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Methodology in Soil-K Research

Summaries of the papers presented on occasion of the 20th IPI Colloquium at Baden near Vienna/Austria (June 23 to 25, 1987)

Chairman of the Colloquium: Prof. Dr. *O. Steineck*, Institute for Plant Breeding and Plant Husbandry, Agricultural University Vienna/Austria; member of the Scientific Board of the International Potash Institute.

1st Working Session of the 20th IPI Colloquium

Mineralogy of Soil-K

Current aspects of the mineralogy of clays and soils

G. Pedro, Soil Science Station, INRA, Versailles/France

The aim of this paper is to present the new look of soil mineralogy, and especially soil clay mineralogy, so as somewhat to redefine the relationships between the mineral constituents of the soil and potassium.

The standard method for characterising separated soil minerals is reviewed. Despite recent improvements in the study of structure and polycrystallinity, this has its limitations. Current problems are then discussed under:

- Mineralogical characterization of undisturbed soil samples in the dry state: optical and electron micromorpholgy in association with X-ray diffraction and electron probe microanalysis.
- Mineralogical characterization of undisturbed hydrated soil samples: the significance of electron-microscopy (SEM and HRTEM) and of small angle scattering (SAS).

The results of current research concerning the different levels of organisation (structure, texture and plasmic fabric) are then presented as they relate to the chief characteristic clays of soils.

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Identification of clays – Data from investigations with strongly hydrated systems

D. Tessier, Station of Soil Science, I.N.R.A. Versailles/France

In conventional studies, clays are identified in strongly dehydrated samples (equilibrated at relative humidities <90%). Under such conditions, their organisation is often very different from that in the natural soil. Clays can also be examined and identified in the range of biological activity (suction pressures <16 bar). For this purpose, the behaviour of clays has been investigated under controlled matric and osmotic potential. Scanning and transmission electron microscopy and X-ray small angle scattering were used to characterize clay-water systems at various water content levels. It was then possible to identify clays not just by reference to properties of the interlayer space but also by description of the particles as they are found in well hydrated systems.

It was shown that, in the range of high moisture content, the interlayer hydration and particle characteristics of potassium smectites were comparable with those of sodium smectites. In this case, identification rests upon study of all states of hydration which is not possible with the classical methods (interlayer spacing ⩽2 layers of water).

Development of K containing minerals during weathering and suitable methods for their determination

H. Tributh, Institute of Soil Science, Justus-Liebig-University, Giessen/Fed. Rep. of Germany

The development of clay minerals includes the processes of formation, transformation, and decomposition of clay minerals in soils.

The clay formation in soils of temperate climate is mainly a result of mica weathering in the silt and sand fractions. Transformation means alteration of minerals which leads to expansion of K containing clay minerals for which a decrease in layer charge and potasium release are the most important requirements.

Clay decomposition is a consequence of soils becoming increasingly poor in bases and their additional pollution with acidic substances from the environment.

An analysis of individual stages of development is only posible after dividing the clay component into subfractions.

The X-ray methods, the determination of the layer charge by the n-alkylammonium method, and the contraction behaviour after KCl treatment are means of determining the stages of clay mineral development. As long-term K fertilizing proves, K shortage both decreased yields and accelerates clay mineral transformation. Liming benefits the development of clay minerals because sufficient base saturation prevents clay decomposition. Methodological aspects are described.

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Scanning electron microscopy and microprobe techniques for soil-K characterization

Lelia Arcan, SEM Laboratory, The Volcani Center, Bet Dagan/Israel

Scanning Electron Microscopy (SEM) and Energy Dispersive Spectrometry (EDS) provide, as a system, a powerful tool for direct investigation of soil structure and composition. Soil characteristic fabrics were obtained, reflecting correlations between soil composition, exchangeable complex and the electrolyte content in pore water. SEM micrographs of soils after rain simulation experiments, present at the very surface of fractured samples, a clean silt grain layer due to the clay dispersion and to the downward movement into a clay accumulating 'washed in' zone. The thickness of the silt and of the 'washed in' layers are reflecting the size fraction content and soil sodicity.

Due to the fact that lack of homogeneity and surface roughness are strong disturbing parameters in X-ray microanalysis, specific methodology for potassium evaluation was recommended: (i) characterizing the active part of the soil matrix using oriented films of intermediate thickness on carbon support, (ii) using standards having mass absorption coefficients for potassium Kα line close to the analyzed sample, (iii) optimizing working parameters e.g. electron energies at low values and take off angles related to the topographic effect.

