9

Constraints and Solutions to Maintain Soil Productivity: A Case Study from Central Europe

Witold Grzebisz and Jean Diatta
Department of Agricultural Chemistry and Environmental Biogeochemistry, Poznan University of Life Sciences, Poland

1. Introduction

Yield improvement in old farming areas has been recently recognized as a practice that will further increase crop production. One of the most important old farming areas is Europe (EU 27), which accounts only for 4% of World agricultural area, but at the end of the 20th century produced 14% of total cereals and 20% of meat (Olesen & Bindi, 2002). At present, Europe has a very diversified level of agriculture development. European agriculture is currently divided into eight agricultural regions based on natural and socio-economic factors. Two of them, i.e., the North Eastern region comprising Czech Republic, Slovak Republic, Poland and the South Eastern region, including Bulgaria, Hungary, Romania, Bosnia & Herzegovina, Croatia, Macedonia, Slovenia, Serbia and Montenegro, are of special interest to this chapter. Due to the "planned economy" experiment, which took place from the end of the 1940s to the end of the 1980s, these two regions are generally classified as Central Europe (CE). This macro-region is considered nowadays as one of the most important future producers of cereals (Rosegrant et al., 2001; Kelch & Osborne, 2001).

The current level of agriculture production in the CE is much lower than in the Western part of the continent. Yield potential of winter wheat, as the key crop in this region, excluding Bulgaria, is at the level of *ca* 10 t ha^{-1}. The "water limited" yield for most countries of the region shows the level of 6.5 t ha, but for Bulgaria and Romania it has been assessed at 4.5 t ha^{-1}. However, actual yields of all CE countries are much lower, representing only from 55 to 71% of attainable yields (Rabbinge & Diepen, 2000; Supit et al., 2010). Two main reasons for this deep disparity:

1. Natural climate and soil conditions;
2. Political transformations at the beginning of the 1990s.

The first group of factors is considered to be responsible for regional differences in volume of harvested yields, expressed as the yield gap (YG) (Dobermann & Casman, 2002). Its assessment requires insight into factors affecting crop growth and production. The realization of a plant yield potential, i.e., exploitation of a crop variety capacity under fixed climatic conditions, is undoubtedly related to the soil fertility level (Atkinson et al., 2005;

Rabbinge, 1993). The second reason of the YG, between Western and Central Europe countries is strictly rooted into the history of both parts of the continent during the 20th century. The general objective of agricultural growth in these two mega-regions was to reach food self-sufficiency after World War II. In Western Europe, due to the market-oriented economy system, this target was achieved by the end of the 1970s. In CE, where the "planned economy" ruled agricultural production for more than 40 years, this key objective was also reached. However, it was based on a system of state subsidies, prevailing as cheap prices of agricultural commodities such as fertilizers, pesticides, machinery. The sudden cut of subsidies at the beginning of the 1990s and huge increase of production prices forced farm managers to restructure the farm economy. The first step of its transformation into the market-oriented production system was to decrease the number of employees and reduce amount of applied fertilizers (Csatho & Radimszky, 2009). As a consequence, the naturally-occurring yield differences among these macro-regions increased unexpectedly, producing a new type of YG termed *the temporary yield gap (TYG),* (Grzebisz et al., 2010).

The primary objective of this contribution is to outline key developments leading to improved yields of wheat, maize grain and sugar beet over a 23 year period, from 1986 to 2008, in the CE countries. Explanatory objectives for the present yield performance rely on the fertilizer nitrogen (N) index (partial factor productivity of fertilizer N, PFP_N). It was used (1) to calculate, for each of indicatory crop, indices of the yield gap expressed as the quantity of (a) virtually lost yield and/or (b) unassimilated fertilizer N, and (2) to make a long-term prognosis of crop yields, on the basis of the developed set of yield gap indices. The third part of this chapter describes some conceptual solutions, based on case studies aiming at improving soil productivity.

2. Natural constraints for crop production

The regionally diversified land productivity in Europe can be well assessed by using net primary productivity (NPP). The NPP of CE land, except the southern part of the Balkan Peninsula, ranges from 800 to 900 g m^{-2} y^{-1}, i.e., it is lower by 200 to 300 g m^{-2} y^{-1} than in Western Europe (Fronzek & Carter, 2007). Many reports discussing climate change stress the increasing sensitivity of key crops to year-to-year weather variability, including cereals (barley, wheat) grown in Central-Eastern Europe (Olesen et al., 2011; Falloon & Betts, 2010; Supit et al., 2010).

2.1 Climatic conditions

In agriculture, climate is considered as the driving factor for crop plant adaptations to prevailing weather conditions. Yield potential is strongly influenced by radiation, the sum of daily temperature and precipitation, and also on their distribution over the growth season. The first two factors, as a rule, are used for calculating yield potential, i.e., a realization of crop varieties' potential under undisturbed conditions of growth (Evans & Fisher, 1999). In real production conditions (country or regional scales) a third climatic constraint – water limitation - is the limiting factor of crop plant growth, as discussed by Rabbinge (1993). Base on it, the "water limited" yield (attainable yield) of a crop plant has been defined. Taking into account these factors, Europe is divided into several environmental zones, reflecting dominating weather patterns (Jongman et al., 2006). The Western part of the continent and British Islands are characterized by a humid climate, highly suitable for cultivating most of C_3 crops. Mild winters and sufficiently high precipitation in spring are prerequisites for high yields of cereals also supporting good yields of sugar beets, potatoes and maize in summer months (Supit et al., 2010). For example, in Belgium and Germany, harvested yields of wheat are about 75% of wheat yield potential, whereas French farmers reach about 85% of sugar beet yield potential. In Belgium and The Netherlands, farmers are able to harvest *ca* 90% of maize yield potential (FAOSTAT, 2011).

Most of the CE area is located in the Continental zone, which covers the northern part of the region and also northern part of the Balkan Peninsula. The Pannonion zone extends from the Black Sea up to Alps. The southern part of the region, including Albania, belongs to Mediterranean Mountains and Mediterranean North zones. Main attributes of dominating climatic patterns are irregular precipitations in summer months and frequently occurring droughts, negatively affecting plant growth and harvestable yield. For example, maize yield potential in Romania is calculated at the level of 13.0 t ha^{-1}, but grain yields harvested by farmers within the period 2005-2009 amounted to 3.2 t ha^{-1}. In Poland, yield potential of potatoes is fixed at the level of *ca* 40 t ha^{-1}, however tuber yields harvested by farmers are below 50% of this level (FAOSTAT, 2011; Supit et al., 2010). In spite of climatic disadvantages, a spatial analysis of the YG for grain crops undertaken by Neumann et al. (2010) indicates, that CE is a region with great opportunity for intensifying the production of wheat and maize. Therefore, current yield gaps in this region cannot be explained solely by seasonal weather variability.

