New environment-friendly and cost-saving fertiliser recommendation system for supporting sustainable agriculture in Hungary and beyond

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Abstract

In the current economic situation the former, intensive fertiliser recommendation system is unfit to help Hungarian farmers in their fertilising practice. The aim of the new system has been to apply the lowest possible NPK rates required to achieve safe and high yields as well as allowing minimal agricultural NP losses to surface and subsurface waters. The new system was developed by using the correlations revealed by analyzing the results of long-term fertilisation experiments set up in Hungary between 1960 and 2000. Several field experiments as well as comparative analyses confirmed the correctness of the basic principles as well as of the methods of calculating fertiliser rates of the new system. An estimated amount of 3,200,000 € was saved for the Hungarian farmers in 2007 alone by giving recommendations for more than 160,000 ha arable land applying the new system.

Keywords: long-term experiments, database, cost saving, environmentally friendly, fertiliser recommendation, expert system

Extended abstract in Hungarian

Az 1960 és 2000 között beállított hazai szabadföldi trágyázási tartamkísérletek adatbázisában kapott összefüggésekre alapozva egy új, költség- és környezetkímélő trágyázási szaktanácsadási rendszert hoztunk létre. Az új rendszer célja, hogy a lehető legkisebb műtrágyahasználat mellett érjünk el nagy terméseket, és a területegységre jutó nettó jövedelem a lehető legnagyobb legyen.

Az új trágyázási szaktanácsadási rendszerben számos újszerű megközelítést alkalmaztunk a régi, intenzív (MÉM-NAK) rendszerhez képest. A régi (MÉM-NAK), intenzív és az új (TAKI-MgKI), környezet- és költségkímélő trágyázási szaktanácsadási rendszer filozófiája közötti legfontosabb különbségeket az alábbi táblázat foglalja össze.

MÉM NAK	MTA-MgKI
• Maximális termésszintre való törekvés	• Gazdaságos termésszintre való törekvés
• Minden évben PK-trágyázás	• A vetésforgó (periodikus) PK-trágyázása
• PK-trágyázás minden talaj PK-ellátottsági szinten	• PK-trágyázás csak jó-közepes és annál gyengébb talaj PK-ellátottsági szinten
• Nagyobb talaj tápelem-ellátottsági határértékek	• Kisebb talaj tápelem-ellátottsági határértékek
• Egységes talaj tápelem-ellátottsági határértékek	• Növénycsoporttól függő talaj tápelem-ellátottsági határértékek
• Nagyobb fajlagos tápelemtartalmak	• Kisebb fajlagos tápelemtartalmak
• A tervezett termésszinttől független fajlagos tápelemtartalmak	• A tervezett termésszinttől függő fajlagos tápelemtartalmak

A Nemzetközi Foszfor Intézet (IMPHOS) finanszírozásával a különböző hazai trágyázási szaktanácsadási rendszerek tesztelését, köztük az új MTA TAKI – MTA MgKI költség-, és környezetkímélő rendszert, egy hároméves program keretében őszi búza, kukorica és tavaszi árpa növényekkel, három jellegzetes talajon (barna erdőtalaj, csernozjom, réti talaj) végeztük el. Az IMPHOS tesztkísérletek mindhárom talajon, valamennyi növénynél igazolták az új rendszer alapelveinek, műtrágya adag számítási módszerének helyes voltát: a MÉM NAK intenzív összes NPK adag ajánlásainak esetenként 40-60%-ának kijuttatásával az új MTA TAKI-MTA MGKI rendszer a MÉM NAK intenzív ajánlásával kapottal azonos, nagy terméseket eredményezett (4. ábra).

A Közép és Kelet Európai országok 19. konferenciáján (Visegrád, 2007) több mint 30 növénytáplálási szakember részvételével, 11 ország trágyázási szaktanácsadási rendszere került összehasonlításra. 11 ország összesen 22 talajmintájának felhasználásával, 6 növényre (őszi búza, kukorica, repce, rozs, burgonya és silókukorica) összesen 132 szaktanács készült a résztvevő országok szaktanácsadási rendszerének segítségével. Az eredmények alapján (5. ábra) kiderült, hogy a Közép és Kelet Európai országokban továbbra is intenzív jellegű PK szaktanácsadási rendszereket használnak. Kivételnek egyedül a litván és a magyar TAKI-MgKI rendszer volt tekinthető.

A új környezet- és költségkímélő trágyázási szaktanácsadási rendszer ajánlásait szimulációs növénytermesztési modellben felhasználva kimutattuk, hogy a TAKI-MgKI rendszer használatával jelentősen csökkenthető a túlzott nitrogén trágyázásra visszavezethető nitrátlemosódás kockázata (6. ábra).

