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Using Kalyan 227 wheat grown on soils low in exchangeable $K^+$ a small response to added potash was observed. X-ray diffraction analyses showed large amounts of illitic minerals in the soils. Extraction with $H_2SO_4$ indicated a large reserve of $K^+$ in the soil. Even though the $NH_4OAc$ exchangeable $K^+$ was not sufficient for a wheat crop, enough $K^+$ was released to provide adequate levels of $K^+$ throughout the growing season.

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# CHARACTERIZATION OF THE RESPONSE TO POTASSIUM FERTILIZATION ON THREE PUNJAB(INDIA) SOILS

A THESIS

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the Degree Master of Science in the Graduate
School of The Ohio State University

by

Thomas C. Stilwell, B.Sc.

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# INTRODUCTION

The location chosen for this project was the state of Punjab in Northwest India (Fig. 1). Punjab State lies between the lattitudes 29°30' and 32°30' North and the longitudes 74° and 77° East. It covers a total area of 50,376 Sq. Kilometers and contains approximately 4% of the national population. The average population density is 262 persons per sq. kilometer with over 70% of this population classified as rural.[10] Thus, even though the Punjab is one of the more industrialized states in India, the majority of the population has its' life and business centered around agriculture.

This area of northwest India is classified as having a semiarid, tropical climate with scanty precipitation at all seasons (DA'd) by Thornthwaite.[15] However, within the State of Punjab, the climate varies from hot and arid in the southwest to warm and wet in the northeast. One of the districts chosen for this experimental work was Ludhiana. This district lies in the part of central Punjab classified as the hot and semi-dry east central zone. The second district used for this work was Gurdaspur. This is located in northwestern Punjab in what is locally called the hot but less dry zone adjoining the hills.[10] Thornthwaites classification for

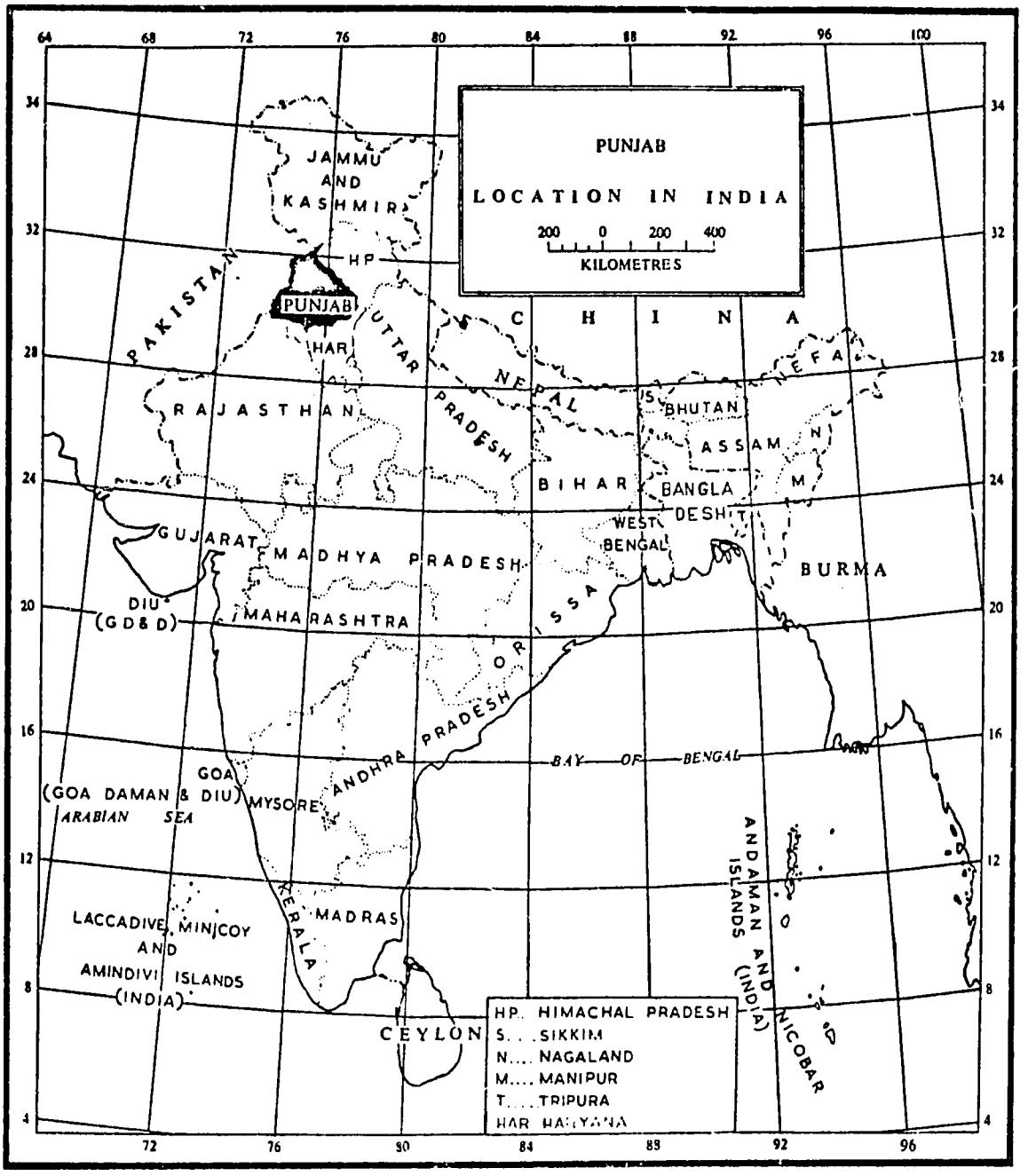



Figure 1. Location of Punjab State in India.

Gurdaspur district is D3-A'2-d-a'2 and for Ludhiana is D2-A'2-d-a'2.[32] The major climatic characteristics of these two districts are presented in Table 1.

TABLE 1

CLIMATE OF GURDASPUR AND LUDHIANA DISTRICTS

| | Gurdaspur | Ludhiana |
|---|---|---|
| Yearly Precipitation | 978.0 mm | 537.0 mm |
| Mean Yearly Max. Temperature | 30.2°C* | 31.2°C |
| Mean Yearly Min. Temperature | 16.2°C* | 17.7°C |
| Mean Yearly Temperature | 23.2°C* | 24.4°C |
| Mean Yearly Rel. Humidity | 66% * | 67% |
| Rainy Days each Year | 46.8 * | 35.5 |

*Gurdaspur data obtained by interpolation between values for Pathankot and Amritsar.
Adapted from Agricultural Atlas of the Punjab

In general, Gurdaspur has significantly greater total rainfall and is somewhat cooler over the entire year. This cooler temperature is especially significant during the winter season since the wheat crop approaches maturity in February. Also, Gurdaspur receives 64.7 mm rainfall in January as opposed to 38.3 mm at Ludhiana. Since this occurs during the active growth period of the wheat crop, the distribution and quantity of these January rains are considered to be quite important even for irrigated wheat.

The monsoon rains normally begin during the first week in June and continue until the first week of October. The highest

monthly rainfall occurs in July and the lowest in November and April. The highest temperatures occur in June and the coldest month is January.

The landforms occurring within the state are also varied. However, the locations chosen for this project are all on relatively stable floodplains. At present the drainage of the north and western parts of the state goes through the Beas and Sutlej rivers into the Indus river system, but in the past, this drainage pattern shifted from the Gangetic river system.[16]

Project Background

Within Punjab State there is one major agricultural university, Punjab Agricultural University, located at Ludhiana. It is presently organized under a system similar to the American land grant colleges. This gives the university much of the responsibility for advising farmers through the state agricultural extension system. To provide accurate fertilization recommendations, the Soils Department has conducted soil test-crop response trials over the last ten years. These have consistently shown expected yield increases from addition of various rates of nitrogen and phosphorous. However, significant increases in yields of several wheat crops was not observed when potash fertilizers were used. This occurred even when traditional soil testing methods indicated a deficiency of readily exchangeable potassium. With the introduction of high yielding wheat varieties, this question of

potash fertilization has come into sharp focus. As a result a project was drawn up with the Ohio State University, Punjab Agricultural University and the U. S. Agency for International Development cooperating, to determine the reason for the reported lack of response to fertilizer K and to investigate methods of promoting response of wheat to fertilizer K on low K soils.

On the basis of limited preliminary information, two working theories were formulated. Analyses of several soil samples from K deficient soils showed that the exchange complex of these soils are dominated by $Ca^{++}$ and $Mg^{++}$ ions. The mineralogy of the clays includes mostly illitic materials. Based on this information, the primary theory was formed as follows: that the abundance of illitic minerals coupled with $Ca^{++}$ and $Mg^{++}$ promoted fixation of fertilizer K and thus prevented uptake by plants. An alternate theory centered around the large amounts of exchangeable Ca and Mg. This theory based the lack of response to fertilizer K on the well known antagonism between $K^{+}$ and $Ca^{++}$ and $Mg^{++}$ ions both at the root-soil interface and within the plant. The laboratory and field plot techniques used to test these theories are detailed in the section on Methods and Materials.

## REVIEW OF LITERATUR

Since the beginnings of agriculture, men have attempted, with varying degrees of success, to improve the yields of the crops which they raised. Early attempts at agricultural improvement centered largely around cataloging practices which had been proven beneficial. Even at this point (circa 500 BC) the usefulness of potash was indirectly recognized through the practice of application of ashes to improve soil fertility.[30] However, most attempts to evaluate agricultural lands were based entirely upon a knowledge of past yields and little was done to actively improve soil fertility.

Active scientific research has occurred only within the last 150 years and only within the last 50 years has it been directly responsible for large increases in crop yields. But from the start, it was evident that there were problems in the application of potassic fertilizers to soils. As early as 1850 Way conducted investigations on the nature of potassium fixation in soils.[5] Investigations by others followed and various theories were proposed and discarded through the years giving rise to a large field of literature on the subject.

Field experiments have also evolved rather recently. The

first European agricultural experiment station was set up by J. B. Boussingault in 1834. A similar experiment station was started in India in 1904 by C. V. Sane under the Maharaja of Baroda.

Since then a large amount of effort has been expended trying to develop methods by which the potassium supplying status of soils can be easily determined. These efforts have centered mainly around chemical extraction procedures which correlate well with demonstrable crop responses under field conditions. Because potassium is intimately involved with the structure of clay minerals and because of the variety of clay minerals in existence, this problem has yet to be suitably solved.

One area which has received much attention concerns fast laboratory methods of evaluating the potassium supplying ability of a soil. In most cases the soils researched were ones in which exchangeable $K^+$ was a poor criterion for estimating the potassium released to a crop. The variety of these extractants has been limited only by the imagination of the researchers. The most common and widely used extractant is neutral normal ammonium acetate. Sodium acetate is also useful on soils having a pH nearer 7.5-8.5. Both generally give useful results for most soils tested and offer advantages of economy and speed. Where these extractants have not proven useful in estimating exchangeable $K^+$ other acids and salts or combinations of both have been tried.

Concentrations of 2.5% or 3.0% acetic acid mixed with soil in the ratio 1:2 was said to be useful in determination of $K^+$ available to wheat in the Punjab.[1] A method tested in North Carolina consists of extraction of soil for 5 minutes with 0.05 N HCl + 0.025 N $H_2SO_4$ with a soil-extractant ratio of 5:20.[29] Magnesium chloride was found useful by Rich but magnesium acetate was not effective in displacing $K^+$ on Nason soils.[27] In 1969 Peaslee concluded that extraction with a mixture of 0.025 N HCl + 0.03 N $NH_4F$ did not give suitable correlation with K uptake by tomatoes.[21] One of the more promising extractants in recent years has been sodium tetraphenylboron (NaTPB). Schulte and Corey extracted Wisconsin and Iowa soils with 0.3 N NaTPB in a soil-extractant ratio of 1:5 and found excellent correlation with plant uptake in a greenhouse situation.[31] By varying concentrations and extraction times either exchangeable or slowly exchangeable $K^+$ can be determined. Unfortunately NaTPB is more expensive than most common extractants and is not useful for estimation of other exchangeable cations.

Use of an ion exchange resin was rated the most effective method for determining the uptake of K by hay crops by Salmon and Smith using a Rhode Island soil.[29] Such work was carried further by Blanchet and Bosc in their extraction of soils using ion exchange resins. They concluded that soils testing low in readily exchangeable $K^+$ tended to hold this exchangeable K less strongly

than high K soils and began to free nonexchangeable $K^+$ before the exchangeable $K^+$ supply was exhausted.[4]

In another attempt at determining plant available K, Reitemeier, et al. found good correlation between K uptake by clover and that extracted by 30 days of electrodialysis.[26]

The most generally accepted laboratory method of determining K available to crops has been the Neubauer method. This involves growing plants such as barley on the soil in question and analyzing the plants to determine the amount of nutrient actually present in the plant. Studies by researchers such as Stanton and Orchard[37] and Olson and Shaw[18] have shown the usefulness of this method compared with chemical methods. However, the time required to perform this analysis is a major drawback and permits its use only in research problems.

Attempts to evaluate the "fixed" potassium which becomes available to plants during a cropping season have likewise stressed quick laboratory analysis. These depend largely on extraction of soils by acid solutions. Work by Hunter and Pratt on Ohio and New York soils in 1957 indicated that a good indicator of $K^+$ released from non-exchangeable sources during cropping, was obtained by extraction with concentrated $H_2SO_4$.[14] Halstead and Heeney evaluated the effectiveness of boiling nitric acid extractions in estimating tomato yield response to potash applications and found that this method did not give good correlation on 33 Canadian

soils.[17] Scott found that prolonged extraction by NaTPB resulted in nearly complete removal of K from certain clays.[32]

In contrast to these direct methods of estimating the amount of soil $K^+$ available to plants, a number of workers have attempted indirect calculations using exchangeable Ca+Mg or CEC. The potassium adsorption ratio (KAR) was found to be useful in predicting plant available K on Egyptian soils with similar CEC. On other similar soils a ratio was calculated using total exchangeable cations and Ca+Mg and this ratio correlated well with K uptake by barley.[28] Various other ratios such as percent saturation of CEC by K or $pK-\frac{1}{2}p(Ca+Mg)$ have proved useful under some conditions but overall no single calculated figure has proven adequate.[3]

The net result of all these foregoing works is to illustrate that no single laboratory method has been evolved which can quickly and efficiently measure how much $K^+$ is available to plants during a cropping season. The most suitable solution to date has been to measure the various fractions of soil K and through regression analysis develop a formula related to a certain crop on a given soil.

