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SATURS/CONTENTS

Autoru iesniegtie manuskripti ir zinātniski rediģēti./The authors' contributions have been scientifically edited.

Priekšvārds

Mēslošanas līdzekļu lietošana cilvēces labklājībai, pārtikas vajadzības nodrošināšanai, dzīves kvalitātes paaugstināšanai. Mēslošanas līdzekļu lietošana, ņemot vērā produkcijas kvalitāti, iespējamos kaitējumus un slodzi dabīgajām ekosistēmām. Mēslošanas līdzekļi un neatjaunojamo dabas resursu racionāla izmantošana. Mēslošanas ekonomika. Šie un iespējams vēl citi aspekti iekļaujas mūsdienās plaši lietotajā terminā "ilgtspējīga lauksaimniecība" vai arī ir šīs koncepcijas stūrakmeņi. Tas ir moto cilvēkiem visā pasaulē, kas veic pētījumus, nodarbojas ar praktisko lauksaimniecību, tirdzniecību un dabas pārraudzību. Tas ir arī ļoti svarīgi reģionam, kurā iekļaujas Baltijas valstis, Baltkrievija un Polija. Šī reģiona valstīm jāvelta lielas pūles lauksaimniecības stabilizācijai un modernizācijai, lai tā varētu iekļauties ES kopējās struktūrās. Reģions atrodas no vides viedokļa jutīgajā Baltijas jūras sateces baseinā.

Šo problēmu nozīmība, iespējams, bija veicinošs faktors Reģionāla semināra organizēšanai, kas tika realizēts, sadarbojoties Starptautiskajam Kālija institūtam (Bāzele, Šveice) un LLU Augsnes un agroķīmijas katedrai. Seminārs **KĀLIJS UN FOSFORS ILGTSPĒJĪGAS LAUKSAIMNIECĪBAS KONTEKSTĀ** notika 2002. gada 7.-8. februārī Jelgavā un pulcēja dalībniekus no Latvijas, Lietuvas, Igaunijas, Baltkrievijas, Polijas un Šveices. Tā programma bija veltīta dažāda rakstura pētījumiem par augu barības elementu pārvaldību, sevišķu vērību veltot kālijam un fosforam. Semināra mērķi, kas tika akcentēti kā tikšanās galvenais diskusiju loks, bija šādi un, pēc manām domām, vairāk vai mazāk tika arī sasniegti.

1. Ziņojumi par pašreizējo stāvokli pētījumu un praktiskās darbības jomā attiecībā uz kālija un fosfora izmantošanu lauksaimniecībā. Jauniegūtie rezultāti, koncepcijas, metodes, situācijas analīze. Tas ietvēra arī mēģinājumu objektīvi izvērtēt pašreizējo situāciju, saistot to kopā ar nākotnes vajadzībām.
2. Pieredzes apmaiņa pētniecības, ieviešanas, Ilgtspējīgas lauksaimniecības koncepcijas ideju izskaidrošanas jomā. Kā stiprināt zinātnieku lomu jauno lauksaimniecības metožu un organizācijas formu apguvē.
3. Izvērtēt sabiedrības mainīgās vajadzības un paaugstināt zinātniskās informācijas pielietošanu. Zinātnes–konsultatīvās darbības saites. Zinātnes un tās iegūto atziņu veicināšanas prioritātes kālija un fosfora minerālmēslu lietošanas jomā.
4. Izvērtēt, vai mūsdienu lauksaimniecība ir ilgtspējīga attiecībā uz kālija un fosfora lietošanu pašreizējā apjomā? Vai pētniecība var ietekmēt šo situāciju?

Participants of the seminar / Semināra dalībnieki

5. Atrast jaunus kopintereses punktus, iezīmēt nākamās sadarbības plānus un diskutēt par savstarpēji interesējošām problēmām.
6. Stiprināt eksistējošās profesionālās sadarbības saites.

Šajā Rakstu krājumā publicēta daļa materiālu, ko sagatavojuši semināra dalībnieki un kurus autori prezentēja mutiski vai stenda referātu veidā.

Semināra orgkomiteja: Dr. Ādolfs Krauss (priekšsēdis, Starptautiskais Kālija institūts), prof. Aldis Kārkliņš, (sekretārs, LLU), prof. Josifs Bogdēvičs (Baltkrievijas Augsnes zinātnes un agroķīmijas ZPI), Dr. Sigitas Lazauskas (Lietuvas Zemkopības ZPI), Dr. Ināra Lipenīte (LLU).

Prof. Aldis Kārkliņš

Foreword

Use of fertilizers for the benefit of people, for improvement of food supply and life quality. Fertilizer use taking into consideration quality aspects, possible harmful effects, loads on natural ecosystems. Fertilizers and rational use of non-renewal natural resources. Economics of fertilizer use. These and possibly some more aspects are included in the well-known term "sustainable agriculture" or are building blocks for this concept. This is a motto of many people all around the world involved in research, farming, trade, and monitoring of environment. These aspects are very important also for the region, which includes the Baltic States, Belarus, and Poland. This region is characterized by agriculture that needs many efforts for its stabilization and modernization in order to integrate into the EU framework. This region is located in the vulnerable zone of the Baltic Sea drainage basin.

The importance of these problems probably encouraged organization of the Regional Workshop what was realized by International Potash Institute (Basel, Switzerland) and the Department of Soil Science and Agrochemistry, Latvia University of Agriculture. The workshop **POTASSIUM AND PHOSPHORUS FOR SUSTAINABLE AGRICULTURE** was held in Jelgava, February 7-8, 2002 and brought together participants from Latvia, Lithuania, Estonia, Belarus, Poland, and Switzerland. The Workshop program included different topics of plant nutrient management studies focussing on potassium and phosphorus. The objectives put as the main point of the meeting were as follows and, up to my opinion, were more or less realized:

1. Report on the status of research activities and practical situation regarding the potassium and phosphorous use in agriculture. New research findings, concepts, methods, situation analysis. This included attempts to objectively evaluate the current situation relative to the future needs.
2. Exchange of experience within the area of research, implementation, promotion of ideas of the concept of Sustainable Agriculture. How to strengthen the role of researchers within the activities in order to adopt new methods and organization forms of agriculture.
3. Evaluate the changing demands of the society and increase the use of information provided by research. Research–extension relationships. Priorities of research and promotion regarding use of the potassium and phosphorous fertilizers.
4. Evaluate: is farming sustainable at the current level of the potassium and phosphorus use? Can research influence this situation?
5. Find new common points of interest, draw up the future cooperation plans and discuss the problems of mutual interest.
6. Strengthen the already established professional links.

This volume of Proceedings contains a part of publications prepared by the participants of the Workshop and is based on the authors' oral and poster presentations.

Organizing committee: Dr. Adolf Krauss (Chairman, International Potash Institute), Prof. Aldis Karklins (Secretary, Latvia University of Agriculture), Prof. Iossif Bogdevich (Belorussian Research Institute for Soil Science and Agrochemistry), Dr. Sigitas Lazauskas (Lithuanian Institute of Agriculture), Dr. Inara Lipenite (Latvia University of Agriculture).

Prof. Aldis Karklins

Quality concern of consumers and its implication for nutrient management in crop production
Patērētāju interese par pārtikas kvalitāti un tās saistība ar augu barības elementu lietošanu kultūraugu audzēšanā

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Abstract. Food quality plays a dominant role in selecting food at the market. With increasing income, the demand for high quality food increases as well. Recent food crises like BSE, FMD or misuse of agrochemicals fuel the demand for safe food. The increasing market for so-called bio-food reflects the change in food habit. On the other hand, globalization and international trade tariff agreements bring a wider range of food different in kind and quality to the market. In consequence, the farmers are forced to respond according to the changing market demand, namely to produce food that is quality wise, competitive, but safe at the same time. However, quality is not a simple and standardized character, it refers to the value, which is subjectively or objectively attached to food. On principle, quality can be expressed in its nutritional property, functional property, hygienic and organoleptic properties, its environmental compatibility and its safety when consumed. In complying with the demand from the consumer for better and safer food, the farmer becomes more competitive at the market. Applying balanced fertilization secures the farmer's market position and increases his income, the farmer can also certify quality and origin of his produce. Demonstrating a transparent production would give him an extra bonus at the market.
Key words: plant nutrient management, balanced fertilization, food quality.

Introduction

Quality has become a major concern in selecting food – what are the reasons?

Food crisis. BSE, food and mouth disease, almost daily news on the use of illegal growth regulators and antibiotics in crop and animal production have caused serious concern on safety and quality of food. Whereas conventional farmers like in the European Union have to fight to survive from the food crisis, so-called „bio-farmers" enjoy rapid increase in demand for their products. The distributors of „bio-food" in Germany assume a 20 to 30% increase in sales last year (2001), the current „bio-market" in Germany is estimated at ɑ5 billion and will grow further as it is observed in other European countries, USA and Japan. With each food related crisis, sales of „bio-food" jump up and remain at the higher level, a kind of „staircase" effect. The move to „bio-products" is supported by the political goal to convert up to 20% of farmland in Germany to „organic farming". This is of course a tremendous challenge to conventional farms.

Urbanization. FAO (2002) estimates that, by the year 2030, the proportion of the world's population living in towns will have grown to 61%, compared with 40% in the 80-ies and 48% today. The increase in urbanization will be greatest in developing countries (1980 <30%, 1999 – 40%, 2030 – 57%). In contrast, in developed countries, urbanization, already 74%, is expected to increase only slightly to 82% in 2030.

Dietary habits alter with urbanization and income. In general, developed countries, with their high proportion of urban people, consume much more fruits, vegetables and meat than developing countries. The per capita supply of fruits and vegetables of people in developed countries is, according to FAO (2002), with 193 kg per year about 30% higher than in developing countries (147 kg $year^{-1}$), whereas consumption of staple food like rice shows a reverse trend (11 kg $year^{-1}$ in developed and 71 kg $year^{-1}$ in developing countries; figures for 1999). Correspondingly, in California for instance, the value of fruits and vegetables produced in the local agriculture has more than doubled in the last 20 years to currently $13 billion, whereas the value of field crops has even decreased slightly to $3.6 billion (Johnston and Carter, 2000).

Income. As indicated in Figure 1, with increasing income the diet shifts from low value subsistence crops like cereals and root crops towards animal protein, fruits and vegetables, and quality comes into picture. It is also obvious that the wealthy „high-tech" urban society spends less time on food preparation and looks for packed and processed food. Another observation is that the market, for instance in Germany, has become more polarized. There is a distinct shift from the traditional price structure with 3 segments, i.e. a certain low price segment, a large moderate price segment and a relatively small high price segment, to a price structure with only two components – a large low price and a large high

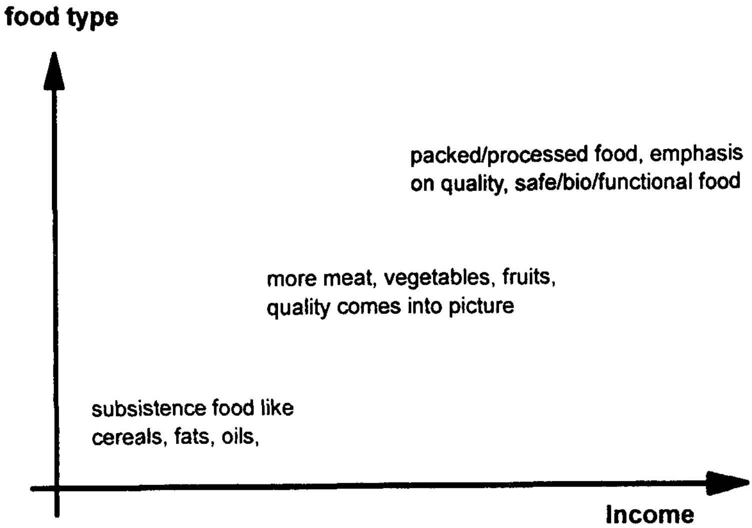

Fig. 1. Relationship between income and food habit (after KERN, 2000).

price segment. „Bio-food" is found in the latter, whereas the bulk of consumers, especially in developing countries, looks for cheap and affordable food. The moderate price segment seems to disappear.

Demographic development. According to OECD (2002), the share of aged people (older than 65 years) in industrialized countries will steadily increase. As an example, the share of „above 65" in Germany will increase from currently 16.4 to 26.1% in 2030, in Italy – from 18.2 to 29.1% and in USA – from 12.5 to 25%. This will certainly have an impact on the food habit towards processed food, functional food and higher quality, but at reasonable costs because it is doubtful whether with the demographic evolution, the current level of retirement payments can be maintained.

Concerning the functional food, there is an increased public interest in this type of food which may have a potential to lower body fat, cure gut maladies, provide gender and age-related medical needs, improve skeletal strength, lower cholesterol or improve the optical vision, etc. (Kern, 2000). Ingredients such as lycopene in tomato, allicin in garlic or isoflavones in soybean are associated with prevention or treatment of cancer, diabetes, hypertension, and heart disease (Bruulsema, 2000). The diet can also play a critical role in a wide spectrum of diseases. Keen and Zidenberg-Cherr (2000) refer to the antioxidant effects of vitamins C and E in human plasma, what are prolonged in the presence of the phytochemical catechin, a phenolic compound found in fruits, vegetables, green tea, red wine and chocolate.

Quality counts at the market place

Irrespective of whether agricultural products are grown for the domestic market or for export, the quality of the produce determines success at the market. A survey in 7 European countries shows that quality, though largely a subjective property, is rated as the most important determinant of acceptability by 25% of consumers, followed by price (16%), brand name/ reputation (14%) and freshness (9%) (Fig. 2) (Traill, 1999).

Food quality is "... an intrinsic property of food by which it meets pre-defined standard requirements. Determinants of food quality can be grouped into several properties. Food quality therefore refers to the value, which is subjectively or objectively attached to food with respect of quality properties ..." (Abalaka, 1999).

Major quality components consist of the nutritive value, functional property, hygienic, organoleptic properties, and whether the food has been produced in context with the environment. The different traits are interrelated to each other and should not be seen in isolation.

Nutritional properties

↓

hygienic properties → FOOD QUALITY ← organoleptic properties

↑ ↑

functional properties environmental compatibility

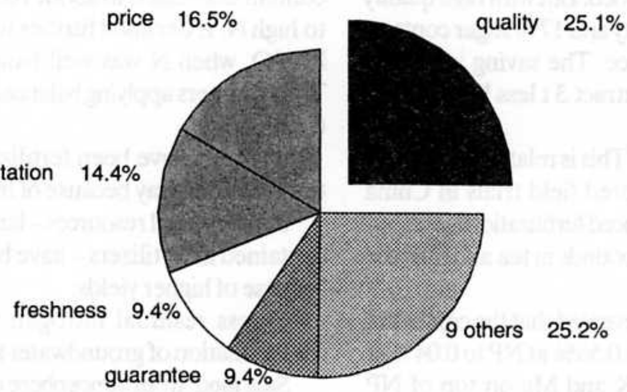

Fig. 2. Relative importance of product attributes in product choice (after Traill, 1999).

More detailed quality indicators were compiled by Haerdter and Krauss (1999), listing next to nutritional value also aspects of health, sensorial, suitability, socio-physiology, political-societal and ecological values.

Focus on quality necessitates balanced fertilization

The multi-functionality of potassium predestines this nutrient to play a dominant role in quality management.

Nutritional properties. This refers to the content of certain constituents such as protein, oil or fat, starch, mineral components and vitamins. Contents of fiber and ballast substances as well as the energy content are widely used parameters in human diet. The content of nutritive elements like protein or oil is used in many countries as a basis for procurement systems and thus, is an economic factor.

Numerous field trials conducted by IPI and other fertilizer associations have shown that balanced fertilization with potassium increases the protein content in wheat, oil content in soybean, groundnut and rape seed, the vitamin C content in vegetables and fruits, or the content of functional substances like lycopene or isoflavones in tomato and soybean, respectively. The involvement of potassium can be seen in its role as an enzyme activator in N metabolism. As shown by Koch and Mengel (1974), K deficient tobacco plants not only absorbed 26% less nitrate than plants receiving adequate potassium, from the nitrate taken up only 15% were incorporated into protein and 45% still remained as nitrate. In contrast, plants well fed with potassium converted 40% of nitrate into protein and kept only 30% as nitrate. The higher protein content of plants with adequate potassium improves the nutritive value. Less remaining nitrate in the tissue at higher conversion rates complies with the demand of the consumer for "safe" food, and the higher nitrate uptake at adequate K supply matches with the requirement of environmentally friendly crop production.

Functional properties. This refers to sugar content in beets and cane, fiber content and quality in cotton, flax, jute, starch content in potato, etc. Sugar beet in Hungary receiving adequate potash gave a higher root yield with increased sugar content and consequently a much higher sugar yield (Kulcsar and Debreczeni, 1997). The latter counts when quality–based procurement systems are established. Farmers in Germany earned an additional $140 per ha from sugar beet at 360 kg ha^{-1} of K_2O in spite of higher fertilizer costs because, at adequate soil K levels, quality of beet improved and commanded a higher procurement price (Orlovius, 1996).

A lower sugar content in beet receiving inadequate potash derives from reduced translocation of assimilates from the leaves into the storage organ due to restricted phloem loading. This was demonstrated by supplying potato plants with labeled C and subjecting them to varying K supply. In plants receiving reasonable amounts of K, 80% of foliar applied ^{14}C was translocated within 2 hrs into the tubers, whereas K-deficient plants retained more than 50% of the absorbed ^{14}C in the shoot (Haeder et al., 1975). In addition to lower sugar translocation, beets grown at unbalanced high N and inadequate K have a high content of noxious nitrogen. Noxious N reduces the extractability of sugar from beet. Noxious N accumulates because synthesis of protein is restricted at K deficiency as shown before with tobacco. Furthermore, the sugar content is low because more assimilates are required for N metabolism (Krauss and Beringer, 1988).

Apart from the economic loss the farmer has when he delivers beets low in sugar content, there is also damage to the national economy. Oehlund (1999) has calculated that in order to produce one ton of sugar from low quality beet (e.g. 80% extractability and 13%

sugar content typical of unbalanced fertilization) around 10 tons of roots would be needed. But with high quality beet having 95% extractability and 17% sugar content, less than 7 tons would suffice. The saving in energy required to transport and extract 3 t less high quality beet is obvious.

Organoleptic properties. This is related to the taste and appearance. IPI sponsored field trials in China showed for instance that balanced fertilization increased the content of aromatic compounds in tea and thus the quality.

Potato trials in Bulgaria revealed that the content of reducing sugar dropped from 0.56% at NP to 0.04% at balanced fertilization with K and Mg on top of NP (Nikolova, 1999). A low content of reducing sugar in potato tubers is the main prerequisite of tasty and bright colored potato chips.

In Russia, cabbage stored during 4 months showed substantial loss in weight (35%) and serious incidence of spot necroses when there is unbalanced fertilization with NP only. Balanced fertilization in contrast improved the shelf-life (weight loss 27%) and considerably reduced the incidence of spot necroses. After 4 months, these cabbage heads also had a rather favorable K:N ratio of 1.18, whereas the cabbage heads at NP control contained substantially more nitrate (K:N 0.49). Comparable results were also found in carrots and red beet in Russia.

And finally, fissures, cracks and lesions observed on K-deficient fruits and leaves not only offer easy access to invading pathogens but also repel potential consumers at the market. The appearance and thus the quality are poor, and the farmer cannot sell his produce.

Hygienic properties. Plants adequately supplied with potash show fewer incidences of pests and diseases. K-deficient plants have a higher content of low molecular organic compounds, such as amino acids or sucrose in the tissue, which is, on the other hand, the preferred food stock for pathogens. The tissue of plants fed with unbalanced nutrition is also softer and less resistant to invading or chewing pests and diseases. K-deficient plants are also pale in color and show early wilting, which seems to attract pests (Krauss, 2001). Less diseases comply with sanitary and phytosanitary regulation in international trade. Better crop resistance to pests and diseases would also reduce the input of agrochemicals and thus, minimize the concern on residual effects.

Environmental compatibility. Consumers will ask more than before whether the crop has been produced in context with environmentally friendly practice. One major factor is the amount of N left in soil after harvest. Trials like those conducted by IPI in China showed a substantial decrease of residual N at balanced fertilization. Under farmer's practice, some 140 kg ha^{-1} of nitrate–N was measured in subsoils, and farmer's practice in China means N first of all. The $N–NO_3$ content decreased to about 100 kg ha^{-1} after adding K to high N. It declined further to less than 40 kg ha^{-1} of $N–NO_3$ when N was well balanced with potassium. Those farmers applying balanced fertilization can prove that:

a) plants have been fertilized in a 'balanced' and thus, 'natural' way because of less residual N in soil;

b) the natural resources – land, fertilizer and energy contained in fertilizers – have been utilized efficiently because of higher yields;

c) less residual nitrogen means less potential contamination of groundwater and the atmosphere.

Safe food. In an atmosphere of uncertainties on food safety such as nitrate content of vegetables, residues of agrochemicals, beef and BSE, quality auditing of production could bring back confidence of consumers. And, balanced fertilization in an integrated approach is one of the most important components in quality auditing. It also adds a particular image to the produce, the added value increases the competitiveness. Moerschner et al. (1999) see a good market chance for those farmers who adopt management systems with respect to quality and environment. This refers to production based on demonstrable quality norms. By so doing, it secures old and opens new markets, the farmer can certify quality and origin of his produce, he proves compliance with legislative rules, there is no problem with product liability, etc. Of course, quality auditing requires continuous recording, book keeping, nutrient accounting, etc., however, it offers an important market niche.

Conclusions

The demographic evolution on one hand, globalization, free trade and a multiple choice of the consumer at the market on the other – agricultural production is confronted with a considerable change in food demand, both in quantity and even more, in quality. The consumer wants a transparent production to be sure to get "safe" food. He wants to follow-up how the food is produced, whether environmentally friendly and resource saving production methods are applied. And certification schemes for quality and environmentally sound production processes subject the farmers to more complex decision schemes.

Balanced fertilization, which takes care of all nutrients according to site and crop–specific needs, assists the farmer to comply with the consumer's demand. His crop is healthy and of good quality. Higher yield at balanced fertilization ensures better income, especially when high yield is linked with top quality. The farmer will reinvest money into agriculture, and also in non-agricultural products, which in turn attract other businesses and thus, contribute to the development of the rural area. Higher yield also indicates better use efficiency of the natural resources – land and energy in form of fertilizers, and transport. It protects the environment by better utilization of applied nutrients. Less processing energy at high contents of nutritive ingredients conforms to the request of resource saving food production.

To respond to the rapidly changing demand from the market, the farmer requires appropriate information, also in terms of the latest development in plant nutrients related research. IPI intends to bridge the gap in knowledge by conducting demonstration trials as well as seminars, workshops, etc. Publications in local languages also assist to disseminate the information.

There is also need to inform decision–makers and politicians on the benefits of balanced fertilization. They have to provide the correct policy frame in terms of regulative measures to ensure availability of inputs at affordable costs and, at the same time, an appropriate market structure to sell his produce at fair prices.

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Anotācija

Paaugstinoties iedzīvotāju ienākumiem, pieaug prasības pārtikas kvalitātei, kas mūsdienās būtiski ietekmē lauksaimniecības produktu tirgu. Pieaugošais pieprasījums pēc tā sauktajiem bioloģiski audzētajiem produktiem atspoguļo iedzīvotāju mainīgo attieksmi pret pārtiku. No otras puses, globalizācija un starptautiskā tirdzniecība ir ļoti paplašinājusi pārtikas sortimentu un arī dažādojusi tās kvalitātes izvēli. Taču arī terminam "kvalitāte" var būt dažāda jēga – ar to apzīmē vērtību, kas noteiktam pārtikas produktam ir dota, balstoties uz subjektīvu un objektīvu novērtējumu. Mēslošanas līdzekļu balansēta pielietošana uzlabo zemnieka konkurētspēju tirgū un paaugstina viņa ieņēmumus. Zemnieks var arī apliecināt sava ražotā produkta kvalitāti un izcelsmi. "Caurspīdīgas" ražošanas demonstrējums viņam var sniegt papildus priekšrocības pārtikas tirgū.

The efficiency of new types of potassium and complex fertilizers on sod-podzolic sandy soil
Jaunu kālija un komplekso minerālmēslu veidu efektivitāte velēnu podzolētajās smilts augsnēs

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Abstract. The efficiency of standard and slow-acting potassium and complex NPK fertilizers for different agricultural crops was studied in long-term field and lysimeter experiments on sod-podzolic sandy soils of Belarus. The new types of fertilizers showed their advantage over standard fertilizers. Application of the new forms of fertilizers resulted in the increase of crop yields and allowed to reduce the losses of nutrients leached from light-textured soil.
Key words: slow-acting fertilizers, biological amendments, sandy soil, yield, losses of nutrients.

Introduction

Light-textured soils are prevailing in Belarus. The soils classified as very light-textured (sandy) cover 20.1% of arable land, light-textured (loamy sand) – 48.5%, medium and heavy – 25.7%. In Belarus, light-textured soils are predominantly poor in organic colloids, they have a low water retention capacity and a naturally low nutrient content. Sandy soils are characterized by a relatively low total K_2O content (1-1.7%) and its exchangeable forms (0.8% from the total content). The efficiency of K fertilizer is significantly reduced due to high annual leaching losses of potassium that reach on average 29 kg K_2O per hectare on sandy soil. Soil phosphorus reserve is about 0.11-0.17% from its total mass.

The improvement of soil fertility status requires long-term application of animal manure, green manure, fertilizers and lime. Consumption of fertilizers and productivity of agricultural land have remarkably declined for the last years during the transition to market economy. Continued application of insufficient fertilizer rates disturbs the nutrient balance and leads to depletion of the soil potassium and phosphorus reserves as well as to poor utilization of nitrogen fertilizer. Development of slow-acting potassium fertilizers was suggested as one of methods to increase the K fertilizer efficiency.

Material and methods

New forms of slow-acting fertilizers with different modifying components in "soil-fertilizer-plant" system, lysimeter's solution and plant production were the objectives of the present research. Field experiments with new types of fertilizers were carried out on sod-podzolic sandy soil developed on consolidated sand and underlaying loose sand at the depth of 0.3 m. Agrochemical parameters: pHKCl – 5.6; humus – 1.31%; total clay content – 2.9%; mobile P_2O_5 – 237 and K_2O – 125 mg kg^{-1}. First crop rotation: legume-grass (1991-1992), winter rye+oil radish (1992-1993), potato (1993-1994), barley+oil radish (1994-1995), oat+white mustard (1995-1996). Second crop rotation: pea-oat mixture (1996-1997), winter rye+lupine (1997-1998), potato (1998-1999), barley+oil radish (1999-2000), and oat (2000-2001).

Several types of tested slow-acting fertilizers – potassium chloride with biologically active organic amendments, plant growth regulator "Epin," micro-elements (Cu or Zn) – were used. Complex NPK fertilizers with different nutrient ratios and with plant growth regulators were developed from peat or from buckwheat husks (patent RB 1291, 3905). The slow-acting fertilizers were compared with standard ones produced in Belarus. Fertilizer response was studied basing on conventional management technology for sandy soils, i.e. farmyard manure (7-14 t ha^{-1}), green manure (intermediate crops after cereal harvest), liming, and integrated plant protection system.

Results and discussion

Application of potassium fertilizers in complex with NP supply is known to be effective for the development of the fertility status of sod-podzolic soils. Potassium fertilization is effective for light-textured soils characterized by a low clay and humus content and also because of a very low level of K fixation in soil. Agrochemical investigations carried out in 1997-2000 revealed that 13.7% of arable land have a very low and low (27.9%) content of available potassium. As for phosphorus, 43.5% of soils are characterized by a very low and low mobile phosphorus content.

Extensive experimental information is available about the efficiency of standard potassium fertilizer for main varieties of sod-podzolic soils and for different agricultural crops (Соколов, 1968; Кулаковская, 1978; Прокошев, Богдевич, 1994; Прокошев, Дерюгин, 2000). Many researchers have recently focused their attention to the method for promoting fertilizer efficiency through development of slow-acting fertilizer forms (Можейко и др., 1977; Лясковский, 1989; Laiche, 1996; Пироговская, 2000).

In long-term field experiments, new forms of K fertilizer with balanced NP fertilization have shown their advantage over standard K fertilizer. Application of slow-acting potassium fertilizers with plant growth regulators (hydrohumate, phenomelane, maltamin, epin) during two crop rotations provided the increase of annual crop productivity by 0.5 t ha^{-1} feed units (f.u.), compared with standard fertilizer (4.4 t ha^{-1} f.u.). The yield response per 1 kg K_2O of slow-acting fertilizer reached 6.6 feed units while standard fertilizer response was roughly twice lower, 2.9 f.u. (Table 1).

The use of slow-acting K fertilizer led to the increase of winter rye yield by 0.2 t ha^{-1}, barley and oats – by 0.2, potato – by 1.8, annual grasses – by 4.9 t ha^{-1}. Average levels of the total crop response as a result of slow-acting K fertilizer application, compared with standard K fertilizer, were within range of 8-29% (Fig. 1).

The nutrient losses were studied in long-term lysimeter experiments. Experimental data showed intensive leaching of nutrients on sod-podzolic sandy soil. A significant reduction (27-30%) in potassium losses was observed due to application of a slow-acting form of K fertilizer as compared with standard ones. An increase in potassium losses was observed when higher K fertilizer rates were applied. The humus and nitrogen leaching tended to decrease when slow-acting K fertilizer was applied (Fig. 2).

Balanced fertilization is the most important prerequisite for sustainable agriculture. For the last decade, several new types of complex NPK fertilizers with different N:P:K ratios have been developed. These new types of fertilizers contain amendments and one of the plant growth regulators – "Hydrohumate," "Oxyhumate" or "Phenomelane".

The Gomel chemical plant now produces several types of complex slow-acting fertilizers with $N:P_2O_5:K_2O$ ratio 16:12:20 (for spring cereals and potato) and $N:P_2O_5:K_2O$ ratio 5:16:35 (for winter cereals).

The use of new forms of complex fertilizers with biological additives resulted in the increase of annual crop rotation productivity by 0.7 t ha^{-1} feed units on sod-podzolic sandy soil. The yield response per 1 kg

Table 1

Efficiency of the new forms of K fertilizers in two crop rotations (1991-2000)

Treatment*	Annual productivity, t ha^{-1} f.u.	Response, t ha^{-1} f.u.		Response, f.u. per 1 kg of K_2O
		to control	to standard fertilizer	
Control	2.7	–	–	–
$N_{104}P_{68}$	4.0	1.3	–	–
$K_{136\,st}$ + NP	4.4	1.7	–	2.9
$K_{136\,sa}$ + NP	4.9	2.2	0.5	6.6
$LSD_{0.05}$	0.31			

* – here and afterwards K_{st} – standard fertilizers, and K_{sa} – slow-acting fertilizers.

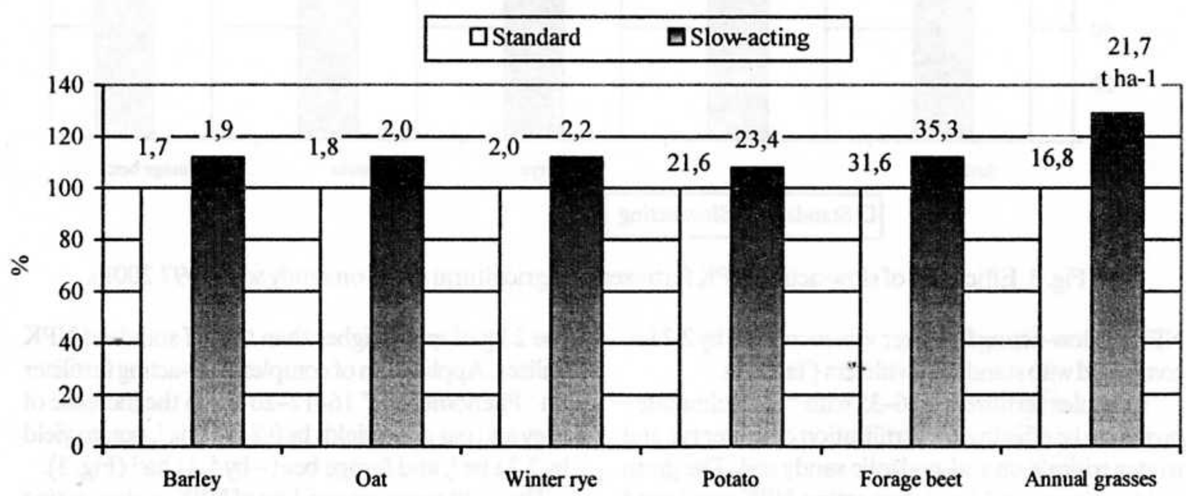

Fig. 1. Influence of slow-acting K fertilizers on the yield of main crops, t ha^{-1}.

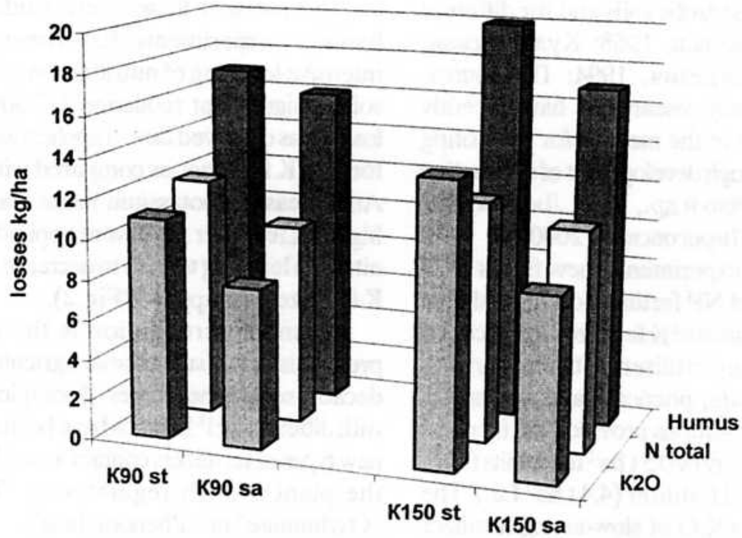

Fig. 2. Leaching of nutrients at different forms and rates of K fertilizer application on sandy soil (lysimeter depth 0-80 cm, 1990-1996).

Table 2

Efficiency of the new forms of NPK fertilizers in crop rotations (1991-2000)

Treatment	Annual productivity, t ha^{-1} f.u.	Response, t ha^{-1} f.u. to control	Response, t ha^{-1} f.u. to standard fetilizer	Response, f.u. per 1 kg of NPK
$N_{104}P_{68}K_{136}$ (for main+intermediate crops)				
Control	2.7	–	–	–
NPK_{st}	4.6	1.9	–	6.2
NPK_{sa}	5.3	2.6	0.7	8.4
$LSD_{0.05}$	0.31			

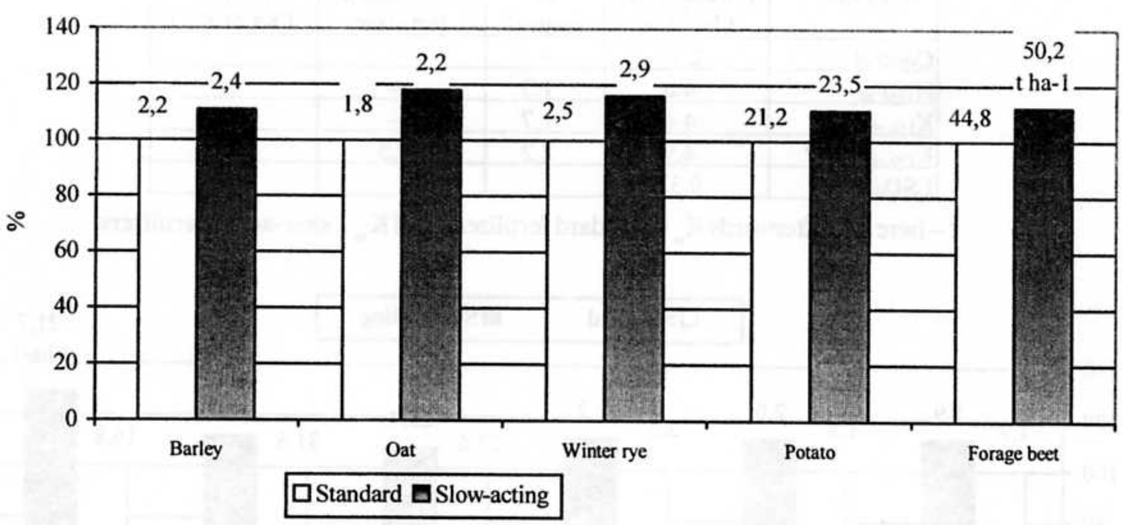

Fig. 3. Efficiency of slow-acting NPK fertilizers to agricultural crops on sandy soil (1997-2001).