Introduction

From the 1960s in many countries in the world, including Hungary the agricultural production has gone through tremendous improvement. In Hungary the average yields of maize **(***Zea mays***)** and winter wheat (*Triticum aestivum*), the two main crops of the country, were tripled in three decades compared to those of the 1950s. Together with introducing new, intensive cultivars and hybrids, one of the main factors behind this development was the enormous increase in fertiliser use. Compared to 1960, by 1980 Hungarian arable land was given 10 times as much fertiliser. The same trend could be observed worldwide. Owing to the subsidization and the socialist ideal of production there were some state farms where 900 and 600 $kgha^{-1}$ of active ingredient $N\text{-}P_2O_5\text{-}K_2O$ fertiliser was applied annually in the 1970s and 1980s for maize and winter wheat respectively. The political and mostly the economic changes in the late 1980s and early 1990s radically changed the fertilising practice of Hungarian farmers. Because of the withdrawal of subsidies, N fertiliser consumption dropped by 80% while PK fertiliser consumption decreased by more than 95% in a few years in Hungary compared to the earlier intensive period. Later on a slow, gradual increase of NPK fertiliser use could be observed.

Many soil science related institutes, universities and fertiliser producer companies have developed their own recommendation systems [30] [21] [1] [39] [12] [26] [16] [32] [6] [38]. Systems developed by fertiliser companies tend to recommend higher doses than those developed by ‘disinterested’ research institutes [31]. Practically each recommendation system is based on simple nutrient balance equations, though the elements of the input and output sides could be calculated using quite different methods. One possible way is to use sophisticated dynamic models [34] while the generally used method is to utilize correlations that were established based on a database of long-term fertiliser experiments [8]. Sometimes it is not only scientific principles, but business interests or even political deliberations are also incorporated into certain advisory systems.

In the MÉM-NAK, intensive fertiliser recommendation system [5] that was developed before the democratic transformation of Hungary several security concepts were applied to guarantee the secure and high yields as well as good reputation in the former Comecon countries by excessive fertiliser doses. Consequently, a significant PK pool accumulated in the Hungarian soils. This soil PK reserve considerably helped the Hungarian agriculture to survive the hard times of the 1990s when the use of P and K fertilisers practically decreased down to zero.

In the current economic environment the MÉM-NAK system is unfit to help the farmers in their fertilising practice. Nonetheless there are fertilising consultants still using this system or in better (or worse) cases an ad-hoc modified version of it causing serious financial and/or environmental damages. After the political and economic changes in Hungary an enormous need has risen for developing a cost saving and environmentally friendly fertiliser recommendation system.

The main objectives of this paper are the following:

- Present the most important steps of developing a new fertiliser recommendation system.
- Present the key features of the new system.
- Present some of the important, practical results that the recommendation system has achieved since its first release in 2004.

Materials and Methods

One of the major goals of the Hungarian Academy of Sciences concerning the basic and applied research results achieved in the 35 academic research institutes is for these results to be utilized in practice as soon as possible. Based on the correlations revealed by analyzing the results of the long-term (1960-2000) fertilisation experiments of various Hungarian experts [20] [22] [23] [4] [2] [13] [25] [28] [7] [18] [29] [19], the development of a new cost-saving and environment-friendly fertiliser recommendation system was launched in the Research Institute for Soil Science and Agricultural Chemistry (RISSAC) and the Agricultural Research Institute (ARI) in the mid-1990s. The aim of the new system was to apply the lowest possible NPK rates required to achieve high yields. The principle was not to have the highest possible yield but to reach the maximum income per unit area while allowing minimal agricultural NP losses to surface and subsurface waters. The new system represents a new approach in many ways compared to the former intensive recommendation system. A comparison of the philosophy behind the intensive system and the new, cost-saving, environment-friendly fertiliser recommendations is presented in Table 1.

The new system uses new approaches (Table 1), as well as elements of the former, intensive MÉM-NAK system [5]. The new system uses the following formula for calculating the recommended NPK fertiliser amount (x):

Eq. 1. $$x = Y \cdot SNC_Y \cdot F_{SNS} \pm C$$

Where Y denotes the planned yield level (tha^{-1}), SNC_Y is the specific nutrient content at the planned yield level (kgt^{-1}), F_{SNS} is a factor depending on the nutrient status of the soil and C is a correction factor the value of which depends on the characteristics of the previous year(s): type and yield of the pre-crop, fate of pre-crop by-product, amount of applied liquid and/or farmyard manure, etc. During the development of the new system the aim was to find the method and the quantity of changing the explicit as well as the implicit factors of the above formula (1) to decrease the calculated fertiliser amount to the lowest limit that still ensures high yields and guarantees the highest possible income per unit area. Maize and winter wheat, the two main crops in Hungary, are used as examples to present the methodology. More details can be found in [8] and in [11]. Based on the correlations established in the database of the long-term fertilisation experiments in Hungary (Fig. 1.) the following improvements have been made:

1. Plant species were divided into two groups: (N-, P-, K-) demanding and less-demanding. This approach was first introduced in Hungary by Várallyay Sr. [36].

