They stated that this accumulation is reflected by higher crop yields and greater uptake of potassium but may not necessarily be reflected by the usual rapid extraction procedures. Hanway et al., (1953) found little evidence of potassium losses through leaching. These researchers conducted a two-year experiment in which phosphorus and potassium fertilizers were top dressed, on alfalfa-timothy meadow grown on a sandy loam soil, at the rates of 0, 28, 56 Kg P/ha and 0, 53, 106 Kg K/ha alone and in all combinations. Recovery of applied P in the hay crop ranged from 33-46% while complete recovery of the 53 Kg K/ha application occured by the end of the second year. Seventy-four percent of the 106 Kg K/ha applied was recovered where no P was added but complete recovery was indicated where P was applied in the two years. Soil tests of samples taken from 0-5 cm and 5-15 cm depth showed that considerable available P had accumulated in the top 5 cm of the soil but that soil K levels had not increased.

Hoover (1943) also found that relatively little of the applied K leached from the A (0-15 cm) horizon to B (15-30 cm) horizon of Mississippi soils even under conditions conducive to extreme leaching. The exchange capacities of these soils ranged from 3-7 me/100 g soil in the A horizon and from 5-7 me/100 g soil in the B horizon respectively. Findings of Caldwell et al., (1975) are in good agreement with the above worker. They found that 80% of applied potassium was still in the top 60 cm of a loamy soil which had received 1168 mm of irrigation water after potassium application. Maclean (1977) also found no evidence of leaching of potassium below the 0-30 cm layer following addition of a total of 2,232 Kg K/ha to a loamy and a sandy loam soil in a three-year field experiment.

Availability of residual K was studied by Maclean and Doyle (1962). They showed that residual K, from a long-term experiment with potatoes, in which a total of 4150 Kg K/ha had been applied, was highly effective in supplying K requirements of a crop of ladino clover in a greenhouse experiment. The clover was grown on soils sampled to a depth of 69 cm from the field experiment after 24 years of annual potato growing on an acid sandy loam, which had received an annual potassium application in excess of potato requirements.

E. The Effect of Soil Moisture Upon K Availability and Uptake By Plants

Experimental results of Rowell et al., (1967) and Vaidyanathan et al., (1968) have demonstrated that the diffusion of ions in the soil medium is considerably influenced by soil moisture. Availability of plant nutrients should therefore be influenced by soil moisture, provided that a significant proportion of the nutrients required by the plant cannot be obtained directly by root interception but must be transported by diffusion or mass flow to the roots (Barber et al, 1963).

Experiments of Drew and Nye (1969) with rye grass (Lolium Perenne L.) revealed that only six percent of the total potassium demand was supplied by the soil volume of the root hair cylinder. Ninety-four percent of the potassium taken up therefore originated from beyond the limit of the root hair cylinder. The above finding is in agreement with calculations of Mengel and Kirkby (1978) which show that even for a soil high in exchangeable potassium, the amount of potassium in direct contact with plant roots can only satisfy a small fraction of the plant's potassium requirement. It can therefore be concluded that the bulk of potassium required by plants must be transported to the roots. The transport of potassium in the soil medium to plant roots may take place by mass flow or diffusion. Barber et al., (1963) however estimated that only about ten percent of the total potassium requirement of the crop is transported by mass flow. Using $^{86}Rb^{+}$, Place and Barber (1964) found a high degree of correlation (r^2=0.89) between the level of rubidium in the soil and the diffusion coefficient and also between the soil moisture content and the diffusion coefficient. The uptake of $^{86}Rb^{+}$ by the corn roots was also influenced in the same manner by the level of exchangeable rubidium and the soil moisture levels so that variations in rubidium uptake was highly correlated (r^2=0.97) with the variations in rubidium diffusion coefficient that was caused by these variables.

Mengel and Van Braunschewing (1972) studied the influence of soil moisture on the availability of K and the effect of K availability on growth of young maize plants (Zea Mays L.). In this study, the plants were grown with a split root system in an apparatus which enabled one part of the roots to be in contact with a nutrient solution medium containing all plant nutrients except K and the other with the soil maintained at different p^F

values and, providing the only source of K supply. Various levels of K as K_2SO_4 were thoroughly mixed with the soil which had previously been leached with a $CaCl_2$ solution and water to remove some of the exchangeable K. The final exchangeable K levels of the soil for various K treatments were 7.5; 11.0; 17.0; 31.0; and 46.0 mg K/100 g soil while P^F treatments were 1.6; 2.0; 2.4; and 2.7. In summarizing their data, the authors made the following observations:

(1) For various K treatments, the highest yields and the largest quantities of K taken up by the corn shoots were obtained at P^F2. With increasing water tensions (P^F 2.4 and 2.7) the yields and the quantities of K taken up by the plants declined sharply. The yield level of the various P^F treatments increased with an increase in the exchangeable K of the soil.

(2) A linear highly significant relationship (r^2=0.88) was obtained between the potassium diffusion rates and the total uptake by plants.

In their conclusion, the authors argued that the observed yield depressions at higher P^F (2.4 and 2.7) were due to K unavailability effected by restricted K diffusion. Since part of the root system was grown in a nutrient solution, water deficit in the plant could not have developed and therefore there was no direct negative influence of moisture on plant growth.

F. Plant Absorption of Potassium

The mechanism by which plants absorb K is not well understood. It is however known that both active and passive processes are involved in ion absorption by plants. According to Kernan (1966), cations are drawn across the cell membrane by movement of other ions if the passive process is in operation whereas an active process requires a carrier transport across the cell membrane as well as metabolic energy to work against the electrochemical gradient of the cell membrane. It is however well established that although ions enter by diffusion into the free space external to the endodermis, continuing uptake is dependent upon metabolic activities. This is demonstrated by the influence of respiration rate and the supply of carbohydrates on absorption as well as the effect of respiration inhibitors (Russell and Clarkson, 1971).

While ion transport through plant membranes includes both metabolic and non-metabolic components, the relative contributions of these components to total ion uptake strongly depend on both external ion concentration and nutrient status of the plant (Jensen 1981). According to findings of Glass and Dunlop (1978), K uptake is mainly metabolic at low external concentrations of K ($<$ 1mM), while it becomes increasingly non-metabolic at higher ($>$ 1mM) external K concentrations. Experiments of Cheeseman and Hanson (1979) with corn roots have also shown that K can be taken up against an electrochemical gradient. The authors assume that this active K uptake is brought about by an ATPase which is inhibited by higher K concentrations in the ambient solution and thus works only at concentrations of less than 5 mMK.

Petterson (1981) studied the passive fluxes of $K^+(^{86}Rb^+)$ into roots of sunflower at low K concentration (0.1 mM) and at high K concentration (1.0 mM) in the ambient solution. The plants had been previously grown in solution cultures with different K levels so that when the study was conducted, the plants were of different K status. 10^{-4}M 2,4-dinitrophenol (DNP) was used to inhibit metabolic uptake of K. The author found that in plant roots of high K status, passive uptake was directly proportional to the potassium concentration of the uptake solution indicating free diffusion. This assumption was supported by the fact that passive Rb^+ uptake was not affected by high K concentration. In roots of low K status, passive uptake of K was higher than in roots of high K status. K effluxes were found to be quantitatively similar to influxes suggesting that passive K fluxes represented exchange diffusion without relation to net potassium transport.

Erdei et al., (1984) working with wheat seedlings noted three distinct phases of K uptake; at low external K concentrations, K uptake increased with increasing K concentrations and culminated at 0.1 mMK; between 0.1 and 1 mM it decreased, and it increased again above 1 mM. The authors concluded that the first two phases depend on metabolic energy while the third phase was mostly passive. This conclusion was supported by the fact that of the three phases, only the first two could be inhibited by 2,4-dinitrophenol.

Involvement of auxin in K uptake has been suggested. Erdei et al., (1979) found that auxins stimulated K uptake through their influence on ATPase activity. These authors concluded from their in vivo and in vitro experiments with young rice roots that

ATPase and auxins are involved in the K uptake process.

G. The Role of Potassium on Cell Turgor and Water Economy of the Plant

The role of potassium as an osmoticum is well documented. The movement of water from the soil to plant tissues and from the tissues to the xylem vessels has been shown to depend upon potassium supply (Baker and Weatherby, 1969). The uptake of water by roots and the ability of the plant to exploit soil water thus depends upon optimum potassium supply. Mengel and Simic (1973) observed that when potassium was low or absent in the root medium, both the quantity of water moved up by the root pressure and the concentration of a number of solutes such as nitrates and amino acids in the xylem sap were considerably depressed.

Accumulation of potassium in plant cells leads to an increase in their osmotic pressure so that water moves into the cell and this in turn increases the turgor pressure of the cell. Since turgor is essential for cell extension, supplying the necessary pressure from inside the cell facilitates cell wall extension and cell enlargement (Mengel and Forster, 1979).

Potassium plays a dominant role in the opening and closing of stomates (Fischer and Hsiao, 1968). Optimum potassium supply reduces water losses by transpiration so that more organic matter can be produced per unit water consumed by the crop (Brag, 1972). The influence of potassium on water use efficiency has also been confirmed by Mengel and Forster (1979). They demonstrated in a nutrient culture experiment with sugarbeet that yield of beet increased with increasing potassium concentrations while water consumption per beet remained constant. Less water per beet was thus consumed at higher potassium levels.

H. Influence of Potassium on Yield and Potassium Content of Plants

The absorption and consequently the potassium content of a plant depends to a great extent on the K concentration of the nutrient medium. In a solution culture experiment, Williams (1961) observed that K content of young barley shoots, harvested at 2-, 4-, and 6 week intervals, reflected the concentration of K in the root medium.

In a study of the effect of potassium on the growth and potassium content of 14 plant species in solution, maintained at constant potassium concentrations, Asher and Ozanne (1967) observed increases of dry weight of both the tops and roots as the potassium concentration in the nutrient solution increased from 94.6 uMK. The potassium concentrations used were 1.2, 7.7, 23.7, 94.6 and 1016 uMK. At 7.7 uMK concentration, yields were greatly reduced although symptoms of severe deficiency were not evident. Barley showed significant yield increases above 94.6 uMK. The two researchers found that potassium deficiency generally reduced growth of tops more than that of roots so that at final harvest most species had higher root/top ratio at lower potassium concentrations of 1-8 uM. It was also observed from the same experiment that in all potassium treatments, the concentration of potassium in the tops was higher than in the roots when concentrations were expressed on dry weight basis. The lowest concentrations at which maximum yield was obtained ranged from 112-197 uM/g for tops and 54-126 uM/g for roots.

Ewanek (1970) found that application of potassium fertilizer increased yield, potassium uptake and potassium concentration in wheat, barley and oats. The latter were sampled at 21 and 28 days after seeding and at the fifth leaf stage of growth. While final oats and barley grain yields were significantly (.05 level) correlated with the potassium concentration at these early stages, the author found no significant correlation for wheat.

Walker and Peck (1975) regressed corn yield upon potassium concentration of whole plants that averaged 25 and 75 cm in height respectively and upon the average potassium concentration of the fifth, sixth and seventh leaves at early tassel. They found that the coefficients of multiple determinations (R^2) for the quadratic equations were 0.71, 0.74 and 0.78 respectively. The critical % K (the percent resulting in maximum predicted yield for whole corn plants 25 cm in height) was determined to be 3.98, and for plants 75 cm in height it was 3.90. Sobulo (1983) determined critical plant potassium for maize. He found that for plants 17 days old, the optimum percent potassium was 4.0-4.5. Severe potassium deficiency symptoms were observed in the leaves of the plants when potassium in the tissues was 2-3 percent. The author however found a poor relationship between yield and percent K.

Leigh and Johnson (1983) investigated the relationships between K concentration and grain yield of field-grown spring barley. They found a significant positive correlation (r=0.76; 0.001) between maximum % K in dry matter of young plants and the grain yield at final harvest. Percent potassium increased to a maximum during tillering and then declined steadily until harvest. The early rise in % K in dry matter was however small in relation to the subsequent decline.

I. Interaction of Potassium and Nitrogen in Relation to Nitrogen Uptake, Yield and Protein Formation

Potassium is known to influence either positively or negatively, the yield responses of plants to other nutrients depending on its amount in the soil. Soofi and Fuehring (1964) observed that when available potassium was lacking, yield responses to nitrogen and phosphorus were negative. On the other hand, excessive potassium fertilization reduced uptake of other nutrients and upset crop growth. Washko (1949) working with bromegrass noted 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 K in solution, the materials harvested after two months showed a decrease in its nitrogen concentration.

Strong interactions between potassium and nitrogen have been observed. Macleod (1969) found that yields of both grain and straw of barley grown in hydroponic culture showed maximum response to high rates of nitrogen only with the provision of adequate potassium. Similar responses have been reported in grasses (Widdowson et al., 1961). The work of Koch and Mengel

(1977) is in good agreement with the above researchers. The latter found a substantially higher uptake of nitrogen as well as a higher proportion of nitrogen in the grains of wheat at a higher potassium treatment. They attributed this result to the higher production of plant material from the higher potassium treatment than from the plants grown in lower potassium treatments.

The influence of potassium on grain filling of cereals is not only as a result of its effect on carbohydrate production and translocation, but is also related to amino acid metabolism. Koch and Mengel (1977) reported that potassium promotes amino acid translocation from the vegetative wheat plant to grains. This, according to these authors, favors grain protein synthesis especially glutelin and prolamin. Ashly et al., (1972) suggested that the positive influence of potassium on grain filling is related to its effect on phloem transport. This idea is supported by investigations of Mengel and Haeder (1977) who found that potassium promotes phloem loading with sugars and amino acids in Ricinus Communis L.

In an experiment to investigate the effect of potassium on protein formation and amino acid turnover in developing wheat grains, Mengel et al., (1981) observed that potassium increased the rate of amino acid translocation into the grain as well as the conversion of free amino acids into grain protein. The accumulation of free amino acids in grain of higher potassium treated plants led these researchers to suggest that the influence of potassium was stronger on the translocation of amino acids into the grains than on the conversion into protein. They concluded that an indirect effect of potassium on grain protein formation results from amino acid translocation into grain and not from the influence of potassium on peptide bond formation.

J. Effect of Potassium on Yield Components of Cereals

It is well known that potassium is mainly taken up during the vegetative growth of the plant. Pitman (1972) has demonstrated in barley plants that the rate of K uptake is directly related to growth rate. Inadequate supply of potassium therefore retards the vegetative development of the plant which may not only affect the production of vegetative plant material but also the development of reproductive organs as well as the filling of storage tissues with photosynthate. The influence of potassium starvation for wheat at the tillering stage of growth has been studied by Chapman and Keay (1971). These workers found that withholding potassium supply at tillering stage led to a reduction in inflorescence weight, number of grains per spiklet and the grain weight.

Mengel and Forster as reported by Mengel and Kirkby (1980) found that a 16-day interruption of potassium supply to spring barley between tillering and stem elongation stages resulted in a grain yield depression of about forty percent. This yield depression was brought about mainly by a reduction in the number of ears per plant as well as a lower single grain weight. The interruption of potassium supply during the stage of ear emergence also depressed grain yield. In this case, however, the depression resulted largely from a decrease in single grain weight.

Chapter 3

ANALYTICAL PROCEDURES

A. Soil Analysis

1. Soil pH

Soil pH was determined electrometrically by the method described by Peech (1965). Fifty ml of distilled water were added to 50 g of air-dry soil. The soil and water were mixed well in 200 ml beaker and allowed to stand for 30 minutes. The pH of the suspension was then determined using a Beckman zero-matic pH meter.

2. Soil Texture

Particle size analysis was performed by the standard pipette method (Kilmer and Alexander, 1949).

3. $NaHCO_3$ Extractable Phosphorus

Phosphorus was measured using the acid molybdate method of Murphy and Riley (1962). Five grams of air-dry soil were extracted with 100 ml of 0.5M $NaHCO_3$ extracting solution. The mixed molybdate-ascobic acid reagent was used to reduce the phosphomolybdate complex and the absorbance of the blue color developed was measured using a spectrophotometer at 885 nm.

4. Exchangeable Potassium

Exchangeable K was extracted by the Pratt (1965) modified procedure. A five-gram soil sample was weighed into a 500 ml shaking bottle. 100 ml solution containing 1.0 N NH_4OAc and 250 ml $LiNO_3$ were added and shaken for one hour. The solution was filtered through Whatman #42 filter paper. Potassium concentration in the filtrate was determined using a Perkin-Elmer 303 Atomic Absorption spectrophotometer.

5. Nitrate Nitrogen

10.0 grams of air-dry soil were extracted with 50.0 ml of NO_3 extracting solution consisting of 0.02 M $CuSO_4$ and 0.6% Ag_2SO_4. Nitrate was measured calorimetrically in a nitrate form of phenoldisulphoric acid in alkaline solution using an ultraviolet spectrophotometer at 415 nm.

6. Inorganic Carbon

$CaCO_3$ was determined by the method of Skinner et al., (1959). One gram of air-dry soil was heated with 40 ml of 10% HCl for ten minutes. The CO_2 evolved was drawn by suction through a drying and absorption train consisting of concentrated H_2SO_4, a tube of dehydrite and calcium chloride. The amount of CO_2 evolved was determined by weighing the tube before and after trapping the gas. The results were expressed in $CaCO_3$ equivalents.

7. Field Capacity

Soil samples (2 mm-size) from Haywood were placed in plastic cylinders, the bottom of which were fitted with porous cloth.

The surface of the samples were saturated with water and equilibrated for 24 hours. Tops of the cylinders were covered with parafilm to minimize surface evaporation. The moist soil was then subsampled, oven-dried at 105 degrees C and moisture content, so determined was expressed on an oven-dry basis.

B. Plant Analysis

1. Total Phosphorus

One gram sample of ground plant tissue was digested using 10.0 ml of concentrated HNO_3 and 15.0 ml of 70% $HCLO_3$. The resulting digest was diluted with distilled water to 25 ml and filtered. 0.5 ml was drawn from the 25 ml solution. 9.5 ml distilled water were then added to bring the volume to 10 ml. From the 10 ml solution, 0.5 ml was drawn and mixed with 7.5 ml distilled water plus 2 ml ascorbic acid molybdate mixture. The absorbance was read on spectrophotometer at 885 nm.

2. Potassium

A one gram sample of ground plant tissue was digested using 10.0 ml of concentrated HNO_3 and 15.0 ml of 70% $HCLO_3$. The digest was filtered and distilled water was added to make up the volume to 25 ml. 0.5 ml was taken from the 25 ml solution and the volume was made up to 10 ml by adding 9.5 ml of distilled water. A 0.5 ml aliquot was then taken from the 10 ml solution and a total of 9.5 ml consisting of 8.5 ml distilled water and 1.0 ml $LiNO_3$ was added. Potassium concentration was then determined using a Perkin-Elmer 303 Atomic Absorption spectrophotometer.

3. Total Nitrogen

Total N was determined by a modified Kjeldahl method (Jackson, 1958).

4. Zinc, Copper, Manganese and Iron

A one gram sample of ground plant tissue was digested using 10.0 ml of concentrated HNO_3 and 15.0 ml of 70% $HCLO_3$. The mixture was digested until clear as described by Robert and Kerber (1980). The plant digest was filtered and the volume made to 25 ml by adding distilled water. After centrifuging, the concentrations of Cu, Zn, Mn, and Fe in the solution was determined using Perkin-Elmer 303 Atomic Absorption spectrophotometer.

Chapter 4

FIELD STUDY 1982

INTRODUCTION

It is well known that to obtain maximum yield of wheat or any other crop, all the factors that influence plant growth have to be non-limiting. Yields of a given variety of wheat vary from place to place as well as from year to year depending on a set of conditions that operate during the growing season. Since it is difficult to have all growth conditions at optimal levels, maximum yield can only be defined under specific conditions.

From soil fertility studies, potassium has been shown to have a major influence on plant growth and yield. Inadequate supply of potassium therefore, leads to sub-optimal yields. In view of the above facts, a three-year experiment was started in the spring of 1982, to evaluate how limiting potassium is for maximum yield of wheat, under rain-fed conditions, if other factors are close to optimum. Since large quantities of potassium were to be applied, attention was paid to the method of placement (i.e., broadcast and incorporation and, banding of some amount of potassium with the seed). Banding was done to provide information as to whether this practice is beneficial even when large amounts of potassium have been incorporated into the soil.

MATERIALS and METHODS

Three sites were chosen for this experiment on the basis of their soil potassium content and geographical location. The locations were Haywood, Elm Creek and Winkler. Haywood soil rates low in available K. Elm Creek soil is medium, while Winkler soil is high in available K. Table 1 shows some of the characteristics of these soils.

The trial consisted of four replicates and was laid down in a split-split plot design. A replicate (block) measuring 51.2 by 6.4 m was divided parallel to the shorter side into two equal halves to provide the main plots. The main plots were each sub-divided again parallel to the shorter side into four sub-plots measuring 6.4 m by 6.4 m. Rates of 0, 100, 200 and 400 Kg K/ha as KCl were randomly hand broadcast to the sub-plots and roto-tilled to a depth of 0-7.5 cm in one main plot and to a depth of 0-15 cm in the other (shaded) area (figure 1). Nitrogen (NH_4NO_3) and phosphorus (MCP) were also hand broadcast in both main plots and roto-tilled to a depth of 7.5 cm. At all the three sites, phosphorus was added at the rate of 100 Kg P/ha. At Haywood and Winkler nitrogen was added at the rate of 150 Kg N/ha while at Elm Creek, 200 Kg N/ha was applied. The amount of N and P applied were based on the results of soil test for these locations. At the time of seeding, each replicate was divided lengthwise into two equal halves to provide 16 sub-sub-plots (A and B), per replicate (figure 1). Sub-sub-plots (A) received 17 Kg P/ha banded with the seed to a depth of 2.5 cm while sub-sub-plots (B) received 33 Kg K/ha + 17 Kg P/ha also banded with the seed to the same depth as for A sub-sub-plots. Seeding was done with a 9 row seed drill. Each of the sub-sub-plots A and B consisted of 18 rows. At all sites, wheat (Triticum aestivum var. Columbus) was seeded at the rate of 100 Kg/ha. Soil samples for moisture determination were taken from the three locations before seeding time.