NPK of slow-acting fertilizer was increased by 2.2 f.u. compared with standard fertilizers (Table 2).

Complex fertilizer 5–16–35 with "Hydrohumate" proved to be effective for fertilization of winter rye and winter triticale on sod-podzolic sandy soil. The grain yield response per 1 kg of slow-acting NPK was found to be 2 kg of grain higher than that of standard NPK fertilizer. Application of complex slow-acting fertilizer with "Phenomelane" 16–12–20 led to the increase of barley and oat grain yields by 0.2-0.4 t ha^{-1}, potato yield – by 2.3 t ha^{-1}, and forage beet – by 5.4 t ha^{-1} (Fig. 3).

The yield response per 1 kg of NPK of slow-acting

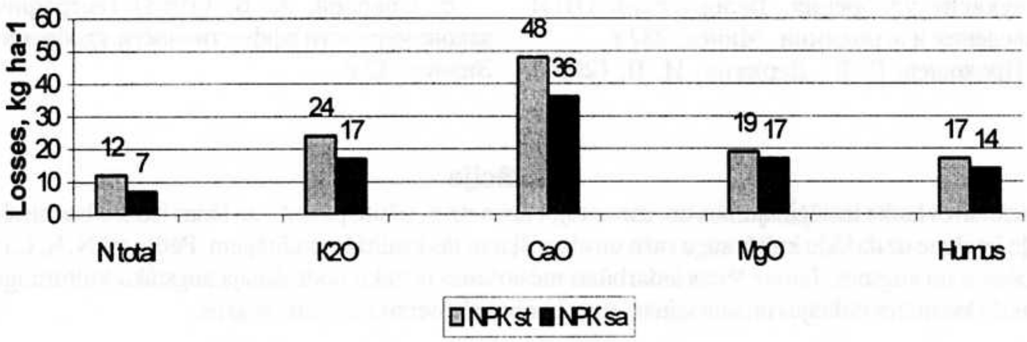

Fig. 4. Nutrient losses on sandy soil (lysimeter depth 100 cm, 1987-1990).

Table 3

Influence of the new forms of slow-acting fertilizers on crop yield quality

Parameters	Crop	K with NP			NPK		
		K_{st}	K_{sa}	response due to K_{sa}, %	NPK_{st}	NPK_{sa}	response due to NPK_{sa}, %
Nitrates, mg kg^{-1}	Potato	91	80	–12	107	79	–26
	Fodder beet	365	274	–19	2443	1913	–22
Starch, %	Potato	13.4	14.1	+0.7	15.1	16.0	+0.9
Protein yield, kg ha^{-1}	Winter wheat	454	499	+10	405	463	+14
	Winter rye	151	174	+15	150	171	+14

NPK was higher as compared with standard fertilizer (by 2.5 kg of grain, or 8 kg of potato, or 44 kg of forage beet).

The advantage of the new complex fertilizer types is their ability to reduce the nutrient losses. A significant decrease in the leaching of main nutrients with infiltration rainfall was observed in lysimeter experiment (Fig. 4).

The new forms of potassium and complex slow-acting fertilizers also demonstrated a positive effect on the crop yield quality (Table 3).

Due to application of slow-acting fertilizers, the content of nitrates in potato tubers was reduced by 12-26%, in forage beet – by 19-22%. The starch content in potato tubers was 0.7-0.9% higher at treatments with new fertilizer forms. For grain crops, slow-acting fertilizers affected the protein yield. A 10-15% increase in protein yield was found for grain crops. The protein content reached 20% in annual grasses as a result of introduction of slow-acting fertilizers.

Conclusion

The new forms of slow-acting K and NPK fertilizers showed their advantage over standard fertilizers on sod-podzolic sandy soil. Crop responses per 1 kg of nutrients of the new fertilizer forms were 30-50% higher, but nutrient losses with infiltration waters were significantly lower compared with the application of standard fertilizers. Application of new fertilizer forms also favored the improvement of crop yield quality (increase of the protein content in grain and starch content in potato tubers).

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Anotācija

Stacionāros lauka izmēģinājumos un, izmantojot lizimetrus, pētīta parasto un lēnas iedarbības mēslošanas līdzekļu ietekme uz dažādu kultūraugu ražu un atsevišķiem tās kvalitātes rādītājiem. Pētīta arī N, K, Ca un Mg izskalošanās no augsnes. Jaunie lēnas iedarbības mēslošanas līdzekļi nodrošināja augstāku kultūraugu ražu, labākus tās kvalitātes rādītājus un samazināja augu barības elementu zudumus augsnē.

Fertilizer recommendations to meet objectives for Good Agricultural Practice approach
Mēslošanas rekomendāciju modelis, kas nodrošina Labas Lauksaimniecības prakses noteikumu izpildi

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Abstract. A new relatively simple fertilizer recommendation model is proposed which could be used for fertilizer planning and follows the principles of the Code of Good Agricultural Practice. The need for a rather simple and easy performable fertilizer planning scheme is actual at present and will remain such also in the near future when fulfillment of EU Directives 91/676 – Nitrate Directive and 2000/60 – Water Policy will take place in Latvia.
Key words: fertilizer recommendations, Code of Good Agricultural Practice.

Introduction

Plant nutrient management for economically and environmentally reasonable and balanced crop production is a motto for many researchers. Administration of farming activities, especially in so-called vulnerable zones, becomes stricter and more important in order to reduce the nutrient loads in the environment. Code of Good Agricultural Practice (Code of ..., 1999) encourages farmers and their advisors to adopt new methods of fertilizer planning, plant nutrient balance calculation and environmental risk assessment. Therefore, despite the great number of recommendation systems, optimization models and other methods developed, the need for comparatively simple and locally well-functioning and adopted method is still valid.

There are at least three main objectives for fertilizer planning in the modern context of sustainable agriculture:

1. to follow administrative demands,
2. to realize principles of Good Agricultural Practice,
3. to provide economically reasonable crop production.

One example for the actual need of a relatively simple and easy performable fertilizer planning scheme is fulfillment of European Union Directives 91/676 – Nitrate Directive and 2000/60 – Water Policy (Directive 2000/60/EC..., 2000) in Latvia. These actions primarily will be binding for farmers located in the vulnerable zones, which already are designed in Latvia, and also – for others who wish to make fertilizer plans as a tool for the improvement of farm management. Therefore, in the nearest future, for many farmers these calculations will be necessary as annual routine, but for administrators – to make evaluation of farm management including fertilizer planning in respect of how environment regulations are followed. Calculation results are also important for reporting on agro-environmental indicators of Latvian agriculture to international institutions. This is a simple method, which might be realized using computer program or manually, a possibility for farmers to follow all steps in calculations and change the input values to get the optimal final result in terms of cutting fertilization costs and maximizing economic returns.

Traditionally, several fertilizer recommendation schemes have been developed and used in Latvia. More popular have been "Augsne – raža" (Daiga et al., 1990) for field crops and "Method of plant nutrition optimization" mainly used for crops grown in greenhouses as well as for horticulture (Ринькис et al., 1989). Despite the great job invested into development of these systems and the long period of their successful practical use, they do not fit into the framework of the modern concept of sustainable agriculture where environmental awareness, protection and conservation are a dominating priority. Based on that, a number of EU directives, international agreements, guidelines and other relevant documents have been developed (Archer, Marks, 2001; Jakobsson, 2001; Sandstrom, 2002; Thyssen, 1998, 2001). These requirements are already included into the recent Latvian legislative acts and are in the implementation stage (Noteikumi par ..., 2001; Ūdens apsaimniekošanas likums, 2002).

Previous recommendation systems can not provide adequate know-how support and their algorithms mainly can not be readjusted for this need. A similar problem is experienced in a number of countries and therefore intensive research and development is going on to tailor new requirements into the modern fertilizer recommendation systems (Aarts, 2000; Bujnovsky et al., 2000; Bujnovsky, Fotyma, 2001; Fotyma & Fotyma, 2001; Klir, 2001; MacKenzie, 2001; Shepard, 2002).

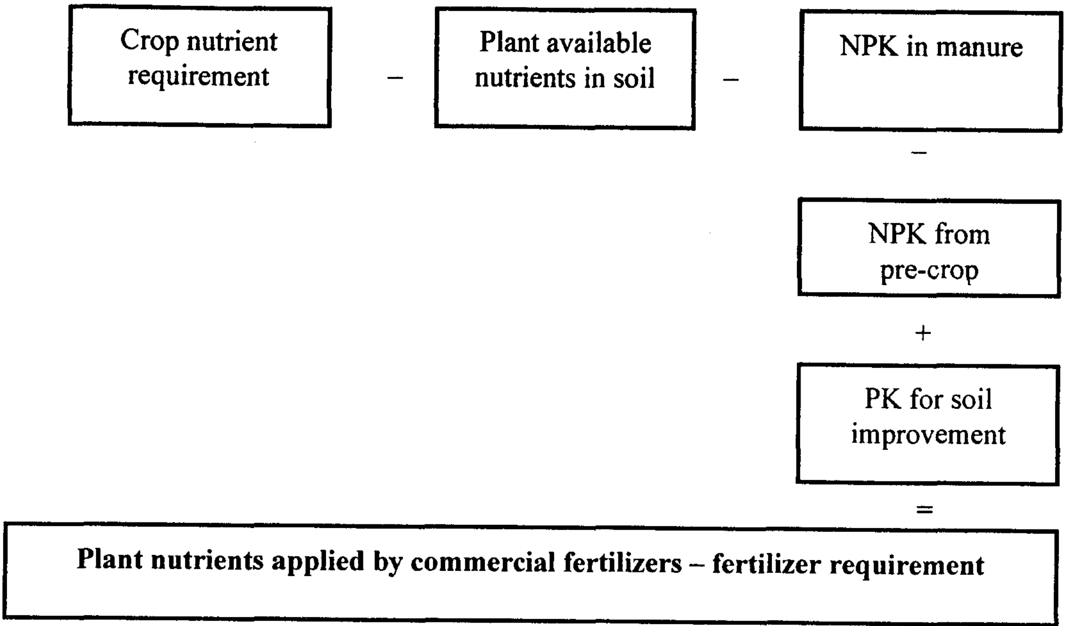

Fig. 1. The general layout of fertilizer recommendation system.

Material and methods

The logistics of the proposed fertilizer recommendation model is its use for fertilizer planning in accordance with the principles of the Code of Good Agricultural Practice. Recommendation scheme includes several steps. (1) To evaluate **growing conditions** – screening of soil parameters and giving advice to farmers about the possibility to grow a certain crop and obtain the selected yield goal. (2) **Crop nutrient requirement** – determination of NPK requirement for each crop commercially grown in Latvia, based on the selected yield level and PK status in soil. (3) **Plant nutrient adjustment** based on a) **manure**, applied for current crop and/or pre–crop, b) **pre–crop** effect to provide some extra nutrients for the current crop and, c) **green manure** as nutrient source. (4) **Actual plant nutrient need** which should be covered by commercial (mineral) fertilizers. (5) Selection of agronomically and economically **most useful commercial fertilizer**. Figure 1 illustrates the general layout of recommendation scheme and the main steps of calculation.

Results and discussion

The presented scheme is quite traditional and is used in many fertilization recommendation systems worldwide. Still, it might be under interest at least for the following reasons. It is simple and easy understandable which in this case is important priority, as many farmers will be obliged to make annual routine calculations. It uses a number of reference values, e.g. plant nutrient removal by yield, manure composition calculation values, etc., which are developed using some international standards and also applied for environmental risk assessment. Therefore, unification of calculation methods, reference values and data interpretation becomes very important in this context.

Unification causes also some negative aspects. It is extremely difficult to quantify different crops' growing factors and make a reasonable compromise between very detailed datasets, supposed to reflect the local conditions and rather simple unified reference data even for a small country like Latvia. The possible solution is to make them well-explained and consider that they might be easily changed during calculations, if more reliable local information is available.

Recommendation systems always contain some risk aspect: will all the objectives be reached if somebody is strictly following the given advice? For this situation – will high and economically reasonable yields always be obtainable if all administrative rules and Good Agricultural Practice advices are strictly followed, even if the weather conditions are not the best and soil fertility is not within the range of optimum. Obviously, the system should be flexible and stated limitations, e.g. maximum allowable fertilizer rates, time limits of their application, minimum nitrogen apparent recovery etc., reasonable. Well-defined and explained reference values may facilitate their reasonable modifications during the process of calculation to get the best final version. This approach will stimulate the need for real input data, which are relevant to the certain farm, e.g. soil testing results, manure composition, field history data, etc.

This recommendation scheme does not contain such details as nutrient requirement differentiation based on the crop's variety, targeted quality standards, specifications of fertilizer application technology, adjustments of the soil organic matter and crop residues mineralization, etc. Recognizing the importance of these factors, we should accept that they will substantially complicate the whole system and limit its wide use, for which in this case preference is given. But it is surely possible to use such adjustments as an extra component to the proposed general framework.

Besides, presently proposed scheme does not include regional differentiation of reference values used for calculation. The assumption was that for such a small country like Latvia it is not so important due to the more or less similar meteorological conditions for all territory. Of course, this is another approximation used exclusively for simplification of the recommendation system. Further development and enlargement of the proposed scheme based on relevant research data, which reflect the regional (local) individuality, is highly desirable.

The recommendation system is designed for all field crops commercially grown in Latvia. For practical calculations, several data sets are necessary. The first one, growing conditions, is a criterion to evaluate soil suitability for the selected crop to avoid miscalculations. Example of this data set is given in Table 1.The next data set consists of series of tables developed for each crop (example is not represented). It shows the crop nutrient requirement depending on yield goal, the plant available phosphorus and potassium sufficiency level, assumptive plant nutrient removal from soil and expected NPK balance. Actually, these are most important tables, which are developed to calculate the

Table 1

Crops' growing conditions (example)

Code	Crop	Limitation factor	Units of measurement	Min. value	Max. value
1	Winter wheat	Physical clay content	%	11	80
		pHKCl	–	5.8	8.0
		Organic matter	%	1.8	10
		P_2O_5 in soil	mg kg^{-1}	50	999
		K_2O in soil	mg kg^{-1}	80	999

Table 2

Draft manure normative for Latvia (per one animal after storage)

Housing system	Manure type	Tons per year	Dry matter, %	Content, kg per ton of manure N	P_2O_5	K_2O
Slaughter pig, 20-100 kg live weight						
Slotted floor	Slurry					
	washing	8.7	3	1.2	0.6	1
	periodical flush	3.4	6	2.7	1.6	3.8
Solid floor	Slurry	3.6	6	3.3	1.6	2.8
	Solid manure	2.6	20	5.7	3.2	6

Table 3

Plant nutrient utilization from manure in the first year (under current crop) and in the 2nd year (1st year aftereffect) in % from the amount applied

Type of manure	Year of use	Soil texture: Clay N	Clay P_2O_5	Clay K_2O	Loam N	Loam P_2O_5	Loam K_2O	Sandy loam N	Sandy loam P_2O_5	Sandy loam K_2O	Sand N	Sand P_2O_5	Sand K_2O	Peat N	Peat P_2O_5	Peat K_2O
FYM, cows,pigs	*	17	21	33	17	26	36	19	26	40	17	32	45	10	26	36
	**	10	11	29	10	11	24	8	11	19	4	5	17	6	5	17
Poultry manure	*	22	32	39	23	35	44	26	38	48	26	38	51	18	27	33
	**	12	14	22	9	13	18	7	10	15	5	7	10	15	21	28
Slurry, cows,pigs	*	41	44	40	44	44	44	44	53	49	44	53	53	33	35	31
	**	15	26	27	8	26	27	4	18	22	4	17	18	19	26	22
Urine, pigs	*	50	-	59	56	-	66	61	-	69	61	-	69	44	-	50
Urine,cows	*	22	-	24	24	-	26	27	-	28	24	-	28	20	-	20

* – under current crop

** – 1st year aftereffect

Table 4

Pre-crop and green manure effect, nutrient supply, kg ha^{-1}

Pre-crop effect				Green manure			
Crops	N	P_2O_5	K_2O		N	P_2O_5	K_2O
Cereals	0	0	0	Green manure, legumes			
Pea	15	0	0	1st year effect	40	10	20
Potatoes	10	0	5	2nd year effect	20	0	10
Rape	10	0	0	Green manure, non–legumes			
Clover	20	5	10	1st year effect	15	10	20
Alfalfa	30	10	15	2nd year effect	0	0	10
Grasses	10	0	10				
Sugar beet	10	10	20				

plant nutrient requirement, soil nutrient supply, PK necessary for soil improvement (if nutrient levels are very low or low), NPK removal with planned yield and its balance. As each of these tables contain some additional information in the form of short comments, they quite well could be used even without other data sets for a simple and fast fertilizer planning or reference.

The last set of tables is devoted to the so-called corrective factors, quantifying the amount of NPK which is available for the current crop but comes from other sources than soil and fertilizers. These sources might be manure applied to the crop directly or some years before, green manure, as well as pre-crop effect.

Information about plant nutrients supplied by manure is taken from so-called normative tables developed for multi-purpose needs (the NPK balance and manure value calculations, environment risk assessment). Example is given in Table 2. This table is joined with another (Table 3), where plant nutrient utilization from different types of manure in the first year (under the current crop) and in the second year (1st year aftereffect) based on soil texture, is given.

NPK supply from pre-crop and green manure incorporated directly before the current crop or one year before is given in Table 4. These values are supposed to be available for the current crop and therefore fertilizer need can be diminished. Final result is supposed to be the fertilizer requirement – amount of NPK recommended to apply with commercial fertilizers. Recommendation system also includes data set with all kinds of fertilizers available in Latvia, their composition and possible (expected) selling price. Therefore their selection could be performed basing on agronomical and economical considerations, as well as eventual fertilization costs might be calculated.

Additionally to fertilizing costs, plant nutrient balance is calculated to show the farmer the possible fertilization effect on soil and environment. Unbalanced fertilizer use still is a problem for many farmers. Tendency for fast and short-term economic returns is a reason to give preference to nitrogen application even beyond the agronomically and ecologically reasonable level. At the same time, saving on phosphorus and potassium supply leads to soil fertility decline and forms crop-growing environment not sustainable for obtaining high yield potential in the future.

Conclusion

Expected advantages of the proposed method are simple logistics and possibility of easy change of the reference values if new or more detailed information is available. Together with rather high reliability of output data, this will stimulate its wide application for routine calculations.

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Anotācija

Ieteiktajam modelim raksturīga vienkāršība, kas ir noteicoša tā plašai pielietošanai mēslošanas plānošanai saimniecībās. Masveida mēslošanas plānu izstrāde paredzama jau tuvākā nākotnē, kad Latvijai būs jāsāk izpildīt ES Nitrātu direktīvas un Ūdens apsaimniekošanas likuma prasības, kuras jau ir iestrādātas Latvijas likumdošanā.

The effect of K fertilizers on different levels of sod-podzolic loamy sand soil supply with exchangeable potassium
Kālija mēslošanas līdzekļu efektivitāte velēnu podzolētajā smilts augsnē ar atšķirīgu apmaiņas kālija nodrošinājumu

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Abstract. The effect of soil K supply and K fertilization on the crop yields and quality as a result of three crop rotation field experiments on sod-podzolic loamy sand soil is presented. The efficiency of potassium fertilizer rates was remarkably dependent on soil K supply level. An optimal potassium content in soil (K_2O) was found within the range of 168-248 mg kg^{-1} and the highest net return provided the application of 60-90 kg ha^{-1} of K_2O.
Key words: K in soil, K fertilizers, K content in plants.

Introduction

In Belarus, consumption of fertilizers and productivity of agricultural land have declined during the last years. The results of soil tests indicated a decrease in exchangeable potassium and other nutrients. It is very important to prevent soil fertility and crop production from decline. Development of K fertilizer recommendations requires knowledge of soil–plant response to fertilizer input considering specific management conditions at farm level. Long-term experiments provide basic data for economical and ecological optimization of soil K status and fertilizer rates. The research objectives were to determine the optimal potassium content in sod-podzolic loamy sand soil and to find effective K fertilizer rates.

Material and methods

A long-term field experiment was carried out on sod-podzolic loamy sand soil (Eutric Podzoluvisols, FAO Legend, 1990) at the state farm "Druzhba," Minsk region. The soil was characterized by favorable agrochemical parameters: pHKCl – 6.0-6.2, mobile P_2O_5 content (Kirsanov method – 0.2 M HCl) – 300-350 mg kg^{-1}, humus – 2.5%, exchangeable calcium – 800-850 mg kg^{-1}, exchangeable magnesium – 140-150 mg kg^{-1}.

Four levels of soil exchangeable potassium supply were prepared: 1st level – about 100, 2nd – 200, 3rd – 300, and 4th – 400 K_2O mg kg^{-1}. Preliminary application of increasing potassium fertilizer rates (KCl) was used to establish potassium levels at the depth of ploughing layer. Several corrections in soil potassium levels (once per rotation) were performed during the investigation period.

The treatments included two factors: K content in soil, and use of K fertilizers. Five treatments were established for each prepared soil K level. N rates varied depending on the crops, but P fertilizer rate was 60 kg ha^{-1} P_2O_5. Application of K fertilizers: 60 (K_1), 90 (K_2), 120 (K_3) kg ha^{-1} of K_2O. Crop rotation: maize, barley, legumes for green mass, winter rye, and oat. For maize, 60 t ha^{-1} of farmyard manure was applied.

In 2001, soil mobile potassium content was: 1st level – 114, 2nd – 208, 3rd – 288, and 4th level – 436 mg kg^{-1} K_2O. These levels were characterized by following ratios of exchangeable cations – K/(Ca+Mg): 1st level – 0.05, 2nd – 0.07, 3rd – 0.14, and 4th – 0.18.

Following soil potassium forms were studied: mobile (Kirsanov method – 0.2M HCl), water soluble and exchangeable (Maslova method – 1M CH_3COONH_4), non-exchangeable (Ptchelkin method – 2M HCl) (Пчелкин, 1966).

Results and discussion

Two years after the last correction of the formed levels, a significant reduction in K content was observed only at the fourth K supply level – from 251 to 227 mg kg^{-1}. Variations in mobile potassium content at first, second and third levels were insignificant (Table 1). Saturation of soil with potassium resulted in increase of water soluble, exchangeable and non-exchangeable K forms. In 1998, correction of potassium content levels led to the increase of water soluble and exchangeable K fractions for all studied levels: 1st level – 36 and 120, 2nd – 57 and 208, 3rd – 57 and 219, and 4th level – 71 and 300 mg kg^{-1}, respectively. There was an increase in non-exchangeable potassium content at the 1st and 2nd supply levels. Two years after the correction, a reduction of water soluble and exchangeable fractions of potassium was observed. A considerable reduction of non-exchangeable K was observed only at the 1st and 2nd established levels, but for mobile potassium –

throughout the whole experiment.

In 2001, potassium content at all studied levels agreed well with the experiment plan. The correction of K supply and application of organic fertilizer caused a rise in water soluble and exchangeable potassium content at the 2nd level – 33 and 210 mg kg^{-1}, 3rd level – 52 and 374, 4th level – 108 and 444 mg kg^{-1}. A considerable increase of non-exchangeable potassium concentration at 2nd and 3rd levels of K supply was observed.

Average crop rotation productivity was signif-icantly increased only at the 2nd level of K supply (168-248 mg of K_2O kg^{-1}) (Table 2). Further increase in mobile potassium content in soil did not provide a rise in crop productivity and reduced the efficiency of fertilizer application. The average annual crop rotation productivity tended to decrease by 0.03-0.29 t ha^{-1} feed units at the 3rd K content level in soil. The same tendency was observed at the 4th level of potassium supply. Potassium fertilizer rates within 60 and 90 kg ha^{-1} provided the highest response at the 2nd soil K supply level, on average for three rotations 6.2-6.6 feed units per 1 kg of K_2O applied.

The influence of increasing soil K supply and potassium fertilizer rates on K content in plants and on K/(Ca+Mg) ratio is of prior importance to evaluate the yield quality as forage (Мазаева, Неугодова, Лапшина, 1981; Небольсин, Небольсина, Яковлева, 2001). K uptake by maize was dependent on the level of soil supply with potassium. The increase of K content in soil and higher rates of potassium fertilizers resulted in a rise of ratio K/(Ca+Mg) in the green mass of maize, which did not exceed 2.2 for all studied levels of soil potassium content (Table 3). The content of potassium and other nutrients varied insignificantly in the grain of rye, barley and oat. However, a significant rise in potassium uptake by the straw of cereals was found. Potassium content in barley straw reached 1.40-1.60% at the 1st level and 1.90-2.40% at the 4th level; in oat straw – 1.02-1.58% and 1.26-1.87%, respectively (Table 3).

As a result of the increase of potassium concentration in soil and higher K fertilizer rates, K/(Ca+Mg) ratio in barley straw increased from 1.87-2.25 at the 1st level to 1.94-2.50 at the 2nd, and to 2.42-2.70 at the 4th level of potassium supply. The least negative effect on K/(Ca+Mg) ratio provided the lowest rate of K fertilizer (60 kg ha^{-1}). For oat straw, the same tendency was found for the variation of K/(Ca+Mg) ratio. Due to application of 120 kg ha^{-1} K_2O at a high soil K supply (204-436 mg K_2O kg^{-1}), K/(Ca+Mg) ratio exceeded the permitted value for the green mass of legume (2.2). Potassium content in green mass varied from 1.93-2.27% at the 1st level to 3.29-3.69% at the 4th. At the second studied

Table 1

Dynamics of potassium forms in arable layer of sod-podzolic loamy sand soil

K supply levels	1996	1998	2000	2001
Mobile potassium, mg kg^{-1}				
I	86	113	111	114
II	118	172	167	208
III	152	204	203	288
IV	176	251	227	432
LSD_{05}	9	13	12	23
Water soluble potassium, mg kg^{-1}				
I	24	36	19	21
II	48	57	27	33
III	37	57	29	52
IV	42	71	41	108
LSD_{05}	2	4	2	6
Exchangeable potassium minus water soluble, mg kg^{-1} (Maslova method)				
I	86	120	121	119
II	124	208	162	210
III	133	219	222	374
IV	159	300	242	444
LSD_{05}	10	18	15	27
Non-exchangeable potassium, mg kg^{-1} (Ptchelkin method)				
I	152	170	102	188
II	191	205	156	305
III	215	216	219	512
IV	208	215	204	549
LSD_{05}	13	13	13	31

Table 2

Average annual productivity of crop rotations depending on K supply levels and K fertilizer rates

Treatment	Yield, t ha^{-1} f.u. (feed units)				Crop response, f.u.	
	1986-1990	1991-1995	1996-2000	average	to K soil levels, t ha^{-1}	per 1 kg of K_2O
1st level of soil K_2O supply (95-111 mg kg^{-1})						
NP-background	4.29	3.36	4.70	4.12	–	–
Background + K_{60}	4.75	3.60	5.12	4.49	–	6.2
Background + K_{90}	4.94	3.86	5.24	4.68	–	6.2
Background + K_{120}	5.03	4.16	5.38	4.86	–	6.1
2nd level of soil K_2O supply (168-248 mg kg^{-1})						
NP-background	5.39	4.60	5.44	5.14	1.02	–
Background + K_{60}	5.90	4.99	5.78	5.56	1.07	6.9
Background + K_{90}	6.21	4.93	6.06	5.73	1.05	6.6
Background + K_{120}	5.77	4.66	5.87	5.43	0.57	2.4
3rd level of soil K_2O supply (203-356 mg kg^{-1})						
NP-background	5.47	4.41	5.46	5.11	–0.03	–
Background + K_{60}	5.72	4.68	5.75	5.38	–0.18	4.6
Background + K_{90}	5.94	4.61	5.78	5.44	–0.29	3.7
Background + K_{120}	5.69	4.50	5.56	5.25	–0.18	1.2
4th level of soil K_2O supply (227-470 mg kg^{-1})						
NP-background	5.39	4.24	5.36	5.00	–0.11	–
Background + K_{60}	5.43	4.39	5.60	5.14	–0.24	2.3
Background + K_{90}	5.63	4.25	5.50	5.13	–0.31	1.4
Background + K_{120}	5.54	4.08	5.46	5.03	–0.22	0.2
LSD_{05} – K levels	0.50	0.33	0.27	0.40	–	–
LSD_{05} – K treatments	0.42	0.44	0.31	0.36	–	–

Table 3

The influence of soil potassium supply on K content and ratio K/(Ca+Mg) in the straw and green mass of crops

Treatment	Straw				Green mass			
	barley		oat		maize		legume grass	
	K, %	K/(Ca+Mg)	K, %	K/(Ca+Mg)	K, %	K/(Ca+Mg)	K, %	K/(Ca+M
103-114 mg K_2O kg^{-1}								
NP-background	1.40	1.87	1.02	1.19	1.30	1.12	1.93	1.14
NP + K_{60}	1.70	2.03	1.10	1.32	1.47	1.19	1.98	1.17
NP + K_{90}	1.50	1.85	1.14	1.80	1.54	1.36	2.17	1.56
NP + K_{120}	1.60	2.25	1.58	1.63	1.63	1.58	2.27	1.34
172-208 mg K_2O kg^{-1}								
NP-background	1.60	1.94	1.08	1.30	1.86	1.51	2.57	1.53
NP + K_{60}	1.60	2.00	1.30	1.50	1.80	1.57	2.96	1.76
NP + K_{90}	1.80	2.17	1.47	1.80	1.59	1.38	2.92	1.74
NP + K_{120}	1.80	2.50	1.59	1.91	1.85	1.98	3.16	1.90
204-288 mg K_2O kg^{-1}								
NP-background	2.10	2.74	1.20	1.49	1.71	1.58	2.91	1.50
NP + K_{60}	1.70	2.19	1.49	1.74	1.82	1.31	3.54	2.13
NP + K_{90}	2.00	2.23	1.54	1.73	1.93	1.55	3.61	2.20
NP + K_{120}	2.30	2.71	1.73	2.12	2.00	1.65	3.65	2.22
251-436 mg K_2O kg^{-1}								
NP-background	1.90	2.63	1.26	1.57	1.80	1.60	3.29	2.00
NP + K_{60}	2.00	2.70	1.63	1.85	2.00	1.54	3.57	2.18
NP + K_{90}	2.10	2.68	1.86	2.08	1.96	1.72	3.64	2.18
NP + K_{120}	2.40	2.42	1.87	1.86	2.06	1.78	3.69	2.21
LSD_{05} - K levels	0.17	–	0.13	–	0.12	–	0.25	–
LSD_{05} - K treatments	0.16	–	0.12	–	0.10	–	0.23	–

soil K level, K/(Ca+Mg) ratio in green mass was not higher than 2.2. There were no significant differences in protein content in the barley, oat and winter rye grain as a result of K soil supply increase from 103 mg kg^{-1} up to the optimal level.

Conclusion

The efficiency of potassium fertilizer rates was strongly dependent on soil K supply levels during three crop rotations. An optimal potassium content in sod-podzolic loamy sand soil (K_2O) was found within the range of 168-248 mg kg^{-1}, where highest crop yields and highest crop response to K fertilizer at rates of 60-90 kg of K_2O ha^{-1} were observed.

No significant changes were observed in K content in cereal grain due to saturation of soil by potassium. However, a reliable increase in K concentration in straw and rise in ratio K/(Ca+Mg) were found. The ratio K/(Ca+Mg), which is a quality parameter for tested crops, was within permitted limits at low and optimal (second) levels of K soil supply with moderate rates of 60-90 kg K_2O ha^{-1}.

It is evident that K fertilizer is essential to increase crop yields in Belarus. Experimental results are suggested as useful for selecting optimal K fertilizer rates.

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Anotācija

Pētījumi veikti augsekā, aptverot trīs rotācijas. Noskaidrots, ka par vēlamo apmaiņas kālija saturu šādās augsnēs var uzskatīt 168-248 mg kg^{-1} K_2O. Šādā situācijā, ar mēslošanas līdzekļiem pielietojot 60-90 kg ha^{-1} K_2O, iespējams iegūt augstas kultūraugu ražas un augstu atdevi no iestrādātā mēslojuma. Graudaugiem kālija mēslošanas līdzekļu lietošana nemainīja tā saturu graudos, bet salmos – tā daudzums augstās mēslojuma devās palielinājās, vienlaicīgi izmainot arī K/(Ca+Mg) attiecību.

The effect of mineral fertilizing and liming on soil phosphorus regime
Mēslošanas līdzekļu un kaļķošanas ietekme fosfora režīmu augsnē

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Abstract. The long-term soil liming experiments on very acid automorphic loamy sand soil (Dystric Cambisol, WRB 1998) were started in Eastern Lithuania in 1972 and 1984. The aim of the study was to establish the effect of liming on the total amount of available soil phosphorus, changes in the form and distribution of mineral fractions of phosphates. Observations showed that in the system of excessive fertilizing with mineral phosphorus, available P_2O_5 increased by 80 mg kg^{-1} of soil compared with unfertilized soil. It suggests that almost 50% of applied phosphorus was transformed into soluble forms. The phosphorus transformation process was changed under the influence of liming intensity. Soil liming changed the phosphate forms and the ratio between mineral fractions of phosphates. The changes were dependent on the periodicity of liming and the amount of limestone applied. The amount of organic soil phosphorus was directly related to soil pHKCl level and the time passed after the last liming. The largest amounts of organic phosphorus (1006-1036 mg kg^{-1} P_2O_5) were observed in the soil with 5.1-5.4 pHKCl level. More alkaline or acidic condition resulted in a decrease of organic phosphorus amount. Later limed soil had a higher content of soluble hydro– and dihydrophosphates and a lower content of orthophosphates. Comparison of various methods of soil phosphorus availability analyses showed that evaluation of soil available phosphorus content in limed soil was dependent on the chosen method. In limed soil, extraction in hot water and by A–L analytical methods demonstrated greater values compared with the analysis in NH_4Cl solution.
Key words: soil, liming, phosphorus regime, phosphorus fractions.

Introduction

Light textured soils, mainly naturally acid and of limited capacity, are dominant in the eastern part of Lithuania. From the ecological point of view, this region represents the vulnerable zone and is highly sensitive. The content of humus in these soils varied between 0.5-1.2% on sands and up to 1.3-1.5% on loamy sands (Mažvila, 1998). Humus can account for 20-90% of the adsorbing power of mineral soils (Brady and Weil, 1999). Results of the experimental work showed that even under hard application of manure the increase of humus is short-termed and negligible because of intensive mineralization (Tripolskaja, 2001). Soil fertility is mainly controlled by fertilizers – most important component in agricultural production on such infertile sandy soils. Proper use of fertilizers under diverse soil, climate and ecological conditions is an important research area for sustainable agriculture. The processes controlling the nutrient availability in the soil–plant–atmosphere cycle should be well understood for an efficient fertilizer use.