X-ray and neutron diffraction

I.G. Wood, Rothamsted Experimental Station, Harpenden, Herts/United Kingdom

X-ray and neutron diffraction are important methods for the identification, quantitative analysis and study of the potassium-bearing layer silicate clay minerals found in soil. The basic principles of the structural chemistry of these compounds are described and recent advances in experimental facilities reviewed. Methods for examining both micaceous and interstratified minerals are discussed, with particular emphasis on the fundamental principles of the diffraction process. Diffraction patterns from these materials can be extremely complex and great care must be taken in their interpretation if meaningful results are to be obtained.

Coordinator's report on the first working session

H. Laudelout, Soil Science Dept., University of Louvain/Belgium; member of the Scientific Board of the International Potash Intitute

The general feeling might have been that the subjects treated during the first session were far removed from the day-to-day preoccupations of the average agronomist. This impression was dispelled by the lecture delivered by Dr. *Pedro* (Versailles). He described the changes in the approach of the soil scientist to the study of clay mineralogy from the early colloid chemistry of clays considered as amorphous substances through what may be termed the classical approach consisting in X-ray or I.R. studies of highly purified

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mineralogical clay samples. The present day approach is characterized by the use of more and more sophisticated physical techniques on the one hand and, on the other hand, by the study of natural soil samples in undisturbed field conditions. This implies that mineralogical clay studies are now carried out at 'their natural water content' and no longer on perfectly dessicated soil samples with one or two layers of water. The advantages of this approach are obvious: first of all direct measurement of important properties relating to the surface chemistry of clay minerals becomes possible; secondly the architecture of the natural pore systems becomes directly visible. The concepts of 'domains' and 'quasi-crystallinity' which had been used rather loosely in the past, are now firmly established.

Classical methods such as the well known soil water retention curve may be combined with modern observation techniques as demonstrated by *Tessier.* The interest of this communication lies in the fact that the fabric of the porous material is examined at 'biological water contents' *i. e.* at water contents which are normally found in the soil. At these water contents the interlayer spacings become much larger than 2 layers of water and important processes such as electrolyte exclusion or surface diffusion of ions are considerably modified.

The conclusion presented by *Tessier* that understanding the properties of clays requires that their geochemical environment and their energetic history be taken into account is illustrated in more detail by the presentation of *Tributh* on the formation, transformation and decomposition of clay minerals. It should be emphasized that a process which he describes and which has been referred to recently as 'cationic denudation' has assumed tremendous importance over the last few years. The reason for this interest is twofold: the impact of acid precipitation on soil and vegetation in industrial countries is well known. On the other hand, in many countries of the humid tropics, especially at high elevation, this terminal stage of cationic denudation has reached a point where the productivity of the soil has sunk to a very low level due to aluminium toxicity. In many countries, no economic correction of this situation is possible. It must be recognized that the easy correction of soil acidity in industrial countries by the use of marl, lime, basic slag, etc. has led to neglect of the study of the correction of soil acidity by way of a minimum input technology. To what extent complexation by organic substances, magnesium and potassium fertilization can alleviate this situation remains a pressing object of study.

The use of highly sophisticated techniques was described by *Arcan* and *Wood.* Rather than go into a summary of their presentations, which were much condensed anyway, I think that it would be fitting to emphasize two incidental comments made by the two speakers. As mentioned by *Arcan,* sophisticated hardware will only do what it is told to do and not what we expect it to do. It is also noteworthy that for the first time in a potash symposium, the phrase 'expert systems' was mentioned. It was mentioned here in the rather restricted context of data acquisition and treatment. It seems obvious that in the not too distant future, accumulated knowledge will be organized in expert systems from which the practical agronomist, making full use of his own expertise and of the possibility of the machine, will arrive at an optimalised prediction of the economic return from potash manuring.

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2nd Working Session of the 20th IPI Colloquium

K Release and K Fixation

Potassium fixation and release

K. W. T. Goulding, Rothamsted Experimental Station, Harpenden, Herts/ United Kingdom

The fixation and release of potassium in soil are part of a dynamic, reversible process controlled primarily by the type and particle size of the primary and secondary minerals present. The process is also affected by soil structure, soil pH and liming, manuring, temperature, wetting and drying and freezing and thawing, and the action of plant roots. Potassium exchangeable to a solution of an ammonium salt is the most widely used estimate of plant available K. Non-exchangeable K is usually determined, if at all, by the historical methods of exhaustive cropping in pots or by extraction with acids. Electroultrafiltration is used by some organizations to produce a multi-element extract. There has been some sucess in modelling K availability and uptake to field crops. Potassium fixation is generally measured against K exchangeable to ammonium, magnesium or rubidium salts, but acids and ion exchange resins have been shown to extract fixed K.

