Potassium availability as influenced by application rates and incubation time in Montana soils
by Jia Shung Wang

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Soils
Montana State University

Abstract:
Four surface soil samples and one subsoil sample were collected to represent potentially different K fixation capacities based on results of field trials with K fertilizer. Rates of 20, 40, 80, and 160 kg/ha K were added in each soil and incubated from zero to six months in moist condition at room temperature. Barley was grown in soils which had been incubated for zero, three, and six months after K was applied.

Fixation of K occurred within three days after K was added, and some originally present exchangeable K also was fixed at certain levels of K addition. Within one month K release occurred, with two to five times more K than the amounts added being released from all soils. Extractable K appeared to have increased steadily and reached its maximum in the fourth month followed by slight decreases to six months. Similar results were obtained from high rates of K application (200-1600 kg/ha). Relatively small K applications may trigger the release of additional K from non-exchangeable sources.

Large amount of K release and excess K uptake resulted in maximum plant K concentrations but failed to produce the highest yields on most soils which had been incubated three months. The reason may be nutrient balance problems. Generally, a beneficial response to yield was directly related to incubation time.

Soil tests after barley growth indicated that the 160 kg/ha rate followed by three and six months incubation periods had the highest supplying power for subsequent crops.

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Abstract

Four surface soil samples and one subsoil sample were collected to represent potentially different K fixation capacities based on results of field trials with K fertilizer. Rates of 20, 40, 80, and 160 kg/ha K were added in each soil and incubated from zero to six months in moist condition at room temperature. Barley was grown in soils which had been incubated for zero, three, and six months after K was applied.

Fixation of K occurred within three days after K was added, and some originally present exchangeable K also was fixed at certain levels of K addition. Within one month K release occurred, with two to five times more K than the amounts added being released from all soils. Extractable K appeared to have increased steadily and reached its maximum in the fourth month followed by slight decreases to six months. Similar results were obtained from high rates of K application (200-1600 kg/ha). Relatively small K applications may trigger the release of additional K from non-exchangeable sources.

Large amount of K release and excess K uptake resulted in maximum plant K concentrations but failed to produce the highest yields on most soils which had been incubated three months. The reason may be nutrient balance problems. Generally, a beneficial response to yield was directly related to incubation time.

Soil tests after barley growth indicated that the 160 kg/ha rate followed by three and six months incubation periods had the highest supplying power for subsequent crops.

INTRODUCTION

Potassium fixation undoubtedly is detrimental to crop utilization of K fertilizers under certain conditions. Maintenance of adequate K throughout the growing season to get high crop yields is a major problem, even in Montana. During the last few years, a great deal of field research has shown that top yield of many crops, including potatoes, sugar beets, winter wheat, spring grains, and hay, pasture and range grasses often are not attained, apparently due to a limited supply of K during critical times during the plant growth period. Fertilizing with K is the obvious solution to this problem. However, the effectiveness of K fertilization and the development of proper practices in this regard will depend to a large degree on each soil's ability to "fix" added K and/or to release it for crop growth when needed.

Split applications of K may be one solution to this problem, and has been shown to be beneficial to many crops (Brown 1957, Brown et al. 1946, Gears and Blaser 1957). However, this approach is inconvenient and uneconomical in practical agriculture. For the purpose of using K efficiently, it is helpful to know the relationship between K fixation and application time after different rates of K are applied to different soils.

Applied K will be tied up by certain soils quite rapidly. The fixed K may be released to exchangeable form as long as the exchangeable K is removed until some minimal level is reached (Tabatabai and Hanway 1959). If fixed K releases fast enough, soils could supply enough K for growth of several crops following one large application of K.

Kresge and Younts (1962) indicated that a heavy application of K can be wasteful, resulting in 1) luxury consumption, 2) loss by leaching, and 3) unbalanced plant uptake. However, incubating a soil a period of time before plants are grown on it might solve the previous three problems, if excessive exchangeable K is tied up by soil or converted to non-exchangeable forms. This will remove it from the readily available form and as such it can not be taken up by crops in excess or lost by leaching. If conditions are right the non-exchangeable K will return to exchangeable K as it is depleted by growing crops (Wood and Deturk 1940).

With these relationships in mind, experiments were initiated to:

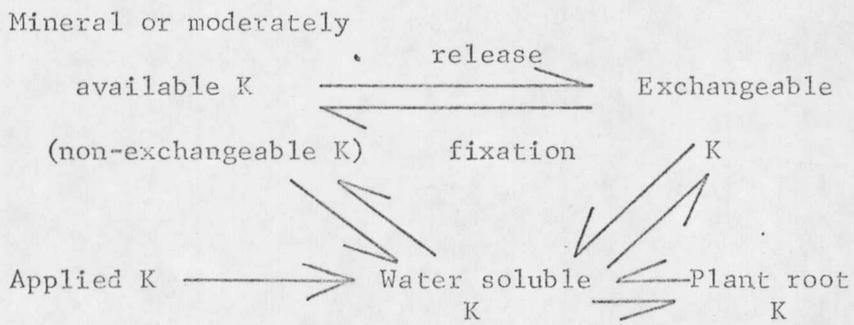
1) Determine the influence of time on the amount of exchangeable K in soil after applying rates of K fertilizers.
2) Investigate the plant availability of added K after varying periods of incubation.
3) Study the exchangeable K situation in soils after plants were grown in them following application of varying rates of K fertilizers.

LITERATURE REVIEW

Forms of K

Soil potassium exists in many forms. Water soluble and exchangeable forms are immediately available to plants. Non-exchangeable and strongly adsorbed K are of considerable importance to plants during the growing season. Although mineral K is not directly available to plants, it plays an important role in supplying.

Attoe and Truog (1945) concluded that 97 to 98 percent of the soil potassium exists in mineral form. They also concluded that approximately 90 percent of the available K exists in the exchangeable form. Jackson (1964) suggests the following relationship of soil K:



Factors Influencing Fixation and Release of K

Fixation of K is the conversion of exchangeable form to non-exchangeable form (DeTurk et al.1943). It has been assumed that an equilibirum exists between exchangeable and non-exchangeable K and that a low level of exchangeable K results in release of non-exchangeable form whereas a high level leads to fixation. Fixation occurs when K is applied to soil and release takes place during the growing season by K removal or loss by leaching from soils.

Fixation and release of K as influenced by time, rates of K addition, soil factors, and management have been discussed by many workers (Deturk et al. 1943, Doll et al. 1959, Barns and Barber 1961, Luebs and Scott 1956). These factors are discussed in the following section:

Effect of Time on K Fixation and Release

Fixation of K requires a certain period of time to occur in soils. The difference between soils could be from several days to several months, depending on soil and environmental factors.

Deturk et al. (1943) found that when fixation occurs very slowly most of the applied K was absorbed by current crops before the maximum fixation was accomplished on selected Illinois soils. Wood and DeTurk (1940) reported maximum fixation was attained at about sixteen weeks, with a progressive release from non-exchangeable to exchangeable forms as the time of storage was increased in several soils of Illinois. However, Sturgis and Moore (1930) found that only half of the applied K was fixed up to the sixteenth week after K application on selected Louisiana soils.

The situation of K in soil changes from time to time. The available K varies with seasonal changes. Robinson et al. (1962) indicated time of application of K fertilizer had a marked effect on the seasonal uptake. Several studies (Robinson et al. 1962, Doll et al. 1959, Brown 1957) have shown that an annual summer application of K was relatively effective in maintaining a moderate level of available K throughout the year and was as effective as the same total amount of K but in three split applications.