Harvests of the above ground portions of the plant at early tillering, boot stage, heading, milk stage and at maturity were made on an area of 1.0 m^2. The harvested materials were dried at 60 degrees C and then weighed to determine the dry matter yield. The plant matter from the four replicates for each rate of applied K was bulked. The bulking for A and B sub-sub-plots was done separately. The bulked samples were ground in a wiley mill and analysed for K, N, P, Zn, Cu, Fe and Mn to see if they were growth limiting. At maturity, the harvested materials were dried, weighed and threshed. The grains were weighed to determine grain yield. Bulking of grain samples was done in a similar manner as described for dry matter. Grinding of the grain samples was done and analysis of plant nutrients, listed earlier, was performed. Bulked straw samples were handled in the same way as described for grain.

In September of 1982, all the remaining wheat in the plots was combined and straw removed. This was done in all the three locations in preparation for the second year of the experiment. Soil samples for moisture determination were taken from all three locations. In 1983, no K was broadcast but all the plots at all locations received broadcast N in the same quantities as described for 1982. In addition 15 Kg Cu/ha and 20 Kg Zn/ha were sprayed into all the plots at Haywood and Winkler. This was done since 1982 tissue analysis data showed that these micronutrients were marginal. All the experimental plots at the three locations were roto-tilled to a depth of 7.5 cm. Soil samples from every treatment in the three locations were taken prior to seeding to determine the amount of residual K and moisture content of the soil. At the time of seeding, 17 Kg P/ha was banded with the seed to (A) sub-sub-plots of every replicate while (B) sub-sub-plots received 33 Kg K/ha + 17 Kg P/ha banded with the seed. Harvesting, drying, grinding and analytical procedures for nutrients were done as described for 1982 samples.

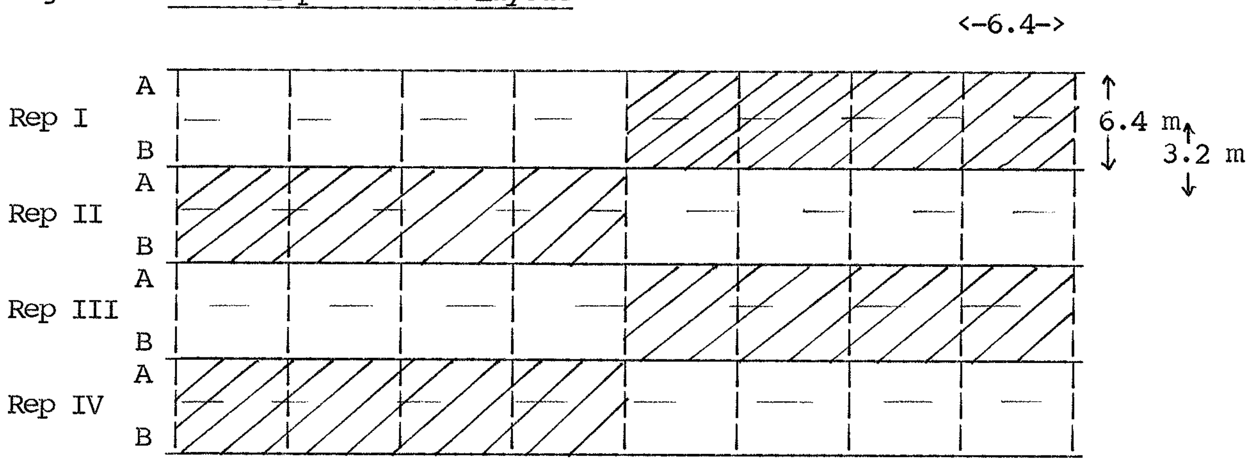
Table 1: Some Characteristics of the Soil Used for the Field, Lysimeter and Growth Chamber Experiments.

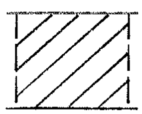
LOCATION	HAYWOOD[1]	ELM CREEK[1]	WINKLER[2]
Soil series Sub-group	Almassipi Gleyed-carbonated Rego Black	Elm Creek Orthic-Black	Rignold Gleyed Black
Texture	V.F.S.	F.S. - L.V.F.S.	V.F.S.L.
Carbonate content	Low	Low	Low
pH	8.1	8.2	8.0
NO_3-N (Kg/ha) (0-60 cm)	84	42	125
Available P (Kg/ha) (0-15 cm)	6	25	31
Available K (Kg/ha) (0-15 cm)	146	449	602

1. Soil classification by Michalyna and Smith (1972).

2. Soil classification by Smith and Michalyna (1973).

Fig. 1. <u>Field Experimental Layout</u>




0-15 cm depth of K incorporation


0-7.5 cm depth of K incorporation

A: 17 Kg P/ha was banded with the seed in A rows.

B: 33 Kg K/ha + 17 Kg P/ha were banded with the seed in B rows.

RESULTS AND DISCUSSION

Plant Appearance

At the three locations (i.e., Haywood, Elm Creek and Winkler), seedling emergence in each of the two years of this study, was good and uniform in all plots irrespective of the rate of K applied. No visual symptoms of deficiency of K or any other nutrients were evident on the plants at Elm Creek and Winkler throughout the 1982 and 1983 seasons. At Haywood, however, the stunted growth of the plant, and the marginal leaf scorch, characteristic of potassium deficiency were observed about 3 weeks after seeding in plots where no K was applied. These symptoms persisted throughout the season in each of the two years of this study. In 1982 season a severe lodging of plants occured at Winkler, where close to 80 percent of the plants were affected. Such an incident did not occur in 1983 season. Plants at Elm Creek and Haywood were free from lodging in both seasons.

Haywood 1982

Results of sampling at the boot stage of growth showed that the 0-7.5 cm depth of K incorporation resulted in a significantly higher plant dry matter yield compared to the 0-15 cm depth (table 3a). The influence of the depth of K incorporation on grain yield was, however, the opposite of the above observation. It was, however, observed that at the early tillering, the heading and the milk stages of growth as well as at maturity, the 0-7.5 cm depth of K incorporation resulted in a substantial though non-significantly higher plant dry matter yield than the 0-15 cm depth. It is not clear why the influence of the depth of K incorporation was not the same for both plant dry matter and the grain yield. For the same levels of applied K, percent K in the shoot from plots where K was incorporated to 7.5 cm did not differ substantially from that in the shoots from plots where K was incorporated to 15 cm depth. However, at various stages of growth, total K uptake from plots where K was incorporated to 0-7.5 was higher compared to that from plots where K was incorporated to 0-15 cm. This higher K uptake was therefore as a result of the differences in plant dry matter yield and not a reflection of the differences in K availability.

Since the depth of K incorporation was only significant at the boot stage of growth, the data on the influence of K on plant dry matter yield at other stages of growth are averaged over the depth of K incorporation. A significant response in plant dry matter yield to levels of broadcast and banded K was observed throughout the sampled stages of growth. Results from the plots which received broadcast K only showed that plant dry matter and grain yield from the check were significantly lower than those obtained from plots receiving broadcast K. In fact at the early tillering stage of growth (table 2), each successive level of broadcast K resulted in a significantly higher yield compared to the preceding level. At the boot stage of growth (table 3b) plant dry matter yield resulting from broadcast K levels of 100 and 200 Kg K/ha were not significantly different. However, application of 400 Kg K/ha resulted in significantly higher plant dry matter yield than any of the other K levels. At the heading stage of growth (table 4), plant dry matter yields from plots which received 100, 200 or 400 Kg K/ha were not significantly different from each other. Plant dry matter yield at the milk stage of growth and at maturity (tables 5 and 6) showed, however, that increasing levels of applied K resulted in a corresponding plant dry matter yield response. But grain yield (tables 7b and c) was not significantly influenced by broadcast K levels above 100 Kg K/ha except in plots where K was incorporated to 15 cm depth.

When 33 Kg K/ha was banded in plots which did not receive broadcast K, the plant dry matter yield was as good as when 100, 200 Kg K/ha and in some cases 400 Kg K/ha were applied (tables 2, 3b and c, 4 and 6). Where 200 Kg K/ha and/or 400 Kg K/ha was applied, banding 33 Kg K/ha resulted either in depression or no change in yield. Of all the plots which received broadcast K as well as banded K, the lowest grain yield was obtained from plots which received 400 Kg K/ha. When averaged over the levels of broadcast K, the main effect of banding shows that plots that received banded K resulted in significantly higher plant dry matter yield compared to those which received broadcast K only. This observation was true throughout the sampled stages of growth as well as for the grain yield at maturity.

Averaged over both the depth of K incorporation as well as the levels of banding, the main effect of K mixing shows that the check yielded significantly lower plant dry matter than any broadcast K treatment. However, yield responses due to 200 Kg

K/ha and/or 400 Kg K/ha were not significantly different from those obtained by applying 100 Kg K/ha (tables 2, 3b and c, 4, 5 and 6). In plots where K was incorporated to 7.5 cm, results of the main effect of K on grain yield (table 7b) were similar to those described for the plant dry matter. However, where broadcast K was incorporated to 15 cm depth, grain yield (table 7c) from plots receiving 100 Kg K/ha was significantly less than that resulting from application of 200 or 400 Kg K/ha.

Yield response to applied K was expected since the soil was K deficient. However, the results seem to suggest that for vegetative yield some broadcast K together with banded K was necessary but not for grain yield. Since adequate K is required in the early stages of growth, the provision of adequate amounts of K close to the seed would result in the early establishment of the plant and a subsequent high yield. The efficiency of K uptake is also better when K is banded than when broadcast is the method of K application. It can therefore be concluded that if the method of K application is by broadcast and incorporation into the soil, then a large amount of K is required in order to maintain the necessary concentration near the seed.

The depression in yield observed at the early tillering and the boot stages of growth when 33 Kg K/ha was banded in plots which had received broadcast K levels of 200 Kg/ha or more may have been due to seedling injury. This adverse effect was, however, not severe enough to cause a measurable damage at later stages of growth since no depression in yield was observed at maturity.

Table 2: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha) Averaged Over Two Depths of K Mixing at Early Tillering Stage of Growth. (Haywood 1982).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha)		Main Effect of K Mixed With Soil
	0	33	
	Dry Matter Yield (Kg/ha)		
0	72 a	150 d	111 a
100	140 c	152 d	146 b
200	150 d	133 b	142 b
400	156 e	144 c	150 b
Main Effect of Banding	130 A	146 B	

Means with the same small or capital letter(s) are not significantly different at P = .05, Tukey's w-procedure.

Table 3a: Influence of Depth of K Mixing with the Soil Averaged over the Rates of K Mixing and K Banded with Seed on Dry Matter Yield (Kg/ha) at the Boot Stage of Growth. (Haywood 1982).

Depth of K Mixing (cm)	K Banded with the Seed (Kg/ha)		Main Effect of Depth
	0	33	
		Dry Matter Yield (Kg/ha)	
0 - 7.5	1041	1158	1100 a
0 - 15	886	1057	972 b

Means with the same letter are not significantly different at P = 0.05, Tukey's w-procedure.

Table 3b: Influence of K Mixed with the Soil to a Depth of 7.5 cm and K Banded with the Seed on Dry Matter Yield (Kg/ha) at Boot Stage of Growth. (Haywood 1982).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixing
	Dry Matter Yield (Kg/ha)		
0	362 a	1253 c d	808 a
100	1236 c	1328 d	1282 b
200	1204 c	1074 b c	1139 b
400	1361 d	979 b	1170 b
Main Effect of Banding	1041 A	1158 B	

Means with the same small or capital letter(s) are not significantly different at P = .05, Tukey's w-procedure.

Table 3c: Influence of K Mixed with the Soil to a Depth of 15 cm and K Banded with the Seed on Dry Matter Yield (Kg/ha) at Boot Stage of Growth. (Haywood 1982).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixing
	Dry Matter Yield (Kg/ha)		
0	184 a	1067 c	626 a
100	917 b	1087 c	1002 b
200	1135 c	1087 c	1111 b
400	1309 d	987 b	1148 b
Main Effect of Banding	886 A	1057 B	

Means with the same small or capital letter(s) are not significantly different at P = .05, Tukey's w-procedure.

Table 4: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha) Averaged over Two Depths of K Mixing at Heading Stage of Growth. (Haywood 1982).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
		Dry Matter Yield (Kg/ha)	
0	1597 a	4220 c	2909 a
100	3564 b	4247 c	3906 b
200	3795 b	4002 b c	3898 b
400	3872 b c	4223 c	4048 b
Main Effect of Banding	3207 A	4173 B	

Means with the same small or capital letter(s) are not significantly different at P = 0.05, Tukey's w-procedure.

Table 5: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha) Averaged over Two Depths of K Mixing at Milk Stage of Growth. (Haywood 1982)

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
		Dry Matter Yield (Kg/ha)	
0	2813 a	6598 b	4705 a
100	7223 c	7814 d	7518 b
200	8101 d e	7884 d	7993 b
400	8444 e	7935 d	8189 b
Main Effect of Banding	6645 A	7558 B	

Means with the same small or capital letter(s) are not significantly different at P = .05, Tukey's w-procedure.

Table 6: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha) Averaged over Two Depths of K Mixing at Maturity. (Haywood 1982).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
	Dry Matter Yield (Kg/ha)		
0	2794 a	7020 b	4907 a
100	7089 b c	7841 c d	7465 b
200	7552 c	8318 d e	7935 b
400	8710 e	7950 d	8330 b
Main Effect of Banding	6536 A	7782 B	

Means with the same small or capital letter(s) are not significantly different at P = .05, Tukey's w-procedure.

Table 7a: Influence of Depth of K Mixing with the Soil Averaged over the Rates of K Mixing and K Banded with Seed on Grain Yield (Kg/ha) at Maturity. (Haywood 1982).

Depth of K Mixing (cm)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of Depth
	Dry Matter Yield (Kg/ha)		
0 - 7.5	1743	1973	1858 a
0 - 15	2053	2514	2284 b

Means with the same letter are not significantly different at P = .05, Tukey's w-procedure.

Table 7b: Influence of K Mixed with the Soil to a depth of 7.5 cm, and K Banded with the Seed on Grain Yield (Kg/ha) at Maturity. (Haywood 1982).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha)		Main Effect of K Mixing
	0	33	
		Grain Yield (Kg/ha)	
0	797 a	2008 b	1403 a
100	2138 b	2043 b	2091 b
200	1947 b	2069 b	2008 b
400	2091 b	1774 b	1933 b
Main Effect of Banding	1743 A	1973 B	

Means with the same small or capital letter(s) are not significantly different at P = .05, Tukey's w-procedure.

Table 7c: Influence of K Mixed with the Soil to a Depth of 15 cm and K Banded with the Seed on Grain Yield (Kg/ha) at Maturity. (Haywood 1982).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha)		Main Effect of K Mixing
	0	33	
		Grain Yield (Kg/ha)	
0	674 a	2415 c	1545 a
100	2200 b	2539 c d	2370 b
200	2641 d	2750 d	2696 c
400	2698 d	2351 b c	2525 c
Main Effect of Banding	2053 A	2514 B	

Means with the same small or capital letter(s) are not significantly different at P = .05, Tukey's w-procedure.

Table 8 shows the results of shoot K concentration at various stages of growth. Also included in this table are the data for percent potassium in the grains and in the straw. Throughout the vegetative stages of growth, percent K in the shoots from plots which received broadcast K only, increased with increasing levels of K. A similar trend was observed for % K in the straw. However, percent K in the grains remained almost constant across the levels of broadcast K. At the early tillering stage of growth, plots which received banded K showed no increase in percent K in shoots from plots receiving over 200 Kg K/ha broadcast treatment. Also at the boot stage of growth the only increase in percent K in the shoots from the K banded plots was when 100 Kg K/ha was applied. Percent potassium in the straw from plots which received banded K only (table 8) was higher than that from plots receiving higher levels of broadcast K in addition to banded K. This observation is probably erroneous since throughout the stages of growth, the shoots from the check had the least K concentration. Additionally an increasing trend in percent K in the shoots was observed as the levels of broadcast K increased from 100 to 400 Kg K/ha.

According to Melsted et al., (1969) K supply is considered to be limiting growth and yield when K concentration in the shoots of wheat at boot stage of growth is below 1.80% K, with the exception of the check, however, percent K in the shoots from plots which received 100 Kg K/ha or more was close to and in some cases higher than the 1.80% K critical level. However, no plant dry matter or grain yield depression was observed even in plots

Table 8: K Concentration and Uptake as Influenced by Amount of K Mixed with the Soil and K Banded with the Seed, Averaged over Two Depths of K Mixing. (Haywood 1982).

Stage of Growth	K Banded (Kg/ha)	K Mixed with Soil (Kg/ha) 0	100	200	400
Early Tillering	0	1.30 (0.94)	3.30 (4.62)	3.95 (5.93)	4.00 (6.24)
	33	3.47 (5.21)	3.67 (5.72)	4.00 (5.32)	3.65 (5.26)
Boot	0	0.90 (2.46)	1.67 (17.98)	1.92 (22.45)	2.77 (36.98)
	33	1.42 (16.47)	2.23 (26.93)	1.75 (18.91)	1.87 (18.38)
Heading	0	0.78 (12.46)	0.90 (32.07)	1.18 (44.78)	2.13 (82.47)
	33	1.10 (46.42)	1.41 (59.88)	1.62 (64.83)	1.71 (72.21)
Milk	0	0.45 (12.66)	0.79 (57.06)	1.10 (89.11)	1.50 (126.66)
	33	0.58 (38.27)	0.92 (71.89)	1.40 (110.38)	1.75 (138.86)
Grain	0	0.60 (4.41)	0.41 (8.89)	0.53 (12.16)	0.49 (11.73)
	33	0.45 (9.95)	0.47 (10.77)	0.40 (9.64)	0.51 (10.52)
Straw	0	0.41 (8.22)	0.70 (34.40)	1.17 (62.92)	1.84 (116.23)
	33	1.88 (90.44)	0.80 (44.40)	1.11 (65.39)	1.45 (84.72)

*Note: 1. Numbers in brackets represent K uptake (Kg/ha).

2. Numbers outside brackets represent K concentration (% K).

where shoot percent K was as low as 1.4% K. Ward et al., (1973) reported that a range of 1.5 - 3.0% K in the shoots at the heading stage of growth is sufficient for optimum wheat growth. In this study, however, plant dry matter and grain yields from plots whose shoot % K was as low as 0.9% were not significantly lower compared to the yield from plots whose shoot K concentration was higher. The dramatic increase in plant dry matter yield, at the heading stage of growth, in response to application of 100 Kg K/ha or banding 33 Kg K/ha may have resulted in diluting percent K in the shoots.

Results of K uptake at the vegetative stages of growth as well as the K content of the grain and the straw are also shown in table 8. K uptake like percent K in the shoots from plots which received broadcast K only increased with increasing levels of broadcast K. This observation was true throughout the vegetative stages of growth. When 33 Kg K/ha was banded in the plots which had received various levels of broadcast K, no clear trend in K uptake was observed. At the early tillering and the boot stages of growth, K uptake increased with the application of 100 Kg K/ha broadcast. Higher levels of broadcast K led to some decrease in K uptake. At the heading and the milk stages of growth, however, K uptake increased with increasing levels of broadcast K. The total K content of the grain and the straw from plots which received broadcast K only also increased with increasing levels of broadcast K. However, the K content of the grains from plots which received banded K increased or decreased, though slightly, as the levels of broadcast K increased. With the exception of the check, the straw K content from plots which received banded K also increased with increasing levels of broadcast K. The high value of the K content in the straw from the check was due to the perhaps erroneously high percent K in the straw.

The depression in plant dry matter yield at the early tillering and at the boot stages of growth when 200 Kg K/ha or more was broadcast, in plots receiving banded K, together with a substantial decline in % K may help to explain the observed decline in K uptake. Lack of change in K uptake at the boot stage of growth when 200 or 400 Kg K/ha was applied was perhaps due to the counter-balancing effect of the slight increase in shoot % K and the slight depression in plant dry matter yield with increasing levels of broadcast K.

Results of nitrogen concentration in the shoots as well as N uptake are shown in table 9. At the early tillering, the boot and the heading stages of growth, percent N in the shoots from plots which received broadcast K only showed a declining trend as the levels of broadcast K increased. This trend was, however, not observed at the milk stage of growth where increasing levels of broadcast K resulted either in an increase or a decrease in shoot percent N. Also when 33 Kg K/ha was banded, no consistent relationship between levels of broadcast K and the shoot percent N was observed. These results of shoot nitrogen concentration are surprising since, as observed by Washko (1949), an increase in K supply results in an increase in shoot percent N. However, the decrease in shoot percent N at the early tillering, the boot

Table 9: Influence of K Mixed with the Soil and K Banded with the Seed on N Concentration (% N) and N Uptake (Kg/ha), at Early Tillering, Boot, Heading and Milk Stages of Growth of Wheat, Averaged over Depth of K Mixing. (Haywood 1982).

Stage of Growth	K Banded With the Seed (Kg/ha)	K Mixed with the Soil (Kg/ha) *1 0	100	200	400
Early Tillering	0	4.80 (3.46)	5.13 (7.18)	4.90 (7.35)	4.83 (7.53)
	33	5.02 (7.57)	5.01 (7.61)	4.88 (6.49)	4.92 (7.09)
Boot	0	4.51 (12.31)	4.22 (45.43)	4.20 (49.12)	4.24 (56.60)
	33	4.32 (50.11)	4.25 (51.32)	4.10 (44.30)	4.27 (41.97)
Heading	0	2.53 (40.40)	2.19 (78.05)	2.17 (82.35)	2.14 (82.86)
	33	2.26 (95.37)	2.29 (97.26)	2.38 (95.25)	2.31 (97.55)
Milk	0	1.35 (37.98)	1.25 (90.29)	1.37 (110.98)	1.33 (112.31)
	33	1.25 (82.48)	1.36 (106.27)	1.27 (100.13)	1.34 (106.33)

*1 - Numbers in brackets represent N uptake (Kg/ha).