Perhaps the most promising work to date concerning the K release capabilities of soils is that done by Scott, et al.[35] Their results showed that release of soil K is primarily a diffusion process with the rate of release depending on the distance through the mica particle which the ions must travel. Therefore, large

particles have different K release rates than small particles. Their work showed that the curve for K release from a soil is the combination of curves for the various sizes of mica present. Although this work has yet to be tested in field applications, it is very attractive or interesting. The implication is that determination of the various clay fractions can be done for a particular soil type and the results directly applied to plant nutrition requirements. At the very least these results may help eliminate much of the confusion concerning estimation of available soil K.

A large amount of work has also been spent on merely recording and evaluating those factors which affect K release and/or fixation in the field. In most cases these studies are not done with the intent of controlling these factors but as a means of better understanding potassium behaviour in the soil. Because so many factors affect K release and fixation, only those which have a major bearing on the conditions studied will be covered.

A well known factor affecting plant uptake of $K^+$ is the presence of $Ca^{++}$ in large amounts. But Wiklander also found that $K^+$ fixation was greatest when clays were $Ca^{++}$ saturated.[39] York, et al. further determined that on certain New York soils this type of $K^+$ fixation was greatest when $Ca^{++}$ comprised 78% of the total CEC.[40] These findings are significant when the large amount of Ca is noted in the Punjab soils studied.

Another factor affecting $K^+$ fixation which has bearing on these Punjab soils is pH. Stanford noted that $K^+$ fixation increased with pH on illite taken from Iowa soils.[36] This same pattern was confirmed by Grewal in a study of soils from the Punjab.[11] The general conclusion is that illitic clays tend to have increased $K^+$ fixation capacity as pH increases through the normal pH ranges of the soils tested. Above a pH of approximately 8 other factors such as Na levels and salinity become more important than pH.

Temperature was found by Burns and Barber to affect release of fixed K. Their laboratory study showed that the rate of release of nonexchangeable K increased as temperature increased.[6] Therefore, soil temperatures would directly affect release of fixed K for use by plants during a cropping season.

The moisture changes within soils have a great bearing on the release or fixation of K in soils. Attoe demonstrated release of fixed K by drying several Ohio soils at room temperatures.[2] However, on some of the Ohio soils the reverse took place. The work previously cited by Grewal found that K fixation occurred upon drying in several Punjab soils.[11] Given the great changes in soil moisture conditions in Punjab throughout the year, this factor is of considerable importance. Such importance was demonstrated on Formosa by Su.[38] In that work, exchangeable $K^+$ decreased after the rainy months in light textured soils but increased or remained the same in more heavy textured soils. Although this fact has not been demonstrated in the Punjab it is certainly worth consideration.

The relationship between the degree of soil weathering and K fixation/release has been shown by Pratt on Iowa soils.[23] He found that exchangeable $K^+$ was a poor indicator of K released to a crop where the soils are moderately to strongly weathered. On the other hand exchangeable $K^+$ was a good indicator of K release to crops from less strongly weathered soils. This conclusion is in agreement with the observation that exchangeable $K^+$ is a poor indicator of wheat uptake on the well weathered Punjab soils.

A work which may also have bearing on Punjab soils was published by Reeuwijk and DeVilliers.[25] Their study with synthetic aluminosilica gels showed potassium fixation occurred in varying amounts depending on the nature of the replacing cation. Drying of these gels further increased their capacity to fix potassium. As with many soils, the amount of $K^+$ fixation increased as the pH at which $K^+$ fixation occurred was increased. If significant amounts of amorphous gels in the Punjab soils are subjected to yearly drying, they could be a major factor in potassium behaviour in these soils.

Although the preceeding review does not pretend to be a comprehensive statement of the state of potassium research, two salient points can be made with reference to the Punjab soils studied. The first is that there is still no single method which can quickly and accurately predict how much $K^+$ a crop will extract from any soil. This becomes most pronounced in many soils which are considered to be low in available potassium. The second

noteworthy point is that there are several major factors present in these Punjab soils which could serve to reduce the overall amounts of $K^+$ readily available to plants.

## MATERIALS AND METHODS

### Materials

The soils used were typical of those developed on the Indo-Gangetic flood plain in Punjab. The only major deviation is that the soil types used tended to be light textured, whereas most other agricultural soils in the area contain more clay. These soils are primarily of alluvial origin. The origin of the parent materials is the Siwalik system of hills which is itself a part of the larger Himalyan complex. The Siwalik system was formed 8 to 10 million years BP in the Pliocene and Miocene periods. Most of the soils in the Punjab are formed on materials coming from the middle and lower Siwaliks. The middle Siwaliks are composed primarily of sandstones and shales while the lower Siwaliks consist of pseudo-conglomerates, red shales and grey sandstones. The sandstones are generally felspathic and micaceous with some lower strata containing ferruginous matter. The overall indication is that these sediments came from older, well oxidized terrain.[16] This sediment has been carried into the plains of the Punjab through the Beas and Sutlej rivers.

Apparently there has also been large movements of material by wind action and this still continues to a lesser degree at the

present time. But the source, amounts and qualities of this aeolian deposition remain unknown.

The soils of the Punjab have never been subjected to detailed soil mapping and description, so only generalizations are possible about statewide soil type distributions. However, several attempts have been made at classification into groups based largely on climatic basis and a limited number of profile descriptions. The 7th Approximation orders of Alfisol and Inceptisol cover nearly all types of soils found in the more central regions. The moisture regime is ustic in Gurdaspur and Ludhiana districts thus placing these soils in the Ustalfs of Ustepts.[34]. Other names which correspond to these suborders are Arid Cinnamonic, rouges méditerranéens non lessivés or châtains rouges et bruns rouges subtropicaus, Reddish Brown and Non-calcic Brown.[20] Within Ludhiana district most soils are Ustochrepts with local Ustipsamments. Within Gurdaspur district most soils are Haplustalfs.

Because no detailed soil mapping has been done in these areas of the Punjab, it was necessary to describe and classify the soils at each of the 7 locations used for field plots. The summaries of these descriptions appear in Figures 2 through 8 and their physical, chemical and mineralogical characteristics appear in Tables 2 through 8 in the appendix. These descriptions were correlated with soil series established in the Regional Pilot Project at Patiala.[24]

Because these soil series have not been correlated on a national level, the series names must be considered tentative.

One comment is in order concerning the clay mineralogy of these soils. Behavior of the clay sized fraction of several soil samples during preparation for X-ray diffraction indicated presence of varying amounts of amorphous materials. Upon preliminary flocculation after decantation, some clay samples formed highly cohesive gel-like masses. Variation of salt concentrations did not affect dispersion of these samples. Initial washing with NaOAc to remove any carbonates present also did not change the dispersion status. Treatment with $H_2O_2$ did act to disperse the samples to a limited degree, indicating that organic and/or manganese compounds were involved in the gel-like formation. The persistence of flocculation after $H_2O_2$ treatment in turn indicated the presence of iron related materials in the cohesive samples. The primary objective of the pretreatments was to obtain samples suitable for x-ray diffraction. Therefore, when partial dispersion was achieved after $H_2O_2$ treatment, further treatment by the sodium dithionate-citrate-bicarbonate method was not done. This avoided possible further alteration of the clays due to the treatments.

Inspection of the CEC data shows inconsistencies that can most probably be attributed to the presence of significant amounts of amorphous materials. The most obvious example is seen in the C2 horizon of the Birk soil. This has a CEC of 92.6 me/100 gms. But the

clay fraction consists largely of Illite with some Vermiculite. Based on these percentages, a calculated CEC is less than 5 me/100 gms. Even assuming some active exchange occurring within the silt fraction, only a small part of this large CEC can be attributed to crystalline clay minerals. The only conclusion now possible is that noncrystalline clay minerals are present in these soils, normally in larger quantities in subsurface horizons and in certain cases contribute a large portion of the active CEC of these horizons. Further investigations on the causes of these CEC discrepencies are planned.

The crop used for field plots was wheat (Triticum aestivum) variety Kalyan 227 (Fig. 16). This variety was developed in Punjab and Uttar Predesh from the cross Penjamo sib x Gabo 55. This is nearly identical to Sieto Cerros 66 used in Mexico and the Mexipak 65 variety in Pakistan. It is a two gene dwarf with medium maturity, amber grain, profuse tillering and high yield potential.[9] Plant height is around 90 cm with thick straw and broad erect leaves. It responds well to heavy fertilization and is resistant to the common rusts and loose smut. It is considered to be an adaptable variety, suitable for early and late planting and varying fertility levels. Average yield of this variety under favorable conditions in the Punjab is 4400 kg/hectare.[22]

Field plots were irrigated using the water source normally available to the farmer. In 6 locations this was ground water pumped from a "tube well." In one location a dug well was the irrigation water source.

Fertilizers used were obtained through local commercial outlets. These were Calcium Ammonium Nitrate (25% N), Ammonium Sulfate (20.5% N), Single Superphosphate (16% $P_2O_5$) and Muriate of Potash (60% $K_2O$). The Calcium Ammonium Nitrate and Superphosphate were granulated.

Methods - Laboratory Studies

Laboratory analyses were performed on soil, irrigation water, plant and grain samples.

Prior to site selection, surface (0-15 cm) soil samples were taken from fields on 11 different farms in Gurdaspur and Ludhiana districts. These districts were chosen because of their participation in the Intensive Agriculture Development Program and because certain farms within these districts were known to have low potassium soils. Samples were air dried, ground to pass a 2mm seive and stored in plastic jars. These samples were then randomized and extracted with 1N Ammonium acetate. The extracts were analyzed for $K^+$ and $Ca^{++}$ by flame photometry. The results of this set of analysis was used to help select plot locations.

A second set of soil samples were taken from the actual plot areas one day prior to planting. From each plot four, three sample composites were taken from the surface (0-15 cm) and subsurface (15-30 cm). In addition a profile description was made in a border area of the field and samples were taken from each horizon delineated. These samples were then air dried at 40°C and

crushed to pass a 2mm sieve. They were stored and randomized in plastic jars.

The first extraction of the samples was made with 1N neutral ammonium acetate. Ten grams of each sample was mixed with 12.5 ml of ammonium acetate, shaken at ten minute intervals, and after 30 minutes the supernatant was decanted through Whatman No. 1 filter paper and collected in a 50 ml volumetric flask. The extraction was repeated 3 more times to ensure removal of adsorbed cations. Strontium was added (1500 ppm) to suppress interfering ions during analysis.[8] Sodium hexametaphosphate was added (0.1 ml of 1% solution) to retard calcium precipitation in the extracts. Formaldehyde was also added (0.1 ml of 10% solution) to retard fungus growth. Finally the entire extract mixture was made up to 50.0 ml. These extracts were then analyzed for $K^+$, $Ca^{++}$, and $Mg^{++}$ using atomic absorption spectroscopy.

A second set of extractions was performed using 1N sodium acetate adjusted to pH 8 as the extractant. This particular extractant was chosen because its pH was thought to be close to the natural pH of the soils under study. The extraction and analysis procedure was the same as described in the preceeding paragraph except that Mg analysis was not performed.

To estimate the release of K from non-exchangeable forms during cropping, the soil samples were extracted using cold sulfuric acid.[14] This procedure involved extracting 10.0 gms soil with 25 ml distilled water plus 10.0 ml concentrated sulfuric acid for 30 minutes. The acid-soil mixture was then diluted with 25 ml distilled

water and the extract filtered into a 100 ml volumetric flask. The soil was washed with 15 ml portions of 0.1 N sulfuric acid to make the extract up to 100.0 ml. This was then analyzed using atomic absorption spectroscopy. Analysis of irrigation water samples was performed by atomic absorption spectroscopy. The water samples were taken from each location during an irrigation in February. These were analyzed for $K^+$, $Ca^{++}$, and $Na^+$.

Whole plant samples were taken at two times during the season. Green plant samples were taken from three locations in Gurdaspur district on 10 February, 1972. This was approximately 85 days after planting and before head formation had become evident. Each sample consisted of 10-15 plants taken from three areas within a plot. These samples were then dried 24 hours at 60°C and stored. The upper one-third of the plant was later cut off and ground for analysis.

At harvest, plant samples were again taken in a similar manner from all plots. This was done for two reasons. All previous plant analysis of this nature at P.A.U. had been done using harvest age plant samples and it was desired to be able to relate the results of this study to previous work done at the university. Secondly, the harvest age plant samples provided a relatively good sample of mature grain for use in grain weight determinations. After collection the heads were removed and the entire stalk and leaves ground.

Because complete plant analysis facilities were not available

at P.A.U. at that time, selected samples were sent to the OARDC Plant Analysis Laboratory at Wooster, Ohio. The green plant samples from Kaunta and Waraich, and the harvest plant samples from Mundian Khurd and Waraich were chosen. Inclusion of the detailed results of this analysis would be of little value for the purposes of this thesis. Where statistically significant, K, Ca and Mg plant analysis results for certain treatments are discussed in the section concerning results. Other elements for which analysis was performed were P, Na, Si, Mn, Fe, Bo, Cu, Zn, Al, Sr, Ba, and Mo.

Grain samples from Waraich and Mundian Khurd locations were used to determine 100 grain weights. The heads from each plot were hand threshed and cleaned. The grains were then subdivided so as to yield approximately 150-200 grains. After weighing, the exact number of grains were counted and the weight per 100 grains calculated.

Methods - Field Studies

The seven field plot locations are shown in Figures 9 and 10. They were located on fields in which wheat was a normal part of the cropping sequence. The management ability of the farmer was also an important consideration.

In the layout and execution of the field plot phase of this work, five variables were considered. These were, in order of priority: (1) rate of potash applied, (2) split versus whole

Figure 9. Map of Gurdaspur Locations.