Kresge and Younts (1962) found the percent recovery of added K may be strongly influenced by luxury consumption of K, which usually does not coincide with its efficient use. Perhaps more important than recovery is seasonal distribution of K in the plant as it relates to seasonal changes in plant requirements. They concluded that luxury consumption was greatest in those cases in which all the K was applied in the early spring. According to Brown (1957), luxury consumption took place as long as there was a large supply of easily absorbed K in soils.

On the other hand, Doll et al. (1959) found that there was no difference in total yield or K uptake between heavy initial or annual application of K to grass-legume pastures and the exchangeable K in both treated soils remained in the same level until the fourth year. They also concluded that the effect of the initial as compared with the annual applications was associated with fixation of K applied initially with subsequent release over a long period.

Different investigators (Chandler 1945, Hoagland 1933, Legg 1952, Pearson 1952) cropped soils in the greenhouse for extended periods to study long term K supplying power of soils. Those studies generally showed that plants can remove K from soils for long periods with only relatively small reductions in the exchangeable K levels in the soils. DeTurk et al. (1943) concluded significant release to the replaceable form has been attained within 30 days under conditions of non-equilibrium favorable to release. That K release from the non-exchangeable form usually occurs to maintain a somewhat constant level of exchangeable K also has been reported by several other workers (Berland et al. 1950, Smith and Matheus 1957, MacLean 1961, Matthews and Sherrell 1960).

Tabatabai and Hanway (1969) had similar results on undried soils. They found that long term K supplying power of selected Iowa soils was highly correlated with their minimal levels of exchangeable K. Plants may take up K from soil at this minimal level of exchangeable K for an extended period without further reducing the exchangeable K content of soils.

Rate of K Applications and K Availability

The fate of K added at different rates which might be used in field practice is of considerable importance. The release and fixation of K depends on the amount added to the soil (Seatz and Winter 1943). The greater the amount of K added, the more was fixed; and as more was fixed, greater amounts were subsequently released (DeTurk et al. 1943). With large additions the release was always less than the amounts fixed. The value of K which has been fixed in the soil must depend in large part on the rate at which the fixed K can be released in the soil to forms usable by subsequent crops.

Jones et al. (1974) found that 186 kg-K/ha were needed as an annual application to maintain the initial level of available K in a surface soil of Virginia. Lutz et al. (1973), also in Virginia, found that the available K content in the surface soil decreased rapidly during the first three years of cropping all levels of applied K (0, 11, 28, 44, 56 kg-K/ha), but the rate of decrease lessened after the third year with the highest rate of applied K (56 kg-K/ha). They also found that the available K in pots receiving 28 and 56 Kg K annually were greater than those receiving no K by 6 and 13 percent, respectively. Comparisons between a 500 Kg initial and 125 Kg annual K applications, both of which received equal amounts of K over 4 years (Doll et al. 1959) showed that the total yield did not differ significantly, but the uptake of K was higher from annual applications than from the initial during the third and fourth years.

Soil Factors Influencing K Fixation and Availability

Many soils have a different effect on fixation of exchangeable K if the K is added to field moist as opposed to air dried samples. Higher exchangeable K contents are usually found in air dried soils (Hanway and Scott 1957; 1959, Luebs 1956, Scott and Hanway 1957). MacLean (1962) concluded fixation of K was invariably higher in the sample subjected to cycles of wetting and drying than in those kept moist or in those air dried. Many investigators (Barber 1961, Barber et al. 1971, Hanway et al. 1962, Scott et al. 1960) have shown that drying samples before testing markedly changes K availability to plants and/or to chemical extraction on many soils. They suggested that undried soil samples should be used for determining exchangeable K in soils.

Potassium availability is affected by the diffusion and mass flow conditions of the soil, for example, by soil moisture. Mengel et al. (1972) reported that the availability if K in the soil depends considerably on the soil moisture. Leubs et al. (1956) found that fluctuations in soil moisture levels in the surface one inch layer were accompanied by marked changes in content of exchangeable K. Below this layer, exchangeable K remained nearly constant since moisture did not drop so low as in the surface.

It appears that fixation of K is accomplished most rapidly in relatively immature soils having a large capacity for release of K from non-exchangeable forms (Wood and DeTurk 1943, Pratt 1951). In highly weathered soils, fixation of K proceeds very slowly, and exchangeable K values may not clearly reflect the relative K supplying ability of soil (Rouse and Bertramson 1950, Schmitz and Pratt 1951).

Most of the K fixed in soil is probably due to the action of clay minerals. The K fixation in illite occurs by the emplacement of K between the basal surface of the mineral in the positions normally occupied by K in this mineral (Volk, 1938). Stanford (1947) showed that presence of hydrogen, iron, and aluminum ions tends to block the fixation of K by illite. In the case of smectite and vermiculite, as with illite, any fixation would take place on the basal planes between the unit layer. Volk (1938) found that expandable 2:1 layer silicates trapped K in the facing ditrigonal holes causing K fixation. Barshad (1954), studying cation exchange in micaceous minerals, concluded that the replaceability of interlayer NH_4 and K is strongly affected by the magnitude of interlayer crystal lattice charge, particle size, presence of difficultly replaceable K, and the nature of the replacing cations.

Fixation tends to be greater in soils that contain the highest proportion of mica and montmorillonite-type of clay minerals (Dowdy and Hutcheson 1963, Seatz et al. 1943). Gholston and Hoover (1948), in Mississippi, found that K release is directly related to the type of soil parent material and its state of weathering. Illite and dioctahedral mica have the ability to supply appreciable amounts of K for plant growth (Fawzi et al. 1966, Lutz and Jones 1973).

Potassium fixation and availability appear to be pH dependent. Release of K was increased as the pH was lowered (Rich 1964, Rich and Black 1964). Martin et al. (1945) showed that at pH values up to 2.5, there was essentially no fixation, between 2.5 and 5.5, the amount of fixation increased very rapidly, and above 5.5 the amount of fixation increased more slowly.

Calcareous soils seem to require higher levels of exchangeable K to support good crop growth than do the normally acid soils (Allaway 1939). However, plant availability of K at a given level of exchangeable K is higher in calcareous soil than in noncalcareous soils (Suarez-Hernandez and Hanway 1974). Allaway and Pierre (1939) found that the Ca:K ratio in soil solution influences the response of plant to K fertilization. They also found that excessive amounts of available Ca may exert a depressive effect upon the absorption of K by plants.

The reason may be due to Ca-K uptake antagonism in high lime soils. Furthermore, it is reasonable to suspect that the balance of K and Ca in the plant must be maintained within certain limits for the plant to function normally.

MacLean (1962) concluded the amount of exchangeable K was independent of the anion of added salts. The percent of K-saturation and of K fixation were similar for either KC1 or K_2CO_3 sources of K. However, DeTurk et al. (1943) found that addition of K as a phosphate (K_2HPO_4) resulted in greater K fixation than did the addition of an equivalent amount as the chloride (KC1). The phosphate form also resulted in a higher ratio of replaceable to water soluble K.

Pierre and Bower (1943) concluded that K absorption by plants was usually decreased by the presence of high concentration of other cations in solution. The decreased absorption of K may have a detrimental, beneficial, or no effect on yield, depending on the amounts absorbed in relation to the needs of the plant.

The rate of release of non-exchangeable K is temperature dependent. Burns et al. (1961) and Haagsma and Miller (1963) found the higher the temperature, the greater was the rate of release of exchangeable potassium. Temperature also has a large influence on plant metabolism and on the rate of K uptake. Wallace (1957) found that K content of barley increased from 12 to 22°C but decreased at 32°C. This factor is perhaps one of the most important in relation to crop response to added K in areas of more northern latitudes, such as Montana.