The nitrogen, phosphorus and potassium supply and solubility of phosphates and their availability to plants is the most complicated problem. Phosphorus deficiencies are common in managed ecosystems. About 66% of Eastern Lithuania's soils are very low or low in the amount of plant available phosphorus (Mažvila, 1998). Natural phosphorus regime on such soils is directly affected by periodical application of phosphorus fertilizers and indirectly – by liming (Debreczeni and Dvoracsek, 1989). Accumulation of phosphorus in soil occurs when a positive P balance in soil is ensured, and coefficient of compensation by fertilizing makes up 150-200% (Minin and Osipov, 2000; Vigovskis and Jermušs, 2000). Part of phosphorus, applied with fertilizers, turns into insoluble forms in the soil. Thus it is excluded from the biological cycle and leads to a decrease in the efficiency of phosphoric fertilizing. Some authors point out that on limed soil, insoluble and unavailable to plants phosphorus is transformed into more readily available forms. Application of lime increases the phosphorus fixing by 20% in the form of secondary Ca and Mg phosphates. The amount of soluble phosphate decreases more than twice (Небольсин и др., 1998; Zorn and Krause, 1999).

Data analysis of well-planned and properly conducted long-term experiments can help to assess the impact of fertilizers on agricultural sustainability and environmental quality. The purpose of this research was to evaluate the effect of liming (differing in intensity and periodicity) on the total amount of available soil phosphorus, the changes in the form and distribution of mineral fractions of phosphates in Eastern Lithuania. The objectives of this study were to evaluate:

1) the impact of liming practice on P fertilizer efficiency;

2) the effect of soil liming on the forms of phosphates

and on the extraction and structure of mineral phosphates.

Materials and methods

Experiments were set up at the Voke Branch of the Lithuanian Institute of Agriculture. The experimental site was located on very acid loamy sand overlaying loamy sand with gravel below Dystric Cambisol (according to WRB classification). Soil texture includes 77-88% sand, 10-17% silt, 2-6% clay fraction. The soil is well drained, the depth of the arable layer is 18-22 cm, carbonate horizon is located at the depth of 70-110 cm. It is a typical arable soil characterized by a low humus content (about 2.0%), naturally acid reaction (pHKCl. 4.4-4.5) and low content of plant available phosphorus and potassium. The soil has a low fixation capacity. Soil samples were taken from long-term soil liming experiments (trials A, B, C).

Trials A–B with moderate liming were established in 1972-1973 (Tables 1, 2). The soil was limed up to 3.5 times with $CaCO_3$ according to soil hydrolytic acidity (H). Soil samples from the arable layer were continuously collected to determine plant available P_2O_5 every 5 years, starting from 1972 through 1998. Soil available P_2O_5 was measured by A–L method. Total P in plants was measured by calorimetric method.

Soil samples for analysis of P forms were taken in 1998 and 1999 from the following treatments: 1, 2 and 6 in experiment A, and 7 and 10 in experiment B. Also three treatments were analyzed from the samples

Table 1

Intensity of liming in trial A

Treat-ments	Rates of ground limestone according to hydrolytic acidity (H)				Total for 4 rotations	
	before establish-ment	before crop rotation II	before crop rotation III	before crop rotation IV	rates according to H	$CaCO_3$, t ha^{-1}
1*	–	–	–	–	–	–
2	–	–	–	–	–	–
3*	0.50		–		0.50	3.38
4	0.25	–	–	–	0.25	1.81
5	0.50	–	–	–	0.50	3.68
6	1.00	–	–	–	1.00	7.18
7	0.25	–	0.25	–	0.50	3.72
8	0.50	–	0.50	–	1.00	6.62
9	0.50	–	0.25	0.25	1.00	6.98
10	0.25	0.25	0.25	0.25	1.00	7.12

* – unfertilized treatments

Table 2

Intensity of liming in trial B

Treat-ments	Rates of ground limestone according to hydrolytic acidity (H)				Total for 4 rotations	
	before establish-ment	before crop rotation II	before crop rotation III	before crop rotation IV	rates according to H	$CaCO_3$, t ha^{-1}
1*	–	–	–	–	–	–
2	–	–	–	–	–	–
3*	0.50	–	0.50	–	1.00	7.84
4	0.25	–	–	0.75	1.00	7.08
5	0.50	–	0.50	–	1.00	7.18
6	0.50	–	1.50	–	2.00	14.36
7	1.00	–	1.00	–	2.00	15.72
8	0.25	–	0.50	0.25	1.00	7.84
9	0.50	–	0.75	0.75	2.00	14.64
10	0.25	0.25	1.50	1.50	3.50	24.64

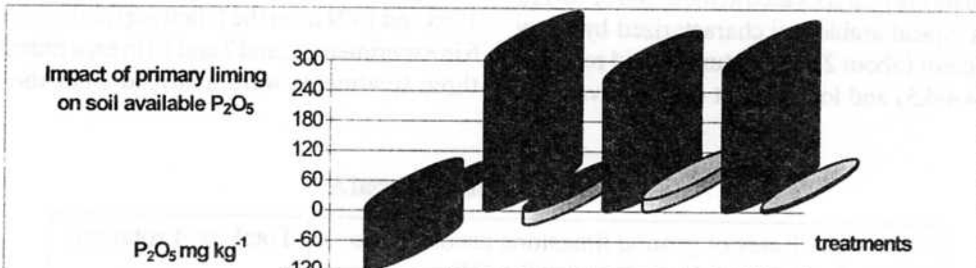
* – unfertilized treatments

collected from trial C (intensive liming, established in 1984):

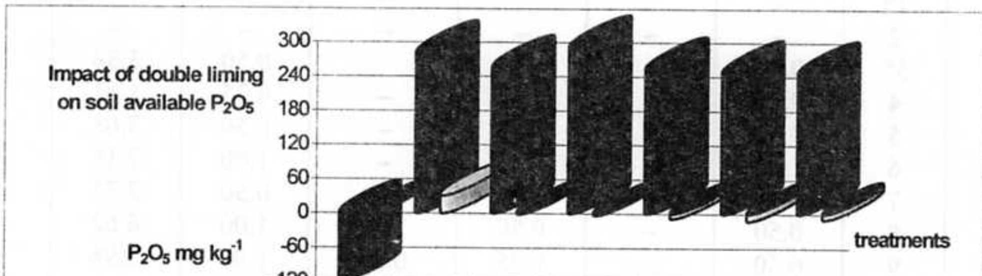
1. NPK;
2. NPK+1.0 t ha^{-1} $CaCO_3$ annually;
3. NPK+6.0 t ha^{-1} $CaCO_3$ every 6 years.

Soil samples for determination of phosphorus forms and mineral phosphate structure were taken at the depth of 0-20 cm in four replications.

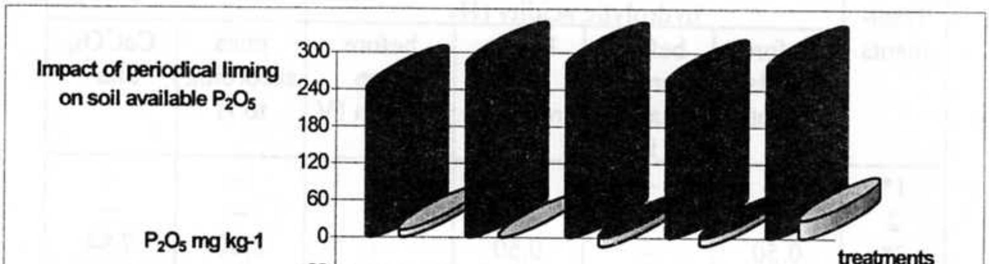
Total phosphorus (P total) was determined by oxidation of the soil sample by mixture of concentrated H_2SO_4 and $HClO_4$. Plant available phosphorus was determined by A–L method. Solubility of phosphates was determined in hot water (soil/solution – 1:5). Fractional composition of phosphates was determined according to the method of Chang and Jackson, modified by Askinazi, Ginsburg and Lebedeva (Аскинази и др., 1963; Chang and Jackson, 1957). Mineral and organic phosphorus compounds were extracted in various solutions: in 1M NaOH – water-soluble phosphorus; first extraction in 0.5M NH_4F and



	0.5*	0,25	0,5	1,0
■ P2O5 balance	-224	295	258	278
□ change in available P2O5	-3,00	-27,25	24,75	5,00



	1.0*	0,5	1,0	1,0	1,0	2,0	2,0
■ P2O5 balance	-262	280	255	290	253	247	246
□ change in available P2O5	-4	30,50	-1,50	-3,5	-8,25	-12,5	-9,75



	1,0	1,0	1,0	2,0	3,5
■ P2O5 balance	240	279	279	251	275
□ change in available P2O5	12,00	0,00	-14	-12,25	-29,5

* – unfertilized treatments

Fig. 1. Impact of the liming periodicity and intensity on P balance and available P resources.

0.1M NaOH – most available to plants Al, Fe, Ca phosphates; extracted in 0.25M H_2SO_4 – high-base Ca phosphates; second extraction in 0.5M NH_4F and 0.1M NaOH – highly crystallized Al phosphates, Al–Fe phosphates. After all extractions, the remaining part is soil insoluble phosphorus.

All data were subjected to analysis of variance. Significance of differences was examined using t–test for normal distribution. MSTAT– C statistical analysis package was used for all calculations.

Results

Plant available phosphorus is likely to be one of major limitations to productivity on acid sandy soils (Holford, 1997). Excessive fertilizing with greater quantities of phosphorus than the amounts taken up by crops was used. As a result, poor soil was transformed into phosphorus rich soil. Our obser-vations showed that soil was drastically enriched in the amount of available phosphorus. Excessive fertilizing during a 25-26 years period with double superphosphate increased the amount of available P_2O_5 by 80 mg kg^{-1} of soil compared with unfertilized soil. It suggests that, in total, almost 50% of applied phosphorus surplus (total surplus of 161 mg kg^{-1} of soil) was transformed into soluble forms.

Utilization of P fertilizers was dependent on limestone rate or intensity of primary liming in the cases of secondary and periodical liming. The impact of liming on P balance and available P resources in the soil is presented in Fig. 1.

P fertilizers were utilized best in the soil treated with 0.5 rate of ground limestone (positive balance 258 mg kg^{-1}) in the case of primary and single soil liming. If the soil was limed twice or more, utilization of P was not dependent on the total amount of limestone applied. Positive P changes varied from 253 to 290 mg kg^{-1} on the soil treated with a total of 1.0 rate of ground limestone split into 2 applications. At application of 2.0 rates, P utilization was similar, and positive P changes varied between 246-251 mg kg^{-1}. Favorable response was obtained in all cases of 0.5 or 1.0 primary soil liming (246-255 mg kg^{-1}), and lower utilization (at 275-290 mg kg^{-1}) – at primary 0.25 rate application.

The data also allowed analyzing the impact of liming on soil available P in both cases – with a positive and negative P trend. In the case of soil liming without fertilization, soil P reserves depleted. A negative balance in limed but unfertilized soil during 25-26 years was 224-262 mg kg^{-1} of P, but the amount of available phosphorus in soil, compared with primary values, was not reduced. Even unfertilized soil annually could maintain average crop requirements for P_2O_5 (up to 9-10 mg kg^{-1}).

The impact of liming on soil P regime was dependent on the periodicity and intensity of ground limestone application. Moderately intensive liming (1-2 rates applied) increased the soil pHKCl up to 4.8-5.5, but available P_2O_5 levels did not differ significantly. Under more intensive liming conditions (3.5 rates applied), increase in soil pHKCl up to 6.4 was accompanied by a significant increase in soil available P_2O_5 by 38-40 mg kg^{-1} of soil compared with unlimed or moderately limed soil.

More detailed investigations on the forms and structural changes of phosphates showed the impact of liming on the changes of phosphate solubility and the ratio between various P forms. Under the influence of fertilizers and liming, the amount of total phosphorus, determined in H_2SO_4 and $HClO_4$ solutions, increased up to 0.070-0.074%, while in unfertilized soil it was as low as 0.064%. Fractional composition of phosphates

Table 3

Influence of liming on fractional composition of phosphates (P_2O_5 mg kg^{-1} of soil)

Treatment	pHKCl	P total	P mineral	P organic	Insoluble P
Trials A – B					
1. Without NPK and $CaCO_3$	4.2	1339	639	673	27
2. NPK	4.2	1425	746	654	25
3. NPK + 1.0 r. $CaCO_3$	4.4	1616	748	844	23
4. NPK + 2.0 r. $CaCO_3$	5.4	1963	892	1036	35
5. NPK + 3.5 r. $CaCO_3$	6.4	1867	841	976	50
LSD_{05}		260	133	266	11
Trial C					
1. NPK	5.1	1968	935	1006	27
2. NPK+1.0 t ha^{-1} $CaCO_3$ annually	6.7	1511	788	680	43
3. NPK+6.0 t ha^{-1} $CaCO_3$ every 6 years	6.2	1454	826	600	28
LSD_{05}		278	109	211	10.6

also varied. The amount of mineral phosphates increased from 639 mg kg^{-1} in unfertilized soil up to 748-892 mg kg^{-1} in fertilized and limed soil (Table 3). At an equal fertilizing level, the greatest amount of mineral phosphates was in the soil with 5.4 pHKCl level. The amount of mineral phosphates was reduced when soil reaction became more acid or neutral.

The amount of organic phosphorus varied in relation to soil pHKCl and the time passed after the last liming. In fertilized and moderately limed soil (A-B trials), the amount of organic phosphorus in comparison with unlimed and unfertilized soil increased by 171-363 mg kg^{-1} and was greatest at pH 5.4. In the trial with intensive liming of soil (trial C), the greatest amount of P organic was also in the soil with pHKCl 5.1. At a higher soil reaction, the pool of P organic decreased. The decrease of organic phosphorus at pH 6.0 and higher might be the outcome of more intensive activity of micro-organisms and enzymes. It leads to mineralization of organic phosphorus forms. The amount of insoluble phosphorus in limed soil was low – 23-50 mg kg^{-1}. Variations between different rates of liming were not significant. It is possible to note that at pH 6.4-6.7 the amounts of insoluble phosphorus were increased. Fox presented similar results in 1979 (Fox, 1979).

The analysis of fractional composition of mineral phosphates showed that their changes were dependent on the level of pH and on the time elapsed after the last liming. The amount of more soluble calcium, magnesium and aluminium phosphates extracted in the first extraction of NH_4F and NaOH increased in limed soil. Less soluble phosphates, depending on liming, varied insignificantly. The assessment of changes in mineral phosphate fractions showed that at moderate liming (trials A–B) the amount of plant available phosphates declined. In fertilized but not limed soil, there were 36.1% first extraction phosphates, and in limed – 28.9-30.4%. In limed soil, the amount of high-base phosphates, compared with unlimed soil, increased by 6.9%. In limed soil, high-base phosphates increased up to 9.1-11.2% from total phosphorus. Under intensive liming conditions (trial C), when ground limestone was applied more frequently, the amount of more soluble hydro- and dihydrophosphates was increased in the soil. In limed soil, they accounted for 34.6-40.9%, in unlimed soil – for 32.8% from total phosphorus. The changes of water-soluble phosphates under the influence of liming were irregular.

The amount of plant available phosphates was determined by A–L method, in hot water and extracted in 1M NH_4Cl solution. Analyses of the obtained data showed that not all the mentioned methods equally reflect the changes in the phosphoric regime in limed soil. The data of A–L method showed that the amount of mobile phosphorus was dependent on phosphoric fertilizing and intensity of liming. In trials A–B, the amount of mobile phosphorus extracted by A-L method under the influence of fertilizing increased by 74% and made up 13.7% from total phosphorus (Table 4).

At the application of lower rates of ground limestone, mobility of phosphorus did not vary significantly and only at application of 3.5 rates essential increases occurred. In the case of regular liming (trial C), similar changes were observed. In limed treatments with the same rates of mineral fertilizers, the amount of mobile phosphorus in comparison with unlimed soil increased by 40.0-45.0 mg kg^{-1} P_2O_5 of soil and made up 18.1-19.1% (in unlimed soil – 11.8%).

Table 4

Impact of liming on labile forms of phosphates

Treatment	Extraction A-L method	Extraction in hot water	Extraction in NH_4Cl	% from P total A-L method	% from P total in hot water	% from P total in NH_4Cl
	P_2O_5, mg kg^{-1} of soil					
Trials A – B						
1. Without NPK and $CaCO_3$	112	5.1	10.2	8.4	0.4	0.8
2. NPK	195	8.5	10.8	13.7	0.6	0.8
3. NPK + 1.0 r. $CaCO_3$	200	20.2	9.0	12.4	1.2	0.6
4. NPK + 2.0 r. $CaCO_3$	202	25.3	7.2	10.3	1.3	0.4
5. NPK + 3.5 r. $CaCO_3$	241	24.1	10.5	12.9	1.3	0.6
LSD_{05}		13.4	3.3			
Trial C						
1. NPK	233	40.4	8.5	11.8	2.1	0.4
2. NPK+1.0 t ha^{-1} $CaCO_3$ annually	273	76.6	9.4	18.1	5.1	0.6
3. NPK+6.0 t ha^{-1} $CaCO_3$ every 6 years	278	79.1	6.5	19.1	5.4	0.4
LSD_{05}	13.4	25.6	3.2			

Comparison of the data of trials A–B and C leads to the conclusion that more frequent liming enables to preserve phosphoric compounds in a more mobile form and is more rational from the point of view of mineral fertilizer efficiency. Determination of the mobile forms of phosphorus in hot water most precisely reflects the effect of liming. This method showed that liming increases the amount of phosphates available to plants almost double. In unlimed soil (trial A), the amount of phosphates was 8.5 mg kg^{-1} P_2O_5, and in limed soil – 20.2-25.3 mg kg^{-1}, what made up 0.6 and 1.2-1.3% of total phosphorus, accordingly. Determination of phosphates in hot water correlates with the data of A–L method, i.e. at regular liming the mobility of phosphoric compounds is increased.

The amount of available phosphates, determined by this method, in regularly limed soil made up 76.6-79.1 mg kg^{-1} or 5.1-5.4% of total phosphorus. The amount of water-soluble phosphorus determined in 1M NH_4Cl was lower and made up 7.2-10.8 mg kg^{-1} in moderately limed soil and 6.5-9.4 mg kg^{-1} in more intensively limed soil.

Discussion

Many results have been reported on the accumulation of various P forms from fertilizers. In the studies by Yakutina, the increase in available P forms was 25% higher (comparing the results from fertilized and unfertilized treatments) than the applied amount of P fertilizers identified in the first year after application (Якутина, 2001). Sokolov and Gladkova have reported on up to 30% P accumulation from totally applied amount of P fertilizers under long-term fertilizing (Соколов, Гладкова, 1979). The investigations suggest that P accumulation might reach up to 50% of soluble phosphorus forms under conditions of long-term excessive fertilizing. It was observed that changes in the amount of available phosphorus 24 years after the application were mainly related to the applied fertilizers, but surplus in balance did not lead to proportional increase. Many authors have reported on the influence of liming on P mobility in soil. Such relations also were proved in the present experiments. Holford has found that liming can also influence the availability of native and/or fertilizer P (Holford, 1989). Phosphorus is resistant to leaching in most soils, but available P forms in the soil are controlled by soil pH (Fox, 1979; Holford, 1989). Experimental results showed that phosphorus transformation processes were changed under the influence of liming intensity and distribution of rates over time.

Regular liming with ground limestone changed fractional composition of phosphates and mineral phosphate forms in loamy sand soil. Highest amount of mineral phosphates was observed in the soil with pHKCl 5.4. Intensive liming by limestone (6.0 t ha^{-1} every 6 years or 1.0 t ha^{-1} annually) increased the soil reaction up to neutral. Such level of reaction was not favorable to available forms of phosphorus. In acid soil, liming until neutral reaction (pHKCl more than 6.2) decreased the amount of mineral and organic phosphorus and increased the amount of insoluble phosphorus. In limed soil, aluminium, iron and manganese ions, which are present in acid soils, precipitated the soluble phosphorus ions available for the plants. However, in the course of time, different available compounds of phosphorus are transforming in less soluble or insoluble. Liming of soil with 2.0-3.5 rates of ground limestone essentially increased the amount of plant available phosphates, which are determined in hot water extraction and by A–L method.

Conclusions

1. In cases of secondary and periodical liming, utilization of P fertilizers was dependent on the intensity of primary liming.

2. Changes in available phosphorus amount were mainly related to the fertilizers applied, however, the changes were not proportional to the P fertilizing surplus.

3. Liming of acid soils increased the mobility of phosphoric forms. The extent of changes was dependent on the amount of applied lime and on the time passed after the last liming.

4. Regular liming had a positive effect on utilization of mineral fertilizers. The amount of most plant available hydro- and dihydrophosphates increased up to 34.6-40.9% from total phosphorus (in unlimed soil – up to 32.8%).

5. The amounts of insoluble phosphoric forms were dependent on soil pHKCl and increased up to neutral soil reaction. The changes of soil reaction from pHKCl 4.4-5.4 to pHKCl 6.4-6.7 significantly increased the insoluble P amount (from 23-35 mg kg^{-1} P_2O_5 to 43-50 mg kg^{-1} P_2O_5).

6. The influence of liming on the mobility of phosphates was best reflected by A–L method and by phosphate determination in hot water.

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Anotācija

Pētījumi veikti skābā mālsmilts augsnē, kurā 1972. un 1984. gadā ierīkoti ilgtermiņa kaļķošanas izmēģinājumi. Noskaidrota kopējā un noteiktu fosfora savienojumu (organiskais, neorganiskais, augiem izmantojamais, labilais, nešķīstošais) akumulācija augsnē ar un bez mēslošanas līdzekļu lietošanas. Noskaidrota kaļķošanas pozitīvā ietekme uz augiem izmantojamo fosfora savienojumu akumulāciju augsnē.

Regional differentiation of the soil surface phosphorus and potassium balance in Polish agriculture
Reģionālās atšķirības fosfora un kālija lauka bilancē Polijā 1999. - 2000. gadā

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Abstract. This publication presents the phosphorus and potassium balances at national and regional level. Regional balances from the years 1999-2000 provide a better picture for policy makers enabling them to identify areas of high surplus or with permanent deficit. The regional differentiation of potential soil degradation, which is indicated by nutrient balances, is presented on the maps. The regional differentiation of nutrient balance is affected by the animal and crop production intensity.
Key words: soil PK surface balance, regional differentiation, potential environment pollution.

Introduction

The modern agriculture apart from production and economic targets must pursue wide-range ecological aims, understood as the protection of the natural environment against different kinds of pollution (Kopiński, 1999). Nutrient balance can be a relatively simple tool for estimation of farm sustainability (Igras, Kopiński, 2001; Oenema, Velthof, 2000). Surplus or deficit is a very important indicator for developing nutrient management strategies by national or regional scale. Balance can be prepared on different levels (field, farm, region, and country) and differentiated into soil surface and farm gate. One of this methods proposed by international organizations, such as PARCOM (PARCOM, 1995) and OECD, is the soil surface nutrient balance (OECD, 2001). This balance measures the difference between the nutrient inputs to an agricultural system (mainly from livestock manure and chemical fertilizers) and the outputs of nutrients from agriculture (mainly uptake by crops and forage). There are many publications concerning the efficiency of nitrogen use (Hansen, 2000), but the phosphorus and potassium balances are also important for potential crop production assessment (Igras et al., 2000).

The aim of this paper is to present the soil phosphorus and potassium surface balances in the framework of administrative division of Poland. The regional differentiation of nutrient balances is presented on the maps.

Material and methods

The phosphorus and potassium balances were calculated basing on annual statistical data for the years

Table 1

Elements of the phosphorus and potassium balance

Design-ation	Element of balance	Methodology of calculation
S_{org}	Manure	Using SFOM model (Jadczyszyn et al., 2000), taking into consideration the number of animals in groups (GUS, 2000)
S_{fer}	Fertilizer	Quantity of used phosphorus and potassium in mineral fertilizers (GUS, 2001)
S_{sat}	Seeds and tubers	Quantity of phosphorus and potassium in seeds and seed-potatoes, quantity of the material relative to the sown area, standard values of PK content in seeds and seed-potatoes (Fotyma and Mercik, 1995)
S_{caf}	Uptake by crops and forage	Quantity of phosphorus and potassium taken up by crops and forage (GUS, 2000), standard values of PK content in yield (Fotyma and Mercik, 1995)
SSNB	Soil surface nutrient balance	The phosphorus and potassium surplus or deficit $SSNB = S_{org} + S_{fer} + S_{sat} - S_{caf}$

Table 2

Values of nutrient balance elements in agricultural land in Poland, on average (1999-2000)

Nutrient	Balance elements, kg ha⁻¹			
	S_{org}	S_{fer}	S_{caf}	S_{sat}
P	5.9	7.2	11.1	0.7
K	32.1	17.3	69.3	3.0

Table 3

The phosphorus and potassium balances in agricultural land in Poland, on average, kg ha^{-1} (1999-2000)

Nutrient	Soil surface balance
P	2.7
K	−16.9

1999–2000 (GUS, 2000a; GUS, 2000b; GUS, 2001). The main aim of the investigations was to study the four basic elements of the phosphorus and potassium balances for the new Polish voivodeships (after the administrative reform). Values of particular balance elements were estimated as averages for the country according to OECD method (OECD, 1999) modified for Polish conditions and using SFOM model (Jadczyszyn et al., 2000). The elements of balance and the way how to calculate them are presented in Table 1 and are expressed for agricultural land (AL). The balances are given for nutrients expressed in elementary form and presented on the maps with the new administrative division of Poland.

Results

The elements of the phosphorus and potassium balance are presented in Table 2, but total balance in Table 3. The highest rates of phosphorus were applied in mineral fertilizer, while those of potassium – in organic fertilizer. The amount of potassium supplied in mineral fertilizers is equal to half of the quantity supplied in organic fertilizers. The very highest quantity of potassium was uptake by crops and forage. The soil surface phosphorus balance in Poland in the years 1999–2000 was sustainable, but potassium balance showed a deficit of about -17 kg K ha^{-1} of agricultural land.

P and K balances presented on the maps (Figs. 1, 2) show the country's regional differentiation in the new

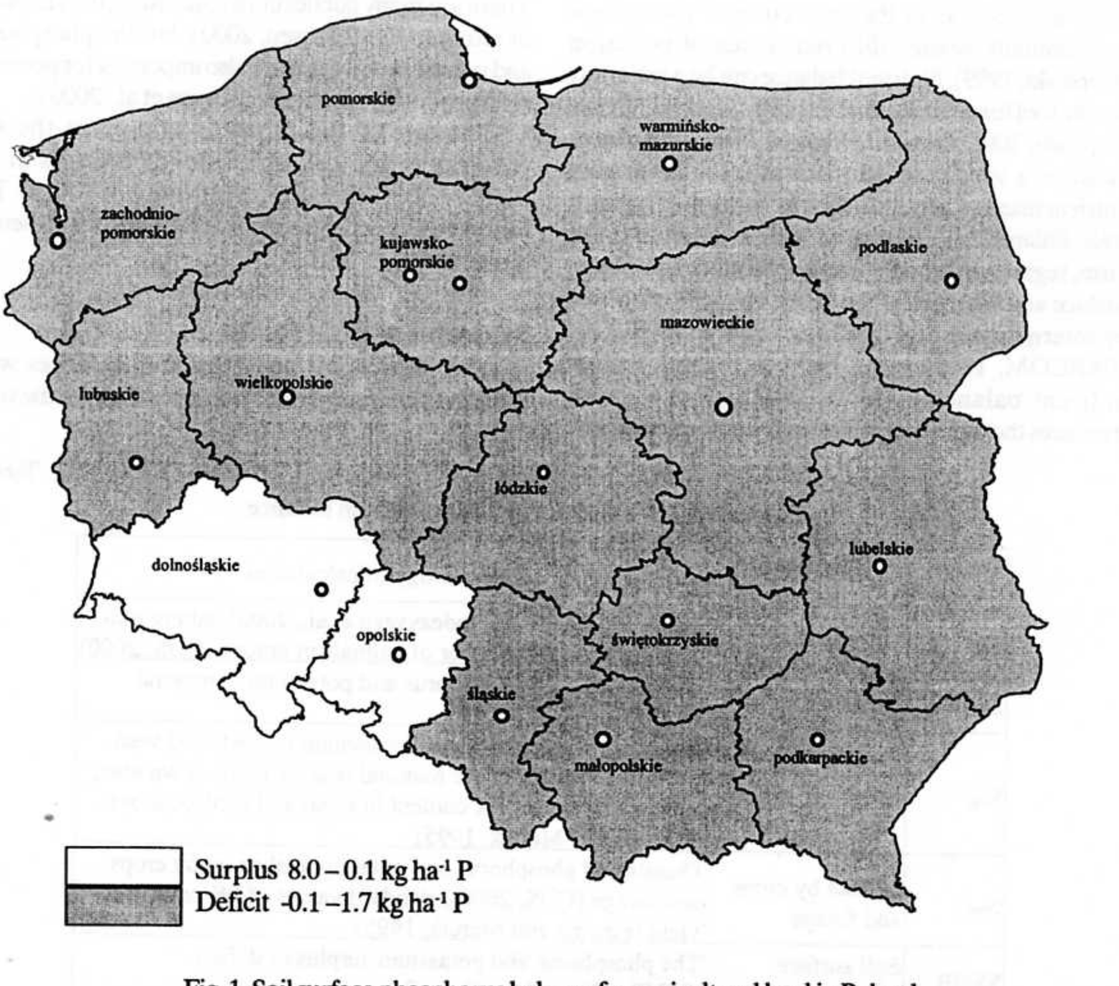

Fig. 1. Soil surface phosphorus balance for agricultural land in Poland.

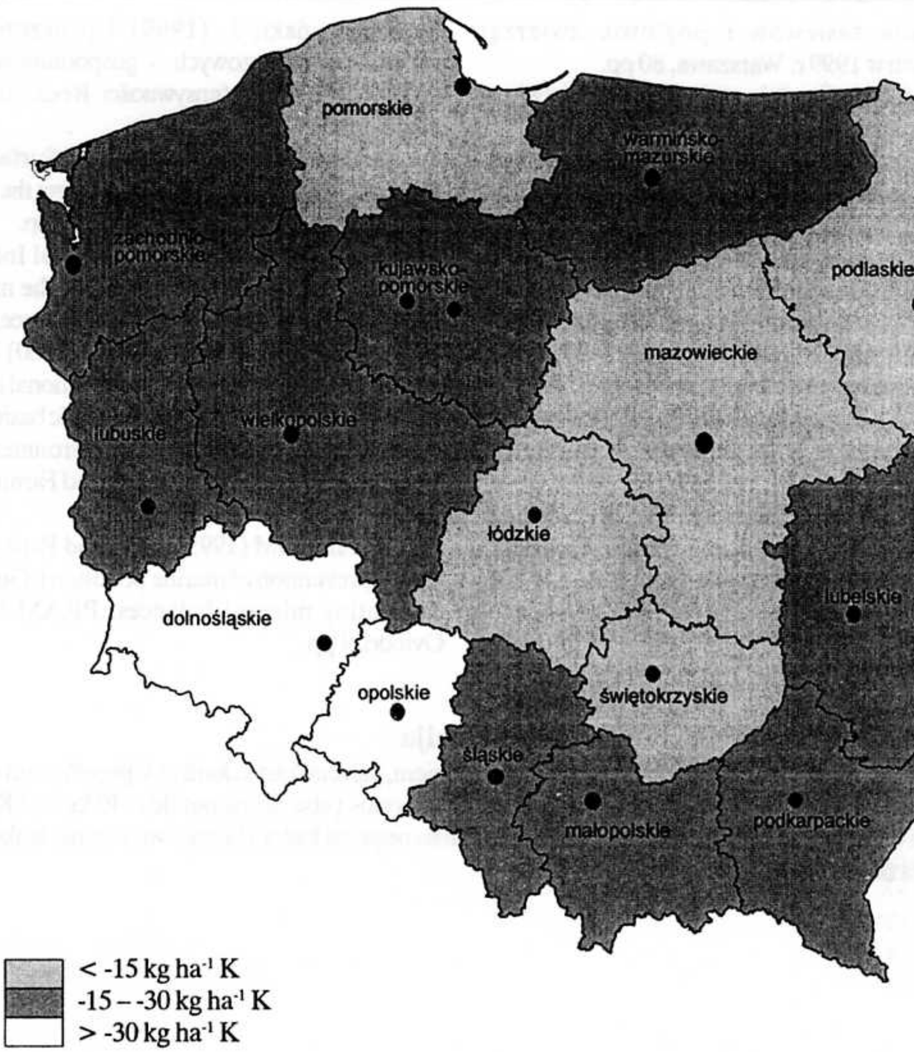

Fig. 2. Soil surface potassium balance for agricultural land in Poland.

administrative division starting from 1999. The regional differentiation of nutrient balances is affected by the intensity of animal and crop production.

The total phosphorus balance in the majority of voivodeships is sustainable, however, not all the phosphorus is utilized by crops. In some southwestern regions of Poland – the Opolskie and Dolnośląskie voivodeships – the phosphorus balance is negative. These two voivodeships have very good soil–climatic conditions what results in a high crop production intensity. Decreasing of plant available phosphorus content in the soil in this region due to a negative balance could increase the soil degradation risk.

The potassium balance was negative in the whole country, but regional distribution is shown in Fig. 2. The highest deficit is in the Dolnośląskie and Opolskie voivodeships, which is almost -40 kg K ha^{-1}. The permanent potassium deficit in the long run may lead to soil degradation. Central and north provinces present a relatively small K deficit – less than 15 kg ha^{-1}. These voivodeships have a various structure of land use and average soil–climatic conditions, but the crop and animal production intensity is very low.

Conclusion

The soil surface phosphorus balance in Poland is sustainable, except for the Opolskie and Dolnośląskie voivodeships where it was found negative.

The potassium balance was negative throughout the whole country. A critical situation for potassium was observed in the Opolskie and Dolnośląskie voivodeships where the deficit reached -40 kg ha^{-1} K.

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Anotācija

Novērotas samērā būtiskas atšķirības starp valsts reģioniem, galvenokārt sakarā ar lopkopības un augkopības dažādo intensitāti. Kālija bilance ir negatīva visos valsts reģionos (atsevišķos pat līdz -40 kg ha^{-1} K), savukārt fosfora – tikai Opolskie and Dolnośląskie vojevodistēs. Ilgstoša negatīva fosfora bilance var veicināt lauksaimniecībā izmantojamās zemes augšņu degradāciju.

The effect of potassium and phosphorus fertilizers on the potato yield depending on pedoclimatic conditions
Fosfora un kālija minerālmēslu ietekme uz kartupeļu ražu atkarībā no augsnes un klimatiskajiem apstākļiem

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Abstract. On potassium poor soils, the average effectiveness of K_{60} fertilizer norm is 60-80 kg of tubers per kg of K_2O, while in favorable years it can be as high as 120-140 kg. On soils with lactate soluble potassium below 130 mg K_2O kg^{-1}, moderate amounts of potassium fertilizers provide a yield increase of potato almost every year. On soils with very high potassium content, potassium fertilizers ensure yield increase only in one to three years out of ten. An increase in soil potassium content by 10 mg K_2O kg^{-1} decreased the average effectiveness of the K_{60} rate by 5.5 kg of tubers per 1 kg of K_2O applied. Phosphorus fertilizers produce a positive effect every other year on soils with the lactate soluble P_2O_5 content below 200 mg kg^{-1}. On phosphorus poor soils (below 70 mg kg^{-1}), the effect of phosphorus fertilizers is evident almost every year, and the effectiveness of the use of low phosphorus amounts (P_{60}) is on average higher than 50 kg of tubers per kg P_2O_5. The increase of plant available phosphorus in soil by 10 mg kg^{-1} results in reduction of P_{60} use by 3.2 kg of tubers on average per 1 kg of P_2O_5 applied.
Key words: PK fertilizers and balance, potatoes, profitability of fertilization.