- Numbers outside brackets represent N concentrations in tissues.

and the heading stages of growth was likely due to dilution effect resulting from the slight increase in plant dry matter yield.

N uptake (table 9) from plots which did not receive banded K increased with increasing levels of broadcast K. This observation was true throughout the stages of growth sampled. Nitrogen uptake from plots which received banded K was not very much influenced by the levels of broadcast K, particularly at the early tillering and the boot stages of growth. At the milk stage of growth, however, the 0 Kg K/ha broadcast treatment resulted in a substantially lower N uptake compared to higher levels of broadcast K. These results therefore seem to indicate that the influence of levels of applied K on N uptake was most likely due to the direct effect of K on plant dry matter yield rather than through its influence on increased absorption of N from the soil. Since 33 Kg K/ha was enough for maximum plant dry matter yield, it is not surprising therefore that levels of broadcast K were without any substantial effect on N uptake from plots which received banded K.

Table 10 shows the results of percent protein in the grains as influenced by levels of applied K. These results show that percent protein in the grains was increased by application of K. When no K was banded, the lowest protein concentration was observed in the grains from the check. With the application of 100, 200, or 400 Kg K/ha there was very little change in grain protein concentration. Percent protein in the grains from plots which received banded K increased slightly with increasing levels of broadcast K.

Table 10: Influence of K Mixed with the Soil and K Banded with the Seed on % Protein in the Grain, Averaged over the Two Depths of K Mixing. (Haywood 1982).

K Mixed with Soil (Kg/ha)	K Banded with the Seed (Kg/ha)	Percent Protein in Grain at 13.5% Moisture Content
0	0	13.71
	33	14.74
100	0	16.03
	33	14.94
200	0	15.63
	33	15.48
400	0	16.18
	33	15.78

The influence of K supply on percent protein has been reported. Koch and Mengel (1977) observed that ample K supply promotes translocation of nitrogenous compounds from the vegetative plant parts to the grains and thus enhances protein synthesis. The amount of nitrogen translocated to the grain will depend, in part, on the amount accumulated during the vegetative growth. As was observed earlier (table 9), N uptake during the vegetative growth generally increased with increasing levels of applied K. One can therefore conclude that under conditions of yield response to K, N uptake and therefore the percent protein in the grain will increase with increasing K supply if N supply is not limiting.

The shoot concentration of phosphorus and some micronutrients (Appendix 1) were examined to see if they were adequately supplied from the soil. The concentration of P and Zn at the heading stage of growth were within the sufficiency ranges of 0.2-0.5% P and 15-70 ppm Zn reported by Ward et al., (1973). Copper concentration in the shoots at the boot stage of growth was within or slightly above the optimum levels of 3.2-3.3 ppm Cu suggested by Gupta and Macleod (1970), but below the critical level of 5 ppm Cu reported by Melsted et al., (1969). Manganese concentration in the shoots at the boot stage of growth were slightly below the 30 ppm critical level suggested by Melsted et al., (1969). The shoot concentration of the above examined plant nutrients were, however, not influenced by levels of applied K. Since the shoot concentration of all the nutrients examined with the exception of K were within or slightly lower than the sufficiency levels, it can be concluded that any observed differences in plant dry matter or grain yield responses were mostly due to applied K.

Haywood 1983

As was mentioned earlier, the main objective in the second year of this study was to evaluate the residual effect of the various K treatments, applied in 1982, on growth and yield of wheat. Results of the depth of K incorporation were consistent throughout the stages of growth. Both plant dry matter and the grain yields from the 0-7.5 cm depth of K incorporation were slightly higher than those resulting from the 0-15 cm depth but only significant at the milk stage of growth (table 14a). The observed effect of the depth of K incorporation was perhaps due to less K fixation in plots where K was mixed to 7.5 cm compared to 15 cm depth, since the amount of soil in contact with K was less in the former than in the latter. However, it is unlikely that the depth to which K was incorporated influenced K availability. As shown in tables 14b and 14c the effect of the depth of K incorporation was observed irrespective of whether the plots received banded K or not, although banded K was almost enough for maximum yield.

Since the depth of K incorporation did not significantly influence the plant dry matter yield for most of the growth stages, the results presented on the influence of broadcast and banded K, except the yield at milk stage of growth, were averaged over the two depths. Throughout the stages of growth, plant dry matter and the grain yield from plots which had received various levels of broadcast K only responded to increasing levels of broadcast K. From the heading stage of growth to maturity (tables 13, 14b and c, and 15), each successive level of broadcast K resulted in a significantly higher plant dry matter yield than the preceding one. This observation was also true for the grain yield (table 16). The simple effect of banding 33 Kg K/ha into plots which received various levels of broadcast K was very much dependent upon the stage of growth. At the early tillering stage of growth (table 11), banding 33 Kg K/ha led to yield depression as the levels of broadcast K increased. However, these yields were still better than those obtained from plots receiving any level of broadcast K only. The plant dry matter yield depression at the boot stage of growth (table 12) became slight and nonsignificant.

At the heading stage of growth (table 13), plant dry matter yield resulting from plots receiving both the banded K as well as 400 Kg K/ha was significantly higher than that resulting from plots receiving other levels of broadcast K. Plant dry matter yield at the milk stage of growth (tables 14b and c) also showed a general increase from one level of broadcast K to another with the highest yield resulting from the 400 Kg K/ha broadcast treatment. At maturity, however, plant dry matter and grain yields from plots receiving both broadcast and banded K (tables 15 and 16) were not significantly influenced by levels of broadcast K.

The average effect of broadcast K at various stages of growth shows that response to levels of broadcast K depended on the stage of growth. With the exception of the early tillering stage of growth (table 11), where no significant plant dry matter yield response was observed, response to at least one level of applied K, at other stages of growth was observed. Lack of plant dry matter yield response at the early tillering stage of growth, as indicated by the main effect of incorporated K, was obviously due to the masking effect of banded K. At the boot and the heading stages of growth (tables 12 and 13), the main effect of broadcast K shows no significant yield difference between 0 and 100 Kg K/ha broadcast treatments. At the boot stage, plots receiving 200 or 400 Kg K/ha had about the same yield. These yields were, however, significantly different from those obtained from plots receiving 0 or 100 Kg K/ha. At the heading stage of growth, the 400 Kg K/ha treatment resulted in significantly higher plant dry matter yield over the other treatments. However, plant dry matter yield resulting from the 200 Kg K/ha treatment was not significantly different from that resulting from application of 100 Kg K/ha but differed significantly from the yields resulting from plots receiving no broadcast K. At the milk stage of growth results of plant dry matter yield from the plots where broadcast K was incorporated to 7.5 cm (table 14b) shows that each successive level of broadcast K resulted in a significantly higher plant dry matter yield than the preceding one. However, where broadcast K was incorporated to 15 cm depth (table 14c) there was a significant difference in plant dry matter yield between 0 and 100 Kg K/ha treatments. The 200 and 400 Kg K/ha treatments resulted in a significantly higher yield than either the 0 or 100 Kg K/ha treatments. The difference in plant dry matter yield between 200 and 400 Kg K/ha treatments was, however, nonsignificant. At maturity (tables 15 and 16), plant dry matter and the grain yields from the check were significantly lower than those obtained from other levels of broadcast K. Yields from plots receiving 100 and 200 Kg K/ha were not significantly different. The highest plant dry matter and grain yields were, however, obtained from plots receiving 400 Kg K/ha.

At the early stages of growth, plant dry matter yield from plots receiving 33 Kg K/ha only, was significantly higher than that from plots receiving any level of broadcast K. Also the main effect of banding shows that vegetative yields from plots receiving broadcast as well as banded K were higher compared to those from plots which received broadcast K only. This observation was true throughout the stages of growth. Grain yields were significantly influenced by banding.

Yield response to applied K was expected since in the first year of this study, significant yield responses to applied K at various stages of growth were observed. The depression in plant dry matter yield across the levels of broadcast K as a result of banding 33 Kg K/ha was only observed at the early tillering stage of growth. It is likely, therefore, that banding 33 Kg K/ha into plots which had received various levels of broadcast K might have resulted in increased salt concentration, thus causing some damage to the seedlings. This adverse effect brought about by banding K was, however, short lived since it was not observed at later stages of growth.

The superiority of banded over broadcast K was clearly demonstrated by plant dry matter yield at both the early tillering as well as at the boot stages of growth. The plant dry

Table 11: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha) Averaged over Two Depths of K Mixing at Early Tillering Stage of Growth. (Haywood 1983).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
	Dry Matter Yield (Kg/ha)		
0	12 a	179 f	96 a
100	39 a b	116 d e	78 a
200	67 b c	114 d e	91 a
400	92 c d	123 e	108 a
Main Effect of Banding	53 A	133 B	

Means with the same small or capital letter(s) are not significantly different at P = .05, Tukey's w-procedure.

Table 12: Influence of K Mixed with Soil and K Banded with the Seed on Plant Dry Matter Yield (Kg/ha) Averaged over Two Depths of K Mixing at Boot Stage of Growth. (Haywood 1983).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed With Soil
	Dry Matter Yield (Kg/ha)		
0	183 a	970 d	576 a
100	277 b	869 d	573 a
200	637 c	914 d	776 b
400	631 c	954 d	793 b
Main Effect of Banding	432 A	927 B	

Means with the same small or capital letter(s) are not significantly different at P = .05, Tukey's w-procedure.

Table 13: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha) Averaged over Two Depths of K Mixing at Heading Stage of Growth. (Haywood 1983).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha)		Main Effect of K Mixed With Soil
	0	33	
	Dry Matter Yield (Kg/ha)		
0	968 a	3303 d	2140 a
100	1636 b	3393 d	2515 a b
200	2396 c	3219 d	2808 b
400	3382 d	3946 e	3664 c
Main Effect of Banding	2023 A	3465 B	

Means with the same small or capital letter(s) are not significantly different at P = .05, Tukey's w-procedure.

Table 14a: Influence of Depth of K Mixing with the Soil Averaged over the Rates of K Mixing and K Banded with Seed on Dry Matter Yield (Kg/ha) at Milk Stage of Growth. (Haywood 1983).

Depth of K Mixing (cm)	K Banded with the Seed (Kg/ha)		Main Effect of Depth
	0	33	
	Dry Matter Yield (Kg/ha)		Dry Matter Yield (Kg/ha)
0 - 7.5	4222	5650	4936 a
0 - 15	3924	5121	4523 b

Means with the same letter are not significantly different at P = .05, Tukey's w-procedure.

Table 14b: Influence of K Mixed with the Soil to a Depth of 7.5 cm and K Banded with the Seed on Dry Matter Yield (Kg/ha) at Milk Stage of Growth. (Haywood 1983).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixing
	Dry Matter Yield (Kg/ha)		Dry Matter Yield (Kg/ha)
0	1662 a	5437 d	3550 a
100	4245 b	5128 c d	4687 b
200	4960 c	5751 d e	5356 c
400	6019 e	6285 e	6152 d
Main Effect of Banding	4222 A	5650 B	

Means with the same small or capital letter(s) are not significantly different at P = 0.05, Tukey's w-procedure.

Table 14c: Influence of K Mixed with the Soil to a Depth of 15 cm and K Banded with the Seed on Dry Matter Yield (Kg/ha) at Milk Stage of Growth. (Haywood 1983).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixing
	Dry Matter Yield (Kg/ha)		Dry Matter Yield (Kg/ha)
0	2344 a	4870 c	3607 a
100	3309 b	4939 c	4124 b
200	4773 c	5194 c d	4984 c
400	5274 d	5481 d	5378 c
Main Effect of Banding	3925 A	5121 B	

Means with the same small or capital letter(s) are not significantly different at P = .05, Tukey's w-procedure.

Table 15: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha) Averaged over Two Depths of K Mixing at Mature Stage of Growth. (Haywood 1983).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed With Soil
	Dry Matter Yield (Kg/ha)		
0	2051 a	5918 d	3984 a
100	3772 b	6193 d	4982 b
200	4491 c	6304 d	5398 b c
400	6191 d	6054 d	6123 c
Main Effect of Banding	4126 A	6117 B	

Means with the same small or capital letter(s) are not significantly different at P = .05, Tukey's w-procedure.

Table 16: Influence of K Mixed with Soil and K Banded with the Seed on Seed Yield (Kg/ha) Averaged over Two Depths of K Mixings at Mature Stage of Growth. (Haywood 1983).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed With Soil
	Grain Yield (Kg/ha)		
0	601 a	2609 d	1605 a
100	1414 b	2670 d	2042 b
200	1953 c	2652 d	2303 b c
400	2558 d	2561 d	2559 c
Main Effect of Banding	1632 A	2623 B	

Means with the same small or capital letter(s) are not significantly different at P = .05, Tukey's w-procedure.

matter yield resulting from even 400 Kg K/ha broadcast treatment was lower than that resulting from plots which received 33 Kg K/ha only. The fact that no such a difference was observed at later stages of growth is an indication that K availability, at the early stages of growth, was a growth limiting factor. The ability of plants to exploit large volumes of soil for K in plots receiving only broadcast K was perhaps limited by the small size of the root system. As the size of the root system increased, with time, plants were then able to explore large volumes of soil for K. These results, therefore, seem to indicate that if only one broadcast application of K is to be done in a period of two years, large quantities of K are required to avoid K deficiency. In contrast, annual application of 33 Kg K/ha banded with the seed is enough for maximum yield in this soil. However, the observed residual effect of mixed K was perhaps less than it could have been if the straw was returned.

Results of shoot K concentration at various stages of growth as well as in the grain and straw are shown in table 17. In general, the observed percent K was influenced to some extent by all levels of broadcast as well as banded K. A few exceptions were, however, observed. At the early tillering stage of growth percent K in the shoots from plots which did not receive banded K, was about the same whether 100 or 200 Kg K/ha was broadcast. An increase in percent K was then observed as the broadcast K increased to 400 Kg/ha. In the plots which received banded K, both 100 and 200 Kg K/ha broadcast treatments resulted in a lower percent K in the shoots compared to the check. The 400 Kg K/ha treatment, however, resulted in the highest shoot K concentration. At the boot stage of growth, percent K in the shoots from plots which received no banded K showed a slight drop when levels of broadcast K increased from 0 to 100 Kg/ha. An increase in shoot K concentration was then observed as the levels of broadcast K increased to 400 Kg/ha.

At the heading stage of growth, increase in percent K with increasing levels of broadcast K was observed. This observation was true whether the plots received banded K or not. A similar trend of increasing tissue percent K with increasing levels of broadcast K was observed in the shoots at the milk stage of growth as well as in the straw at maturity. Throughout the stages of growth except the early tillering stage, banding 33 Kg K/ha resulted in higher percent K in the shoots compared to that in the shoots from plots which received no banded K. Percent K in the grain tissues remained almost constant across the levels of broadcast K. Banding 33 Kg K/ha into plots receiving 0, 100 or 200 Kg K/ha resulted in a slight decline in percent K compared to that in the grains from plots which did not receive banded K. In plots which received 400 Kg K/ha, banding 33 Kg K/ha, however, resulted in the highest K concentration in the grains.

K uptake (table 17) was influenced, in a similar manner as the percent K, by levels of broadcast as well as banded K treatments. With the exception of the early tillering stage of growth, increasing levels of broadcast K up to 400 Kg K/ha resulted in increased K uptake. K uptake at the early tillering stage of growth from plots which received banded K increased or

Table 17: K Concentration and Uptake as Influenced by Amount of K Mixed with the Soil and K Banded with the Seed (Averaged over Two Depths of K Mixing). (Haywood 1983).

Stage of Growth	K Banded (Kg/ha)	K Mixed with Soil (Kg/ha)			
		0	100	200	400
			K*		
Early Tillering	0	1.82 (0.22)	2.44 (0.95)	2.43 (1.63)	2.98 (2.74)
	33	2.61 (4.67)	2.10 (2.44)	2.17 (2.47)	3.13 (3.85)
Boot	0	1.66 (3.04)	1.53 (4.24)	2.08 (13.25)	2.52 (15.90)
	33	1.91 (18.53)	1.90 (16.51)	2.36 (21.57)	2.66 (25.38)
Heading	0	0.83 (8.03)	0.93 (15.21)	1.22 (29.23)	1.80 (60.88)
	33	0.87 (28.74)	1.08 (36.64)	1.59 (51.18)	1.95 (76.95)
Milk	0	0.60 (12.02)	0.79 (29.84)	1.02 (49.63)	1.70 (96.00)
	33	0.74 (38.13)	0.98 (49.32)	1.13 (61.84)	1.84 (106.08)
Grain	0	0.65 (3.91)	0.65 (9.90)	0.61 (11.91)	0.60 (15.35)
	33	0.53 (13.83)	0.51 (13.62)	0.53 (14.06)	0.72 (18.43)
Straw	0	0.40 (7.46)	0.66 (14.99)	0.73 (18.53)	1.75 (64.00)
	33	0.56 (16.70)	0.87 (30.65)	1.21 (43.57)	2.06 (74.28)

K* 1. Numbers in brackets represent K uptake (Kg/ha).

2. Numbers outside brackets represent tissue K concentration (% K).

decreased as the levels of broadcast K increased. In general plants from plots which received banded K took up more K, at any level of broadcast K, than those from plots which did not receive banded K.

The increase in percent K as well as K uptake with increasing levels of applied K, is a clear indication that K availability to the plant was a major growth limiting factor. Also the plant dry matter yield, like the percent K and K uptake, increased as the levels of applied K increased. K deficiency in the soil was also indicated by results of percent K in the shoots at the boot stage of growth. At this stage, percent K in the shoots from plots receiving less than 200 Kg K/ha and no banded K was below the critical level of 1.80% K suggested by Melsted et al., (1969). However, for the plots which received banded K, percent K at the boot stage was above the 1.80% K critical level. This may help to explain the lack of grain yield and plant dry matter yield response to levels of broadcast K at many of the growth stages sampled. The results of percent K in the shoots at the boot stage of growth, however, fail to explain the observed results of plant dry matter yield at the milk stage of growth. At this stage the highest vegetative yields were obtained from plots receiving 200 and 400 Kg K/ha in addition to banded K. This was not true for the earlier stages of growth since banded K alone seemed to be very effective.

The influence of applied K on percent nitrogen and nitrogen uptake at various stages of growth is shown in table 18. At the early tillering stage of growth, percent nitrogen in the shoots and N uptake from plots which did not receive banded K increased with increasing levels of broadcast K. This is an indication that the reduced plant growth, as a result of K deficiency particularly at lower levels of broadcast K, may have been a limiting factor in N absorption. When 33 Kg K/ha was banded, the trend was reversed. Both percent N and N uptake decreased, though slightly with increasing levels of broadcast K. A similar trend for the plant dry matter yield was observed at the early tillering stage of growth. It is therefore likely that the depressed plant growth was responsible for the observed decline in percent N and N uptake.

At the boot, the heading and the milk stages of growth, percent N in the shoots from plots which did not receive banded K showed a declining trend with increasing levels of broadcast K. From the same plots, however, increase in N uptake with increasing levels of broadcast K was observed. The observed decline in percent N was likely due to dilution effect resulting from the increased plant dry matter yield as levels of broadcast K increased. This conclusion is supported by the fact that N uptake increased as the broadcast K levels increased. The effect of banding 33 Kg K/ha into plots which had received various levels of broadcast K was not consistent. At the boot and the heading stages of growth, percent N and N uptake either increased or decreased as the levels of broadcast K increased. At the milk stage of growth, percent N either increased, decreased or remained unchanged as broadcast K increased from one level to another. N uptake, however, increased, though slightly, with

Table 18: Influence of K Mixed with the Soil and K Banded with the Seed on N Concentration (% N) and N Uptake (Kg/ha), at Early Tillering, Boot, Heading and Milk Stages of Growth of Wheat, Averaged over Depth of K Mixing. (Haywood 1983).

Stage of Growth	K Banded With the Seed (Kg/ha)	K Mixed with the Soil (Kg/ha) 0	100	200	400
Early	0	4.56 (0.55)	4.71 (1.84)	4.91 (3.29)	4.93 (4.54)
Tillering	33	4.76 (8.52)	4.65 (5.39)	4.62 (5.27)	4.68 (5.76)
Boot	0	4.30 (7.87)	4.09 (11.33)	4.04 (25.73)	3.83 (24.17)
	33	3.91 (37.93)	3.98 (34.59)	3.84 (35.10)	3.73 (35.58)
Heading	0	2.65 (25.65)	2.41 (39.43)	2.22 (53.19)	1.94 (65.61)
	33	2.10 (69.36)	2.23 (75.66)	2.18 (70.17)	2.17 (85.63)
Milk	0	1.85 (37.06)	1.73 (65.34)	1.37 (66.66)	1.52 (85.83)
	33	1.46 (75.23)	1.50 (75.50)	1.45 (79.18)	1.45 (85.30)

Numbers in brackets represent N uptake (Kg/ha).

Numbers outside brackets represent N concentrations in tissues.

increasing levels of broadcast K. Lack of consistent influence of levels of broadcast K on percent N and N uptake when 33 Kg K/ha was banded is a clear indication that the main influence of K on N uptake was through its influence on plant dry matter yield.

Table 19 shows the percent protein in the grains as influenced by various levels of applied K. Where no K was banded, the lowest percent protein recorded was in the grains from plots which received 0 Kg K/ha broadcast treatment. With the addition of 100 Kg K/ha an increase in percent protein over the check was observed. While there was very little change in grain percent protein with the application of 200 Kg K/ha compared to 100 Kg K/ha, addition of 400 Kg K/ha resulted in the highest percent protein in the grains. For the plots which received 33 Kg K/ha in addition to various levels of broadcast K, there was a slight increase in percent protein as the levels of broadcast K increased. The difference in grain percent protein between the check and the 400 Kg K/ha broadcast treatments was, however, small.