Soil Management Influencing Potassium Availabilty

Good management may promote K availability. Jones and Lutz (1974) concluded that there was considerably more K in irrigated plots than in non-irrigated plots in which K was applied. MacLean (1962) and Peech and Bradfield (1943) found liming a soil increased K fixation and reduced the amount of K in soil solution. Potassium leaching was reported to be a lesser problem in limed soil than in acid soil (Baver 1943, Thomas and Coleman 1959).

From the standpoint of preventing loss of K by leaching, the fixation process is beneficial. The loss of K by leaching is not a serious problem in most areas. Under most farming conditions, K loss by leaching is not more than 10 to 15 kg/ha per year (Truog and Jones 1938). Sandy soils with low cation exchange capacities are the ones most likely to lose large amounts of K by leaching, particularly in areas of high rainfall or under irrigation.

MATERIALS AND METHODS

Soils Used and Their Preparation

Soil samples were collected from four fields to represent a wide area of Montana. Field experiments had been conducted on these fields, with varying degrees of crop response to added K fertilizer(P. 20 for detail).

Undried samples from four surface soils (0-15 cm) and one subsoil (15-30 cm) were collected to represent different K fixation capacities. Each sample was thoroughly mixed, sealed in polyethylene sacks and stored in a field moist condition at room temperature ($20^{o}C$-$25^{o}C$).

Sample number and appropriate locations are listed in Table 1. Sample site locations are illustrated in Figure 1. The data of mechanical analysis and chemical characteristics of soils are presented in Table 2.

Treatments:

Four levels of K (20, 40, 80, and 160 kg-K/2.5 million kg oven dry soil) were added in each pot (2 kg oven dry soil), respectively. The K was added as a solution of KCl. Three replicates of each treatment were employed in a factorial experimental design.

The treated soils were incubated from 0 to 6 months in moist condition at room temperature.

High rates of K (200, 400, 800, and 1600 kg- /ha) were added to samples of the same five soils. These samples were incubated zero to three months under the same procedures and conditions as used for the 20-160 kg/ha rates.

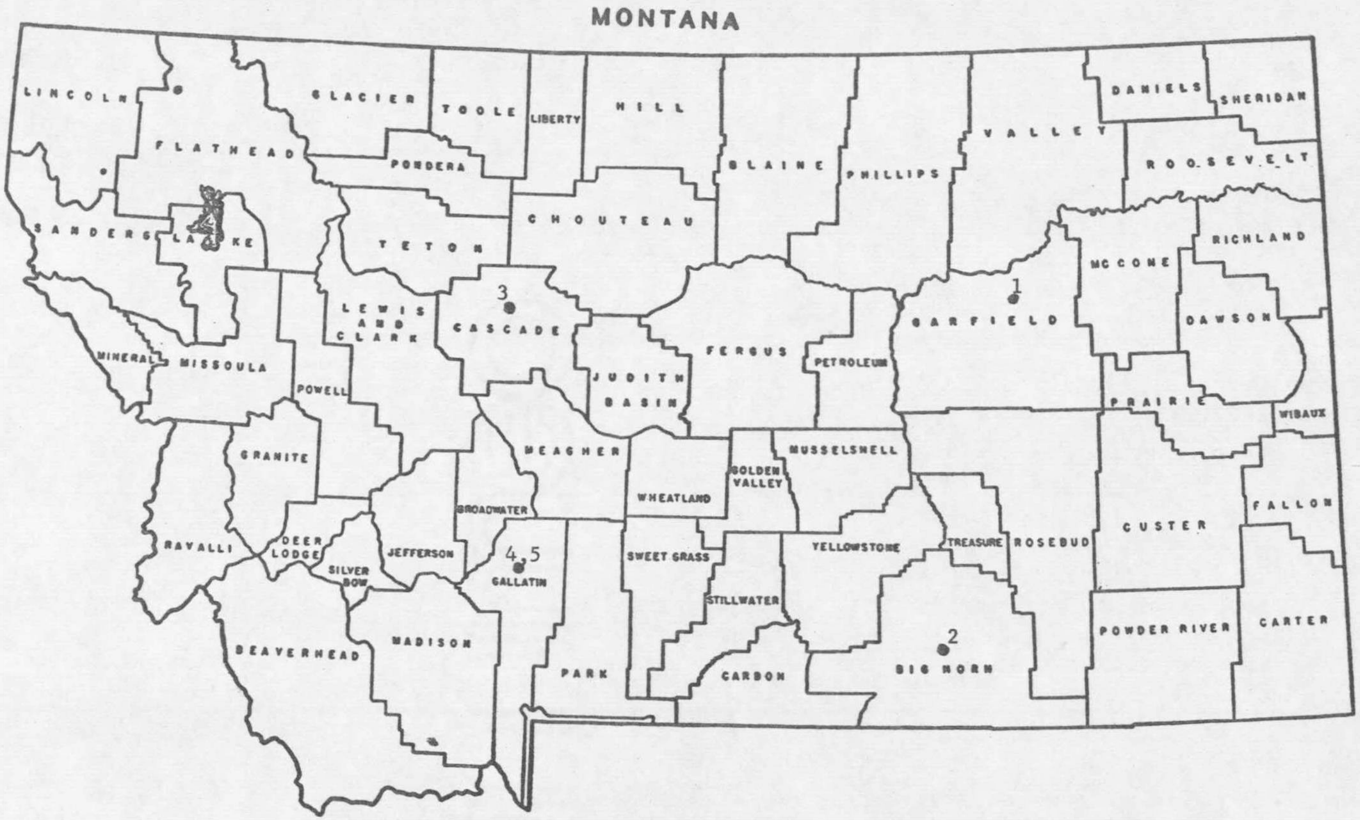


Figure 1. Sample site locations

Table 1. Sample number, location, series, and farm cooperator's name.

Location	Soil Series	Cooperator's name	County	Depth (cm)	Legal Description Sct	Tsp	Rge
1	Cherry loam	Coulter	Garfield	0-15	4	19N	34E
2	Giltedge clay	Torske	Big Horn	0-15	21	1S	33E
3	Cargill clay loam	Gettel	Cascade	0-15	6	22N	1E
4	Amsterdam silt loam	Bates	Gallatin	0-15	8	1S	3E
5	Amsterdam silt loam	Bates	Gallatin	15-30	8	1S	3E

Table 2. Mechanical analysis and chemical characteristics of soils.

Sample number soil	Mechanical composition (%) 1/ Sand (2-0.05mm)	Silt (0.05-0.002mm)	Clay (<0.002mm)	Texture	CEC 2/ (me/100g soil)	pH 3/	O.M. 4/ (%)
1. Cherry	35	41	24	Loam	13	6.6	2.8
2. Giltedge	23	31	46	Clay	28	7.8	1.6
3. Cargill	34	36	30	Clay loam	36	7.9	3.8
4. Amsterdam (surface soil)	29	58	13	Silt loam	30	8.0	2.3
5. Amsterdam (sub soil)	28	59	13	Silt loam	26	8.0	1.0

1/ Hydrometer method

2/ According to the procedure of H.D. Chapman, Cation-exchange capacity by sodium saturation, Method of Soil Analysis, Part 2. C. A. Black et al. American Society of Agronomy, Inc., Publisher, Madison, Wisconsin, U.S.A., 1965.

3/ Soil pH as measured on a 1:1 soil water ratio after an equilibration period of one hour.

4/ Determined by oxidation with a potassium dichromatic solution.

Plant Growth Studies

Barley (variety Unitan) was grown in the greenhouse in pots which had been incubated for 0 (3 days), 3, and 6 months after K was applied.