Introduction

The European agricultural production and agrarian policy has undergone dramatic changes during the last decade, which have considerably influenced the development of rural areas as well as the whole agricultural sector. Reforms have been particularly large-scale in East European countries and in the former republics of the Soviet Union (FAOSTAT; Ruben et al., 1998; Csaki, 2000). Sustainable use of natural and economic resources has gained increasing importance (Veldkamp and Fresco, 1997; Bade and Kruseman, 1998). Besides conventional agricultural production, the role of alternative farming systems has increased significantly, which ensures an ecologically cleaner and healthier environment. The applied farming system determines the efficiency of utilization of resources (Struik and Bonciarelli, 1997; Uhlin, 1998), the nutrient balance of soils (Schröder, Asperen et al., 1996; Kätterer and Andren, 1999; Roostalu et al., 2000; Ross et al., 1999) as well as the general state of the environment and agroecosystems (Waldon et al., 1998; Hoffmann et al., 2000). By increasing the efficiency of plant nutrient recycling within agricultural system, it is possible to reduce the load to the environment. Depending on the pedoclimatic conditions of a particular region, it is necessary to establish an optimum level of the intensity of crop and livestock production as well as their proportions on the levels of the farm, the region and the state (Granstedt, 2000).

Agricultural production in present-day Estonia has become extremely unstable and brings in little profit. According to the FAO, crop production has decreased to 28% in Estonia (FAOSTAT; Roostalu et al., 2000). The decline in crop production as well as in the level of all agricultural production is due to soaring prices of machinery, fertilizers and pesticides as well as to drastic changes in the marketing of agricultural products. Compared with the 1980s, the average amount of nitrogen fertilizers applied per hectare of arable land in the period of regained independence has decreased up to 6 times, the amount of phosphorus fertilizers – 20 times, the amount of potassium fertilizers – 30 times, the amount of organic fertilizers – 4 times, and the amount of pesticides – 5 times. Basing on the results of variety comparison experiments, the yield of cereals in agricultural enterprises and on farms makes 40-50%, and the yield of potato – 35-40% of the potential yield.

In the period of large-scale production when an average of up to 84-96 kg of potassium, 46-69 kg of phosphorus and 10-12 t of manure were used per hectare of arable land, the total balance of these nutrients was markedly positive (Roostalu et al., 2000).

The amount of potassium removed with the yield was 72 kg K_2O ha^{-1}, while the amount applied for crops was approximately twice as large. In the case of phosphorus, an average of 28-30 kg P_2O_5 per hectare of arable land was removed with the yield, while the amount applied with fertilizers was 78-85 kg of P_2O_5 per hectare. Proceeding from this, the content of lactate soluble potassium in the soil increased on average by

22%, while the content of lactate soluble phosphorus increased more than twice during this period.

During the period of Estonia's re-independence, the balance of all main nutrient elements has become negative as a consequence of inadequate fertilization. The average amounts removed from the soil with the yield were 55 kg N, 21 kg P_2O_5, and 54 kg K_2O, while the amounts returned to the soil – 30 kg N, 11 kg P_2O_5, and 18 kg K_2O. Thus, the present production takes place largely at the expense of the soil resources created by farmers in the 1970s-1990s. The content of soil lactate soluble potassium of Estonian arable land is low for 43.4%, moderate for 42.6%, and high for 14.0% of soils. The content of lactate soluble phosphorus is very low or low for 28.9%, moderate for 46.8% and high or very high for 24.3% of soils (Järvan et al., 1996).

In the case of general balance of potassium and phosphorus, it is necessary to take into account that in the first year plants utilize only certain part of available nutrients. Among mineral fertilizers, plants utilize 50-70% of potassium in the first year of application with a total of 60-80% per rotation (Piho, 1973; 1977). From manure, plants assimilate 50-70% of potassium in the first year and with a total of 70-80%. Assimilation of phosphorus from superphosphate varies from 10 to 30% in the first year of application, while the amount assimilated from manure is 20-40%, with a total of 25-45% and 40-60% per rotation, respectively. Utilization of potassium and phosphorus from soil resources depends on the crop, and even more on the content of nutrient elements available in the soil. In the case of a very low content of soil nutrient elements, the plants are able to utilize 8-26% of phosphorus resources and 15-90% of potassium resources. Thus, considering our current application of potassium and phosphorus fertilizers, it can be supposed that the active balance of these nutrient elements is significantly more negative than is reflected by their total balance.

Materials and methods

The present study summarizes the results of previous fertilization experiments conducted with potato (Aamisepp, 1939; Eesti põllumajandusteadus..., 1946; Ümarik, 1946; Talpsepp, 1966, 1969, 1970; Viileberg, 1966; Sutter, 1967; Sirendi, 1969; Turbas, 1969; Sepp, 1972, 1974, 1978; Piho, 1971, 1973, 1977, 1978; Kärblane and Tartlan, 1989; Valgus, 1992), as well as analyses of crop response to the application of the potassium and phosphorus fertilizers and related agroeconomic risk factors. The database, which contains the results of more than 250 field experiments

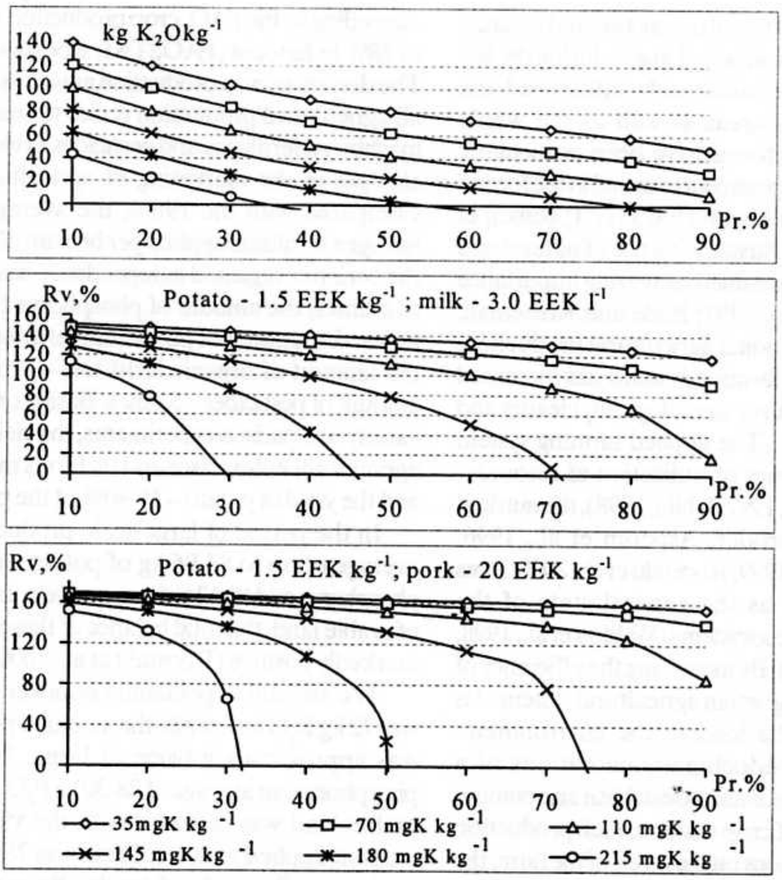

Fig. 1. Probability of the average effectiveness and profitability of potassium fertilizer rate K_{60} depending on soil lactate soluble K_2O content.

performed in Estonia with medium- or late-maturing potato varieties, was used. These experiments have been carried out on soils with very different texture and other properties. The impact of soil and climate conditions on the effectiveness of fertilizers has been assessed according to the theory of probability.

The assessment is based on regression analysis, which has the following general form of the equation:

$$y = a_0 + a_1x - a_2Pr + a_3Pr^2 - a_4Pr^4,$$

where y – average effectiveness of fertilizer rate K_{60} or P_{60} per kg K_2O or P_2O_5 kg^{-1};

x – lactate soluble K_2O or P_2O_5 content in soil, mg kg^{-1};

Pr – probability, %.

In the calculation of the profitability of fertilization (Rv, %) it was assumed that the commercial yield (60% from total) is sold at 1.5 EEK kg^{-1}, but the rest of the yield is converted to milk or pork, the selling price of which is 3.0 and 20 EEK kg^{-1}, respectively. The cost of fertilizers is 3.3 EEK kg^{-1} for K_2O and 10.9 EEK kg^{-1} for P_2O_5, the cost of harvesting is 0.2 EEK kg^{-1}. The feeding of animals proceeded from a balanced feed ration and the calculation of the requirement for metabolizable energy and protein was based on the requirement for purchased concentrated fodder and its cost.

Results and discussion

The effectiveness of potassium fertilizers to a great extent depends on soil potassium level, use of the nitrogen and phosphorus fertilizers and manure, and the crop specifics, and also on climatic conditions during the potato growth period (Fig. 1). For a longer period average, the effectiveness of fertilizer rate K_{60} for potatoes, compared with NP background on soils with very low and low content of available potassium, is 60 to 80 kg of tubers per kg of K_2O applied. However, in one favorable year out of ten it may even reach 120 to 140 kg of tubers per kg K_2O applied. On soils with moderate and high potassium content, average effectiveness was 25 to 40 kg K_2O kg^{-1}, but in 1-2 years out of ten, fertilizer use may not increase the yield of potato. On soils with very high potassium content, the probability of yield increase, which will pay back the expenses of potassium use, is low – 30-60%. If only potassium fertilizers are applied on the background of manure, their effectiveness remains considerably lower. According to Piho (1973), the effectiveness of potassium fertilizers higher than average can be expected if the summer is relatively cool, but agronomically effective fertilizer rate is 66 to 200 kg of K_2O ha^{-1}, which may vary more than two times depending on the weather conditions.

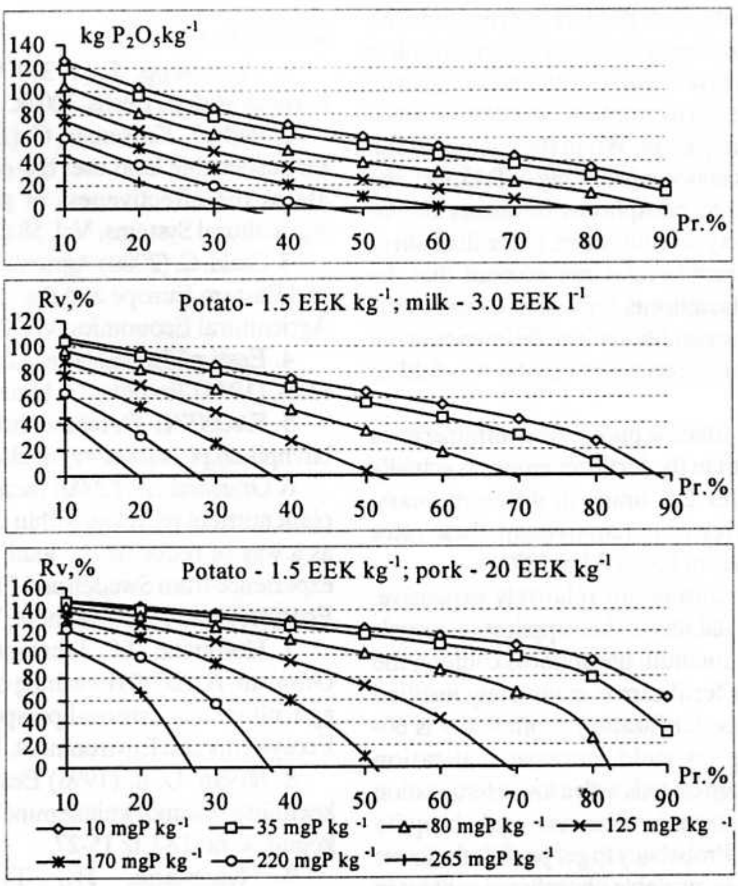

Fig. 2. Probability of the average effectiveness and profitability of phosphorus fertilizer rate P_{60} depending on soil lactate soluble P_2O_5 content.

As potassium fertilizers can significantly increase the potato yield and are relatively cheap (3.3 EEK per kg of K_2O), their application using moderate rates is profitable and involves small economic risk on soils where the content of available potassium does not exceed 110 mg K_2O kg^{-1}. However, on soils with low potassium requirement the probability of economic risk is relatively high.

The effectiveness of phosphorus fertilizers and the fertilization profitability depend on the soil fertilizer requirement and also on the weather conditions (Fig. 2).

Analysis of all experimental results suggest that average effectiveness of fertilizer rate P_{60} on soils with a very high and high fertilizer requirement is 50-60 kg of tubers per kg P_2O_5 when phosphorus fertilizer is used together with nitrogen. However, in this case it is necessary to take into consideration that the effectiveness of phosphorus fertilizers increases when nitrogen fertilizer is used. When nitrogen fertilizers are not applied, the effectiveness of phosphorus fertilizer remains markedly lower.

On soils with a medium content of available phosphorus, the average effectiveness of fertilizer rate P_{60} was approximately 40 kg of tubers per kg P_2O_5, while on soils with a low fertilizer requirement, the expected average effectiveness was 24 kg of tubers per kg P_2O_5. On soils with a low phosphorus requirement, appli-cation of phosphorus fertilizers may not result in yield increase at all in two years out of ten. On soils with still higher phosphorus content, weather-related economic risk is far greater. When the content of soil lactate soluble phosphorus is 220 mg of P_2O_5 kg^{-1}, the yield increase due to phosphorus fertilizers can be expected only in 3-5 years out of ten. In fertilization of potato, it is necessary to take into account that the effectiveness of phosphorus fertilizers considerably depends on climatic conditions. The difference in the effectiveness of these fertilizers can be 4-7–fold in different years.

Agronomically effective phosphorus fertilizer rates are usually higher than the fertilizer amounts actually used and can differ 2-3 times in different years. Depending on soil fertilizer requirement, these rates can be 90-250 kg ha^{-1} of P_2O_5 (Piho, 1973).

Phosphorus fertilizers are relatively expensive. Analysis of the profitability of their application reveals that on soils with a medium phosphorus content, the use of phosphorus fertilizers is completely justified because the average fertilization profitability is 60-120%, depending on yield increase realization possibilities. Although on soils with a lower fertilization need, profit gained from fertilizer use could be quite large in some years. Probability to get profit is the lower the higher is the plant available phosphorus content in soil.

Conclusion

The complex analysis of the results of fertilization experiments allowed determining the impact of natural and economic risk factors on the effectiveness of fertilization. The higher is the soil nutrient content, the lower are the effectiveness of fertilizers and agroecologically and economically grounded application rates of fertilizers. The difference in the average effectiveness of potassium fertilizers (K_{60}) between favorable and unfavorable years can be up to 80-90 kg of K_2O kg^{-1}, that of phosphorus fertilizers (P_{60}) – up to 90-100 kg of P_2O_5 kg^{-1}. The profitability of fertilization depends primarily on fertilizer effectiveness and also on such economic risk factors as the cost of fertilizers, the cost related to the management of yield increase as well as sales income. On soils with high potassium and phosphorus requirement, the profitability of the application of fertilizer rate K_{60} or P_{60} can exceed 140-170%. But in the case of lactate soluble potassium- and phosphorus-rich soils, considerable profit from fertilization can be obtained in less than two or three years out of ten.

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Anotācija

Augsnēs ar zemu kālija nodrošinājumu, lietojot 60 kg K_2O ha^{-1}, mēslošanas efektivitāte sasniedz 60-80 kg bumbuļu uz katru ar mēslojumu izmantoto K_2O kilogramu. Labvēlīgos gados šis rādītājs var sasniegt pat līdz 120-140 kg bumbuļu. Augsnēs, kurās laktātā šķīstošā kālija saturs ir mazāks par 130 mg kg^{-1}, mērenas kālija minerālmēslu normas gandrīz ik gadus nodrošina kartupeļu ražas pieaugumu. Palielinoties augsnes kālija nodrošinājumam, pakāpeniski samazinās atdeve no izlietotā kālija mēslojuma. Praktiski ikgadēju atdevi no fosfora mēslojuma var iegūt, ja tā laktātā šķīstošo savienojumu saturs augsnē ir zem 70 mg kg^{-1}.

Phosphorus uptake and balance by winter and spring wheat
Fosfora uzņemšana un bilance ziemas un vasaras kviešu sējumos

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Abstract. The impact of mineral fertilizers on P uptake and balance by winter and spring wheat was studied on experimental farm "Pēterlauki" of the Faculty of Agriculture, LLU. The experiments were carried out on sod-pseudogley sandy clay loam soil in 1999–2001. Potassium fertilizer rate K_{90} was constant over the entire experiment, but phosphorus rates were as follows: P_0, P_{60}, P_{90} and P_{120} for winter wheat, and P_0, P_{45}, P_{60}, P_{90} for spring wheat. Two different nitrogen levels N_{60} and N_{120} for winter wheat, and N_{60} and N_{90} for spring wheat were used. Meteorological conditions during the experimental years were quite different. The experiment showed that P content in the grain of winter wheat changed depending on fertilizer rate and meteorological conditions. More significant P changes were observed at a lower nitrogen rate (N_{60}). Neither fertilizer nor weather conditions affected the P content in straw. Changes of P content in the grain and straw of spring wheat varied. Higher P fertilizer rates resulted in increased phosphorus removal by the yield of winter and spring wheat, but this tendency was more expressed at lower N fertilizer rates. Growing P fertilizer rates for winter wheat increased N utilization coefficient from 0.64 to 0.93 at $N_{60}K_{90}$, but at $N_{120}K_{90}$ – from 0.59 to 0.63. In spring wheat, growing P fertilizer rates increased N utilization coefficient from 0.52 to 0.56 at $N_{60}K_{60}$, but at $N_{90}K_{60}$ – from 0.47 to 0.49. All P fertilizer rates applied in winter wheat and spring wheat provided a positive total P balance.
Key words: phosphorus, balance, uptake.

Introduction

The purpose of this research was to study the influence of mineral fertilizers on P uptake and balance in winter and spring wheat. This is of importance in investigating plant nutrient turnover and ecological aspects of fertilizer application. Data obtained by many researchers regarding P fertilizer utilization are rather contradictory. Efficiency of P commercial fertilizers depends on P level in soil, weather conditions, balance of other plant nutrients in soil, and other factors (Feizienė, 2000; Амелин, 1999; Постников, 1988). Soils and meteorological conditions are quite variable in Latvia, thus having impact on phosphorus uptake and utilization by plants. Differences in P content (DL-method) were confirmed by the results of soil agrochemical investigations over the period 1959-1990 and agricultural land monitoring in sample farms (1995-1996). Fertility survey results show that 37-38% of agricultural land in Latvia are very low and low (<70 mg kg^{-1}), 33% – medium, but 29-30% – high and very high in available phosphorus (Skromanis, 1994; Zemes ..., 1997). Investigations showed correlation between soil nutrient status and crop response to fertilizers, i.e. more fertile the soil, the lower the fertilizer use efficiency (Амелин, 1999; Vaisvila, 2000). Recent investigations showed some changes in soil fertility status due to the nutrient management practice, what is commonly used in the farming practice in Latvia today. Plant nutrient balance in agricultural land of Latvia was negative. Particularly for phosphorus it was -5 kg ha^{-1} of P_2O_5 (Livmanis, 2001). Similar relationship was observed in long-term stationary experiments of Agricultural Land Monitoring program, where in 1993–1999 the phos-phorus content in soil of monitoring plots decreased approximately by 46 mg kg^{-1} or 24% on average. In this period, P level in the soil essentially increased in 10% of plots, decreased in 60%, and did not essentially change in 30% of plots (Gemste, 2001).

Research results presented in this paper are a part of long-term complex investigations on plant nutrient turnover in cereal crop rotation.

Materials and methods

The impact of mineral fertilizers on uptake and balance of P in winter wheat 'Moda' and spring wheat 'Eta' was studied on experimental farm "Pēterlauki" of the Faculty of Agriculture, LLU. The experiments were carried out on sod-pseudogley sandy clay loam soil (Stagnic Luvisols according to FAO Legend, 1990) from 1999 to 2001. The main agrochemical properties were: organic matter (Tyurin's method) – 26-29 g kg^{-1} (15-17 g kg^{-1} $C_{org.}$); pHKCl – 7.0-7.3; plant available phosphorus (DL-method) – 110-150 mg kg^{-1}, and exchangeable potassium (DL-method) – 185-240 mg kg^{-1} of soil. Potassium fertilizer rate K_{90} was constant over the whole experiment. Applied phosphorus fertilizer rates were as follows: P_0, P_{60}, P_{90}, and P_{120} for winter wheat, and P_0, P_{45}, P_{60}, P_{90} for spring wheat*.

* – Here and afterwards designation $P_{45}K_{90}$ means 45 and 90 kg ha^{-1} of P_2O_5 and K_2O, respectively.

These investigations were conducted at different N fertilizer levels: N_{60} and N_{60+60} for winter wheat, and N_{60} and N_{90} for spring wheat. Previous crop for winter wheat was 1st year clover, and oil radish for spring wheat. The experiment consisted of 9 treatments in four replicates. The total plot size was 100 m^2, the harvested area – 24.24 m^2. Fertilizer application was hand broadcast, kinds of fertilizers: ammonium nitrate, single superphosphate, and potassium chloride.

During the investigation years, unusually early and warm spring was observed. Daily temperatures in 1991 averaged 5°C higher in April and in the last decade of March 1999, therefore the beginning of vegetation started comparatively early. The first half of May in 1999 was cold and dry with rather severe frost, but weather conditions in this period of 2000 and 2001 were close to long-term averages. Most favorable weather conditions during tillering stage and anthesis in 2001 gave about 9 to 13 grains per ear more than in other investigation years. During grain yield formation there was enough moisture and heat over all investigation period. This period of 2001 was characterized by higher temperatures compared with long-term averages and resulted in small grain increase in yield. In 2000, abundant rainfall in the period of grain maturation and harvesting negatively affected the grain quality. From yield formation aspect, more suitable meteorological conditions were observed in 2000. The year 1999 was characterized by early and cold spring, as well as by dry first half of the vegetation period, but 2001 was wet with warm end of June and start of July.

Results and discussion

Experimental data showed changes in the P_2O_5 uptake and content in wheat what was influenced both by fertilizer rate and meteorological conditions of the growing season. Analysis of winter wheat (Table 1) showed a higher P content in grain in 1999, but lower – in 2000, when the highest total yield was obtained due to weather conditions during the vegetation period.

Increasing both N and P fertilizer rates resulted in changes of P_2O_5 content in wheat. The effect of used P_2O_5 rates on P content was more obvious in 2000. Obtained average data show that P_2O_5 rate increased from 0 to 120 kg ha^{-1} at nitrogen level N_{60}, resulting in 0.07% more P in grain. At nitrogen level N_{120}, the increase of P_2O_5 rate up to 60 kg ha^{-1} resulted in 0.14% more P in grain. Further increase of P fertilizer up to 120 kg ha^{-1} resulted in P content reduction by 0.05%. Neither fertilizer nor weather conditions affected the P content in winter wheat straw. In spring wheat, more expressed variability in P content was observed both in grain and straw. In 2000, increased P rates resulted in increased P_2O_5 content both in grain and straw at both N levels. However, in 1999, this tendency was observed only at lower N rate (N_{60}). Further increase in N fertilizer

Table 1

P_2O_5 content in winter wheat, %

Treatment	Grain				Straw			
	1999	2000	2001	average	1999	2000	2001	average
$N_0P_0K_0$	0.96	0.77	0.83	0.85	0.16	0.21	0.16	0.18
$N_{60}P_0K_{90}$	0.96	0.67	0.88	0.84	0.15	0.17	0.16	0.16
$N_{60}P_{60}K_{90}$	0.97	0.78	0.90	0.88	0.17	0.16	0.14	0.16
$N_{60}P_{90}K_{90}$	0.97	0.82	0.92	0.90	0.18	0.16	0.14	0.16
$N_{60}P_{120}K_{90}$	0.97	0.80	0.95	0.91	0.21	0.16	0.14	0.17
$N_{120}P_0K_{90}$	0.93	0.64	0.89	0.82	0.15	0.17	0.14	0.15
$N_{120}P_{60}K_{90}$	0.99	0.91	0.97	0.96	0.14	0.18	0.15	0.16
$N_{120}P_{90}K_{90}$	0.99	0.89	0.97	0.95	0.16	0.17	0.16	0.16
$N_{120}P_{120}K_{90}$	0.99	0.76	0.97	0.91	0.15	0.17	0.16	0.16

Table 2

P_2O_5 content in spring wheat, %

Treatment	Grain				Straw			
	1999	2000	2001	average	1999	2000	2001	average
$N_0P_0K_0$	1.06	1.00	0.96	1.00	0.15	0.23	0.28	0.23
$N_{60}P_0K_{90}$	1.03	1.00	0.98	1.00	0.14	0.23	0.27	0.22
$N_{60}P_{45}K_{90}$	1.08	1.03	1.00	1.03	0.13	0.26	0.29	0.24
$N_{60}P_{60}K_{90}$	1.07	1.03	1.00	1.03	0.12	0.26	0.29	0.24
$N_{60}P_{90}K_{90}$	1.15	1.04	0.98	1.05	0.12	0.28	0.27	0.24
$N_{90}P_0K_{90}$	1.16	1.01	1.01	1.05	0.15	0.28	0.25	0.23
$N_{90}P_{45}K_{90}$	0.87	1.05	0.95	0.97	0.12	0.30	0.27	0.24
$N_{90}P_{60}K_{90}$	0.87	1.05	1.04	1.00	0.15	0.28	0.29	0.25
$N_{90}P_{90}K_{90}$	0.93	1.09	1.06	1.04	0.15	0.30	0.29	0.26

rates resulted in reduction of P_2O_5 content (Table 2). In our experiment, significant P_2O_5 changes in grain and straw were not observed in 2001. In 2000, for spring wheat, close correlation was found between the P content in grain and the straw crop yield (r=0.820).

The 3-year averages showed increase in P_2O_5 content by 0.03–0.05% in spring wheat grain due to growing P fertilizer rates at lower N level, but at higher N level decrease in P_2O_5 content was observed.

In straw, lower phosphorus content was observed in 1999 when application of increased P fertilizer rates resulted in decrease of phosphorus content by 0.02% at a lower nitrogen rate (N_{60}). However, in 2000, 0.5% increase was observed. At higher N level, some tendency of increased P_2O_5 content was found in 2001. Average results showed increase in P content at lower N level provided only by P fertilizer rate 45 kg ha^{-1}, but at higher N level this tendency was observed with other P fertilizer rates.

Collinearity Diagnostics testing between grain, straw yield and P content in yield showed that this relationship in spring wheat was observed only in 2000 with more suitable meteorological conditions and the highest yield: for grain r=0.798, and for straw r=0.874. For winter wheat, close correlation between grain yield and its P content was found in 2001 (r=0.905), but between straw yield and its P content – in 2000 (r=-0.678).

Increase of P fertilizer rates in winter wheat resulted in most expressed tendency to increase the P removal with grain yield, as it was observed in 2001 (Table 3) as well as in 1999, except for treatment $N_{120}P_{120}K_{120}$. For straw yield, this tendency was observed over all experimental years at the lowest nitrogen rate (N_{60}). Total P removal was highest in 2000, when the highest grain and straw yields of winter wheat were obtained. An increased P_2O_5 rate resulted in increase of total (grain+straw) P removal from 41.5 to 54.3 kg ha^{-1} on average applying N_{60}. At N_{120}, P removal was from 46.7 to 59.5 kg ha^{-1}. This observation was found when applying up to P_{90}, but at P_{120}, some reduction in phosphorus removal was found.

The increase of P fertilizer rates at both N levels contributed to N uptake in winter and spring wheat by 12.7-30.7 and 14.3-18.6 kg of N ha^{-1}, respectively. In spring wheat, certain variation in P removal was observed between the experimental years. However, highest P removal was observed in 2000. In this year, correlation between the increase of P rates and P removal was closest. In spring wheat, increased P

Table 3

P_2O_5 removal by winter wheat yield, kg ha^{-1}

Treatment	Grain				Straw				Grain+straw			
	1999	2000	2001	average	1999	2000	2001	average	1999	2000	2001	average
$N_0P_0K_0$	26.5	32.8	29.7	30.1	3.6	9.9	6.6	7.4	30.1	42.7	36.3	37.5
$N_{60}P_0K_{90}$	31.3	34.1	35.4	33.7	4.1	9.6	7.8	7.8	35.3	43.6	43.1	41.5
$N_{60}P_{60}K_{90}$	36.0	45.1	38.7	40.7	4.9	10.5	7.6	8.4	41.0	55.6	46.4	49.1
$N_{60}P_{90}K_{90}$	35.4	50.3	41.1	43.6	5.0	11.6	8.1	9.2	40.4	61.9	49.3	52.7
$N_{60}P_{120}K_{90}$	38.7	49.7	43.3	44.7	6.3	11.7	8.4	9.5	45.0	61.4	51.7	54.3
$N_{120}P_0K_{90}$	34.9	37.4	40.2	37.6	4.3	11.6	8.5	9.1	39.1	49.1	48.7	46.7
$N_{120}P_{60}K_{90}$	39.6	58.5	44.5	49.2	4.3	13.4	9.2	10.2	43.8	72.0	53.7	59.4
$N_{120}P_{90}K_{90}$	39.7	57.6	45.2	49.1	4.8	13.0	10.0	10.4	44.5	70.6	55.2	59.5
$N_{120}P_{120}K_{90}$	39.2	49.4	45.7	45.6	4.5	12.8	10.1	10.3	43.7	62.2	55.8	55.9
$\gamma_{0.05}$*	5.9			–	1.4			–	6.7			–

* – this criteria is applicable for evaluation of differences between both treatments and years.

Table 4

P_2O_5 removal by spring wheat yield, kg ha^{-1}

Treatment	Grain				Straw				Grain+straw			
	1999	2000	2001	average	1999	2000	2001	average	1999	2000	2001	average
$N_0P_0K_0$	28.0	38.3	32.2	33.4	4.5	9.7	12.2	9.3	32.5	48.0	44.4	42.7
$N_{60}P_0K_{90}$	31.5	42.1	37.2	37.5	4.9	9.4	13.0	9.5	36.4	51.5	50.2	47.0
$N_{60}P_{45}K_{90}$	35.1	46.3	40.0	41.1	4.4	11.6	14.7	10.9	39.5	57.9	54.7	51.9
$N_{60}P_{60}K_{90}$	34.2	47.4	39.4	41.1	4.2	12.3	14.4	11.0	38.4	59.7	53.8	52.1
$N_{60}P_{90}K_{90}$	37.3	48.2	38.9	42.1	4.0	13.4	13.5	11.0	41.3	61.6	52.3	53.1
$N_{90}P_0K_{90}$	37.3	46.2	38.6	41.2	5.6	12.8	12.3	10.6	42.9	59.0	50.9	51.9
$N_{90}P_{45}K_{90}$	28.8	50.2	37.8	40.3	4.4	14.2	14.7	11.9	33.2	64.4	52.6	52.1
$N_{90}P_{60}K_{90}$	28.6	50.9	41.4	41.7	5.4	13.7	16.2	12.6	34.0	64.6	57.6	54.3
$N_{90}P_{90}K_{90}$	31.4	52.8	42.3	43.4	5.3	14.7	16.1	12.8	36.6	67.4	58.4	56.3
$\gamma_{0.05}$*	5.1			–	2.0			–	6.5			–

* – this criteria is applicable for evaluation of differences between both treatments and years.

fertilizer rates at N_{60} resulted in total P removal from 47.0 to 53.1 kg ha^{-1} on average, but at N_{90} – from 51.9 to 56.3 kg ha^{-1} (Table 4). The increase of P fertilizer rates at both N levels resulted in higher N uptake – by 8.7-11.2 and 8.7-10.6 kg ha^{-1}, respectively.

Results of Anova Two-Factor analysis indicate that P removal by 1 ton of grain and 1 ton of grain+straw of winter wheat was influenced by fertilizers (P=0.019–0.033) and weather conditions in a particular experimental year (P<0.01). As to spring wheat, differences were observed in P removal by 1 ton of grain and straw in a particular experimental year (P=0.004) as a result of nitrogen and phosphorus fertilizer application.

Table 5 presents the amount of removed P in winter wheat by 1 ton of grain and 1 ton of grain+straw. In treatments with P fertilizer, applying N_{60}, the removal of P was 7.6-7.8 kg t^{-1} reaching 8.4-8.5 kg ha^{-1} at N_{120} in treatments $N_{120}P_{60}K_{90}$ and $N_{120}P_{90}K_{90}$, and 7.8 kg t^{-1} in treatment $N_{120}P_{120}K_{90}$. Phosphorus removal at lower N level was 9.2-9.5 kg t^{-1}, but in corresponding treatments at higher N level – 10.1-10.2 kg t^{-1} and 9.5 kg t^{-1}, respectively.

Considering that phosphorus content was higher in spring wheat than in winter wheat, P removal by 1 ton of product was also higher (Table 6). Removal by grain at N_{60} changed from 9.1 to 9.2 kg t^{-1}, but at higher N rate (N_{90}) – from 8.7 to 9.3 kg t^{-1}. Total removal (grain+straw) changed from 11.5 to 11.7, and from 11.2 to 12.0 kg t^{-1}, respectively.

The obtained data showed that phosphorus

Table 5

P_2O_5 removal by 1 ton of winter wheat, kg ha^{-1}

Treatment	Grain				Grain+straw			
	1999	2000	2001	average	1999	2000	2001	average
$N_0P_0K_0$	8.26	6.62	7.14	7.33	9.37	8.61	8.72	9.12
$N_{60}P_0K_{90}$	8.26	5.76	7.57	7.04	9.33	7.38	9.23	8.67
$N_{60}P_{60}K_{90}$	8.34	6.71	7.74	7.60	9.48	8.28	9.27	9.17
$N_{60}P_{90}K_{90}$	8.34	7.05	7.91	7.89	9.52	8.68	9.48	9.55
$N_{60}P_{120}K_{90}$	8.34	6.88	8.17	7.82	9.70	8.50	9.76	9.48
$N_{120}P_0K_{90}$	8.00	5.50	7.65	6.88	8.98	7.21	9.27	8.54
$N_{120}P_{60}K_{90}$	8.51	7.83	8.34	8.45	9.49	9.62	10.07	10.21
$N_{120}P_{90}K_{90}$	8.51	7.65	8.34	8.36	9.55	9.38	10.19	10.13
$N_{120}P_{120}K_{90}$	8.51	6.54	8.34	7.75	9.49	8.23	10.19	9.51

Table 6

P_2O_5 removal by 1 ton of spring wheat, kg ha^{-1}

Treatment	Grain				Grain+straw			
	1999	2000	2001	average	1999	2000	2001	average
$N_0P_0K_0$	9.33	8.60	8.26	8.84	10.83	10.78	11.39	11.30
$N_{60}P_0K_{90}$	9.03	8.60	8.43	8.79	10.42	10.52	11.38	11.02
$N_{60}P_{45}K_{90}$	9.50	8.86	8.60	9.08	10.69	11.07	11.77	11.48
$N_{60}P_{60}K_{90}$	9.40	8.86	8.60	9.09	10.56	11.16	11.74	11.52
$N_{60}P_{90}K_{90}$	10.15	8.94	8.43	9.23	11.25	11.42	11.35	11.65
$N_{90}P_0K_{90}$	10.20	8.69	8.69	9.22	11.73	11.09	11.46	11.59
$N_{90}P_{45}K_{90}$	7.69	9.03	8.17	8.67	8.88	11.58	11.35	11.22
$N_{90}P_{60}K_{90}$	7.55	9.03	8.94	8.91	8.98	11.46	12.44	11.59
$N_{90}P_{90}K_{90}$	8.21	9.37	9.12	9.25	9.59	11.98	12.58	11.98

Table 7

Plant nutrient utilization coefficients, on average in 1999-2001

Winter wheat				Spring wheat			
treatment	N	P_2O_5	K_2O	treatment	N	P_2O_5	K_2O
$N_{60}P_0K_{90}$	0.42	-	0.20	$N_{60}P_0K_{90}$	0.38	-	0.20
$N_{60}P_{60}K_{90}$	0.64	0.13	0.31	$N_{60}P_{45}K_{90}$	0.52	0.11	0.35
$N_{60}P_{90}K_{90}$	0.78	0.12	0.37	$N_{60}P_{60}K_{90}$	0.56	0.09	0.32
$N_{60}P_{120}K_{90}$	0.93	0.11	0.40	$N_{60}P_{90}K_{90}$	0.56	0.07	0.35
$N_{120}P_0K_{90}$	0.47	-	0.48	$N_{90}P_0K_{90}$	0.37	-	0.28
$N_{120}P_{60}K_{90}$	0.59	0.21	0.74	$N_{90}P_{45}K_{90}$	0.47	-	0.51
$N_{120}P_{90}K_{90}$	0.60	0.14	0.74	$N_{90}P_{60}K_{90}$	0.49	0.04	0.63
$N_{120}P_{120}K_{90}$	0.63	0.08	0.74	$N_{90}P_{90}K_{90}$	0.49	0.05	0.68

utilization from fertilizers was rather low. It could be explained by a comparatively high soil P content. Nevertheless, during the experimental years, P was utilized better by winter wheat than by spring wheat. It should be emphasized that P fertilizers affected N use efficiency and uptake by wheat (Table 7).