The increase in percent protein with increasing levels of broadcast K was in some way related to N uptake. For most of the stages of growth and particularly at the milk stage, N uptake increased with increasing levels of applied K. This means that there was more N, in the plants receiving higher levels of K, that was later translocated into the developing grains. These results seem to indicate that although maximum grain yield may be obtained by banding 33 Kg K/ha only, maximum protein content in

Table 19: Influence of K Mixed with the Soil and K Banded with the Seed on % Protein in the Grain, Averaged over the Two Depths of K Mixing. (Haywood 1983).

K Mixed With Soil (Kg/ha)	K Banded With the Seed (Kg/ha)	Percent Protein in Grain at 13.5% Moisture Content
0	0	13.61
	33	14.06
100	0	14.13
	33	14.20
200	0	14.08
	33	14.23
400	0	14.87
	33	14.79

the grains may be obtained only with higher levels of broadcast K. However, since the differences in grain percent protein resulting from one level of broadcast K to another are small and may not be significant, more work would be needed to confirm these findings. Apart from its influence on N uptake, K is however known to promote phloem loading with sugars and amino acids and thus it enhances translocation of nitrogenous compounds from the vegetative plant to the grains for protein synthesis (Mengel et al., 1981).

Tissue phosphorus and some micronutrient concentrations at the boot and the heading stages of growth (Appendix 2) were examined. Percent P at the heading stage of growth was within the sufficiency range of 0.2-0.5% P suggested for wheat by Ward et al., (1973). Copper and zinc concentrations at the boot stage of growth were above the critical levels of 5 ppm Cu and 15 ppm

Zn reported for wheat by Melsted et al., (1969). Iron (Fe) concentration in the shoots at the heading stage of growth also exceeded the critical level of 25 ppm while manganese concentration was slightly lower than the critical level of 30 ppm reported by Melsted et al., (1969). Since these nutrients were available in sufficient amounts, any difference in yield was either due to K supply or any factor other than the nutrients examined.

Elm Creek 1982

Plant dry matter yield throughout the stages of growth as well as the grain yield were not significantly influenced by the depth of K incorporation. It was, however, observed that the 0-7.5 cm depth of K incorporation resulted in slightly higher plant dry matter yield throughout the stages of growth than the 0-15 cm depth. Since no significant influence of the depth was observed, the data on the influence of levels of broadcast and banded K on plant dry matter and grain yields were averaged over the two depths of K incorporation.

Throughout most of the vegetative stages of growth sampled (tables 20, 21, 22 and 23) plant dry matter yield, from plots which did not receive banded K, was not influenced by levels of broadcast K. However, at mature stage of growth (table 24), the 100 Kg K/ha broadcast treatment resulted in significantly higher plant dry matter yield compared to the 200 and 400 Kg K/ha treatments. There were, however, no significant differences in yields resulting from 0, and 100 Kg K/ha treatments though the 100 Kg K/ha broadcast treatment was the best.

Banding 33 Kg K/ha in plots which received various levels of broadcast K resulted in plant dry matter yield depression at the early tillering stage of growth (table 20). At this stage of growth, the main effect of banding K showed that plots which did not receive banded K produced significantly higher plant dry matter yield than those which did. Also at any level of broadcast K except the 400 Kg K/ha, plots which received banded K produced significantly less plant dry matter yield than plots which did not. At the boot, the heading and the milk stages of growth (tables 21, 22 and 23), plant dry matter yields from plots which received banded K, in addition to various levels of broadcast K, were not significantly different from those obtained from non K banded plots.

The main effect of broadcast K was only significant at the mature stage of growth (table 24). At this stage, the 100 Kg K/ha resulted in a significantly higher plant dry matter yield compared to the yield resulting from the 400 Kg K/ha treatment. There was, however, no significant yield difference between the 0, 200 or the 400 Kg K/ha treatments. Also the levels of 0, 200, and 400 Kg K/ha broadcast treatments resulted in about the same yield level.

Grain yield (table 25) like plant dry matter yield at earlier stages of growth was not significantly influenced by levels of broadcast or banded K. However, unlike the early tillering stage of growth, banding 33 Kg K/ha did not have a depressive effect on grain yield.

Lack of significant yield response to applied K and, in some cases, the depression in plant dry matter yield particularly at the early tillering stage of plant growth was not surprising since the soil was sufficient in available K. Due to this adequate level of available K, the depth to which applied K was incorporated could not be expected to influence the K availability to the plant. As pointed out by Welch et al., (1966), the depth to which broadcast K is incorporated may be of some importance in as much as it can lead to positional unavailability

Table 20: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha) Averaged Over Two Depths of K Mixing at Early Tillering Stage of Growth. (Elm Creek 1982).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
	Dry Matter Yield (Kg/ha)		
0	189 a	167 b c	178 a
100	188 a	151 c	170 a
200	190 a	164 b c	177 a
400	171 a b	172 a b	171 a
Main Effect Of Banding	185 A	164 B	

Means with the same small or capital letter (s) are not significantly different at P = .05, Tukey's w-procedure.

Table 21: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha), Averaged Over Two Depths of K Mixing at Boot Stage of Growth. (Elm Creek 1982).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
	Dry Matter Yield (Kg/ha)		
0	1413 a	1304 a	1369 a
100	1449 a	1436 a	1442 a
200	1487 a	1267 a	1377 a
400	1490 a	1288 a	1484 a
Main Effect of Banding	1460 A	1324 A	

Means with the same small or capital letter (s) are not significantly different at P = .05, Tukey's w-procedure.

Table 22: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha) Averaged Over Two Depths of K Mixing at Heading Stage of Growth. (Elm Creek 1982).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
	Dry Matter Yield (Kg/ha)		
0	4205 a	3922 a	4063 a
100	4193 a	4072 a	4133 a
200	4277 a	4011 a	4144 a
400	4121 a	4224 a	4173 a
3*Main Effect Of Banding	4199 A	4057 A	

Means with the same small or capital letter (s) are not significantly different at P = .05, Tukey's w-procedure.

Table 23: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha), Averaged Over Two Depths of K Mixing at Milk Stage of Growth. (Elm Creek 1982).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
	Dry Matter Yield (Kg/ha)		
0	9636 ab	9368 b	9502 a
100	9860 ab	10171 a	10016 a
200	9988 a	9654 ab	9821 a
400	9631 ab	9631 ab	9631 a
Main Effect of Banding	9779 A	9706 A	

Means with the same small or capital letter (s) are not significantly different at P = .05, Tukey's w-procedure.

Table 24: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha), Averaged Over Two Depths of K Mixing at Maturity. (Elm Creek 1982).

K Mixed (Kg/ha)	K Banded with Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
	Dry Matter Yield (Kg/ha)		
0	9779 a b	9230 b c	9605 ab
100	10100 a	10268 a	10184 a
200	9598 b	9590 b	9594 ab
400	9090 c	9463 b	9277 b
Main Effect of Banding	9642 A	9638 A	

Means with the same small or capital letter (s) are not significantly different at P = .05, Tukey's w-procedure.

Table 25: Influence of K Mixed with Soil and K Banded with the Seed on Grain Yield (Kg/ha), Averaged Over Two Depths of K Mixing at Maturity. (Elm Creek 1982).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
	Grain Yield (Kg/ha)		
0	3780 a	3545 a	3663 a
100	3671 a	3849 a	3760 a
200	3656 a	3629 a	3643 a
400	3593 a	3674 a	3634 a
Main Effect of Banding	3675 A	3674 A	

Means with the same small capital letter (s) are not significantly different at P = .05, Tukey's w-procedure.

of K to plants. This effect may, however, be of significance only in K deficient soils.

The depression in plant dry matter yield at the early tillering stage of growth when 33 Kg k/ha was banded was likely due to seedling injury. However, there were no visible signs of this effect on the plant. It is possible, however, that high concentrations of salt near the seed/or seedling may impair some important physiological functions of the plant, such as water uptake. These effects may only show on the morphology of the plant if they are very severe. The fact that the observed yield depressions at the early stages of growth were not manifested in later stages of growth is an indication that they were not very severe.

The observation that maximum plant dry matter yield at maturity (table 24) was obtained from plots which received 100 Kg K/ha in addition to banded K is surprising. The soil was medium to high in exchangeable K and therefore no response to added K was expected even at later stages of growth. Exchangeable K has however, been shown to be a poor indicator of K availability to the plants in some soils than the solution K. Jankovic and Nemeth (1974) found a negative correlation between the exchangeable soil K and sunflower seed yields harvested from five different locations. The same yields, however, were positively correlated with the K concentration of the soil solution. In this study, however, it is unlikely that soil solution K was a yield limiting factor particularly in the check plots since no significant plant dry matter yield response to applied K at the early stages of growth or grain yield response at maturity was observed.

Shoot tissue % K and K uptake at various stages of growth are shown in table 26. Throughout the vegetative stages of growth sampled, there was no clear relationship between % K and the levels of applied K. Small variations in % K with increasing levels of broadcast K were observed particularly in plots which did not receive banded K. Where 33 Kg K/ha was banded, a greater variation in % K, with increasing levels of broadcast K was observed. Also percent potassium in the grains was not influenced by levels of broadcast or banded K. In the straw tissues, the situation was different. The % K in the straw from both the plots which received banded K as well as those which did not, increased with increasing levels of broadcast K. The straw from the plots which received banded K was however higher at all levels of broadcast K except the 400 Kg K/ha. At this level, straw from both the plots which received banded K as well as those which did not had the same percent potassium.

Lack of increase in % K with increasing levels of applied K was an indication that the soil was able to supply enough K for normal plant growth. At the boot stage of growth the % K in the shoot tissues, even from the check was very much above the 1.80% K critical level for wheat suggested by Melsted et al., (1969). This may therefore help to explain the lack of yield response to applied K at the earlier stages of growth but fails to account for the observed plant dry matter yield response at maturity.

Table 26: K Concentration and Uptake as Influenced by Amount of K Mixed with the Soil and K Banded with the Seed (Average Over Two Depths of K Mixing). (Elm Creek 1982).

Stage of Growth	K Banded (Kg/ha)	K Mixed with Soil (Kg/ha) 0	100	200	400
			K*1		
Early Tillering	0	3.95 (7.47)	4.00 (7.52)	3.90 (7.41)	3.80 (6.50)
	33	3.90 (6.50)	4.20 (6.34)	3.85 (6.31)	3.90 (6.71)
Boot	0	3.71 (52.42)	3.51 (50.86)	3.69 (54.87)	3.77 (56.17)
	33	3.18 (41.47)	3.99 (65.28)	3.74 (47.39)	3.81 (40.96)
Heading	0	2.48 (104.28)	2.35 (98.54)	2.50 (106.93)	2.63 (108.38)
	33	2.44 (95.70)	2.55 (103.84)	2.35 (94.26)	2.77 (117.00)
Milk	0	1.97 (189.83)	2.27 (223.82)	2.14 (213.74)	1.88 (181.06)
	33	1.80 (168.62)	2.30 (233.93)	2.16 (208.53)	2.14 (206.10)
Grain	0	0.17 (6.43)	0.19 (6.98)	0.18 (6.59)	0.17 (5.94)
	33	0.18 (6.38)	0.16 (6.16)	0.19 (6.90)	0.17 (6.25)
Straw	0	0.92 (57.03)	0.93 (59.83)	1.11 (75.46)	1.39 (77.80)
	33	1.22 (69.36)	1.28 (82.16)	1.28 (76.30)	1.39 (85.46)

*1 Numbers in brackets represent K uptake (Kg/ha)
Numbers outside brackets represent tissue K concentration (% K)

K uptake like % K was also variable and did not seem to be influenced by levels of applied K. At maturity, however, straw K content like % K in the straw increased with increasing levels of applied K. This observed increase in K uptake was more likely due to the observed plant dry matter yield response at maturity rather than due to differences in K availability. Both % K and K uptake do not, however, explain why response to applied K was only at maturity.

Nitrogen concentration as well as N uptake (table 27) were examined to determine if they were affected by applied K. Both percent nitrogen and N uptake were found to be little affected by levels of broadcast or banded K for most of the stages of growth sampled. At the milk stage of growth, percent nitrogen and N uptake from plots which received no banded K increased slightly with increasing levels of broadcast K. However the increase was very small. For the plots which received banded K increasing levels of broadcast K led to a slight increase or decrease in % N and N uptake. This inconsistent trend was observed throughout the stages of growth.

The above results indicate that even without application of fertilizer K, soil K supply was sufficient for all plant needs. It is therefore not surprising that applied K did not influence significantly the percent N in the tissues or N uptake by the plant. The supply of N could not have limited N uptake as the levels or applied K increased since adequate amount of fertizer N, based on soil test was applied. Additionally percent N in the

Table 27: Influence of K Mixed with the Soil and K Banded with the Seed on N Concentration (% N) and N uptake (Kg/ha), at Early Tillering, Boot, Heading and Milk Stages of Growth of Wheat, Averaged Over Depths of K Mixing. (Elm Creek 1982).

Stage of Growth	K Banded with the seed (Kg/ha)	K Mixed with the Soil (Kg/ha) 0	100	200	400
			N*1		
Early Tillering	0	5.21 (9.85)	5.38 (10.11)	5.11 (9.71)	5.15 (8.81)
	33	5.09 (8.50)	5.22 (7.88)	5.03 (8.25)	5.00 (8.60)
Boot	0	4.17 (58.92)	4.13 (59.84)	4.15 (61.71)	3.95 (58.86)
	33	4.25 (55.42)	4.28 (61.46)	3.60 (45.61)	4.20 (54.10)
Heading	0	2.78 (116.90)	2.26 (94.76)	2.53 (108.21)	2.66 (109.62)
	33	2.94 (115.31)	2.66 (108.32)	2.46 (98.67)	2.60 (109.82)
Milk	0	1.10 (106.00)	1.12 (110.43)	1.20 (119.86)	1.25 (120.39)
	33	1.23 (115.23)	1.19 (121.03)	1.08 (104.26)	1.13 (108.83)

*1 Numbers in brackets represent N uptake (Kg/ha).

Numbers outside brackets represent N concentrations in tissues.

shoot tissues at heading stage of growth was within the sufficiency range of 2.0-3.0% N reported for wheat by Ward et al., (1973).

Percent protein in the grains (table 28) remained almost the same throughout the levels of applied K. There were, however, small up and down variations in percent protein with increasing levels of applied K. Protein content in the grain is mostly dependent on the amount of N taken up by the plant during the vegetative stages of growth and the translocation of this N to the grain for protein synthesis. According to Koch and Mengel (1977), N uptake by wheat plant and its translocation to the grains is influenced to some extent by the supply of K. Under the conditions of this experiment, however, the influence of K on N reported by the above researchers was not observed since the soil supply of K was sufficient perhaps for all plant functions in which K participates.

Table 28: Influence of K Mixed with the Soil and K Banded with the Seed a % Protein in the Grain, Averaged Over the Two Depths of K Mixing. (Elm Creek 1982).

K Mixed with Soil (Kg/ha)	K Banded With the Seed (Kg/ha)	Percent Protein in Grain at 13.5% Moisture Content
0	0	14.74
	33	14.66
100	0	15.38
	33	14.99
200	0	14.64
	33	14.74
400	0	15.14
	33	15.19

All the other plant nutrients examined at the boot stage of growth (Appendix 3) were all above the critical levels reported by Melsted et al., (1969). These researchers reported critical levels for P, Zn, Fe and Mn as 0.3% P, 15, 25, and 30 ppm respectively. Cu concentration in the shoots, also at the boot stage of growth, was within or slightly above the 3.2-3.3 ppm range for optimum plant growth, reported by Gupta and Macleod (1970). None of these nutrients was however influenced by levels applied K. It is therefore evident that the examined nutrients were not growth limiting.

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In the second year of this study, the depth of K incorporation did not significantly influence the plant dry matter yield throughout the stages of growth or the grain yield at maturity. This observation is consistent with the results of 1982 season. As in 1982, the 1983 data on the influence of levels of broadcast and banded K on plant dry matter as well as grain yields were therefore averaged over the 0-7.5 cm and 0-15 cm depths of K incorporation.

At the early tillering and the boot stages of growth (tables 29 and 30), there were no significant plant dry matter yield responses to either the levels of broadcast K or broadcast plus banded K. In the plots which did not receive banded K, however, the 200 and the 400 Kg K/ha levels of broadcast K resulted in slightly higher yield than the check and the 100 Kg K/ha plots. Also plots receiving banded K in addition to various levels of broadcast K had slightly higher yield than those which received broadcast K only.

At later stages of growth, however, the situation was different. Though the main effects of broadcast and banded K were not significant, a few significant plant dry matter yield responses to applied K were observed. At the heading stage of growth (table 31), results from plots which did not receive banded K show that the 100 Kg K/ha broadcast treatment resulted in significantly higher plant dry matter yield than the check and the plots which received 400 Kg K/ha. However, plant dry matter yields from plots receiving 100 or 200 Kg K/ha were not significantly different. At the milk stage of growth (table 32), the yield data from plots receiving no banded K, show that the lowest plant dry matter yield was obtained from the check. Although this yield was significantly lower than that from plots receiving either 200 or 400 Kg K/ha, it did not differ significantly from that resulting from 100 Kg K/ha broadcast level. At the mature stage of growth (table 33), yield data from plots which did not receive banded K show that the 200 Kg K/ha broadcast treatment resulted in significantly lower yields than the 100 or 400 Kg K/ha treatments. However, plant dry matter yield resulting from plots receiving 200 Kg K/ha was not significantly different from that obtained from the check. The 400 Kg K/ha broadcast treatment resulted in the highest plant dry matter yield of all the plots receiving no banded K. This yield, however, did not differ significantly from that obtained from the plots receiving 0 or 100 Kg K/ha broadcast treatments.

Throughout the stages of growth sampled, banding 33 Kg K/ha did not influence significantly the plant dry matter yield at any level of broadcast K. However, at the early tillering and the boot stages of growth, the plots which received various levels of broadcast K in addition to banded K resulted in slightly higher plant dry matter yield than those receiving corresponding levels of broadcast K only. At the early tillering stage of growth, the 400 Kg K/ha was, however, an exception to this general pattern. At this level of broadcast K, the plots which received banded K produced slightly, though nonsignificantly, lower plant dry matter yield than the plots which received only 400 Kg K/ha of broadcast K.

Results in table 34 show that the grain yield was not significantly influenced by levels of broadcast or banded K. Also the small, though nonsignificant, benefit of banding over broadcast K application observed in the early stages of growth was not obvious for grain yield.

Results of 1983 season were to some extent consistent with the observations made for the 1982 season on the same site. Lack of yield response to applied K was a clear indication that the soil K level was adequate for maximum wheat yield even in the second year of the experiment. It is not surprising therefore, that the depth of K incorporation did not influence significantly the availability of K to the plants. K availability to the plants in the check plots, in the 1983 season, was marginal. Although no significant yield responses were observed at the early tillering and the boot stages of growth, increasing levels of broadcast K in plots which did not receive banded K resulted in slight increase in plant dry matter yield. Additionally at the heading, the milk and the mature stages of growth, small but, in some cases, significant plant dry matter yield responses to levels of broadcast K were obtained compared to the yield from the check. The fact that the grain yields were not significantly influenced by the levels of broadcast K is perhaps an indication that whatever influence the levels of broadcast K had, in the early stages of growth was too small to cause any significant difference in the amount of photosynthate translocated into the grains. It is also more likely, however, that factors other than

Table 29: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha), Averaged Over Two Depths of K Mixing at Early Tillering Stage of Growth. (Elm Creek 1983).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
	Dry Matter Yield (Kg/ha)		
0	234 a	257 a	246 a
100	228 a	259 a	244 a
200	241 a	279 a	260 a
400	253 a	229 a	241 a
Main Effect of Banding	239 A	256 A	

Means with the same small or capital letter (s) are not significantly different at P = .05, Tukey's w-procedure.

Table 30: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha), Averaged Over Two Depths of K Mixing at the Boot Stage of Growth. (Elm Creek 1983).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
	Dry Matter Yield (Kg/ha)		
0	1339 a	1385 a	1362 a
100	1315 a	1395 a	1355 a
200	1417 a	1591 a	1504 a
400	1487 a	1673 a	1580 a
Main Effect of Banding	1390 A	1511 A	

Means with the same small or capital letter (s) are not significantly different at P = .05, Tukey's w-procedure.

Table 31: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha), Averaged Over Two Depths of K Mixing at Heading Stage of Growth. (Elm Creek 1983).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
	Dry Matter Yield (Kg/ha)		
0	4108 a	4242 a b	4175 a
100	4785 c	4166 a	4476 a
200	4540 b c	4270 a b	4405 a
400	4325 a b	4433 b	4379 a
Main Effect of Banding	4440 A	4278 A	

Means with the same small or capital letter (s) are not significantly different at P = .05, Tukey's w-procedure.

Table 32: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha), Averaged Over Two Depths of K Mixing at Milk Stage of Growth. (Elm Creek 1983).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
	Dry Matter Yield (Kg/ha)		
0	7567 a	8211 ab	7889 a
100	8364 ab	7910 ab	8137 a
200	8510 b	8373 ab	8442 a
400	8468 b	8329 ab	8399 a
Main Effect of Banding	8227 A	8229 A	

Means with the same small or capital letter (s) are not significantly different at P = .05, Tukey's w-procedure.

Table 33: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha), Averaged Over Two Depths of K Mixing at the Mature Stage of Growth. (Elm Creek 1983).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
	Dry Matter Yield (Kg/ha)		
0	8830 ab	9023 ab	8926 a
100	9253 a	9285 a	9269 a
200	8506 b	9150 ab	8828 a
400	9480 a	8833 ab	9157 a
Main Effect of Banding	9017 A	8823 A	

Means with the same small or capital letter (s) are not significantly different at P = .05, Tukey's w-procedure.

Table 34: Influence of K Mixed with Soil and K Banded with the Seed on Grain Yield (Kg/ha), Averaged Over Two Depths of K Mixing at Maturity. (Elm Creek 1983).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
	Grain Yield (Kg/ha)		
0	3109 a	3228 a	3168 a
100	3269 a	2889 a	3079 a
200	2895 a	3161 a	3028 a
400	3293 a	3116 a	3204 a
Main Effect Of Banding	3141 A	3098 A	

Means with the same small or capital letter (s) are not significantly different at P = .05, Tukey's w-procedure.