Considering the low fertility status of the soil samples, nitrogen and phosphorus were supplied to provide adequate amounts of these elements for greenhouse studies. Nitrogen was added in each pot as a solution of NH_4NO_3 at the rate of 300 kg/ha (For greenhouse studies this is about 4 times the recommended rate of 75 kg-N/ha in the field). One additional application of nitrogen at the same rate was added 24 days after sowing. Phosphorus was added in each pot as a solution of $CaH_4(PO_4)_2 \cdot H_2O$ at the rate of 120 kg/ha (four times the recommended rate of 30 kg-P/ha in the field).

Six barley seeds were sown 2.5 cm under surface in each pot. These were thinned to leave four in each pot following emergence.

The plants were watered every 2 days and weighed every 6 days to maintain the soil near field capacity until harvest.

Eight weeks after sowing, the above ground parts of all plants were harvested, dried (65°C, 48 hrs.) and weighed.

Chemical Analysis

Soils

Exchangeable K was determined for all soils, including those in which barley was grown (both before and after barley was grown).

Exchangeable K was extracted with 1 N neutral ammonium acetate and determined with atomic absorption spectrophotometer[1/].

Because of problems in scheduling the use of the spectrophotometer, some of the extracted solutions from the two, three and five month incubation periods had erratic results. This was probably due to fungal growth in these solutions. As the time element did not allow for a repeat of the experiment, these data were omitted from this study. Data were reliable from the zero, one, four and six month incubation periods, providing a complete time curve for the study.

Plant Tissue

Harvested barley was dried at 65°C for 48 hours, weighed, and ground in a Wiley mill to pass a 60 mesh screen.

Potassium content in barley was determined by Atomic Absorption Spectrophotometer according to the procedure of Grewelling[2/].

Statistical Procedures

Analytical data for both soils and plant tissue from this experiment were analyzed statistically as described by Steel and Torrie (1960) for nested factorial effects.

The Duncan Multiple Range test was used for mean sepa ation.

1/ Montana State University Soil Testing Lab Procedure as presented in Appendix.

2/ Grewelling, Thomas. Director of Laboratories, Agronomy Department, Cornell University, Ithaca, New York, 1960.

RESULTS AND DISCUSSION

Effect of Application Rates on Initial K Fixation

The application of KCl to soil samples at rates equivalent to 20-160 kg/ha of K did not influence appreciably the amount of extractable K in the samples three days later (Table 3). At only the highest rate of application, and then only in the Cherry and Cargill surface and Amsterdam subsoil samples, did the amount of ammonium acetate extractable K increase. Two possible explanations exist for this. First, since K was applied as a KCl solution, intimate contact between the soil and the added K was assured and probably allowed for maximum rate of reaction. Any K-fixing capacity of the soil could be expressed within the three day time interval, especially at room temperature.

Second, it is possible that the slight amount of moisture which was added to the soil sample to attain the higher level of exchangeable K may have triggered a reversal of the K release which normally accompanies soil drying. The amount of K being added at the 20 kg/ha rate is a small percentage (approximately 1-2%) of the original amount of exchangeable K present in the soil. This amount, or even an amount four to eight times as great, apparently was not adequate to satisfy the initial K-fixing capacity of the Giltedge or Amsterdam surface soil samples. When the fixation of added K occurred, it appeared that some originally present exchangeable K also was fixed, resulting in decreased level of ammonium acetate extractable K in all samples, at least at certain levels of K addition.

Table 3. Ammonium acetate extractable K in five soils at various application rates after three days.

Application rates (kg/ha)	Soil Series: Cherry	Giltedge	Cargill	Amsterdam: surface soil	Amsterdam: subsoil
0	428 b	596 a	936 a	635 a	262 ab
20	416 b	514 b	938 a	606 ab	215 ab
40	412 b	497 b	869 a	612 ab	201 b
80	434 b	537 b	956 a	592 b	217 ab
160	470 a	581 a	995 a	608 ab	283 a

Means followed by the same letters are not significantly different at the 5% probability level by Duncan's Multiple Range Test, within a soil.

These particular soils had been selected for this study because of differences in crop response to added K fertilizers. The Cherry soil, which had the lowest K soil test level, varied from no response in 1969 to a positive response in 1970 and a negative response in 1971. The Giltedge soil produced no response to K fertilizer during each of these three years. Positive yield responses to K fertilizers were recorded on the Amsterdam soil in 1969 and 1971, but not in 1970. Only one year's data were collected on the Cargill soil, but a positive response resulted from K fertilizer added for barley on this site in 1971.

No differences are apparent in the patterns of K tie-up or release in Table 3 which would help explain the differences in yield response to added K fertilizers which had been observed under field conditions. Long-term (six month) incubation studies were conducted to investigate whether differences in K fixation or release over longer periods could explain these differences in the field.

The Relationship between K Fixation and Release and Incubation Time

It was expected that the level of extractable K would decrease over time following K addition if the soil has a capacity to fix K (when the soil was prevented from drying). The relationships of extractable K and incubating time at varying application rates are presented in Tables 4 and 5. Analysis of variance Table is given in Appendix Table 3. Significant interactions between soils and application rates, and soils and incubation time were recorded. Considerable K was released from all five soils within the first month, and tended to reach a maximun at four

Table 4. Ammonium acetate extractable K as influenced by K application rates and incubation time, with statistical comparisons for application rates within each soil.

Soil series	application rates		incubation time month			
	kg/ha	(ppm)	0	1	4	6
			ppm			
Cherry loam	0	0	428 b	453 c	456 d	470 c
	20	8	416 b	505 b	616 c	589 a
	40	16	412 b	524 b	648 bc	572 b
	80	32	434 b	512 b	669 ab	575 a
	160	64	470 a	595 a	718 a	619 a
Giltedge clay	0	0	596 a	587 d	627 d	613 b
	20	8	514 b	626 bc	663 cd	655 ab
	40	16	497 b	605 cd	695 bc	653 ab
	80	32	537 b	642 b	716 ab	717 a
	160	64	597 a	697 a	747 a	742 a
Cargill clay loam	0	0	936 a	958 c	987 b	975 c
	20	8	938 a	1023 b	1161 a	1080 b
	40	16	869 a	1035 b	1163 a	1145 a
	80	32	956 a	1032 b	1209 a	1138 ab
	160	64	995 a	1085 a	1251 a	1178 a
Amsterdam silt loam (surface soil)	0	0	635 a	646 d	652 c	661 a
	20	8	606 ab	700 c	747 b	669 a
	40	16	612 ab	713 bc	771 b	676 a
	80	32	592 b	745 ab	792 ab	730 a
	160	64	608 ab	763 a	849 a	774 a
Amsterdam silt loam(subsoil)	0	0	262 ab	281 c	270 c	283 a
	20	8	215 ab	302 c	293 bc	295 a
	40	16	201 b	336 b	323 abc	297 a
	80	32	217 ab	345 ab	347 ab	323 a
	160	64	283 a	373 a	370 a	341 a

Means followed by the same letters within a column for each soil are not significantly different at the 5% level by Duncan's Multiple Range Test.

Table 5. Ammonium acetate extractable K as influenced by incubation time and K application rates with statistical comparison for incubation time within each soil.