Growing P fertilizer rates from 0 to 120 kg ha^{-1} resulted in increase of N utilization coefficient by winter wheat from 0.64 to 0.93 at $N_{60}K_{60}$, and from 0.59 to 0.63 at $N_{120}K_{90}$. For spring wheat, the obtained average data indicate low P fertilizer use efficiency, though in particular years these parameters were higher. For winter wheat, high N use efficiency affected by P fertilizers should be emphasized. For spring wheat, P fertilizer effect on N utilization was lower. Increased P fertilizer rates at $N_{60}K_{90}$ increased N utilization coefficient from 0.52 to 0.56, but at $N_{90}K_{90}$ – from 0.47 to 0.49. Input of P fertilizer showed positive effect on K utilization for both crops, however, higher parameters were obtained for winter wheat. In balance calculations, P removal by straw was not considered, as straw was chopped and left on the field. Phosphorus balance calculations showed that for winter and spring wheat, positive balance was obtained in all treatments where P fertilizers were used. We consider that P fertilizer rate should be increased from 45 to 60 kg ha^{-1}, because meteorological conditions during the experimental years were not very favorable and the obtained yields under similar soil conditions usually might be higher.

Conclusions

Based on the results obtained in field experiments on sod-pseudogley sandy clay loam soil with medium and high phosphorus sufficiency level during 1999-2001, the following conclusions are proposed:

1. phosphorus mineral fertilizer showed low effect on P uptake by wheat plants;
2. nitrogen fertilizer influenced the P uptake by wheat more than phosphorus fertilizer. Growing P fertilizer rates tended to increase the P content in crop yield;
3. phosphorus removal was more influenced by meteorological conditions of a particular growing season and was responsible for significant yield variations;
4. the used P fertilizer rates for winter and spring wheat provided a positive phosphorus balance in soil.

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Anotācija

Pētījumu mērķis bija noskaidrot mēslojuma ietekmi uz fosfora uzņemšanu un bilanci ziemas un vasaras kviešos, kā arī noskaidrot mēslojuma izmantošanos. Lauka izmēģinājumi veikti Augsnes un agroķīmijas katedras augsekas stacionārā smaga smilšmāla pseidoglejotā augsnē LLU Mācību un pētījumu saimniecībā "Pēterlauki" 1999.-2001. gadā. Kālija mēslojuma deva bija nemainīga visos mēslojuma variantos (K_{90}), bet fosfora mēslojuma devas bija sekojošas: ziemas kviešiem – P_0; P_{60}; P_{90}; P_{120} un vasaras kviešiem – P_0; P_{45}; P_{60}; P_{90}. Fosfora mēslojuma efektivitāte tika pētīta pie diviem slāpekļa līmeņiem: N_{60} un N_{120} (ziemas kviešiem), kā arī N_{60} un N_{90} (vasaras kviešiem). Atšķirīgo meteoroloģisko apstākļu ietekmē pētījumu gados bija vērojamas graudu ķīmiskā sastāva un iznesu svārstības. Slāpekļa mēslojums fosfora uzņemšanu ietekmēja vairāk nekā fosfora mēslojums. Savukārt fosfora mēslojums palielināja slāpekļa izmantošanās koeficientu no minerālmēsliem līdz 0.93. Visas lietotās P mēslojuma normas ziemas un vasaras kviešiem nodrošināja pozitīvu kopējo fosfora bilanci.

The effect of phosphorus and potassium fertilization on the efficiency of flax bacterization
Kālija un fosfora mēslojuma ietekme uz linu bakterizācijas efektivitāti

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Abstract. Results of the pot and field experiments showed that balanced phosphorus and potassium nutrition is the main prerequisite for biological nitrogen fixation of associative N_2 fixing bacteria *Azospirillum brasilense* in association with flax roots. Phosphorus and potassium are of prior importance for the formation of beneficial N_2 fixing bacteria–plant roots association. Inoculation technology in complex with P and K fertilization provided a significant increase in flax yield and improvement of fiber quality.
Key words: phosphorus, potassium, flax, diazotrophs, inoculation.

Introduction

Flax is a traditional crop for Belarus. At present, flax occupies 68 000 hectares. It is of great importance to develop a modern ecologically friendly and economically profitable technology for flax growing. It is known that flax needs a relatively low level of N nutrition, and high doses of nitrogen negatively influence the yield and quality of flax (Афонин, Коренский, 1979). It is supposed that flax nitrogen requirement might be partly supplied by biological nitrogen fixed by diazotrophs bacteria in association with the flax roots. In this case, balanced potassium and phosphorus nutrition is of prior importance.

Azospirillum brasilense are plant growth pro-moting rhizobacteria. These bacteria are widespread in soils of temperate zones (Умаров, 1986). Data from the experiments with cereal crops have demonstrated benefit from *Azospirillum* inoculation (Bashan, Levanony, 1990; Boddey, Dobereiner, 1995). Local natural strain *Azospirillum brasilense* B-4485 possesses high N_2 fixing activity both in pure culture and in association with cereal roots. *A. brasilense* B-4485 was very effective for the barley, wheat and perennial grasses inoculation (Вильдфлуш, 1997; Ми-хайловская, 1997, 1999).

Azospirillum brasilense was found to possess no obligate specificity in respect of the host plant (Bashan, Levanony, 1990; Bashan et al., 1995). Thus, it is of great practical interest to test the effect of *Azospirillum brasilense* B-4485 on the flax plant growth. As it is known, flax requirement in nitrogen fertilization is relatively low. Excess of nitrogen may result in lodging of plants and development of diseases (Афонин, Коренский, 1979). There is information about the reduction of fiber yield and quality due to excess of nitrogen (Афонин, Коренский, 1979). The relatively low need of flax plants for nitrogen suggests the possibility to stimulate biological N_2 fixation by means of associative diazotrophs introduction. The aim of the present experiment was to study the aspects of flax supply with biological nitrogen fixed by the diazotrophs bacteria in association with the flax roots.

Materials and methods

The influence of phosphorus and potassium fertilization on the activity of the flax–*Azospirillum brasilense* association was studied in the pot and field experiments on sod-podzolic sandy loam soil during the years 1999-2001.

In the pot experiment, the effect of inoculation was studied at different levels of fertilizer application. Mineral nutrition treatments were: P_1K_1, P_2K_2, $N_1P_1K_1$, $N_2P_2K_2$. Fertilizer doses applied (mg kg^{-1}): N_1 – 20, P_1 – 40, K_1 – 60, N_2 – 40, P_2 – 80, K_2 – 120. Flax cultivar 'Start' was grown. The soil was characterized by following agrochemical parameters: humus – 2.43% (Tyurin method); pHKCl – 5.7; P_2O_5 – 280 mg kg^{-1}; K_2O – 190 mg kg^{-1} (Kirsanov method).

Fertilizer treatments in the field experiment were as follows: $N_0P_{60}K_{90}$, $N_{15}P_{60}K_{90}$, $N_{30}P_{60}K_{90}$* . Soil agro-chemical parameters: humus – 1.55% (Tyurin method); pHKCl – 5.5; P_2O_5 – 180 mg kg^{-1}; K_2O – 160 mg kg^{-1} (Kirsanov method). The weather conditions in 1999 and 2001 were characterized by lack of precipitation, but in 2000 – an excess of rainfall was observed.

In the pot and field experiments before sowing, flax seeds were inoculated with peat mixed with local strain of *Azospirillum brasilense* B-4485. Bacteria con-centration in biological fertilizer was equal to 10 billion cells per gram.

Flax fiber was obtained by water-retting. Fiber quality was estimated using the quality index or average

* – Here and afterwards for field experiment designation $P_{60}K_{90}$ means 60 and 90 kg ha^{-1} of P_2O_5 and K_2O, respectively.

straw number (Афонин, Коренский, 1979).

Results

The pot experiment showed benefit from a balanced phosphorus and potassium fertilization in complex with *Azospirillum brasilense* inoculation of flax. This technology has led to significant improvement of the flax yield component – the total and technical stem lengths. PK application demonstrated highest responses of the technical stem length – 8.20-8.45 cm. Introduction of *Azospirillum brasilense* was equivalent to mineral nitrogen application. Inoculation responses of the technical stem length on the background of NPK treatment did not exceed 0.25 cm (Fig. 1). The same tendency was observed for the total stem length which was increased by 8.2-8.5 cm due to inoculation.

A beneficial effect of N_2 fixing bacteria on the flax straw and flax seed yields was observed: the yield of straw was 1.5-1.7 times and yield of flax seeds was 1.7 times higher compared with uninoculated P+K treatments (Figs. 2, 3).

Experimental data showed that efficiency of bacteria application at both studied NPK treatments was lower in comparison with P+K+inoculation variants. Inoculation responses of straw and flax seeds were approximately two times lower (Figs. 2, 3).

Data of the pot experiments corresponded well with the results of the three-year field experiment performed also on sod-podzolic sandy loam soil. Effects of *Azospirillum brasilense* inoculation on the yield of flax seeds and flax fiber were equivalent to the application of 15 kg ha^{-1} N on the background with optimal doses of phosphorus and potassium ($P_{60}K_{90}$) (Table 1). High and comparable yields of flax seeds and flax fiber were obtained at treatments $P_{60}K_{90}$+*A. brasilense* and $N_{15}P_{60}K_{90}$; $N_{15}P_{60}K_{90}$+*A. brasilense* and $N_{30}P_{60}K_{90}$ (Tables 1, 2). Top yields of flax seeds and long fiber were observed as a result of $N_{15}P_{60}K_{90}$+*A. brasilense* and $N_{30}P_{60}K_{90}$ application (Tables 1, 2). The field experiment showed that use of the biological preparation

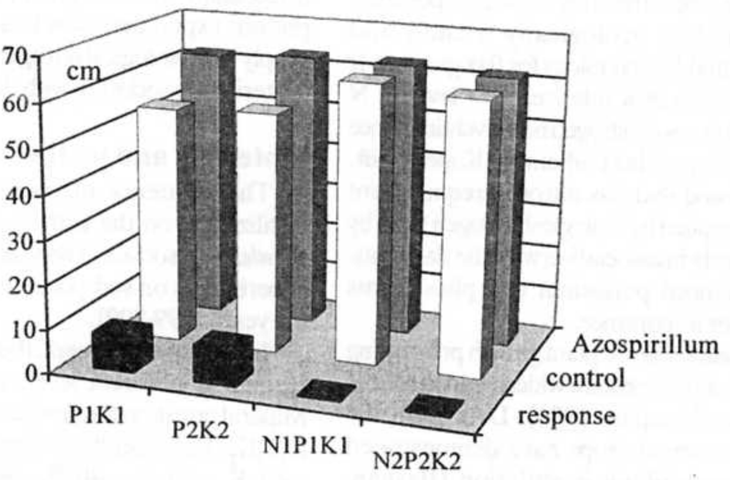

Fig. 1. Effect of the fertilizer and bacteria application on the technical stem length of flax (2001).

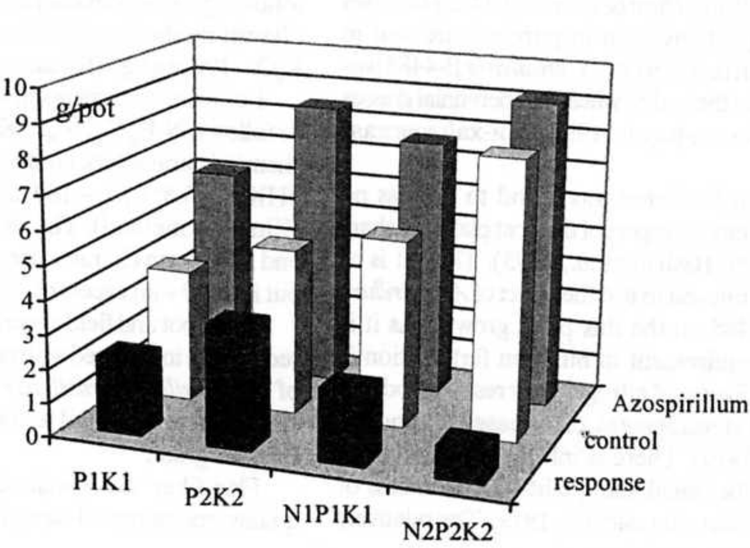

Fig. 2. Influence of fertilizers and inoculation on the yield of flax straw (2001).

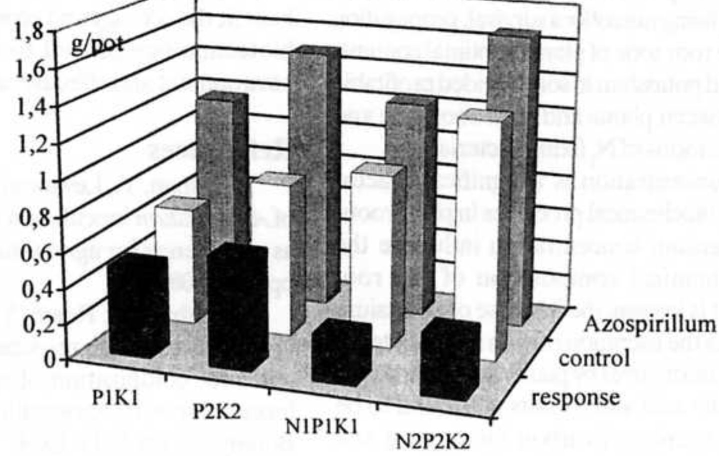

Fig. 3. Effect of fertilizers and inoculation on the yield of flax seeds (2001).

Table 1

The effect of fertilizers and *A. brasilense* B-4485 on the yields of flax seeds and straw (1999-2001)

Treatment	Flax seeds, t ha^{-1}		Flax straw, t ha^{-1}	
	control	*A. brasilense*	control	*A. brasilense*
$N_0P_{60}K_{90}$	0.65	0.84	5.00	6.19
$N_{15}P_{60}K_{90}$	0.78	0.90	5.95	7.04
$N_{30}P_{60}K_{90}$	0.93	–	7.01	–
LSD	0.05		0.41	

Table 2

The effect of fertilizers and *A. brasilense* B-4485 on the yield and quality of flax fiber (1999-2001)

Treatment	Fiber yield, t ha^{-1}				Fiber quality	
	total		long fiber		control	*A. brasilense*
	control	*A. brasilense*	control	*A. brasilense*		
$N_0P_{60}K_{90}$	1.26	1.70	0.67	1.09	1.50	2.30
$N_{15}P_{60}K_{90}$	1.58	1.85	0.96	1.15	2.00	2.25
$N_{30}P_{60}K_{90}$	1.88	–	1.19	–	2.00	–
LSD	0.15		0.08		0.17	

of diazotroph bacteria has resulted in a significant improvement of the flax fiber yield and quality. The total yield of fiber was 1.5 times higher and the yield of long fiber was 1.7 times higher at $N_{15}P_{60}K_{90}$+*A. brasilense* application compared with $N_0P_{60}K_{90}$ application without nitrogen fixing bacteria introduction. The best average quality index or "number" of flax straws was obtained due to biological soil management of flax N nutrition and PK fertilizing (Table 2).

Discussion

The pot and field experiments gave a possibility to compare the efficiency of two different technologies of flax growing – NPK fertilizing and biological N nutrition together with PK application. The experimental data demonstrated no nitrogen deficit for flax plant at inoculated treatments compared with N fertilizer treatments. Efficiency of PK+*A. brasilense* soil management exceeded the effect of NPK fertilizing. Balanced phosphorus and potassium nutrition was the main precondition for flax nitrogen requirement supply with biological nitrogen.

For the formation of beneficial N_2 fixing bacteria–plant roots association, phosphorus and potassium concentrations in soil play the dominant role. Underestimation of the phosphorus and potassium supply for plants and rhizobacteria leads to the failure of inoculation experiments. Balanced phosphorus and potassium nutrition is one of most important preconditions for a successful inoculation of crops with N_2 fixing microorganisms.

Phosphorus and potassium concentrations in soil strongly affect N_2 fixing microflora survival, propagation and activity in the root zone of plants. Optimal contents of phosphorus and potassium in soil provided profitable relationships between plants and both aborigine and introduced populations of N_2 fixing bacteria.

Potassium concentration is a significant factor affecting specific biochemical processes in plant roots. Changes in potassium concentration influence the amounts and chemical composition of the root metabolites. As it is known, the increase of potassium content stimulates the excretion of such metabolites as malic acid and its derivatives by plant roots (Kraffczyk, et al., 1984). Malic acid and its salts are found to be most preferable sources of carbon for survival and activity of associative N_2 fixing bacteria of the genus *Azospirillum* (Умаров, 1986; Bashan, Levanony, 1990; Kraffczyk, et al., 1984). Therefore potassium concentration strongly affects formation of beneficial association between the introduced population of *Azospirillum brasilense* and the plant roots.

The three-year field experiment showed that balanced phosphorus and potassium nutrition ($P_{60}K_{90}$) together with application of active natural strains of *Azospirillum brasilense* is a beneficial technology for flax nitrogen requirement supply.

Associative N_2 fixing bacteria *Azospirillum brasilense* may benefit plants through several mechanisms: production of plant growth promoting substances, stimulation of root development, improvement of mineral nutrients uptake and root-associated nitrogen fixation activity. Plant growth promoting effect of bacteria of the genus *Azospirillum* was found to exceed the influence of diazotrophs of other taxonomic groups (Okon, 1982).

Conclusions

The experimental data showed possibility of a partial or full replacement of flax N fertilization by bacteria application. The main precondition for successful bacterization is a balanced phosphorus and potassium fertilizing. Balanced PK nutrition provides formation of profitable roots-introduced bacteria relationships and stimulation of nitrogen fixation activity in the root zone. No nitrogen deficit for flax plants was found due to *Azospirillum brasilense* inoculation in complex with phosphorus and potassium fertilizing compared with NPK application. The three-year field experiment demonstrated that the effect of inoculation on the yield of flax seeds and fiber was equivalent to 15 kg ha^{-1} N application with an optimal phosphorus and potassium rate ($P_{60}K_{90}$). The application of the biological preparation resulted in a significant improvement of flax fiber quality. The best quality of flax fiber was obtained due to application of biological soil management of flax N nutrition and PK fertilizing. Implementation of the biotechnology may benefit the ecology and economy of flax growing. The biotechnology proved to ensure sustainability of environment and effective use of plant resources.

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Anotācija

Noskaidrots, ka sabalansēts PK mēslojums ir viens no galvenajiem priekšnoteikumiem slāpekļa saistītājas baktērijas *Azospirillum brasilense* darbībai asociācijā ar linu saknēm. Inokulācijas tehnoloģijas pielietošana kopā ar PK mēslojumu nodrošināja būtisku linu ražas pieaugumu un šķiedras kvalitātes uzlabošanos. Pētījumu rezultāti liecina, ka bioloģiski fiksētais slāpeklis var daļēji vai pat pilnībā nodrošināt linu vajadzību pēc šī barības elementa.

Fertilization systems and plant available PK in soil and in the crop yield
Augiem viegli izmantojamā fosfora un kālija savienojumi augsnē un šo elementu saturs ražā, lietojot dažādas mēslošanas sistēmas

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Abstract. Two fertilization systems (organo-mineral and mineral) were studied in a field crop rotation containing 52% of cereals in southeastern part of Lithuania over the period 1978–1996. Results show that farmyard manure (FYM) applications (104 t ha^{-1}) in combination with fertilizers $N_{300}P_{162}K_{362}$ once or twice per rotation (organo-mineral fertilization system) increased the content of plant available phosphorus and potassium in topsoil (0-20 cm). This fertilization system significantly increased the accumulation of both elements in crops. Organo-mineral fertilization system significantly increased the crop yield and the phosphorus and potassium removal. This fertilization system also maintained a positive PK balance in the field crop rotation. Combination of FYM (rate 52 t ha^{-1}) with $N_{300}P_{162}K_{362}$ considerably increased the plant available phosphorus content in topsoil, whereas potassium increase was insignificant. Potassium removal with the crop yield was very high, what resulted in a negative balance. Mineral fertilization system after a 18-years application almost did not change the plant available phosphorus and potassium content in soil. Application of $N_{300}P_{162}K_{362}$ twice per rotation increased the phosphorus and potassium removal with the crop yield. For this reason, potassium balance was negative, but for phosphorus – positive.

Key words: fertilization system, phosphorus, potassium, removal, balance.

Introduction

Sod-podzolic loamy sand soils prevail in the southeast of Lithuania. Their distribution is 64.3% from the total area of agricultural land in this part of Lithuania. These soils have a weak structure with a low content of humus. The plant available phosphorus (P_2O_5) and potassium (K_2O) level is very low (Mazvila et al., 1992). Therefore, the purpose of fertilization systems is to supply crops with nutrients and provide soil fertility increase.

Experimental results of Lithuanian and foreign researchers show that yield of agricultural crops greatly depends on plant available phosphorus content in soil (Tripolskaja, 2000). E. Otabbong with co-workers investigated the soil P status and distribution in soil in the Ultuna long-term soil organic matter experiment over the period 1957-1992. Balance sheet calculations were performed based on cumulative P uptake in 35 years (1957-1997). Results showed that P deficit was within range 10-60 kg ha^{-1} indicating that some of P had migrated to the subsoil (Otabbong, Person et al., 1997).

Long-term fertilizer experiments were set up in northern Germany in 1988 to study the influence of growing potassium fertilizer rates in sandy soils (0, 60, 120, and 180 K ha^{-1}) on soil K test values and crop yield. Rye and barley did not respond to K fertilization in a 7-year period even though the soil test value of K_0 plots (without K fertilizers) decreased from 90 to 30 mg kg^{-1} within 3 years. This value remained almost constant thereafter. Crop potassium removal reached 75 kg ha^{-1} of K and probably was supplied from the soil's non-exchangeable K fraction. Maximum potato yield was obtained applying 60 kg ha^{-1} of K annually, what resulted in soil K test value of 60 mg kg^{-1}. The yield in control plots decreased to 21% from the level in above mentioned fertilized plot (Wulf, Schulz et al., 1998).

Fertilization intensity changes the level of available phosphorus and potassium in soil (Nillson, 1993; Niklicek et al., 1984). Therefore, the role of a fertilization system is very important.

Application of various organic materials and in their combination with mineral fertilizers has a positive effect on physical and agrochemical properties of different soils (Eriksson, 1980; Gerzabek et al., 1995). Plant nutrient removal with crops depends on the yield size. As the yield depends on the mineral and organic fertilizer rates (Nillson, 1993), a rational fertilization system should provide a high yield of crops as well as increase the soil fertility. Therefore, plant nutrient balance should be positive regardless of a crop rotation type.

Materials and methods

The experiment was carried out on Sod-podzolic sandy loam soil (Haplic Luvisols, FAO, 1990) formed on fluvioglacial deposits at the Voke branch of Lithuanian Institute of Agriculture over the period 1979-1996. The influence of the two fertilization systems (organo-mineral and mineral) on the content of available phosphorus and potassium in soil and their accu-mulation in the crop yield were studied.

Soil agrochemical properties before the experiment were as follows: pHKCl 5.1-5.4, hydrolytic acidity (according to Kappen) – 2.6-3.1 cmol(+) kg^{-1}, exchangeable bases (according to Kappen-Gilkovich) – 5.6-7.4 cmol(+) kg^{-1}, plant available phosphorus – 110-139 P_2O_5 mg kg^{-1} and potassium – 149-204 K_2O mg kg^{-1} (A–L method), humus (Tyurin method) – 2.07-2.51%.

Farmyard manure (FYM) with peat or straw litter was used as organic fertilizer. The average composition was as follows: dry matter – 25.7%, total N (according to Kjeldahl) – 0.59%, P_2O_5 (calorimetric method) – 0.20%, K_2O (flame photometer) – 0.45%. Ammonium nitrate, granulated superphosphate and potassium chloride were used as mineral fertilizers. The crop fertilization scheme is seen in Table 1.

Soil samples were taken after each rotation (every 6 years). In the study, data from 1978 (before the experiment), 1984, 1990, and 1996 are presented. Single FYM (52 t ha^{-1}) rate was calculated according to the nitrogen amount in it and corresponded to 300 kg ha^{-1} of N. Phosphorus and potassium applied with mineral fertilizers were equivalent to 0.5 manure rate and corresponded to 55 kg ha^{-1} of P_2O_5 and 118 kg ha^{-1} of K_2O. In this study, designations P and K mean P_2O_5 and K_2O, respectively. The phosphorus and potassium field balance was calculated taking into account PK applied with FYM and mineral fertilizers as input value, and PK removed by crops as output value. Recovery rate was considered as ration between PK applied with fertilizers and PK removed by crops expressed as percentage. For statistical analysis (LSD_{05}), yield variations among years were taken as replications.

Results

Data presented in Table 2 show a significant influence of various fertilization systems on the plant available P_2O_5 and K_2O content in topsoil (0-20 cm).

Table 1

Crop fertilization scheme in field rotation

Crop	Treatment 1	2	3	4	5	6
	Unfertilized	FYM twice per rotation		FYM once per rotation		Mineral NPK fertilizers
		104 t ha^{-1} FYM+NPK	52 t ha^{-1} FYM+NPK	52 t ha^{-1} FYM+NPK	104 t ha^{-1} FYM+NPK	
Potatoes	–	52 t ha^{-1} FYM+$P_{81}K_{181}$	26 t ha^{-1} FYM+$P_{81}K_{181}$	52 t ha^{-1} FYM+$P_{81}K_{181}$	104 t ha^{-1} FYM+$P_{81}K_{181}$	N_{150} $P_{136}K_{299}$
Barley	–	N_{90}	N_{90}	N_{60}	N_{60}	N_{120}
Lupine–oats mixture	–	N_{90}	N_{90}	N_{60}	N_{60}	N_{120}
Rye+undersown perennial grasses	–	52 t ha^{-1} FYMrate+$P_{81}K_{181}$	26 t ha^{-1} FYMrate+$P_{81}K_{181}$	N_{90} $P_{81}K_{181}$	N_{90} $P_{81}K_{181}$	N_{90} $P_{136}K_{299}$
Perennial grasses	–	0	0	0	0	0
Rye	–	N_{120}	N_{120}	N_{90}	N_{90}	N_{120}

Table 2

Influence of fertilization systems on the plant available phosphorus and potassium content in topsoil (0-20 cm)

Year	Treatments 1	2	3	4	5	6	LSD_{05}
	P_2O_5, mg kg^{-1} soil						
1978	125	131	117	123	110	139	
1984	125	135	141	140	141	155	19.1
1990	93	137	127	123	118	119	
1996	100	176	181	183	152	152	
	K_2O, mg kg^{-1} soil						
1978	149	155	160	204	164	195	
1984	174	248	240	279	270	263	49.5
1990	110	208	218	223	235	171	
1996	83	347	249	230	224	191	

Both rates of FYM (52 t ha^{-1} and 104 t ha^{-1}) similarly increased the P_2O_5 amount in soil – 2.3-3.5 mg kg^{-1} soil per year. Using mineral fertilization system, the level in soil increased by 0.72 mg kg^{-1} per year. In this case, P increase was insignificant compared with its initial value. On unfertilized plots, during 18 years of crop cultivation, the level of plant available P_2O_5 decreased from 125 mg kg^{-1} to 100 mg kg^{-1} of soil.

FYM application (104 t ha^{-1}) once or twice per rotation significantly increased the plant available K_2O content in topsoil (treatments 2 and 5) compared with its value before the experiment. A significant increase in the content of available K_2O was also observed at the application of 52 t ha^{-1} of FYM in combination with NPK fertilizers twice (26+26 t ha^{-1}) per rotation (treatment 3). Using this rate once per rotation or applying mineral fertilizers alone had no influence on available K_2O forms in the soil.

Table 3 illustrates the P_2O_5 and K_2O removal with the crop yield. After 18 years of manure use, the field crops removed P_2O_5 from 52.6 kg ha^{-1} to 101.4 kg ha^{-1}, and K_2O from 186.4 kg ha^{-1} to 578.5 kg ha^{-1}. In unfertilized soil, phosphorus removal was from 48.3 kg ha^{-1} to 65.4 kg ha^{-1}, but that of potassium – from 111.6 kg ha^{-1} to 252.2 kg ha^{-1}. The total (18 years) field balance of P_2O_5 and K_2O is seen in Table 4. Data show that the field balance of phosphorus was positive under all fertilization systems. Recovery rate was from 167.5% to 225.3%.

Field balance of potassium was positive under application of 104 kg ha^{-1} of FYM in combination with NPK once or twice per rotation. Recovery rate was from 115.9% to 119.2%. Using 52 t ha^{-1} of FYM or mineral fertilizer alone, the field balance of potassium was negative and its recovery rate was under 100%.

Discussion

The available phosphorus content in soil during the experiment increased unevenly (Table 2). It was very intensive during 1990-1996, what is connected with the composition of used FYM. During the last three years, FYM with straw litter was with a high P_2O_5 and K_2O content. Previously, FYM with peat litter was used. The P_2O_5 content in organic matter of peat was more constant compared with straw (Gerzabek et al., 1995). This explains why P_2O_5 level in soil was higher in 1996 than in 1984 and 1990. The influence of mineral fertilization system on the content of available phosphorus in soil was insignificant. It might be explained by increasing mineral fertilizer rates what caused soil acidification (from 5.4 to 4.6 pHKCl, respectively) after a 18-years application. In this case, part of available phosphorus was possibly transformed into insoluble ferro-aluminium compounds.

In 1996, the level of available potassium in soil

Table 3

PK removal with crop yield, kg ha^{-1}, 1979-1996

Crops	Treatments 1		2		3		4		5		6	
	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O
Potatoes	48.3	230.6	66.9	369.4	60.3	350.8	62.2	356.1	71.3	389.0	62.6	392.2
Barley	55.0	138.4	91.0	305.9	91.0	294.7	81.3	258.0	85.9	272.4	82.4	267.4
Lupine-oats mixture	65.4	221.1	99.8	578.5	101.4	503.2	91.1	467.9	96.4	531.1	96.4	483.0
Rye+grasses	58.3	111.6	89.2	198.6	84.0	186.4	92.9	256.0	91.4	268.2	92.3	254.0
Perennial grasses	55.6	252.2	65.4	389.4	62.4	361.5	53.5	294.0	58.8	315.7	52.6	292.0
Rye	79.8	192.5	97.5	284.5	103.8	290.4	94.9	283.2	94.7	291.1	98.0	308.2

Table 4

PK field balance, 1979-1996

Treat-ments	Applied with fertilizers, kg ha^{-1} (manure+mineral fertilizers)		Removed with crops, kg ha^{-1} (main+by-product)		Balance, kg ha^{-1}		Recovery rate, %	
	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O
1	–	–	362	1146	–362	–1146	–	–
2	1122	2466	510	2126	612	340	220.0	115.9
3	804	1774	503	1987	301	–213	159.8	89.3
4	804	1774	476	1915	328	–141	168.9	92.6
5	1122	2466	498	2068	624	398	225.3	119.2
6	804	1774	480	1997	324	–223	167.5	88.8

significantly increased compared with its initial content under application of 104 t ha^{-1} of FYM in combination with NPK fertilizers once or twice per rotation. However, the increase in available K_2O over the period 1978-1996 was variable and probably was dependent on soil's sampling time and also some unknown factors. Insignificant decrease in available K_2O in topsoil under mineral fertilization system might be connected with the high removal of this element together with the crop's yield and intensive application of nitrogen fertilizers (1800 kg ha^{-1} over the period 1979-1996), what increased the leaching of K_2O to subsoil.

Lupine-oats mixture, winter rye and barley used very high amounts of phosphorus (Table 3). Compared with unfertilized soil, phosphorus removal increased from 26.3 to 36.0 kg ha^{-1} (barley), from 25.7 to 36.0 kg ha^{-1} (mixture), from 12.0 to 23.0 kg ha^{-1} (potatoes). The influence of fertilization systems on P_2O_5 removal was approximately the same and was not directly dependent on FYM rates.

Potassium removal was considerably higher compared with phosphorus removal. The highest potassium removal was with lupine-oats mixture, potatoes, and perennial grasses. Cereal crops, such as barley and winter rye, also removed comparatively high amounts of K_2O. Applying FYM twice (52+52 t ha^{-1}) or once (104 t ha^{-1}) per rotation (treatments 2 and 5) considerably increased the potassium removal compared with 52 t ha^{-1} of FYM use only. However, removal of this element from soil, compared with unfertilized plots, was very high. Application of mineral NPK fertilizers only (mineral fertilization system) also significantly increased the K_2O removal with the crop yield.

Phosphorus field balance was positive under all fertilization systems and was directly dependent on the FYM rate. Mineral fertilization system also maintained a positive phosphorus balance and its influence was equal to 52 t ha^{-1} of FYM. At this fertilization system, the recovery rate was within 160-168%. 104 t ha^{-1} of FYM increased a positive phosphorus balance with recovery rate from 220 to 225%.

Application of 52 t ha^{-1} of FYM in combination with mineral fertilizers once or twice per rotation as well as mineral fertilizers alone maintained a negative potassium field balance (Table 4). In this case, the recovery rate was from 89 to 93%.

A positive potassium balance with recovery rate from 116 to 199% was provided applying 104 t ha^{-1} of FYM in combination with mineral fertilizers once or twice per rotation.

Conclusions

1. Use of 104 t ha^{-1} of FYM in combination with $N_{300}P_{162}K_{362}$ (organo-mineral fertilization system) once or twice per rotation increased the plant available phosphorus and potassium content in sandy loam soil as well as the PK content in crop yield. PK removal with the crop yield was directly dependent on the used FYM rate.

2. Fertilization with mineral fertilizers only (mineral fertilization system) insignificantly increased the level of plant available phosphorus and slightly reduced the level of available potassium in the soil.

3. The P_2O_5 and K_2O field balance directly correlated with the FYM application rate. Higher FYM rates provided a higher positive PK balance in the soil. Lower rates provided a positive phosphorus, but negative potassium balance.

4. Mineral fertilizer system maintained a positive phosphorus balance, the same as 52 t ha^{-1} of FYM. Potassium balance in this case was negative.

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Anotācija

Pētījumi veikti 1978.-1996. gadā augsekās, kurās graudaugu īpatsvars sasniedza 52%. Iegūtie rezultāti rāda, ka kūtsmēslu lietošana (104 t ha^{-1}) kopā ar minerālmēsliem $N_{300}P_{162}K_{362}$ reizi vai divas reizes rotācijā paaugstināja augiem izmantojamo PK savienojumu daudzumu augsnes 0-20 cm slānī un šo elementu akumulāciju kultūraugu ražā. Šāds mēslojums nodrošināja pozitīvu PK bilanci augsekas rotācijā. Savukārt, lietojot tikai minerālmēslus, 18 gadu laikā augiem izmantojamo PK savienojumu daudzums augsnē praktiski nemainījās. Mēslošanas norma $N_{300}P_{162}K_{362}$ divas reizes rotācijā palielināja šo elementu iznesi ar ražu un veidoja negatīvu kālija, bet pozitīvu fosfora bilanci.