At present, the routine determination of K fixation and release seems likely to continue to be made by simple and inexpensive procedures involving extractions with ammonium salts or acids. More sophisticated methods, which provide data on all categories of soil K, appear destined to remain the favoured tool of some scientists, and to be used only for research purposes. Progress is most likely to come from the application of models which take into account the amount and especially the rate of release of exchangeable and non-exchangeable K, soil structure and heterogeneity, the movement of nutrients through the soil, root distribution, morphology and uptake, and climate.

Adsorption and exchange of K in multi-ionic soil systems as affected by mineralogy

A. Bar, A. Banin and Y. Chen, The Seagram Center for Soil and Water Sciences, The Hebrew University, Rehovot/Israel

The adsorption characteristics of potassium in soils that received high applications of K-fertilizers in greenhouses were studied. By comparison to control soils that did not receive such high applications of fertilizers and by detailed potassium-calcium exchange isotherms, it was shown that both in the multi-ionic greenhouse soils and the binary Ca-K exchange in the soils, a pronounced decrease in adsorption affinity towards potassium is observed above a certain exchangeable potassium content. This content was defined as the *'Preferential Adsorption Capacity for Potassium' (PAPC),* and was found to correlate strongly and linearly to the content of illite in the clay fraction of the soils. The contribution of mica-type minerals in the coarser frac-

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tions of the soil to the PAPC was apparently smaller than that of illite in the clay fraction. Furthermore, montmorillonite, a major mineral in these soils did not affect profoundly the adsorption at low potassium contents. Reassessment of data from several previous studies of potassium adsorption in arid lands, including those reported by the *Riverside Salinity Laboratory* in the U.S.A., reveals that a similar abrupt change in the affinity towards potassium is present. It is recommended that it will be considered as an additional characterization parameter of potassium exchange in soils.

The surface mobility of exchangeable cations in soil

S. Staunton and P.H. Nye, Soil Science Laboratory, Department of Plant Sciences, University of Oxford/United Kingdom

It is well established that in pure clays echangeable cations are mobile and make an important contribution to the total diffusive flux through clay pastes. On the other hand in soils the evidence has been that diffusion occurs very largely through the soil solution, the exchangeable cations contributing little. Using an accurate pulse labelling method for determining self-diffusion coefficients, we have recently obtained evidence in a variety of soils that exchangeable cations may have considerable mobility. This means that estimates of the diffusion coefficients of these cations in such soils need to be increased.

Critical evaluation of soil testing methods for K

I. Novozamsky and V. J. G. Houba, Department of Soil Science and Plant Nutrition, Wageningen Agricultural University, Wageningen, Netherlands.

Various methods and approaches for determining available soil potassium are discussed and compared. It is concluded that a theoretical model describing K behaviour in soil is not yet applicable in practical soil testing, and that extraction methods supplying information on exchangeable K are useful in soil testing only when the values obtained are corrected with the use of soil parameters affecting exchange reactions in soils.

A 0.01 *M* $CaCl_2$ extraction procedure was tentatively compared with more established extraction procedures (0.1 *M* HCl and electroultrafiltration). Since different fractions of soil potassium are extracted with the three methods, different correction parameters are needed for estimating available K. With the use of such correction factors, all three methods appear equally useful. Preference for anyone of them can therefore be based on economic factors, such as ease and speed of operation and costs involved.

Translation of laboratory K-data into K fertilizer recommendations

P. Villemin, Research Centre, S.C.P.A., Aspach-le-Bas/France

Following a review of present methods for interpreting soil analysis, the methods now used at the *Aspach Research Centre* are explained. While exchangeable K does not fully describe the K supplying power of a soil, the inclusion of modifying factors reduces uncertainty in the relation between soil potential as indicated by response to K fertilizer and soil analysis results. Such factors are estimates of those forms of potassium which are not exchangeable but which contribute to the nutrition of plants. Fertilizer advice so derived is then described as well as the consequences of such a philosophy for field experimentation.

Coordinator's report on the second working session

A. van Diest, Dept. of Soil Science and Plant Nutrition, Agricultural University, Wageningen/Netherlands; member of the Scientific Board of the International Potash Institute

The topic of the second session *'K release and K fixation'* has important implications for practical agriculture. It is clear that for their direct K requirements plants depend on the K that can be readily released by the soil. *Goulding*, however, rightfuly claimed that in the long run plants also benefit from the fact that many soils are capable of retaining K that was applied to them and was not absorbed by the first crop grown after application.

In fact, it should not be forgotten that the boundary line we draw between exchangeable and non-exchangeable portions of soil K is an arbitrary and artificial one, and that during one growing season crops often manage to withdraw from soils quantities of K which are several times larger than the quantity of K originally present in so-called exchangeable or available form.

