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Potassium, an integral part for sustained soil fertility and efficient crop production

Demographic processes due to fast growth of the global population and urbanization are the main reason for increasing demands for food and feed. Due to urbanization processes about 50% of food is exported into towns. In consequence on a world scale about 83 million t NPK are also transferred into towns and hardly recycle to the land where they came from. In the last decade the global production of cereals, oilseed crops, sugar crops showed some specific trends, i.e. the sown area declined (cereals, sugar beets), but the production level has been almost constant due to higher yields per ha. It means higher nutrients removal from the field with the harvest. The increasing intensity of oilseed crops, root crops and sugar crops production requires, in turn, higher level of soil fertility due to relatively poor root systems when compared to cereals. However, the current fertilizer use patterns are much worse that at the end of the 80-ies. The consumption of fertilizers, generally decreased, but also the structure of NPK use underwent some negative changes. The special attention should be focused on the potassium consumption. The resulting NK ratio in global fertilizer use depreciated rapidly from a fairly balanced ratio of 1:0,4 to currently 1:0,27. This ratio dramatically worsened in the Central Europe countries, including Poland. It has been documented, through long-term experiments, that negative K balance results in a huge reduction in the content of soil K, causing its mining. On the other hand, numerous field trials give evidence that adequate use of potassium fertilizers, i.e. in balance with the other essential nutrients increases yield and improves its quality. It is important to many countries, like Poland, that adequate K fertilization also increases crops response to water deficits, increases resistance to diseases. There are some other benefits of balanced potassium use (i) environmental — higher efficiency of nitrogen (ii) economic — increasing farmer's profits generates income, which is partly used for purchase of non-agricultural products; business attraction to the rural areas (iii) social — rural areas development, social security, etc.

Keywords: K mining, nutrients balance, population growth, potassium, yield

Procesy demograficzne, ze względu na szybki wzrost światowej populacji ludności i urbanizację, są główną przyczyną zwiększającego się zapotrzebowania na żywność i pasze. Procesy urbanizacyjne doprowadziły do tego, że ok. 50% żywności jest odprowadzane do miast. W związku z tym, w skali światowej, ok. 83 mln ton NPK również jest transportowane do miast i prawie nic z tego nie wraca na obszary rolnicze. W ostatnim dziesięcioleciu globalna produkcja zbóż, roślin oleistych i cukrowniczych wykazywała specyficzny trend: tzn. powierzchnia tych upraw malała (zboża, burak cukrowy), lecz poziom produkcji pozostawał prawie niezmieniony dzięki wyższym plonom. Oznacza to również wzmożone usuwanie składników mineralnych z gleb. Zwiększająca się intensywność upraw roślin oleistych, okopowych i cukrowniczych wymaga z kolei wyższego poziomu urodzajności gleb z powodu stosunkowo słabych systemów korzeniowych tych roślin, w porównaniu ze zbożami. Jednak obecne sposoby stosowania nawozów są o wiele gorsze, niż w końcu lat osiemdziesiątych. Zużycie nawozów zmalało, poza tym i struktura NPK uległa negatywnym zmianom. Szczególną uwagę należy zwrócić na zużycie potasu. Stosunek N do K w globalnym zużyciu nawozów szybko zmniejszył się z nieźle zbalansowanych wartości 1:0,4 do obecnych 1:0,27. Proporcja ta szczególnie pogorszyła się w krajach Europy Środkowej, w tym i w Polsce. Na podstawie długoterminowych doświadczeń polowych zostało udokumentowane, że negatywny bilans potasu w ogromnym stopniu obniża zawartość tego pierwiastka w glebie. Z drugiej strony liczne eksperymenty polowe wykazują, że odpowiednie użycie nawozów potasowych, tj. w równowadze z innymi niezbędnymi składnikami zwiększa plon i poprawia jego jakość. W wielu krajach, w tym i w Polsce, ważny jest fakt, że odpowiednie nawożenie potasem poprawia reakcję upraw na brak wody i zwiększa odporność na choroby. Są również inne korzyści ze zrównoważonego nawożenia potasem: a) środowiskowe — wyższa efektywność azotu, b) ekonomiczne — zwiększenie dochodów rolników, co generuje popyt na towary nierolnicze i przyciąga biznes na tereny wiejskie, c) socjalne — rozwój terenów wiejskich, bezpieczeństwa socjalnego etc.