Soil series	incubation time, month	K application rates, kg/ha (ppm)				
		0 (0)	20 (8)	40 (16)	80 (32)	160 (64)
		ppm				
Cherry loam	0	428 c	416 c	412 d	434 c	470 c
	1	453 b	505 b	524 c	512 b	595 b
	4	456 b	616 a	648 a	669 a	718 a
	6	470 a	589 a	572 b	575 b	619 b
Giltedge clay	0	596 c	514 b	497 b	537 c	597 a
	1	587 c	626 a	605 b	642 b	697 a
	4	627 a	663 a	695 a	716 a	747 a
	6	613 b	655 a	653 ab	717 a	742 a
Cargill clay loam	0	936 d	938 b	869 c	956 c	995 c
	1	958 c	1023 ab	1035 b	1032 b	1085 bc
	4	987 a	1161 a	1163 a	1209 a	1251 a
	6	975 b	1080 ab	1145 a	1138 a	1178 ab
Amsterdam silt loam (surface soil)	0	635 c	606 c	612 c	592 b	608 b
	1	646 b	700 ab	713 b	745 a	763 a
	4	652 ab	747 a	771 a	792 a	849 a
	6	661 a	669 b	676 b	730 a	774 a
Amsterdam silt loam(subsoil)	0	262 b	215 c	201 b	217 b	283 b
	1	281 a	302 b	336 a	345 a	373 a
	4	270 b	293 a	323 a	347 a	370 a
	6	283 a	295 a	297 a	323 a	341 a

Means followed by the same letters within a column for each soil are not significantly different at the 5% level by Duncan's Multiple Range Test.

to six months.

Extractable K appeared to have increased steadily and reached its maximum in the fourth month followed by slight decreases to six months. The levels were generally greater for each additional increment in K added, and even at six months the differences due to rate of addition were expressed. Only a very slight increase in extractable K occurred on the soils which received no K.

In general, the degree of release was found to vary widely with different incubation times and quite regularly with application rates under moist condition. The reasons for the steady increase in extractable K with time are not clear. It appears that none of these soils have a tendency to fix K, except for a very brief period after its addition. The most striking feature of these data is the magnitude of increased extractable K which occurred with relatively small additions of KCl to the soil. The increase in K was generally more than twice the total addition of K, and in some cases up to four or five times as much. It is known that drying greatly increases ammonium acetate extractable K. The soils were incubated in plastic sacks, but no additional care was taken to insure that moisture remained constant during the study. However, results of K extraction from the 0-K treatment indicate that only slight increases in extractable K occurred on these soils. This suggests that soil drying was not solely responsible for the large increase in extractable K which occurred in this study.

The large increase in extractable K following the addition of much smaller amounts of K is a phenomenon not previously reported, and one for which certain explanations probably exist. However, no definite mechanism can be concluded from results of this study. Mechanisms which may be involved include the following:

First, conditions during the incubation period were very good for growth of soil microorganisms and the addition of K may have stimulated it even more. The resultant microorganism population could have extracted large amounts of interlayer K to meet their requirements for this element. Subsequent release of this K upon the decline of microbial populations could result in elevated levels of extractable K. Second, the increased microbial population would result in breakdown of soil organic matter with the conversion of organic N to NH_4 ions. The NH_4 ion substitutes well for K in interlayer positions, so it is feasable that fixed K may have been replaced by NH_4. These explanations seem reasonable for the longer incubation periods, but not for the initial extraction which was made only three days after K addition.

A third possibility is that chemical equilibria were altered by the addition of K in these calcareous soils. For example, consider the following reaction upon the addition of KCl to a soil high in $CaCO_3$:

$$CaCO_3 + 2KCl \rightleftharpoons K_2CO_3 + CaCl_2$$

This would result in considerably increased solubility of Ca, which in turn could drive more exchangeable K into solution. This could conceivably increase the amount of K extracted by ammonium acetate.

Perhaps a combination of these mechanisms (and others which are not obvious at this time) is responsible for the elevated level of K following the addition of lesser amounts. Detailed studies would be required to answer this question.

As in the initial situation of K fixation and/or release, no apparent differences in the extractable K patterns were expressed which would help explain why differences in response to added K were observed in the field. Some differences in the level of extractable K in these soils is apparent, but none that would relate to field K response. It is possible that under certain conditions in the field the amount of K which is available for plant uptake, or the rate at which the plant can absorb available K, may be limited, more or less regardless of the K level. Such things as cold soil temperatures, excess soil moisture, and low light intensities (cloudiness) may thus regulate plant K status.

Perhaps the major importance of these results is the indication that these particular soils cannot be considered to be K "fixers". The addition of K to these soils (at least under warm, moist conditions) resulted in a large increase in exchangeable K. The magnitude of increase was considerably in excess of the amount of K added, suggesting that small additions of K may trigger a release of less readily available forms of K in the soil, as discussed above.

The Effect of High Application Rates on K Release

The 200 to 1600 kg/ha rates of K application were beyond those which could be normally utilized in field practice in Montana on an annual basis. They were used to investigate the situation of K fixation and release in these particular soils under conditions which would simulate a large application rate intended to suffice for several years. It was expected that all or part of the applied K would be fixed if the soil has a capacity to fix K. However, the results showed that the extractable K was increased to five times as much as the amount of K added. Thus, K was released from these soils instead of being tied up. These results also correspond well with those of lower rates of applications (20-160 kg-K/ha). It appears that application of high rates of K triggers the release of additional K from non-exchangeable sources just as the low rates did.

The percentages of K release after 200 to 1600 kg/ha rates of K were added are presented in Table 6. The percent of K release was calculated as follows:

$$\%\ \text{K release} = \frac{\text{ppm extractable K} - \text{ppm extractable K of check} \times 100}{\text{K addition (ppm)}}$$ 1/

1/ The extractable K is presented in Appendix Table 2.

Table 6. The percent of K release* following high rates of K.

Soil Series	K addition (kg/ha)	K addition (ppm)	Month incubated 0	1	2	3
			------	%	------	
Cherry loam	200	80	425	305	460	327
	400	160	333	367	468	373
	800	320	389	452	466	452
	1600	640	355	387	405	386
Giltedge clay	200	80	333	190	362	300
	400	160	250	261	378	278
	800	320	300	350	429	370
	1600	640	480	273	369	406
Cargill clay loam	200	80	148	-157	352	177
	400	160	126	- 42	323	231
	800	320	271	219	353	334
	1600	640	321	391	343	387
Amsterdam silt loam (surface soil)	200	80	- 23	220	403	251
	400	160	243	231	370	305
	800	320	265	257	411	366
	1600	640	353	266	375	372
Amsterdam silt loam (subsoil)	200	80	361	206	538	402
	400	160	386	196	485	359
	800	320	351	247	493	420
	1600	640	282	191	361	335

$$* \quad \% \text{ K release} = \frac{\text{ppm extractable K} - \text{ppm extractable K of check}}{\text{K addition (ppm)}} \times 100$$

Generally, K released 200 to 500 percent at all application rates on five soils, except at the 200 Kg/ha rate after incubation zero months on Amsterdam surface soil, and the 200 and 400 kg/ha rates after incubation zero and one month on Cargill soil. On these soils it appears that some initial fixation of added K occurred. The percent of K release reached its maximum after two months incubation in most cases, especially on Amsterdam subsoil.

Effect of Soil Incubation Time on Barley K Content and Yield

Grain plants normally contain between 1.5 and 4% K on a dry weight basis, with the highest percentages usually corresponding with the earlier growth stages. Likewise, the most rapid rate of K uptake normally occurs while the plant is growing very rapidly during the first two or three weeks after emergence. For this study, barley was grown for eight weeks, harvested while still at an immature stage, and its K content determined. Differences in the percentage of K in plant tissues and total plant growth were studied in relation to the length of time the soils had been incubated following the addition of various rates of K. Soils from only the zero, three, and six month incubation period were included in this study. Results of plant analysis for K tissue concentration are presented in Tables 7 and 8.