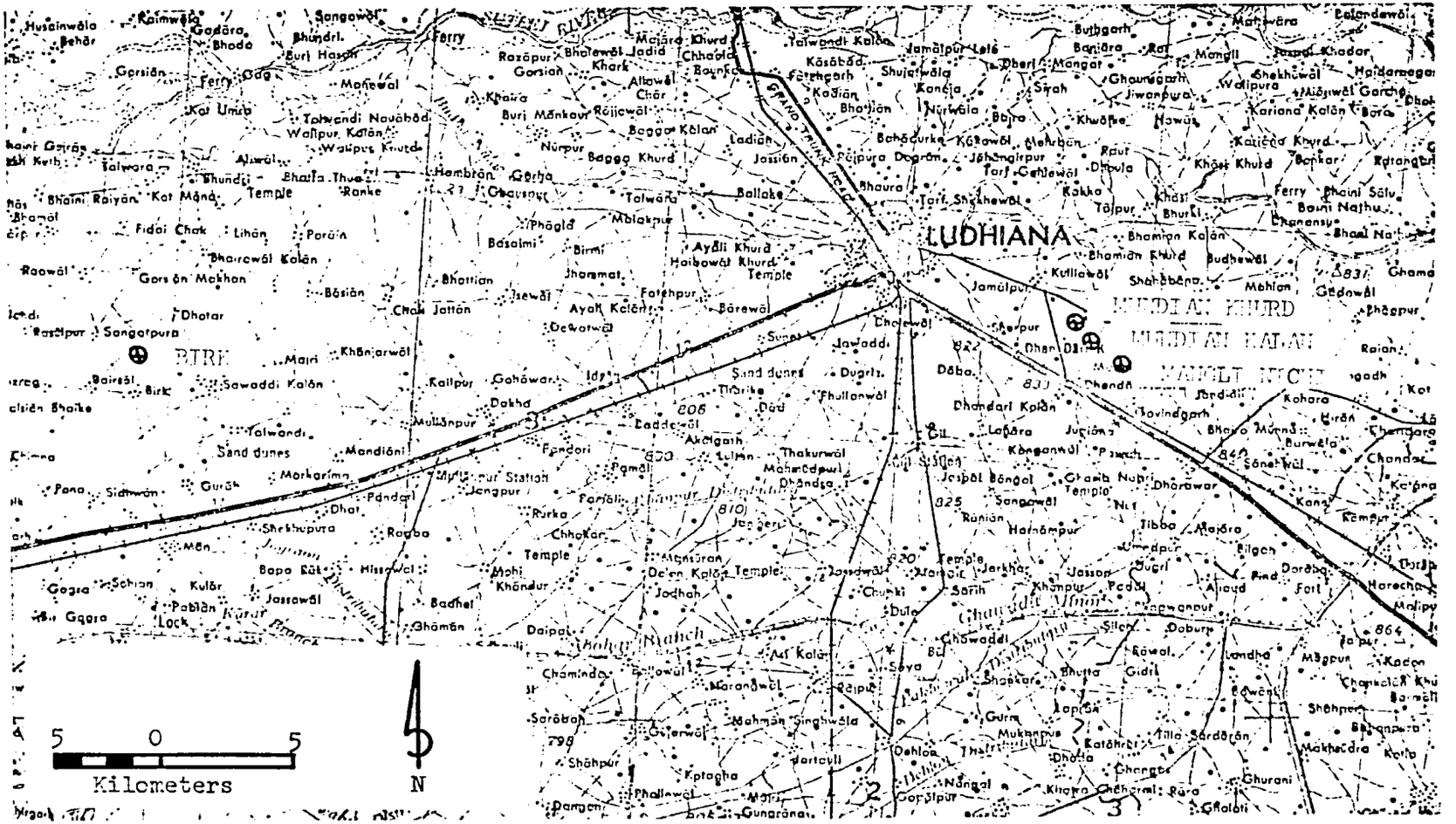



Figure 10. Map of Ludhiana Locations.

application of higher rates of potash fertilizer, (3) band versus broadcast application of fertilizer, (4) calcium ammonium nitrate (CAN) versus ammonium sulfate (A/S) as the source of nitrogen and (5) location effects. The selection of relatively high potash rates was based on the premise that some temporary saturation of the fixation capacity might be achieved by higher rates. Also, higher rates of K would assist in overcoming any Ca-Mg antagonism occurring. Split applications were an attempt to reduce overall fixation of potassium by introduction of potassium during active plant growth. Use of banding was intended to emphasize or amplify these 'immobility of K' effects, if any. Ammonium sulfate was used as a means of estimating the effect of the Ca addition in CAN. Location parameters considered were primarily ammonium acetate exchangeable $K^+$ and $Ca^{++}$ determined in the preliminary laboratory analysis.

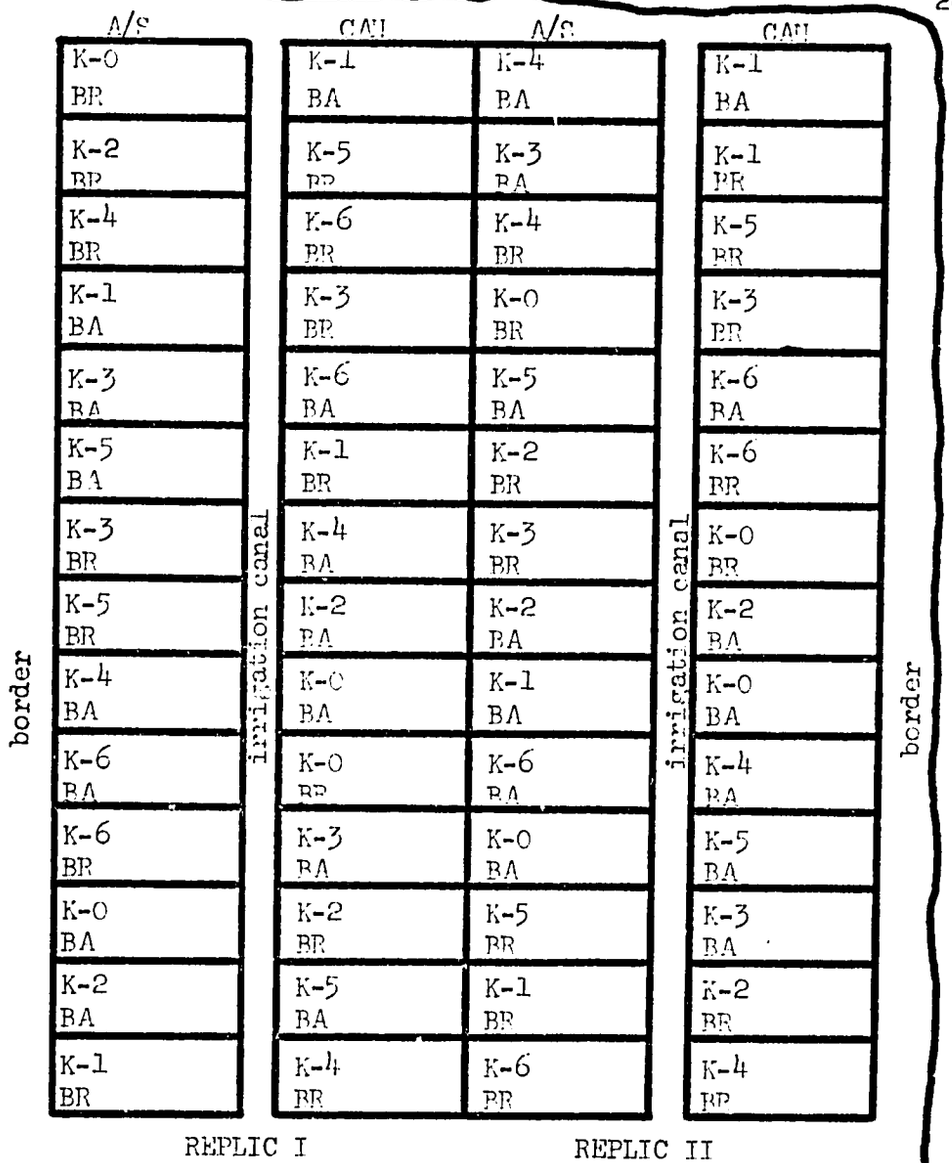
The basic experiment design was that of a split block. The basic split was between CAN and A/S arranged in columns. Potash and band-broadcast treatments were randomized within the columns. This results in greater degrees of freedom for estimation of effects of potassium and band-broadcast treatments. The breakdown of the degrees of freedom for the effects evaluated are shown in Tables 13 through 18. One of the drawbacks to this use of Dr. Harvey's 126 K program was that it was not possible to separate out the CAN-A/S x REPS x LOCATION interaction. This is the most proper error term for use in comparisons involving these three factors.

Because of the structure of the computer program, it was possible to separate only an error term which combined BR-BA 3 and 4 factor interactions and the CAN-A/S x REPS x LOCATION interaction. The error term including BR-BA interactions was used to evaluate LOCATION, REPS, CAN-A/S and BR-BA effects. In order to evaluate the effect of using this error term, f values were calculated for all Br-Ba and K-RATE 2 factor interactions using two error terms. In the first case the entire error SS was transferred to the K effects error SS and f values calculated and evaluated against this mean square. This tested the extreme case in which the CAN-A/S x REPS x LOCATION SS is assumed to be zero. In the second case it was assumed that all BR-BA 3 and 4 factor interaction SS were zero. Therefore, only the appropriate degrees of freedom were shifted to the K effect error term and the f values were calculated using this new error mean square. In reality, the true condition can be assumed to lie between these two extremes. As expected, the actual f values changed, but the most important item, significance or nonsignificance at the 5% and 1% levels, remained unchanged for the GRAIN, 100-GRAIN WEIGHT, K ANAL, Ca ANAL and Mg ANAL comparisons. The STRAW analysis of variance showed a shift from 5% to 1% significance level for the BR-BA comparison. Also the LOCATION x K-RATE interaction became significant by a small margin when all BR-BA interaction SS were assumed to be zero. Therefore it may be assumed that the conclusions of the ANOVA are not affected by use of either error term.

The remaining question of how this affects the CAN-A/S comparison is answered by reference to the standard error terms for the CAN-A/S comparison. In order for these two means to be significantly different at the 5% level it would be necessary for the means to differ by more than 2 standard deviations. This occurrs for STRAW, 100 GRAIN, K ANAL, Ca ANAL and Mg ANAL comparisons. It does not occur for the GRAIN comparison. Since the error term for this comparison is most likely smaller than the one used for this comparison, it is also more likely that the f values will be greater than those calculated with the resulting increased significance of the results. This would alter conclusions for only three items; STRAW, 100 GRAIN and K ANAL. Comment on these three comparisons has been omitted.

On 6 locations two replications were made. On the Shri Hargobindpur site only one replication was possible because of the small size of the field provided. A drawing of the field layout at Mangli Nichi is shown in Figure 26 to illustrate the general layout used.

The rates of potash applied were multiples of the recommended rate of 20 kg Muriate of potash/acre (30 kg $K_2O$/ha). The five rates applied were 0, 52.2, 104.2, 208.4 and 312.6 kg muriate of potash per hectare. The 208.4 and 312.6 kg/ha rates were applied both whole and split with the second application at 3 weeks after planting. Broadcasting of fertilizers was done immediately prior to




K-0, K-1, K-2, K-3, K-5: consecutive K rates
K-4, K-6: split applications of K rates K-3 and K-5
BR: fertilizer broadcast at planting
BA: fertilizer banded at planting
A/S: ammonium sulfate
CAN: calcium ammonium nitrate

Figure 26. Field Layout of Plots at Mangli Nichi.

seeding. Banding was done by means of a local adaptation to the plow (phora) as shown in Figure 11. While this equipment is useful for sowing seed in lines, it was not originally intended to be used for fertilizer placement. Because of this and other variables such as quality of seedbed preparation and operator skill, the actual placement of the seed and fertilizer varied. In most plots the fertilizer was at least one inch below and slightly to one side of the seed. But in some plots the seed and fertilizer were much closer and caused a noticeable reduction in germination and yield. The two nitrogen sources, CAN and A/S were applied at the recommended rate of 50 kg N/ac (123.5 kg N/ha). Phosphorus was applied at the recommended rate of 155 kg single superphosphate per acre (61.8 kg $P_2O_5$/ha). All of the phosphate, all of the potash (except when split as noted above) and one-half of the nitrogenous fertilizers were applied at planting. The remaining one-half of the nitrogen and potassium fertilizers were broadcast three weeks after planting, prior to the first irrigation. All plots were 50 square meters in area. The seed rate used was 32 kg/ac (80 kg/ha). Actual planting was done between 2 November and 18 November, 1971.

All seedbed preparation and planting were done using local equipment and techniques. The type of equipment and procedures used are illustrated in Figures 12 through 14.

After planting, the farmer was responsible for management of the plots and supervised operations such as irrigation and weeding.

Periodic inspections were made of the plots and significant observations were recorded. An interesting contrast between non-fertilized wheat and that grown in the plots is shown in Figure 15 as it appeared in January, 1972. The yield of the non-experimental wheat seen in the foreground was approximately one-half of the zero K plots at the same location.

Harvesting of the plots was started on 20 April and completed on 27 April. All cutting was done by hand. The wheat was then bundled and tagged and weighed as shown in Figures 17 and 18. Threshing of the dried wheat was started on 5 May and completed on 20 May. Initially both mechanized and hand threshing methods were used. But it soon became evident that use of the machine thresher involved greater labor and loss of grain. As a result, hand labor was used wherever possible. The total weight of cleaned grain from each plot was recorded. Threshing operations are shown in Figures 19 and 20.

Figure 11. Banding Attachment (Phora).

Figure 12. Field Equipment Used for Planting.

Figure 13. Planting

Figure 14. Planking (Sohaga) After Planting.

Figure 15. Birk Plots in January, 1972.

Figure 16. KALYAN 227 Wheat Variety.

Figure 17. Harvesting Individual Plots.

Figure 18. Recording Grain and Straw Weight.

Figure 19. Threshing by Hand.

Figure 20. Threshing with Mechanical Thresher.

## RESULTS AND DISCUSSION

The results of the ammonium acetate, sodium acetate and sulfuric acid extractions are summarized in Tables 10 and 11. The data for the profile samples is included in Tables 2-8 in the Appendix. The results of the water analyses are given in Table 9 which follows.