K were limiting in the process of grain filling.

Potassium concentration in the tissues as well as K uptake (table 35) were examined in an attempt to find an explanation for the observed variations in plant dry matter and grain yields. Throughout the vegetative stages of growth sampled, there was no consistent relationship between the percent K and and the levels of broadcast K. This observation was true for most of the plots which received banded K as well as those which did not. At the early tillering stage of growth, the situation was different. Percent K in the shoots from plots which received banded K increased with increasing levels of broadcast K. However, the difference in % K in the shoots from plots which received 200 or 400 Kg K/ha was small. Percent potassium in the grain tissues remained almost constant throughout the levels of broadcast K. This observation was true for both the plots receiving banded K and those which did not. In the straw tissues, % K increased with increasing levels of broadcast K only in plots which did not receive banded K. However, the % K in the straw from plots which received banded K, was higher at any level of broadcast K than that from the plots receiving no banded K.

K uptake (table 35) like % K varied a great deal with levels of broadcast K. Increases or decreases in K uptake with increasing levels of broadcast K were observed throughout the stages of growth sampled. K uptake from plots which received banded K, did not differ much in comparison with the K uptake from the plots which did not except at the milk stage of growth. The K content of the grains was also not influenced by levels of applied K. Consistent relationship between the K content of the straw and the levels of broadcast K was observed but, only for the plots which did not receive banded K.

From the results of % K and K uptake, it is clear that K supply was not limiting growth since tissue K concentration and K uptake from the check plots was about the same as in plots receiving various levels of applied K. At the boot stage of growth, the % K in the shoot tissues was above the 1.80% K critical level for wheat reported by Melsted et al., (1969). Also at the heading stage of growth % K in the shoot tissues was within the range of 1.5-3.0% K considered sufficient for wheat growth by Ward et al., (1973). The results of K concentration in the shoots and K uptake do not, however, account for the small variations in yields observed during the vegetative stages of growth. However, lower % K in the shoots at the early tillering stage of growth than at the boot stage of growth was perhaps an indication that K availability, though sufficient, was marginal at the early tillering stage of growth. Also at later stages of growth, the observed significant plant dry matter yield responses to broadcast K levels, in plots receiving no banded K is an indication that soil K supply could have been limiting growth to some extent. This conclusion is not, however, supported by tissue % K and/or K uptake which show that the check treatment was as good as any other treatment.

Results in table 36 show the shoot tissue % Nitrogen and N uptake as affected by various levels of applied K. At the early tillering and the boot stages of growth, percent N in the shoots

Table 35: K Concentration and Uptake as Influenced by Amount of K Mixed with the Soil and K Banded with the Seed (Averaged Over Two depths of K Mixing). (Elm Creek 1983).

Stage of Growth	K Banded (Kg/ha)	K Mixed with Soil (Kg/ha) 0	100	200	400
			K*		
Early Tillering	0	2.75 (6.44)	2.48 (5.65)	2.41 (5.81)	2.94 (7.44)
	33	2.60 (6.68)	2.75 (7.12)	2.83 (7.90)	2.84 (6.50)
Boot	0	4.27 (57.18)	3.92 (55.82)	3.32 (47.04)	4.06 (72.15)
	33	3.55 (49.17)	3.43 (44.08)	3.46 (55.05)	3.83 (64.46)
Heading	0	2.95 (121.19)	2.85 (136.37)	3.02 (137.11)	3.15 (136.24)
	33	2.98 (126.41)	2.88 (119.98)	2.96 (126.39)	3.09 (133.88)
Milk	0	2.04 (154.37)	2.24 (187.35)	2.14 (182.11)	1.85 (156.66)
	33	2.92 (239.76)	3.16 (249.96)	2.57 (215.19)	2.72 (227.38)
Grain	0	0.41 (12.75)	0.39 (12.75)	0.4 (11.58)	0.38 (12.51)
	33	0.39 (12.58)	0.42 (12.13)	0.37 (11.70)	0.41 (12.78)
Straw	0	1.65 (94.40)	1.84 (110.11)	1.90 (108.13)	1.94 (120.03)
	33	1.91 (110.68)	1.87 (100.91)	2.32 (138.94)	2.22 (126.94)

K* Numbers in brackets represent K uptake (Kg/ha).
Numbers outside brackets represent tissue K concentration (% K).

decreased as the levels of broadcast K increased. However, the decrease was very small. The corresponding N uptake increased or decreased, though slightly, with increasing levels of broadcast K, indicating that the effect of decreasing percent N on N uptake was counter-balanced by the effect of the slight increase in plant dry matter yield. At the heading and the milk stages of growth, shoot percent N and N uptake from plots which received no banded K were variable and did not show any consistent relationship with levels of broadcast K.

Throughout the stages of growth mentioned above, percent N and N uptake from plots which received banded K were not influenced by levels of broadcast K. Shoot % N and N uptake from the check were about the same as those from plots receiving higher levels of broadcast K. There were, however, small up and down variations in shoot percent N and N uptake across the levels of broadcast K. Except at the boot stage of growth, there was no added benefit of banded K. Shoot % N at the boot stage of growth from plots which received banded K was slightly higher at any level of broadcast K compared to that in the shoots from plots which received broadcast K only. However % N in the shoots at heading stage from the K banded or the 0 K banded plots was within the sufficiency range of 2.0-3.0% N reported by Ward et al., (1973). It can therefore be concluded that K supply, even from the check plots, was adequate perhaps for all the physiological functions of the plant that require potassium.

Table 36: Influence of K Mixed with the Soil and K Banded with the Seed on N Concentration (% N and N Uptake (Kg/ha), at Early Tillering, Boot and Milk Stages of Growth of Wheat, Averaged Over Depths of K Mixing. (Elm Creek 1983).

Stage of Growth	K Banded with the Seed (Kg/ha)	K Mixed with the Soil (Kg/ha) 0	100	200	400
Early Tillering	0	5.03 (11.77)	4.94 (11.26)	4.89 (11.78)	4.78 (12.09)
	33	4.90 (12.59)	4.84 (12.54)	4.89 (13.64)	4.46 (10.21)
Boot	0	3.31 (44.32)	3.22 (45.85)	3.12 (44.21)	3.02 (44.91)
	33	3.48 (48.20)	3.54 (49.38)	3.38 (53.78)	3.31 (55.37)
Heading	0	2.30 (94.48)	2.36 (112.93)	2.37 (107.60)	2.35 (101.64)
	33	2.36 (100.11)	2.24 (93.32)	2.31 (98.64)	2.45 (108.61)
Milk	0	1.58 (119.56)	1.48 (123.79)	1.61 (137.01)	1.57 (132.95)
	33	1.48 (121.52)	1.46 (115.49)	1.37 (114.71)	1.56 (129.93)

Numbers in brackets represent N uptake (Kg/ha).
Numbers outside brackets represent N concentrations in tissues.

An examination of percent protein in the grains (table 37) shows that neither the levels of broadcast K nor the banded K had any influence on grain protein content. Percent protein in the grains from the check was about the same as that from plots receiving any level of applied K. This again confirms that K supply from the soil was enough for promoting maximum grain protein formation.

Table 37: Influence of K Mixed with the Soil and K Banded with the Seed on % Protein in the Grain, Averaged Over the Two Depths of K Mixing. (Elm Creek 1983).

K Mixed with Soil (Kg/ha)	K Banded with the Seed (Kg/ha)	Percent Protein in Grain at 13.5% Moisture Content
0	0	15.16
	33	15.16
100	0	14.64
	33	15.09
200	0	15.31
	33	14.84
400	0	15.24
	33	15.14

Shoot tissue concentration of phosphorus and some micronutrients (Appendix 4) were examined at the boot and the heading stages of growth. The concentration of phosphorus at the heading stage of growth was within the sufficiency range of 0.2-0.5% P suggested for wheat by Ward et al., (1973). Zinc concentration in the shoot at boot stage of growth was above the critical level of 15 ppm Zn reported by Melsted et al., (1969). Cu concentration in the tissues, also at the boot stage of growth, was above the optimum range of 3.2-3.3 ppm Cu reported for wheat by Gupta and Macleod (1970). Shoot tissue concentrations of Fe and Mn at the boot stage of growth also exceeded the critical levels of 25 and 30 ppm respectively, suggested for wheat by Melsted et al., (1969). It is clear therefore, that the examined nutrients were in sufficient supply. No variation in yield is therefore attributable to these nutrients.

Winkler, 1982

Results of wheat sampling at various stages of growth showed that the depth of K incorporation significantly influenced plant dry matter yield only at the boot stage of growth. As shown in table 39a, the 0-7.5 cm depth of K incorporation resulted in a significantly higher plant dry matter yield compared to the 0-15 cm depth. It was, however, observed that the 0-7.5 cm depth resulted in a slightly higher plant dry matter and grain yield than the 0-15 cm depth of K incorporation at all other stages of growth.

The observed significant influence of the depth of K incorporation is difficult to explain. Since the soil rated high in available K, the depth to which applied K was incorporated would not have been expected to influence K availability. It is likely therefore that the influence of the depth of K incorporation on plant dry matter yield was more of a tillage rather than a direct effect on K availability. Since the significant influence of the depth of K incorporation was observed at the boot stage of growth, it is likely that deep tillage might have resulted in reduced tillering. Maximum production of tillers occurs between early tillering and the boot stages of growth. Such factors as moisture loss through evaporation, which may occur as a result of exposure of moist soil by deep tillage, may reduce the production of tillers. This may then lead to reduced plant dry matter yield. Whatever the cause of the observed depression in plant dry matter yield at the above-mentioned stage of growth, the plants were able to recover since no significant differences in yields between the two depths were observed at later stages of growth.

Since there was no significant differences in plant dry matter and grain yields between the two depths of K incorporation at the other stages of growth, the data on the influence of broadcast and banded K were averaged over the two depths. Throughout the stages of growth sampled, there was no significant plant dry matter or grain yield response to applied K (tables 38, 39b and c, 40, 41, 42 and 43). Also there were no significant interactions between or among the factors examined. However, a few aspects of these results are worth noting. At the early tillering stage of growth (table 38) plant dry matter yield from plots which received banded K were, at any level of broadcast K, lower than those from plots which did not. A similar observation was made at the boot stage of growth for the 0, 100 and 400 Kg/ha broadcast K treatments. For the 200 Kg K/ha broadcast treatment, however, the opposite was true. At this level of broadcast K, the plant dry matter yield from plots which received banded K was slightly higher than that from plots which did not.

For most of the remaining stages of growth, with the exception of the milk stage, plant dry matter and grain yields from the check plots were substantially, though nonsignificantly, lower than yields resulting from other levels of broadcast K. At the milk stage of growth (table 41), the difference in yield between the check and the 100 Kg K/ha level were very small. However, yields resulting from 200 or 400 Kg K/ha differed substantially from those resulting from 0 or 100 Kg K/ha broadcast treatment.

When 33 Kg K/ha was banded, plant dry matter yield throughout the stages of growth varied from one level of broadcast K to another without any consistent trend. Increasing levels of broadcast K led to increasing or decreasing plant dry matter yield without any clear pattern particularly at the early tillering stage of growth and at maturity. The grain yield also showed a similar trend. Results of sampling at the heading and the milk stages of growth (tables 40 and 41), however, showed an increasing trend, in plant dry matter yield, with increasing levels of broadcast K.

As mentioned earlier, neither the main effect of banded nor that of broadcast K had any significant influence on plant dry matter yield at any of the vegetative stages of growth sampled or on grain yield. On the average however, banding 33 Kg K/ha led to a slight depression in yield at the early tillering, the boot and the heading stages of growth while the opposite was true at later stages of growth as well as for grain yield. The main effect of broadcast K was not consistent throughout the stages of growth. At the early tillering and the boot stages of growth, increasing levels of broadcast K led to a slight depression in plant dry matter yield. The opposite was, however, true for plant dry matter yield at the heading and the milk stages of growth, while no consistent trend in plant dry matter and grain yield was observed at maturity.

Table 38: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha) Averaged over Two Depths of K Mixing at Early Tillering Stage of Growth. (Winkler 1982).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
		Dry Matter Yield (Kg/ha)	
0	294 a	242 a	268 a
100	267 a	243 a	255 a
200	279 a	223 a	251 a
400	265 a	224 a	244 a
Main Effect of Banding	276 A	233 A	

Means with the same small or capital letter are not significantly different at P = .05, Tukey's w-procedure.

Table 39a: Influence of Depth of K Mixing with the Soil Averaged over the Rates of K Mixing and K Banded with Seed on Dry Matter Yield (Kg/ha) at the Boot Stage of Growth. (Winkler 1982).

Depth of K Mixing (cm)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of Depth
		Dry Matter Yield (Kg/ha)	
0 - 7.5	1860	1775	1818 a
0 - 15	1514	1477	1496 b

Means with the same letter are not significantly different at P = .05, Tukey's w-procedure.

Table 39b: Influence of K Mixed with the Soil to a Depth of 7.5 cm, and K Banded with the Seed on Dry Matter Yield (Kg/ha) at the Boot Stage of Growth. (Winkler 1982).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixing
	Dry Matter Yield (Kg/ha)		
0	2025 a	1848 a	1937 a
100	1789 a	1764 a	1777 a
200	1807 a	1830 a	1819 a
400	1817 a	1658 a	1738 a
Main Effect of Banding	1860 A	1775 A	

Means with the same small or capital letter are not significantly different at P = .05, Tukey's w-procedure.

Table 39c: Influence of K Mixed with the Soil to a Depth of 15 cm and K Banded with the Seed on Dry Matter Yield (Kg/ha) at the Boot Stage of Growth. (Winkler 1982).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixing
	Dry Matter Yield (Kg/ha)		
0	1434 a	1461 a	1448 a
100	1467 a	1409 a	1438 a
200	1582 a	1446 a	1514 a
400	1572 a	1592 a	1582 a
Main Effect of Banding	1514 A	1477 A	

Means with the same small or capital letter are not significantly different at P = .05, Tukey's w-procedure.

Table 40: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha) Averaged over Two Depths of K Mixing at the Heading Stage of Growth. (Winkler 1982).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	K Banded with the Seed (Kg/ha) 33	Main Effect of K Mixed with Soil
	Dry Matter Yield (Kg/ha)		
0	5554 a	5560 a	5557 a
100	5890 a	5784 a	5837 a
200	5944 a	5906 a	5858 a
400	5803 a	5912 a	5925 a
Main Effect of Banding	5798 A	5791 A	

Means with the same small or capital letter are not significantly different at P = .05, Tukey's w-procedure.

Table 41: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha) Averaged over Two Depths of K Mixing at the Milk Stage of Growth. (Winkler 1982).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	K Banded with the Seed (Kg/ha) 33	Main Effect of K Mixed with Soil
	Dry Matter Yield (Kg/ha)		
0	10,001 a	9,769 a	9,885 a
100	10,044 a	9,846 a	9,945 a
200	9,898 a	10,013 a	9,955 a
400	9,695 a	10,170 a	10,036 a
Main Effect of Banding	9,910 A	9,950 A	

Means with the same small or capital letter are not significantly different at P = .05, Tukey's w-procedure.

Table 42: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha) Averaged over Two Depths of K Mixing at Mature Stage of Growth. (Winkler 1982).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
	Dry Matter Yield (kg/ha)		
0	8495 a	8723 a	8609 a
100	8875 a	9026 a	8951 a
200	8570 a	8896 a	8733 a
400	8640 a	9244 a	8952 a
Main Effect of Banding	8645 A	8972 A	

Means with the same small or capital letter are not significantly different at P = .05, Tukey's w-procedure.

Table 43: Influence of K Mixed with Soil and K Banded with the Seed on Grain Yield (Kg/ha) Averaged over Two Depths of K Mixing at Maturity. (Winkler 1982).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
	Grain Yield (Kg/ha)		
0	2270 a	2416 a	2343 a
100	2528 a	2654 a	2591 a
200	2478 a	2586 a	2532 a
400	2431 a	2733 a	2582 a
Main Effect of Banding	2427 A	2598 A	

Means with the same small or capital letter are not significantly different at P = .05, Tukey's w-procedure.

Lack of significant plant dry matter yield response to any level of applied K was not surprising considering the high level of available soil K. The slight depression in plant dry matter yield at the early tillering stage of growth was likely due to the salt injury to the seedlings. This adverse effect of applied K was not observed at later stages of growth. In fact plant dry matter yield at the heading and the milk stages of growth as well as at maturity showed some response to applied K though it was nonsignificant. Though the reasons for these changes are difficult to explain, it was nevertheless clear that plots receiving applied K produced substantially higher plant dry matter yield than the check plots.

It is well established (Nemeth et al, 1970) that finely textured soils and particularly those rich in 2:1 clay minerals contain fairly high amounts of exchangeable K associated with relatively low K in the soil solution. On these types of soil, soil solution K may be growth limiting and thus response to applied fertilizer K is likely. Since in this soil (Winkler) the observed yield response to applied K was not significant, more work is required to fully establish whether or not application of small amounts of fertilizer K would be beneficial.

Results in table 44 show the effect of applied K on percent K and K uptake at various stages of growth as well as grain and straw % K and K content. Throughout the vegetative stages of growth, % K was not consistently influenced by levels of applied K. Increases or decreases in shoot percent K were observed as broadcast K increased from one level to another. A similar trend was also recorded for the plots which received banded K. As well, there were no clear differences in shoot K concentration between plots which received banded K and those which did not, except at the milk stage of growth. At this stage, plots which received banded K had slightly lower shoot K concentration, at any level of broadcast K, than plots which did not. Percent K in the grains remained almost constant throughout the levels of broadcast K. As in most of the vegetative stages of growth, banding 33 Kg K/ha did not change this pattern. Also the observed differences in grain % K at any level of broadcast K, between plots receiving banded K and those which did not was small. Percent K in the straw from the check plots was lower than that from plots receiving higher levels of broadcast K. There was however no difference in % K in the straw obtained from plots receiving 100 and 200 Kg K/ha. The 400 Kg K/ha led to a slight drop in the concentration of K in the straw. Percent K in the straw from plots which received banded K in addition to various levels of broadcast K was lower at any level of broadcast K than % K in the straw from plots which received broadcast K only. However, % K in the plots receiving banded K generally increased with increasing levels of broadcast K.

Potassium uptake throughout the stages of growth varied in a manner similar to K concentration. K uptake, like % K, was not influenced in a consistent way by levels of applied K. This was to be expected since even the plant dry matter yield at any stage of growth did not differ significantly between levels of broadcast or banded K. From the above results, it is obvious

Table 44: K Concentration and Uptake as Influenced by Amount of K Mixed with the Soil and K Banded with the Seed (Averaged over Two Depths of K Mixing). (Winkler 1982).

Stage of Growth	K Banded (Kg/ha)	K Mixed with Soil (Kg/ha) 0	100	200	400
			K*		
Early Tillering	0	4.82 (14.17)	3.98 (10.63)	4.78 (13.34)	4.90 (12.99)
	33	3.99 (9.66)	4.75 (11.54)	4.72 (10.53)	3.96 (8.87)
Boot	0	4.13 (71.43)	3.15 (51.28)	3.54 (59.98)	3.29 (55.75)
	33	3.68 (57.21)	3.53 (54.24)	3.42 (59.44)	3.44 (54.18)
Heading	0	2.45 (136.07)	2.44 (143.72)	2.67 (158.70)	2.78 (161.32)
	33	2.48 (137.89)	2.58 (149.23)	2.67 (157.69)	2.04 (120.60)
Milk	0	2.05 (205.02)	1.90 (190.84)	2.13 (210.83)	2.13 (206.50)
	33	1.81 (176.82)	1.77 (174.27)	1.88 (188.24)	1.85 (188.15)
Grain	0	0.34 (7.72)	0.28 (7.08)	0.29 (7.19)	0.27 (6.56)
	33	0.28 (6.76)	0.31 (8.23)	0.30 (7.76)	0.28 (7.65)
Straw	0	1.52 (94.62)	2.03 (118.50)	2.02 (123.06)	1.93 (115.69)
	33	1.47 (92.15)	1.53 (97.49)	1.73 (109.16)	1.69 (110.03)

K* 1. Numbers in brackets represent K uptake (Kg/ha)

2. Numbers outside brackets represent tissue K concentration (% K)

that the observed lack of plant dry matter and grain yield response was primarily due to the already high levels of available soil K. This conclusion is supported by the fact that the shoot % K at the boot stage of growth was above the critical level of 1.80% K suggested for wheat by Melsted et al, (1969). Also at the heading stage of growth % K in the shoots was within the range of 1.5-3.0% K reported by Ward et al., (1973). The % K in the shoots does not, however, help to explain the observed slight increases in plant dry matter and grain yield at the heading, and the milk stages of growth as well as at maturity that resulted from the application of 100 Kg/ha broadcast K or 33 Kg/ha banded K treatment.

Results of shoot nitrogen concentration and nitrogen uptake at the early tillering, the boot, the heading and the milk stages of growth are shown in table 45. Throughout the above stages of growth, percent nitrogen in the shoots did not show any consistent relationship to levels of applied K. Percent nitrogen in the shoots either increased or decreased, though slightly, with increasing levels of broadcast K. This observation was true for shoots from plots which received banded K as well as those which did not. In general, however, plots which received banded K had lower percent N, at any level of broadcast K, than plots which did not.

Nitrogen uptake followed a similar trend to that of percent N. Variations in N uptake corresponded very well to variations in percent N. Since levels of applied K did not significantly influence the plant dry matter yield at any stage of growth, the

Table 45: Influence of K Mixed with the Soil and K Banded with the Seed on N Concentration (% N) and N Uptake (Kg/ha), at Early Tillering, Boot, Heading and Milk Stages of Growth of Wheat, Averaged over Depths of K Mixing. (Winkler 1982).