Słowa kluczowe: bilans składników odżywczych, plon, potas, ubytki potasu, wzrost populacji

CROP PRODUCTION IN THE GLOBAL CONTEXT

The global population is expected to reach eight to nine billion inhabitants within the next two to three decades. Most of the population growth will occur in developing countries. Another important factor in the global demographic development is that urbanization proceeds further. FAO (2002) estimates that, within the next 20–30 years, more than 60% of the global population will live in towns compared with 40% in the eighties and 48% in the nineties.

More people need more food. Rosegrant et al. (1995) calculated that the global demand for cereals will increase till 2020 by almost 1 billion to 2.7 billion tons, and for meat by 75% to 283 million tons. This would require a growth rate of more than 2% per annum to meet the demand for cereals. However, the current situation in cereals domain shows a stagnating production, which contrasts sharply the need for higher production (Fig. 1).

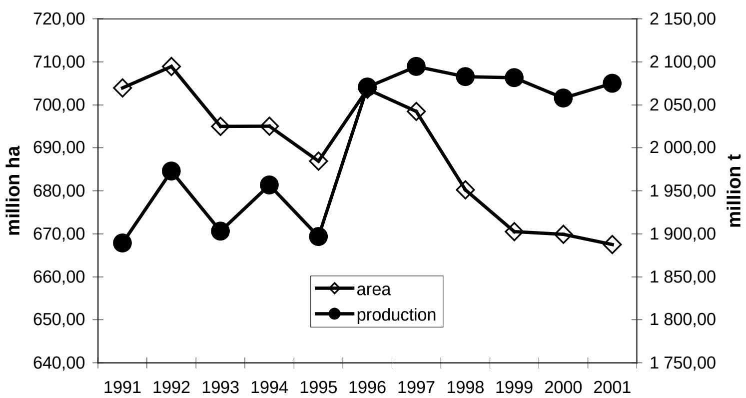

Fig. 1. Global cereal area and production (FAO, 2002)

It is also shown that the area planted with cereals decreases worldwide. Low cereal prices at the world market prevent substantial investments in cereal production. Figure 1 also indicates a higher productivity through higher yield, which on the other hand, goes in line with the demand for a vertical increase in cereal production due to a growing scarcity of arable land.

Closely related to the expected increase in demand for meat is the steady growth in oilseed production. Most of the higher oilseed output comes from larger planting area (+28% in the last 10 years), but yields also increased by 18%. Major portion of this progress comes from soybean. This crop showed during the last decade an area expansion by 39% to currently 76 million ha (Mha) and a yield increase by 23% to 2.32 t/ha, which results in an output increase of 72% to currently 177 million t (Mt). Rapeseed contributes 36.2 Mt and groundnuts (in shells) 34.7 Mt to the total oilseed output (figures for 2001). On the lower end of the scale is sunflower. Its production fluctuated from about 20 to 28 Mt, the global area stagnates at about 18 Mha, and the yield remains at a level of 1.2 to 1.3 t/ha. On the global scale, root and tuber crops show a continuous increase in area and production. However, the progress in output happens primarily in developing countries, where the production increases annually by more than 10 Mt. In contrast, root and tuber production in developed countries even shows a slightly negative trend with an annually decline of more than 1 million tons. Interestingly, India ranks 3rd after China and Russia in the global potato production, and China contributes also 86% of the global output of sweet potatoes. This shows the increasing importance that developing countries play in the global production of root and tubers.

The trend in production of sugar plants differs between the types. Sugar beet area and production decreased during the last decade by almost 30 and 15%, respectively (Fig. 2).