TABLE 9

ANALYSIS OF IRRIGATION WATER

| Location | pH | K ppm | Na ppm | Ca ppm |
|---|---|---|---|---|
| Mangli Nichi | 7.6 | 4.7 | 6.1 | 29.5 |
| Birk | 7.6 | 7.2 | 11.4 | 20.5 |
| Mundian Khurd | 7.6 | 5.2 | 12.4 | 27.0 |
| Mundian Kalan | 7.3 | 5.0 | 15.0 | 28.8 |
| Kaunta | 7.3 | 1.5 | 9.3 | 18.8 |
| Waraich | 7.6 | 2.8 | 37.0 | 49.5 |
| Shri Hargobindpur | 7.6 | 5.3 | 12.3 | 41.0 |

### Discussion of Grain Yield Results

The mean grain yield versus rates of potash application are shown in Figure 21. The response continues to increase until

TABLE 10

SUMMARY OF EXTRACTION DATA - SURFACE 0-15 cm

me./100gm

| Location | AmAc K | NaAc $K^+$ | AmAc $Ca^{++}$ | NaAc $Ca^{++}$ | AmAc $Mg^{++}$ | Sulf $K^+$ |
|---|---|---|---|---|---|---|
| Mangli Nichi | 0.068 | 0.12 | 2.55 | 1.34 | 0.32 | 1.58 |
| Birk | 0.074 | 0.10 | 3.03 | 1.35 | 0.23 | 1.98 |
| Mundian Khurd | 0.082 | 0.10 | 2.90 | 1.22 | 0.37 | 2.06 |
| Mundian Kalan | 0.055 | 0.08 | 2.83 | 1.15 | 0.18 | 1.87 |
| Kaunta | 0.071 | 0.08 | 4.68 | 2.61 | 0.54 | 1.65 |
| Waraich | 0.153 | 0.17 | 3.68 | 1.70 | 0.41 | 3.08 |
| Shri Hargobindpur | 0.117 | 0.12 | 6.55 | 3.24 | 0.54 | 3.98 |

AmAc = Ammonium acetate extract
NaAc = Sodium acetate extract
Sulf = Sulfuric acid extract

TABLE 11

SUMMARY OF EXTRACTION DATA - SUBSURFACE 15-30 cm

me/100gm.

| Location | AmAc $K^+$ | NaAc $K^+$ | AmAc $Ca^{++}$ | NaAc $Ca^{++}$ | AmAc $Mg^{++}$ | Sulf $K^+$ |
|---|---|---|---|---|---|---|
| Mangli Nichi | 0.068 | 0.08 | 3.28 | 1.40 | 0.40 | 2.77 |
| Birk | 0.068 | 0.07 | 6.53 | 2.79 | 0.22 | 3.54 |
| Mundian Khurd | 0.087 | 0.09 | 6.70 | 3.66 | 0.60 | 3.98 |
| Mundian Kalan | 0.081 | 0.08 | 6.45 | 3.15 | 0.30 | 3.10 |
| Kaunta | 0.065 | 0.08 | 4.48 | 2.61 | 0.52 | 1.78 |
| Waraich | 0.125 | 0.12 | 5.53 | 2.72 | 0.66 | 3.99 |
| Shri Hargobindpur | 0.104 | 0.10 | 7.30 | 3.90 | 0.71 | 4.57 |

AmAc = Ammonium acetate extract
NaAc = Sodium acetate extract
Sulf = Sulfuric acid extract

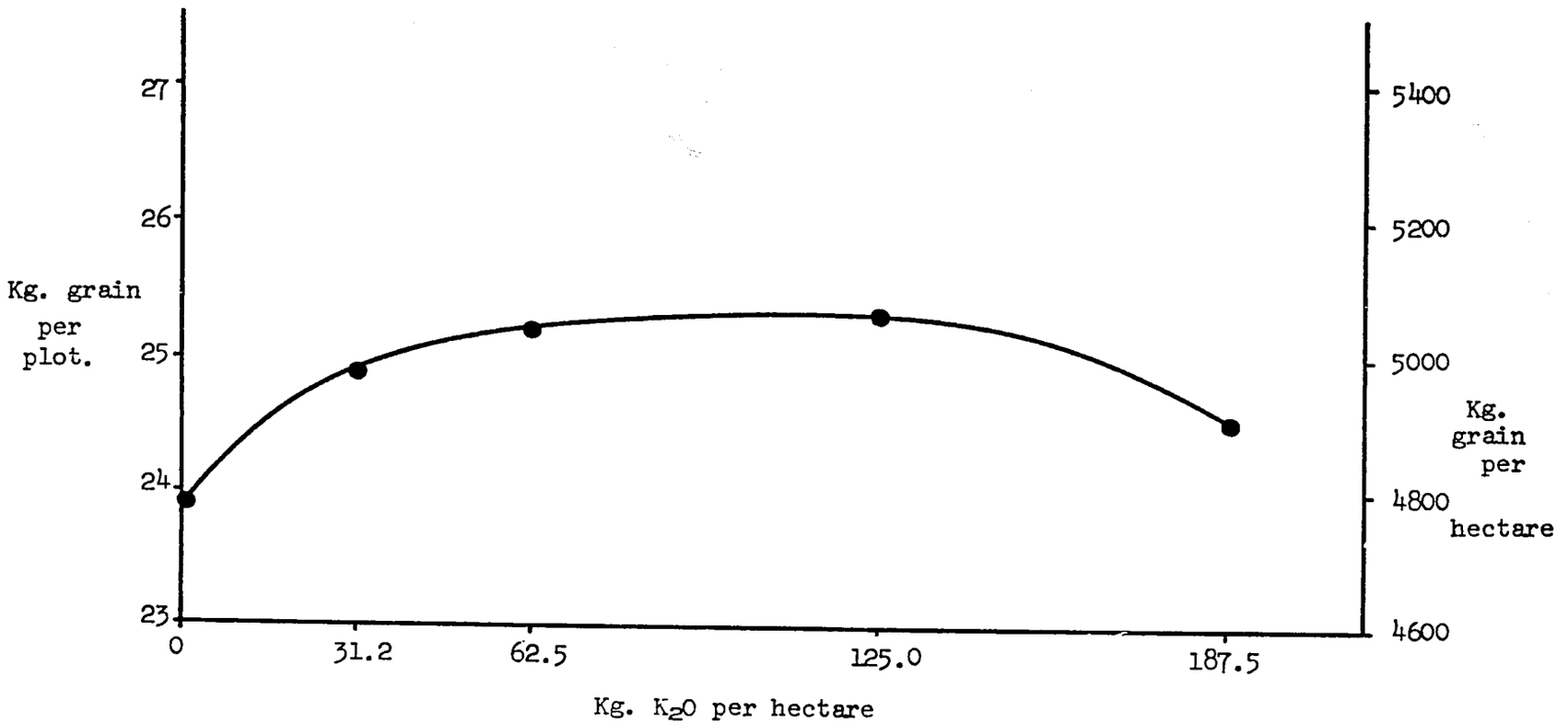



Figure 21. Mean grain yield versus K applications for all locations.

TABLE 12

SIGNIFICANT f VALUES FROM ANALYSIS OF VARIANCE

| Variable | 6 locations | | | Plant analysis | | |
|---|---|---|---|---|---|---|
| | Grain yield | Straw weight | 100 grain wt. | K anal. | Ca anal. | Mg anal. |
| LOCATION | ** | ** | ** | * | | |
| REPS | | | | * | ** | * |
| CAN-A/S | | | | | * | * |
| BR-BA | ** | * | | | * | |
| LOCATION x REPS | ** | * | | | | |
| LOCATION x CAN-A/S | ** | ** | | * | | |
| LOCATION x BR-BA | ** | ** | | | | |
| REPS x CAN-A/S | ** | | | | | |
| REPS x BR-BA | | | | | | |
| CAN-A/S x BR-BA | | | | | | |
| K-RATE | ** | ** | * | ** | ** | ** |
| LOCATION x K-RATE | | | * | | | * |
| BR-BA x K-RATE | | | | | | |
| CAN-A/S x K-RATE | | | | | | |
| REPS x K-RATE | | | | | | |
| % Coeff. of variance | 5.9 | 6.9 | 8.6 | 16.8 | 14.2 | 13.6 |

Significance levels: ** 1% level
* 5% level

Coeff. of variance is based on total error remaining after reduction by the above analysis of variance.

KEY: LOCATION = all variables due to location differences
REPS = replication differences
CAN = calcium ammonium nitrate as N source
A/S = ammonium sulfate as N source
BR = broadcast fertilizer application
BA = band fertilizer application
K-RATE = rates of application of fertilizer

125 kg $K_2O$/ha is reached. After this point added K serves to depress yield showing the almost classic fertilizer-plant response curve. This clearly shows a response to the first increment of applied potash but nonsignificant yield responses thereafter. It should be noted that split applications tended to show slight increases over whole applications of potash but these were significant at only the highest rate of K application. In this case the whole application was significantly lower than the other three treatments. This same treatment was also significantly different from all other K rates except zero K when evaluated by Duncan's Multiple Range test. Therefore, in the final statistical analysis the effects of split application were not separated. The trend of the yield increases does suggest that further work may be worthwhile in evaluating split application of lower rates of potash on these soils. However, in this work, the effect of split application seems largely to have been mitigation of the effects of higher rates of K application.

The results of the overall statistical analysis are shown in Table 12. The analysis of variance was performed by the least-squares method using the 126 K model program written by Dr. W. R. Harvey.[13] For this analysis all data from Shri Hargobindpur was ignored due to irregularities in part of the data and the presence of only one replication. Therefore, the final analysis of variance is strictly applicable only to the remaining 6 locations. Even with this small

limitation, the significance of the yield increase shown in Figure 21 is born out by the significant f value for K-RATE. This increase seems to be clearly due to application of the recommended rate of potash. The other K-RATE interaction values are not significant for the grain yield data and would seem to refute the premise that banding would affect plant response to potash. Also the lack of significance for the CAN-A/S x K-RATE interaction indicates no effect on K nutrition from the Ca present in CAN. Perhaps most surprising is the lack of a significant LOCATION x K-RATE interaction. This indicates that within the range of exchangeable K tested, the response to fertilizer K was identical. That is, the crop responded in a similar manner whether the original K supply was especially low or barely within the upper limits set for low potassium soils. Therefore, it may be assumed that within the limits examined, wheat will respond to application of potash but differences in exchangeable $K^+$ are not of major importance. Part of the reason for this can be seen in the $H_2SO_4$ extraction data shown in Table 10. These soils all have a very large reserve of K which is subject to release during a cropping cycle. It is probable that the actual amount of K which this reserve contributes to the K uptake of the plant is only a small fraction. But a release of only 2-3% of this fraction would be sufficient to provide adequate $K^+$ for the wheat crop.

In consideration of these facts, it may be assumed that a

minimal application of potash will result in a significant grain yield increase for wheat on these soils.

Most of the other treatments showed significant f values for grain yield data. The differences between locations were quite large and only two locations, Birk and Waraich, were statistically similar. But little can be concluded from this since location effects include a large number of uncontrollable factors, the largest and most important being the management level of the farmer involved. The LOCATION x BR-BA interaction was significant largely due to the effects of those plots where the fertilizer placement was poor. Although overall band yields were higher, in these cases the banded plots had lower yields than the broadcast and gave rise to the significant f value.

The significant LOCATION x CAN-A/S interaction was again a side effect of the banding. One location in particular, Birk, had very poor placement on the banded plots. Because ammonium sulfate is more soluble than CAN, it resulted in a greater reduction in germination. This was evident when the plots were observed at three weeks after planting. The same situation was further affected by severe water stress on the crop during the first part of the growing season. At the remaining five locations the differences between CAN and A/S were not significant. When the CAN-A/S comparison is made overall, there is no significant deviation from the mean although the conditions at Birk caused an increase in this

f value. On these soils it may be concluded that there were no differences between CAN and A/S as a nitrogen source.

The significant BR-BA comparison showed the better yields due to banding in spite of the poor placement on some plots. The average increase in grain yield due to banding was 67.6 kg per hectare.

Discussion of Straw Yield Results

Significant effects for the straw weight at cutting were caused by factors similar to those discussed for the total grain yield. One notable exception occurred in the response pattern of straw weight to rates of K application. Where grain yield tended to conform to a quadratic response curve, the straw yield followed a more flattened response curve. This is shown in Figure 22.

Discussion of 100 Grain Weight Results

During threshing operations it was noted that the grains were noticeably more plump and well filled than the grain in surrounding fields. This was substantiated by the analysis of 100 grain weights from Mundian Khurd and Waraich. The mean 100 grain weight for Mundian Khurd was 3.057 gms. and for Waraich was 2.781 gms. The overall K response curve was similar to the overall grain yield and is not shown here. The significant increase in grain weight occurred between the weight of 2.72 gms/100 grains at 0K rate and the 31.2 kg/ha application rate with a weight of 2.98 gms/100 grains.