2. Limits of soil nutrient supply categories were lowered.

3. The category of ‘excessive’ soil nutrient supply was introduced.

4. A more detailed soil supply category system for phosphorus was put in place. This approach was first introduced in the RISSAC-KSzE integrated recommendation system [37].

5. A specific crop nutrient coefficient, depending on the planned yield level, was introduced to take the nutrient dilution effect into account.

6. Pertaining EU regulations have been incorporated.

Table 11 Comparison of the philosophies of the intensive and the environment-friendly fertiliser recommendation systems.

Intensive nutrient supply system (MÉM NAK)	Environment-friendly fertilisation system (RISSAC-ARI)
• Aimed at achieving maximum yield level	• Aimed at achieving economical yield level
• Aimed at fertilising the soil	• Aimed at fertilising the plant
• Achievement and maintenance of good or very good soil PK supplies	• Achievement and maintenance of moderate or good soil PK supplies
• Rapid PK replenishment of the soil	• Slow PK replenishment of the soil
• PK fertilisation every year	• PK fertilisation to the crop sequence/ rotation (periodic PK fertilisation)
• PK fertilisation at all soil PK supply levels	• PK fertilisation only at good or poorer soil PK supply levels
• Higher limit values for soil nutrient supply categories	• Lower limit values for soil nutrient supply categories
• Absence of an excessive soil nutrient supply category	• Introduction of an excessive soil nutrient supply category
• Uniform limit values for soil nutrient supply categories	• Separate soil nutrient supply categories for demanding and for less demanding crop groups
• Higher specific crop nutrient contents	• Lower specific crop nutrient contents
• Specific crop nutrient contents independent of the planned yield level	• Specific crop nutrient contents adapted to the planned yield level

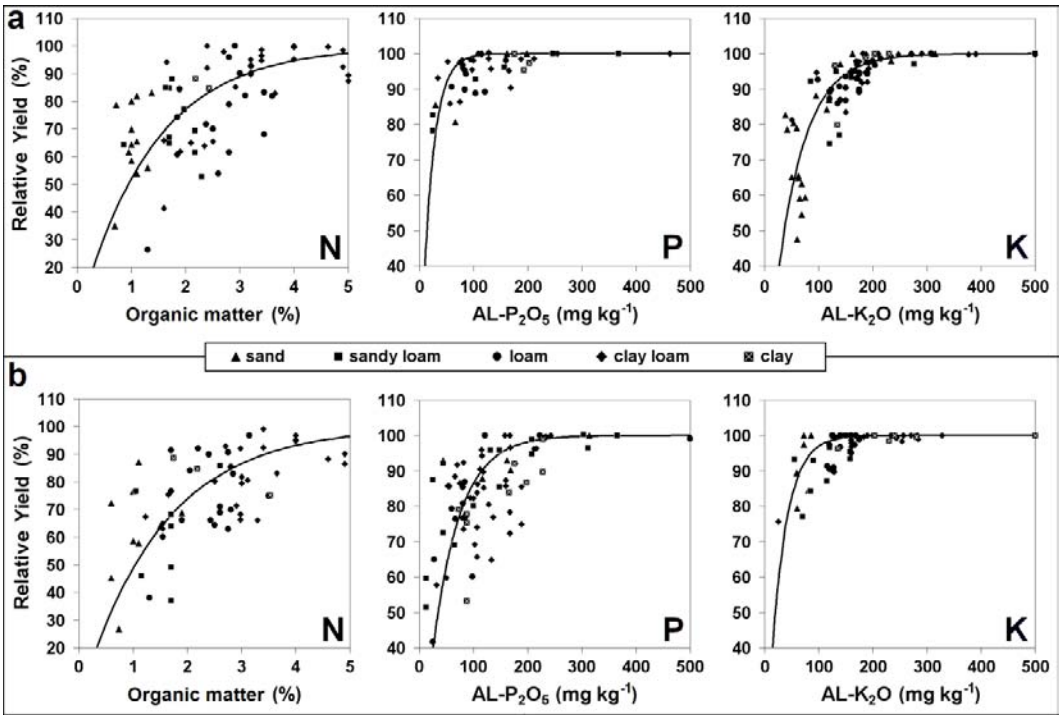

Fig. 1. 10 year average relative yields vs. soil organic matter [35], AL-P2O5 and AL-K2O [14] content in the Hungarian long-term N-, P- and K-fertilization experiments, (a) maize, (b) winter wheat. Relative yield is defined as a ratio of the yield observed in N-deficient (PK), P-deficient (NK) or K-deficient (NP) treatment and the yield observed in the treatment with harmonic nutrient supply (NPK).