2.2 Soil cover: Origin and distribution

Soil cover in CE is not uniform, taking into account prevailing soil types. The gradient of diversification extends from north to the south in this mega region. The natural borders of distinct soil types are Sudety and Carpathian Mountains. They were the first natural barriers seriously limiting the transgression of Fenno-Scandian and Alp's ice sheets during the Pleistocene epoch towards south of Europe. At the same time, edges of both transgressing glaciations were natural borders of climatic zones. The average annual temperature at the glacial edge was -6°C, but on the permafrost zone extending several kilometres to the south or east, close to 0°C. Extremely low temperatures during ice-sheet transgression created a high pressure gradient favourable to long-distance transport of air-born silt particles. Wind mineral deposits, termed as loess, covered large areas of CE, mainly south of Carpathian and Sudety. Loess became an excellent parent material for Chernozems and chernozem-like soils. Severe climatic conditions in the permafrost zone resulted in intensive weathering of surface rock layer. Consequently, huge layers of loam materials were formed both *in situ* or transported as alluvial deposits, being precursors in the development of Cambisols (Catt, 2001; Plant, et al., 2005).

The mineralogical composition of soil parent material is therefore, significantly different on both sides of Sudety and Carpathian Mountains. European countries lying over the northern part, i.e., Poland and also eastern part of Germany, are dominated by soils originating from sands, loamy sands and sandy loams. Consequently, the current soil cover is mostly consisted of associations of Luvisols and Podzoluvisols. In addition, in Poland *ca* 22% of the soil cover, partly used by farmers, is classified as associations of Arenosols and Podzols. Soil cover in other countries of the CE represents mainly Cambisols (Czech Republic, Serbia &

Montenegro, Slovakia, Slovenia) contributing to more than 20%. Another attribute of the region south of Carpathians is associations of Chernozems (Bulgaria, Hungary, Romania, Serbia & Montenegro), (Table 1).

Country/soil types	Cambi-sols[1]	Cherno-zems[2]	Fluvisols	Luvisols[3]	Total carbon stock[5] t ha^{-1} soil depth, m	
					0.0 – 0.3	0.0 – 1.0
Albania (AL)	31.6	10.6	5.5	25.3	67.0	131.0
Bulgaria (BU)	20.0	22.0	9.0	31.0	69.6	146.2
Croatia (CR)	23.6	0.9	2.4	12.6	64.9	117.8
Czech Republic (CZ)	45.1	13.2	5.9	19.3	69.3	135.0
Hungary (HU)	10.8	21.8	17.4	6.5	81.1	184.4
Macedonia (MC)	40.6	1.3	5.1	9.7	68.0	124.8
Poland (PL)	14.6	3.5	4.7	27.3	62.0	119.9
Romania (RO)	23.2	28.5	10.7	26.3	72.5	155.0
Serbia & Mt[4] (S&M)	44.9	21.8	8.6	11.9	73.6	149.8
Slovak Rep. (SK)	46.8	11.6	6.5	29.0	67.1	129.3
Albania (AL)	45.3	0.0	5.4	6.4	68.8	124.5

[1] & vertisols;[2] & Chernozems-like; [3] & Rendzinas; [4]Montenegro; [5] based on Batjes (2002)

Table 1. Main soil associations (average coverage) of the Central European countries

Using soil potassium (K) supply as the key indicator of soil fertility level, it can be assumed, that soil type significantly reflects inherent parent material properties, i.e., soil quality. Nikolova, (1998) has classified soils in three main groups based on their K-sorption characteristics (Table 2). The highest K-fixation capacity is attributed to soils originated from loess or loams from Pliocene and Quaternary deposits. The lowest potential of K supply occurs in soils formed from sandy materials. Therefore, relatively to this rating, CE countries may be additionally divided into two main groups, i.e., Poland and parts of Bulgaria *versus* all other countries. In Poland, soils with low and even very low K sorption capacity are prevalent. About 45% of the agricultural area in Poland is covered by soils originated from sands and loamy-sands. This explains the serious limitation of crop productivity by insufficient soil K supply (Grzebisz & Fotyma, 2007).

K-sorption ability classes	Particles < 0.01 mm, %	CEC cmol$_{(+)}$ kg^{-1} soil	Soil types
High	> 50	> 40	Vertisols, Planasols, Kastanozems
Medium	30 - 50	20 - 40	Haplic & Luvic Chernozems, Molic Planasols
Low	< 30	< 20	Luvisols, Eutric Planasols

[1]Nikolova (1998)

Table 2. General potassium sorption characteristics of main soil types in Central Europe (source: Nikolova, 1998)

3. Agriculturally induced constraints - Fertilizer management

The recorded yield increase of most crops in the last 60 years is a result of two main factors. The first is the progress in plant breeding, which took place in the 60s and 70s during the *Green Revolution* (Sinclair et al., 2004). However, fulfilling nutritional requirements of modern, high yielding varieties requires a well balanced supply of nutrients. The second factor contributing to modern yield increases is fertilizer use. In intensive agriculture, it is related to the consumption of fertilizers, such as N, P and K. Therefore, a reliable estimation of agriculturally induced constraints for crop production in CE requires an insight into past and current nutrient management strategies.

3.1 Long-term patterns of fertilizers' consumption

Data on historical fertilizer consumption in the period 1986-2008 were obtained from the IFA databank (2011). Fertilizer use per hectare was calculated by dividing the total use of N, P and K fertilizers in a given year per actual area of arable land, as the target area of application. The quantities of fertilizers annually used by farmers over the studied period were both nutrient and country specific (Table 3). During the period 1986-2008, total consumption of N-P-K fertilizers in CE countries has undergone significant changes with respect to:

a. the quantity of fertilizers annually applied per hectare;
b. the structure of applied fertilizers, as related to P:N and K:N ratios.

Statistical parameters	Countries[1]											
	AL	B&H	BU	CR	CZ	HU	MC	PL	RO	S&M	SV	SL
Nitrogen												
Average	45.0	31.1	63.3	100.7	93.1	72.4	46.7	71.0	39.9	45.8	70.3	200.0
SD[2]	44.1	23.1	37.2	38.9	22.3	25.1	13.6	18.2	20.1	16.4	31.3	129.9
CV[3], %	97.9	74.2	58.8	38.6	23.9	34.6	29.0	25.7	50.5	35.7	44.5	64.9
RI_N	86.6	75.3	68.0	53.3	41.4	52.6	45.8	37.7	62.9	51.0	60.9	80.0
Phosphorus												
Average	14.9	14.4	15.2	44.0	32.2	21.3	22.8	30.5	16.5	14.4	30.4	69.8
SD[2]	14.7	12.1	23.2	15.4	32.3	21.4	8.10	16.3	13.1	12.1	33.3	33.7
CV[3], %	98.7	84.5	152.8	35.0	100.5	100.4	35.5	53.4	79.6	84.6	109.4	48.3
RI_P	91.4	81.2	97.6	42.5	83.9	85.4	53.1	65.7	80.0	83.8	86.6	64.1
Potassium												
Average	2.4	13.9	7.1	48.1	30.3	26.0	17.5	36.6	6.4	15.7	29.1	85.1
SD[2]	2.1	11.3	10.6	20.9	34.3	26.9	9.3	18.3	8.5	10.0	34.8	46.1
CV[3], %	87.4	81.4	149.3	43.3	113.3	103.6	53.4	49.9	132.4	64.1	119.7	54.2
RI_K	96.5	80.0	97.0	53.7	89.2	86.3	68.4	61.9	93.1	70.6	88.8	71.8

[1] IFA data bank, accessed 2011-05-24. [2]standard deviation, [3]coefficient of variation,

Table 3. Consumption of N, P and K fertilizers (in kg ha^{-1}) in Central European countries during the period 1986-2008 and the reduction index (RI) for each nutrient – a statistical overview. [1]Country acronyms are provided in Table 1.