The efficiency of potassium fertilizers on the yield of agricultural crops and agrochemical properties of soils of different genesis
Kālija mēslojuma ietekme uz kultūraugu ražu un dažādas ģenēzes augšņu agroķīmiskajām īpašībām

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Abstract. Fertilization experiments were carried out in crop rotation established on Epicalcari–Endohypogleyic Cambisols moraine sandy loam in Central Lithuania and on glacial lacustrine silty loam soil in Lower Nemunas. Plant available potassium in topsoil (0-20 cm) was 58 and 87 mg kg^{-1}, and non-exchangeable potassium – 153 and 624 mg kg^{-1}, respectively. It was found that potassium fertilization in combination with medium nitrogen and phosphorus rates essentially increased the yield of winter wheat, sugar beet, spring barley grain and annual grasses. However, use of potassium fertilizers on silty loam soil did not increase the yield of winter wheat and sugar beet. Crops grown in silty loam soil assimilated potassium better than those grown in sandy loam. After application of medium (109 kg ha^{-1}) potassium fertilizer rate, the amount of available potassium taken up by plants was 20 kg ha^{-1} lower in sandy loam soil and 20 kg ha^{-1} higher in silty loam, compared with the amount used with fertilizers.
Key words: soil genesis, potassium fertilizer, agricultural crops.

Introduction

The main source of potassium for growing plants under natural conditions is weathering of potassium-containing minerals. Potassium in soil is found in the structure of minerals, absorbed on the surface of clay minerals and organic matter, and also found in soil solution (Barber, 1984; Ониани, 1984).

All forms of potassium are in equilibrium and are important for plant nutrition, although potassium availability from different forms is different (Ониани, 1984). The main source for plant nutrition is exchangeable soil potassium (Barber, 1984; Gosek, 2000).

According to the literature, efficiency of potassium fertilizers greatly depends on the content of plant available (exchangeable) potassium in soil (Švedas, 1993; Vaišvila, 1996; Kraus, 2000). The research in Germany shows that the effect of K fertilizer is different even at similar amounts of exchangeable potassium. It is so because in soils of loess origin the crops can use potassium from non-exchangeable fraction (Kuhlman, Wehrman, 1984).

In Lithuania, a number of experiments have been carried out to study the effect of potassium fertilizer on the content of available potassium in soil (Vaišvila, 1996; Švedas, 1993). However, not enough data is available on agricultural crops grown in soils of different genesis with a different potassium content. Therefore, the objective of this study was to determine the effect of potassium fertilizer on the yield of agricultural crops and the productivity of a full crop rotation. The influence of K fertilizers on the changes of plant available potassium taking into consideration the soil genesis and potassium content in soil was also studied.

Materials and methods

Investigations were carried out in Middle Lithuanian lowland (1987-1991, Panevėžys district, Ramygala) and Lower Nemunas plain (1990-1995; Šakiai district, Kriūkai).

The soil in Ramygala is formed on moraine – Epicalcari-Endohypogleyic Cambisol, sandy loam, and is characterized by low plant available (58 mg kg^{-1}; A–L method) and non-exchangeable (154 mg kg^{-1}; Pchiolkin's method) potassium content in topsoil. Soil pHKCl – 7.5.

The soil in Kriūkai is formed on glacial lacustrine sediments – Epicalcari-Endohypogleyic Cambisol, silty loam, and is low in plant available potassium (86 mg kg^{-1}), but high in non-exchangeable potassium (619 mg kg^{-1}), pHKCl – 7.4.

For the trials, four fields were used where winter wheat, sugar beet, spring barley and annual grasses were grown. Experimental scheme is presented in Table 1.

The yield of winter wheat and spring barley is presented at standard moisture (14%) content, that of annual grasses – on dry matter basis, and of sugar beet – at natural moisture content.

The potassium balance by agricultural crops was calculated according to simple methodology: the input was K amount applied with fertilizers, and output – removed from the soil with agricultural crop yield.

Table 1

The influence of fertilizers on the yield of agricultural crops and crop rotation productivity

Winter wheat and spring barley			Sugar beet		Annual grass		Metabolic energy	
kg ha^{-1}	yield, t ha^{-1}		kg ha^{-1}	yield, t ha^{-1}	kg ha^{-1}	yield, t ha^{-1}	kg ha^{-1}	GJ, ha^{-1}
	wheat	barley						
Cambisol, sandy loam (1987–1991)								
P_{60}			P_{90}		P_{45}		P_{64}	
$+N_{60}K_0$	3.98	2.85	$+N_{120}K_0$	26.6	$+N_{60}K_0$	3.66	$+N_{75}K_0$	64.8
$+N_{60}K_{60}$	4.45	3.49	$+N_{120}K_{120}$	33.4	$+N_{60}K_{60}$	4.04	$+N_{75}K_{75}$	78.6
$+N_{60}K_{90}$	4.58	3.73	$+N_{120}K_{165}$	31.3	$+N_{60}K_{90}$	4.18	$+N_{75}K_{109}$	73.9
$+N_{120}K_{60}$	4.80	3.44	$+N_{210}K_{120}$	32.5	$+N_{60}K_{60}$	4.45	$+N_{128}K_{75}$	80.8
LSD_{05}	0.220	0.150	LSD_{05}	1.60	LSD_{05}	0.260	LSD_{05}	7.30
Cambisol, silty loam (1990–1995)								
P_{60}			P_{90}		P_{45}		P_{64}	
$+N_{60}K_0$	5.60	4.24	$+N_{120}K_0$	36.5	$+N_{60}K_0$	6.38	$+N_{75}K_0$	91.3
$+N_{60}K_{60}$	5.54	5.02	$+N_{120}K_{120}$	37.4	$+N_{60}K_{60}$	6.58	$+N_{75}K_{75}$	95.5
$+N_{60}K_{90}$	5.54	4.80	$+N_{120}K_{165}$	36.2	$+N_{60}K_{90}$	6.84	$+N_{75}K_{109}$	93.8
$+N_{120}K_{60}$	6.12	5.31	$+N_{210}K_{120}$	38.4	$+N_{60}K_{60}$	6.38	$+N_{128}K_{75}$	101.0
LSD_{05}	0.210	0.200	LSD_{05}	1.90	LSD_{05}	0.260	LSD_{05}	4.20

The amount of metabolic energy was calculated by equations using the total content of digestible organic material (Jankauskas, Jankauskienė, Švedas, 1999).

In the study, phosphorus and potassium are expressed as oxides (P_2O_5 and K_2O).

Results

Winter wheat. According to previous research – in moraine sandy loam soils with plant available potassium of 50-100 mg kg^{-1}, K fertilizer application (together with nitrogen and phosphorus) increased the yield of winter wheat by 0.51 t ha^{-1}. If K content in soil was higher than 100-150 mg kg^{-1}, the same fertilizer rates increased the yield only by 0.27 t ha^{-1} (Vaišvila, 1996).

Data presented in Table 1 show that the yield of winter wheat grain reached 5.60 t ha^{-1} in potassium-poor silty loam using only the nitrogen and phosphorus fertilizers. Potassium fertilizers in combination with medium rate of the nitrogen and phosphorus fertilizers did not increase the yield of wheat. The yield in sandy loam without potassium fertilization was lower (3.98 t ha^{-1}). However, the yield of winter wheat grain was increased by potassium fertilizers (0.60 t ha^{-1} or 13.1%) compared with the yield obtained in plots without potassium fertilizers.

When the rate of nitrogen fertilizers was increased from 60 to 120 kg ha^{-1}, the yield of winter wheat increased by 0.35 t ha^{-1} in sandy loam, and in silty loam – even by 0.58 t ha^{-1}.

Sugar beet. According to the research data, the yield of sugar beet increased by 3.0 t ha^{-1}, using potassium fertilizers in soils formed on moraine, when the content of available potassium in soil was 50-100 mg kg^{-1} (Vaišvila, 1996).

It was found that potassium content was almost sufficient for sugar beet and winter wheat in silty loam, where potassium availability was higher than in sandy loam soil, and K might be used also from non-exchangeable resources. The yield of sugar beet in silty loam was 9.9 t ha^{-1} or 37.2% higher than in sandy loam soil where the content of potassium was similar. An essential increase in sugar beet yield was not obtained after using potassium fertilizers (120 kg ha^{-1}) in combination with medium rate of nitrogen and phosphorus fertilizers. Compared with plots without potassium fertilizers, significant yield increase (1.9 t ha^{-1}) was obtained in silty loam after using high rate of nitrogen (210 kg ha^{-1}). As to sugar beet, the yield increased by 6.8 t ha^{-1} or 25.6% in sandy loam soil using potassium fertilizers (120 kg ha^{-1}) in combination with medium rate of nitrogen and phosphorus fertilizers.

Spring barley. Utilization of potassium from silty loam soil by spring barley was also very effective, therefore maximum yield (4.24 t ha^{-1}) was obtained in plots without potassium fertilizers. Vegetation period for barley is shorter than for other crops, therefore potassium fertilizer use in sandy loam increased the yield by 0.88 t ha^{-1} (30.9%), but in silty loam – by 0.78 t ha^{-1} (18.4%), compared with the yield in plots without potassium fertilizers. The optimal rate of potassium fertilizers was 90 kg ha^{-1} in sandy loam, and 60 kg ha^{-1} – in silty loam soil.

Annual grasses were more productive in silty loam with more favorable soil physical properties, more constant moisture regime and a higher plant nutrient content. In silty loam soils, after applying only potassium

Table 2

The influence of potassium fertilizers on plant available potassium content in soil

Average annual fertilization rate in crop rotation	Average removal of K_2O, kg ha^{-1} with		Potassium balance, ± kg ha^{-1}	Content of potassium in topsoil, mg kg^{-1}	
	a yield	yield increase		before experiment	after experiment
Cambisol, sandy loam, 1988-1991, 58 mg kg^{-1} K_2O					
$N_{75}P_{64}K_0$	70.7	0	–70.7	59	52
$N_{75}P_{64}K_{75}$	85.1	14.4	–10.1	57	56
$N_{75}P_{64}K_{109}$	90.2	19.5	18.8	58	57
$N_{128}P_{64}K_{75}$	93.0	22.3	–18.0	77	61
Cambisol, silty loam, 1990-1995, 87 mg kg^{-1} K_2O					
$N_{75}P_{64}K_0$	116.6	0	–116.6	88	107
$N_{75}P_{64}K_{75}$	126.4	9.8	–51.4	89	113
$N_{75}P_{64}K_{109}$	127.4	10.8	–18.4	88	124
$N_{128}P_{64}K_{75}$	139.1	22.5	–64.1	89	116

and phosphorus fertilizers, the yield of annual grasses was 6.38 t ha^{-1}, in sandy loam soil – only 3.66 t ha^{-1}. In these soils, potassium fertilizers applied at a rate of 90 kg ha^{-1} increased the annual grass yield by 0.46 and 0.52 t ha^{-1}, respectively.

Crop rotation productivity. According to the research data, average metabolic energy in silty loam in plots without potassium fertilizers reached even 26.5 GJ ha^{-1}, what is 40.9% higher than in sandy loam. Potassium fertilizers in moraine sandy loam with low content of potassium were very effective: average crop rotation productivity increased by 13.8 GJ ha^{-1} (21.3%) compared with plots without potassium fertilizers, whereas in glacial lacustrine soil – only by 4.2 GJ ha^{-1} (4.6%).

Potassium balance and content in soil. According to calculations, the crops removed comparatively more potassium than it was used annually applying 75 or 109 kg ha^{-1} fertilizers in silty loam soil. Almost in all cases negative balance was obtained, with the exception of sandy loam soil where 109 kg ha^{-1} potassium fertilizers were applied annually (Table 2).

The maximum soil K utilization by crops was obtained in silty loam. However, in this type of soil (probably because of buffer capacity) the potassium content did not decrease. In sandy loam soil, the amount of available potassium decreased by 9 mg kg^{-1}. Due to application of potassium fertilizers, the amount of available potassium in arable layer of sandy loam almost did not change during the study period. In silty loam, 27 mg kg^{-1} more potassium was found compared with plots without fertilization.

Discussion

Complicated processes of plant nutrient migration, transformation, and sorption take place in the soil. However, the intensity of these processes differs in soils of different genesis (Barber, 1984; Ониани, 1984).

The research showed that soil exchangeable fertilizer potassium influenced the crop yield and exhibited certain specific characteristics in soils of different genesis. The yield of crops cultivated in silty loam Cambisol of glacial lacustrine origin was significantly higher than that obtained in sandy loam soil. Potassium fertilizers were effective for all crops grown in sandy loam Cambisol, while in silty loam soil, K fertilizers were efficient only for spring barley and annual grasses despite the fact that the content of exchangeable potassium in soil was similar. The experiment showed that the efficiency of potassium fertilizers is influenced both by non-exchangeable potassium content in soil and other soil characteristics, as well as specifics of plant physiology.

Conclusions

1. The yield of winter wheat in silty loam soil of glacial lacustrine deposits without potassium fertilizer use was 1.62 t ha^{-1} or 40.7%, of sugar beet – 9.9 t ha^{-1} or 37.2%, spring barley – 1.39 t ha^{-1} or 48.8%, annual grasses (dry matter) – 2.72 t ha^{-1} or 74.3%, but productivity of a full crop rotation was 26.5 GJ ha^{-1} of metabolic energy or 40.0% more than in sandy loam soil on moraine with a similar content of potassium.

2. The yield of winter wheat in sandy loam soil was increased by potassium fertilizers by 0.6 t ha^{-1} or 15.1%, of sugar beet – by 6.8 t ha^{-1} or 25.6%, barley – 0.88 t ha^{-1} or 30.9%, annual grasses in dry matter – 2.72 t ha^{-1} or 74.3%, and average productivity of crop rotation – 13.8 GJ ha^{-1} of metabolic energy or 21.3%. Potassium fertilizers were not effective in silty loam soil on glacial lacustrine deposits with a similar content of potassium for winter wheat and sugar beet, but the yield of barley and annual grasses, and productivity of crop rotation in this soil was increased by potassium fertilizers: by 0.78

t ha^{-1} or 18.1%; 0.4 t ha^{-1} or 7.2%; 4.2 GJ ha^{-1} or 4.6%, respectively.

3. When annual potassium rate was 109 kg ha^{-1}, the crops in sandy loam took up about 20 kg ha^{-1} less, but in silty loam – 20 kg ha^{-1} more potassium than supplied with fertilizers.

4. During the research period, plant available potassium content in silty loam plots without K fertilizer use almost did not change, but in sandy loam increased by 9 mg kg^{-1}.

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Anotācija

Pētījumi veikti divās Epicalcari–Endohypogleyic Cambisol augsnēs, viena veidojusies uz morēnu mālsmilts, bet otra – ledāja ezera nogulumiem, putekļaina mālsmilts. Veicot ilggadīgus izmēģinājumus, skaidrota mēslojuma ietekme uz augsekas rotācijas produktivitāti un kālija satura izmaiņām augsnē. Noskaidrots, ka augsne, kas veidojusies uz ledāja ezera nogulumiem, spēj pilnīgāk nodrošināt kultūraugus ar tiem nepieciešamo kāliju, tādējādi samazinot mēslojuma vajadzību.

The influence of fertilization on different forms of phosphorus and their change in soil
Mēslojuma ietekme uz dažādu fosfora savienojumu uzkrāšanos augsnē

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Abstract. Total, fractional, and phosphorus extracted by 7 different extragents were determined in soil samples from crop rotation fertilization experiments in Skemiai, Radviliskis region, in Kriukai, Sakiai, and Rumokai, Vilkaviskis region. A reliable increase of total phosphorus in layers 0-20 cm and 21-40 cm was obtained in plots of long-term fertilization (28 years) experiment where high rates (90-180 kg ha^{-1}) of phosphorus fertilizers were used. However, total amount of phosphorus did not change essentially even in arable layer where 60-120 kg ha^{-1} of P_2O_5 was applied annually during the period of 8 years. When fractional phosphorus was determined by the method of Chang-Jackson, the most significant increase in 1M NH_4Cl soluble phosphorus was found in Skemiai experiment, while in Kriukai and Rumokai the changes were insignificant. Compared with the A–L method, other investigated extragents extracted smaller amount of mobile phosphorus from soil – from 0.17% to 94.0%.
Key words: soil, methods, fertilization rate, phosphorus.

Introduction

High and invariable crop yield in most cases depends on soil agrochemical properties (especially amount of plant available P_2O_5) and fertilization. When research on P fertilizer efficiency is carried out, it is necessary to determine the phosphorus forms in soil, their transformations, select analytical methods and derive correlation coefficients in order to compare the data from various methods.

According to Ribakova (Рыбакова et al., 1981), who investigated various methods for phosphorus determination in soil, the closest correlation of phosphorus content with the crop yield was obtained when anionic resin method was employed. The data obtained by this method was very similar to the data obtained by radiometric method. Use of 0.5% $NaHCO_3$ gives closer correlation with the crop yield compared with 0.1M HCl+0.3% NH_4F. In pot experiments carried out in England, correlation of phosphorus in soil and crop yield was high when it was determined using 0.01M $CaCl_2$ and the method of Egner–Riehm–Domingo (Hynlauder et al., 1996).

After comparing the methods of Olsen, Bray–1, Bray–2, Morgan, Williams–Stuart, Dajer, Egner, Trog and others in India, it was concluded that essential correlation was obtained using methods of Dajer, Williams–Stuart, Bray–1, Bray–2, and Olsen (Milap and Dhillon, 1994).

According to the research data in Great Britain and Greece, extraction of available phosphorus by 2% $NaHCO_3$ was dependent on temperature. When temperature was increased by 1°C, the amount of phosphorus in the extract increased by 3% (Simonis, 1996). With reference to V. Machacek, the amount of phosphorus extracted by 0.01M $CaCl_2$ correlated with phosphorus accumulated by plants (Machacek, 1996). However, in Luvisol, with the rate of phosphorus fertilizers 0-50 kg, the increase of phosphorus was linear using the 0.01M $CaCl_2$ extraction. The changes were not significant when high rates of fertilizers (80 kg ha^{-1} P) were used.

L. Vorobyova (Polese, Ukraine) found that in forest soil, 0.01M $CaCl_2$ solution extracted phosphorus from the soil liquid phase and partly from that part of reserve pool which relatively easily moves from the soil solid phase to the liquid one. This exhibits the phosphate availability in non-calcareous soils (Воробьева et al., 1995).

Material and methods

The investigations were carried out during 1971–2000 on the basis of multi-factor experiments in four locations. In Skemiai, Radviliskis region, the soils were Epicalcari- and Endocalcari Endohypogleyic Cambisol (WRB, 1998), morainic sandy loam (Brown gleyic calcareous sandy loam, Lithuanian Soil classification).

Crop rotation experiment in Kriukai, Sakiai district, lasted for 8 years. The soil was Epicalcari–Endohypogleyic Cambisol (WRB, 1998), glacial lacustrive silty medium loam.

Crop rotation experiment in Rumokai, Vilkaviskis region, lasted for 3 years, and the soil was Calcari–

Epihypogleyic Luvisol (WRB, 1998), glacial lacustrive silty light loam. Soil samples were mineralized by concentrated H_2SO_4 in Kjeldahl apparatus. Total phosphorus was determined using colorimetric method, fractional phosphorus – by the method of Chang-Jackson (Аскинази et al., 1963), mobile phosphorus – by following methods:

- M–01 buffer solution: $CH_3CH(OH)COOH+CH_3COOH+CH_3COONH_4$, pH 3.7 (Egner–Riehm–Domingo), 1:20*;
- M–02: 2% $NaHCO_3$+0.76% $(NH_4)_2SO_4$, pH 7.0, 1:25;
- M–03: 0.01M $CaCl_2$, 1:25;
- M–04: 0.03% $MgSO_4$, 1:5;
- M–05: Pi test – H_2O 1:50 sorption on anion resins and re-extraction by 0.1M HCl;
- M–06: 0.5M CH_3COONH_4+ +0.05M CH_3COOH+0.02M Na_2EDTA, pH 4.65, 1:10;
- M–07: 0.5M CH_3COONH_4+ +0.05M CH_3COOH+0.02M Na_2EDTA, pH 7.0, 1:10.

Phosphorus fertilizer rates and their content in soil are presented in oxide form (P_2O_5).

Results and discussion

According to the research data, concentration of total phosphorus in soil might be changed using long-term fertilization with a high phosphorus fertilizer rate. In the experiments, the amount of total phosphorus in comparison with the control increased 1.48-1.51 times in Skemiai, where fertilization was used for 28 years ($N_{120-180}P_{120-180}$** and $N_{120-180}P_{120-180}K_{90-120}$). Where high phosphorus and potassium fertilizer rates without nitrogen were used – even 1.7 times higher (Table 1). Use of moderate fertilization rates for 8 and 3 years did not significantly change the phosphorus content.

Use of fertilizers influenced distribution of phosphorus among different fractions detected by the method of Chang-Jackson (Fig. 1). In long-term experiment in Skemiai, in plots with $N_{60-90}P_{90-120}K_{90-120}$, the phosphorus amount in arable layer (0-20 cm) doubled; in 21-40 cm layer – increased 1.46 times. When phosphorus fertilization rate was 120-180 kg ha^{-1}, the amount of soil phosphorus in arable layer 0-20 cm increased 3.1-3.4 times, and in layer 21-40 cm – doubled. Using phosphorus extraction from topsoil samples by ammonium fluoride, due to phosphorus fertilizer use the relative amount of phosphorus increased more in organic fraction than in mineral fraction, but in subsoil – just the opposite. An analogous tendency was also observed using phosphorus extraction by 0.1M NaOH. In plots where phosphorus fertilizers were used, changes in 1M NH_4Cl extractable phosphorus were very low and formed only 1.3% from all other fractions. In plots with systematic fertilization, the phosphorus content increased 9.6 to 24.8 times. A considerable increase of aluminum phosphates (extractable by 0.5M NH_4F solution) and calcium phosphates was found, although the increase of tricalcium phosphate concentration was not so expressed. Crop rotation experiment in Kriukai lasted for 8 years and revealed that in topsoil (0-20 cm) the sum of phosphorus in all fractions did not change significantly in comparison with unfertilized control.

Table 1

Long-term fertilization and total phosphorus (P_2O_5) content (%) in soil, and standard deviation, 1998

Skemiai, Radviliskis region			Kriukai, Sakiai region		
Treatment	0-20 cm layer	21-40 cm layer	Treatment	0-20 cm layer	21-40 cm layer
Control	0.106±0.008	0.083±0.007	Control	0.125±0.009	0.104±0.007
$N_{60-90}P_{90-120}$	0.118±0.009	0.100±0.008	$P_{60}K_{90}$	0.127±0.009	0.105±0.007
$N_{60-90}P_{90-120}K_{90-120}$	0.144±0.014	0.093±0.007	$N_{60}P_0K_{90}$	0.122±0.009	0.110±0.008
$P_{120-180}K_{120-180}$	0.180±0.009	0.119±0.008	$N_{60}P_{60}K_{90}$	0.124±0.009	0.106±0.007
$N_{120-180}P_{120-180}$	0.157±0.013	0.111±0.009	$N_{60}P_{120}K_{90}$	0.125±0.009	0.106±0.007
$N_{120-180}K_{120-180}$	0.105±0.008	0.082±0.007	$N_{120}P_{60}K_{180}$	0.130±0.009	0.096±0.007
$N_{120-180}P_{120-180}K_{90-120}$	0.160±0.013	0.122±0.010	$N_{120}P_{120}K_{180}$	0.127±0.009	0.106±0.007

* – Here and afterwards – soil/extractant ratio, w/v.

** – Here and afterwards designation $P_{120}K_{180}$ and similar means 120 and 180 kg ha^{-1} of P_2O_5 and K_2O, respectively.

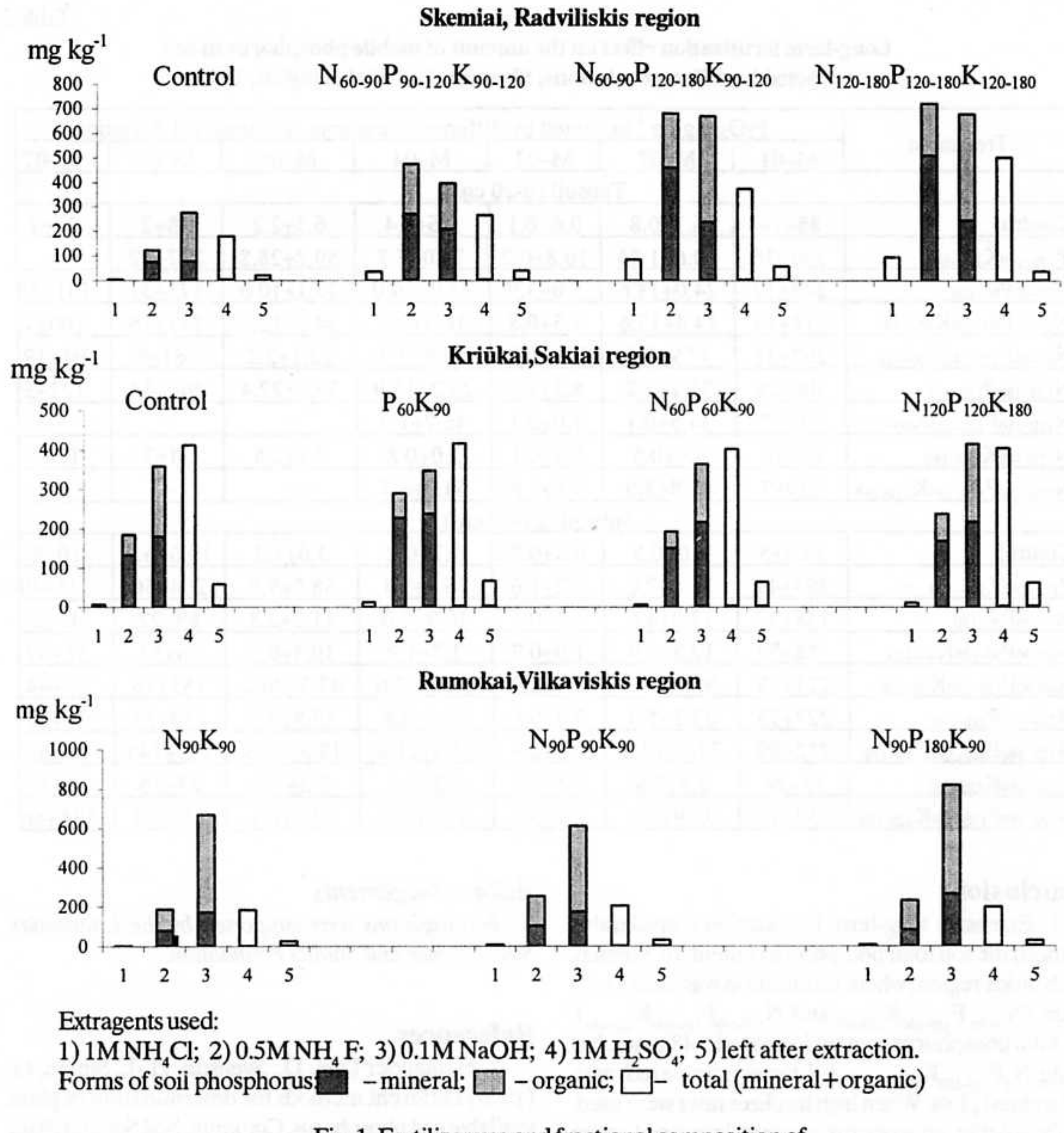

Fig. 1. Fertilizer use and fractional composition of topsoil (0-20 cm) phosphorus, mg kg^{-1}, 1998.

Mineral phosphorus soluble in 0.5M NH_4F increased, but part of organic phosphorus soluble in 0.1M NaOH decreased. However, in Rumokai, where investigations were carried out in silty light loam soil only for 3 years, the sum of phosphorus in all fractions increased even by 21% in plots where the maximum fertilizer rate was used.

In long-term experiment in Skemiai, significant changes of mobile P_2O_5 were obtained using different analytical methods (M–01–M–07). The lowest amount of mobile P_2O_5 was obtained in plots where phosphorus fertilizers were not used, but only $N_{120-180}K_{120-180}$. The highest amount of mobile P_2O_5 was obtained when $P_{120-180}K_{120-180}$ was applied (Table 2). However, the amount of phosphorus analyzed by different methods in above mentioned soil/solution ratio increased unequally. The amount of mobile P_2O_5 analyzed by A–L method (M–01) increased 4.0 times in comparison with the control, but using following solutions: 2% $NaHCO_3$+0.76% $(NH_4)_2SO_4$ (M–02), Pi test (M–05), and 0.5M CH_3COONH_4+0.05M CH_3COOH+0.02M Na_2EDTA, pH 4.65 (M–06) – increased 6.2-9.4 times, using 0.03% $MgSO_4$ solution (M–04) – increased 18 times, but in 0.01M $CaCl_2$ solution (M–03) – 47.5 times.

Comparison among concentrations of soil phosphorus extracted by different solutions revealed that compared with A–L method (M–01) other extractants extracted a lower amount of mobile phosphorus, e.g. 11-53% – using M–02; 0.17-0.40% – M–03; 0.47-20.0% – M–04; 6.1-16.0% – M–05; 31.0-94.0% – M–06; 8.9-46% – M–07.

Table 2

Long-term fertilization effect on the amount of mobile phosphorus in soil extracted by different solutions, Skemiai, Radviliskis region, 1998

Treatment	P_2O_5 mg kg^{-1} extracted by different extragents, and standard deviation						
	M–01	M–02	M–03	M–04	M–05	M–06	M–07
Topsoil (0-20 cm)							
Control	88±10	6.1±0.8	0.6±0.1	1.6±0.4	6.3±2.2	38±2	21±2
$P_{120-180}K_{120-180}$	350±35	40.6±1.84	10.8±0.2	76.0±7.7	59.2±28.8	237±32	–
$N_{60-90}P_{90-120}$	243±12	24.0±18.6	5.0±3.9	23.9±16.0	33.1±10.0	173±31	101±34
$N_{60-90}P_{90-120}K_{90-120}$	218±18	14.4±13.6	3.5±0.8	16.5±2.9	34.2±12.3	177±15	100±1
$N_{60-90}P_{120-180}K_{90-120}$	297±32	37.9±9.6	3.0±0.59	17.9±2.7	22.1±2.2	161±6	94±19
$N_{120-180}P_{120-180}$	300±28	35.1±5.2	8.3±2.5	23.2±18.9	39.6±22.4	200±14	122±3
$N_{120-180}P_{120-180}K_{90-120}$	315±7	34.5±0.1	7.0±0.1	46.7±1.3	–	–	–
$N_{120-180}K_{120-180}$	67±13	4.4±0.5	0.3±0.1	2.0±0.8	4.1±2.5	24±7	12±5
$N_{120-180}P_{120-180}K_{120-180}$	320±7	42.8±3.0	9.6±1.6	64.8±6.7	–	–	–
Subsoil (21-40 cm)							
Control	79.5±5	3.0±0.5	0.4±0.2	1.7±0.2	3.6±1.2	19.6±6.7	10±8
$P_{120-180}K_{120-180}$	305±49	35.8±7.0	4.2±1.6	36.4±7.1	38.0±9.9	204±50	128±49
$N_{60-90}P_{90-120}$	158±37	17.0±4.6	1.1±0.5	10.9±6.0	11.2±2.3	89±27	45±6
$N_{60-90}P_{90-120}K_{90-120}$	158±52	12.8±5.9	1.0±0.7	3.7±1.9	10.3±0.9	76±51	51±37
$N_{60-90}P_{120-180}K_{90-120}$	221±78	30.0±11.5	2.4±2.0	22.9±12.6	42.3±26.2	153±76	77±44
$N_{120-180}P_{120-180}$	227±35	23.1±5.3	2.0±0.6	12.4±4.8	17.8±9.6	139±13	76±22
$N_{120-180}P_{120-180}K_{90-120}$	232±89	27.3±13.7	2.6±2.9	24.4±21.4	18.3±13.3	143±145	88±65
$N_{120-180}K_{120-180}$	83±24	2.9±0.8	0.4±0.1	2.2±0.1	5.2±1.6	23±15	18±17
$N_{120-180}P_{120-180}K_{120-180}$	252±19	30.9±2.3	2.6±0.2	21.8±0.4	30.4±0.1	155±14	138±66

Conclusions

1. Extensive long-term fertilization considerably changed the soil total phosphorus content. In Skemiai, Radviliskis region, where fertilization was used for 28 years (N_{60-90} $P_{120-180}K_{120-180}$ and $N_{120-180}P_{120-180}K_{120-180}$), the total phosphorus content increased 1.48 times, but using $N_0P_{120-180}K_{120-180}$ – 1.7 times compared with unfertilized plots. When high fertilizer rates were used, easily soluble phosphorus content increased more rapidly compared with other fractions.

2. Correlation analysis between A–L method and others used in this study showed a relationship which in all cases was reliable. The closest relationship was found using ammonium acetate+Na_2EDTA, pH 4.65 and ammonium acetate+Na_2EDTA, pH 7.0, but weakest – using 0.01M $CaCl_2$.

3. Evaluation of the positive and negative sides of all investigated methods showed that A–L method (uncertainty 7.9-9.5%) was the most appropriate. Also the following solutions, because of their simplicity, low costs and universality, can be recommended for testing the soil mobile phosphorus and potassium: (1) 0.03% $MgSO_4$, (2) 0.5M CH_3COONH_4+0.05M CH_3COOH+ 0.02M Na_2EDTA, pH 4.65, or (3) 0.01M $CaCl_2$.

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Anotācija

Augsnes paraugi vākti stacionāros, ilggadīgos mēslošanas izmēģinājumu laukos, no aramkārtas (0-20 cm) un zemaramkārtas (21-40 cm) augsnes slāņiem. Augsnē noteikts kopējais fosfors un fosfora savienojumi, kas pāriet šķīdumā, lietojot noteikta sastāva ekstraģentu (kopumā salīdzināti 7). Ilgstoša fosfora minerālmēslu lietošana ir būtiski mainījusi gan kopējā fosfora saturu augsnē (pie lielām minerālmēslu normām), gan arī fosfora savienojumu frakcionālo sastāvu. Izvērtējot dažādas augsnes fosfora noteikšanas metodes, analizējot to priekšrocības un trūkumus, secināts, ka A-L metodi var uzskatīt par piemērotāko pētītajām augsnēm.

The effect of a fertilization system on the yield and its quality in crop rotation
Augsekas rotācijas produktivitāte un ražas kvalitāte atkarībā no lietotās mēslošanas sistēmas

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Abstract. The study reports on the most effective fertilization system found for sod-podzolic loamy sand soil underlaid by sand with high PK supply. This fertilization system included 100% compensation of yield PK removal using fertilizer rates: $P_{40}K_{90}$ and split application of 105 kg ha^{-1} of nitrogen. The system provided high crop rotation productivity (6.14 t ha^{-1} feed units) and yield quality.
Key words: fertilization system, yield, crop quality.

Introduction

A rational fertilization system should ensure the planned yield level of agricultural crops, improve the yield quality and maintain the soil fertility. However, use of technologies oriented to high crop yields not always results in the improvement of product quality. Weather conditions, fertility status, soil management, crop variety and nitrogen fertilizers play important role in the formation of the crop yield and its quality. On sod-podzolic loamy sand soil, which is characterized by good potassium and phosphorus supply, both level of nitrogen nutrition and terms of N fertilizer application during vegetation are of great importance (Шкель, Прудников, Перепелица, 1989).

The purpose of this investigation was to develop a new fertilization system for high and sustainable productivity and yield quality in crop rotation (potato, barley, winter rye and oat) on sod-podzolic loamy sand soils with a high PK supply.

Material and methods

A long-term field experiment (1995-2000) was carried out on sod-podzolic loamy sand soil underlaid by sand at the depth of 0.3-0.5 m in Uzda district, Minsk region. The soil was characterized by following agrochemical properties: pHKCl – 5.9-6.2, hydrolytic acidity – 1.58-1.92, exchangeable cations (S) 9.10-9.52 cmol(+) kg^{-1}, exchangeable calcium – 4.4-4.8, exchangeable magnesium – 1.3-1.6 cmol(+) kg^{-1}, mobile phosphorus (Kirsanov method) P_2O_5 – 170-290, mobile potassium K_2O (Kirsanov method) – 130-230 mg kg^{-1} of soil, humus (Tyurin method) – 2.5-3.0%.