1. Dividing plant species into two groups: (N-, P-, K-) demanding and less-demanding.

As it can be clearly seen on Fig. 1. even on soils having very poor soil P supply 80 % of the maximum yields for maize could be obtained without P fertilisation. Thus maize was classified as less-demanding for P. Winter wheat proved to be a P demanding crop having only 50 % yield without fertilisation on the soils very poor in P. Following this train of thoughts maize is a demanding while winter wheat is a less-demanding crop for K. Both crops belong to the N demanding group. Each crop that was incorporated into the new system was classified following this process.

This division of crops influences the determination of the soil nutrient supply categories. For example the *moderate* soil supply category for demanding crops is *good* for less-demanding crops.

2. Lowering the limits of soil nutrient supply categories

In the new system the NPK supply categories are determined by the soil humus content, measured with Tyurin's [35] as well as the AL-P_2O_5 and AL-K_2O contents, measured with Egnér's [14] method. On soils having good or very good soil PK supply practically no extra yield could be expected due to extra PK application, however, for yield safety reasons, many advisory systems recommend smaller or bigger amounts of PK fertiliser even for this category. In the former, intensive system the lower limit of the good soil K supply category is 200, 280 and 380 $mgkg^{-1}$ AL-K_2O for loam, clay-loam and clay soils, respectively. In the Hungarian long-term fertilisation experiments one could hardly find and example when applying K fertiliser on soils, having more than 200 $mgkg^{-1}$ AL-K_2O, caused significant yield increase (Fig. 1.). Consequently, the lower limit of the good soil K supply category was decreased by up to 180 $mgkg^{-1}$ for demanding crops, depending on the soil type. For less-demanding crops even lower category limits were introduced. Similarly to this the lower limit of the good soil P supply category was lowered by up to 90 $mgkg^{-1}$ AL-P_2O_5, depending on the crop category and the soil type.

3. Introducing the ‘excessive’ soil nutrient supply category

The former, intensive system recommends applying fertilisers at every level of soil nutrient status. Experiments prove that there are certain extreme limits of soil nutrient supply above which there is no point applying any fertiliser since it won’t realize yield increase in circumstances of any sort. In fact giving superfluous P fertiliser on Zn-deficient soils could cause yield loss of maize up to 2000 $kgha^{-1}$ due to Zn-P antagonism [9] that could be eliminated by foliar or soil Zn application. Therefore, the ‘excessive’ soil nutrient supply category has been introduced in the new system that recommends no PK fertiliser for soils of this category either in mineral or in organic form. The lower limit of the ‘excessive’ category is defined by 1.5 times the lower limit of the ‘good’ category.

4. Introducing a more detailed soil supply category system for phosphorus

Depending on the soil type and lime content the former system distinguishes between 8 different soil categories in determining the soil P supply status. Based on the enormous amount of available data a much more detailed system was introduced with 42-42 different soil categories for P demanding and less-demanding crops. The new system provides a much more accurate determination of the soil P supply status, thus the required P fertiliser amount.

5. Introducing specific crop nutrient coefficient depending on the planned yield level

In contrast with the former intensive system, the principle of ‘nutrient dilution effect’ has been incorporated into the new one. It is a general observation that the greater the yield level the lower the specific plant nutrition content (Fig. 2.) [17]. An important consequence of incorporating this principle into the new system is that the recommended nutrient doses have crop specific upper bounds that are not exceeded, not even in the case of planning record yields.

6. EU environmental protection requirements and regulations (Nitrates Directive, 91/676/EEC) have been incorporated into the new system

Software version of the new, cost and environmentally friendly system

Based on the correlations calculated from the database of long-term fertilisation experiments carried out in Hungary between 1960 and 2000, as well as on the above mentioned principles, a user friendly software was created in order to make the incorporated knowledge available in a practical manner for farmers. An object-oriented software development environment was used for implementing the electronic version of the advisory system. Its latest version is able to prepare recommendations for more than a hundred different plants: field crops, field vegetables, fruits and grape. An assortment of any fertiliser company could be linked to the software that is able to find the fertiliser type that fits best to the calculated N:P:K active ingredient ratios. For farmers or agricultural enterprises with numerous plots the software is able to sort the plots according to their need for fertilization. Though the software has its own data handling module, input soil data can be imported from other applications, such as MS Excel, which can be very useful for large farms when the results of the soil analysis arrive from the laboratory. The functioning of the software is demonstrated on Fig. 3. The software has been operated by the fertilization experts of Nitrogénművek Ltd. since 2005, as well as by the consultants of the Hungarian Chamber of Agriculture since 2006.