The long-term course of fertilizers' consumption showed some resemblances. Therefore, the whole investigated period has been divided into three well defined phases: (1) High Consumption Level (HCL); (2) Collapse and Transition (CT); (3) Post Transition (PT) (Fig. 1). Two distinct procedures have been applied to make a reliable estimate of the length of each phase. The HCL was separated from the CT when there was more than 25% change in the baseline – yearly values. The PT was established using a linear regression model, assuming statistically proven change.

The key attribute of the first phase, lasting from four to five years was characterized by high levels of consumed fertilizers, mainly N, irrespective of the country (Fig. 1). The consumption of other nutrients, i.e., P and K was country specific. The CT phase was characterized by a dramatic, sudden decrease in use of each fertilizer. This process occurred for one or two years in some countries (Czech Republic, Croatia, Hungary, Poland, Slovakia, Slovenia), but in others up to 10 years, showing prolonged depression. The reason of this drastic decline was well described in economy the *scissor phenomena* (Cochrane 2004). The PT phase has been appearing in three distinct forms, i) increase (PT-I, above the baseline HCL level); ii) restoration (PT-R, significant trend, but below the baseline, HCL level), iii) stagnation (PT-S, no significant changes over time).

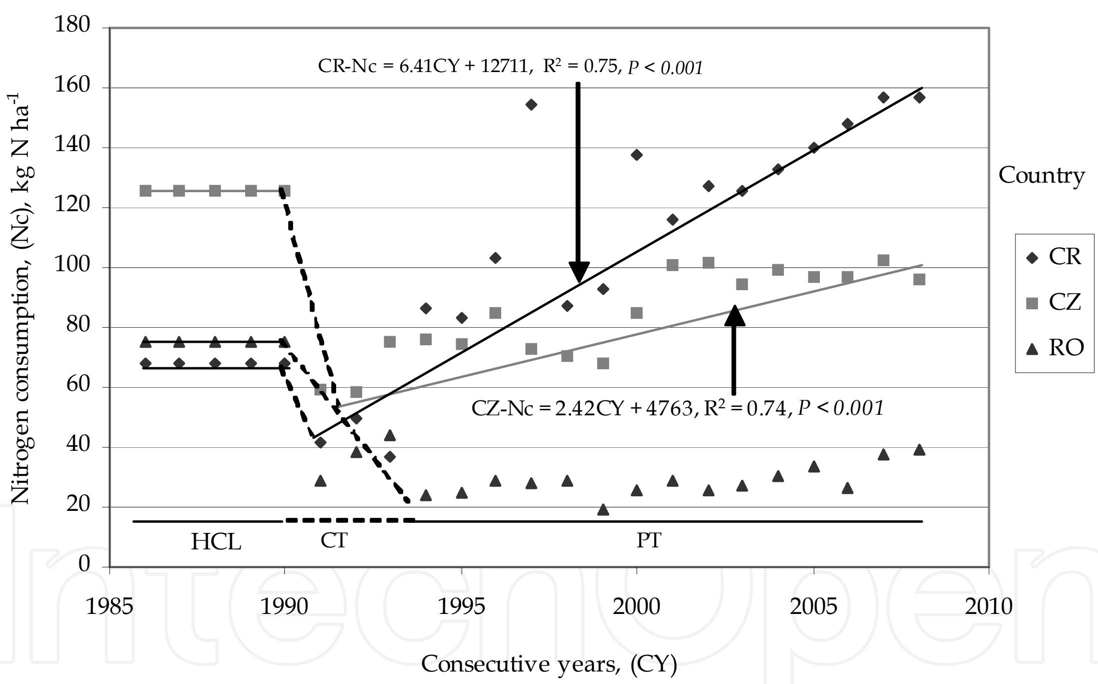


Fig. 1. Patterns of N fertilizers' consumption in selected Central European countries - Croatia (CR), Czech Republic (CZ) and Romania (RO) during the 1986-2008 period (based on: IFA database, accessed: 2011-05-24). Significant (P<0.05) trends are indicated with solid lines and linear regression equations given. The CT periods are marked with dashed lines.

Nitrogen, considered as the key nutrient in crop production, but at the same time potentially unfriendly to the environment, requires much deeper attention. Its consumption in the HCL period was high, varying around 100 kg N ha^{-1} for most countries in the region (Table 3). The lowest consumption (defined by 0.25 percentile) took place during the CT phase. The degree of collapse can be simply assessed by using a fertilizer use reduction index, (RI):

$$RI = [1- (0.25P/0.9P) \cdot 100\%]$$

where: 0.25P and 0.9P are the 25th and 90th percentiles of fertilizer consumption over the period 1986-2008.

Fertilizer N management in CE during the PT phase relies on consumption trends, evaluated for a period of 18 years, i.e., since 1991 onwards. On the basis of elaborated regression models, countries of the region have been divided into three defined groups:

1. Increase (PT-I): Croatia, Slovenia;
2. Restoration (PT-R): Czech Republic, Hungary, Poland, Slovakia, Slovenia;
3. Stagnation(PT-S): Albania, Bosnia & Herzegovina, Macedonia, Bulgaria, Romania, Serbia & Montenegro.

Phosphorus is a nutrient of basic importance for any crop plant, because all seed crops are highly sensitive to its deficiency during the onset of ripening. In the HCL phase, the consumption of P fertilizers was in the range of *ca* 35 to 95 kg P_2O_5 ha^{-1} (Table 3). During the period of study, its use underwent a great, mostly negative change. Its consumption trends evaluated for years 1991-2008 showed much greater variability compared to N fertilizers' use in CE countries:

1. Increase: Croatia, Slovenia;
2. Restoration: Poland, Hungary, Macedonia;
3. Stagnation: Albania, Czech, Slovakia, Serbia & Montenegro;
4. Recession: Bosnia & Herzegovina, Bulgaria, Romania.

The occurrence of the fourth group stresses the fact that P fertilizers' consumption was below the levels required to support current crop production, leading to *nutrient mining* in three countries of the region.

Potassium is generally considered as a nutrient significantly affecting water management in plants during their life cycle (Cakmak, 2005). Therefore, this nutrient requires special care on farm in regions like CE that experience frequent drought during the vegetative growth period (Falloon & Betts, 2010). Potassium fertilizers' consumption during the HCL period varied among countries of the region from *ca* 5 kg K_2O ha^{-1} (Albania) to more than 100 kg K_2O ha^{-1} (former Czechoslovakia) (Table 3). As in the case of P, the greatest decline in K consumption occurred in countries significantly increasing the use of nitrogen, like the Czech and Slovak Republics, and also Hungary (estimated from the potassium fertilizer use reduction index, RI_K).