The significant LOCATION x K-RATE interaction was a result of

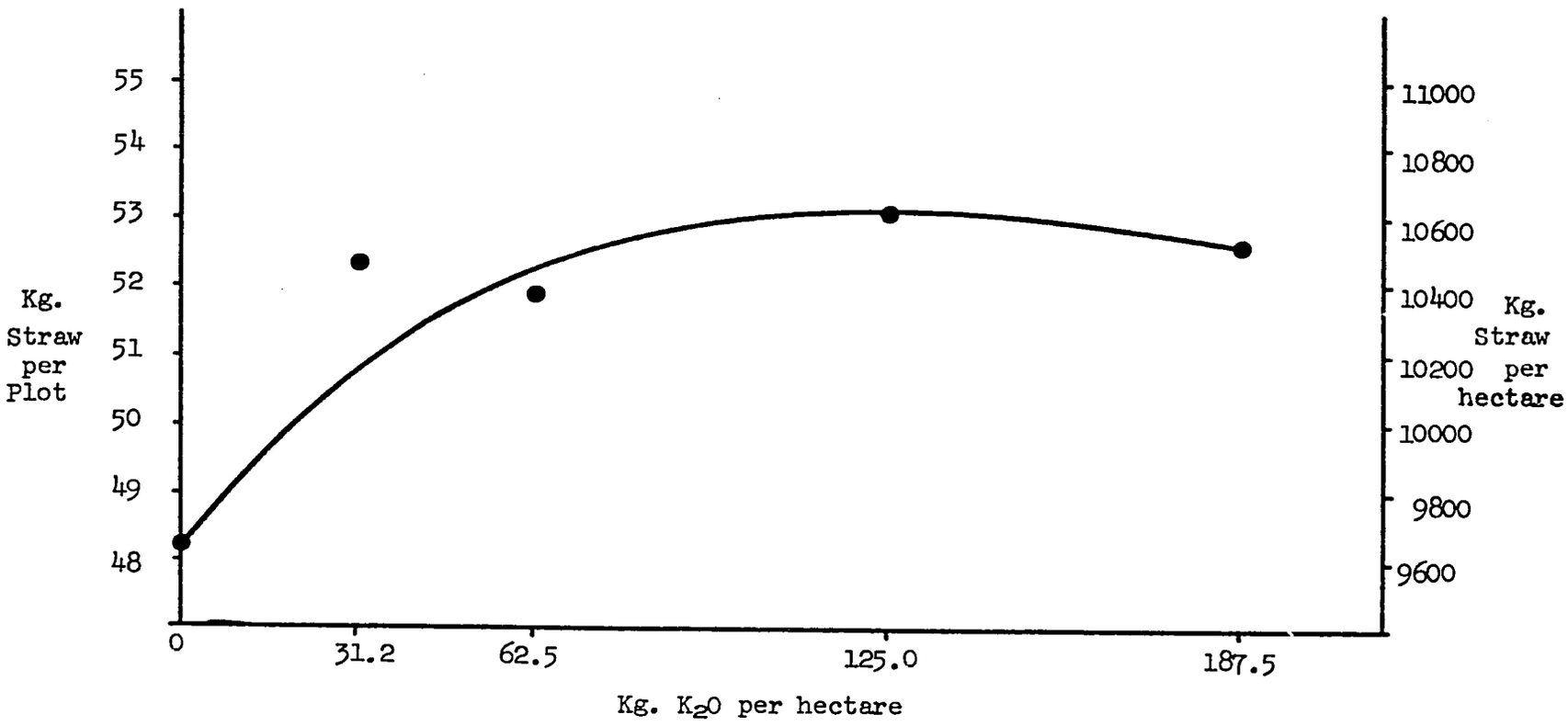



Figure 22. Mean straw yield versus K applications for all locations.

different response patterns between Waraich and Mundian Khurd. The 100 grain weight at Waraich rose slightly with initial K application but then dropped and even went below the 0 K level at one point. In contrast, the weights for Mundian Khurd rose with K applica ion and tended to maintain a higher 100 grain weight with higher rates of K application. The only explanation seems to be a possible micronutrient deficiency at Waraich. The level of Zn in the plants was low, but not deficient, and the increased plant vigor due to application of K could have brought on a near deficiency condition. A more satisfactory explanation is not available.

Discussion of Plant Analysis Results

As mentioned previously, the detailed results of the plant analyses have not been included. Using guidelines developed for use on Ohio wheat plant samples taken before heading, no deficiencies or toxic levels of elements were observed. The results of the plant analysis show a definite increase in K uptake with a corresponding decrease in Ca+Mg uptake for changes in K rate. These trends are shown in Figure 23. As expected, K uptake shows the effect of "luxury consumption". The corresponding decrease in Ca+Mg uptake is also as expected. Thus it seems confirmed that the large amount of Ca+Mg did not interfere significantly with K uptake.

This increased K uptake occurred in spite of increased Ca and Mg uptake from CAN. As theorized, the use of CAN introduced

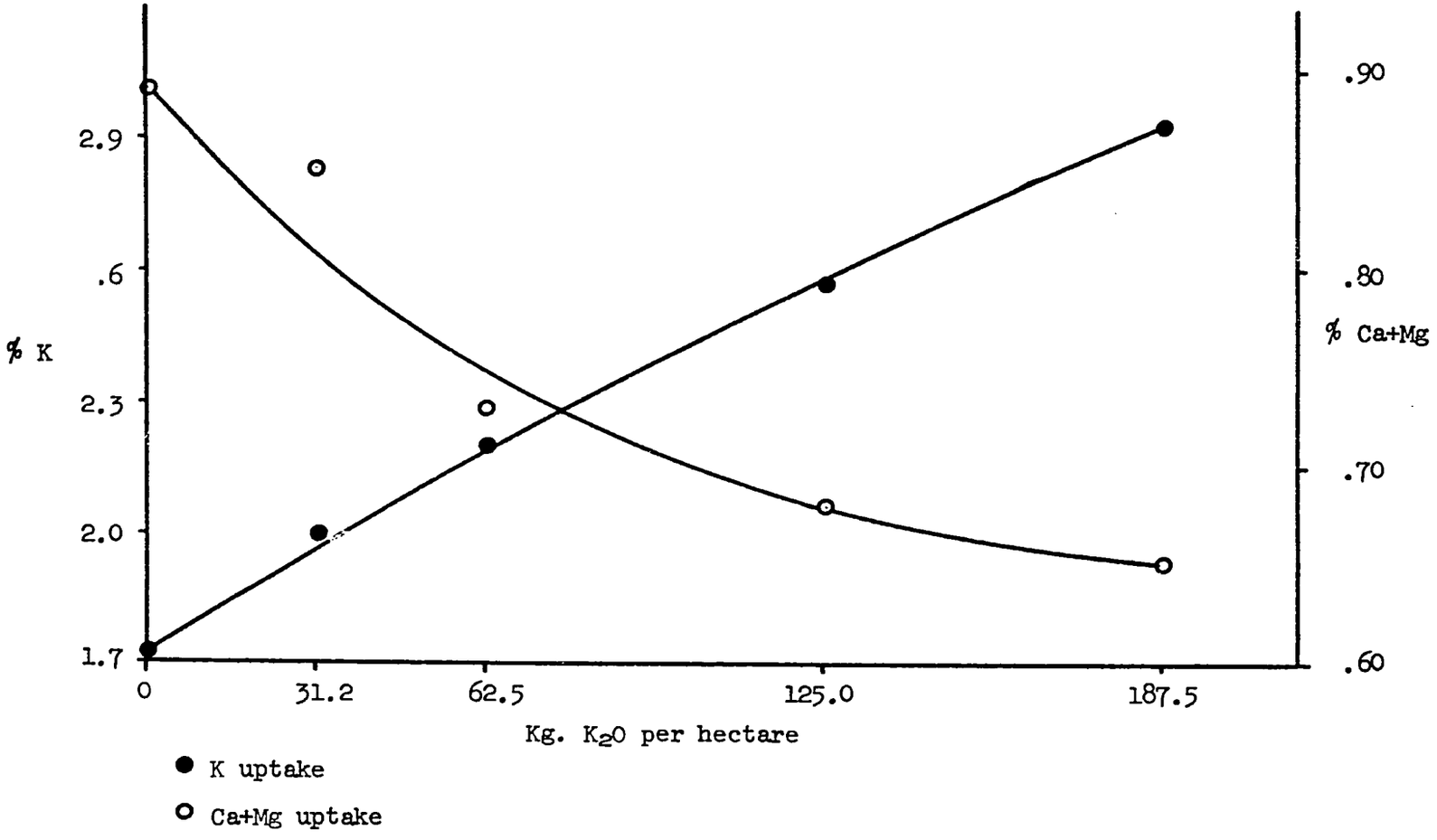



Figure 23. K and Ca+Mg uptake versus K applications.

additional Ca into the soil and plant system. This was indicated by the significant CAN-A/S value for the Ca and Mg analyses. In this case the mean percent Ca for the CAN treatment was 0.50 and for A/S 0.47. For the Mg analysis the figures were CAN; 0.25% Mg and A/S; 0.23% Mg uptake. Clearly the use of CAN resulted in somewhat greater plant uptake of Ca and Mg. But as can be seen from Figure 23, this uptake was more than offset by the reduction caused by additional K coming into the plant system. It can be concluded that use of CAN does provide slightly more Ca and Mg for plant uptake but this had little or no significant effect on K uptake or on grain and straw yields of wheat on these soils.

The significant BR-BA comparison for Ca analysis showed that the total mean percent Ca under broadcast was 2.42% versus 2.37% for banded plots. Because this includes the results from only 2 locations it is possible that poor banding on one location caused bias in the results but no completely satisfactory answer is available.

Several conclusions may be drawn from the preceeding discussion of the data. The first is that there was a definite increase in grain yield, straw yield and individual grain weight resulting from application of potash. But there was no significant increase in yield or grain weight above 31.2 kg $K_2O$ per hectare and the yields tended to decrease with application of additional potash. Split application of potash at high rates had little effect

other than causing a reduction in the negative response at high rates of $K_2O$. Banding the fertilizers below the seed at planting also served to increase both grain and straw yields. The skill of the farmer is, however, of prime importance in this operation. Banding had no effect on the response of wheat to the potash fertilizer. Use of CAN instead of A/S did result in increased plant uptake of Ca and Mg but this had no observable effect on yield. The level of soil exchangeable $K^+$ did not appear to affect the response to fertilizer K.

Comparison with Other Research Done at PAU

Only one item has been omitted up until this point. Much of the previous work at PAU indicated that there was no response to application of potash on low exchangeable $K^+$ soils. These experiments were also conducted under similar farmer supervision as this one and covered a period of several years. Why then did they not show a similar increase? An understanding of the overall situation tends to answer this question. The previous field experiments had all been conducted for the purpose of observing the rather large responses which occur by N or P fertilization. Because these nutrients involve 100-150% yield increases, any differences as small as 4% are relatively unimportant. In fact, if the experimental conditions are not favorable, the error becomes sufficiently great so as to make even a 10 or 20% deviation from the mean insignificant. These two factors, apart from any innate soil properties, may have

served to mask the actual response to potash fertilization of wheat in the past. Undoubtedly, the large amount of easily released "fixed K" in the local soils prevented any obvious K deficiency symptoms from appearing in crops.

Economic Factors

One of the first very legitimate questions to arise concerning the foregoing results concerns their economic and practical applicability. Because of India's present emphasis on an immediate increase in food production, there is little encouragement for research that does not directly contribute to increasing total food production. Given this background, an evaluation of related economic data was performed.

Because much basic economic data is not available concerning farming operations, certain assumptions were made. The most important was that use of potash entailed no extra expenditure other than the actual cost of the fertilizer.

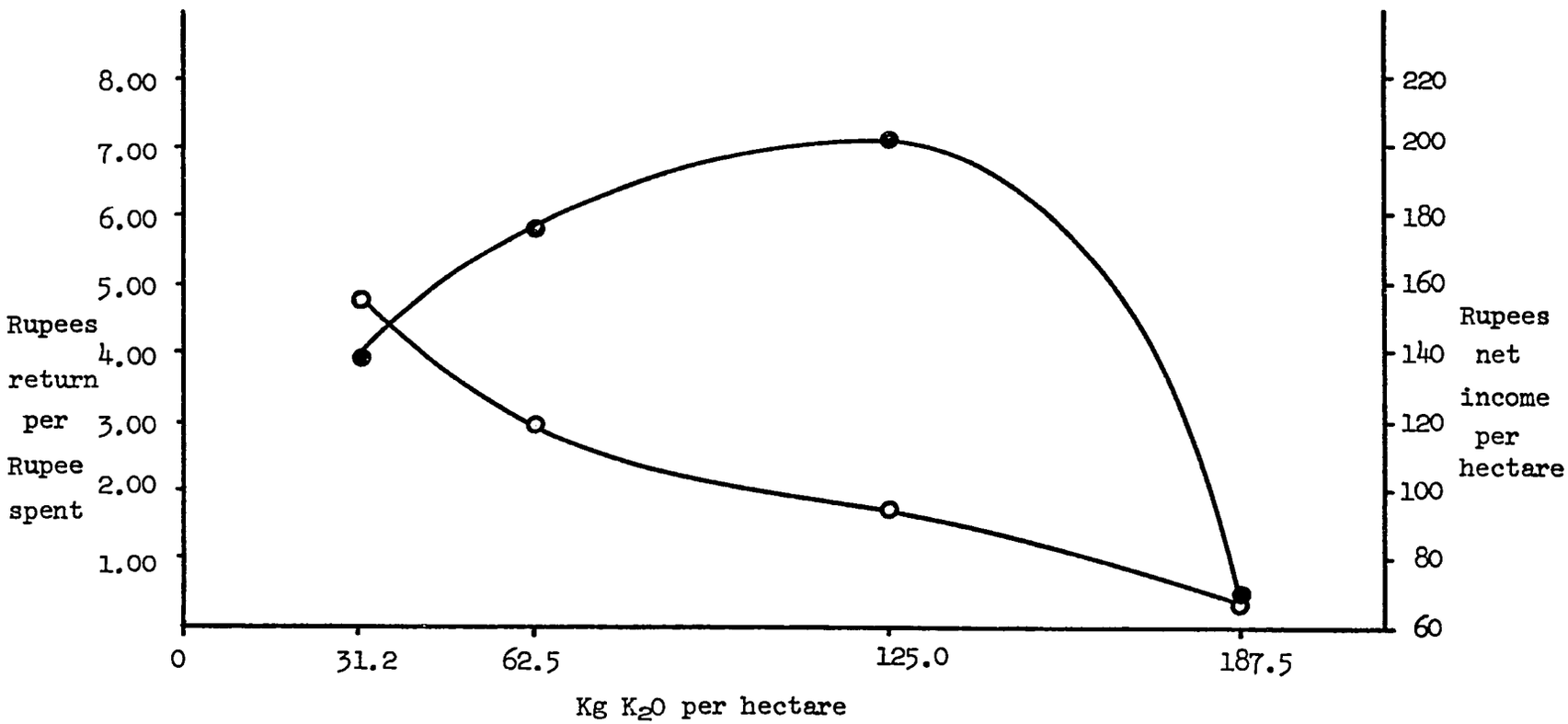
Wheat and fertilizer rates are fixed by government order and these rates are used in the following calculations. With muriate of potash selling at Rs 56.70 per 100 kg. and Kalyan 227 wheat being bought at Rs 76.00 per 100 kg., the problem becomes one of a single cost versus returns. The relationship for grain yield is shown in Figure 24. Clearly the income increases until the 125 kg $K_2O$/ha level is reached. After this point it is less profitable to add K. However, an additional factor needs to be considered. To permit

proper consideration of these results it is necessary to calculate the more meaningful relationship of Rupees spent versus Rupees returned. This is also shown in Figure 24. The greatest return on investment occurs at the minimum K rate and decreases until a negative return occurs at the maximum K rate.