Results varied considerably between soils. On Cherry and Giltedge soils, all rates of K in excess of 20 kg/ha resulted in maximum plant K concentrations after incubation for three months. Extending the

Table 7. Potassium concentration in barley as influenced by soil incubation time and K application rates, with statistical comparisons for application rates within each soil

Soil series	K application rates kg/ha	ppm	soil incubation time month 0	3	6
			-------	%	-------
Cherry loam	20	8	2.90 a	2.90 a	3.04 ab
	40	16	2.70 ab	3.70 ab	3.36 a
	80	32	2.51 b	3.71 ab	2.83 b
	160	64	2.68 ab	3.40 b	3.45 a
Giltedge clay	20	8	2.30 a	2.84 b	3.03 a
	40	16	2.31 a	3.74 a	3.38 a
	80	32	2.07 b	3.80 a	3.17 a
	160	64	2.54 a	3.59 a	3.39 a
Cargill clay loam	20	8	3.09 b	3.92 a	3.63 a
	40	16	2.96 b	4.19 a	3.51 a
	80	32	3.94 a	3.33 b	3.86 a
	160	64	3.66 a	3.28 b	3.80 a
Amsterdam silt loam (surface soil)	20	8	3.64 a	3.08 b	3.79 a
	40	16	3.59 a	3.31 ab	3.33 b
	80	32	3.61 a	3.71 a	3.52 ab
	160	64	3.70 a	3.59 a	3.61 ab
Amsterdam silt loam (subsoil)	20	8	3.10 a	3.19 ab	2.98 a
	40	16	3.45 a	3.30 ab	3.19 a
	80	32	3.06 b	3.00 b	3.12 a
	160	64	3.37 a	3.62 a	3.24 a

Means followed by the same letters within a column for each soil are not signigicantly different at the 5% level by Duncan's Multiple Range Test.

Table 8. Potassium concentration in barley as influenced by soil incubation time and K application rates, with statistical comparisons for incubation time within each soil.

Soil series	soil incubation time month	K application rates kg/ha (ppm) 20 (8)	40 (16)	80 (32)	160 (64)
		%			
Cherry loam	0	2.90 a	2.70 b	2.51 b	2.68 a
	3	2.90 a	3.70 a	3.71 a	3.40 a
	6	3.04 a	3.36 ab	2.83 ab	3.45 a
Giltedge clay	0	2.30 b	2.31 b	2.07 c	2.54 b
	3	2.84 ab	3.74 ab	3.80 a	3.58 a
	6	3.03 a	3.38 a	3.17 b	3.39 ab
Cargill clay loam	0	3.09 a	2.96 b	3.94 a	3.66 a
	3	3.92 a	4.19 a	3.33 b	3.28 a
	6	3.63 a	3.51 ab	3.86 a	3.80 a
Amsterdam silt loam (surface soil)	0	3.64 a	3.59 a	3.61 a	3.70 a
	3	3.09 b	3.31 a	3.71 a	3.59 a
	6	3.78 a	3.33 a	3.52 a	3.61 a
Amsterdam silt loam (subsoil)	0	3.10 a	3.45 a	3.06 a	3.37 ab
	3	3.21 a	3.30 ab	3.00 a	3.62 a
	6	2.98 a	3.19 b	3.12 a	3.24 b

Means followed by the same letters within a column for each soil are not significantly different at the 5% level by Duncan's Multiple Range Test.

incubation time to six months increased the K in tissues grown on the 20 kg/ha rate, but generally decreased its concentration for higher rates. These results appear to correlate reasonably well with the extractable K values of soils as shown in Table 4.

On Cargill soil, the 80 and 160 kg/ha rates have the minimum plant K concentrations after incubation three months and the reverse situation from 20 and 40 kg/ha rates. On Amsterdam surface soil, barley K concentrations were the same among all rates of K after incubation zero months (three days), but it tended to slightly decrease with increasing time of incubation on the 20 and 40 kg/ha rates of application. The large increase from the 20 kg/ha rate after six months of incubation would appear to be experimental error. Values from the 80 and 160 kg/ha rate remained quite constant with time of incubation. On Amsterdam subsoil, the 20 and 160 kg/ha rates of K had maximum barley K concentrations after incubation three months. The 80 kg/ha rate of K varied only slightly over time, and barley K concentrations decreased with increasing incubation time with the 40 kg/ha rate. Generally, Cargill soil had the highest average barley K concentrations among the five soils. Amsterdam surface soil had higher barley K concentrations than the subsoil, as expected.

Results of barley yield are presented in Tables 9 and 10. In the Cherry soil, barley yields increased with increasing incubation times at all rates over 20 kg/ha. On the 20 kg/ha rate, the highest yield occurred

Table 9. Barley yield at eight weeks after seeding as influenced by soil incubation time and K application rates, with statistical comparisons for application rates within each soil.

Soil series	K application rates kg/ha	ppm	soil incubation time month 0	3	6
			--------gram/pot-------		
Cherry loam	20	8	2.21 a	2.48 a	2.36 a
	40	16	2.24 a	2.30 a	2.50 a
	80	32	2.19 a	2.44 a	2.64 a
	160	64	2.08 a	2.41 a	2.42 a
Giltedge clay	20	8	1.74 b	1.94 ab	2.43 a
	40	16	2.10 a	1.99 ab	2.22 a
	80	32	1.82 ab	2.12 a	2.27 a
	160	64	1.84 ab	1.92 b	2.34 a
Cargill clay loam	20	8	2.19 a	2.19 a	2.25 a
	40	16	2.06 a	2.16 a	2.20 a
	80	32	2.14 a	2.21 a	2.32 a
	160	64	2.16 a	2.18 a	2.34 a
Amsterdam silt loam (surface soil)	20	8	2.12 a	2.37 a	2.39 a
	40	16	2.09 a	2.35 a	2.31 a
	80	32	2.15 a	2.31 a	2.25 a
	160	64	2.04 a	2.40 a	2.27 a
Amsterdam silt loam (subsoil)	20	8	1.82 ab	2.25 a	1.95 a
	40	16	1.67 b	2.28 a	2.04 a
	80	32	2.04 a	2.10 a	2.04 a
	160	64	1.83 ab	2.23 a	1.93 a

Means followed by the same letters within a column for each soil are not signigicantly different at the 5% level by Duncan's Multiple Range Test.

Table 10. Barley yield at eight weeks after seeding as influenced by K application rates and soil incubation time, with statistical comparisons for incubation time within each soil.

Soil series	soil incubation time month	K application rates kg/ha (ppm) 20 (8)	40 (16)	80 (32)	160 (64)
		gram/pot			
Cherry loam	0	2.21 b	2.24 a	2.19 b	2.08 a
	3	2.48 a	2.30 a	2.44 ab	2.41 a
	6	2.36 a	2.50 a	2.64 a	2.42 a
Giltedge clay	0	1.74 b	2.10 a	1.82 b	1.84 b
	3	1.94 b	1.99 a	2.12 ab	1.92 b
	6	2.43 a	2.22 a	2.27 a	2.34 a
Cargill clay loam	0	2.19 a	2.06 a	2.14 a	2.16 a
	3	2.19 a	2.16 a	2.22 a	2.18 a
	6	2.25 a	2.20 a	2.32 a	2.34 a
Amsterdam silt loam (surface soil)	0	2.12 b	2.09 b	2.15 a	2.04 b
	3	2.37 a	2.35 a	2.31 a	2.40 a
	6	2.39 a	2.31 a	2.25 a	2.27 ab
Amsterdam silt loam (subsoil)	0	1.82 b	1.67 b	2.04 a	1.83 b
	3	2.25 a	2.28 a	2.10 a	2.23 a
	6	1.95 b	2.04 ab	2.04 a	1.93 b

Means followed by the same letters within a column for each soil are not significantly different at the 5% level by Duncan's Multiple Range Test.