The second indicator of fertilizer management is in the proportions of macronutrients consumed, indicated during the study by the P:N and K:N ratios. The P:N ratio did not show a clear trend for two countries, Albania and Bosnia & Herzegovina. In other countries, negative tendencies were detected, appearing as the increasing value of P:N ratio, meaning that proportionately more N fertilizer than P fertilizer was applied by farmers. This process took place mainly during CT and PT phases. Its course during the PT phase outlines three decisive patterns of P fertilizers' management:

a. negative: Czech Republic, Croatia, Serbia & Montenegro, Romania;
b. positive: Hungary, Macedonia, Poland;
c. stagnation: Slovakia.

The first trend covers the whole study period, differing only in the annual rate of decrease, as indicated by the coefficient of the linear regression equation. In the case of Romania, it was almost four times faster than for Croatia (Fig. 2). The second pattern occurred in countries like Hungary and Poland, showing a slightly positive trend, since 1991.

Trends of K:N ratios show similar patterns as described for P:N ratios (Fig. 3). Three patterns of ratios can be also distinguished, but comprising different sets of countries:

a. negative: Macedonia, Slovenia;
b. positive: Hungary;
c. stagnation: Croatia, Czech, Poland, Slovakia, Bulgaria and Romania (since 1993), Serbia & Montenegro (since 2000).

All above-described attributes of long-term fertilizers' consumption were evaluated in Table 4, to develop a ranking based on three types of nutrient management in CE countries, as follows:

1. *Extensive*; generally showing low consumption of all fertilizers, including N; the most negative attribute is the low P and K inputs, leading to crop plants reliance on inherent soil P and K supply and potentially leading to nutrient mining (Albania, Bulgaria, Macedonia, Serbia & Montenegro, Romania);
2. *Unbalanced*; high consumption of fertilizer N, but at the same time not balanced by adequate use of other nutrients, such as P and K, at least (Croatia, Czech, Slovakia, Slovenia);
3. *Balanced*; high consumption of N fertilizer, which is in part balanced by relatively high consumption of P and K fertilizers (Hungary, Poland).

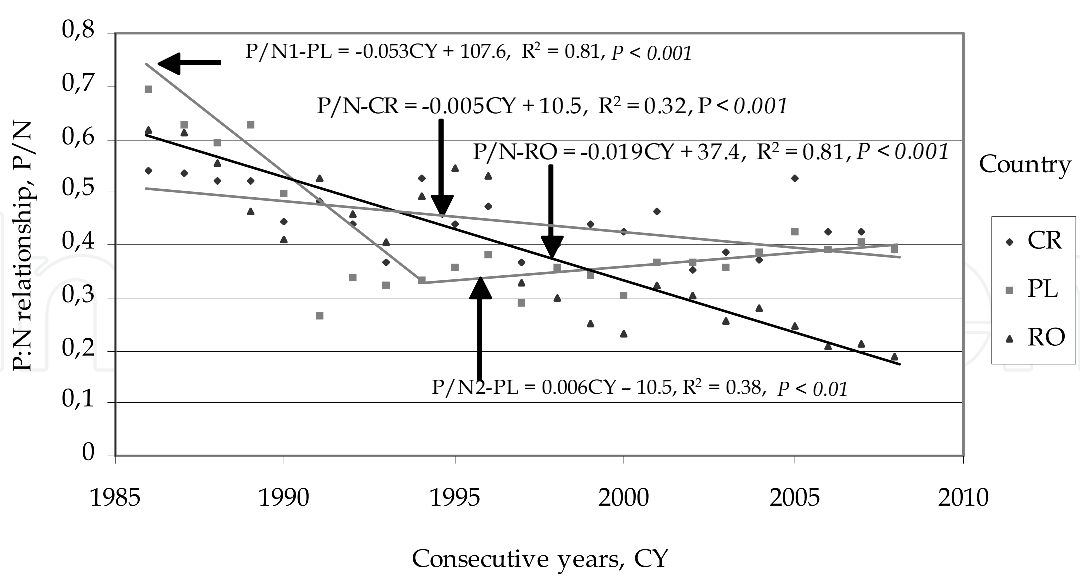


Fig. 2. Typical patterns of P:N ratios in selected Central European countries - Croatia (CR), Poland (PL) and Romania (RO) during the period 1986-2008. Significant (*P*<0.05) negative linear equations are shown for CR and RO, while the PL data fitted to a negative linear equation in the period 1986-1996 and thereafter showed a positive linear relationship.

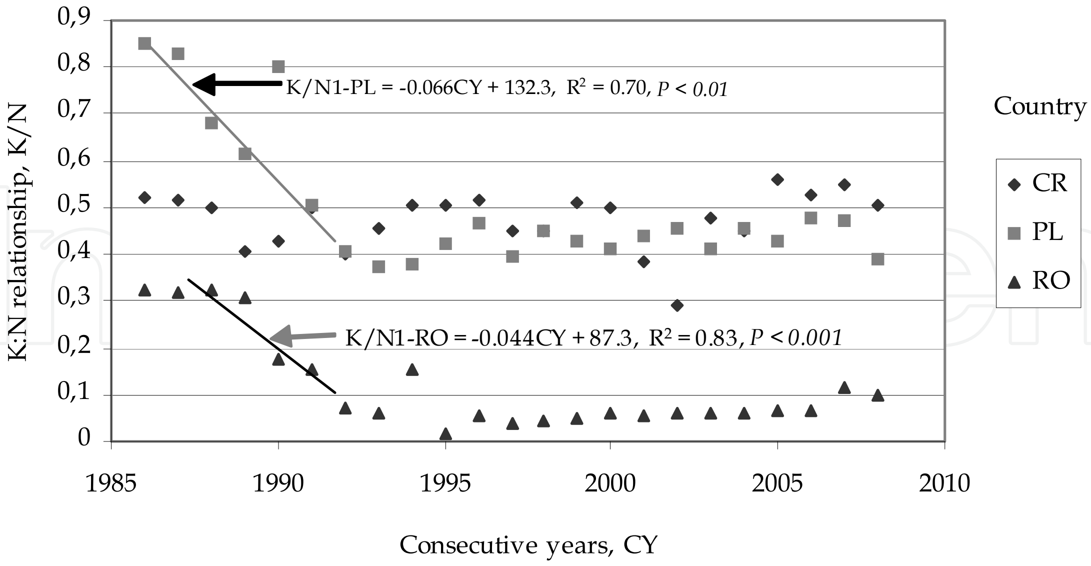


Fig. 3. Typical patterns of K:N ratios in selected Central European countries - Croatia (CR), Poland (PL) and Romania (RO) in the period 1986-2008. Significant (P<0.05) negative linear equations are shown for CR and RO in the 1986-1992 period, thereafter showed non-significant trends. For CR the K:N trend was non-significant for the whole period.

Estimated Parameters	Country[3]											
	AL	B&H	BU	CR	CZ	HU	MC	PL	RO	S&M	SK	SL
Nitrogen	0[1]	0	0	++	+	+	0	+	0	0	+	+/-
Phosphorus	0	-	-	++	0	+	+	+	-	0	0	+/-
Potassium	0	0	0	++	0	+	0	+	0	0	0	0
P:N	0	0	0	-	-	+	0	++	-	0	0	-
K:N	0	0	0	0	0	+	-	0	0	0	0	-
Ranking[2]	0	0	0	2	2	1	0	1	0	0	2	2

[1]evaluation of trends: ++ - increase; +- restoration; 0 - stagnation; - - decrease; +/- - time variable;
[2] fertilizer management ranking: 0 – extensive; 1 – balanced; 2 – unbalanced.
[3] Country acronyms are provided in Table 1.