In addition, straw yield should be mentioned. In Punjab, as in other parts of India, straw has significant value and must be considered as part of the crop income. Because of this the return on investment has been calculated as for the grain. However, because wheat bhusa (chopped wheat straw) has a value of only Rs 2.50 per 100 kg, the return per rupee invested is below 1.00 for all rates of K application. Therefore, K fertilization for the sole purpose of increasing straw yield is not economically feasible.

When both straw and grain incomes are combined the net income and net return on investment are as shown in Figure 25.

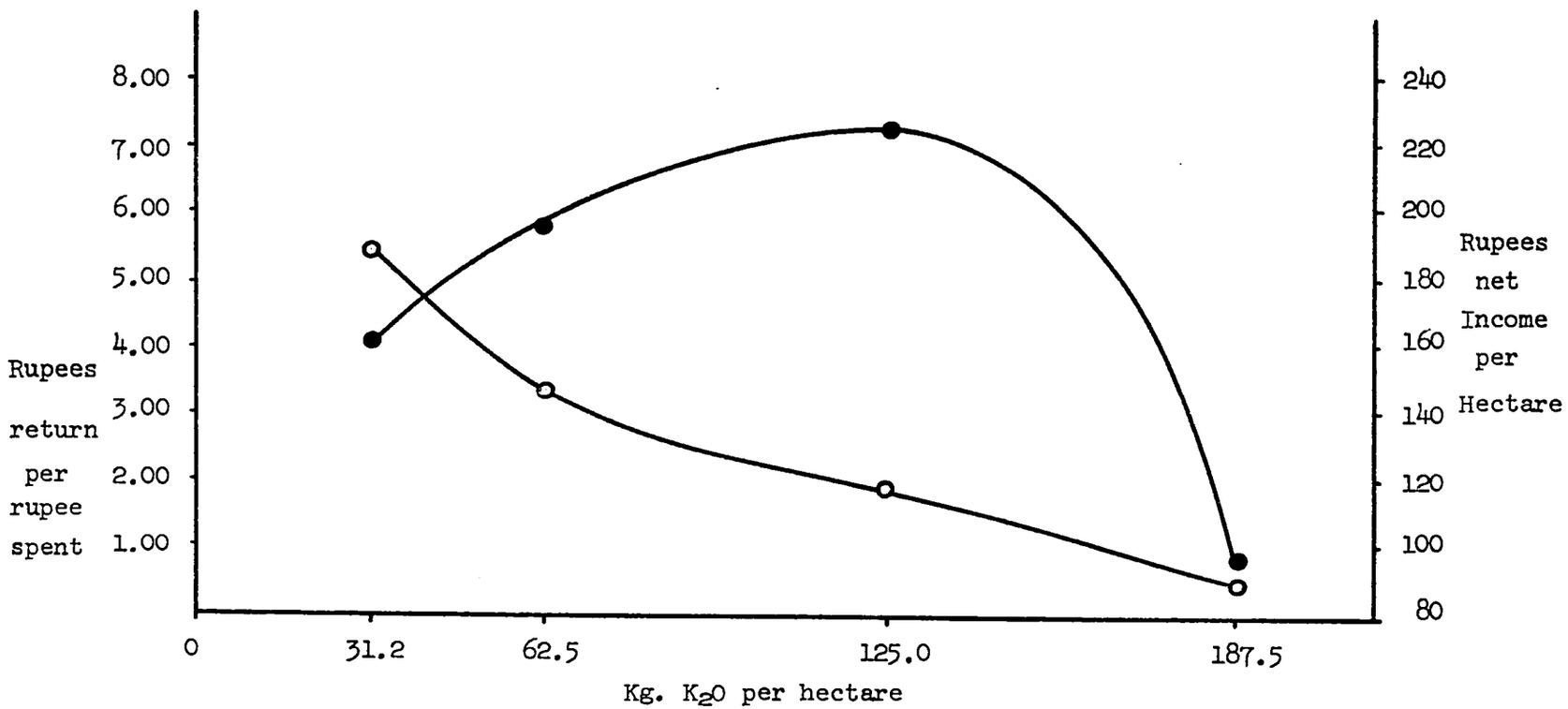
Because the wheat crop is only a part of the overall farming operation, the individual farmer is faced with the decision of where to allocate his resources (time and money) so as to maximize his overall returns. In this area basic information is completely lacking in the Punjab and it is possible only to guess at the possible returns from a single enterprise. Because of this the highest rate of return, Rs 5.41 per Rupee spent, is the best choice. However, even this may be displaced by certain higher return enterprises. The actual choice must be made at the individual farm level.




● Net income per hectare

○ Net return on potash investment

Figure 24. Net Grain Income and Grain Return on Potash Investment versus K Rate.




● Net income

○ Net return on potash investment

Figure 25. Total Net Income and Return on Investment versus K Rates (Includes grain and straw).

Possibilities for further increase in wheat yields are quite good. This was indicated by the top single plot yields of 6240 and 6040 kg/ha. These were plots which received 125 and 62.5 kg $K_2O$/ha respectively. Two 187.5 kg/ha split application plots also showed slightly lower yields. Although such yields may be more difficult to attain over a large area, certainly this does indicate that improved yields are still possible with Kalyan 227 variety. Inspection of the available data did not indicate what factors gave rise to these high yields but micronutrient nutrition seems to be a significant factor.

## SUMMARY

This work has demonstrated the following conclusions concerning wheat grown on the soils described. (1) There is a definite and profitable response in wheat yield when the minimum recommended rate of potash is applied to soils testing low in ammonium acetate exchangeable $K^+$. (2) Split application at high rates of potash serves to mitigate the yield depressive effects of potash but does not result in significant yield increases over lower potash application rates. (3) Use of either calcium ammonium nitrate or ammonium sulfate does not significantly affect wheat yields or wheat response to potassium. (4) Banding of fertilizers does result in higher overall yields but does not affect wheat response to potassium application. The presence of $Ca^{++}$ and $Mg^{++}$ do not appear to be limiting $K^+$ uptake. There is a large amount of slowly available $K^+$ which provides potassium in amounts adequate for plant uptake under reduced yield conditions.

The present Punjab Agricultural University Soil Testing guidlines for potash application on $K^+$ deficient soils seems to be valid for the soil types tested. Prospects for increasing wheat yields on $K^+$ deficient soils by potash application are quite good. There are indications that further yield increases may also be possible but this requires still further research.

# APPENDIX

TABLE 2

PARTICLE SIZE DISTRIBUTION OF MANGLI NICHI SOIL (SAMANA SERIES)

| Horizon | % SAND mm | | | | | | % SILT μ | | | % CLAY μ | | | texture |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | very coarse | coarse | medium | fine | very fine | total | fine | coarse | total | fine | coarse | total | |
| | 1-2 | .5-1 | .25-.5 | .1-.25 | .05-.1 | .05-2 | 2-20 | 20-50 | 2-50 | <.2 | .2-2 | < 2 | |
| Ap | 0.2 | 4.8 | 24.5 | 52.2 | 10.4 | 92.1 | 1.2 | 1.1 | 2.3 | 1.8 | 3.8 | 5.6 | sand |
| B2 | 0 | 3.2 | 16.2 | 42.9 | 9.1 | 71.4 | 7.3 | 6.0 | 13.3 | 5.6 | 9.7 | 15.3 | sandy loam |
| B3 | 0 | 4.3 | 16.9 | 43.1 | 8.5 | 72.8 | 7.4 | 5.0 | 12.4 | 6.1 | 8.7 | 14.8 | sandy loam |

TABLE 2a

CHEMICAL PROPERTIES AND CLAY MINERALOGY OF MANGLI NICHI SOIL

| Horizon | pH 1:1 | organ C % | ECe μmhos/cm | CEC me/100 gm | Illite % | Verm % | Inter-strat. % | Kaol. % | Quartz % | Ammon. Ac. K me/100 | Ammon. Ac. Ca gms. | Exch. Mg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ap | 7.4 | .43 | 181.2 | 20.7 | 89 | 8 | 0 | 0 | 3 | .05 | 2.30 | .27 |
| B2 | 7.4 | .36 | 109.9 | 23.4 | 69 | 12 | 15 | 2 | 2 | .08 | 5.33 | .66 |
| B3 | 7.5 | .31 | 73.3 | 22.7 | 47 | 22 | 22 | 2 | 6 | .07 | 7.13 | .39 |

NOTE: Organic C is based on total %C by ignition.
Clay minerals were subjected to $H_2O_2$ and NaOAc pretreatment.
CEC is by Ba saturation.

TABLE 3.

PARTICLE SIZE DISTRIBUTION OF BIRK SOIL (TEMPLE SERIES)

| Horizon | % SAND mm | | | | | | % SILT μ | | | % CLAY μ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | very coarse | coarse | medium | fine | very fine | total | fine | coarse | total | fine | coarse | total | texture |
| | 1-2 | .5-1 | .25-.5 | .1-.25 | .05-.1 | .05-2 | 2-20 | 20-50 | 2-50 | <.2 | .2-2 | < 2 | |
| Ap | 0.1 | 9.0 | 21.7 | 46.0 | 11.8 | 88.6 | 2.0 | 2.2 | 4.2 | 3.2 | 4.0 | 7.2 | loamy sand |
| B21 | 0 | 3.5 | 11.0 | 41.1 | 15.0 | 70.6 | 8.5 | 7.7 | 16.2 | 4.9 | 8.3 | 13.2 | sandy loam |
| B22 | 0.1 | 2.5 | 8.1 | 38.0 | 17.7 | 66.4 | 9.7 | 10.9 | 20.6 | 6.0 | 7.0 | 13.0 | sandy loam |
| C1 | 0.3 | 2.3 | 6.8 | 37.9 | 19.0 | 66.3 | 10.0 | 11.9 | 21.9 | 4.5 | 7.3 | 11.8 | sandy loam |
| C2 | 1.0 | 2.2 | 6.0 | 54.6 | 14.5 | 78.3 | 7.4 | 5.9 | 13.3 | 4.8 | 3.6 | 8.4 | loamy sand-sandy loam |

TABLE 3a.

CHEMICAL PROPERTIES AND CLAY MINERALOGY OF BIRK SOIL

| Horizon | pH 1:1 | organ C % | ECe μmhos /cm | CEC me/100 gm | Illite % | Verm % | Inter-strat. % | Kaol. % | Quartz % | Ammon. Ac. Exch. K me/100 | Ca gms. | Mg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ap | 7.6 | .36 | 168.5 | 17.5 | 72 | 14 | 0 | 3 | 11 | .09 | 3.58 | .25 |
| B21 | 7.6 | .40 | 113.6 | 21.4 | 57 | 25 | 7 | 0 | 11 | .06 | 7.00 | .26 |
| B22 | 7.5 | .56 | 300.4 | 16.9 | 39 | 38 | 11 | 0 | 12 | .04 | 12.65 | .19 |
| C1 | 7.9 | .77 | 201.5 | 28.9 | 37 | 44 | 8 | 1 | 9 | .04 | 12.25 | .22 |
| C2 | 8.1 | 1.54 | 175.8 | 92.6 | 41 | 35 | 12 | 2 | 9 | .03 | 10.98 | .19 |

TABLE 4.

PARTICLE SIZE DISTRIBUTION OF MUNDIAN KHURD SOIL (TULEWAL SERIES)

| Horizon | % SAND mm | | | | | | % SILT μ | | | % CLAY μ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | very coarse | coarse | medium | fine | very fine | total | fine | coarse | total | fine | coarse | total | texture |
| | 1-2 | .5-1 | .25-.5 | .1-.25 | .05-.1 | .05-2 | 2-20 | 20-50 | 2-50 | <.2 | .2-2 | < 2 | |
| Ap | 0 | 4.9 | 19.8 | 50.9 | 11.6 | 87.2 | 5.0 | 1.8 | 6.8 | 3.0 | 3.0 | 6.0 | loamy sand |
| B1 | 0 | 3.6 | 13.8 | 29.3 | 9.1 | 55.8 | 17.3 | 7.4 | 24.7 | 7.9 | 11.6 | 19.5 | sandy loam |
| B2 | 0 | 4.0 | 14.5 | 29.7 | 8.5 | 56.7 | 16.9 | 6.4 | 23.3 | 8.6 | 11.4 | 20.0 | sandy loam-sandy clay loam |

TABLE 4a.

CHEMICAL PROPERTIES AND CLAY MINERALOGY OF MUNDIAN KHURD SOIL

| Horizon | pH 1:1 | organ C % | ECe μmhos /cm | CEC me/100 gm | Illite % | Verm % | Inter-strat. | Kaol. % | Quartz % | Ammon. Ac. Exch. K me/100 gms. | Ca | Mg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ap | 7.9 | .29 | 212.5 | 9.3 | 83 | 7 | 0 | 4 | 7 | .08 | 2.80 | .37 |
| B1 | 7.2 | .38 | 174.1 | 23.8 | 71 | 16 | 0 | 3 | 10 | .10 | 9.48 | .60 |
| B2 | 7.2 | .34 | 210.4 | 13.7 | 63 | 22 | 0 | 3 | 12 | .09 | 9.85 | .54 |

See Note Table 2.

TABLE 5.

PARTICLE SIZE DISTRIBUTION OF MUNDIAN KALAN SOIL (SAMANA SERIES)

| Horizon | % SAND mm | | | | | | % SILT μ | | | % CLAY μ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | very coarse | coarse | medium | fine | very fine | total | fine | coarse | total | fine | coarse | total | texture |
| | 1-2 | .5-1 | .25-.5 | .1-.25 | .05-.1 | .05-2 | 2-20 | 20-50 | 2-50 | < .2 | .2-2 | < 2 | |
| Ap | 0 | 9.2 | 21.4 | 46.2 | 10.5 | 87.3 | 3.3 | 2.6 | 5.9 | 3.9 | 2.9 | 6.8 | loamy sand |
| B1 | 0.1 | 6.7 | 19.8 | 38.4 | 8.4 | 73.4 | 11.2 | 2.8 | 14.0 | 7.1 | 5.5 | 12.6 | sandy loam |
| B2 | 0 | 7.0 | 17.9 | 40.0 | 8.9 | 73.8 | 11.5 | 2.9 | 14.4 | 6.7 | 5.1 | 11.8 | sandy loam |

TABLE 5a.