Stage of Growth	K Banded with the Seed (Kg/ha)	K Mixed with the Soil (Kg/ha) 0	100	200	400
Early Tillering	0	4.70 (13.82)	4.81 (12.84)	4.78 (13.34)	4.86 (12.88)
	33	4.66 (11.28)	4.64 (11.28)	4.58 (10.21)	4.79 (10.73)
Boot	0	4.38 (75.75)	4.51 (73.42)	4.24 (71.85)	4.35 (73.71)
	33	4.31 (67.00)	4.36 (66.99)	4.29 (74.56)	4.22 (66.47)
Heading	0	2.40 (133.30)	2.27 (133.70)	2.17 (128.98)	2.21 (128.25)
	33	2.50 (139.00)	2.15 (124.36)	1.89 (111.62)	2.08 (122.97)
Milk	0	1.70 (170.02)	1.59 (159.70)	1.54 (152.43)	1.57 (152.21)
	33	1.47 (143.60)	1.51 (148.67)	1.34 (134.17)	1.45 (147.47)

Numbers in brackets represent N uptake (Kg/ha)

Numbers outside brackets represent N concentrations in tissues (% N) observed variations in N uptake were likely due to the slight and perhaps nonsignificant variations in percent N in the shoots. Lack of increase in percent N or N uptake as the levels of applied K increased could not be attributed to N unavailability since enough fertilizer N was applied in accordance with soil test values. Additionally at the heading stage of growth, percent N in the shoots even from the check plots was above the sufficiency range of 2.0-3.0% N for wheat reported by Ward et al, (1973).

Results of percent protein in the grains are shown in table 46. Various levels of applied K either as broadcast or banded did not influence protein content in the grains. For all levels of broadcast K including the check, percent protein was relatively high. The range between the highest and the lowest was very small and perhaps nonsignificant. Lack of grain protein response to applied K is in line with the previous observations made on % N. Thus from the above results, it is clear that application of fertilizer K to a soil already high in available K would rarely, if at all, influence shoot % N, N uptake or grain protein content.

Results of shoot concentration of other nutrients, examined to see if they were yield limiting, are shown in Appendix 5. At the heading stage of growth, shoot % P was within the sufficiency range of 0.2-0.5% P reported by Ward et al., (1973). Zinc, iron and manganese concentrations in the shoots, at the boot stage of growth, were all above the critical levels of 15 ppm Zn, 25 ppm Fe and 30 ppm Mn reported by Melsted et al, (1969). Also at the

Table 46: Influence of K Mixed with the Soil and K Banded with the Seed on % Protein in the Grain, Averaged over the Two Depths of K Mixing. (Winkler 1982).

K Mixed with Soil (Kg/ha)	K Banded with the Seed (Kg/ha)	Percent Protein in Grain at 13.5% Moisture Content
0	0	16.27
	33	16.27
100	0	16.32
	33	16.22
200	0	16.17
	33	16.07
400	0	15.88
	33	16.07

boot stage of growth, copper concentration was above the optimum range of 3.2-3.3 ppm Cu suggested by Gupta and Macleod (1970). From the foregoing therefore, it is evident that these nutrients were not yeild limiting.

Winkler, 1983

In the 1983 season the residual effect of K, applied in 1982 season, on yield of wheat at Winkler was evaluated. Results of wheat yield in 1983 season are presented below. Throughout the sampled stages of wheat growth, the effect of the depth of K incorporation on plant dry matter and grain yields was not significant. The data on the influence of broadcast and banded K were therefore averaged over the two depths of K incorporation.

As shown in tables 47, 48, 49, 50, 51 and 52, there was no significant plant dry matter or grain yield response to applied K. Yields from plots which received broadcast K only were not influenced in a consistent manner by various levels of broadcast K. At the early tillering stage of growth, the highest plant dry matter yield was obtained from the check. Increasing levels of broadcast K led to either an increase or a decrease in plant dry matter yield though only slightly. The 400 Kg K/ha broadcast treatment, however, resulted in the lowest yield. At later stages of growth, except at the milk stage, a slight increase in plant dry matter yield was observed as the broadcast K levels increased up to 200 Kg K/ha. With the application of 400 Kg K/ha, there was a slight drop in plant dry matter yield. The grain yield (table 52) followed a trend similar to that discussed for vegetative yield. Results of plant dry matter yield at the milk stage of growth did not show any clear pattern.

When 33 Kg K/ha was banded in plots which had received various levels of broadcast K, some yield depressions particularly at the early stages of growth were observed. At the early tillering stage of growth (table 47) a slight plant dry matter yield depression was observed. This observation was true at any level of broadcast K. At the boot stage of growth, the depression in plant dry matter yield was significant. Yield from plots which received banded K were, at any level of broadcast K, lower than those resulting from plots which received broadcast K only. This depression in plant dry matter yield continued through to the heading stage of growth but it was not significant. At the milk stage of growth and at maturity, however, the results were the opposite of the observations recorded at the earlier stages of growth. Plots which received banded K in addition to various levels of broadcast K were slightly, though, nonsignificantly higher than those from plots which received broadcast K only. On the average, the grain yield from plots which received broadcast as well as banded K were slightly higher than that resulting from plots which received various levels of broadcast K only.

The main effect of broadcast K, like the simple effect did not significantly influence plant dry matter yield at any stage of growth or the grain yield at maturity.

Lack of significant yield response to applied K even after the second year of K application confirms that the initial level of available soil K was high enough to supply the plants with this nutrient for at least two years. This finding was expected considering the initially high level of available K (602 Kg/ha NH_4OAC exchangeable K). The significant depression in plant dry

Table 47: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha) Averaged over Two Depths of K Mixing at the Early Tillering Stage of Growth. (Winkler 1983).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
	Dry Matter Yield (Kg/ha)		
0	275 a	241 a	258 a
100	260 a	248 a	254 a
200	272 a	261 a	267 a
400	249 a	245 a	247 a
Main Effect of Banding	264 A	249 A	

Means with the same small or capital letter are not significantly different at P = .05, Tukey's w-procedure.

Table 48: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha) Averaged over Two Depths of K Mixing at the Boot Stage of Growth. (Winkler 1983).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
	Dry Matter Yield (Kg/ha)		
0	2609 a	2129 b	2369 a
100	2664 a	2128 b	2396 a
200	2699 a	2123 b	2411 a
400	2623 a	1961 b	2292 a
Main Effect of Banding	2649 A	2085 B	

Means with the same small or capital letter are not significantly different at P = .05, Tukey's w-procedure.

Table 49: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha) Averaged over Two Depths of K Mixing at the Heading Stage of Growth. (Winkler 1983).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed
		Dry Matter Yield (Kg/ha)	
0	4716 a	4556 a	4636 a
100	4953 a	4893 a	4923 a
200	5229 a	4699 a	4964 a
400	4984 a	4920 a	4952 a
Main Effect of Banding	4970 A	4767 A	

Means with the same small or capital letter are not significantly different at P = .05, Tukey's w-procedure.

Table 50: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha) Averaged over Two Depths of K Mixing at the Milk Stage of Growth. (Winkler 1983).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
		Dry Matter Yield (Kg/ha)	
0	7724 a	7919 a	7822 a
100	7714 a	7714 a	7714 a
200	7728 a	8270 a	7999 a
400	8219 a	8193 a	8206 a
Main Effect of Banding	7846 A	8024 A	

Means with the same small or capital letter are not significantly different at P = .05, Tukey's w-procedure.

Table 51: Influence of K Mixed with Soil and K Banded with the Seed on Dry Matter Yield (Kg/ha) Averaged over Two Depths of K Mixing at the Mature Stage of Growth. (Winkler 1983).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
		Dry Matter Yield (Kg/ha)	
0	8835 a	9110 a	8973 a
100	8988 a	8284 a	8636 a
200	9211 a	9363 a	9287 a
400	8863 a	8821 a	8842 a
Main Effect of Banding	8974 A	8894 A	

Means with the same small or capital letter are not significantly different at P = .05, Tukey's w-procedure.

Table 52: Influence of K Mixed with Soil and K Banded with the Seed on Grain Yield (Kg/ha) Averaged over Two Depths of K Mixing at Maturity. (Winkler 1983).

K Mixed (Kg/ha)	K Banded with the Seed (Kg/ha) 0	33	Main Effect of K Mixed with Soil
		Grain Yield (Kg/ha)	
0	3119 a	3521 a	3320 a
100	3379 a	3271 a	3325 a
200	3499 a	3575 a	3537 a
400	3350 a	3473 a	3411 a
Main Effect of Banding	3350 A	3460 A	

Means with the same small or capital letter are not significantly different at P = .05, Tukey's w-procedure.

matter yield at the boot stage of growth, when 33 Kg K/ha was banded is difficult to explain. No such significant effect of banding was noted in the first year of the experiment. Whether a total of 66 Kg/ha of banded K in two years could have such an adverse effect is unclear. Also if this was the case, it would have been expected to be significant even at the early tillering stage of growth.

Results of % K and K uptake are shown in table 53. Throughout the vegetative stages of growth sampled, percent K either increased or decreased, though slightly, with increasing levels of broadcast K. This observation was true for both the plots receiving banded K as well as those which did not. Shoots from the check plots had about the same K concentration as those from plots which received other levels of broadcast K. This indicates that even the check plots were able to supply sufficient K for plant needs. Percent K in the grains remained almost constant. This observation was true thoughout the levels of broadcast K irrespective of whether the plots received banded K or not. Potassium concentration in the straw from plots which did not receive banded K was higher, at any level of broadcast K, than the % K in the straw from plots which received broadcast as well as banded K. Percent potassium in the straw from plots receiving 100 or 200 Kg K/ha was equal but was higher than that in the straw from the check. The 400 Kg K/ha broadcast treatment resulted in the highest % K in the straw. In the plots which received banded K, the % K in the straw from plots receiving 0, 100 and 200 Kg K/ha was about the same but slightly lower than that in the straw from the check. Application of 400 Kg K/ha, however, resulted in the highest percent K in the straw.

In most of the vegetative stages of growth discussed above, K uptake varied more with the variations in % K than with plant dry matter yield. Slight increases or decreases in K uptake were observed across the levels of broadcast K. However at the boot stage of growth, K uptake from plots which received banded K were lower, at any level of broadcast K than uptake from plots which did not receive banded K. Since % K in the shoots from plots which received banded K and those which did not was about the same, the observed low values of K uptake were evidently due to the depressed plant dry matter yield. The low values of % K and K content of the straw from plots which received banded K in addition to various levels of broadcast K are difficult to explain since unlike the early stages of growth, no depression in yield was observed at maturity.

Table 53: K Concentration and Uptake as Influenced by Amount of K Mixed with the Soil and K Banded with the Seed (Averaged over Two Depths of K Mixing). (Winkler 1983).

Stage of Growth	K Banded (Kg/ha)	K Mixed with Soil (Kg/ha) 0	100	200	400
			K*		
Early Tillering	0	2.30 (6.33)	2.68 (6.97)	2.69 (7.32)	2.40 (5.98)
	33	2.66 (6.41)	2.80 (6.94)	2.19 (5.72)	2.36 (5.78)
Boot	0	3.04 (79.32)	2.98 (79.39)	3.11 (83.94)	3.06 (80.26)
	33	2.97 (63.23)	3.01 (64.05)	2.96 (62.84)	3.05 (59.81)
Heading	0	2.21 (104.22)	2.27 (112.43)	2.21 (115.56)	2.46 (122.61)
	33	2.52 (114.81)	2.07 (101.29)	2.31 (108.55)	2.29 (112.67)
Milk	0	2.07 (159.89)	2.22 (171.25)	2.25 (166.59)	2.08 (170.96)
	33	2.02 (159.96)	2.15 (165.85)	2.21 (184.98)	2.19 (179.43)
Grain	0	0.39 (12.16)	0.36 (12.16)	0.40 (16.10)	0.36 (12.06)
	33	0.39 (13.73)	0.41 (13.41)	0.39 (13.94)	0.38 (13.20)
Straw	0	2.45 (140.04)	2.84 (159.30)	2.84 (165.08)	2.98 (164.29)
	33	2.23 (124.63)	2.19 (109.78)	2.18 (118.08)	2.35 (125.68)

K* 1. Numbers in brackets represent K uptake (Kg/ha)

2. Numbers outside brackets represent K concentration in the shoots (% K)

In general the results of potassium concentration in the shoots as well as K uptake confirm that K supply from the soil did not limit plant growth and yield. Additionally % K at the boot stage of growth was above the critical level of 1.80% K suggested for wheat by Melsted et al., (1969), while at the heading stage of growth it was within the sufficiency range of 1.5-3.0% K reported by Ward et al., (1973).

Results of nitrogen concentration in the shoots and nitrogen uptake at various stages of growth are shown in table 54. Throughout the vegetative stages of growth, there was no consistent relationship between shoot percent N and the levels of broadcast K. A few and perhaps nonsignificant increases or decreases in percent N in the shoots with increasing levels of broadcast K were observed. However, percent N in the shoots from plots which received banded K and those which did not was about the same.

Nitrogen uptake, like nitrogen concentration, was not influenced by levels of broadcast K. Also, with the exception of the boot stage of growth, N uptake from plots which received banded K was about the same as the uptake from plots which did not. At the boot stage of growth, nitrogen uptake from plots which received banded K was lower than that from plots which did not.

Table 54: Influence of K Mixed with the Soil and K Banded with the Seed on N Concentration (% N) and N Uptake (Kg/ha) at Early Tillering, Boot, Heading and Milk Stages of Growth of Wheat, Averaged over Depths of K Mixing. (Winkler 1983).

Stage of Growth	K Banded with the Seed (Kg/ha)	K Mixed with the Soil (Kg/ha) 0	100	200	400
Early Tillering	0	4.49 (12.35)	5.16 (13.42)	4.39 (11.94)	5.03 (12.52)
	33	4.17 (10.05)	4.31 (10.69)	4.20 (10.96)	4.26 (10.44)
Boot	0	3.51 (91.58)	3.46 (92.17)	3.28 (88.53)	3.73 (97.84)
	33	3.57 (76.01)	3.64 (77.46)	3.59 (76.22)	3.69 (72.36)
Heading	0	2.11 (99.51)	1.92 (95.10)	2.05 (107.19)	2.04 (101.67)
	33	2.08 (94.76)	2.15 (105.20)	2.21 (103.85)	2.14 (105.29)
Milk	0	1.63 (125.90)	1.55 (119.57)	1.45 (112.06)	1.44 (118.35)
	33	1.48 (117.20)	1.31 (101.05)	1.59 (131.49)	1.55 (127.00)

Numbers in brackets represent N uptake (Kg/ha)

Numbers outside brackets represent N concentrations in tissues.

The depressed yields at this stage of growth were responsible for these observed lower N uptake values. Since an adequate amount of N, according to soil N test values, was applied each year for the two years of the experiment, lack of increase in % N and N uptake with increasing levels of broadcast K was obviously not due to N unavailability. This conclusion is confirmed by the fact that at the heading stage of growth, percent N in the shoots from plots receiving various levels of applied K was within the sufficiency range of 2.0-3.0% N reported for wheat by Ward et al., (1973).

Table 55 shows the results of grain protein content as influenced by levels of applied K, averaged over the depth of K incorporation. It is evident from these results that grain protein was not affected by increasing levels of broadcast K. Also percent protein in the grains from plots which received banded K in addition to broadcast K was about the same as that from plots which received broadcast K only.

Analysis of shoot phosphorus, copper, zinc, iron and manganese was done to see if these nutrients were available to plants in sufficient amounts. The results of this analysis at boot and heading stages of growth are shown in Appendix 6. These results show that none of the above nutrients showed a consistent trend across the levels of broadcast K. This observation was true for plots which received banded K and those which did not. However, the examined nutrients were available in adequate amounts since all of them were either above or within the critical levels reported by various authors. At the heading

Table 55: Influence of K Mixed with the Soil and K Banded with the Seed on % Protein in the Grain, Averaged over the Two Depths of K Mixing. (Winkler 1983).

K Mixed with Soil (Kg/ha)	K Banded with the Seed (Kg/ha)	Percent Protein in Grain at 13.5% Moisture Content
0	0	15.41
	33	15.73
100	0	15.41
	33	15.42
200	0	15.46
	33	15.43
400	0	15.82
	33	15.48

stage of growth, shoot % P was within the sufficiency range of 0.2-0.5% P considered sufficient by Ward et al., (1973). Iron, copper, zinc and manganese concentrations in the shoots at the boot stage of growth were all above the critical levels of 25 ppm Fe, 5 ppm Cu, 15 ppm Zn and 30 ppm Mn reported by Melsted et al., (1969). It is therefore clear that the examined nutrients were not yield limiting.

Chapter 5

FIELD STUDY 2

LYSIMETER EXPERIMENT

INTRODUCTION

In spring of 1982, a lysimeter experiment was started adjacent to the field experiment described earlier. The objective of this experiment was to provide further information on the influence of potassium on wheat yield as well as to supplement the data obtained from the large field experiment. With the use of lysimeters, operations performed on the large plots, particularly the depth of K mixing, could be done with greater precision than otherwise. It was therefore possible to make thorough mixing of fertilizer with the soil since the volumes of soil involved were relatively small.

MATERIALS AND METHODS

The experiment was conducted on an almasippi soil (at Haywood) with low available K, as is shown in table 1. The experiment consisted of three rates of K; 0, 100 and 200 Kg K/ha and four depths of potassium mixing as follows: 0-7.5 cm, 0-15 cm, 15-30 cm and 0-30 cm. A check for the depth was also included. The experiment was laid down in a randomized complete block design with four replicates.

The lysimeters used were hollow steel cylinders measuring

30.5 cm long and with a cross-section area of 0.10 m^2. These lysimeters were spaced 63 cm apart between replicates and 35 cm apart within replicates, and were pushed into the ground to a depth of about 20 cm. Soil was dug out of each lysimeter from the appropriate depths leaving the soil below it undisturbed. For the 15-30 cm depth of K mixing, soil from 0-15 cm layer was dug out first and put aside and replaced later. The soils were thoroughly mixed with the appropriate amount of K as KCl. The mixture of soil and KCl was then replaced into the lysimeter at the appropriate depths. Phosphorus (DCPD) and nitrogen (NH_4NO_3) at the rate of 100 Kg P/ha and 150 Kg N/ha respectively were applied. These fertilizers were mixed with soil from the 0-7.5 cm layer.

About 23 seeds (equivalent of 100 Kg/ha) of wheat (Triticum Aestivum var. Columbus) were seeded in each lysimeter. The area between the lysimeters as well as the surrounding area extending about 1.0 m from the lysimeters was seeded with the same variety, using a hand driven one-row seed drill. This area was also fertilized with N, P and K prior to seeding. Emergence of seedlings was good in all lysimeters. At maturity, the number of effective tillers (those with fertile heads) were counted. The above ground portions of the plants were then harvested, air dried and total dry matter yield determined. Threshing was done by hand and the clean grains weighed. 100 kernel weight from each lysimeter was also done. The straw and grains were then separately ground in a wily mill and the nutrient concentrations of K, P, N, Zn, Cu, Mn and Fe were determined.

RESULTS AND DISCUSSION

Results in table 56 show that the number of fertile tillers resulting from the application of either 100 or 200 Kg K/ha were not significantly different. The check, which received no K, produced significantly fewer fertile tillers than any of the other levels of applied K. The volume of the soil and the position from which it was obtained did not influence significantly the number of fertile tillers for any level of applied K. Volumes of soil obtained from the 0-7.5 cm depth, however, resulted in slightly more tillers, for the same level of applied K, than the 0-15 cm or the 0-30 cm depth. The least number of fertile tillers were obtained where the soil from the 0-30 cm or 15-30 cm depth was mixed with 100 Kg K/ha. Mixing 200 Kg K/ha with the soil from the 0-30 cm depth also resulted in about the same number of tillers as when the same volume of soil was mixed with 100 Kg K/ha.

The above ground plant dry matter yield (table 56) followed a trend similar to that for the number of tillers. The plant dry matter yield from the check was significantly lower than yields resulting from other levels of applied K. When 100 Kg K/ha was mixed with soil from various layers, the highest plant dry matter yield recorded was from the soil obtained from 0-7.5 cm depth. This yield was also significantly different from yields resulting from soils from other depths which received the same level of applied K. Plant dry matter yield also decreased as the volume of soil that was mixed with K increased. The lowest yield, however, was obtained from the soil from the 15-30 cm depth.

When 200 Kg K/ha was mixed with soil from various layers, the highest yield was obtained from 0-7.5 cm layer. As was the case when 100 Kg K/ha was applied, this yield level was significantly higher compared to yields resulting from soils obtained from other depths. The lowest plant dry matter yield was, however, obtained when 200 Kg K/ha was mixed with the soil from 0-30 cm depth. There was no significant difference in plant dry matter yields resulting from the application of either 100 or 200 Kg K/ha to the soil from 0-7.5 cm depth.

Grain yield (table 56) also responded to applied K. Yield from the check was significantly lower than those resulting from lysimeters which received applied K. Grain yields from other K treatments were influenced by the layer of the soil that was mixed with K. Where 100 Kg K/ha was mixed with various layers of soil, the 0-7.5 cm layer resulted in the highest grain yield. This yield was, however, about the same as that recorded from the soil obtained from 0-15 cm layer. For the same 100 Kg K/ha rate of application, soils obtained from the 0-30 cm and 15-30 cm layers had the lowest grain yield. When 200 Kg K/ha was applied, the highest yield was recorded from the soil obtained from 0-7.5 cm depth while the soil from the 0-30 cm depth had the lowest yield. Application of 200 Kg K/ha to the soil from the 15-30 cm depth resulted in significantly higher grain yield than when 100 Kg K/ha treatment was mixed with the soil from the same depth.

Results of 100 kernel weight are also shown in table 56. The 100 kernel weights for treatments receiving 0, 100 and 200 Kg K/ha were not significantly different. It was, however, observed

Table 56: Influence of K Mixed with the Soil and the Depth of K Mixing on Number of Tillers, Plant Dry Matter Yield, Grain Yield and 100 Kernel Weight of Wheat.