Goulding pointed out that in practical agriculture we are faced with the dilemma that many laboratory techniques capable of describing and predicting the behaviour of K in soils are too cumbersome and too expensive for practical use. In their survey of methods in use for determining available K, *Novozamsky and Houba* could only list simple extraction methods, none of which can shed any light on the behavior of K in soil.

Staunton in her paper made it clear that for a proper evaluation of the rate of supply of K to plant roots not only diffusion through soil solution, but also diffusion along exchange sites will have to be taken into account. When soils differ in the ease with which such diffusion processes can take place, one must realize that simple laboratory extraction procedures will never be able to account for such differences.

In many West European countries the study of K-behaviour in soil may be simplified by the circumstance that only one type of clay mineral is involved. In their contribution to this Colloquium, *Bar and coworkers* pointed out that the adsorption characteristics of soils may be far more complex when more than one type of clay mineral is present.

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Another important issue is the choice between a one-nutrient and a multi-nutrient extracting agent. Both systems are in use and both have their advantages and disavantages. *Villemin's* contribution is an example of a system in which only potassium is under investigation. When every nutrient has its own extracting agent, soil testing can become so expensive that farmers may show a reluctance to regularly submit samples for testing. In order to avoid such an unsatisfactory situation, I think that multi-nutrient extracting agents will become more important in the near future.

Also with the use of such multi-nutrient extractants, the disadvantage remains that the multitude of soil characteristics affecting the availability of K in soil cannot be properly evaluated in a laboratory extraction procedures. For further progress in this field I can visualize a system in which a farmer places a number of strips of cation- and anion exchangers in his soil and, after a certain period of contact between soil and exchangers, recovers the strips and submits these to a soil-testing laboratory for analysis. After recharging, the strips could be returned to the farmer for repeated use. In such a procedure, the time-consuming collecting and handling of soil can be avoided. The quantities of nutrients collected on the exchangers are a function of more soil characteristics than can be evaluated in laboratory extractions of soil material, and can therefore serve as better estimates of nutrient availability than those obtained with the conventional soil-testing procedures.

Even with such a more natural system of nutrient withdrawal, a number of factors influencing the behaviour of soil K will be overlooked. For instance, the effects that root systems have on the availability of nutrients will not be fully evaluated, and weather conditions during the growing season may differ from those in the extraction period.

Nevertheless, I expect that in the near future progress will be made in the realm of more natural techniques employed to withdraw from a soil those fractions of nutrients which under field conditions make a contribution to the nutrition of our crops. In that way, the gap may be breached between knowledge compiled by mineralogists and the analytical ease and efficiency required by agronomists. It is in my opinion the task of agronomists to devise rapid and simple extraction methods that still allow full use to be made of knowledge acquired by mineralogists on the behaviour of K and other minerals in their natural habitat, namely the undisturbed soil exposed to regular climatic fluctuations.

3rd Working Session of the 20th IPI Colloquium

Potassium Dynamics in the Rhizosphere

Potassium dynamics in the rhizosphere and potassium availability

R. O. Kuchenbuch, Institute of Agricultural Chemistry, Göttingen/Fed. Rep. of Germany

Diffusion is the main process supplying K to the root. Methods for study of K concentration distribution near the root are briefly described. The extent of

K depletion can be influenced by factors which affect diffusivity and results show that:

- Plants use both exchangeable and non-exchangeable K. Non-exchangeable K is taken up from within 1-2 mm of the root surface while exchangeable and non-exchangeable K is desorbed and transported further. Fertilization of salts not containing potassium and/or proton excretion influence availability of both, exchangeable and non-exchangeable K.
- K fertilization increases K availability because:
  (1) Concentration gradients steepen and K flux towards the root increases;
  (2) Spatial access for K is increased due to higher mobility in soil.

Transport of K to the root is facilitated as soil water content increases. The plant itself is an important factor in K availability.

Methods of sampling and investigation of rhizosphere soil

H.M. Helal and D. Sauerbeck, Institute of Plant Nutrition and Soil Science, Federal Research Center of Agriculture, Braunschweig-Völkenrode (FAL) Braunschweig/Fed. Rep. of Germany

The rhizosphere is an area of intensive interactions between plant roots and soil. These interactions are of considerable significance for the nutrient availability to the roots. However, limited progress has been so far achieved towards clarifying and quantification of the nutrient dynamics in the rhizosphere. This is mainly attributed to the lack of appropriate methods. One of the most serious problems which retarded research progress in this field is the difficulty of separating and sampling the actual rhizosphere soil for analysis. This paper gives a comparative evaluation of various methods with special reference to the techniques developed by the authors.