Table 4. Fertilizer consumption trends –summary and country management ranking for countries in Central Europe during the period 1986 to 2008.

3.2 Soil fertility status

Soil is considered as a slowly renewable or non-renewable resource that requires the same level of protection as other limited resources, like phosphorus rock. There is strong agreement that productivity of arable land depends on both a soil's fertility potential (soil quality, inherent soil fertility) and present state of soil properties (soil health) to sustain primary production and other ecological functions. The minimum data set to describe current fertility status of arable land, i.e., soil health, should contain indicators reflecting both past and actual organic matter content, soil pH and management of nutrient soil resources (Atkinson et al., 2005; Karlen et al., 2003).

Total organic carbon (TOC) stock in the topsoil (0.0-0.3 m) or its content (%) in arable soils is a good descriptor of short-term trends in soil organic matter (SOM) management. However, the organic carbon stock measured to a depth of 1 m in the soil profile can be considered as an indicator of soil fertility potential. The actual content of TOC in an averaged arable soil unit was calculated by weighted mean content of organic carbon for main soil types (Batjes, 2002) and its percentage share in the soil cover for each CE country (see Table 1). Analysis of this data showed that TOC in the average topsoil unit of CE countries is insufficient, ranging from *ca* 60 (Poland) to 80 (Hungary) t TOC ha^{-1}, i.e., about 1.4 to 1.8% TOC. Differences between CE countries can be evaluated by TOC stock in the soil profile to a depth of 1 m. Based on this criterion, countries can be classified into three groups:

a. low (≤ 120 t TOC ha^{-1}): Croatia, Poland;
b. medium, (121-160 t TOC ha^{-1}): Albania, Bulgaria, Czech Republic, Macedonia, Romania, Serbia & Montenegro, Slovakia, Slovenia;
c. high (> 161 t TOC ha^{-1}): Hungary.

Phosphorus and Potassium are key nutrients for achieving high productivity of arable soils. Available resources of both nutrients are the most important indicators of soil health, i.e., its current productivity. The country status of current soil nutrient management was evaluated by means of soil fertility index (SFI) expressed as the sum of the percentage share of arable land characterised by the very high, high and half of medium rating of available P or K (Grzebisz & Fotyma, 2007). It has been assumed, that SFI for P and K exceeding 70% of arable land share is a prerequisite for high yield of any crop. In the 1980s, this target was achieved in many countries of the region, like Czechoslovakia, Hungary and some countries of the former Yugoslavia (Serbia & Montenegro, Slovenia), (Fig. 4). In these countries, the rates of applied fertilizers were far in excess of crop removal capacity. Poland, in spite of currently high K consumption, differs from other CE countries. The sufficiency level for P and K of 70% was never reached, due to much lower inherent soil potential for nutrient supply. At the beginning of 2000, significant changes of P and K fertility were recorded. The increase of the P sufficiency level was recorded only in Slovenia and Poland. In Slovenia, the reason was high consumption of P fertilizers at the beginning of the 21st century. In Poland, the increase is related to sufficiently well balanced use of N and P fertilizers and slightly lower yields, than in the 80s. In all other CE countries, the percentage of P-fertile soils generally decreased, nevertheless, the rate of the decrease differed across the region. A slight decrease occurred in Czech and Slovak Republics, as well as in Hungary. The greatest drop was recorded in Bulgaria followed by Serbia and Montenegro. The potassium SFI presents much more alarming trend. As reported by Grzebisz & Fotyma (2007) for countries of the Northern Agricultural Zone (Czech, Hungary, Poland, Slovakia), the K sufficiency level decreased below the target value within two decades. Based on K fertilizers' consumption trends, it can be assumed that the same trend occurs also in the Southern Zone.

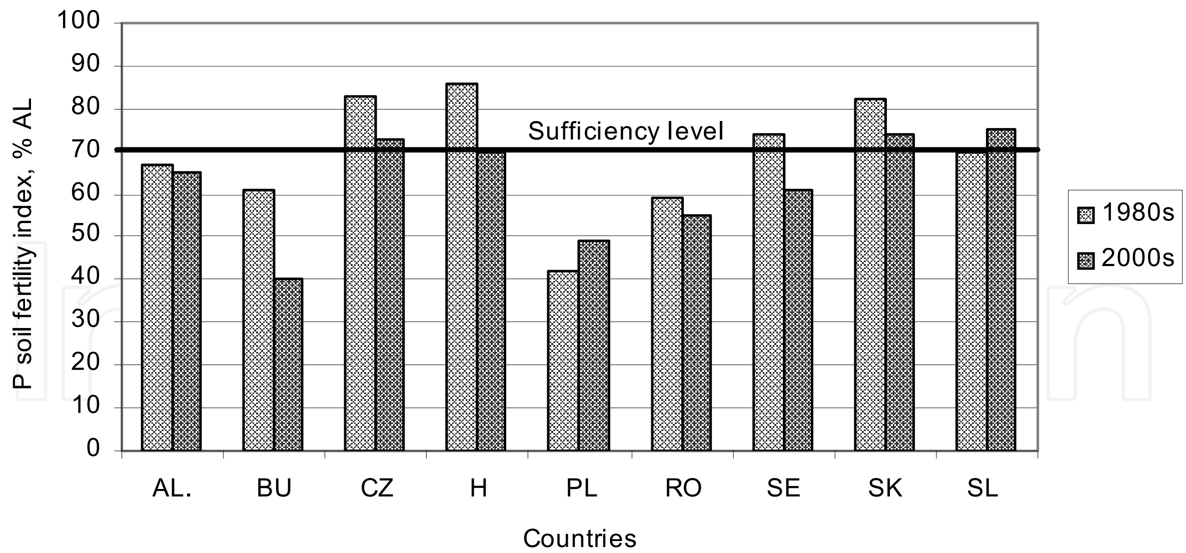


Fig. 4. Phosphorus soil fertility indices (expressed as the percentage of arable land, AL) for selected CE countries during the period 1986 - 2008 (based on: Csatho et al., 2007). The sufficiency level was assumed to be 70%, as described by Grzebisz & Fotyma (2007). Country acronyms are given in Table 1.

4. Soil productivity assessment

4.1 Long-term trends in crop yields

All CE countries grow the same crops and cereal species predominate. The area sown with cereals occupies 64% of arable land in Croatia, 52% - in the Czech Republic, 68% - in Poland and 59% – in Romania. In the Czech Republic, cereals' production is dominated by wheat and barley, but in Poland by wheat and rye. In Romania and Croatia, maize is the key grain crop. Sugar beets, due to EU regulation in the last 10 years, are of minor importance, but this crop is a good indicator of soil quality. Therefore, it has been assumed that these crops would reflect fairly well changes in current soil fertility status, as a consequence of applied nutrient management strategies. This assumption is well documented by observed variability of yields of wheat, maize and sugar beets in selected countries of CE (Table 5). The highest variability was found for Romania and the lowest for Poland. Romania is a country with an extensive pattern of fertilizers' management, typical in the Southern Agricultural Zone of Europe. Poland belongs to countries of the Northern Zone, but presents a balanced patterns of fertilizers' management (Poland, Hungary). Other selected countries are members of the Unbalanced fertilizing group of CE countries.