Depth of K Mixing (cm)	Rate of K Mixed (Kg/ha)	Number of Tillers per Lysimeter	Dry Matter Yield (Kg/ha)	Grain Yield (Kg/ha)	100 Grain Weight g/lysimeter
-	0	31 a	2320 a	510 a	2.10 a
0-7.5	100	62 b	9710 f	2710 b	2.81 a
0-7.5	200	62 b	10120 f	3940 d	3.12 a
0-15	100	51 b	7570 d	2700 b	2.91 a
0-15	200	57 b	8220 e	2760 b	2.78 a
0-30	100	48 b	6740 c	2220 c	2.89 a
0-30	200	49 b	7040 c	2240 c	2.87 a
15-30	100	48 b	6290 b	2240 c	2.91 a
15-30	200	59 b	8370 e	3040 d	2.64 a

Means with the same letter(s) in the same column are not significantly different at P = .05, Tukey's w-procedure.

that the check treatment had a substantially lower kernel weight than any other treatment. For both the 100 and the 200 Kg K/ha rates, the position from which the soil was obtained as well as the volume of the soil had no significant influence on the 100 kernel weight.

The response to applied K, as indicated by the number of tillers, the above ground plant dry matter yield, the grain yield and, to a lesser extent, by the 100 grain weight, was expected since the soil was low in available K. Results show that 100 Kg K/ha, mixed with 0-7.5 cm soil layer was sufficient for maximum plant dry matter yield. However maximum grain yield was attained when 200 Kg K/ha was mixed with the soil from 0-7.5 cm layer. This is perhaps an indication of enhanced translocation of photosynthate to grains as a result of increased K availability.

The difference in number of fertile tillers was likely due to the differences in K availability to the plants during the early stages of growth, particularly when K was mixed in large volumes of soil (e.g., 0-30 cm soil layer). This reduction in the numbers of tillers might have then caused the observed low total plant dry matter and grain yield at maturity. Increasing the amount of applied K from 100 to 200 Kg/ha for an equal volume of soil did not, however, increase the number of tillers, plant dry matter or grain yield significantly. It was also observed that plant dry matter yield obtained when 200 Kg K/ha was mixed with 0-15 cm layer of soil was not as high as that obtained when 100 Kg K/ha was mixed with 0-7.5 cm soil layer. This serves as an indication that tillage effect in this case was more important in influencing tillering than was the rate of applied K. It is not clear how tillage exerted its influence on plant growth but the likelihood of soil compaction when it was replaced back to the lysimeter cannot be ruled out. The results also show that although deep fertilization of soil may have led to reduced yields when 100 Kg K/ha was mixed with 15-30 cm soil layer, this depressive effect could be overcome by doubling the amount of applied K. This means that the amount of K required when deep fertilization is done has to be high to avoid K deficiency.

Lack of significant difference between the weights of the kernels from the check and from treatments receiving 100 and 200 Kg K/ha was an indication that the plumpness of the grains was not much influenced by levels of applied K. Availability of K therefore had its main influence on grain yield through its influence on number of tillers. Plant dry matter yield was associated with the number of tillers while grain yield was associated with both the number of tillers and perhaps the size of individual heads.

Table 57 shows the influence of K mixed with the soil and the depth of K mixing on % K and percent protein in the grains, % K in the straw and K and N uptakes. The % K in grain tissue was not related to grain yield in a consistent manner. The highest concentration of K in the grains was observed when 100 Kg K/ha was mixed with 0-7.5 cm layer of soil. Contrary to what would be expected, however, the second highest % K was observed in the check though the soil was K deficient. For the rest of the treatments, % K in the grains remained relatively constant irrespective of the rate and the depth of K mixing. The % K in the straw (table 57) was lowest in the check. For the 100 Kg K/ha treatment, the layer of soil with which K was mixed did not influence the K concentration in the straw tissues. In the case of 200 Kg K/ha rate of application, however, % K in the straw varied though inconsistently with the layers of soil that K was mixed with.

K uptake (table 57) followed a trend similar to that of the total plant dry matter yield. The check had the lowest K uptake but there was no obvious difference in K uptake as a result of application of 100 or 200 Kg K/ha. As was the case with dry matter yield, the highest K uptake was observed when 100 Kg K/ha was mixed with the 0-7.5 cm soil layer. However, this uptake was only slightly higher than that observed when the 200 Kg K/ha was mixed with the 0-7.5 cm soil layer. From the results of % K and K uptake, it is difficult to decide whether K availability was a yield limiting factor in lysimeters which received 100 or 200 Kg K/ha. Percent K in the grains changed very little with changes in levels of applied K. Additionally, some of the K in the plant may have been leached out from the mature plant before harvest time.

N uptake like K uptake was related to plant dry matter yield. The lowest N uptake was recorded from the check. The depressed plant growth in the check may have reduced the ability of the plants to absorb N. The largest N uptake was observed where 100 or 200 Kg K/ha was mixed with soil from the 0-7.5 cm depth. Percent protein in the grains (table 57) was very

Table 57: Influence of K Mixed with the Soil and Depth of K Mixing on % K and % Protein in the Grains, % K in the Straw and K and N Uptakes.

Treatment Number	Depth of K Mixing (cm)	Rate of K Mixed With Soil (cm)	Grain		Straw	Uptake (Kg/ha)	
			% K	% Protein *1	% K	K	N
1	-	0	0.49	12.37	0.30	9.16	32.01
2	0-7.5	100	0.59	13.22	0.59	57.29	142.25
3	0-15	100	0.36	13.97	0.60	36.34	113.17
4	0-30	100	0.37	12.88	0.60	32.69	90.02
5	15-30	100	0.40	13.68	0.56	30.19	94.04
6	15-30	200	0.38	13.36	0.53	38.08	118.02
7	0-7.5	200	0.36	13.16	0.70	53.64	140.16
8	0-15	200	0.36	13.26	0.45	33.29	113.44
9	0-30	200	0.35	13.56	0.76	39.07	103.14

*1 Percent protein in grain at 13.5% moisture content variable and did not show any relationship to N uptake. While the check had the lowest protein content in the grains, there seemed to be no difference in percent protein between the 100 and the 200 Kg K/ha rates. This seems to indicate that under the condition of this experiment, 100 Kg K/ha was enough for maximum protein irrespective of the soil layer with which it was mixed.

The interpretation of the data on the influence of K on wheat yield is, however, complicated by the fact that during K application, tillage was not uniformly done. In lysimeters where the layer of soil to be mixed with K was 0-7.5 cm, the soil was dug out only to that depth while it was dug through to 30 cm in cases where either all of it or the 15-30 cm soil layer was to be mixed with K. This is probably the reason for the observed influence of tillage even in cases where the same amount of K was mixed with equal soil volumes but from different layers.

Other nutrients examined in the grain and in the straw tissues are shown in Appendix 7. Cu, Zn, and P in the grains and in the straw remained almost constant throughout the levels of applied K. Even the check had about the same concentrations of these elements as other treatments. Their availability was also not affected by the layers of soil with which K was mixed. Cu concentration in the grain tissues was above the 2.3 ppm Cu critical level for field grown wheat grains suggested by King and Aston (1975). It is therefore unlikely that the availability of these elements could be growth limiting.

In general, results of plant dry matter and grain yield from the lysimeter experiment were in good agreement with those from the large field experiment. In both experiments, K availability limited maximum yields in the zero K treatments. Plant dry matter yield at maturity and the grain yield from the lysimeter experiment were, however, lower than those obtained from the check of the 1982 field experiment (compare 2300 and 510 Kg dry matter and grain yield respectively from the lysimeter with 2794 and 736 Kg dry matter and grain yield respectively from the large field experiment). However, with the incorporation of 100 or 200 Kg K/ha to the same depth, plant dry matter and grain yields from the lysimeter experiment were higher compared to those from the large field experiment. Even with the application of 400 Kg K/ha in the field experiment, the resulting yields were still lower than those obtained when 100 or 200 Kg K/ha was applied in the lysimeter experiment. These observations therefore indicate that applied K was more available to the plants in the lysimeter compared to the large field experiment. This is likely due to the restricted lateral movement of K in the lysimeter compared to the large experiment.

A comparison of the effect of the depth of K mixing in the two experiments is difficult. As mentioned earlier, applied K, in the large field experiment was either roto-tilled to a depth of 0-7.5 cm or 0-15 cm. In the lysimeter, however, soil layers were dug out, mixed with the appropriate rates of K, and then returned back into their original positions. Nevertheless, the effect of tillage was evident in both experiments. Plant dry matter yield at maturity from the large experiment was not significantly influenced by the depth of K mixing but the grain yield from the plots where K was incorporated to 15 cm were higher compared to those resulting from 0-7.5 cm depth of K incorporation. The effect of tillage on plant dry matter and grain yields from the lysimeter was the opposite of the observation made on yields from the large experiment.

Chapter 6

STUDY 3

GROWTH CHAMBER EXPERIMENT

INTRODUCTION

In winter of 1983, a growth chamber experiment was conducted. The purpose of the experiment was to provide data on the influence of potassium, in a controlled environment, for supplementing the field data. In particular the interaction of potassium with soil moisture in relation to grain yield and water use efficiency was studied. The fate of applied K was also studied.

MATERIALS AND METHODS

An Almasippi soil was used for this study, primarily for its low available potassium supply. The soil was taken from a plow layer of cultivated field. Soil analysis, in table 1, shows some of the characteristics of this soil. The soil was air dried and passed through a 2 mm sieve to remove roots and stones. The field capacity of the soil was also determined.

A factorial experiment was laid down in a completely randomized design. Two moisture regimes designated as "high" and "low" were factorially combined with 0, 25, 50, 100 and 200 ppm K. The experiment consisted of three replicates giving a total of 30 observations. Various rates of K together with appropriate amounts of N, P, S, Zn and Cu were thoroughly mixed with 12 kg of soil and put into pots measuring 65 cm deep and with a cross-section area of 0.02 m^2. The inner walls of these pots were lined with plastic paper bags. The soil column in each pot was 60 cm deep.

The soil in the pots was brought to field capacity and allowed to equilibriate for one week before seeding. Eight seeds of wheat (Triticum Aestivum Var. Columbus) were seeded. Ten days after emergence, the seedlings were thinned to four. Watering of the plants started two weeks from the time of seedling emergence. Plants which were not to be water stressed received distilled water daily on the basis of water loss per pot. Water stressed plants received water only when majority of plants showed signs of wilting. An arbitrary amount of water ranging from about 10-90 gms were added per pot every time watering was done. This was done to make sure that the amount of water added was not under-estimated due to the effect of increase in the weight of plants. Enough water to bring the soil back to field capacity was added for both moisture regimes at every watering time. The amount of water added at each watering time was recorded.

Light, temperature, day length and humidity in the growth chamber were set as follows:

Light intensity ranged from 500-550 microeinsteins $m^{-2}sec^{-1}$ above the canopy. Temperature was set at 15 degrees C during the night while the day temperature was set at 23 degrees C. Day length was 15 hours. Humidity was out of control throughout the growing period. Also during the grain filling stage, the temperature controls were not functioning properly.

At maturity, the plants were harvested just above the soil level, oven dried at 60 degrees C, weighed and threshed by hand. The total plant dry matter, the grain yield and the 100 kernel weight were determined. Straw and grains were then ground separately in a wiley mill and analysis of K, P, N, Zn, Cu, Fe and Mn was done.

After harvest, the soil from every pot was air dried and sieved to remove roots. A sample of soil from each pot was then taken for analysis of residue potassium.

RESULTS AND DISCUSSION

The influence of moisture treatments and the rates of applied K on the number of tillers with fertile head is shown in table 58. In the low moisture regime, the influence of applied K on the number of tillers was not consistent. The least number of tillers was observed in pots which received 25 ppm K/pot. However this number was not significantly different from the number of tillers obtained from pots receiving 0 or 100 ppm K/pot. The largest number of tillers recorded was from pots which received 200 ppm K/pot but they did not differ significantly from those resulting from application of 50 ppm K/pot. In the high moisture treatment, levels of applied K did not influence the number of tillers significantly. The overall effect of K on the number of tillers, as indicated by the main effect of K treatment was not significant. Additionally, there were no significant interactions between K and moisture levels. The overall effect of moisture treatment on the number of tillers was, however, significant. High moisture regime resulted in significantly more tillers compared to the low moisture treatment.

The results of dry matter yield are shown in table 59. Levels of applied K did not significantly influence the plant dry matter yield at maturity. This observation was true for both moisture treatments. Also the overall effect of K treatments on plant dry matter yield was not significant. However, the main effect of moisture treatments was significant. Low moisture regime resulted in significantly lower plant dry matter yield compared to the high moisture regime. The effect of levels of applied K and the moisture treatments on grain yield was similar to that observed for the plant dry matter yield. As shown in table 60, neither the simple nor the main effect of K on grain yield was significant. However the grain yield from the high moisture treatment was significantly higher than that from the lower moisture treatment.

Although no statistical analysis was performed on the 100 grain kernel weight, results in table 61 seem to indicate that neither the moisture nor the potassium levels had any substantial influence on the plumpness of the grains.

The fact that there were no significant responses in plant dry matter, and grain yield to levels of applied K is an indication that the soil was able to supply adequate potassium for plant needs. This is however surprising since this soil rates low in available K (70 ppm NH_4OAC extractable K). The large quantity of soil used (12 Kg/pot) may partly be responsible for the lack of response. Since only four seedlings per pot were grown to maturity, it is likely that they were able to obtain enough K for normal growth. In the early stages of growth, plants in the check pots showed symptoms of severe K deficiency which disappeared later as plant growth progressed. It is likely therefore that increased root development may have made it possible for the plants to exploit more soil volume for K. The importance of soil volume accessible to plant roots has been reported. Pot experiments of Newman and Andrews (1973), with winter wheat, have shown that if only a small soil volume is available, the amount of K absorbed by the plants is reduced. When the soil volume was restricted, the above authors observed a dense rooting system and inadequate K uptake. Release of K under the growth chamber condition may have also occured thereby increasing the amount of K available to the plant. Plant dry matter and grain yields were closely related to the number of tillers. Since the plumpness of grains did not differ substantially either among the levels of applied K or between the moisture treatments, it can be concluded that the differences in grain yields between the two moisture treatments were more due to the number of tillers with fertile heads rather than to single grain weight.

An examination of the influence of moisture and K treatments on percent K in the straw and grain (table 62) show that percent K in the straw increased with increasing levels of applied K. This observation was true for both moisture treatments. Percent K in the high moisture treatment was, however, lower at any level of applied K compared to that in the low

Table 58: Influence of Moisture Treatments and Rates of K on Number of Fertile Tillers of Wheat.

Rates of Applied K (ppm K)	Moisture Treatment Low	Moisture Treatment High	Main Effect of K Treatment
	# of Tillers/Pot		# of Tillers/Pot
0	19 ab	25 a	22 a
25	16 a	24 a	20 a
50	25 bc	28 a	27 a
100	19 ab	24 a	21 a
200	28 c	27 a	28 a
Main Effect of Moisture Treatment	21 A	26 B	

Means with the same small letter(s) in each column are not significantly different at P = 0.05, Tukey's w-procedure.

Means with the same capital letter are not significantly different at P = 0.05, Tukey's w-procedure.

Table 59: Influence of Moisture treatments and Rates of K on Total Dry Matter Yield of Wheat (g/Pot).

Rates of Applied K (ppm K)	Moisture Treatment Low	Moisture Treatment High	Main Effect of K Treatment
	Total Plant Dry Matter Yield (g/Pot)		
0	33.23 a	42.95 a	38.09 a
25	32.56 a	43.29 a	37.93 a
50	44.94 a	60.61 a	52.78 a
100	36.55 a	49.43 a	42.99 a
200	44.71 a	52.98 a	48.84 a
Main Effect of Moisture Treatment	38.40 A	49.90 B	

Means with the same small letter in each column are not significantly different at P = 0.05, Tukey's w-procedure.

Means with the same capital letter are not significantly different at P = 0.05, Tukey's w-procedure.

Table 60: Influence of Moisture Treatments and Rates of K on Grain Yield (g/pot).

Rates of Applied K (ppm K)	Moisture Treatments Low	Moisture Treatments High	Main Effect of K Treatments
	Grain Yield (g/pot)		
0	17.82 a	24.95 a	21.39 a
25	17.57 a	25.11 a	21.34 a
50	23.00 a	33.20 a	28.10 a
100	16.76 a	25.64 a	21.20 a
200	20.79 a	26.17 a	23.48 a
Main Effect of Moisture Treatment	19.19 A	27.02 B	

Means with the same small letter in each column are not significantly different at P = 0.05, Tukey's w-procedure.

Means with the same capital letter are not significantly different at P = 0.05, Tukey's w-procedure.

Table 61: Influence of K and Moisture Treatment on 100 Grain Weight (g).

Rates of Applied K (ppm K)	Moisture Treatments Low	Moisture Treatments High
	100 Grain Weight (g)	
0	3.79	3.71
25	3.99	3.81
50	3.85	3.74
100	3.70	3.77
200	3.82	3.75

Table 62: Influence of Moisture Treatments and Rates of K on % K in the Straw and Grain Tissues and On K Uptake (mg/pot).

Moisture Treatment	Rates of K (ppm K)	Straw (% K)	Grain (% K)	Total K Uptake (mg/pot)
	0	0.60	0.48	179
	25	1.04	0.44	241
Low	50	1.03	0.47	337
	100	1.32	0.46	325
	200	1.48	0.51	445
	0	0.35	0.49	180
	25	0.58	0.52	238
High	50	0.87	0.52	421
	100	1.10	0.48	390
	200	1.30	0.51	479

moisture treatments. This is perhaps a reflection of dilution effect due to the slight increase in yields in the high moisture treatment. The percent K in the grains remained almost constant throughout the levels of applied K. Also the K concentration in the grain was about the same for both moisture treatments.

K uptake (table 62), like percent K, increased with increasing levels of applied K. The lowest K uptake was recorded in the check pots while the highest uptake was obtained from pots which received 200 ppm K. There was very slight difference in K uptake between moisture treatments. In general, however, K uptake from pots which received the high moisture treatments was slightly higher compared to that from pots receiving low moisture treatment. The increased K uptake over the check when higher levels of K were applied was likely due to luxury consumption of K since the plant dry matter and the grain yields increased only very slightly and, in some cases, decreased with higher levels of applied K.

Adequate soil moisture is known to influence the availability of soil and fertilizer K by enhancing the rate of diffusion of K to the plant roots (Mengel and Van Braunschewing 1972). In this experiment however, diffusion of K was not a limiting factor in K availability since no significant response to any level of applied K was observed in either the low or the high moisture treatment. The influence of moisture treatment was therefore greater on plant growth than on the availability of potassium. This conclusion is supported by the fact that high moisture treatment resulted in significantly more tillers than the low moisture treatment. This increase in number of tillers, as was mentioned earlier, resulted in higher plant dry matter and grain yield at maturity. Percent K and K uptake did not differ much between the two moisture treatments which also confirms that K availability was not influenced differently by moisture treatments.

The results of average percent N in straw plus grain and N uptake are shown in table 63. Percent nitrogen increased, though slightly, with increasing levels of applied K up to 100 ppm K/pot after which a slight drop was observed when 200 ppm K was added. This observation was true for both low and high moisture treatments. In general, however, percent nitrogen in the plants from pots receiving the high moisture treatment was slightly lower, for any level of applied K than that from the low moisture treatment. Since total dry matter yield from pots receiving high moisture treatment was higher, at any level of applied K, than yields from low moisture treatment, it is likely that the low percent N observed in the high moisture regime was due to dilution effect. Nitrogen uptake followed a trend similar to that discussed for percent N. However, nitrogen uptake from pots which received high moisture treatment was greater than uptake from pots receiving low moisture treatment. It is clear from these observations that the negative effect of low N concentrations on N uptake was overcome by the increase in plant dry matter yield.

Table 63: Influence of Moisture and Potassium Treatments on Nitrogen Concentration (% N) and Nitrogen Uptake.

Moisture Treatments	K Rates (ppm K/pot)	Percent Nitrogen (Straw + Grain)	Nitrogen Uptake (mg/pot)
	0	1.61	535
	25	1.77	576
Low	50	1.78	800
	100	2.23	815
	200	2.06	921
	0	1.40	601
	25	1.63	706
High	50	1.64	994
	100	2.06	1018
	200	2.04	1081

Percent protein in the grains (table 64) shows that applied K increased the grain protein content compared to the check in both the low and the high moisture treatments. In the low moisture regime, application of 100 ppm K resulted in a significantly higher percent grain protein than the 0, and 25 ppm K treatments. The 200 ppm K level, however, led to a slight but nonsignificant drop in percent protein compared to that in grains from pots which received 100 ppm K. In the high moisture regime, each successive level of applied K, with the exception of the 50 ppm K, led to a higher percent protein in the grains than preceding levels. Additionally application of 200 ppm K resulted in a significantly higher percent protein compared to that resulting from application of 0, 25 or 50 ppm K.

Since the main effect of moisture treatment was not significant, the influence of K on percent protein in the grain can clearly be understood by an examination of the main effect of K. Although there were no significant differences in percent

Table 64: Influence of Moisture and Potassium Treatments on Percent Protein in the Grains.

Rates of Applied K (ppm)	Moisture Treatment Low	Moisture Treatment High	Main Effect of K Treatment
	Percent Protein in Grain at 13.5% Moisture Content		
0	12.72 a	12.44 a	12.58 a
25	13.49 a	13.16 ab	13.33 a
50	15.12 ab	12.85 a	13.99 ab
100	16.37 b	15.97 bc	16.17 b
200	15.50 ab	16.80 c	16.15 b
Main Effect of Moisture	14.64 A	14.24 A	

Means with the same small letter(s) in each column are not significantly different at P = .05, Tukey's w-procedure.

Means with the same capital letter are not significantly different at P = .05, Tukey's w-procedure.

NB Moisture X K treatments: NS

protein in the grains from the check and pots receiving 25 or 50 ppm K, application of 100 or 200 ppm K resulted in a significant percent grain protein compared to that from lower levels of K. The above results therefore seem to indicate that even though high rates of applied K may not result in spectacular grain yields, they may nevertheless lead to increased grain protein content. As reported by Koch and Mengel (1977), the positive influence of ample supply of K on grain protein is through the enhancing effect of the former on nitrogen uptake and its translocation from the vegetative plant to the grains.