Table 2. Basic data of the IMPHOS field trials in Hungary, 2004-2006.

Identifier	IMPHOS-1	IMPHOS-2	IMPHOS-3
Location in Hungary	Balatonszentgyörgy	Mezőkövesd	Nagyhörcsök
Soil textural group	sandy loam	clay loam	loam
Soil FAO group	Haplic Luvisol	Vertisol	Chernozem
pH_{KCl}	6.45	4.49	7.1
CaCO3 content (%)	0	0	3.9
Humus content (%)	1.62	3.43	2.95
AL-P_2O_5 content (%)	107	38	90
AL-K_2O content (%)	156	209	167
Planned yield (t/ha)			
2004: winter wheat	5	5.5	6
2005: maize	8	7	10
2006: spring barley	4.8	5	5.5

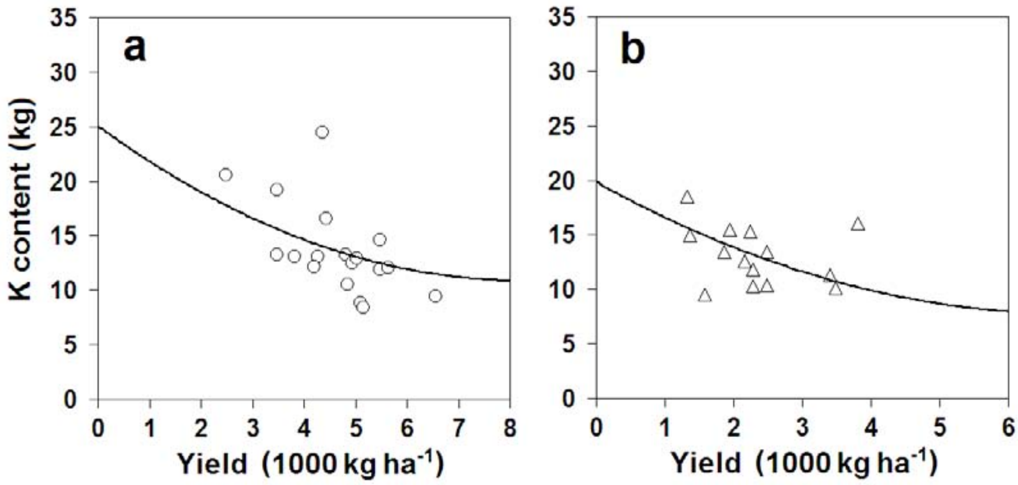

Fig. 2. K content in 1000 kg biomass depending on the yield for (a) maize and (b) winter wheat in the control treatment of plant nutrition experiments [3].