CHEMICAL PROPERTIES AND CLAY MINERALOGY OF MUNDIAN KALAN SOIL

| Horizon | pH 1:1 | organ C % | ECe μmhos/cm | CEC me/100 gm | Illite % | Verm % | Inter-strat. % | Kaol. % | Quartz % | Ammon. Ac. Exch. K me/100 gms. | Ca | Mg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ap | 7.3 | .45 | 142.4 | 11.5 | 79 | 12 | 0 | 2 | 7 | .07 | 3.03 | .21 |
| B1 | 7.3 | .39 | 85.7 | 21.5 | 57 | 18 | 12 | 6 | 8 | .08 | 6.08 | .30 |
| B2 | 7.3 | .35 | 72.6 | 19.4 | 39 | 37 | 11 | 1 | 12 | .07 | 6.75 | .42 |

See Note Table 2.

TABLE 6.

PARTICLE SIZE DISTRIBUTION OF KAUNTA SOIL (TULEWAL SERIES)

| Horizon | % SAND mm | | | | | % SILT μ | | | % CLAY μ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | very coarse | coarse | medium | fine | very fine | total | fine | coarse | total | fine | coarse | total | texture |
| | 1-2 | .5-1 | .25-.5 | .1-.25 | .05-.1 | .05-2 | 2-20 | 20-50 | 2-50 | < .2 | .2-2 | < 2 | |
| Ap | 0.3 | 8.1 | 9.7 | 25.3 | 17.3 | 60.7 | 17.4 | 9.8 | 27.2 | 4.8 | 7.3 | 12.1 | sandy loam |
| B1 | 0.1 | 5.4 | 7.6 | 21.0 | 18.1 | 52.2 | 21.1 | 11.6 | 32.7 | 5.4 | 9.7 | 15.1 | sandy loam |
| B2 | 0.1 | 4.2 | 7.3 | 21.9 | 20.0 | 53.5 | 21.6 | 12.0 | 33.6 | 5.8 | 7.1 | 12.9 | sandy loam |
| B3 | 0.1 | 4.3 | 7.0 | 25.2 | 20.3 | 56.9 | 18.3 | 12.0 | 30.3 | 4.3 | 8.5 | 12.8 | sandy loam |
| C1 | 0.1 | 2.6 | 6.9 | 37.2 | 20.2 | 67.0 | 17.5 | 8.1 | 25.6 | 3.1 | 4.3 | 7.4 | sandy loam |

TABLE 6a

CHEMICAL PROPERTIES AND CLAY MINERALOGY OF KAUNTA SOIL

| Horizon | pH 1:1 | organ C % | ECe μmhos/cm | CEC me/100 gm | Illite % | Verm % | Inter-strat % | Kaol. % | Quartz % | Ammon. Ac. Exch. K me/100 gms | Ca | Mg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ap | 7.1 | .47 | 290.2 | 30.3 | 53 | 30 | 0 | 7 | 10 | .07 | 5.13 | .58 |
| B1 | 7.2 | .32 | 152.4 | 25.7 | 40 | 38 | 0 | 6 | 16 | .06 | 5.70 | .70 |
| B2 | 7.2 | .30 | 146.0 | 17.7 | 43 | 39 | 0 | 4 | 15 | .05 | 5.65 | .62 |
| B3 | 7.1 | .24 | 165.0 | 26.2 | 45 | 41 | 0 | 3 | 12 | .04 | 5.28 | .86 |
| C1 | 7.2 | .21 | 143.3 | 14.8 | 45 | 34 | 0 | 11 | 11 | .03 | 4.38 | .74 |

See Note Table 2.

TABLE 7.

PARTICLE SIZE DISTRIBUTION OF WARAICH SOIL (TULEWAL SERIES)

| Horizon | % SAND mm | | | | | % SILT μ | | | % CLAY μ | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | very coarse | coarse | medium | fine | very fine | total | fine | coarse | total | fine | coarse | total | texture |
| | 1-2 | .5-1 | .25-.5 | .1-.25 | .05-.1 | .05-2 | 2-20 | 20-50 | 2-50 | < .2 | .2-2 | < 2 | |
| Ap | 0.3 | 8.2 | 14.0 | 34.5 | 11.3 | 68.3 | 13.8 | 8.0 | 21.8 | 2.8 | 7.1 | 9.9 | sandy loam |
| B1 | 0.2 | 5.4 | 7.3 | 20.7 | 10.5 | 44.1 | 20.7 | 14.3 | 35.0 | 6.3 | 14.6 | 20.9 | loam |
| B2 | 0.1 | 4.0 | 5.1 | 16.6 | 10.4 | 36.2 | 23.8 | 15.8 | 39.6 | 10.0 | 14.2 | 24.2 | loam |
| B3 | 1.2 | 4.1 | 4.7 | 15.6 | 11.0 | 36.6 | 22.7 | 17.1 | 39.8 | 10.3 | 13.3 | 23.6 | loam |
| C1 | 0.2 | 4.3 | 4.9 | 18.1 | 13.2 | 40.7 | 22.5 | 16.5 | 39.0 | 7.9 | 12.4 | 20.3 | loam |

TABLE 7a

CHEMICAL PROPERTIES AND CLAY MINERALOGY OF WARAICH SOIL

| Horizon | pH 1:1 | organ C % | ECe μmhos/cm | CEC me/100 gm | Illite % | Verm % | Inter-strat. | Kaol. % | Quartz % | Ammon. K me/100 gms. | Ac. Exch. Ca me/100 gms. | Ac. Exch. Mg me/100 gms. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ap | 7.1 | .32 | 163.3 | 22.6 | 84 | 6 | 0 | 4 | 6 | .16 | 3.75 | .44 |
| B1 | 7.1 | .41 | 140.6 | 25.1 | 47 | 24 | 16 | 4 | 9 | .12 | 7.80 | 1.15 |
| B2 | 7.1 | .38 | 150.6 | 33.2 | 45 | 31 | 7 | 3 | 15 | .12 | 9.75 | 1.45 |
| B3 | 7.1 | .35 | 123.4 | 34.3 | 41 | 35 | 11 | 3 | 10 | .14 | 9.98 | 1.73 |
| C1 | 7.2 | .30 | 121.1 | 29.7 | 31 | 29 | 4 | 5 | 11 | .11 | 9.43 | 1.71 |

See Note Table 2.

TABLE 8

PARTICLE SIZE DISTRIBUTION OF SHRI HARGOBINDPUR SOIL (TULEWAL SERIES)

| Horizon | % SAND mm | | | | | | % SILT μ | | | % CLAY μ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | very coarse | coarse | medium | fine | very fine | total | fine | coarse | total | fine | coarse | total | texture |
| | 1-2 | .5-1 | .25-.5 | .1-.25 | .05-.1 | .05-2 | 2-20 | 20-50 | 2-50 | <.2 | .2-2 | < 2 | |
| Ap | 0.4 | 6.2 | 11.0 | 21.4 | 11.3 | 50.3 | 25.5 | 14.3 | 39.8 | 3.3 | 6.6 | 9.9 | loam |
| B1 | 0.3 | 6.0 | 10.6 | 19.8 | 10.7 | 47.4 | 27.1 | 14.1 | 41.2 | 2.8 | 8.6 | 11.4 | loam |
| B2t | 0.2 | 2.5 | 4.8 | 9.2 | 9.3 | 26.0 | 33.0 | 18.5 | 51.5 | 8.9 | 13.6 | 22.5 | silt loam |

TABLE 8a.

CHEMICAL PROPERTIES AND CLAY MINERALOGY OF SHRI HARGOBINDPUR SOIL

| Horizon | pH 1:1 | organ C % | ECe μmhos/cm | CEC me/100 gm | Illite % | Verm % | Inter-strat. % | Kaol. % | Quartz % | Ammon. Ac. Exch. K me/100 gms | Ca | Mg |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ap | 7.0 | .54 | 498.9 | 21.5 | 63 | 26 | 0 | 3 | 8 | .11 | 6.18 | .58 |
| B1 | 7.3 | .45 | 254.9 | 22.3 | 62 | 16 | 0 | 10 | 12 | .10 | 6.08 | .56 |
| B2t | 7.4 | .46 | 217.7 | 28.8 | 40 | 35 | 6 | 4 | 15 | .11 | 9.93 | 1.38 |

See Note Table 2.

TABLE 13

ANALYSIS OF VARIANCE FOR GRAIN YIELD

| Variable | D.F. | Mean S. | f | |
|---|---|---|---|---|
| MEAN | 1 | -- | -- | |
| REPS | 1 | 0.0233 | 0.01 | ns |
| LOCATION | 5 | 351.7774 | 192.18 | ** |
| CAN-A/S | 1 | 2.6429 | 1.44 | ns |
| BR-BA | 1 | 38.5429 | 21.06 | ** |
| LOCATION x REPS | 5 | 7.6853 | 4.20 | ** |
| LOCATION x CAN-A/S | 5 | 20.5119 | 11.21 | ** |
| LOCATION x BR-BA | 5 | 7.7674 | 21.22 | ** |
| REPS x CAN-A/S | 1 | 20.5029 | 11.20 | ** |
| REPS x BR-BA | 1 | 0.3344 | 0.18 | ns |
| CAN-A/S x BR-BA | 1 | 0.0576 | 0.03 | ns |
| remainder | 21 | 1.8305 | -- | |
| K-RATE | 6 | 12.8979 | 5.71 | ** |
| LOCATION x K-RATE | 30 | 2.9488 | 1.31 | ns |
| BR-BA x K-RATE | 6 | 0.6660 | 0.30 | ns |
| CAN-A/S x K-RATE | 6 | 3.0440 | 1.35 | ns |
| REPS x K-RATE | 6 | 1.1897 | 0.53 | ns |
| remainder | 234 | 2.2577 | -- | |

KEY:

| | |
|---|---|
| ** | 1% significance level |
| * | 5% significance level |
| LOCATION | all variables due to location differences |
| REPS | replication differences |
| CAN | calcium ammonium nitrate as N source |
| A/S | ammonium nitrate as N sourse |
| BR | broadcast fertilizer application |
| BA | band fertilizer application |
| K-RATE | rates of application of K fertilizer |
| ns | not significant |

TABLE 14

ANALYSIS OF VARIANCE FOR STRAW YIELD

| Variable | D.F. | Mean S. | f | |
|---|---|---|---|---|
| MEAN | 1 | -- | -- | |
| REPS | 1 | 0.1416 | 0.00 | ns |
| LOCATION | 5 | 8729.4355 | 211.80 | ** |
| CAN-A/S | 1 | 96.1074 | 2.33 | ns |
| BR-BA | 1 | 282.1500 | 6.85 | * |
| LOCATION x REPS | 5 | 118.5676 | 2.88 | * |
| LOCATION x CAN-A/S | 5 | 240.0564 | 5.82 | ** |
| LOCATION x BR-BA | 5 | 211.3383 | 5.13 | ** |
| REPS x CAN-A/S | 1 | 54.3214 | 1.32 | ns |
| REPS x BR-BA | 1 | 24.8086 | 0.60 | ns |
| CAN-A/S x BR-BA | 1 | 80.3407 | 1.95 | ns |
| remainder | 21 | 41.2148 | -- | |
| K-RATE | 6 | 312.4171 | 11.43 | ** |
| LOCATION x K-RATE | 30 | 38.8416 | 1.42 | ns |
| BR-BA x K-RATE | 6 | 25.2490 | 0.92 | ns |
| CAN-A/S x K-RATE | 6 | 28.4493 | 1.04 | ns |
| REPS x K-RATE | 6 | 20.2304 | 0.74 | ns |
| remainder | 234 | 27.3423 | -- | |

Key in Table 13.

TABLE 15

ANALYSIS OF VARIANCE FOR 100 GRAIN WEIGHT

| Variable | D.F. | Mean S. | f | |
|---|---|---|---|---|
| MEAN | 1 | -- | -- | |
| REPS | 1 | 0.1377 | 4.07 | ns |
| LOCATION | 1 | 2.1252 | 62.82 | ** |
| CAN-A/S | 1 | 0.1277 | 3.78 | ns |
| BR-BA | 1 | 0.1776 | 5.25 | ns |
| LOCATION x REPS | 1 | 0.0023 | 0.07 | ns |
| LOCATION x CAN-A/S | 1 | 0.0216 | 0.64 | ns |
| LOCATION x BR-BA | 1 | 0.0007 | 0.02 | ns |
| REPS x CAN-A/S | 1 | 0.0002 | 0.01 | ns |
| REPS x BR-BA | 1 | 0.0422 | 1.25 | ns |
| CAN-A/S x BR-BA | 1 | 0.1716 | 5.07 | ns |
| remainder | 5 | 0.0338 | -- | |
| K-RATE | 6 | 0.1535 | 2.32 | * |
| LOCATION x K-RATE | 6 | 0.1638 | 2.48 | * |
| BR-BA x K-RATE | 6 | 0.0239 | 0.36 | ns |
| CAN-A/S x K-RATE | 6 | 0.0345 | 0.52 | ns |
| REPS x K-RATE | 6 | 0.0169 | 0.26 | ns |
| remainder | 66 | 0.0662 | -- | |

Key in Table 13.