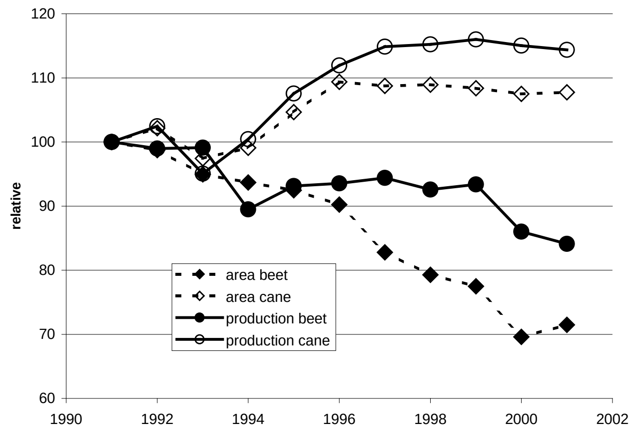

Fig. 2. Development of area and production of sugar plants (FAO 2002)

The decline in beet area was partly compensated by an overall increase in beet yield of 17%. In contrast, cane production increased in the last decades by around 15%, partly due to larger planting area, but it stabilized in the recent years. The decreasing beet and stagnating cane production may reflect the rather unsatisfactory price development, which experienced in the last years a continuous depreciation. In addition to that, sugar consumption in developed countries seems to decline, the per capita supply of sugar (refined equivalent) decreased from 1990 to 1999 by 3.3 kg/year to 30.4 kg. On the other hand, developing countries increased slightly the sugar consumption by 1.4 kg/year to 15.5 kg. However, it seems that the world sugar price starts to recover, the demand for sugar on the world market seems to exceed the current supply. In addition, it should not be overlooked that a rather large portion of cane is converted into alcohol as fuel like in Brazil or in countries of Southern Africa.

Developing countries also play a major role in the global fruit and vegetable production. The output increased in the last decade by 300 Mt to currently 850 Mt, whereas production in developed countries varies at around 280 Mt. Incidentally, the per capita consumption of fruits and vegetables in developed countries appears to be saturated at a fairly high level of more than 190 kg/year, whereas the consumption of fruits and vegetables in developing countries is still rapidly increasing. This trend reflects the obvious change in income because, with growing income, subsistence food will be progressively replaced by fruits, vegetables and animal protein.

CONSEQUENCES OF CHANGING CROPPING PATTERN FOR THE NUTRIENT MANAGEMENT

In consequence of the demand for a higher productivity of the remaining arable land, the crop yield has to be increased. However, in order to achieve a higher yield, the plant has to absorb more nutrients and ultimately, more nutrients are removed from the field with the harvest. Johnston (2002) compared yield and K offtake of wheat from a long-term field trial in Rothamsted and showed that, with increasing yield due to better fertilization and use of improved varieties, the K removal by crops increased as well (Fig. 3). In other words, the demand for vertical increase in crop output can only be met by simultaneous increase in nutrient supply to the plants.

The consequences that urbanization has on nutrient management can be seen in the fact that, with export of food from the rural area into towns, nutrients are also transferred. On a world scale about 175 million t N + P_2O_5 + K_2O are removed with harvested crops. Assuming a global rate of urbanization of 48%, this means that at least 83 million t NPK are transferred into towns and hardly recycled to the land where they came from. Even worse, the high solubility of K in organic waste leaches K in the sewage treatment plants with the water, which is usually drained off into river systems. The remaining solid waste contains mostly N and P. However, health concern, mixing of urban waste with toxic and/or heavy metals prevent widely use of sludge from urban sewage plants. EFMA (2000) estimates that about 2.6% of N, 3.3% of P_2O_5 and only 1.1% of K_2O used in EU agriculture derive from non-livestock urban waste.