Techniques for studying the ionic environment at the soil root interface

B. Jaillard, Dept. Soil Science, INRA – ENSA, Montpellier/France

The study of the ionic medium in the near rhizosphere encounters a problem of the solid phase which prevents access at the study site. This difficulty originates from the diversity of study techniques used and developed in this field: dye indicator and derivative techniques, the techniques of microprobing and of soil labelling, micromorphology and electronic microanalysis. It seems that a particular effort should be made, on the one hand, in the development and the utilization of glass ion-sensitive microelectrodes which permit the direct measurement of ion activity in solution, on the other hand, in the utilization of micromorphology and associated techniques which permit the study of the near rhizosphere in undisturbed soil.

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Methods for quantification of root distribution pattern and root dynamics in the field

M. van Noordwijk, Institute for Soil Fertility, Haren/The Netherlands

For a functional evaluation of root systems in the field, two aspects deserve special interest and require separate methods for their study:

A. Spatial root distribution: heterogeneity of local root density in relation to planting pattern, soil structure, and heterogeneity of nutrient supply. Recently such heterogeneities have become the subject of research as such and are no longer treated as merely a nuisance in establishing effects of experimental treatments on average root densities. On a detailed level the degree of actual soil-root contact has become of interest.

B. Root dynamics in time: root growth and decay in the field can hardly be studied by destructive means, due to the large spatial heterogeneities. They have to be quantified by repeated observations of the same roots, under conditions which approach field conditions as much as possible.

For both types of information additions to and improvements of classical techniques are given: relations between basic root parameters, sampling schemes, quantification of root anisotropy, quantification of pattern in root distribution, quantification of soil-root contact and the mini-rhizotron technique for quantifying root dynamics.

Rhizosphere organisms – Potassium interactions with emphasis on methodology

G. Trolldenier, Agricultural Research Station Büntehof, Hannover/Fed. Rep. of Germany

There are multiple interrelationships between the rhizosphere microflora and plant nutrition involving *inter alia* the potassium nutritional status of plants and potassium availability. To elucidate some of these interactions plants have to be grown under axenic conditions. Exclusion of microorganisms is important *e.g.* for distinguishing between the activity of roots *sensu stricto* and their microbial associates as well as for collecting root exudates. The methods for axenic cultures of plants are briefly outlined. The selected substrate is a major problem in growth studies of sterile and nonsterile plants, as sterilization of soil either by heat or by γ-irradiation produces toxic compounds. Experiments have to be restricted to more or less artificial media like nutrient solution or sand. Using nutrient solution culture it was found that the K nutritional status influences microbial activity on roots via its effect on plant metabolism and root exudation. Low K supply increases the quantity of readily decomposable organic compounds released from roots.

Enumeration of microorganisms is done either directly by microscopical counting or indirectly by plate counting involving incubation on nutrient media. Both techniques showed increasing numbers of bacteria with decreasing K supply, indicating that K availability is not a limiting factor for microbial growth in the rhizosphere. Moreover, rhizosphere bacteria seem to compete successfully with plants for potassium.

Potassium nutrition affects the quantity and quality of low molecular compounds in roots and root exudates, and the composition of the rhizosphere microflora and microbial transformations in the root vicinity. Denitrification in general and certain processes in the rhizosphere of rice like those associated with iron toxicity and N_2 fixation are discussed with a brief description of the methods applied.

Weathering mediated by free living rhizosphere organisms and mycorrhizal fungi is another line of research. The results indicate that potassium release from minerals is insufficient to support optimal growth of crops.

Attempts to enhance K availability by inoculation of seeds with 'silicate' bacteria are mentioned. A recent review is sceptical about the significance of these inoculants.

Coordinator's report on the 3rd working session

U. Kafkafi, Field Crops Research Dept., Faculty of Agriculture, Hebrew University of Jerusalem, Rehovot/Israel; member of the Scientific Board of the International Potash Institute

Physical and biological methodology of the behaviour of nutrients and microbial activity near the root surface were discussed.

Calculations and actual measurements of K concentration at various distances from an active absorbing root surface were presented elegantly by *Kuchenbuch*. He showed that the distribution profile of K in proximity of an absorbing root surface depends on two kinds of parameters: *Soil parameters* like initial K concentration, buffer capacity of the soil, moisture content. *Plant parameter:* the ability of the root to extract K.

According to his calculations the plant is extracting in the root hair region K ions that are not exchangeable by ammonium acetate extraction. Two problems need further studies: 1) the development of an independent method to measure the uptake efficiency of the root(Km – *Michaelis-Manten* constant). 2) A more reliable determination of the amount of K taken up from the interlayer positions.