The treatments included different levels of K and P fertilizer application. The rate calculation was as follows: deficit balance (50% of yield removal compensation), maintenance balance (100% of removal compensation) and positive balance (150% of removal compensation). Estimated crop yields: potato – 25.0 t ha^{-1}; barley, winter rye and oat – 4.0 t ha^{-1}. Crop rotation: potato, barley, winter rye and oat. Cattle manure with straw (70 t ha^{-1}) was applied in autumn over the years 1994-1996. Manure composition: dry matter – 31.5%, pHKCl – 8.55, crude ash – 51.3%, total N – 0.36%, P_2O_5 – 0.18%, K_2O – 0.75%. The experiment was performed in 4 replicates with total plot size 45 m^2. Harvest area for grain crops – 32 m^2 and for potato – 28 m^2. Mineral fertilizers (am-monium nitrate, ammoniated single superphosphate and potassium chloride) were applied under presowing cultivation in accordance with experimental treatments (Table 1). Presowing soil cultivation and plant growing were performed in accordance with intensive technologies' recommendations for the row and grain crops (Шкель, Прудников, Перепелица, 1989; Андреев и др., 1986). Integrated plant protection system was used.

Soil analyses were performed using traditional methods: hydrolytic acidity – Kappen method, exchangeable cations – Kappen-Gilkovitch method, potassium and phosphorus – Kirsanov method, exchangeable calcium and magnesium – in 1M KCl. For evaluation of protein content in plants, Barnshtein method was used. To determine N and P in plants, the endophenol and vanadium-molybdenum calorimetric methods were used. Potassium was determined using flame photometer; calcium and magnesium – by atom absorption. Organic fertilizers were analyzed using traditional methods.

Weather conditions varied during the investigation period of 1995-2000. The driest weather was observed in 1996 and 1999, but 1995 and 1997-1998 were characterized by almost normal weather conditions. Temperature differences were less significant, except for 2000 when strong frost was observed in May and June. Hydrothermic coefficients during the investigations in 1995, 1996, 1997, 1998, 1999 and 2000 for the vegetation period (April, May, June, July, August) were equal to 1.42, 1.18, 1.92, 2.48, 0.85, and 0.98, respectively.

Table 1

Fertilizer application in crop rotation (1995-2000)

Treat-ment	Σ NPK for crop rotation, kg ha^{-1}	Potato 'Orbita', 1995-1997	Barley* 'Sjabra', 1996-1998	Winter rye** 'Verasen', 1997-1999	Oat 'Dukat', 1998-2000
1	Without fertilizer (control)				
2	Manure, 70 t ha^{-1} – background	Manure, 70 t ha^{-1} – background	Aftereffect of 70 t ha^{-1} manure	Aftereffect of 70 t ha^{-1} manure	Aftereffect of 70 t ha^{-1} manure
PK positive balance					
3	$N_{300}P_{280}$	$N_{90}P_{70}$	$N_{60}P_{70}$	$P_{70} + N_{90}$	$N_{60}P_{70}$
4	$N_{300}K_{510}$	$N_{90}K_{150}$	$N_{60}K_{120}$	$K_{120} + N_{90}$	$N_{60}K_{120}$
5	$P_{280}K_{510}$	$P_{70}K_{150}$	$P_{70}K_{120}$	$P_{70}K_{120}$	$P_{70}K_{120}$
6	$N_{180}P_{280}K_{510}$	$N_{60}P_{70}K_{150}$	$N_{30}P_{70}K_{120}$	$P_{70}K_{120} + N_{60}$	$N_{30}P_{70}K_{120}$
7	$N_{300}P_{280}K_{510}$	$N_{90} P_{70}K_{150}$	$N_{60}P_{70}K_{120}$	$P_{70}K_{120}+ N_{90}$	$N_{60}P_{70}K_{120}$
8	$N_{420}P_{280}K_{510}$	$N_{120}P_{70}K_{150}$	$N_{60}P_{70}K_{120}+N_{30}$	$P_{70}K_{120}+N_{90}+N_{30}$	$N_{60}P_{70}K_{120}+N_{30}$
PK maintenance balance					
9	$P_{160}K_{360}$	$P_{40}K_{120}$	$P_{40}K_{80}$	$P_{40}K_{80}$	$P_{40}K_{80}$
10	$N_{180}P_{160}K_{360}$	$N_{60}P_{40}K_{120}$	$N_{30}P_{40}K_{80}$	$P_{40}K_{80}+N_{60}$	$N_{30}P_{40}K_{80}$
11	$N_{300}P_{160}K_{360}$	$N_{90} P_{40}K_{120}$	$N_{60}P_{40}K_{80}$	$P_{40}K_{80}+N_{90}$	$N_{60}P_{40}K_{80}$
12	$N_{420}P_{160}K_{360}$	$N_{120}P_{40}K_{120}$	$N_{60} P_{40}K_{80}+N_{30}$	$P_{40}K_{80}+N_{90}+N_{30}$	$N_{60}P_{40}K_{80}+N_{30}$
PK deficit balance					
13	$P_{80}K_{180}$	$P_{20}K_{60}$	$P_{20}K_{40}$	$P_{20}K_{40}$	$P_{20}K_{40}$
14	$N_{180} P_{80}K_{180}$	$N_{60}P_{20}K_{60}$	$N_{30}P_{20}K_{40}$	$P_{20}K_{40}+N_{60}$	$N_{30}P_{20}K_{40}$
15	$N_{300}P_{80}K_{180}$	$N_{90}P_{20}K_{60}$	$N_{60} P_{20}K_{40}$	$P_{20}K_{40}+N_{90}$	$N_{60}P_{20}K_{40}$

* – additionally N_{30} at phase 32 (Zadoks scale) for barley and oat;

** – N in spring at the beginning of vegetation + N_{30} at phase 32 (Zadoks scale) of winter rye.

Results and discussion

Experimental results showed close correlation between fertilizer efficiency, crop productivity and weather conditions. The highest yield (23.4 t ha^{-1}) and a payback of 21.4 kg of potato tubers per 1 kg NPK applied were obtained using organo-mineral fertilization system with maintenance PK balance ($N_{60}P_{40}K_{120}$*) (Лапа, Ивахненко, 1999). Also for barley 'Sjabra' the highest grain yield (4.4 t ha^{-1}) was observed using fertilization system with maintenance PK balance, what included $P_{40}K_{80}$ application, aftereffect of 70 t ha^{-1} of manure, and split nitrogen application (N_{60} at basal fertilizing and N_{30} at phase 32 of development (Zadoks scale)) (Table 2). This fertilization system provided a 1.7 t ha^{-1} grain response due to NPK application, including 0.8 t ha^{-1} as a result of N fertilizers. Payback of 1 kg NPK was equal to 8.6 kg of grain, but payback of 1 kg N fertilizers reached 8.9 kg of grain (Лапа, Ивахненко, 2000).

The maximum yield of winter rye 'Verasen' (4.1 t ha^{-1}) was observed using fertilization system with maintenance PK balance, when 240 kg ha^{-1} of NPK ($N_{90+30}P_{40}K_{80}$) was applied (Table 2). Payback of 1 kg NPK fertilizers was equal to 7.3 kg, but for 1 kg of N fertilizers – 14.7 kg of grain. Grain response due to aftereffect of organic fertilizers reached 0.11 t ha^{-1}. There was a 0.08-0.20 t ha^{-1} grain yield increase due to application of K and P fertilizers. In 1997 and 1998, efficiency of NP treatment was 0.16 and 0.08 t ha^{-1} higher compared with the use of NK fertilizers. The increase in N fertilizer rates led to the crop yield increase using all studied fertilization systems. Maximum payback of mineral fertilizers (NPK) was obtained using fertilization system with a deficit PK balance. The highest N fertilizer payback was observed at N_{60} application in spring (at the beginning of vegetation) using fertilization system with a deficit or maintenance PK balance (Table 2).

As three years' average, the maximum yield of oat grain (3.73 t ha^{-1}) was obtained after application of 210 kg ha^{-1} of mineral fertilizers including 90 kg of nitrogen (split application) and $P_{40}K_{80}$ (maintenance balance). The payback of 1 kg NPK was equal to 5.0 kg of grain, but payback of 1 kg N – to 9.3 kg of grain (Table 2).

It was found that the highest crop rotation productivity, i.e. 6.14 t ha^{-1} feed units (f.u.), was obtained by split application of the highest N fertilizer rate (105 kg ha^{-1}) using $P_{40}K_{90}$* (100% compensation of the P_2O_5 and K_2O yield removal). At this treatment, payback of 1 kg of NPK was relatively high – 8.7 f.u., but payback

* – Here and afterwards designation $N_{60}P_{40}K_{120}$ and similar means 40 and 120 kg of P_2O_5 and K_2O, respectively.

Table 2

Effect of a fertilization system on crop rotation productivity

Treat-ment	Yield, t ha^{-1}				Annual yield, t ha^{-1} f.u.	Yield increase, t ha^{-1} f.u.		Response, f.u. per 1 kg of fertilizers	
	potato	barley	winter rye	oat		NPK	N	NPK	N
1	14.4	2.22	1.96	2.34	3.40	–	–	–	–
2	18.7	2.71	2.07	2.68	4.09	–	–	–	–
3	21.5	4.16	3.88	3.17	5.67	1.58	–	10.9	–
4	18.8	4.33	3.84	3.49	5.62	1.53	–	7.6	–
5	19.8	3.85	2.56	3.20	5.09	1.00	–	5.1	–
6	21.7	4.25	3.51	3.49	5.69	1.60	0.60	6.6	13.3
7	23.2	4.37	3.86	3.66	6.04	1.95	0.95	7.2	12.7
8	22.9	4.55	3.97	3.92	6.20	2.11	1.11	7.0	10.6
9	20.1	3.61	2.36	2.89	4.72	0.63	–	4.8	–
10	23.4	4.10	3.55	3.30	5.72	1.63	1.00	9.3	22.2
11	21.9	4.14	3.67	3.35	5.68	1.59	0.96	7.8	12.8
12	22.8	4.41	4.12	3.73	6.14	2.05	1.42	8.7	13.5
13	19.9	3.44	2.28	2.85	4.59	0.50	–	7.8	–
14	21.0	3.96	3.46	3.29	5.44	1.35	0.85	12.3	18.2
15	21.8	3.90	3.64	3.50	5.62	1.53	1.03	10.9	13.3
LSD_{05}	1.4	0.26	0.24	0.28	0.20	–	–	–	–

Table 3

Influence of a fertilization system on crop quality

Treat-ment	Potato tubers			Potato (tubers)	Barley (grain)	Winter rye (grain)	Oat (grain)	Annual protein yield, t ha^{-1}
	dry matter	starch	nitrates, mg kg^{-1}	protein content in dry matter, %				
	%							
1	22.3	14.1	54.1	8.7	8.3	6.9	6.0	0.172
2	21.3	14.2	59.6	8.5	8.8	7.3	6.7	0.222
3	20.8	13.9	92.7	10.2	9.0	8.7	8.2	0.335
4	20.3	13.0	94.8	10.0	8.9	8.5	8.0	0.318
5	19.6	13.2	64.0	8.7	8.5	7.8	7.1	0.254
6	19.7	13.6	84.1	10.2	8.6	8.1	7.7	0.319
7	21.0	13.1	97.6	10.1	9.2	8.7	8.2	0.358
8	20.1	13.4	106.2	10.6	9.4	8.9	8.7	0.376
9	20.6	13.4	56.8	9.2	8.5	7.5	7.2	0.252
10	21.0	13.7	82.7	10.0	8.7	8.0	7.7	0.325
11	19.9	13.4	98.5	10.3	9.5	8.6	8.1	0.334
12	20.1	13.2	123.0	10.3	9.5	9.1	8.2	0.366
13	21.6	14.2	55.8	8.6	8.7	7.9	6.9	0.246
14	20.6	13.7	91.3	10.5	8.8	8.1	7.1	0.309
15	20.3	13.4	87.8	10.7	9.0	8.4	7.7	0.329
LSD_{05}	1.01	0.59	11.2	0.4	0.28	0.33	0.35	–

of N fertilizers reached 13.5 f.u. Treatments which included an average annual application of $N_{45\text{-}75}P_{20}K_{45}$ (50% compensation of the P_2O_5 and K_2O yield removal) provided an average annual crop rotation productivity – 5.44-5.62 t ha^{-1} f.u., what was 0.65 t ha^{-1} f.u. less compared with 100% compensation of the potassium and phosphorus removal. However, payback of 1 kg NPK was higher at this treatment – 10.9-12.3 f.u.

PK fertilizer application which ensures its positive balance ($N_{45\text{-}105}P_{70}K_{128}$ average annual rates) did not give a significant crop yield increase in crop rotation. A reduction of payback of 1 kg NPK to 6.6-7.2 f.u. was observed (Table 2).

It is important to determine the main factors effecting the crop yield after N fertilizer application and at different PK balances (negative, maintenance and positive). Among these factors, soil fertility status, soil management and crop variety were found to dominate and affect the crop yield by 56-62%. We estimated that nitrogen affected the plant yield by 16-23%, the potassium and phosphorus influence was estimated as 9-17%, but use of organic fertilizers – 11-13%.

Agricultural production quality is one of most important parameters in selecting an adequate fertilization system. Experimental data showed that application of mineral fertilizers caused reduction in the dry matter and starch content in potato tubers. Also increase in nitrate content in potato tubers was observed: the highest (123 mg kg^{-1}) was obtained using 120 kg of N and $P_{40}K_{120}$ (maintenance balance). However, the nitrate content was within the maximally allowed concentration as set in Belarus (150 mg kg^{-1}). Another important potato quality parameter is the protein content. Peculiarity of potato protein is its high lysine content what is significant in food quality. The content of protein in potato tubers increased from 8.5 to 9.2%, when potassium and phosphorus rates were raised from 0 to $P_{40}K_{120}$. The increase of N fertilizer rates also stimulated the protein accumulation in potato.

Among grain crops, barley was characterized by the highest protein content. The maximum protein content in grain (9.5%) was obtained by split application of nitrogen fertilizers at treatment N_{60} at basal fertilizing + N_{30} at phase 32 (Zadoks scale) using $P_{40}K_{80}$. For winter rye grain – 9.1% at N_{90} in spring at the beginning of vegetation + N_{30} at phase 32 (Zadoks scale) and $P_{40}K_{80}$. For oat grain – 8.7% at N_{60} in spring + N_{30} at phase 32 (Zadoks scale) and $P_{70}K_{120}$ (positive balance).

The highest protein yield (0.376 t ha^{-1}) in crop rotation was obtained using average $N_{105}P_{70}K_{128}$ per year. The treatment with the highest productivity was characterized by a higher protein yield – 0.366 t ha^{-1} (Table 3).

The highest productivity (6.0-6.2 t ha^{-1} f.u.) and crop quality was obtained due to average application of 17.5 t ha^{-1} of organic fertilizers and using PK mineral fertilizers for 100% yield removal compensation.

Conclusion

The highest crop rotation productivity on sod-podzolic loamy sand soil was provided using the following fertilization systems for potato tubers (23.4 t ha^{-1}) – 70 t ha^{-1} of manure + $N_{60}P_{40}K_{120}$; for barley grain (4.4 t ha^{-1}) – $N_{60+30}P_{40}K_{80}$; for winter rye grain (4.1 t ha^{-1}) – $N_{90+30}P_{40}K_{80}$; for oat grain (3.73 t ha^{-1}) – $N_{60+30}P_{40}K_{80}$. Application of maintenance fertilization system provided a high protein content in grain (8.2-9.5%) and good potato tuber quality (starch – 13.2%, nitrates – 123 mg kg^{-1}, protein – 10.3%).

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Anotācija

Pētījumi veikti 1995.-2000. gadā velēnu podzolētā smilšmāla augsnē, kurai 0.3-0.5 m dziļumā atrodas smilšains materiāls un kurai raksturīgs augsts PK nodrošinājums. Lietotās mēslošanas sistēmas tika veidotas tādejādi, lai ar mēslojumu kompensētu noteiktu fosfora un kālija daļu – 50, 100 un 150% apmērā, ko kultūraugi iznes no augsnes ar plānoto ražu. Mēslošanas sistēmas vērtētas gan pēc iegūtās kultūraugu ražas lieluma, galvenajiem tās kvalitātes rādītājiem, gan arī pēc mēslošanas līdzekļu lietošanas agronomiskās efektivitātes.

The effect of long-term fertilizer application on the phosphorus and potassium balance in drained sod-podzolic soil
Ilggadīgas mēslošanas līdzekļu lietošanas ietekme uz fosfora un kālija bilanci drenētā velēnu podzolaugsnē

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Abstract. The effect of annual long-term application of different fertilizer rates on the phosphorus and potassium balance in drained unlimed and limed soil has been investigated. Balance input and output elements were calculated from the field trial data obtained during 1982-1999. It was estimated that application of fertilizer rates less than P_{30} and K_{45} had led to the deficit of these nutrients in soil. A positive balance of potassium (15-47 kg ha^{-1} yr^{-1}) and phosphorus (20-47.8 kg ha^{-1} yr^{-1}) was obtained using fertilizer rates $P_{60}K_{90}$ and $P_{90}K_{135}$. However, such surplus formed due to annual return of nutrients in the crop's by-product. Sufficient increase in available phosphorus content in soil was observed using P_{90}, though the increase in available potassium content was found even using fertilizer rate K_{45}.
Key words: phosphorus, potassium, nutrient balance, off-take, leaching losses.

Introduction

Efficient use of plant nutrients is a necessary action to sustain long-lasting agricultural production. Sufficient nutrient amounts ensure sustainable use of soil recourses and improve the crop productivity. At the same time, intensive fertilizing is related to a surplus balance and nutrient losses. To minimize the high surplus and losses of plant nutrients from the agricultural system, their input needs to be reduced, but recycling within the system – increased (Granstedt, 2000; Parris, 1998).

According to HELCOM and PARCOM recommendations and the EC agricultural policy, nutrient balances should be used: 1) to promote efficient application of fertilizers, 2) to reduce nutrient losses from agriculture, 3) to reduce inputs of nutrients. Although among nutrients the primary limitations have been settled for nitrogen, the use of phosphorus is also a live issue. It is stated that the available phosphorus content in arable topsoil should not exceed the requirements of an acceptable crop production. Phosphorus input should be of the same size as the phosphorus removed (Jakobsson, 2001).

The EC directives do not limit the potassium fertilizer application, but it is known that for an efficient use and setting of potassium fertilizer rates the balance method is the most appropriate (Прокошев, 1988; Diest, 1990). Nevertheless, other experiments show that the difference method for assessing potassium and phosphorus efficiency is not the most appropriate. It is stressed that more useful might be the determination of critical levels of readily soluble nutrients in each soil (Johnston, 2001). An excessive use of potassium can increase its content in crop production, change the Ca:K ratio in soil and stimulate the transfer of available potassium into a more fixed form (Босак, 2001).

In Latvia, large areas of arable land are naturally acid, low in plant nutrients and are characterized by an enhanced soil water percolation. Their effective use is almost impossible without lime and fertilizer applications and drainage. This can cause environmental stress, especially on recultivated drained soils with enhanced soil water percolation. Therefore planning of fertilizer application on such soils should be of major importance.

The purpose of present investigations was to evaluate the effect of long-term application of different phosphorus and potassium fertilizer rates on the changes in plant available phosphorus and potassium contents in soil, losses of these nutrients by drainage water, and the balance of potassium and phosphorus in soil.

Materials and methods

In 1981, a long-term field trial with experimental drainage system was established at the Latvian Research Institute of Agriculture (currently Skrīveri Research Centre of the Latvia University of Agri-culture) on sod-podzolic soil (fine-loamy, mixed, semiactive Boralfic Udic Argiboroll (Soil Taxonomy, 1994); Glossalbi–Luvic Phaeozem (WRB, 2001)). The total area (1.6 ha) of experimental field was split into 16 plots (15x50 m). Each plot was supplied with a seepage tile drain at a depth of 80-100 cm and an inspection well for drain water sampling.

Two-factor experiment layout was used.

Factor A – soil liming (oil-shale ash was spread at the beginning of the experiment):

1. no liming;

2. 2.85 t $CaCO_3$ ha^{-1};
3. 5.7 t $CaCO_3$ ha^{-1};
4. 11.4 t $CaCO_3$ ha^{-1}.

Factor B – fertilizer use (annual rates):

1. no fertilizers;
2. $N_{45}P_{30}K_{45}$*;
3. $N_{90}P_{60}K_{90}$;
4. $N_{135}P_{90}K_{135}$.

Crop rotation since the beginning of the 1982 experiment was as follows: winter rye, spring wheat, spring barley, oats, potato, spring rape, clover. The main soil parameters at the beginning of the experiment were: pHKCl – 4.7-4.9, plant available phosphorus – 10-20 mg kg^{-1} and potassium – 40-60 mg kg^{-1} (Egner–Riehm DL method) (ГОСТ 26209–84), soil organic carbon – 11-12 g kg^{-1} (Tyurin's method) (ГОСТ 26213–84).

The intensity of drain water flow was measured and water samples for analyses from each plot were taken daily during the periods of drainage. Samples were analyzed for phosphorus by colorimetric analysis (molibdate complex), and for potassium – using flame photometry.

The potassium and phosphorus balances were calculated as difference between nutrient input by lime and fertilizers, and nutrient output by crop yield plus leaching losses by drainage water. Removal of phosphorus and potassium by yield was calculated taking into consideration the yield level and its chemical composition for each plot during the whole period of the experiment.

Results and discussion

Soil liming at the beginning of the experiment resulted in an essential change of soil acidity. Application of lime rate 2.85 t $CaCO_3$ ha^{-1} reduced the exchangeable acidity of soil to pHKCl 5.2-5.8, rate 5.7 t of $CaCO_3$ ha^{-1} – pHKCl 5.6-6.4, and 11.4 t of $CaCO_3$ ha^{-1} – pHKCl 5.9-6.6 in comparison with initial pHKCl 4.7-4.9.

During the 17-years period of the experiment, the content of plant available phosphorus and potassium in soil changed significantly according to the lime and fertilizer rates applied. Due to the very low phosphorus content in soil at the beginning of the experiment, the application of P_0 and P_{30} led to further decrease of its content and was below 6 mg P_2O_5 kg^{-1} at the end of the experiment, especially when the soil was limed. Essential increase of soil phosphorus content was observed using only the maximum phosphorus rate P_{90}: by 39-81 mg kg^{-1} depending on the lime rate. Unlike phosphorus, the available potassium content during the experiment had not decreased even without potassium fertilizer application, probably due to its mobilization from soil resources. Regular use of fertilizers (K_{90} and K_{135}) increased the potassium content in soil 2-3 times as it was at the beginning of the experiment. The dynamics of PK changes in soil can be described using the equations in Table 1.

The plant nutrient off-take was calculated from the yield of crops' main product and the nutrient concentration in it. The yield of the by-product always remained on the field and the nutrients taken up by the biomass were directly returned back into the soil. Results showed that phosphorus (P_2O_5) off-take by the crop yield varied from 8 to 46 kg ha^{-1} yr^{-1} according to the phosphorus fertilizer rate. The off-take from limed soil was 3 to 5 kg higher. The potassium removal was always higher than that of phosphorus. In unfertilized soil, the K_2O off-take was 22-28 kg, with fertilizer rates K_{45} – 50-57 kg, K_{90} – 69-85 kg, and K_{135} – 90-98 kg per ha per year (Fig. 1). Due to higher crop yields in limed plots, the removal of phosphorus and potassium was higher from limed soil than that from acid soil.

Leaching losses of phosphorus and potassium

Table 1

Dynamics of the changes of plant available phosphorus and potassium content in soil

Treatment		Phosphorus		Potassium	
Fertilizer rate	$CaCO_3$, t ha^{-1}	Equation of regression	R^2	Equation of regression	R^2
$N_0P_0K_0$	0	$y=19.52-1.11x$	0.76	$y=49.13-2.89x+0.28x^2$	0.96
	5.7	$y=15.89-0.92x$	0.59	$y=50.02-1.12x+0.17x^2$	0.98
$N_{45}P_{30}K_{45}$	0	$y=15.30+1.50x-0.10x^2$	0.49	$y=34.56+2.78x+0.03x^2$	0.98
	5.7	$y=10.83+2.13x-0.13x^2$	0.70	$y=45.58-0.08x+0.20x^2$	0.99
$N_{90}P_{60}K_{90}$	0	$y=5.49+5.81x-0.29x^2$	0.80	$y=48.03+6.58x+0.25x^2$	0.98
	5.7	$y=9.80+5.16x-0.28x^2$	0.45	$y=49.76+7.60x+0.04x^2$	0.98
$N_{135}P_{90}K_{135}$	0	$y=6.45+8.46x-0.33x^2$	0.91	$y=29.79+11.53x+0.13x^2$	0.99
	5.7	$y=24.83+3.76x-0.05x^2$	0.94	$y=83.05-0.004x+0.64x^2$	0.99

Note: x – number of years since the beginning of the experiment,
y – content of plant available phosphorus or potassium in soil, mg kg^{-1}.

* – Here and afterwards designations N_{30}, P_{30}, K_{30} (and similar) show the amount of nitrogen, phosphorus and potassium, kg per ha, which was applied with fertilizers and expressed for phosphorus as P_2O_5 and for potassium as K_2O.

caused by drainage were not significant. Most drainage was formed in spring. The total annual amount of drain water removed was 17-254 mm or 3-37% of the total annual precipitation. Depending on the amount of precipitation, about 0.1-0.5 kg of P_2O_5 ha^{-1} annually leached from both limed and acid soils. The loss of potassium reached 3.5-4 kg ha^{-1} from acid soil and 0.6-1.7 kg ha^{-1} from limed soil (Štikāns et al., 1996).

The phosphorus and potassium balance was related significantly to the fertilizer rate annually incorporated in the soil. Additional input of potassium and phosphorus was by lime: 0.9 kg P_2O_5 ha^{-1} and 12.2 kg K_2O ha^{-1} yr^{-1} for each limed plot using lime rate 5.7 t $CaCO_3$ ha^{-1}. As the results showed (Fig. 2), the deficit of phosphorus occurred in plots without phosphorus fertilizer application. In limed soil with a small fertilizer rate (P_{30}), the balance was also very low – only 0.2 kg ha^{-1}. Annual application of fertilizer rates P_{60} and P_{90} led to a positive phosphorus balance because the increase in phosphorus removal by the crop yield was not very high. In spite of phosphorus accumulation by about 45 kg ha^{-1} per year using P_{90}, the increase in available phosphorus content in the soil was not significant – about 2.2-4.5 mg kg^{-1} yr^{-1} depending on the soil acidity level.

Due to higher removal by yield, the deficit of potassium was more essential (Fig. 3). In experimental plots without potassium fertilizer application, the deficit was higher in acid soil than in limed soil because of potassium input by lime. In spite of a high negative potassium balance, the decrease in soil potassium content during the experiment was not observed. Potassium surplus was found only when fertilizer rates K_{90} and K_{135} were used. Annual accumulation of 42-47 kg of potassium in soil led to a significant increase in plant available potassium content by 10-12 mg kg^{-1} yr^{-1}. Nevertheless, the effect of such enrichment of soil with plant available potassium and phosphorus on the crop yield was not adequate. The increase in crop yield applying $P_{90}K_{135}$, in comparison with $P_{60}K_{90}$ treatment, was very low and gradually decreased during the experiment.

Conclusions

The phosphorus and potassium fertilizer rates annually incorporated into the soil have to be balanced with the nutrient removal by the crop yield and the expected losses. In soils low in available phosphorus and potassium content, fertilizer rates can be increased with the aim to maintain the soil fertility and improve

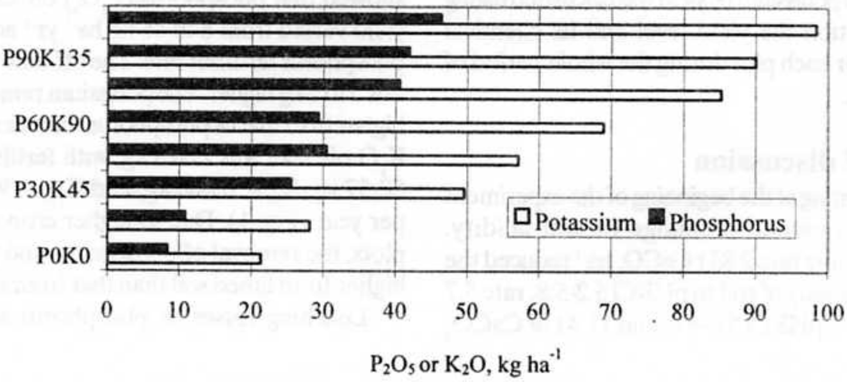

Fig. 1. The effect of fertilizer rates on the phosphorus and potassium removal by the crop yield (main product).

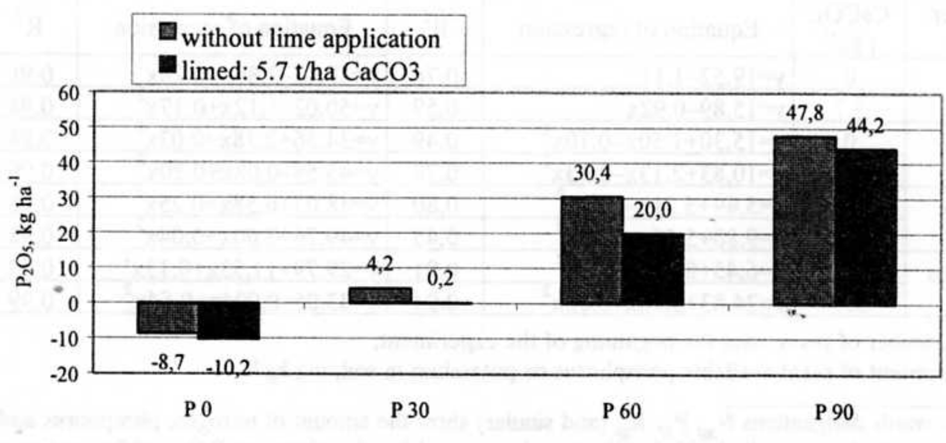

Fig. 2. The effect of fertilizer rates on phosphorus balance in long-term field experiments.

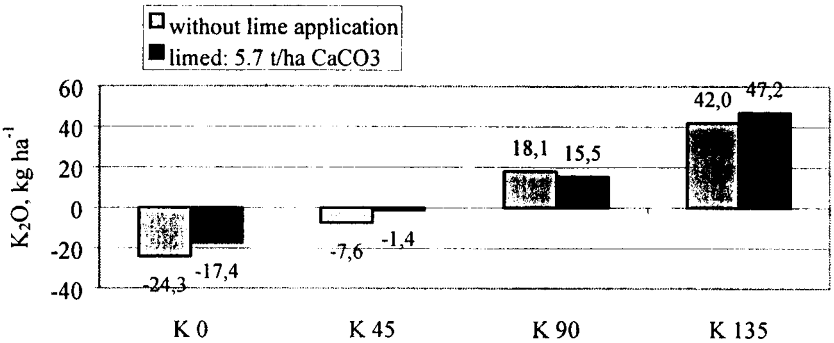

Fig. 3. The effect of fertilizer rates on potassium balance in long-term field experiments.

the soil nutrient level. This mostly refers to phosphorus, as the available phosphorus content was increased only when the input surpassed the output approximately twice. Liming of acid soil produced better conditions for the formation of crop yield and thus enlarged the output of nutrients from the soil. Surplus of nutrients obtained due to large fertilizer rates shows the inefficiency of these rates.

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Anotācija

Lauka izmēģinājumi veikti 1982.-1999. gadā ilggadīgajā lauka drenāžas stacionārā Skrīveros. Pētījumos noteikta augsnes kaļķošanas un regulāras dažādu NPK minerālmēslu normu lietošanas ietekme uz augiem viegli izmantojamā fosfora un kālija saturu un bilanci augsnē. Noskaidrots, ka ik gadu, kā nekaļķotā, tā kaļķotā augsnē iestrādājot fosfora un kālija minerālmēslu normas, kas nepārsniedz 30 kg ha^{-1} P_2O_5 un 45 kg ha^{-1} K_2O, šo augu barības elementu saturs augsnē samazinājās, jo to iznesa ar ražu un izskalošanās zudumi ar drenu noteci pārsniedza ienesu ar kaļķošanas materiālu un minerālmēsliem. Minerālmēslu norma $P_{60}K_{90}$ nodrošināja pozitīvu PK bilanci, bet viegli izmantojamā fosfora daudzums augsnē būtiski palielinājās, tikai ik gadus iestrādājot 90 kg ha^{-1} P_2O_5.

Optimization of mineral nutrition for perennial ryegrass seed production
Mēslošanas optimizācija ganību airenes sēklaudzēšanā

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Abstract. The efficiency of N fertilizer used in perennial grass seed production in Latvia may affect the nitrogen rate, grass species, and soil type. Grass seed production is a very important factor for farmer's income in Latvia. The objective of this research was to obtain productivity results for perennial ryegrass (*Lolium perenne* L.) at different rates of mineral nutrition. Field experiments were carried out on sod-podzolic sandy loam soil. The following mineral fertilizer rates were used: N and P_2O_5, each 0, 30, 60, 90, 120, K_2O – 0, 40, 80, 120, 160 kg ha^{-1}. Productivity of biomass and seeds was dependent on the following variables: genetic characteristics of particular cultivars, mineral fertilizer rates, and meteorological conditions of the growing period. This research examines the effects of varying mineral fertilizer rates on dry matter and seed yields by using perennial ryegrass cultivar 'Spidola' and relies on the local weather conditions. The average biomass yield was 2.21-6.07 t ha^{-1} (on dry matter basis), while the average seed yields were 255-672 and 136-390 kg ha^{-1} in the 1st and 2nd year stand, respectively.
Key words: fertilizer use, perennial ryegrass seed production, yield quality.

Introduction

Grass species often used for forage production as hay or pasture systems include timothy (*Phleum pratensis* L.), perennial ryegrass (*Lolium perenne* L.), meadow fescue (*Festuca pratensis* Huds), orchardgrass (*Dactylis glomerata* L.) and Kentucky bluegrass (*Poa pratensis* L). High yields of perennial ryegrass seed production in Latvia depend on abundant plant-available N.

Perennial ryegrass species has great seed production potential. However, it is very difficult to use, practically due to the many biotic and abiotic factors forming interaction within the system plant–environment–fertilizers. In order to obtain a good perennial grass seed yield, it is important to have these following preconditions: high enough temperature, rain during the flowering stage, seed maturation, as well as the use of proper cultivars with high seed yielding capacity and the application of adequate fertilization.

Perennial ryegrass is a major component in different seed mixtures that are used for grassland management and forage production. This grass species plays an important role in grassland productivity and forage quality. Agro-climatic conditions have a very significant role in grass seed production and optimization of mineral nutrition for perennial ryegrass (Havstad, 1998).

Perennial ryegrass cultivars 'Spidola' were developed at the Skriveri Research Center of the Latvia University of Agriculture (LLU). It is a tetraploid cultivar developed by doubling the chromosomal count of perennial ryegrass 'Priekulu 59'. The 'Spidola' attributes are of higher productivity than those of 'Priekulu 2', have better winter hardiness, good disease resistance, and provide good feedlot. Also 'Spidola' cultivar shows a preference for certain growing conditions, is better suited for mineral soils, prefers loamy or loamy sand soils, and does quite well on clay soils, but is somewhat less responsive on light soils. Peat soils are not suitable for growing of this cultivar of perennial ryegrasses and do not have the ability to tolerate excessive moisture for the long growing season period. It is suitable for inclusion in seed mixtures planned for establishment of permanent pastures and is a late maturing pasture grass, good for late grazing.