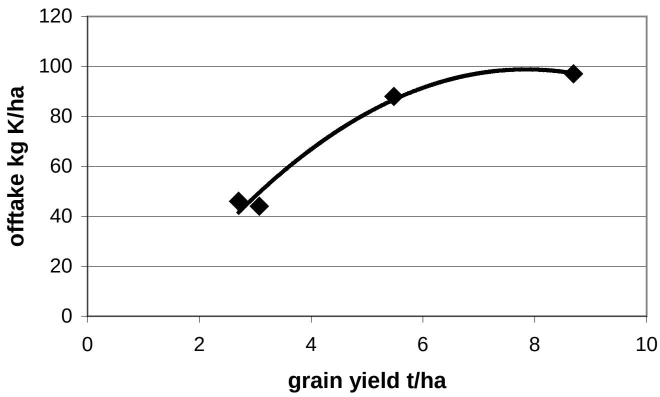

Fig. 3. K offtake of the whole wheat plant in relation to the grain yield (Johnston, 2002)

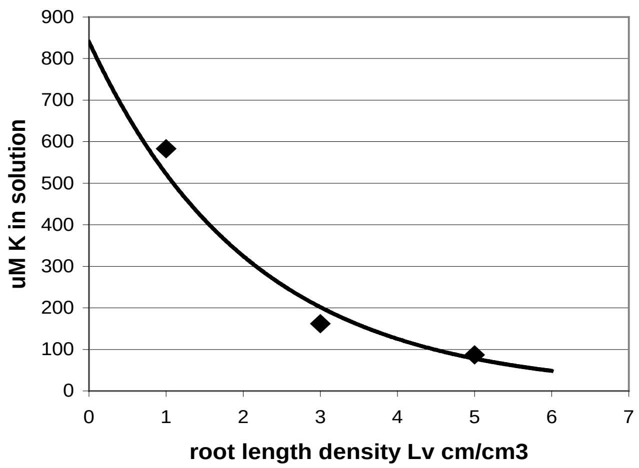

Fig. 4. Soil K concentration needed in soil solution to sustain a high K uptake rate as affected by root length density (after Johnston et al., 1998)

Higher demand for animal protein fuels growth and trade of oilseeds as feed in livestock production. As an example, the European Union imported in 1997, with oilseed cake and seeds, the equivalent of some 570‘000 t K_2O, which adds to the nutrient balance. Consequently, livestock farms in Germany have a highly positive nutrient balance because the bulk of nutrients remain at the farm in form of animal excrements. Only 22% of N and P, and 4% of K, which entered the farm is removed in animal products sold from the farm. In contrast, the same survey by Bach et al. (1997) also showed that stockless arable farms in Germany have a farm-gate nutrient balance almost in equilibrium, even with a slight negative balance for P and K.

Higher demand for oilseeds has also its consequences for the nutrient management of the crop. Oilseeds, and this applies also to vegetables, root and tuber crops and sugar beet, have a relatively poor root system when compared to cereals. This restricts the soil volume, which can be exploited and thus, requires a much higher K concentration in soil solution to meet the demand of the crop (Fig. 4).

UNBALANCED USE OF MINERAL FERTILIZERS, A WIDESPREAD PROBLEM

Figure 5 shows the development of the global fertilizer use as it appeared the last 20 years. The peak in consumption from end of the eighties was followed by a strong decline, mostly caused by the collapse of fertilizer use in CEE and FSU. Economic and ecological considerations in W-Europe and N-America also contributed to the decline in fertilizer use.