TABLE 16

ANALYSIS OF VARIANCE FOR K ANALYSIS

| Variable | D.F. | Mean S. | f | |
|---|---|---|---|---|
| MEAN | 1 | --- | -- | |
| REPS | 1 | 0.4213 | 7.91 | * |
| LOCATION | 1 | 0.5376 | 10.09 | * |
| CAN-A/S | 1 | 0.2595 | 4.87 | ns |
| BR-BA | 1 | 0.0564 | 1.06 | ns |
| LOCATION x REPS | 1 | 0.1557 | 2.92 | ns |
| LOCATION x CAN-A/S | 1 | 0.6667 | 12.52 | * |
| LOCATION x BR-BA | 1 | 0.0780 | 1.47 | ns |
| REPS x CAN-A/S | 1 | 0.0177 | 0.33 | ns |
| REPS x BR-BA | 1 | 0.0446 | 0.84 | ns |
| CAN-A/S x BR-BA | 1 | 0.0650 | 1.22 | ns |
| remainder | 5 | 0.0533 | -- | |
| K-RATE | 6 | 2.9466 | 17.29 | ** |
| LOCATION x K-RATE | 6 | 0.2295 | 1.35 | ns |
| BR-BA x K-RATE | 6 | 0.2717 | 1.60 | ns |
| CAN-A/S x K-RATE | 6 | 0.1330 | 0.78 | ns |
| REPS x K-RATE | 6 | 0.2379 | 1.40 | ns |
| remainder | 66 | 0.1703 | -- | |

Key in Table 13.

TABLE 17

ANALYSIS OF VARIANCE FOR Ca ANALYSIS

| Variable | D.F. | Mean S. | f | |
|---|---|---|---|---|
| MEAN | 1 | -- | -- | |
| REPS | 1 | 0.0454 | 17.27 | ** |
| LOCATION | 1 | 0.0086 | 3.27 | ns |
| CAN-A/S | 1 | 0.0272 | 10.34 | * |
| BR-BA | 1 | 0.0230 | 8.77 | * |
| LOCATION x REPS | 1 | 0.0113 | 4.32 | ns |
| LOCATION x CAN-A/S | 1 | 0.0032 | 1.23 | ns |
| LOCATION x BR-BA | 1 | 0.0012 | 0.47 | ns |
| REPS x CAN-A/S | 1 | 0.0027 | 1.03 | ns |
| REPS x BR-BA | 1 | 0.0141 | 5.37 | ns |
| CAN-A/S x BR-BA | 1 | 0.0001 | 0.04 | ns |
| remainder | 5 | 0.0026 | -- | |
| K-RATE | 6 | 0.0782 | 15.57 | ** |
| LOCATION x K-RATE | 6 | 0.0100 | 2.00 | ns |
| BR-BA x K-RATE | 6 | 0.0064 | 1.27 | ns |
| CAN-A/S x K-RATE | 6 | 0.0066 | 1.33 | ns |
| REPS x K-RATE | 6 | 0.0098 | 1.96 | ns |
| remainder | 66 | 0.0050 | -- | |

Key in Table 13.

TABLE 18

ANALYSIS OF VARIANCE FOR Mg ANALYSIS

| Variable | D.F. | Mean S. | f | |
|---|---|---|---|---|
| MEAN | 1 | -- | -- | |
| REPS | 1 | 0.0081 | 10.70 | * |
| LOCATION | 1 | 0.0046 | 6.04 | ns |
| CAN-A/S | 1 | 0.0111 | 14.62 | * |
| BR-BA | 1 | 0.0027 | 3.64 | ns |
| LOCATION x REPS | 1 | 0.0004 | 0.57 | ns |
| LOCATION x CAN-A/S | 1 | 0.0013 | 1.67 | ns |
| LOCATION x BR-BA | 1 | 0.0002 | 0.22 | ns |
| REPS x CAN-A/S | 1 | 0.0002 | 0.22 | ns |
| REPS x BR-BA | 1 | 0.0008 | 1.04 | ns |
| CAN-A/S x BR-BA | 1 | 0.0000 | 0.00 | ns |
| remainder | 5 | 0.00076 | -- | |
| K-RATE | 6 | 0.0175 | 15.07 | ** |
| LOCATION x K-RATE | 6 | 0.0030 | 2.60 | * |
| BR-BA x K-RATE | 6 | 0.0018 | 1.55 | ns |
| CAN-A/S x K-RATE | 6 | 0.0008 | 0.69 | ns |
| REPS x K-RATE | 6 | 0.0019 | 1.63 | ns |
| remainder | 66 | 0.0011 | -- | |

Key in Table 13.

Figure 2. Soil Profile Description - Mangli Nichi

Location: Mangli Nichi village, Ludhiana block, Ludhiana tehsil, Ludhiana district; Pritam Singh farm; 30 m west of tubewell.

Date: November 2, 1971.

Described by: T. Stilwell

Classification: Haplustalf - Samana Series

Vegetation: Cropland

Climate: Annual Precip. 537 mm; mean annual temp. 24.4°C
Ustic moisture regime

Parent Material: Alluvium

Topography: Level plain

Slope: 0-1%

Elevation: Approximately 250 m

Soil Moisture: Moist throughout

Remarks: Thin patchy clay films in B2, Upper 23 cm may be from aeolian deposition. Colors moist. Noncalcareous throughout.

Profile Description

| Horizon | cm depth | |
|---|---|---|
| Ap | 0-23 | Brown (10YR 4/3) loamy fine sand, light yellowish brown (10YR 6/4) dry, weak fine subangular blocky to single grain structure, very friable, many roots, abrupt smooth boundary. |
| B2 | 23-69 | Dark reddish brown (5YR 3/4) sandy loam, weak fine to coarse subangular structure, friable, many roots, clear smooth boundary. |
| B3 | 69-152 | Brown (7.5YR 4/4) sandy loam, weak coarse subangular blocky structure, friable, few roots. |

Figure 3. Soil Profile Description - Birk

Location: Birk village, Sidhwan Bet block, Jagraon tehsil, Ludhiana district; Raghbir Singh farm, approx. 2 km. north of Birk village, 15 m south of tubewell

Date: November 10, 1971

Described by: T. Stilwell

Classification: Typic Ustochrept - Temple series

Vegetation: cropland (fallow 2-3 years previous)

Climate: Annual Precip. 537 mm; mean annual temp. 24.4°C
Ustic moisture regime

Parent Material: Alluvium

Topography: level plain

Elevation: Approximately 250 m

Soil Moisture: moist throughout

Remarks: Sand dunes in the area. Colors moist.

Profile Description

| Horizon | cm depth | |
|---|---|---|
| Ap | 0-20 | Brown (7.5YR 4.5/4) loamy sand, weak fine to medium subangular blocky and single grain, very friable, abundant roots, noncalcareous, abrupt smooth boundary |
| B21 | 20-53 | Dark reddish brown (5YR 3/4) fine sandy loam, weak medium to coarse subangular blocky structure, very friable, many roots, noncalcareous, gradual smooth boundary. |
| B22 | 53-129 | Brown (7.5YR 4/4) sandy loam, weak medium and coarse subangular blocky structure, friable, many roots, weakly calcareous, few sand streaks and pockets, gradual smooth boundary |
| C1 | 129-141 | Brown (7.5YR 4.5/4) moist, light yellowish brown (10YR 6/4) dry, loamy sand, weak fine and medium subangular blocky structure, friable, few roots, strongly calcareous, gradual smooth boundary |
| C2 | 141-175 | Same as C1 except calcium carbonate nodules (Kankar) less than 2 mm in size present. |

Figure 4. Soil Profile Description - Mundian Khurd

Location: Mundian Khurd village, Ludhiana block, Ludhiana tehsil, Ludhiana district; Pritam Singh farm 1 km. south of Chandigarh road, about 100 m south of tubewell

Date: November 10, 1971

Described by: T. Stilwell

Classification: Typic Ustochrept - Tulewal series

Vegetation: Cropland

Climate: Annual precip. 537 mm, mean annual temp. 24.4°C
Ustic moisture regime

Parent Material: Alluvium

Topography: level plain

Elevation: Approximately 250 m

Soil moisture: moist throughout

Drainage: well drained

Remarks: Nonclacareous throughout, sand filled root channels below 22 cm

Profile Description

| Horizon | cm depth | |
|---|---|---|
| Ap | 0-22 | Light yellowish brown (10YR 6/4) sand or loamy sand, fine, structureless single grain, loose, few roots, clear wavy boundary |
| B1 | 22-43 | Dark yellowish brown (10YR 4/4) sandy loam, massive to weak fine subangular blocky structure, very firm, few roots, diffuse irregular boundary |
| B2 | 43-160 | Dark yellowish brown (10YR 4/4) very gradually grading to dark brown (7.5 YR 4/4) sandy clay loam, massive to weak fine subangular blocky structure, very firm. |

Figure 5. Soil Profile Description - Mundian Kalan

Location: Mundian Kalan village, Ludhiana block, Ludhiana tehsil, Ludhiana district; Jagir Singh farm, about 200 m south of Chandigarh road, 10 m northeast from tubewell.

Date: November 14, 1971

Described by: T. Stilwell

Classification: Haplustalf - Samana series

Vegetation: Cropland

Climate: Annual precip. 537 mm, mean annual temp. 24.4°C
Ustic moisture regime

Parent Material: Alluvium

Topography: level plain

Elevation: Approximately 250 m

Soil moisture: Dry throughout, all colors are moist colors

Drainage: well drained

Remarks: Noncalcareous throughout, very uniform profile

Profile Description

| Horizon | cm depth | |
|---|---|---|
| Ap | 0-15 | Dark yellowish brown (10YR 4/4) sandy clay loam, single grain to weak fine subangular blocky structure, loose, many roots, abrupt wavy boundary |
| B1 | 15-112 | Dark yellowish brown (10YR 4/4) sandy loam, single grain to weak fine subangular blocky stucture, friable, few roots, diffuse smooth boundary |
| B2 | 112-180 | Dark yellowish brown (10YR 4/4) loamy sand, single grain to weak fine subangular blocky structure, firm. |

Figure 6. Soil Profile Description - Kaunta

Location: Kaunta village, Gurdaspur block, Gurdaspur tehsil, Gurdaspur district; Amar Singh farm, about 100 meters north of tubewell and house

Date: November 16, 1971

Described by: T. Stilwell

Classification: Typic Ustochrept - Tulewal series

Vegetation: Cropland

Climate: Annual precip. 987 mm, mean annual temp. 23.2°C
Ustic moisture regime

Parent Material: Alluvium

Topography: level plain

Elevation: Approximately 250 m

Soil moisture: moist throughout

Drainage: well drained

Remarks: Noncalcareous throughout, pronounced hard layer approx. 7 cm thick from 20 to 27 cm depth, sand lenses and sand channels noted at 50 and 95 cm depth

Profile Description

| Horizon | cm depth | |
|---|---|---|
| Ap | 0-15 | Dark yellowish brown (10YR 4/4) sandy loam, massive to weak fine subangular blocky structure, firm, few roots, gradual wavy boundary |
| B1 | 15-41 | Dark brown (7.5YR 4/4) sandy clay loam, massive to weak fine subangular blocky structure, very firm, diffuse smooth boundary |
| B2 | 41-78 | Dark yellowish brown (10YR 4/4) loam, massive to weak fine subangular blocky structure, very firm, diffuse smooth boundary |
| B3 | 78-122 | Dark yellowish brown (10YR 4/4) clay loam, massive to weak fine subangular blocky structure, very firm, diffuse smooth boundary |
| C1 | 122-180 | Yellowish brown (10YR 5/6) sandy clay, massive to weak fine subangular blocky structure, friable |

Figure 7. Soil Profile Description - Waraich

Location: Waraich village, Kahnuwan block, Gurdaspur tehsil, Gurdaspur district; Amar Singh farm, approx. 150 m east of pond

Date: November 17, 1971

Described by: T. Stilwell

Classification: Typic Ustochrept – Tulewal series

Vegetation: Cropland

Climate: annual precip. 987 mm, mean annual temp. 23.2°C

Parent Material: Alluvium

Topography: level plain

Elevation: Approximately 250 m

Soil Moisture: Moist throughout

Drainage: moderately well drained

Remarks: Noncalcareous throughout, Ap thickness varies from 12-16 cm over ¼ acre area, sand filled animal or insect burrow found at 65 cm., two open animal or insect burrows found at 93 and 130 cm about 5 cm diam. Black (10YR 2/1) soft round concretions, 1-3 mm diam. similar to Fe-Mn concretions found at 95-126 cm depth.

Profile Description

| Horizon | cm depth | |
|---|---|---|
| Ap | 0-15 | Yellowish brown (10YR 5/4) sandy loam, fine structureless single grain, loose, few roots, abrupt wavy boundary |
| B1 | 15-62 | Dark yellowish brown (10YR 3/4) sandy clay loam, massive to weak fine subangular blocky structure, very firm, few roots, diffuse smooth boundary |
| B2 | 62-95 | Dark yellowish brown (10YR 3/4) clay loam, massive to weak fine subangular blocky structure, firm, diffuse smooth boundary |
| B3 | 95-126 | Dark yellowish brown (10YR 4/4) clay loam, massive to weak fine subangular blocky structure, firm, gradual smooth boundary, concretions described in remarks |
| C1 | 126-170 | Yellowish brown (10YR 5/4) sandy clay loam, massive to fine subangular blocky structure, firm |

Figure 8. Soil Profile Description - Shri Hargobindpur

Location: Shri Hargobindpur village, Hargobindpur block, Batala tehsil, Gurdaspur district; Comrade Amar Singh Daula farm, approx. 300 m north of buildings on east side of canal

Date: November 19, 1971

Described by: T. Stilwell

Classification: Typic Ustochrept - Tulewal series

Vegetation: Cropland

Climate: Annual precip. 987 mm, mean annual temp. 23.2°C

Parent Material: Alluvium

Topography: Level plain

Elevation: approximately 250 m

Soil Moisture: moist throughout

Drainage: well drained

Remarks: Noncalcareous throughout, very uniform from 26 to 165 cm, thin patchy clay films from 17-26 cm, thin clay films from 26-165 cm

Profile Description

| Horizon | cm depth | |
|---|---|---|
| Ap | 0-17 | Brown (10YR 4/3) sandy loam, weak fine subangular blocky to single grain structure, friable, few roots, abrupt smooth boundary |
| B1 | 17-26 | Dark yellowish brown (10YR 4/4) sandy clay loam, weak coarse subangular blocky structure, very firm, few roots, abrupt smooth boundary |
| B2t | 26-165 | Dark yellowish brown (10YR 4/4) clay loam, moderate medium subangular blocky structure, very firm, few roots |

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