Presently there is no research in Latvia on which it is possible to make good fertilizer use recommendations and provide advisory support to farmers involved in the perennial ryegrass seed production. The objective of this research was to obtain productivity results for perennial ryegrass at different rates of mineral nutrition.

Materials and methods

Field experiments were carried out on sod-podzolic sandy loam soil (Luvic Phaeozem, WRB, 1998), pHKCl 6.5, plant available P_2O_5 110 and K_2O 204 mg kg^{-1} (Egner–Riehm), soil organic carbon 12.2 g kg^{-1} (Tyurins' method). Meteorological conditions of the growing season were characterized by increased rainfall (280-370 mm) during the seed production period (June-August) in both years (2000 and 2001). Randomized complete block design with four replicates was used. The plot size was 16 m^2. Five fertilizer rates were applied in both years. Perennial ryegrass (12 kg ha^{-1}) was planted using Nordsten seed drill in May 1999 and 2000 after field preparation. The following mineral fertilizer rates were used: N and P_2O_5, each of them 0, 30, 60, 90, and 120 kg ha^{-1}, K_2O – 0, 40, 80, 120, and 160 kg ha^{-1} (ammonium nitrate, single superphosphate and potassium chloride). Weed control was performed using MCPA 1 l ha^{-1} in mixture with 8-10 g ha^{-1} of Granstar. Seed yield response of cool-season grasses to spring-applied N is usually limited because of lodging (Young, et al., 1999). Lodging of perennial ryegrass plant is a widespread problem. Crop lodging reduces seed yield and interferes with seed harvest (Young, et al., 1996).

Lodging of the perennial ryegrass stand was evaluated during the growing season using a scale from 1 to 10 (1 = the stand is completely lodged, 10 = lodging is not observable). The biomass, dry matter content, seed yield as well as its chemical composition were determined. Seed yield was recorded from the 1st year and 2nd year sward use. Analysis of yield components and other parameters were also recorded. The Kjeldahl procedure was used for total nitrogen and crude protein determination as described by Bremner and Breitenbeck (1983). Dry matter digestibility *in vitro* was obtained. Analysis of variance (ANOVA) was conducted using the GLM procedure of SAS (SAS Inst., 1990) at P=0.005 to test the effects of year, location, N treatment, and all interactions.

Results and discussion

Fertilizer application showed positive effects on the increase of 1st cut perennial ryegrass biomass. The dry matter yield doubled and even more, compared with unfertilized plots (Fig. 1). Significant increase of seed yield was also obtained in both cases using 1st year and 2nd year sward use (Fig. 2). The clear tendency in the observed yield (both biomass and seed) was more dependent on N fertilizer treatments than on phosphorus and potassium. Even relatively small fertilizer rates provided a significant yield increase, e.g. dry matter (DM) yield of 4.00 t ha^{-1} was reached when only $N_{30}P_{30}K_{40}$* was applied but it is 1.79 times or 81% higher compared with unfertilized treatments. Further increase of nitrogen rates up to the maximum used in the experiment (120 kg ha^{-1}) produced a positive effect. Perennial ryegrass 'Spidola' responded to N fertilizer application; the DM yield for 1st cut increased by 1.85 t ha^{-1} or 60% as applied N rates increased from 30 to 90 kg ha^{-1}. Comparison of treatments with constant nitrogen applications but different PK fertilizer rates demonstrated only a slight effect.

The maximum dry matter yield (6.07 t ha^{-1}) was obtained using the highest (in this experiment) fertilizer rates: $N_{120}P_{120}K_{160}$, or all together 400 kg ha^{-1} plant nutrients. Evaluating the plant nutrient use efficiency by a single parameter – the yield increase per 1 kg of nutrients applied – the range of tested treatments might be as follows: $N_{30}P_{30}K_{40}$ – 17.9, $N_{30}P_{90}K_{120}$ – 10.0, $N_{60}P_{60}K_{80}$ – 14.2, $N_{90}P_{30}K_{40}$ – 22.8, $N_{90}P_{90}K_{120}$ – 12.4, and $N_{120}P_{120}K_{160}$ – 9.7 kg. Medium nitrogen and small PK rates ($N_{90}P_{30}K_{40}$) provided the maximal perennial ryegrass dry matter increase per 1 kg of nutrients applied – 22.8 kg.

Seed harvested early in the season produced a low weight and low germination rate. Such seed was not suitable for longer storage (Slapetys, 2001). Our finding agreed with the research of Loeppky et al. (1999) that

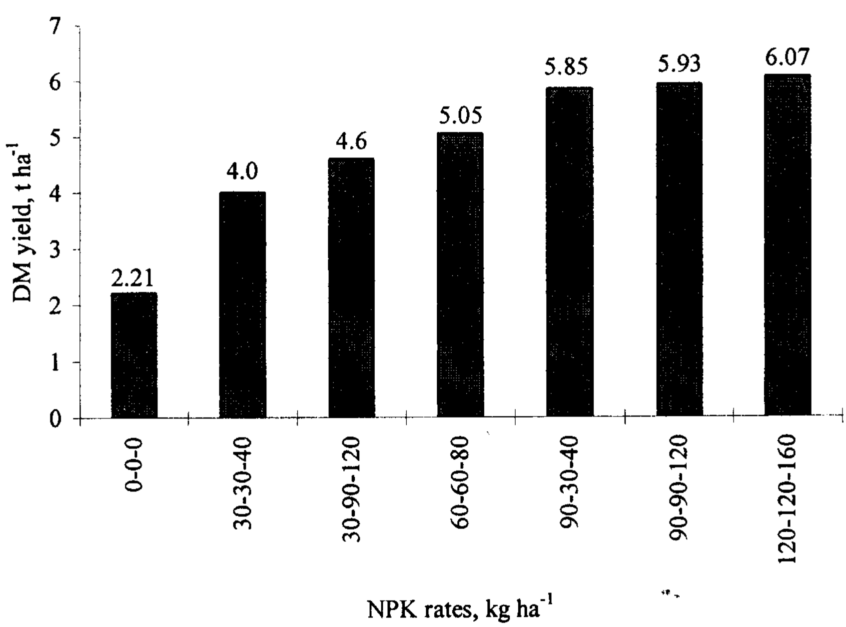
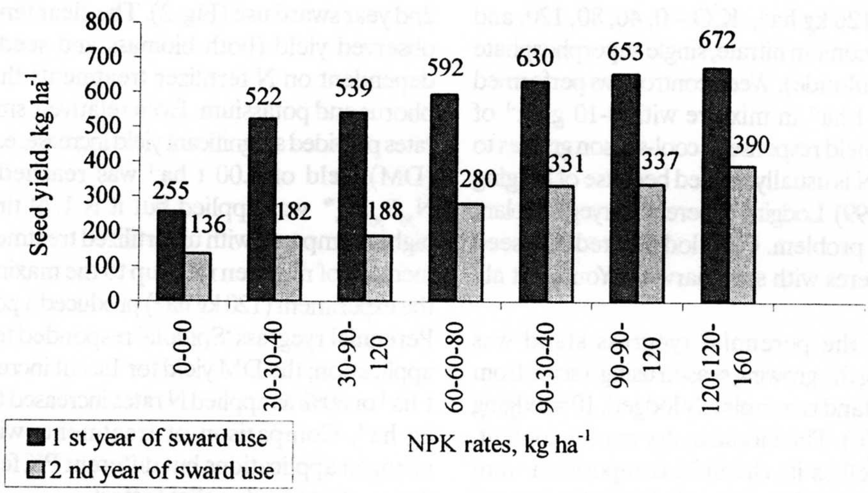


Fig. 1. The dry matter yield (DM) of 1st cut perennial ryegrass, t ha^{-1} (on average for 2000–2001).

* – Here and afterwards designations $P_{30}K_{40}$ and similar mean 30 and 40 kg ha^{-1} of P_2O_5 and K_2O, respectively.



$LSD_{0.05}$ 1st year of sward use 74.5 kg ha^{-1}
$LSD_{0.05}$ 2nd year of sward use 52.56 kg ha^{-1}

Fig. 2. The seed yield of 1st and 2nd cut perennial ryegrass, kg ha^{-1} (on average for 2000–2001).

Table 1

Average DM yield in 1st cut perennial ryegrass (2000–2001)

Treatment	Content in dry matter, g kg^{-1}		Crude protein yield, t ha^{-1}	Digestibility, %
	crude protein	crude fiber		
$N_0P_0K_0$	91.1	257.0	0.20	65.2
$N_{30}P_{30}K_{40}$	92.8	249.8	0.37	66.2
$N_{30}P_{90}K_{120}$	95.8	248.5	0.44	68.1
$N_{60}P_{60}K_{80}$	103.0	242.9	0.52	69.2
$N_{90}P_{30}K_{40}$	111.4	254.8	0.65	62.8
$N_{90}P_{90}K_{120}$	114.6	253.3	0.68	66.5
$N_{120}P_{120}K_{160}$	133.4	254.0	0.81	66.3

nitrogen significantly increased forage seed yields of all species except alfalfa, while phosphorus increased the yields of forage seed for all crops except intermediate wheatgrass. The yield response to N and P fertilizers was affected by available soil N and P.

In the 1st production year, the produced seed yield was 522 kg ha^{-1} or by 267 kg ha^{-1} more in treatment $N_{30}P_{30}K_{40}$ compared with unfertilized plot (Fig. 2). The N fertilizer rate increase from 30 to 90 kg ha^{-1} resulted in increased seed yields by 108 kg ha^{-1} or 21%, however, higher rates of P and K gave a seed yield of 187 kg ha^{-1} or by 54 kg ha^{-1} more in treatment $N_{30}P_{30}K_{40}$, compared with treatment receiving no fertilizer. The seed yield increase by 144 kg ha^{-1} or 77% was reached applying 90 kg^{-1} of N. Increased P and K fertilizer rates resulted in a 5 kg ha^{-1} or 3% seed yield increase.

Increased NPK rates resulted in the following increase of seed yields: 105-164% in the 1st and 41-201% in the 2nd production year. Fertilization proved to be significant in all cases.

The crude protein (CP) content in grasses is one of the quality indices if the grass is to be used as forage. The CP content in the 1st cut grass ranged from 91.1 g kg^{-1} in $N_0P_0K_0$ treatment up to 133.4 g kg^{-1} in $N_{120}P_{120}K_{160}$ treatment (Table 1).

The crude fiber (CF) content was 257.0 g kg^{-1} and digestibility was 65.2% in treatment $N_0P_0K_0$ (Table 1). The CP content increased by 1-5%, but digestibility increased by 1-4% in treatments with NPK applied (except at treatment $N_{90}P_{30}K_{40}$ where digestibility reduced by 2.4%) compared with unfertilized plot.

The 1000 seed mass ranging from 2.8 to 2.9 g and higher by 0.1 g or 4.0% were obtained in the following fertilizer treatments: $N_{90}P_{90}K_{120}$, $N_{120}P_{120}K_{160}$, and $N_{30}P_{90}K_{120}$ (Table 2).

The number of productive stems is one of the yield structure indices and in the experiment in unfertilized treatment constituted 869 per m^2. In plots treated with NPK fertilizer, the amount of productive stems ranged from 1121 to 1298 per m^2 or 25-43% more compared with unfertilized plot.

Lodging resistance is another important parameter for seed production. If the stand is completely free from lodging, usually the grass density is sparse and as a result grass is low productive. A denser stand and higher fertilizer (especially nitrogen) rates produce more

Table 2

Effect of mineral fertilizer rates of 1st year perennial ryegrass on the seed yield and its formative elements

Treatment	Seed yield, kg ha^{-1}	Productive stems, number per m^2	Lodging resistance, scores	1000 seed mass, g
$N_0P_0K_0$	255	869	8.9	2.8
$N_{30}P_{30}K_{40}$	522	1121	7.0	2.8
$N_{30}P_{90}K_{120}$	539	1243	6.0	2.9
$N_{60}P_{60}K_{80}$	592	1298	4.5	2.8
$N_{90}P_{30}K_{40}$	630	1165	2.9	2.8
$N_{90}P_{90}K_{120}$	653	1233	2.9	2.9
$N_{120}P_{120}K_{160}$	672	1234	2.2	2.9
$LSD_{0.05}$	74.05	220.28	1.41	0.15

biomass per area unit but raise the lodging risk, that might seriously limit the obtained grass seed yield. The estimated lodging resistance was 8.9 scores in perennial ryegrass unfertilized plots (Table 2). Lodging resistance decreased in plots with increased NPK fertilizer rates. A relatively good perennial ryegrass seed yield might be obtained if lodging resistance varies between 6 and 7.

Conclusion

The maximum dry matter yield can be obtained using the highest fertilizer rates – $N_{120}P_{120}K_{160}$. The maximum gain in seed yield can be obtained using medium N and small PK rates ($N_{90}P_{30}K_{40}$). Additional increases in PK rates produce a minimal dry mater yield gain.

Using the lowest fertilization rate more than doubled the seed yield compared with unfertilized plots. Subsequent fertilizer rate increases for the first year produced a nearly linear small increase in seed yields. Second year seed yields increased from a little more than a third of the 1st year yield for two lower NPK rates to about one half of the 1st year yield. The second year yields were higher compared with the 1st year's use of higher NPK rates. Optimal productive density in perennial ryegrass seed plot is 1100-1298 productive ears per hectare. The fields of grass seed were comparatively more productive with estimated lodging resistance between 6 and 7. Optimization of mineral nutrition in perennial ryegrass seed production fields has a positive effect on yield structure and seed quality parameters.

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Anotācija

Pētījumi veikti 2000.-2001. gadā velēnu podzolētajā smagas mālsmilts augsnē, kopumā salīdzinot 7 dažādas minerālmēslu kombinācijas. Skaidrota mēslojuma ietekme uz ganību airenes biomasas veidošanos, atsevišķiem tās kvalitātes rādītājiem, sēklu ražu un tās veidojošiem faktoriem. Svarīga nozīme sēklas ražas ieguvē ir airenes veldres izturībai. Mēslojums būtiski palielina sējumu biezību, līdz ar to potenciālo ražu, taču vienlaicīgi pieaug veldres risks, sevišķi nelabvēlīgos laika apstākļos. Autori uzskata, ka vēlamā sējumu biezība ir 1100-1300 produktīvo skaru uz hektāra, taču veldres izturībai jābūt vismaz 6-7 balles (1 balle – sējums pilnībā saveldrējies, 10 balles – veldres nav).

Soil reaction and potassium content in soil
Kālija saturs augsnē atkarībā no tās reakcijas

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Abstract. Plant available (mobile) potassium fraction in soil is the main source of plant nutrition. The acid moraine soils in Lithuania are rich in mobile potassium but its availability is dependent on other soil parameters, especially on soil reaction. Findings from fertilization trials suggest that crop rotation yield is dependent on the mobile potassium content in soil. In the present experiments, liming of acid soils resulted in decrease of the potassium content in topsoil from 400 mg kg^{-1} to 200 mg kg^{-1}. During the soil acidification process, the mobile potassium content mostly increased when soil reaction reached pH 4.5-4.7, and decreased when soil reaction was pH 5.0-5.5 and higher. Under these conditions, potassium fertilizers did not increase the crop yield. Reduction of potassium content in soil was observed as a result of primary and periodical liming due to a higher removal of this element with the yield ($r_{P_2O_5} = 0.57$; $r_{K_2O} = 0.72$) and a more intensive leaching.
Key words: primary and periodical liming, potassium.

Introduction

Acidification of soil is one of the reasons for soil chemical degradation. Liming is the most effective method to improve acid soil. About two thirds of severely affected acid soils are in Western Lithuania. Decrease in acidity as a result of liming is dependent on the rate, method of liming, as well as on soil texture, amount of precipitation, and used mineral fertilizers (Mazvila, 1998). On the other hand, the mobile potassium content in soil strongly correlates with the amount of soil clay fraction (Brenciene and Eidukeviciene, 1995). Field experiments carried out in Lithuania show that in unlimed soil, due to acidification, pH drops down by 0.1 units annually (Knasys, 1985). Soil acidification has been observed already two years after primary liming (Veitiene, 2001).

In Lithuania, changes in the mobile phosphorus and potassium content and ratio (K:P) in soil under liming of different intensity have been studied (Plesevicius, 1986; Staputis, 1999). Some authors have found that liming increases the mobile potassium in soil compared with acid soil. After liming the more active calcium ion displaces the less active potassium ion in the soil adsorption complex. Reiterative liming shows no effect on the content of mobile potassium (Plesevicius, 1986), whereas intensive periodical liming results in decrease of the potassium content in soil (Staputis, 1999). Experiments in neutral loamy Dystric Cambisol have shown that productivity of crop rotation increases when the mobile potassium content reaches 200 mg kg^{-1}, but in light textured soil the maximum grain yield is obtained when the mobile potassium is 150 mg kg^{-1}. The grain yield rapidly decreases when the content of mobile potassium in soil is above 170-250 mg kg^{-1} (Eidukeviciene, Vasiliauskiene et al., 2001). Liming and balanced fertilization is the only way to bridge the gap between the soil nutrient supply and crops' nutrient uptake in order to provide modern farming sustainability (Jankauskas, 1998; Ciuberkiene, 1998; Bansal, 2000).

Materials and methods

The soil liming field experiments were carried out in Western Lithuania (Lithuanian Institute of Agriculture, Vezaiciai Branch), eastern part of littoral lowland with moderately warm climatic conditions. Soil – Dystric Albeluvisol (WRB, 1998), moraine loam. Chemical characteristics of topsoil (0-20 cm) are presented in Table 1. Studies included investigations of the effect of primary (or basic) and periodical liming on the content of mobile potassium in the whole soil profile and were performed in three field trials with the following design:

- 1st trial – unlimed and limed at 1.0 rate according to the soil hydrolytic acidity;
- 2nd trial – unlimed and limed at rates 0.5, 1.0, 2.0, and 2.5 according to the soil hydrolytic acidity;
- 3rd trial – unlimed and limed at rates 0.5 every 7th year, 1.0 every 3rd-4th year, 2.0 every 3rd-4th year, 2.5 every 7th year according to the soil hydrolytic acidity.

Primary liming was performed in 1988 (1st trial) using finely ground limestone (92.5% $CaCO_3$), and in 1949 (2nd trial) using slaked lime containing 68.5% of CaO+MgO (on dry matter basis). Periodical liming was done using finely ground limestone (3rd trial). The following crop rotation was used: winter wheat, fodder beet, barley with undersown grasses, perennial grasses (two years) (1st trial) and sugar beet, barley with undersown grasses, perennial grasses (two years), winter wheat, peas–barley mixture for grain, and vetch–oats

Table 1

Soil chemical characteristics, 1996

Agrochemical parameters	Treatments	
	no liming	after liming
pHKCl	4.05 – 4.60	5.2 – 5.4
Hydrolytic acidity, cmol(+) kg^{-1}	41.6 – 55.0	24.0 – 35.1
Exchangeable bases, cmol(+) kg^{-1}	28.7 – 44.5	71.3 – 93.7
Exchangeable acidity, cmol(+) kg^{-1}	3.6 – 8.7	0.3 – 0.7
Mobile aluminum, mg kg^{-1}	29.0 – 75.9	0.2 – 2.2
Mobile P_2O_5, mg kg^{-1}	105.0 – 125.0	127.0 – 152.0
Mobile K_2O, mg kg^{-1}	238.0 – 262.0	268.0 – 297.0
Total N, %	0.12 – 0.14	0.10 – 0.13
Humus, g kg^{-1}	8.5 – 28.9	n.d.

Table 2

Mobile potassium in soil influenced by liming, 1996

Treatment	Parameter x±Sx		Ratio P_2O_5:K_2O
	pHKCl	K_2O, mg kg^{-1}	
Primary liming 10 years ago			
Unlimed	4.0 ± 0.20	238 ± 17	1.0 : 2.2
1st year after liming	5.4 ± 0.30	296 ± 12	1.0 : 1.9
5th year after liming	5.2 ± 0.08	331 ± 16	1.0 : 2.7
10th year after liming	4.6 ± 0.13	343 ± 17	1.0 : 3.3
Primary liming 50 years ago			
Unlimed	4.1 ± 0.06	331 ± 20	1.0 : 2.0
0.5 rate	4.1 ± 0.04	290 ± 20	1.0 : 1.6
1.0 rate	4.1 ± 0.02	297 ± 22	1.0 : 2.3
2.0 rate	4.2 ± 0.05	244 ± 17	1.0 : 1.9
2.5 rate	4.2 ± 0.03	234 ± 9	1.0 : 2.2
Periodical liming during 50 years			
Unlimed	4.1 ± 0.06	331 ± 20	1.0 : 2.0
0.5 rate every 7th year	4.9 ± 0.03	173 ± 11	1.0 : 1.4
1.0 rate every 3rd–4th year	6.3 ± 0.01	198 ± 10	1.0 : 1.3
2.0 rate every 3rd–4th year	6.7 ± 0.01	183 ± 13	1.0 : 1.0
2.5 rate every 7th year	6.6 ± 0.03	193 ± 11	1.0 : 1.0

Note: x – average, Sx – standard deviation.

mixture for green forage (2nd and 3rd trials).

For all experimental plots, mineral fertilizers were applied at the rate of $N_{60}P_{60}K_{60}$* annually, but organic fertilizers – only once per rotation (for beet) at the rate of 40 t ha^{-1}. Conventional soil tillage was used. Randomized split plot design with four replicates was used for all field experiments. Soil sampling and analysis were performed in 1988-1999 (1st field trial) and in 1996-1999 (2nd and 3rd field trials). Soil samples were taken from topsoil (0-20cm) (1st trial) and from the whole profile down to a 100 cm depth (2nd and 3rd trials) after harvesting. The profile sampling was performed taking 4-9 replicate samples from every 10 cm, paying attention to the soils' genetic horizons. Soil samples were analyzed using the following methods: pH – potentiometrically using glass electrode; hydrolytic acidity – according to Kappen; exchangeable acidity and mobile aluminum – according to Sokolov; exchangeable bases – according to Kappen–Gilkovich; mobile potassium and phosphorus – using AL-method; total nitrogen – by Kjeldahl; humus – by Tyurin; soil texture – by pipette method according to Kachinsky (Соколова, 1975; Вадюнина, Корчагина, 1986).

In littoral climatic region (Western Lithuania), the

* – Here and afterwards designation $P_{60}K_{60}$ means 60 and 60 kg ha^{-1} of P_2O_5 and K_2O, respectively.

average amount of precipitation is more than 800 mm. Such conditions favor leaching of chemical elements and colloids. For the last 10 years the highest rainfall was recorded in 1989 (943 mm), 1990 (1117 mm), 1994 (931 mm), and 1998 (1049 mm). The rainfall was below normal in 1988 (537 mm) and in 1996 (695 mm). Experimental data were processed using correlation-regression analysis.

Results

Primary liming of acid soil changed the soil reaction as well as the content of mobile potassium. In the first year after liming, the content of potassium in the soil was 268-297 mg kg^{-1}. Five years later its content increased to 297-363 mg kg^{-1}, but after ten years – to 312-344 mg kg^{-1}. The average increase of potassium in limed soil was 15% compared with acid soil. Compared with other chemical parameters, the increase in potassium was quite remarkable after five years. Fertilizing of acid soil with potassium in many cases had no effect on crop rotation productivity. It is connected with the disbalance of the P and K ratio in soil. The ratio of potassium and phosphorus in the first year after primary liming was 1.0:1.9, in the fifth year – 1.0:2.7, but in the tenth year after liming – 1.0:3.3 (Table 2).

During 50 years of primary liming using comparatively high lime rates, the potassium content decreased compared with unlimed soil. The P:K ratio was favorable to many crops and varied between 1.0:1.6 and 1.0:2.3. As a result, after 50 years of liming, the soil P:K ratio was similar to that of acid soil.

In plots with long-term (50 years) periodical liming using 1.0 and 2.0 rates every 3-4 years, potassium content decreased from 331 to 173 mg kg^{-1} and the P:K ratio (in oxide form) was the lowest (1.0:1.0) compared with acid and only primary limed soil. From the point of view of plant physiology, for many cereal crops as well as for forage and technical crops, a favorable ratio of phosphorus and potassium in soil solution is 1.0:1.0. The highest content of mobile potassium was found in soil with pH 4.4-4.8 (Fig. 1). We can point out that crop yields were not dependent on the potassium content in soil with the above mentioned reaction level. This might be explained by the fact that many plants in crop rotation are calcifiles and need neutral soil reaction. Also in limed soil, where acidification process occurred and the amount of potassium increased the P:K ratio, fertilizer use was not effective. The mobile potassium content decreased when soil reaction was 5.0-5.5 and more, showing that use of potassium fertilizers is more effective in limed soil than in acid soil.

To evaluate the effect of primary and periodical liming on mobile potassium content in topsoil, initial, i.e. before the experiment, soil characteristics were used. Fifty years before, the soil was very acid with low (70-90 mg kg^{-1}) content of mobile potassium. During the 50 years of manure use (280 t ha^{-1}) and application of mineral fertilizers (P_2O_5 3080 and K_2O 3360 kg ha^{-1}), mobile potassium accumulated in the whole acid soil profile. The highest mobile potassium content was found in the topsoil – 331 mg kg^{-1} (Fig. 2). Compared with acid soil, limed soil (depending on the intensity of liming) with the same fertilization had a significantly lower content of mobile potassium. In plots limed 50 years before, the subsoil had a 43-97 mg kg^{-1} lower mobile potassium content compared with unlimed plots. Regarding the mobile potassium content, the acid and periodically limed soil differed essentially. The mobile potassium content in periodically limed topsoil was 1.7-1.9 times, but in subsoil – 1.3-1.7 times lower compared with acid soil. Both primary and periodical liming reduced the potassium content in soil. We suppose it was due to higher removal of this element with the crops' yield and more intensive leaching what was influenced by liming. The mobile potassium content in bleached tongues of podzolic (E) horizon

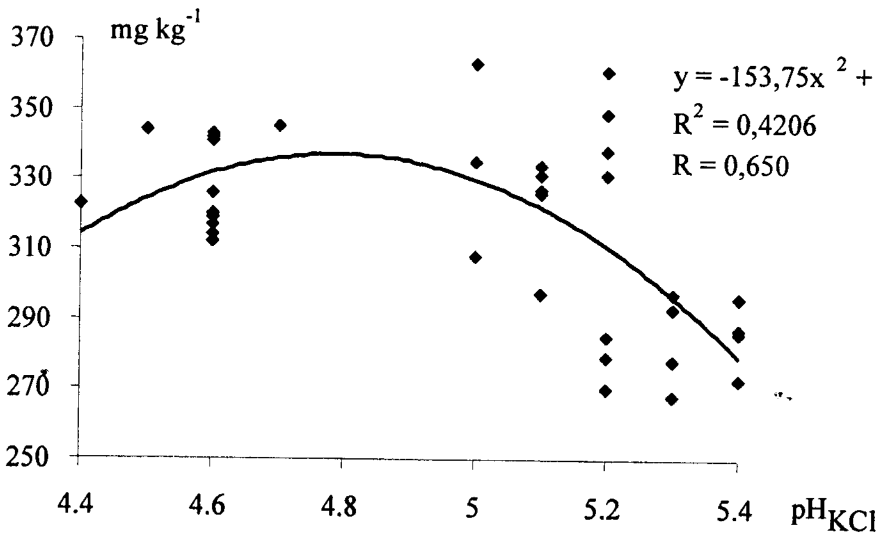

Fig. 1. Mobile potassium content and soil reaction.

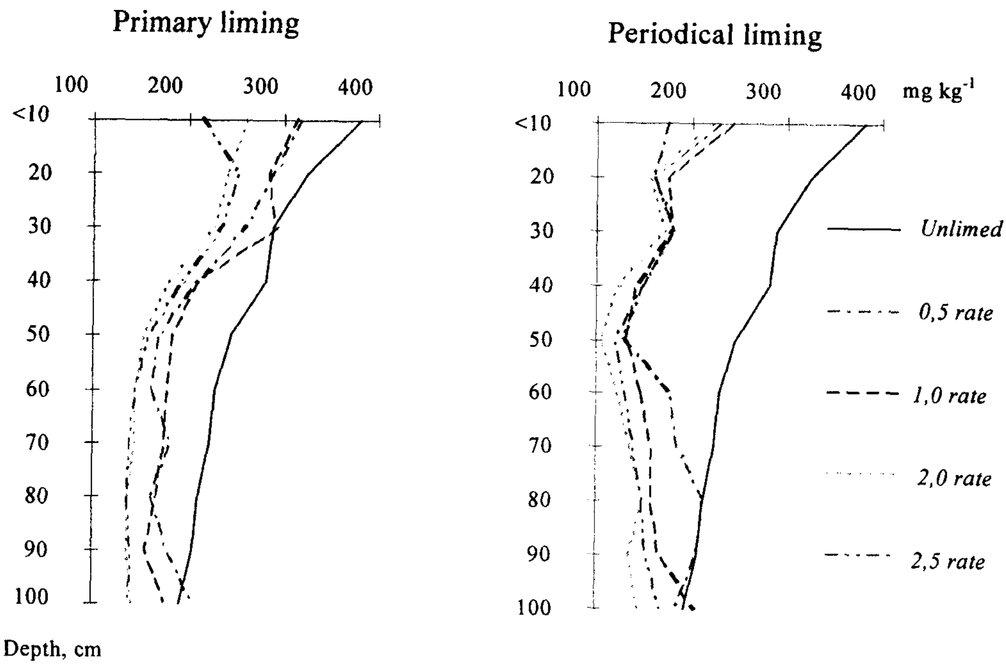

Fig. 2. The effect of primary and periodical liming on mobile potassium content in soil profile, mg kg^{-1} (Vezaiciai, 1999).

was slightly higher compared with intermediate soil between the tongues.

Discussion

The mobile potassium content and P:K ratio in moraine soil (Dystric Albeluvisol) was dependent on the soil reaction. In naturally acid (pHKCl – 4.0-4.1) soil, the mobile potassium content was 238-331 mg kg^{-1}, and P:K ratio in topsoil 1.0:2.1. After ten years of primary liming, soil pH went down again – from pHKCl 5.4 to 4.4. During soil acidification, the mobile potassium content increased and, as a result, the P:K ratio changed from 1.0:2.1 to 1.0:3.3. The primary liming using slaked lime and performed 50 years before, even now shows influence on the content and ratio of macronutrients in soil. At present, the mobile potassium content (234-297 mg kg^{-1}) and P:K ratio (1.0:1.9-2.3) are close to naturally acid soil. In soil with almost neutral reaction (pHKCl 6.6-6.7), due to a 50 years' periodical liming, the mobile potassium content in topsoil was 183-193 mg kg^{-1}, and P:K ratio – 1.0:1.0, but in subsoil – 120-170 mg kg^{-1} K_2O, and P:K ratio the same – 1.0:1.0. Compared with acid soil, the mobile potassium content in topsoil was 1.7-1.9 times lower and in subsoil 1.3-1.7 times lower. From the point of view of plant nutrition, such changes influenced by liming exhibit certain advantages. Still, there is no common opinion about the optimal fertilizer scheme which could be applied to crops in acid and limed soils and could provide the best utilization of the plant genotype potential.

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Anotācija

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Tabulas. Tabulām (visos potenciālo izdevumu manuskriptos) jābūt veidotām programmā *MS Word* vai *Excel*. Tabulu virsraksti, teksts tajās un paskaidrojumi pie tām tulkojami arī angļu valodā. Tabulām jābūt saprotamām arī tad, ja teksts nav lasīts. Tabulu numuri jāraksta ar arābu cipariem labajā pusē virs virsraksta. Tās nedrīkst pārsniegt apdrukai paredzēto lapas laukumu, un tabulu zemteksta piezīmēm jābūt uz tās pašas lapas. Ja tabula turpinās uz vairākām lappusēm, tabulas galva bez virsraksta jāatkārto katrā lapā, virsraksta vietā rakstot «.....tabulas turpinājums» vai «......tabulas nobeigums». Nav ieteicams veidot tabulas, kurām rindu vai kolonnu skaits mazāks par trīs.

Kolonnās skaitļiem jābūt nolīdzinātiem. Daudzzīmju skaitļi jāsadala grupās pa trim. Ja kolonnā uz leju atkārtojas tas pats skaitlis vai teksts, tas jāraksta atkārtoti, nedrīkst likt atkārtojuma simboliku. Kā decimāldalītājs jālieto punkts.

Attēli. Diagrammas, zīmējumus un fotogrāfijas uzskata par attēliem. Skanētos attēlus, digitālās fotogrāfijas un zīmējumus var veidot jebkurā grafiskajā programmā, bet ievietot tos *MS Word* kā attēlus (*Picture*), nevis kā attiecīgās programmas objektus. Diagrammas ieteicams veidot *MS Excel* vai *MS Word*, izmantojot *Microsoft Graph*. Diagrammās vēlams izvairīties no fonu un ierāmējuma līniju lietošanas, tīklu līniju biezumam jābūt ¼ pt, rakstzīmju izmēram jābūt tādam pašam kā pamattekstā. Attēlos jāizvairās no uzrakstiem uz tiem. Uzrakstu vietā lietojami simboli vai cipari, kas atšifrējami zem attēla. Paraksts zem attēla sākas ar attēla numuru, tad seko nosaukums, kas atklāj vai raksturo attēlā redzamo, un tad attēlā lietoto ciparu, simbolu atšifrējums. Attēla nosaukums un visi paskaidrojumi tajā tulkojami arī angļu valodā.

Formulas. Formulas jāraksta *MS Equation* programmā. Formulas tekstā raksta atsevišķā rindā pa vidu. Formulas numurē, numuru rakstot tajā pašā rindā starp divām apaļajām iekavām lapas labajā pusē. Formulās lietotajam pamatvienību lielumam jābūt tādam pašam kā pamattekstā. Kursīvā rakstāmi pieņemto apzīmējumu simboli. Formulās ietverto lielumu mērvienības raksta aiz to nosaukumiem vai skaitliskajām vērtībām tekstā. Formulu paskaidrojumi rakstāmi aiz formulas, katrs savā rindā. Starp paskaidrojumu un mērvienību liek defisi, bet aiz mērvienības – semikolu, un aiz pēdējās mērvienības paskaidrojuma – punktu.

Citējumi. Atsauces tekstā pieraksta, apaļajās iekavās ierakstot izmantotā izdevuma autoru un izdošanas gadu, piem. (Monod, 1963).

Literatūras saraksts darba beigās jānoformē alfabēta kārtībā, atsevišķus darbus pierakstot šādi: **žurnālu raksti** – Monod, J., Changeux, J. P., Jacob, F. (1963) Allosteric proteins and cellular control systems. *J. Mol. Biol.*, 6, pp. 306-329; **grāmatas** – Chard, T. (1995) *An Introduction to Radioimmunoassay*. Elsevier, Amsterdam, 534 pp.; Smith, A., Brown, T. (eds.) (1989) *Cereal Rusts*. Springer Verlag, Berlin, 342 pp.; **grāmatu nodaļas** – Carrey, E. A. (1989) Peptide mapping. In: *Protein Structure*. Creighton, T. E. (ed.) ILR Press, Oxford, pp. 191-224. Ja atsauces pieraksta ar skaitli kvadrātiekavās citēšanas secībā, tad arī literatūras sarakstu noformē citēšanas secībā.

Atsaucēm tekstā jāsakrīt ar literatūras sarakstā minētajiem avotiem, un tiem jābūt publiski pieejamiem.

Fināls. Recenzēto un attiecīgi papildināto manuskripta pēdējo versiju autors(i) elektroniskā veidā kopā ar manuskriptu iesniedz tehniskajam redaktoram. Tekstu atsevišķā *MS Word* failā, bet attēlus, diagrammas u.c. to programmu (*Excel, PowerPoint, CorelDraw*) failos, kurās tie izpildīti. Tikai precīza visu iepriekš minēto prasību ievērošana sekmēs sagatavoto manuskriptu ātrāku publicēšanu.

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