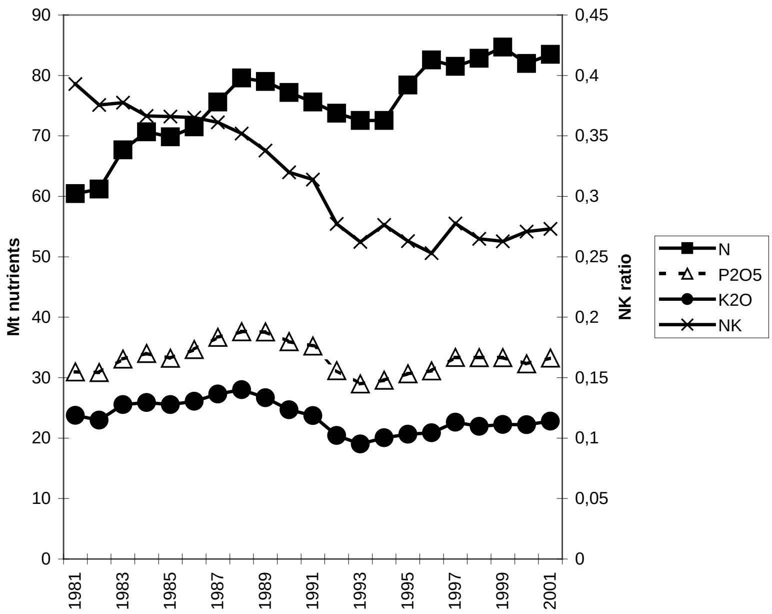

Fig. 5. Global fertilizer consumption

The more recent development is characterized by a substantial recovery of the N consumption, whereas use of P and K in particular still lags behind the peak some 10 years ago. The resulting NK ratio in global fertilizer use depreciated rapidly from a fairly balanced ratio of 1:0.4 to currently 1:0.27.

The NK ratio in fertilizer use varies considerably between the regions. Latin America, North East Asia, North America and West Europe have a rather close NK ratio, developing countries, Asian regions in particular a rather wide NK ratio (Fig. 6). Predominance of soybean in crop rotations of Latin America and a traditionally well established potash promotion in N-America and W-Europe are some of the reasons for the close NK ratio in these countries. Figure 6 also shows that, in the different regions of the developed world, the NK ratio worsened in the last decade whereas some improvement is observed in the developing countries. The current poor status of the regional potash supply becomes more obvious when the potash use is compared with the K removal by crops (Fig. 7). All regions shown in figure 7 have a negative K balance, especially those from the developing worlds. This indicates heavy soil K mining and loss in soil fertility. In contrast to K, the use of N and P is by and large in the same order of magnitude than the N and P removal by crops.

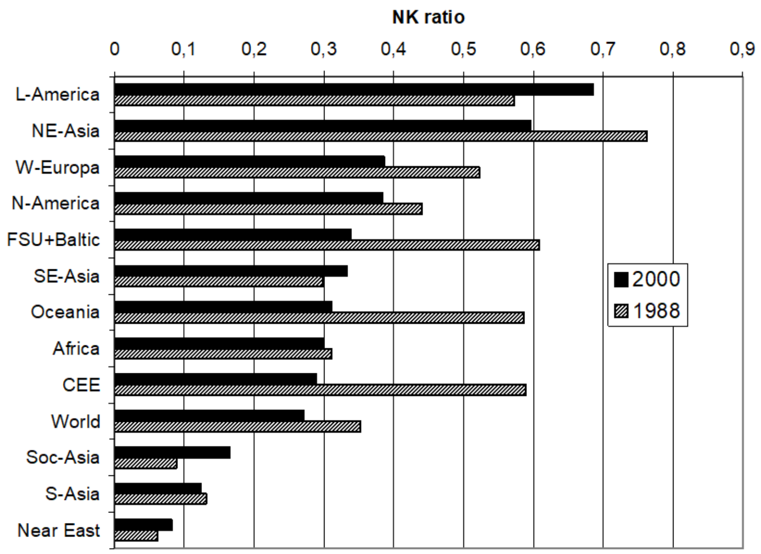

Fig. 6. Regional NK ratio in fertilizer consumption 2000/01 compared to 1988

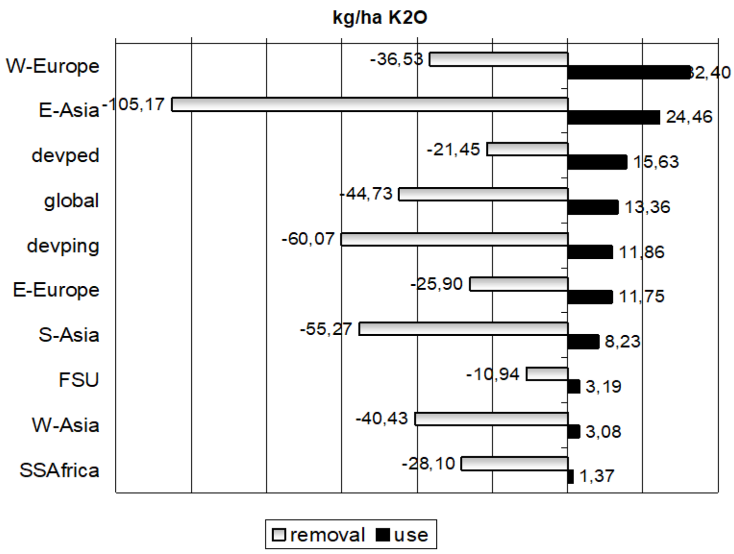

Fig. 7. Regional K removal by crops in relation to potash use (mean 1997–1999)

MONITORING OF SOIL K MINING, CAN WE DO BETTER ?