Water use efficiency as influenced by levels of applied K and moisture treatments is shown in table 65. The data clearly shows that neither the simple nor the main effects of K as well as moisture treatments were significant. Also there was no significant interaction between moisture and K treatments. In general, however, water use efficiency for plants receiving high moisture treatment was better than for plants from the low moisture treatment. Also as indicated by the main effect of K, water use efficiency increased, though slightly, with increasing levels of applied K up to 50 ppm K. High levels of applied K resulted in a decrease in the efficiency of water use. Under low soil moisture conditions, high levels of K in roots are known to enhance water uptake. According to Mengel and Kirkby (1980), a high rate of K uptake by root cells depresses the osmotic potential in the cells thereby inducing water uptake. Potassium is also a major osmotically active component in other plant cells and thus it contributes to turgor and enhances the capacity of plant cells to retain water. Lack of significant increase in water use efficiency, particularly in plants receiving low moisture treatment, when the levels of applied K increased indicates that either the soil was able to supply sufficient K or that the amount of moisture stress applied was not big enough. However, the former rather than the latter is likely to be the case. As observed earlier, the parameters of yield measured such as number of tillers, plant dry matter and the grain yields were all significantly influenced by moisture treatments but not by applied K.

Table 65: Influence of K and Moisture Regimes on Water Use Efficiency.

K Added (ppm)	Soil Moisture Regimes		
	Low	High	K Main Effect
	Kg Grain/ha/cm-H_2O		
0	136 a	145 a	141 a
25	138 a	147 a	143 a
50	148 a	155 a	152 a
100	137 a	141 a	139 a
200	134 a	135 a	135 a
Moisture Main Effect	139 A	145 A	

Means with the same small letter in each column are not significantly different at P = .05, Tukey's w-procedure.

Means with the same capital letter are not significantly different at P = .05, Tukey's w-procedure.

Results of the residual fertilizer and soil K after the experiment are shown in table 66. In both moisture regimes, a lot of added K could not be accounted for either in terms of the quantity of exchangeable K remaining in the soil or plant uptake. While up to 2400 mg/pot (200 ppm K) was added, the maximum uptake by the plant was only about 500 mg/pot. Though the total K content of the roots was not evaluated, it is apparent that most of the added K changed into a form which is non-exchangeable with NH_4OAc. The amount of exchangeable K remaining in the soil in both moisture regimes increased, though slightly, with increasing levels of added K. The quantity of K remaining in the soil did not, however, differ much between the two moisture regimes.

Table 66: Residual[1] Soil and Fertilizer K as Influenced by Levels of Added K.

Added K (ppm)	Moisture Treatments	
	Low	High
	ppm K[2*]	
0	34.7	33.3
25	36.7	34.0
50	38.0	39.3
100	53.3	48.7
200	72.0	80.0

[1] Soil analysis for residual K was done after wheat harvest.

[2*] ppm K (NH_4OAc exchangeable K).

Fixation of added K by a soil of a sandy texture (V.F.S.) is not only rare but quite surprising. A preliminary field study on the fate of large amounts of added K (400 Kg K/ha) to the same soil in 1982 showed that a large portion of added K had disappeared after one year. While some K could possibly be leached deeper into the soil profile in the field, no such a factor could account for the decrease in exchangeable K in the soil from the growth chamber. While it can be concluded that the disappearance of exchangeable K was through K fixation, it is unclear what components of this soil were responsible for fixation. However, apart from the total quantity of clay in a given soil, the type of clay is an important factor in influencing the amount of K fixed. According to Mclean and Brydon (1963) medium silt fractions are also capable of fixing applied K.

Considering the fact that Haywood soil is predominantly sandy in texture and thus of questionable ability to fix K, more study is necessary before any firm conclusions about the fate of added K can be made.

Results of phosphorus, copper, zinc, iron and manganese concentrations are shown in Appendix 8. With the exception of Cu, the lowest concentrations of the examined nutrients in the straw was from the check pots. Application of higher levels of K either increased or decreased, though slightly, the concentrations of these elements particularly in the low moisture treatments. In the straw from pots that received high moisture treatment, however, a general decrease in concentration of the phosphorus and the micronutrients with increasing K levels was observed. Copper concentration in the straw increased or decreased slightly across the levels of applied K. This observation was true for both high and low moisture treatments. The concentration of the nutrients discussed above in the grains with the exception of manganese were not very much influenced by levels of applied K. Manganese concentration in the grains, however, increased with increasing levels of applied K.

Phosphorus, copper and zinc were applied in sufficient amounts and were not, therefore, expected to be yield limiting. Although iron and manganese were not applied in this experiment, the field study discussed earlier indicated that this soil was able to supply enough manganese for normal plant growth.

Chapter 7

SUMMARY AND CONCLUSIONS

A study of the influence of K additions and the methods of application of K on maximum yield of wheat was conducted in field, lysimeter and growth chamber experiments. Three soils were selected on the basis of their NH_4OAc exchangeable K and the results reported are for two years. Sampling for plant dry matter yield determination was done at the early tillering, the boot, the heading and the milk stages of growth while at maturity total plant dry matter and grain yields were determined.

Results from the field experiments showed that maximum yield of wheat could be obtained without addition of K in two soils with medium to high levels of NH_4OAc exchangeable K. Application of various levels of broadcast K had no significant effect on plant dry matter and grain yield in any of the two years. However, slight yield depressions were observed at the early stages of growth when K was banded in plots which had received broadcast K. Shoot K concentration and K uptake remained almost constant across the levels of broadcast K both in plots which received broadcast K only as well as those which received broadcast plus banded K. At the boot stage of growth, percent K in the shoots from plots which received various levels of added K as well as that from the check was above the 1.80 % K critical level. Percent N in the shoots, N uptake as well as percent protein were not influenced by added K.

Of the two soils, the depth of K incorporation influenced plant dry matter yield at the boot stage of growth only in the soil with the high level of available K. At the above stage of growth, the 1982 plant dry matter yield data from plots where K was incorporated to 7.5 cm were significantly higher compared to the 15 cm depth of K incorporation. However, K uptake was not influenced by the depth of K incorporation. This means that the depth of K incorporation did not affect K availability and thus the observed influence of the depth was perhaps through a tillage effect.

In the soil low in NH_4OAc exchangeable K, potassium availability limited maximum yield. In this soil, both plant dry matter throughout the stages of growth as well as grain responded to added K. In the 1982 season, significant plant dry matter and grain yield responses were obtained with the application of 100 Kg/ha of broadcast K but additional rates had no further significant response. In 1983 season, plots receiving 200 Kg K/ha produced significantly higher yield compared to the check or 100 Kg K/ha rate. Although there were no significant yield differences between plots receiving 200 and 400 Kg K/ha, the 400 Kg K/ha rate resulted in the highest grain yield in each of two years.

When 33 Kg K/ha was banded with the seed in plots which did not receive broadcast K, plant dry matter and grain yields in 1982 season were as high as when 100, 200 Kg K/ha, and in some cases 400 Kg K/ha were incorporated. In 1983 season, plant dry matter yield at the early stages of growth from plots receiving banded K was significantly higher than that from plots receiving any level of broadcast K. At later stages of growth, both plant dry matter and grain yields from plots receiving 400 Kg/ha of broadcast K were not significantly different from those obtained from plots receiving banded K only. In this soil, therefore, annual banding of 33 Kg K/ha with the seed would be sufficient for maximum plant dry matter and grain yield.

Shoot potassium concentration and K uptake in both years indicated that K availability was a yield limiting factor. In 1982 season, shoot percent K and K uptake in all vegetative stages of growth increased with increasing levels of broadcast K. This increase in percent K and K uptake corresponded very well with yield increases. In 1983 season, however, percent K in shoots and K uptake increased with increasing levels of broadcast K even in plots which received banded K but no substantial change in yield was apparent in plots which received banded as well as broadcast K levels.

In 1982 and 1983 seasons shoot percent N and N uptake from this site low in available K were not influenced by levels of broadcast K. This observation was true at all vegetative stages of growth. However, the highest N uptake and percent protein in the grains were obtained with the application of either 100 Kg/ha broadcast K or by banding 33 Kg K/ha with the seed.

Depth of K incorporation in the two years of this study was not consistent. In 1982, the 0-7.5 cm depth of K incorporation resulted in significantly higher plant dry matter yield at boot stage of growth, compared to the 15 cm depth. For grain yield, however, the opposite was true. In 1983, the only significant influence of the depth of K incorporation was at the milk stage of growth where the 0-7.5 cm depth of K incorporation resulted in significantly higher plant dry matter yield compared to 15 cm depth. In both years, K availability was not influenced by the depth of K incorporation as evidenced by shoot percent K and K uptake which were about the same for both depths of K incorporation.

A lysimeter study with the soil low in available K showed that 100 Kg K/ha rate was enough for the production of the maximum number of tillers, plant dry matter as well as for maximum K uptake. However, application of 200 Kg K/ha resulted in significantly higher grain yield compared to 100 Kg K/ha rate.

The influence of the depth of K placement on wheat yield and K uptake was also studied in the lysimeter experiment. The highest plant dry matter and grain yield as well as the largest K uptake were obtained when the surface 0-7.5 cm soil layer was mixed with either 100 or 200 Kg K/ha. For both levels of added K (i.e., 100 and 200 Kg K/ha) plant dry matter, grain yields and K uptake were lower when 15-30 cm soil layer was mixed with K as compared to 0-7.5 cm soil layer. Increasing the soil volume with which K was mixed resulted in reduced yield and K uptake.

Addition of K increased N uptake. For a given depth of K mixing, there was no difference in N uptake between lysimeters receiving 100 Kg K/ha and those receiving 200 Kg K/ha. Percent protein in the grains was also influenced by K addition. However

100 Kg K/ha seemed to be enough for maximum grain protein.

Results from a growth chamber study showed no significant plant dry matter or grain yield response to K although the soil used for the experiment was low in available K. K uptake, however, increased with increasing levels of applied K which is perhaps an indication of luxury consumption of K. Water use efficiency was neither influenced significantly by added K nor by the moisture treatments. However high moisture treatment resulted in a significantly higher number of tillers, plant dry matter as well as grain yield compared to low moisture treatment.

Potassium application enhanced N uptake. The largest N uptake was recorded from pots receiving 200 ppm K. Percent protein content of the grains also increased with increasing levels of added K up to 100 ppm K. These results therefore indicate that addition of K beyond the amount required for maximum grain yield could enhance grain protein concentration in situations where N availability is not limiting.

A preliminary study of the fate of added K in the growth chamber indicated that not all of added K could be accounted for. Analysis of soil samples after the end of the experiment showed that most of the added K was not in a form extractable with NH_4OAc. These results therefore, seem to indicate that this soil, though sandy in texture (V.F.S.) was capable of fixing a substantial amount of K over the growing period.

Chapter 8

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Chapter 9

APPENDICES

APPENDIX 1: P, Cu, Zn, Fe and Mn Concentrations as Influenced by Amount of K Mixed with Soil and K Banded with the Seed (Average of Two Depths of K Mixing) Haywood 1982.

Stage of Growth	K Banded (Kg/ha)	K Mixed with Soil (Kg/ha)			
		0	100	200	400
			% P		
Heading	0	0.27	0.23	0.22	0.21
	33	0.27	0.25	0.23	0.26
Boot	0	0.29	0.29	0.29	0.32
	33	0.27	0.30	0.28	0.33
			Cu (ppm)		
Heading	0	3.00	2.63	2.88	2.25
	33	2.75	2.80	2.67	2.35
Boot	0	3.25	3.00	2.63	2.38
	33	4.25	4.13	4.13	4.00
			Zn (ppm)		
Heading	0	22.15	16.30	18.15	18.00
	33	20.70	19.75	17.83	17.90
Boot	0	24.90	24.05	23.55	21.65
	33	25.90	22.75	23.75	22.65
			Fe (ppm)		
Heading	0	98.75	73.00	75.40	63.55
	33	95.50	80.25	69.89	73.80
Boot	0	196.50	162.50	130.50	129.50
	33	160.50	147.00	155.50	172.00
			Mn (ppm)		
Heading	0	22.50	21.15	19.25	21.15
	33	23.45	20.78	18.95	22.25
Boot	0	31.00	29.80	30.90	28.90
	33	27.65	27.15	26.80	32.75

APPENDIX 2: P, Cu, Zn, Fe and Mn Concentrations As Influenced by Amount of K Mixed with Soil and K Banded with the Seed (Average of Two Depths of K Mixing.) (Haywood 1983).

Stage of Growth	K Banded (Kg/ha)	K Mixed with Soil (Kg/ha) 0	100	200	400
			% P		
Heading	0	0.35	0.32	0.29	0.28
	33	0.29	0.31	0.29	0.28
Boot	0	0.50	0.44	0.40	0.42
	33	0.45	0.43	0.41	0.39
			Cu (ppm)		
Heading	0	7.15	7.75	4.90	6.65
	33	5.30	6.05	5.50	5.80
Boot	0	12.10	8.75	8.90	7.40
	33	7.90	6.30	6.65	10.25
			Zn (ppm)		
Heading	0	35.80	30.05	28.90	27.55
	33	29.15	27.30	26.30	25.55
Boot	0	40.25	33.40	35.55	32.05
	33	33.75	32.90	32.65	33.30
			Fe (ppm)		
Heading	0	114.50	110.50	87.05	71.90
	33	85.80	85.65	82.30	84.00
Boot	0	165.00	152.00	142.00	138.00
	33	127.00	130.00	133.00	137.00
			Mn (ppm)		
Heading	0	24.90	21.80	19.80	21.15
	33	17.65	18.90	20.80	19.50
Boot	0	29.15	24.30	25.90	24.65
	33	23.40	22.50	23.15	24.40

APPENDIX 3: P, Cu, Zn, Fe and Mn Concentrations as Influenced by Amount of K Mixed with Soil and K Banded with the Seed (Average of Two Depths of K Mixing). (Elm Creek 1982).

Stage of Growth	K Banded (Kg/ha)	K Mixed with Soil (Kg/ha)			
		0	100	200	400
			% P		
Heading	0	0.40	0.32	0.34	0.35
	33	0.30	0.31	0.32	0.32
Boot	0	0.52	0.50	0.51	0.50
	33	0.50	0.49	0.50	0.48
			Cu (ppm)		
Heading	0	4.38	4.13	3.63	3.25
	33	4.00	4.38	3.28	3.00
Boot	0	4.75	3.25	4.25	3.63
	33	4.00	3.25	4.00	3.38
			Zn (ppm)		
Heading	0	24.55	23.05	27.40	30.00
	33	21.90	25.15	27.80	32.30
Boot	0	36.30	38.00	39.65	43.00
	33	34.75	32.25	37.05	41.25
			Fe (ppm)		
Heading	0	78.15	77.75	72.15	76.65
	33	76.65	72.40	65.90	63.15
Boot	0	99.90	113.50	102.90	110.00
	33	90.65	88.40	90.15	90.15
			Mn (ppm)		
Heading	0	33.15	27.40	35.00	42.40
	33	28.15	29.55	31.15	34.15
Boot	0	38.30	41.00	47.15	55.65
	33	34.34	34.30	47.25	57.75

APPENDIX 4: P, Cu, Zn, Fe and Mn Concentrations as Influenced by Amount of K Mixed with Soil and K Banded with the Seed (Average of Two Depths of K Mixing). (Elm Creek 1983).

Stage of Growth	K Banded (Kg/ha)	K Mixed with Soil (Kg/ha) 0	100	200	400
			% P		
Heading	0	0.36	0.37	0.41	0.40
	33	0.42	0.38	0.41	0.40
Boot	0	0.56	0.56	0.55	0.56
	33	0.54	0.57	0.57	0.53
			Cu (ppm)		
Heading	0	2.50	2.25	2.66	2.48
	33	2.30	2.35	2.59	2.64
Boot	0	4.80	4.30	3.65	4.50
	33	4.30	4.05	5.30	4.80
			Zn (ppm)		
Heading	0	14.63	15.50	18.00	19.25
	33	19.00	14.88	16.25	19.13
Boot	0	32.15	28.30	33.90	30.30
	33	26.40	27.15	26.00	28.40
			Fe (ppm)		
Heading	0	77.00	79.13	75.75	87.00
	33	72.00	74.63	81.75	73.00
Boot	0	194.50	183.50	190.50	230.0
	33	218.00	245.00	239.50	208.0
			Mn (ppm)		
Heading	0	21.13	24.50	27.75	25.63
	33	32.75	19.88	26.75	21.88
Boot	0	41.00	30.10	35.30	42.00
	33	41.70	40.50	35.70	39.60

APPENDIX 5: P, Cu, Zn, Fe and Mn Concentrations as Influenced by Amount of K Mixed with Soil and K Banded with the Seed (Average of Two Depths of K Mixing). (Winkler 1982).

Stage of Growth	K Banded (Kg/ha)	K Mixed with Soil (Kg/ha)			
		0	100	200	400
			% P		
Heading	0	0.40	0.34	0.33	0.36
	33	0.32	0.29	0.33	0.34
Boot	0	0.46	0.47	0.47	0.47
	33	0.49	0.48	0.50	0.48
			Cu (ppm)		
Heading	0	3.63	4.00	3.25	3.63
	33	3.75	3.50	3.88	3.13
Boot	0	4.00	2.93	3.75	4.38
	33	4.63	4.50	5.63	4.50
			Zn (ppm)		
Heading	0	15.00	16.80	18.65	18.90
	33	17.65	20.55	15.75	15.15
Boot	0	25.30	18.65	24.65	26.05
	33	26.15	26.90	29.50	27.15
			Fe (ppm)		
Heading	0	78.50	118.00	95.55	97.65
	33	99.65	106.90	137.00	99.25
Boot	0	130.00	119.50	114.50	125.50
	33	130.00	112.00	135.50	123.50
			Mn (ppm)		
Heading	0	48.40	56.90	61.80	55.80
	33	45.05	51.80	54.90	44.30
Boot	0	50.80	48.30	57.50	58.75
	33	52.55	59.65	61.75	58.80

APPENDIX 6: P, Cu, Zn, Fe and Mn Concentrations as Influenced by Amount of K Mixed with Soil and K Banded with the Seed (Average of Two Depths of K Mixing). (Winkler 1983).

Stage of Growth	K Banded (Kg/ha)	K Mixed with Soil (Kg/ha)			
		0	100	200	400
			% P		
Heading	0	0.34	0.35	0.34	0.38
	33	0.36	0.36	0.34	0.34
Boot	0	0.51	0.48	0.50	0.52
	33	0.42	0.49	0.47	0.49
			Cu (ppm)		
Heading	0	5.15	4.80	4.55	4.90
	33	2.95	2.60	3.30	3.90
Boot	0	5.40	6.30	5.90	5.65
	33	5.15	6.25	6.40	6.15
			Zn (ppm)		
Heading	0	23.90	24.00	22.50	25.25
	33	18.40	17.90	17.75	22.30
Boot	0	36.05	38.30	38.00	37.40
	33	32.90	34.65	36.05	35.00
			Fe (ppm)		
Heading	0	89.90	80.80	107.40	108.00
	33	87.40	84.30	76.65	84.55
Boot	0	194.00	190.50	205.00	203.00
	33	145.00	198.00	185.00	199.00
			Mn (ppm)		
Heading	0	31.40	31.15	35.05	32.90
	33	30.55	32.25	33.90	40.00
Boot	0	40.00	44.66	37.40	37.40
	33	41.65	43.15	43.65	43.80

APPENDIX 7: Effect of K Mixed with the Soil and the Depth of K Mixing on the Concentration of Cu, Zn and P in the Grain and Straw Tissues

Treatment Number	Depth of K Mixing (cu)	Rate of K Mixed with Soil (Kg/ha)	Grain <-- ppm ---> Cu	Grain Zn	Grain % P	Straw <-- ppm ---> Cu	Straw Zn	Straw % P
1	-	0	4.10	26.8	0.41	2.25	8.50	0.11
2	0-7.5	100	4.35	26.2	0.40	2.50	6.80	0.06
3	0-15	100	4.33	32.8	0.33	1.95	7.50	0.04
4	0-30	100	4.45	30.3	0.36	2.15	7.00	0.05
5	15-30	100	3.78	29.5	0.39	2.00	8.60	0.05
6	15-30	200	3.60	27.3	0.38	2.30	9.00	0.04
7	0-7.5	200	4.08	27.2	0.31	2.50	7.10	0.03
8	0-15	200	3.68	28.1	0.32	2.35	6.90	0.03
9	0-30	200	3.75	27.8	0.34	1.85	7.30	0.05

APPENDIX 8: Influence of Moisture and Potassium Treatments on Phosphorus and Some Micronutrient Concentration in the Straw and in Grain.

Moisture Treatment	Rate of K (ppm K/pot)	Straw					Grain				
		%	<----------	ppm	----------	>	%	<----------	ppm	----------	>
		P	Cu	Zn	Fe	Mn	P	Cu	Zn	Fe	Mn
	0	0.21	4.00	15.75	36.17	8.21	0.77	3.00	44.17	43.42	14.33
	25	0.47	4.92	24.25	42.00	11.96	0.80	3.83	45.25	42.50	15.25
Low	50	0.37	4.33	17.75	47.00	10.13	0.87	2.91	44.25	46.92	16.42
	100	0.54	4.33	20.88	55.50	12.96	0.93	2.92	47.17	45.83	17.75
	200	0.39	4.00	21.50	46.13	11.88	0.81	2.92	51.17	47.58	19.33
	0	0.21	5.00	13.42	49.88	10.30	0.80	3.58	34.00	32.75	12.17
	25	0.36	4.83	14.13	55.13	13.05	0.77	3.00	31.50	41.88	12.87
High	50	0.56	4.50	21.17	88.50	15.21	0.81	3.00	36.67	40.42	19.13
	100	0.60	5.08	27.00	78.75	14.63	0.79	3.00	38.58	39.58	18.33
	200	0.61	4.75	24.00	64.13	20.96	0.80	3.50	45.42	46.92	26.13