Jaillard has reviewed the method employed in studying the chemical changes induced by the living root on the immediate soil environment. To study root excretions during growth, the agar with dissolved pH-indicator method is used. It is possible by that method to monitor the active regions of the root that are releasing acid or basic substances to the growth medium

Using the polarized light microscope at the end of the growing stage one can monitor the cumultative effects of the root on the soil around it. It was demonstrated by the use of the Electron Dispersive System that the growing root compresses the clay around the root and reorients it. Calcium carbonate was also demonstrated to concentrate around the root.

Van Noordwijk has discussed the amount of labour involved in root study under actual field conditions. He emphasized the dynamic nature of the root system. There is a dynamic balance between root growth and root decay.

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To observe actual root growth in the field, the use of fiber optics with a video camera enables the research worker to observe actual growth and decay of a single root, as well as the changes in the root density around the lucid tubes inserted in the field. There are tremendous variations in the methods used to study root density in the field which is an indicator of the early stage of this scientific field. The complex reactions near the growing root need a joint effort from several disciplines to synchronize the reactions around the root under field conditions.

Helal and *Trolldenier* have dealt with the methods to study the biological activity around the root.

A new root cage to study the rhizosphere was presented by *Helal*. It allows a better and more accurate sampling of biological activity at predetermined distances from the root surface. He has found that up to 20% of the photosynthetic carbon is released from the root to the soil. If this method proves accurate it is expected that it will spread to other disciplines of plant research.

Trolldenier has surveyed the methods used to study the activity of bacteria around the root. He demonstrated that the C/N ratio, as affected by N application and the levels of available K have an influence on the number and composition of the bacteria in the rhizosphere. The lower the K level the higher the root excretions, hinting to the possibility that the root membrane integrity is damaged in the case of deficient K in the soil.

4th Working Session of the 20th IPI Colloquium

Field Studies on K Availability

The influence of soil structure on rooting, nutrient uptake and yield formation

T. Harrach, B. Keil and Th. Vorderbrügge, Soil Science and Soil Conservation Institute, Justus-Liebig-University, Giessen/Fed. Rep. of Germany

Water supply to the plant, soil aeration and through-rooting are important aspects of soil structure. Together with particle size distribution packing density (degree of soil compaction) is a decisive factor. Bulk density alone is not a good indicator of this; particle size distribution must also be taken into account. Measurement of compaction by penetrometer is not altogether reliable because resistance to penetration depends not alone on packing density reliability but on water content, particle size distribution and other soil properties.

After stoniness, root penetration is hindered or limited mostly by soil aeration or drying out of the soil. Resistance to penetration often gives only indirect information of the reasons for differences in root exploration.

The yield potential of a soil is determined by its rooting capacity – especially in the subsoil – and by the supply of plant available water in the rootroom.

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Root penetration and available water capacity of the soil are of decisive importance for nutrient uptake. Under present-day conditions in central Europe, soil structure is a more important factor in determining crop yield and stability of yield than is nutrient supply.

Field methods for the evaluation of soil factors affecting potassium response

R. Lichtfuss and H. Grimme, Büntehof Agricultural Research Station, Hannover/Fed. Rep. of Germany.

Apart from mobile K content in the soil K availability depends on a number of factors that can readily be assessed with simple methods and satisfactory accuracy directly in the field. Useful information can also be drawn from topographic, geological and soil maps. More sophisticated permanent field installations allow a continuous and non-destructive monitoring of soil nutrient status.

This paper describes in detail, especially, simple field methods that can be carried out without the use of expensive equipment and require only little training. Depending on the problem in hand soil testing can be supplemented by the installation of soil solution probes, tensiometers, etc. in the field or even by weather stations.

Effect of soil-water status as affected by irrigation on potassium transport in soils

B. Bar-Yosef, Agricultural Research Organization, Bet Dagan/Israel

Effects of varying soil-water content on K distribution and transport in soil were analyzed, and the factors limiting K availability to plants are discussed. Restricted soil-root volumes require continuous monitoring of K concentration in the soil solution (C_K). Ceramic vacuum cups inserted in a sandy soil at depth of 20 and 40 cm below a tomato crop provided acceptable C_K values that could be used to improve K fertilization of the crop during the growing period.

Spatial variability of soil K-status

Ph. Beckett, Soil Science Laboratory, University of Oxford/United Kingdom

This paper briefly reviews the short-, medium- and long-term elements of soil K-status. It then discusses the processes that contribute to the long-, medium- and short-range components of the spatial variability of soil K-status. In some cases temporal variability may equal or exceed spatial variability: this may confuse measurements of the latter.