A widely accepted concept divides soil K into four pools or compartments:
— the soil solution K (Ksl)
— the exchangeable K (Kex)
— the fixed or non-exchangeable K (Kf)
— and the K in the lattice of certain primary minerals (Kl).

The amount of K in each fraction varies and depends on past cropping history, past fertilizer and manure use, i.e. the K balance, soil pH and soil water content. As a very general figure, the content of Ksl ranges from 5-20 kg K/ha, the content of Kex from 100–500 kg K/ha, Kf from 1‘000 to 2‘000 kg K/ha and K in the lattice (Kl) is contained in more than 10‘000 kg K/ha.

The plant availability of K from the different fractions or pools varies as well. K dissolved in the soil solution (Ksl) is immediately available to plants. Also Kex is fairly readily available unless soil K is exhausted. Less readily available is the fraction Kf, which is the fixed or non-exchangeable K. And finally, the huge pool of lattice K (Kl) is released only with weathering of the soil minerals.

As indicated in Figure 8, the fractions Ksl, Kex and Kf are related to each other through reversible exchange processes. K removed by uptake of plants and/or leached into the subsoil is replenished by K released from both the Kex and Kf pools. There can be simultaneous release of K from both pools to the soil solution or a linear exchange process, from the non-exchangeable to the exchangeable pool, and from the exchangeable pool to the soil solution. Whether one or other of these two possible mechanisms predominates is of little practical importance provided that the K in the soil solution is replenished quickly enough to meet the maximum demands of a rapidly growing crop. When there is surplus K in the soil solution, after the addition of fertilizer or manures, K is transferred to both fractions through exchange and fixation processes.

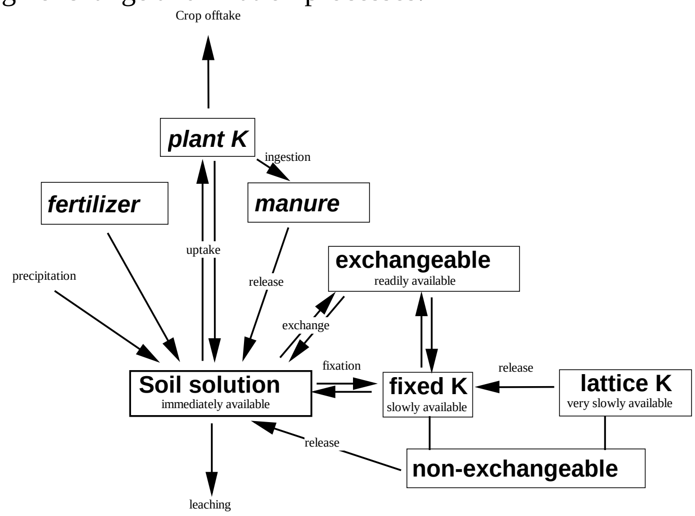

Fig. 8. The potassium cycle in the soil-plant-animal system (from Syers, 1998)

The involvement of exchange processes between the three main pools, namely Ksl, Kex and Kf in the K supply to plants can lead to misinterpretation of soil test results and thus, to inadequate fertilizer recommendations. Few examples:

— A long-term experiment with grassland at Rothamsted showed that the content of Kex after 7 years without potash fertilization hardly changed, it even increased slightly, although considerable amount of K had been removed by the harvested grass (Fig. 9) (Johnston et al., 2001). This shows that substantial quantities of K are absorbed by plants from a fraction of soil K, which is not determined by routine soils tests. The dynamics of exchange between the different soil K fractions were obviously quick enough to hide any change in the content of Kex.