The long-term yield trend can be used as an indicator of key crops' sensitivity to past and current fertilizers' management. As in the case of fertilizers' consumption trends, three consecutive phases of yield development over the period 1986-2008 may be distinguished:

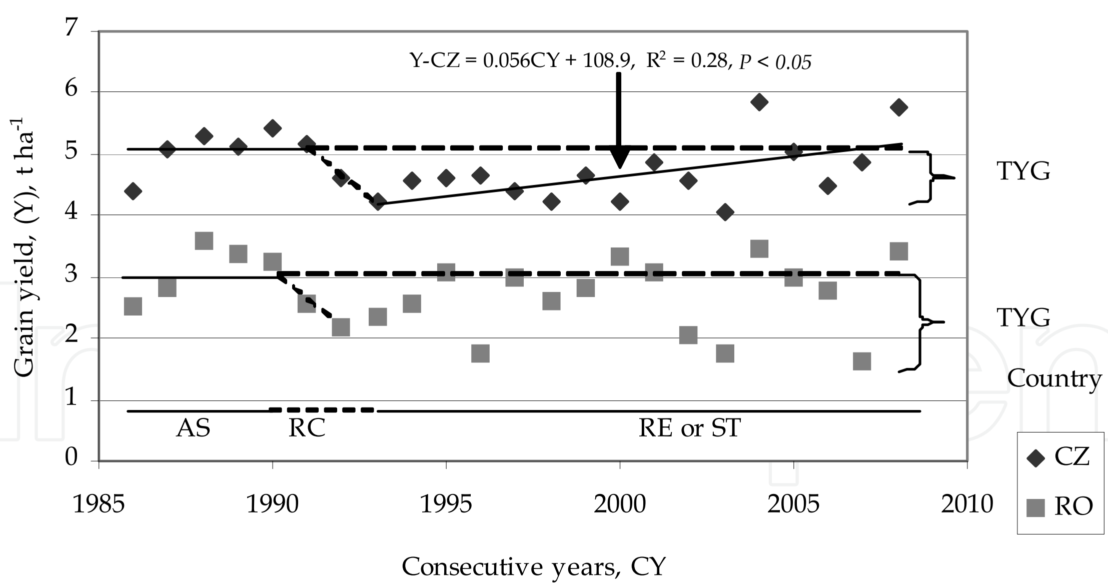
1. Actual-Standard, (AS);
2. Recession, (RC);
3. Restoration, (RS), or Stagnation, (SG).

The observed trends of harvested yields were most pronounced for wheat, other cereals and for seed crops like oil-seed rape (Grzebisz et al., 2010). In the first phase of the study, taking place at the end of the 80s, yields of wheat reached on average the highest recorded levels. Therefore, this particular period is considered as a standard level (AS) for evaluating subsequent phases (Fig. 5). The highest yield decline, i.e., the recession phase (RC) in response to the collapse in fertilizer consumption took place in the Northern Zone, but

Crops	Croatia		Czech Republic		Poland		Romania	
	x ± SD[5]	CV[6], %	x ± SD	CV, %	x ± SD	CV, %	x ± SD	CV, %
Wheat	4.0±0.5[2] 3.9±0.3[3] 4.4±0.9[4]	12.5 8.6 21.6	4.8±0.5 5.1±0.4 5.2±0.6	10.2 7.8 11.3	3.6±0.3 3.7±0.2 3.9±0.4	9.0 5.6 10.0	2.7±0.6 3.1±0.4 2.9±0.8	21.2 14.1 26.5
Maize	4.9±1.0 4.0±0.9 5.5±1.3	20.5 21.7 22.9	5.8±1.3 5.1±0.5 6.9±0.5	21.4 9.3 7.6	5.2±0.8 4.9±0.2 5.6±0.8	14.3 4.1 15.7	3.1±0.8 2.9±0.5 3.4±1.1	24.4 18.0 31.5
Sugar beet	40.4±7.7 39.8±4.9 48.7±5.2	19.2 12.3 10.8	42.4±7.6 34.5±1.5 53.1±4.9	18.0 4.2 4.9	38.1±5.5 34.6±1.9 45.1±3.9	14.5 5.6 8.8	22.8±5.1 21.3±2.9 30.4±3.3	22.2 13.6 10.8

[1]FAOSTAT, available online 2011-05-24; [2]1986-2008, [3]1986-1990, [4]2004-2008, [5]standard deviation, [6]coefficient of variation, %

Table 5. Statistical overview of key crops' yields (t ha^{-1}) in selected Central European countries, during the period 1986-2008 in comparison to the AS phase and the 2004-2008 periods.



Legend: level of harvested yield: AS: Actual-Standard, RC: Recession, RE: Restoration, ST: Stagnation. Dashed line refers to AS level of yield, i.e., an average yield harvested in the period 1986-1990. TYG: Temporary Yield Gap.

Fig. 5. Long-term trends of wheat production in the Czech Republic (CZ) and Romania (RO) during the period 1986-2008. Significant (P<0.05) positive linear trend is shown for the Czech Republic, whereas non-significant for Romania, in the period 1992-2008.

lasted for only two or three years. In other countries, mainly representing the Southern Zone, it was also fast or showed sustained depression. The third phase of yield development was manifested in two distinct trends. The first "restoration" trend has shown a positive yield gain since yield recession. It was revealed in the Northern Zone countries and also for Croatia and Slovenia. The second trend has not shown any significant change in yield since the recession, resulting in yield stagnation. The most interesting attribute of this trend is its high year-to-year variability. The difference between the actually harvested and the AS yield has been termed as the *temporary yield gap* (TYG) (Fig. 5). The time required to recover to the AS level was long, but country specific. In the Northern Zone, it lasted for *ca* 10-12 years, exceeding the AS level in 2004 or 2005. In most other countries, representing the Southern Zone, it has not been reached up to 2008. For maize and sugar beets, the recession was also observed. In the recovery period, maize yields were generally positive, but the rate of the yield increase was much higher in the Balanced and Unbalanced groups than in the Extensive group. Sugar beets yield increase was very high at the beginning of the 90s, exceeding the level reported in the 80s. The main reason was a reduction in area sown with sugar beets, which forced farmers to cultivate this crop on more fertile soils.

4.2 The concept of partial factor fertilizer nitrogen productivity, (PFP_N)

This part of the study relies on two main conceptual pillars. The first one assumes, that each hectare of arable soil, regardless of the current crop is supplied with the same amount of nutrients, including nitrogen. The second assumption takes into account the fact, that the unit productivity of in-season applied fertilizer N, known as PFP_N, is a reliable scientific tool to make simple, but quick discrimination of factors limiting attainable crop yield (Dobermann & Casman, 2002). Therefore, the PFP_N index was used to evaluate some, but selected CE countries that represent the three patterns of current fertilizer management (Table 4). Croatia and the Czech Republic have been selected as examples for the Unbalanced group, whereas Poland is the Balanced group, and Romania represents the Extensive group of fertilizers' use.