after incubation three months, but it dropped down to its lowest when extending incubation time to six months. This may have been due to exchangeable K reaching its maximum about one month after emergence, at which time barley needs more K than at later growth stages. With three months of incubation, the 20 kg/ha rate was adequate to supply optimal K for maximum yield. Barley might absorb much more K than needed from all rates of K in excess of 20 kg/ha. This excess K uptake may limit yield due to nutrient balance problems. When incubation time was extended to six months, the level of exchangeable K decreased (Table 5), and the 20 kg/ha rate failed to supply optimal K for maximum yield. Judging from results of the 80 kg/ha rate, this seemed to be the optimal rate to reach maximum yield after incubation six months. On Giltedge soil, the yield increased with increasing incubation time in all cases except at the 40 kg/ha rate which had been incubated three months. The yield from the 20 kg/ha rate was the highest yield among the four rates when incubated six months. The reason for this may be due to the heavier texture of Giltedge soil (Table 2) and the lower yield level on this soil. Higher rates of K seemed to produce excess K uptake by the plants (Table 6) which could result in nutrient balance problems. On Cargill soil, barley yields did not vary so much as its tissue K concentrations; the reason might be the higher level of extractable K in this soil before any additional K was applied. In spite of the high extractable K which existed in this soil, the yields were not the highest among the five soils, again, probably due to unbalanced nutritional conditions. However, the yield was directly influenced by incubation times in this soil; the longer it incubated, the larger was the yield at all rates of K addition. On Amsterdam soil, the maximum yield occurred following incubation three months, but failed to have a positive response when extending incubation time to six months. The yield response to added K and time of incubation was very similar on Amsterdam subsoil, but at a somewhat lower yield level.Apparently a three month incubation period results in optimal K levels, in relation to other factors, to allow the maximum yield attainable on this soil under these conditions. The lower yield level on this soil is not readily explainable, but may be due to the fact that this is a less weathered soil.

In general, a beneficial response to yield was related to incubation time at least to three months, and in others up to six months.

Within limits, the higher plant K concentration could be expected to create higher yield. This was not true for most soils. One possibility is that of luxury consumption, resulting in high K concentration which did not produce beneficial response to yield. This appeared to be especially so in soils which had been incubated for three months. In the other words, barley absorbed more K than needed when excess K existed in soils, and this excess K could not increase yields because other factors controlled yield levels. The most obvious example was Cargill soil. Further studies on nutrient balance and under varying conditions would be required to determine how these levels of K would interact to produce maximum yields on each soil.

Extractable K in Soils after Barley Growth

It was expected that extractable K would slightly decrease in soil after barley was grown on it. The amount of decrease should have been somewhat proportional to that absorbed by barley, if no K was lost by other sources except through barley uptake. The extractable K in soil after barley growth is presented in Tables 11 and 12. Potassium uptake from soils with different incubation times at various application rates is presented in Table 13.

The results show that extractable K was less in all soils that were incubated three and six months after barley growth than prior to growing plants (Table 5). However, on soils incubated only 3 days, there was no measurable decrease in extractable K following cropping. It appears that barley uses the elevated level of exchangeable K that occurred upon incubation as a readily available source of K for growth. On the soils incubated only three days, the rate of release of K from non-exchangeable forms apparently was adequate to supply the plant needs without decreasing the original exchangeable level. With many exceptions, the highest K taken from the soils was found in that incubated three months and lowest in zero month. These results corresponded well with data of Tables 4 and 11. That is, the higher

Table 11. Ammonium acetate extractable K as influenced by K application rates and incubation time after barley was grown on soils for eight weeks, with statistical comparisons for application rates within each soil.

Soil series	K application rates		soil incubation time month		
	kg/ha	ppm	0	3	6
			ppm		
Cherry loam	20	8	420 a	381 b	378 b
	40	16	421 a	372 b	370 b
	80	32	434 a	358 b	414 ab
	160	64	435 a	477 a	453 a
Giltedge clay	20	8	460 a	433 ab	399 a
	40	16	377 b	373 c	374 a
	80	32	415 ab	397 bc	384 a
	160	64	425 ab	457 a	410 a
Cargill clay loam	20	8	833 b	849 c	879 b
	40	16	912 ab	845 c	947 a
	80	32	965 a	962 b	874 b
	160	64	966 a	1011 a	936 a
Amsterdam silt loam (surface soil)	20	8	567 b	579 c	504 c
	40	16	537 b	593 bc	539 bc
	80	32	556 b	623 ab	575 ab
	160	64	617 a	666 a	594 a
Amsterdam silt loam (subsoil)	20	8	200 a	201 a	146 b
	40	16	184 a	198 a	145 b
	80	32	214 a	199 a	145 b
	160	64	201 a	230 a	184 a

Means followed by the same letters within a column for each soil are not signigicantly different at the 5% level by Duncan's Multiple Range Test.

Table 12. Ammonium acetate extractable K as influenced by incubation time and K application rates after barley was grown on soils for eight weeks, with statistical comparisons for incubation time within each soil.

Soil series	soil incubation time month	K application rates kg/ha (ppm) 20 (8)	40 (16)	80 (32)	160 (64)
		ppm			
Cherry loam	0	420 a	421 a	434 a	435 a
	3	381 a	372 b	358 b	477 a
	6	378 a	370 b	414 a	453 a
Giltedge clay	0	460 a	377 a	415 a	425 a
	3	433 a	373 a	397 a	457 a
	6	399 a	374 a	384 a	410 a
Cargill clay loam	0	833 a	912 a	965 a	966 ab
	3	849 a	845 b	962 a	1011 a
	6	879 a	974 a	874 b	936 b
Amsterdam silt loam (surface soil)	0	567 a	537 a	556 b	617 ab
	3	579 a	593 a	623 a	666 a
	6	504 a	539 a	575 b	594 b
Amsterdam silt loam (subsoil)	0	200 a	184 a	214 a	201 ab
	3	201 a	198 a	199 ab	230 a
	6	146 b	145 a	145 b	184 b

Means followed by the same letters within a column for each soil are not significantly different at the 5% level by Duncan's Multiple Range Test.

Table 13. The relationship of K uptake from soils, incubation time and application rates.

Soil series	Application rates (kg/ha)	(ppm)	Barley K uptake from soils, month incubated: 0	3	6
			ppm		
Cherry loam	20	8	91	103	102
	40	16	86	121	120
	80	32	79	123	106
	160	64	79	117	119
Giltedge clay	20	8	57	79	105
	40	16	70	106	107
	80	32	53	115	103
	160	64	67	98	113
Cargill clay loam	20	8	97	122	117
	40	16	87	130	110
	80	32	120	105	128
	160	64	113	102	127
Amsterdam silt loam (surface soil)	20	8	110	104	120
	40	16	106	111	110
	80	32	111	122	113
	160	64	108	123	114
Amsterdam silt loam (subsoil)	20	8	80	102	83
	40	16	82	107	93
	80	32	90	90	91
	160	64	88	115	89

the extractable K, the more K barley absorbed, the less extractable K remained in the soils.

Comparison among the five soils indicates that K uptake from Cargill and Amsterdam surface soils was higher than from the other three. This relates well to their higher original extractable K. Soil tests also showed that extractable K was the highest in soils which received 160 kg/ha and that were subjected to three and six months incubation periods. This implies that 160 kg/ha rate had high K supplying power to subsequent crops.

There is adequate evidence to indicate that high clay content soils have large K fixation capacities, depending on the clay types present. Extractable K in soils following various application rates might not show much difference on soils with higher fixing capacities. On high clay soils (Giltedge and Cargill), relatively high extractable K existed at 20 kg/ha rate and did not increase much at all four higher rates. This result may help to explain why there are variable responses in field experiments on these soils. Other factors may help control the rate of release of the native soil K and the amount available for plant uptake at any specific period of the growing season.

SUMMARY AND CONCLUSION

The soils had been selected for this study because of differences in crop response to added K fertilizers. Long term (six month) incubation studies were conducted to investigate whether differences in K fixation or release over longer periods could explain these differences in the field.