— Johnston and co-workers (2001) also reported that, in the Garden Clover Experiment in Rothamsted, a total balance of 1667 kg K over a period of 10 years increased the content of exchangeable K by only 690 kg/ha, which is only 41% of the K balance (Fig. 10). Almost 60% of the K balance had gone into a pool of K that did not belong to the Kex fraction always assuming that no large amount of K was lost through leaching. On the other hand, in the same experiment, the subsequent long-term omission of K, and thus, a negative K balance of 1494 kg K/ha due to crop removal, resulted in a reduction in the content of Kex by only 563 kg K/ha, i.e. a reduction by 38%. The other 62% of the K removed had to be supplied by K in other soil K pools.

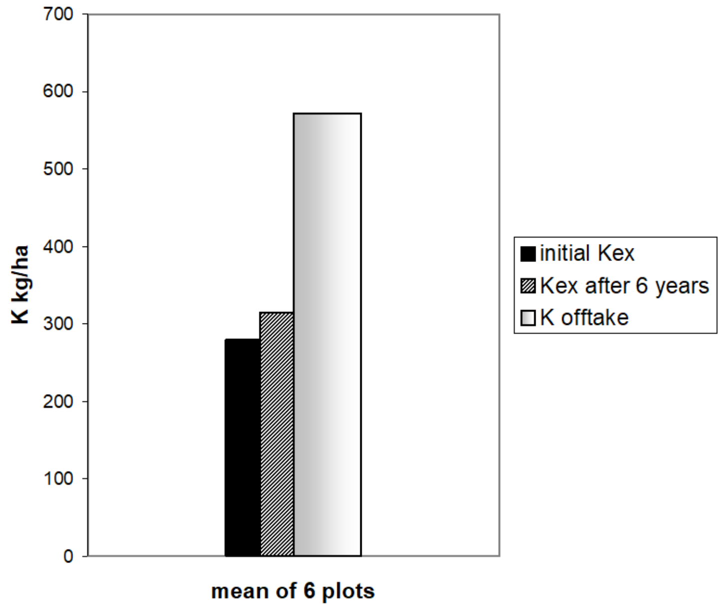

Fig. 9. Relationship between the change in soil Kex and K removal by crops (after Johnston et al., 2001)

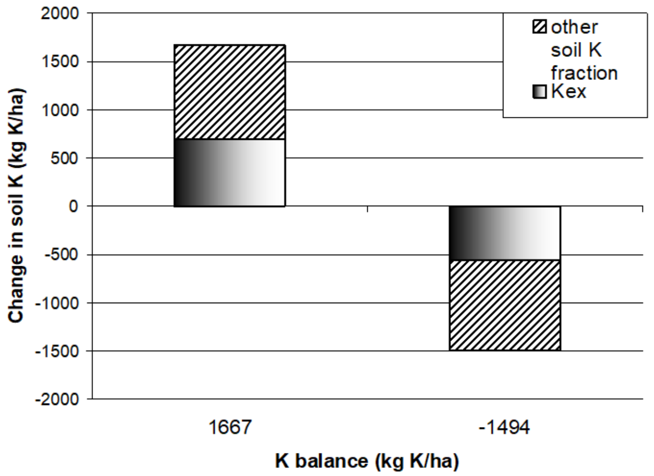

Fig. 10. K balance and changes in Kex (after Johnston et al., 2001)

POTASSIUM, THE KEY FACTOR IN CROP PRODUCTION

Progressing soil K mining due to negative K balances in fertilizing practice questions the sustainability of soil fertility in many countries worldwide. Use of organic manure cannot compensate inadequate use of mineral potash fertilizers, unless nutrients are imported together with feed concentrate and accumulated at the farm level.

On the other hand, numerous field trials give evidence that adequate use of potash in balance with the other essential nutrients increases yields and by that improves use efficiency of inputs like soil, water and energy in form of fertilizers. Dobermann et al. (1999) for instance could demonstrate that adequate potash not only increased yield of rice in SE-Asia but improved at the same time the recovery efficiency of N from 25% to 51%. This also means an effective contribution to protect the environment.