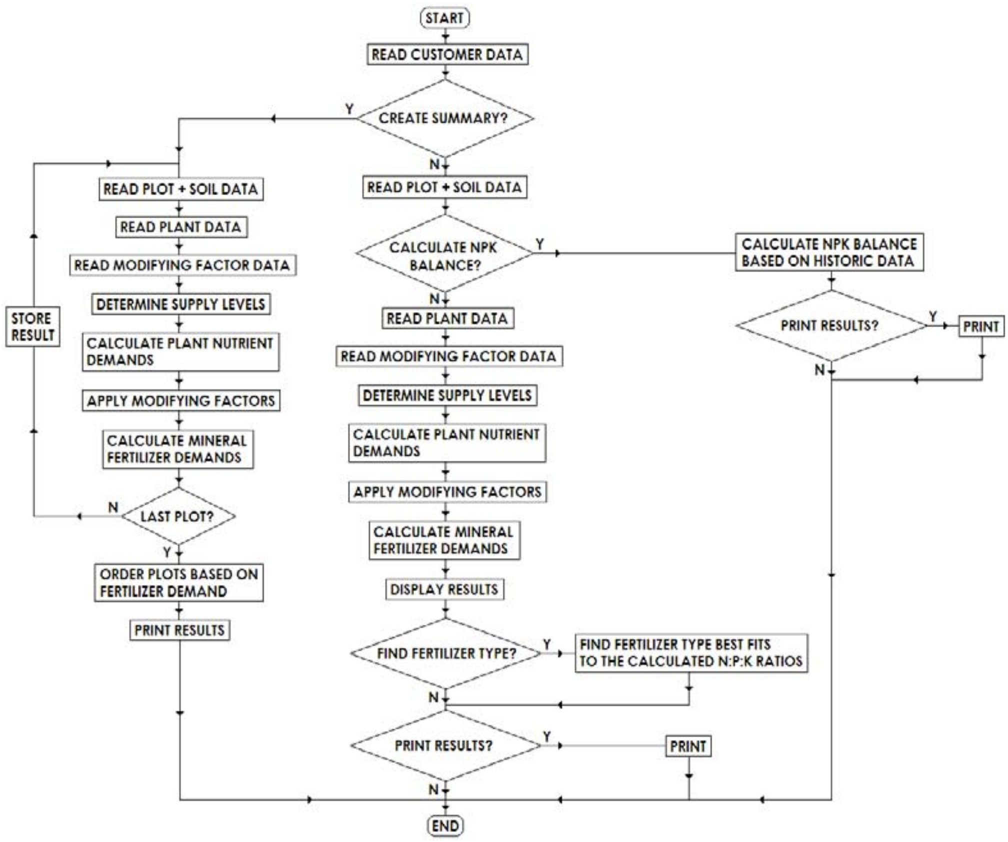

Fig. 3. Flowchart of the software version of the new, cost and environmentally friendly system

Projecting the consequences of different plant nutrition strategies using a crop simulation model

In 1965 a long-term fertiliser experiment was launched at one of the RISSAC pilot farms (Table 2, Nagyhörcsök). In the experiment three treatments were set for a winter wheat – maize crop rotation with 0, 150 and 250 $kgha^{-1}y^{-1}$ N fertiliser rates. Kovács et al. [24] published the details of the experiment including the meteorology and soil related, as well as the agro-technical data that were used for providing the input data required for running the CERES model [33]. The results of this long-term fertiliser experiment were used for parameterizing the crop model. The plant specific parameters and the soil drainage coefficient of the model, which were not measured directly, were determined by an optimization process so that the difference between the simulated and observed occurrence of phenological stages, yields, as well as soil nitrogen balances would be minimal.

After determining the parameters of the CERES model two scenarios were simulated. First, the rates of N fertilisation were determined by the old, intensive MÉM-NAK, system, then by the new, environmentally friendly RISSAC-ARI recommendation system for the first and the second scenario, respectively. The nitrate profile of the soil was recorded during the simulation of a winter wheat – maize crop rotation for the 2010-2050 period. Fertilisation rates were calculated by supposing 6.5 and 9 tha^{-1} yields for wheat and maize, respectively. Meteorological data were created by using the MV-WG stochastic weather generator [15].

Results and Applications

IMPHOS field trials

The World Phosphorus Institute (IMPHOS) has financed a three-year programme for the testing of various Hungarian fertiliser recommendation systems including the former, intensive MÉM-NAK system as well as the new environment-friendly and cost-saving system of the RISSAC and ARI institutes of the Hungarian Academy of Sciences. Recommended fertiliser amounts were applied to three major crops grown on three characteristic Hungarian soils (Table 2) along with six different treatments of a classical deficiency experiment, aimed to check the validity of the NPK-supply categories determined by the various systems.

On all three soils and for all three crops the IMPHOS experiments confirmed the basic principles of the new RISSAC-ARI system, and the correctness of the methods used for calculating fertiliser rates. The new RISSAC-ARI system resulted in high yields, on par with those obtained using the intensive MÉM-NAK system, with total NPK rates that were sometimes as low as 40–60% of the intensive recommendations (Fig. 4.).