The PFP_N index was obtained by dividing the actual yield of a respective crop harvested within a given year by the annual amount of N fertilizers consumed by the country, assuming it was applied at an equal rate for all currently cultivated crops. Operationally, the PFP_N index consists of two components:

a. yield of crop (Y), expressed in kg, or t ha^{-1};
b. nitrogen fertilizer rate (F_N), expressed as kg N ha^{-1}.

$$PFP_N = Y/F_N$$

Based on the long-term trends of PFP_N indices for each of the key crops, two different types of PFP_N indices can be distinguished:

1. The *real* partial factor productivity of applied N – ($rPFP_N$); it reflects actual yields as limited by both water and N availability;
2. The *maximal* partial factor productivity of applied N ($mPFP_N$); it was calculated as the 4^{th} quartile of $rPFP_N$ indices; it refers to yields obtained under ample water supply.

To make a reliable estimate of the yield gap for some crops cultivated in the CE, the *corrected* partial factor productivity of applied N ($cPFP_N$) instead of $mPFP_N$ has been applied.

Operationally, it has been calculated as the average of the 4th quartile, but excluding extremely elevated $r\mathrm{PFP_N}$ values, which emerged in most of investigated countries at the beginning of the 90s. Indices of N productivity ($\mathrm{PFP_N}$: $r\mathrm{PFP_N}$ and $c\mathrm{PFP_N}$) were then used to calculate the yield gap.

The calculated $r\mathrm{PFP_N}$ indices showed, as expected, high year-to-year variability for all tested crops (Table 6). They were crop and country specific when averaged over the 1986-2008 period:

a. wheat: CR < CZ = PL < RO;
b. maize: CR < CZ < PL < RO;
c. sugar beets: CR = CZ < PL < RO.

These ranges are not in line with long-term average yields of all crops, which followed generally the order: CZ > CR > PL > RO.

Maximum productivity of tested crops as evaluated for the 4th quartile of $r\mathrm{PFP_N}$ indices was much higher, rising on average by 43%. However, the increase was country specific, and represents 63% for Croatia, 28% for the Czech Republic, 30% for Poland and 48% for Romania. The concept of $m\mathrm{PFP_N}$ assumes an increase of $r\mathrm{PFP_N}$ indices pursuant to higher efficiency of applied fertilizer nitrogen, due to ample water supply. Its reliability has been corroborated by low coefficients of variation, implicitly indicating the potential productivity of applied fertilizer nitrogen on the background of soil quality. The sequences of countries for each crop are as follows:

a. wheat: CZ = PL < CR < RO;
b. maize: CR = CZ < PL < RO;,
c. sugar beets: CZ < PL < CR < RO.

As presented in Table 6, coefficients of variations of $c\mathrm{PFP_N}$ indices were significantly lower in comparison to $m\mathrm{PFP_N}$, stressing on the reliability of the conducted analysis.

Relationships between sets of developed $r\mathrm{PFP_N}$ and applied fertilizer nitrogen rates can also be a useful tool for making long-term assessment of nitrogen efficiency. This relationship fits the best the power function:

$$r\mathrm{PFP_N} = 911.2\mathrm{N}^{-067} \text{ for } R^2 = 0.77 \text{ and } n = 92$$

where: N – annual rate of fertilizer nitrogen consumption, kg N ha^{-1}.

Analysis of the general curve shape reveals decreasing yield per unit of N fertilizer applied, with highest values of $\mathrm{rPFP_N}$. It has been observed, that irrespective of the applied N rate, long-term productivity of fertilizer nitrogen increased in the order: Romania < Poland < Croatia < the Czech Republic. However, the obtained high $r\mathrm{PFP_N}$ values are, as a rule, related to lower yields of harvested crops. This pattern of crop response refers mostly to Bulgaria, Romania and former Yugoslavia countries, excluding Croatia and Slovenia. As pointed out by Fixen (2004), the target of efficient N fertilizer management based on high fertilizer N use efficiency is counter-productive. In this N supply system plants are forced to take up an appreciable amount of N from its soil resources, which decreases their rate of growth in critical stages of yield performance. Therefore "the elevated" level of the $\mathrm{PFP_N}$ could be used as an attribute of the extensive type of agriculture production.

PFP_N index	Croatia		Czech Republic		Poland		Romania	
	x ± SD[1]	CV[2], %	x ± SD	CV, %	x ± SD	CV, %	x ± SD	CV, %
Wheat, kg yield kg N^{-1}								
$rPFP_N$	48±24	49.8	54±13	23.5	54±15	27.5	81±33	40.5
$mPFP_N$	80±23	28.8	70±11	16.0	72±15	21.2	121±14	11.9
$cPFP_N$	63±11	17.4	62±4	5.9	62±2	3.0	112±8	6.9
Maize, kg yield kg N^{-1}								
$rPFP_N$	56±26	46.4	66±18	28.1	78±21	26.3	95±45	47.8
$mPFP_N$	89±29	28.8	89±7	7.6	103±11	10.2	149±20	13.5
$cPFP_N$	69±10	15.1	89±7	7.6	96±2	2.4	137±9	6.6
Sugar beets, kg yield kg N^{-1}								
$rPFP_N$	471±224	47.7	478±120	25.0	566±136	24.0	695±266	38.3
$mPFP_N$	766±218	28.5	588±49	8.25	728±67	9.3	977±122	12.5
$cPFP_N$	613±86	14.1	588±49	8.25	675±35	5.2	905±36	4.0

[1]standard deviation, [2]coefficient of variation, %

Table 6. Partial factor fertilizer N productivity statistics for key crops in selected Central European countries with unbalanced (Croatia, Czech Republic), balanced (Poland) and extensive (Romania) fertilizers' management, during the period 1986-2008.

4.3 Yield gap (YG) and its attributes

Actual yields of crops harvested by farmers in all areas of the world are much lower than the yield potential of currently cultivated varieties under defined soil and climatic conditions. This "virtual" un-harvested portion of yield is generally termed the *yield gap* (YG), (Evans & Fisher, 1999, Dobermann & Cassman, 2002). However, the CE countries experience another phenomenon, known as *the temporary yield gap* (TYG), (Grzebisz et al., 2010). The main reason of its emergence is the collapse in fertilizer use, leading to elevation of the $rPFP_N$ index. Dibb (2000) relates extremely high N efficiency to low yield, and this trend was fully corroborated by the crop yield data from countries with extensive fertilizer management. Nevertheless, the countries of the Northern Agricultural Zone (Czech Republic, Hungary, Poland, Slovakia), in spite of drastic decrease of consumed fertilizers in the early 90s, were characterized by high yields of wheat and other cereal crops (FAOSTAT, 2011, Grzebisz et al., 2010). The observed $rPFP_N$ indices, extremely elevated at the beginning of the 90s, were a result of the residual effect of applied fertilizer N. This phenomenon could be manifested only under growth conditions created by ample water and sufficiently high supply of immobile nutrients such as P and K, in turn balancing N use by currently growing crops.