Lower yield at inadequate and unbalanced fertilization also means loss of opportunity income. Additional income of up to 300 PLN/ha in Poland, 1000 K/ha in Czech Republic, or 50‘000 HUF/ha in Hungary could be achieved from sugar beet with balanced fertilization. Comparable benefits were obtained with rapeseed in Czech Republic, with potato in Poland and Romania or with grapes in Bulgaria.

Its involvement in the enzymatic control of the metabolism of plants renders potassium also to be a major factor in quality production. As an example, IPI sponsored field trials in Hungary increased the sugar content of sugar beets from about 17.5% at NP only to more than 19% at balanced fertilization with NPK + Mg. With the better beet quality, considerably less beets have to be transported and crushed in order to extract the same amount of sugar from low quality beets (Fig. 11).

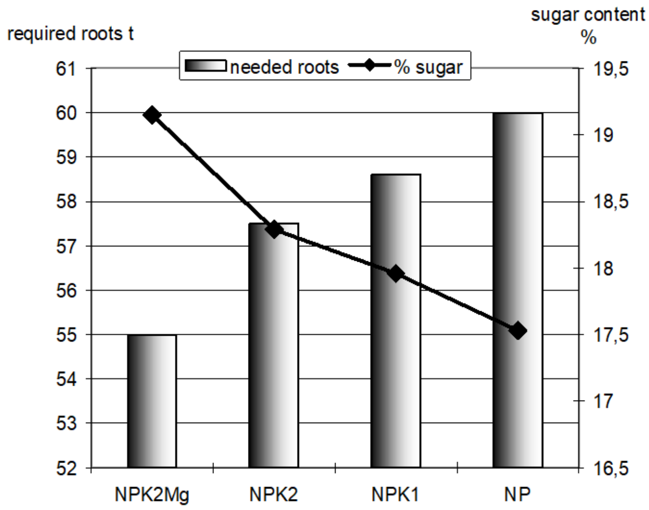

Fig. 11. Required beet roots to extract 1 t sugar as affected by fertilization

Other examples are higher protein content in wheat, higher oil content in rape seed, soybean and groundnut, better fibre quality in cotton and flax, or higher vitamin C content in cabbage.

Balanced fertilization with potash is also crop insurance. The IPI Research Topics No. 3 on "Potassium and plant health" reviewed almost 2450 literature references on this subject and concluded that the use of potassium decreased the incidence of fungal diseases in 70% of cases. The corresponding decrease of other pests was bacteria 69%, insects and mites 63% and viruses 41%. Simultaneously, K increased the yield of plants infested with fungal diseases by 42%, with bacteria by 57%, with insects and mites by 36%, and with viruses by 78% (Perrenoud, 1990). Accumulation of low molecular organic compounds in plant cells, soft tissue and discoloration, which attracts insects, are some of the reasons of a higher susceptibility of plants at unbalanced N oriented nutrition.

A higher frost tolerance as shown in IPI trials with oat in Belarus, or a better drought resistance as found by Wyrwa et al. (1998) in triticale in Poland complete the benefits balanced fertilization has to insure the crop against climatic and/or biotic stress situations.

CONCLUSION

Unbalanced fertilization with inadequate potassium is indeed a worldwide problem. The less spectacular response of crops to potash application as compared to N is certainly one of the factors, which leads to unbalanced fertilization. Another reason might be related to inadequate interpretation of soil test results, especially in context with the availability of soil K. Disregard of crop quality in procurement systems, widely seen in developing countries fails to stimulate use of balanced fertilization. And, last but not least, use of potash is considered as environmentally unproblematic and thus, potash is out of the headlines.

Not using adequate potash will become an environmental problem because of inefficient use of natural resources, waste of energy and pollution of the environment. This should be of concern to the society.

Food safety and availability through higher yields, better quality and more resistant crops should be of concern to policy-makers dealing with population growth, rural development, social security. And lastly, a better economy of crop production should be of concern to farmers. With higher profits at balanced fertilization he generates income, which partly can be used for purchase of non-agricultural products. This attracts other business in the rural area, creates jobs and reduces migration, just to name few of the benefits of balanced fertilization.

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