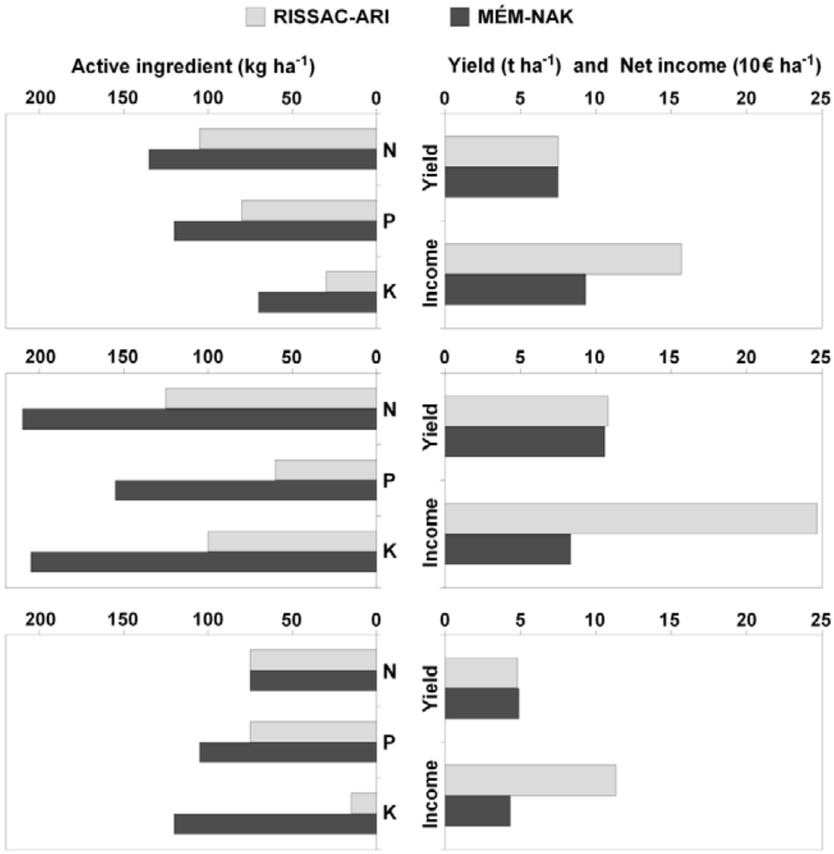

Fig. 4. NPK active ingredients, yields in cereal unit (CU) and income levels of the different treatments according to the old (MÉN-NAK) and new (RISSAC-ARI) advisory systems achieved in the IMPHOS experiments averaged over the three locations and three years (three crops), 2004-2006, Hungary.

19th CEECs conference

The 19th meeting of the Central and Eastern European Countries took place in Visegrad, Hungary in 2007 with the participation of more than 30 plant nutrition experts from 11 countries of Europe. The main objective of the meeting was to compare the PK fertiliser recommendation systems of the participating countries. Two soil samples were collected from each of the 11 countries (22 in total) and recommendations were made for 6 crops (winter wheat, rape, rye, potato, maize and maize for silage) for all of the 22 soils (132 recommendations in total) using the recommendation systems of the participating countries. The recommended P and K amounts of these 132 recommendations were averaged for all of the 11 systems [21] [39] [13] [26] and presented on Fig. 5. It became obvious that each participating country continues to use intensive systems as far as PK fertilisation is concerned. The new, RISSAC-RIA system on the other and, served as an exception, it recommended considerably lower PK doses than each of the other systems.

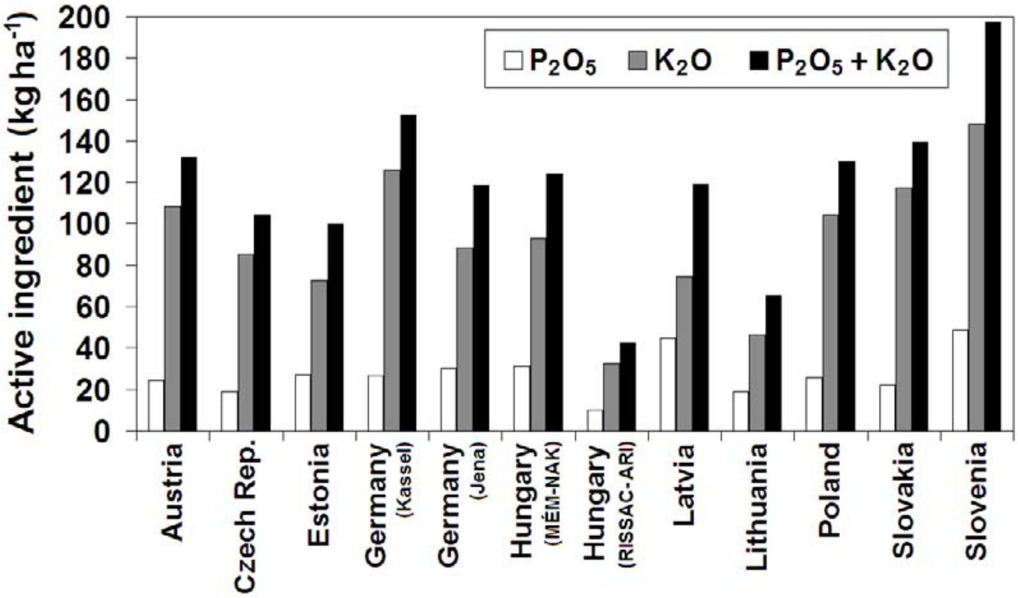

Fig. 5. Average PK amounts calculated by different advisory systems based on 132 recommendations given on 22×6 soil×plant combinations.

Hungarian Innovation Grand Prize

Owing to its solid scientific background the new, cost-saving and environment-friendly system can save around 75 €$ha^{-1}year^{-1}$ for farmers who switch over to using the RISSAC-ARI system because in average it recommends considerably lower N, P_2O_5 and K_2O fertiliser doses than the MÉM-NAK systems (Fig. 4.). In 2007, two years after the software version of the RISSAC-ARI system was officially released consultants issued recommendations for 160,000 ha arable land using the new system. Supposing that in the previous year the MÉM-NAK system was used for preparing the fertilisation plans an amount of 12,000,000 € was saved for Hungarian farmers, excluding the savings resulting from the decreased expenses on fertiliser transportation and application.