It reviews published measurements of the variability of soil K-status. These demonstrate that the distribution of variability is usually not random. The non-random distribution of long-range variability in K status may be crudely described in term of soil classes or map units; these will still include the short-

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and medium-range components of the total variability, of which they may form a substantial part. Semi-variograms describe the spatial dependance of soil variability better, provided they cover all scales of variability. Even so, it may be useful to reduce the contribution of very short-range variability ('noise') by bulking several soil samples from within an area round each sampling site.

It comments on methods for measuring spatial variability, emphasizing that measures of short- or medium-range variability must be distributed over the whole area of interest.

Interpretation of long-term experiments with K manuring

A. Köchl, Institute for Agricultural Chemistry, Vienna/Austria

Results from 3 long-term (30 year) experiments and a survey series at 70 sites over 4 years are presented and discussed leading to the following conclusions:

1. Conventional soil analysis of surface soil (CAL, $BaCl_2$,H_2O, EUF) does not fully reflect the effect of long term differential K fertilizer treatment. Taking into account texture, K fixation and supply of K from subsoil brings about improvement. Correction of CAL K for K saturation of CEC improves interpretation.
2. So far as dressings for individual crops are concerned, conventional methods are helpful but not predicting requirements for ameliorative dressings.
3. Limitations of conventional determinations on top soil are made clear by the fact that on nil K plots, change in CAL K accounts for only 0.1–3% of crop uptake and on high K (300 kg/ha/yr) plots for only 2–12‰ of the excess of K application over removal. Obviously non-exchangeable and subsoil K is important.
4. Needs in terms of both K dressing and soil K content contrast as between rootcrops and cereals. Economically optimum results with cereals are obtained at CAL K values from 6–12 mg/100 g K_2O and K fertilizer rates from 1–110 kg/ha K_2O. For rootcrops the relevant values are 6–19 mg/100 g and 160–290 kg/ha/yr K_2O. Sugar content of beet and dough elasticity of wheat are positively correlated with soil-K content. Starch content of potatoes is slightly decreased by K supply, but this is compensated by higher tuber yield.
5. Economically optimum K dressings are used to the extent of 60% and 90% in supplying the K needs of current crops of cereals and roots. They produce yield increases of 5.5 t beets, 2.4 t potatoes and 0.1 t cereals/ha/yr.

Assessment of optimum application rates of fertilizer K on the basis of response curves

J.J. Neeteson, W.P. Wadman and P.A.I. Ehlert, Institute for Soil Fertility, Haren/The Netherlands

K-response curves of 39 K-fertilizer trials with potato are described by a quadratic and a modified exponential equation. In all experiments the modi-

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fied exponential equation was better when the residual sum of squares (RSS) was taken as a measure of the degree of fit. The economically optimum application rates of fertilizer K, which were calculated on the basis of the modified exponential equation, covered the entire range of fertilizer K_2O levels tested, *viz.*, 0–400 kg ha^{-1}. The confidence intervals ($p > 95\%$) for the optimum K-application rates were frequently very wide. In 18 trials the confidence interval covered the entire range of tested fertilizer levels. Although the calculations were done to demonstrate the method and not to make fertilizer recommendations, the implication is that care should be exercized in using optimum application rates of fertilizer K for making fertilizer recommendations.

Coordinator's report on the 4th working session

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In spite of comprehensive and detailed scientific knowledge about the occurrence of potassium in soils and its availability (transport) to the root, the farmer and advisor are facing tremendous difficulties, when they have to synthesize the mosaic stones of knowledge into reliable K fertilizer recommendations accounting for both, the economical and ecological aspects. The dimensions of the complex relationships in soils and plants and of their interactions are nearly undefinable. Large- and small-scale pedogenesis, soil texture and soil structure, rainfall (irrigation) pattern, etc., all these are parameters contributing to nutrient availability in the soil and thus affecting fertilizer recommendation for cropping systems of different species and yield potentials.

It is therefore important to develop simple field methods which the advisor and farmer can use for improving fertilizer application and efficiency. In his review paper on the 'Influence of soil structure on rooting, nutrient uptake and yield formation' *Harrach* has rigthly stressed the point that in modern agriculture with its high-yielding varieties and improved husbandry techniques priority in research must be given to soil structure and soil moisture availability rather than to further amendments of chemical soil analysis. Root elongation is inhibited by mechanical impedance, reduced gas exchange and decreasing soil moisture availability. Nevertheless, these three parameters can occur in such combinations as to allow a more or less good root elongation. Deep rooting is a prerequisite for high yields. Only this guarantees a satisfactory and uniform water supply of the crop during the growing season or, in other words, contributes to a sufficiently great available water capacity.