Rates of 20, 40, 80, and 160 kg/ha K were added to samples of five soils as a solution of KCl. Fixation of K occurred within three days after K was added. Addition of K as a solution probably would accelerate fixation because the K would be in intimate contact with the soil. When the fixation of added K occurred, some originally present exchangeable K also was fixed at certain levels of K addition. Of the soils tested, Giltedge and Amsterdam surface soils seemed to have the largest capacities to fix K.

The initial fixation of K was short termed since considerable K was released from all five soils within the first month, and extractable K appeared to have increased steadily and reached its maximum in the fourth month followed by slight decreases to six months. The increase in K was generally more than twice the total addition of K, and in some cases up to four to five times as much. Similar results were obtained from the high rates of K application (200, 400, 800, and 1600 kg/ha). It is suggested that relatively small K applications may trigger the release of additional K from non-exchangeable sources. The degree of release varies with different incubation times and application rates.

Barley was grown for eight weeks, harvested while still at an immature stage and its K content determined. Barley tissue contained between 2.1 and 4.2 percent K on a dry weight basis. The percentage of K in plant tissue was different with various incubation times, application rates, and soils. Generally, maximum plant K concentrations occurred in soils which had been incubated three months, but this did not always correspond to the higher application rates (80 and 160 kg/ha). Barley K concentration was relatively high in the Cargill soil and relatively low in the Amsterdam subsoil.

Large amounts of K released after K was added may cause excess K uptake. This excess K uptake may limit plant growth due to nutrient balance problems. A comparison of yields between three and six months incubation periods, indicated that luxury consumption occurred, because high plant K concentration did not produce highest yields on most soils which had been incubated three months. In general, a beneficial response to yield was related to incubation time, at least to three months, and in others up to six months.

The extractable K was less in all soils that were incubated three and six months after barley growth than prior to growing plants, and there was no measurable decrease in extractable K following cropping on soils incubated zero months. On the soils incubated only three days, the rate of release of K from non-exchangeable forms apparently was adequate to supply the plant needs without decreasing the original exchangeable K level. Soil tests showed that extractable K was the highest in soils which received 160 kg/ha and that were subjected to three and six months incubation periods. This implied that 160 kg/ha rate had high supplying power for subsequent crops. On high clay soils, relatively high extractable K existed at the 20 kg/ha rate and did not increase much at all four higher rates.

Judging from the above results, it seems worthy to investigate use of high application rates in the field. It may be possible to maintain high K supplying power to subsequent crops when one large application is made. The six months incubation period was the best among all the incubation times to reach maximum yield and accumulate less K in plant tissue. More detailed studies, including long-term field experiments, will be required before adequate information can be derived in this matter.

APPENDIX

Appendix. Procedure for analyzing available K in soils

1. Weigh 2.5g of soil into each beaker in the shaker racks.
2. Add 50 ml of 1N NH_4OAC to each sample.
3. Shake the soil on the mechanical shaker for 30 minutes.
4. Filter the extract into filter tubes calibrated for 5 ml. (Whatman #1 filter paper).
5. Aspirate the filtrate down to the 5 ml mark.
6. Add 5 ml of 1.0% strontium solution ($SrCl_2 6H_2O$)
7. Analyze the filtrates for K directly on the model 290-B Perkin Elmer atomic absorption spectrophotometer.

Appendix Table 1. Temperature and precipitation data of sample sites.

Sample site (county)	Temperature (°F)						
	Apr.	May	June	July	Aug.	Sept.	Annual* Average
Garfield	44.2	54.9	63.7	72.8	69.9	58.5	43.8
Big Horn	46.3	56.1	63.4	71.8	70.0	59.2	45.9
Cascade	44.8	53.9	60.3	68.7	66.6	57.8	46.0
Gallatin	42.2	51.3	57.7	66.4	64.9	55.8	43.0

Sample site (county)	Precipitation (inches)						
	Apr.	May	June	July	Aug.	Sept.	Annual* Average
Garfield	.88	1.63	3.31	1.45	1.48	1.08	12.86
Big Horn	1.10	1.65	2.74	.86	.99	1.29	12.01
Cascade	.84	2.50	2.59	1.26	1.52	.74	12.06
Gallatin	1.52	2.68	2.49	1.45	.75	1.15	14.08

* average of eight years

Appendix Table 2. Ammonium acetate extractable K of 0 to 1600 kg/ha application rates and four incubation times.

Soil series	K application rates (kg/ha)	(ppm)	Ammonium acetate extractable K, ppm month incubated 0	1	2	3
Cherry loam	0	0	428	453	446	494
	200	80	786	697	814	753
	400	160	961	1041	1195	1092
	800	320	1673	1899	1875	1942
	1600	640	2703	2934	2985	2969
Giltedge clay	0	0	596	589	580	599
	200	80	863	741	870	803
	400	160	997	1007	1185	1045
	800	320	1557	1709	1953	1784
	1600	640	3465	2339	2944	3201
Cargill clay loam	0	0	936	958	940	950
	200	80	1055	832	1222	1092
	400	160	1138	890	1457	1320
	800	320	1803	1659	2072	2019
	1600	640	2990	3466	3140	3432
Amsterdam silt loam (surface soil)	0	0	635	646	617	651
	200	80	616	821	940	852
	400	160	1024	1016	1209	1139
	800	320	1483	1471	1935	1824
	1600	640	2895	2349	3019	3036
Amsterdam silt loam (subsoil)	0	0	262	281	256	277
	200	80	551	446	687	599
	400	160	880	596	1033	852
	800	320	1386	1010	1835	1621
	1600	640	2072	1509	2567	2423

Appendix table 3. The analysis of variance table of soil extractable K for 0 to 160 kg/ha K application rates and incubation time prior to growing plants.

Sources of Variation	Degree of Freedom	Mean Square	F
Soils	4	5101160	7117.37*
K-rates	4	111571	155.67*
Time	3	284256	396.61*
Soils x Time	12	17329	24.18*
K-rates / Time	12	13017	18.16*
Soils x K-rates	16	11975	16.71*
Soils x K-rates / Time	48	1661	2.32*
Error	200	3853	

* Significance at 5% level

Appendix table 4. The analysis of variance table of barley K concentration at eight weeks after seeding.

Sources of Variation	Degree of Freedom	Mean Square	F
Soils	4	211	17.88*
K-rates	3	18	1.53
Time	2	336	26.41*
Soils x Time	6	11	.93
K-rates / Time	12	12	1.03
Soils x K-rates	8	155	13.14
Soils x K-rates / Time	24	29	2.45*
Error	120	12	

* Significance at 5% level

Appendix table 5. The analysis of variance table of barley yield at eight weeks after seeding.

Sources of Variation	Degree of Freedom	Mean Square	F
Soils	4	75.12	24.61*
K-rates	3	5.35	1.75
Time	2	72.81	23.85*
Soils x Time	6	2.55	.84
K-rates / Time	12	2.43	.80
Soils x K-rates	8	9.66	3.16*
Soils x K-rates / Time	24	4.69	1.53
Error	120	3.05	

* Significance at 5% level

Appendix table 6. The analysis of variance table of soil extractable K for 0 to 160 kg/ha K application rates and incubation time after growing plants.

Sources of Variation	Degree of Freedom	Mean Square	F
Soils	4	2651034	1800.97*
K-rates	3	38846	26.38*
Time	2	15888	10.79*
Soils x Time	6	2419	1.64
K-rates / Time	12	4953	3.35*
Soils x K-rates	8	2856	1.94
Soils x K-rates / Time	24	2824	1.91
Error	120	1472	

* Significance at 5% level

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