Following the very same train of thoughts it can be calculated that 4,800,000 kg less N got into Hungarian soils in 2007 owing to the use of the new RISSAC-ARI system, considerably decreasing the risk of contaminating the subsurface waters due to lower nitrate leaching rates.

Since its official release on the Internet, recommendations have been issued for more than 350,000 ha arable land of more than 1000 farmers and agricultural enterprises in Hungary. Recently the second biggest co-operative farm of a neighbouring country, managing almost 100,000 ha of arable land, has indicated the intention of using the RISSAC-ARI system and tested its recommendations on more than an 8000 ha area. Since Mehlich3 is the official method [27] in that country, Mehlich3-AL conversion equations [10] have been incorporated into the recommendation system in order to enable it to determine the soil PK supply status using Mehlich3-PK values as well.

Owing to the above mentioned examples the new environment-friendly and cost-saving fertiliser recommendation system of the RISSAC and ARI institutes of the Hungarian Academy of Sciences was awarded the Hungarian Innovation Grand Prize in 2008 as a good example for a complete innovation chain.

Projecting the consequences of different plant nutrition strategies using a crop simulation model

During the 40 years of the simulated period 6000 and 5000 kgha^{-1} N fertiliser were applied according to the recommendations of the old, MÉM-NAK and the new, RISSAC-ARI systems. As a consequence of this inequality a considerable difference developed between the soil nitrate profiles of the two scenarios (Fig. 6.). According to the model results 900 kgha^{-1} more nitrate (1150 vs. 250 kgha^{-1}) leached below the root zone when the fertilisation practice followed the recommendations of the old, intensive system. Even with the doses of the environmentally friendly system 5 % of the total applied fertilisation amount was wasted due to nitrate leaching. In very dry years a considerable fraction of the N fertiliser could remain in the root zone due to the limited water and N uptake of the plants. The new advisory system does not take into account in the calculations the amount of N fertiliser remained in the root zone after a poor yield thus the surplus would leach out in a moist period sooner or later. The results suggest that the amount of fertiliser applied above the dose recommended by the RISSAC-RIA system is superfluous, thus potentially is a subject of nitrate leaching.

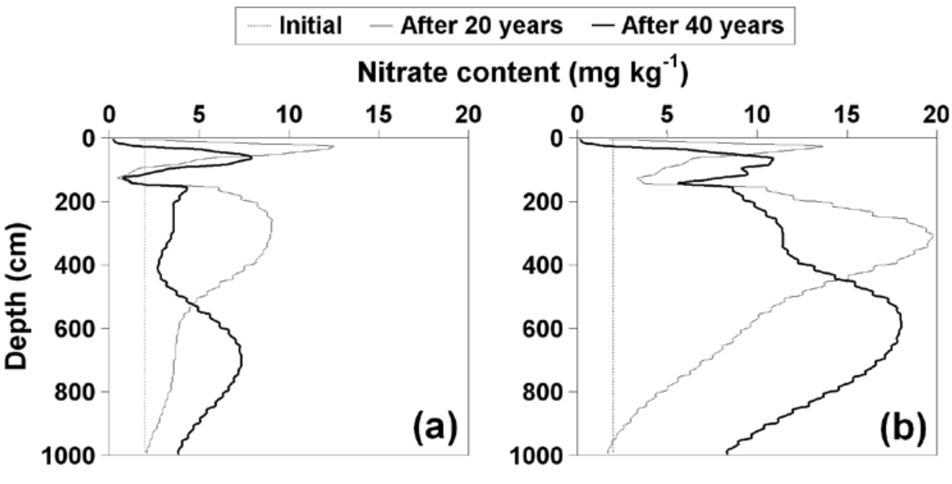

Fig. 6. Simulated nitrate profiles when the N fertiliser rates were calculated with the environmentally friendly (a) RISSAC-ARI and then intensive (b) MÉM-NAK recommendation systems for winter wheat – maize crop rotation between 2010 and 2050.

Conclusions

The political and economic changes in the late 1980s and early 1990s radically altered the fertilising practice of the Hungarian farmers. The new fertiliser recommendation system - based on the evaluation of the results of the published Hungarian long-term field trial data in the period of 1960 to 2000 - faces the new challenges, allowing minimal agricultural NP losses to surface and subsurface waters, while providing adequate NPK doses for safe, high yield level crop production maximizing the income per unit area. Several field experiments as well as comparative analyses have confirmed the correctness of the basic principles as well as the methods of calculating fertiliser rates of the new RISSAC-ARI system. The primary purpose of the computerized system is to assist crop-producing farmers in using the nutrient resources at their disposal as rationally and economically as possible. At the same time, the principles of the system could also be used for decreasing environmental protection related risks, such as nitrate leaching. The new, environmentally friendly system could be enhanced by taking into account in its calculations the N fertiliser amount remained in the soil after a low-yield year

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