The determination of bulk density is a convenient indicator of soil structure. But it has its limitations insofar as it does not really reflect packing density and soil compaction which determine the mechanical impedance to root growth. Penetrometers must therefore be used in addition, although readings by penetrometers are also dependent on other soil factors, of which the

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soil water content seems to be the most important one. The simplest way of diagnosing the soil structure appears to be the use of a flat, square-ended spade to obtain undisturbed samples of the uppermost soil layer (spade diagnosis after *Görbing).*

It has always been the obligation of science to deduce the general principle from observed effects of single factors or their interactions. These endeavours can be achieved in two ways: by an empirical agronomic approach *(Köchl, Neeteson)* and/or by simulation models characterizing soil parameters which are important for root development and nutrient availability (*Beckett, Bar Yosef).*

From a series of long-term experiments in Austria *Köchl,* for instance, concluded that lower levels of exchangeable K would have sufficed for optimum plant productivity in an alluvial soil than those required in a sandy soil, the reason being the higher K buffering capacity in soils with higher clay content. But in spite of the higher K reserves in clay soils, actual K availability may quickly become critical, so that both root crops and cereals responded to K fertilizer. On the other hand, sandy loams require higher levels of exchangeable K/100 g soil and this quantity must be supplemented by K fertilizer to root crops, but not to cereals, although for good baking quality of wheat K fertilizer was found to be beneficial.

There is no doubt that the definition of site-specific fertilizer recommendations require long-term experiments. *Sensu strictu,* however, such recommendations are only valid for the particular site where the long-term experiment had been conducted. This was demonstrated by *Neeteron* et al. who statistically evaluated about 40 annual K fertilizer trials with potato in the period 1949–58. In these trials the confidence intervals for the prediction of optimum K application rates were frequently very wide, ranging between 0–400 kg K_2O/ha. Apart from the fact that correlations between fertilizer rates and yield response must become less close when the yield plateau is reached, one of the most important reasons for poor K fertilizer/yield relationships seems to be the enormous large- and small-range spatial variability of soils and plant-available K *(Beckett).* Even if the soils are grouped together according to families, groups and soil series, the coefficients of variation for exchangeable K can range between 30–200%. Such wide ranges cast some doubts on concepts attempting to improve K fertilizer efficiency by chemical analysis of extrapolations from ‘benchmark soils’. As long as soil porosity and soil moisture regimes are not taken into account, reliability of K fertilizer recommendations will be inadequate. This was demonstrated by Bar-Yosef who simulated the transport of K in a clay and a sand in dependence on hydraulic conductivity as well as on quantity and duration of irrigation. Though not generally applicable, such simulation models based on monitoring nutrient concentrations in the soil solution will definitely lead to a better adjustment of nutrients in the irrigation water with the nutrient demand of the crop.

For productivity evaluation of a field the advisor has to start from two basic requirements. Firstly, he needs information from the farmer about yield potential, climatic conditions and soil tillage practices at the farm. Secondly, he needs a manual of field techniques for the evaluation of a soil profile with regard to texture, soil moisture regime, redox potential, pH, compaction, root penetration, etc. Such guidelines were given by *Lichtfuss and Grimme* who also recommended the use of geological, soil and climatic maps in order to improve the interpretation of soil test data. This approach should be followed more closely than it has been done up to now.

In conclusion, progress in the improvement of fertilization recommendations can be expected from more detailed investigations but also in particular from considering the soil as an integral part of a landscape.

5th Working Session of the 20th IPI Colloquium

Methodology of potash fertilizer recommendations

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Fertilizer advice is only of use to the farmer when it gives results. Advice is based on experiments and only long-term work can give reliable information. Short-term investigation can give misleading results. Survey results should be checked by experiment.

Nutrient removals, soil K content and leaf analysis are all valuable. The use of net K removal (K in marketed produce) is less subject to error in establishing the K balance than gross K uptake. Especially when soil K content is high chemical soil analysis must be supported by analysis of other factors and modified in the light of site factors and crop characteristics. The latter are more important than the development of new extraction techniques.

Fertilizer advice aims to achieve maximum economic return which is obtained when marginal cost of K application and marginal yield increase are in balance. This involves consideration of the whole response curve and of the ratio between produce price and fertilizer cost. The return from K fertilizer is to be found not only in crop yield but also in the build-up of soil fertility.

Potash fertilizer can be applied to meet the needs of individual crops or for the rotation as a whole. On high K soils it may be preferable to apply K only to the K demanding crops. For deep-rooted long-term crops it is advisable to use a heavy dressing before establishment.