In the first step of yield gap calculation, the $cPFP_N$ index was applied to assess the maximal attainable yield, (Y_{AM}). The yield gap was then calculated as a difference between really harvestable yield, (Y_A) and Y_{AM}:

$$Y_{AM} = c\mathrm{PFP}_N \cdot D_N$$

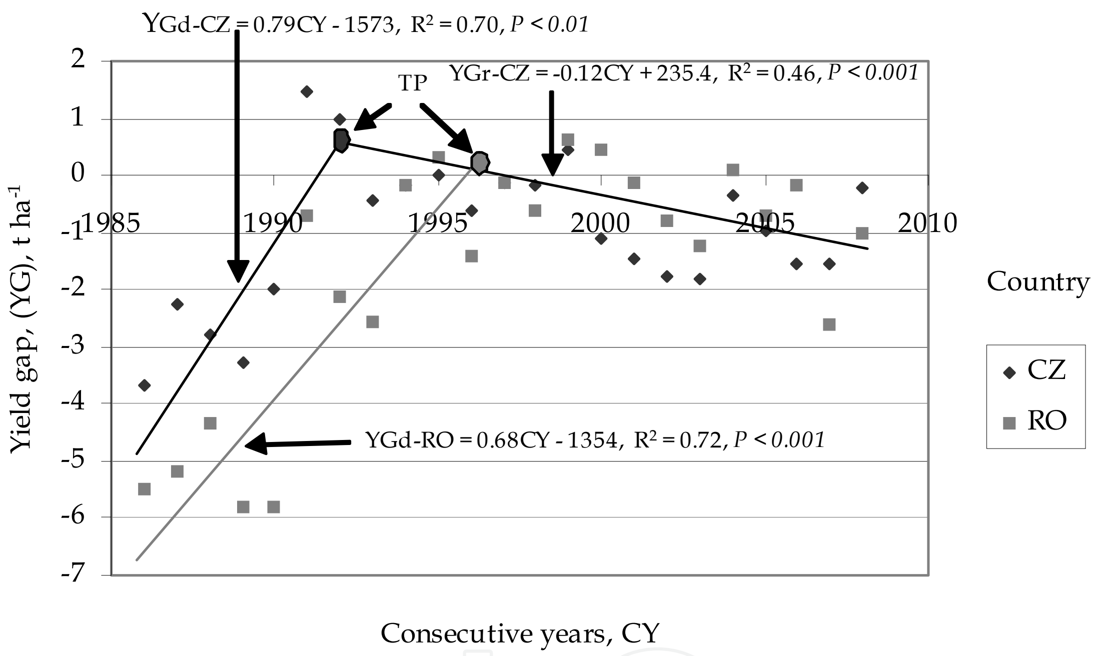
$$YG = Y_A - Y_{AM}$$

where,

D_N is the rate of annually applied fertilizer N, (kg N ha^{-1}), Y_A is the actual yield in t ha^{-1} for a given year and Y_{AM} is the maximal attainable yield, (t ha^{-1}).

The observed similarities of the general yield gap pattern over time for key crops allow to distinguish three consecutive phases of its development in the period 1986-2008 (Fig. 6):

1. First – primary deep yield gap; to the left of the transition point (TP);
2. Second – point of extra yield gain, TP;
3. Third- secondary yield gap; to the right of the TP, alternatively: yield gap stagnation as indicated by the lack of significant ($P < 0.05$) linear trend response.



Legend: TP - Transition Point; YGd - yield gap decline; YGr - yield gap restoration.

Fig. 6. Evolution of the yield gap in wheat in the Czech Republic (CZ) and Romania (RO) during the period 1986 -2008. Significant (P<0.05) positive linear equations are shown for the Czech Republic in the period 1986-92 and for Romania in the period 1986-1995, thereafter showed a negative linear relationship for the Czech Republic and non-significant trend for Romania.

Wheat is the best example of the yield gap course in the CE countries, stressing on the difference in fertilizer management. The main dissimilarities among countries do not refer to the first phase. The YG was deep in spite of relatively high yield, indicating thus a low capacity of contemporary cultivated varieties to achieve further gains in yield. Much more important were YG length and number of years to reach the TP. The time to reach the TP was shorter (6(7) years) in countries such as the Czech and Slovak Republics, Hungary and Poland and also in Croatia and Slovenia, corresponding to rapid rebuilding of fertilizer markets in these countries. In countries with extensive fertilizers' management, the length of the first phase extended up to mid-90s.

The YG evaluation shows that the current nutrient management in CE countries can overcome this phenomenon, especially in the case of wheat and maize. A TYG can be most easily negated in countries belonging to Unbalanced or Balanced nutrient management groups such as the Czech and Slovak Republics, Hungary and Poland and also Croatia, and Slovenia. In countries with extensive fertilizers' management, the TYG has not been overcome, and enters the third phase of yield development, stagnation, due to low use of fertilizers, in turn resulting in the very low and unstable level of annually harvested yields.

4.4 Yield prognosis – The unassimilated nitrogen concept

The medium or long-term food and environmental policy strategies for any country or particular region are supported by yield prognosis considered as an operational tool. However, the *ex-ante* prognosis depends on the reliability of the data used. Two approaches, both relying on the unit productivity of fertilizer nitrogen, (PFP_N) have been considered. The first assumes extrapolation of real and improved yields, based on the linear model (Reilly & Fuglie, 1998). The second one is based on long term trends of the YG, but transformed into unit of temporarily lost fertilizer nitrogen, termed for the purposes of this study as *unassimilated* nitrogen. This approach as related to nitrogen management has been used to make a prognosis of yields of key crops in the CE countries.

Operationally, the concept presented in this chapter assumes, that the total amount of applied fertilizer nitrogen (F_N) is simply divided into three main pools: i) assimilated (Fa_N) – nitrogen taken up by meanwhile grown crop, ii) unassimilated nitrogen (F_{uaN}) – temporary out of use by plants and/or iii) lost from the field (F_{LN}). The quantitative assessment of the F_{uaN} pool relies on the defined YG procedure, individually related to each investigated crop:

$$F_N = F_{aN} + F_{uaN} + F_{LN}$$

$$F_{uaN} = YG/cPFP_N$$

where,

F_{uaN} – unassimilated nitrogen, kg N ha^{-1}; YG - yield gap; cPFPN – the corrected partial factor productivity of applied N, kg yield kg N-1

In the first step of yield prognosis, the *Unassimilated Nitrogen Indices* ($I_{ua}N$) should be computed. Therefore, the original set of YG data for each of the studied crops was transformed into a quantitative amount of nitrogen lost temporarily from the system, marked as minus ($-I_{ua}N$). In the second step of the analysis, both sets of actual (Y_A) and maximum attainable yields (Y_M) of each crop were regressed against corresponding set of $_{ua}N$ indices. The obtained regression models clearly show that actual yields over the period of 20 years did not respond significantly to the $I_{ua}N$, as reported in Fig. 7 for wheat in Romania. The positive and simultaneously significant trends were, however, achieved, when the maximum attainable yield (Y_M) instead of the actual yield (Y_A) was introduced into the regression model. It can be therefore hypothesized that any virtual loss of nitrogen, i.e., the negative $_{ua}$N indices reflect the potential status for a yield increase and *vice versa*. Unfortunately, the positive indices of the $_{ua}$N simply describe a state of N soil mining, which in turn causes direct yield decline. This is consistent with the opinion of Dibb (2000) and typical for many parts of the world, including most CE countries.

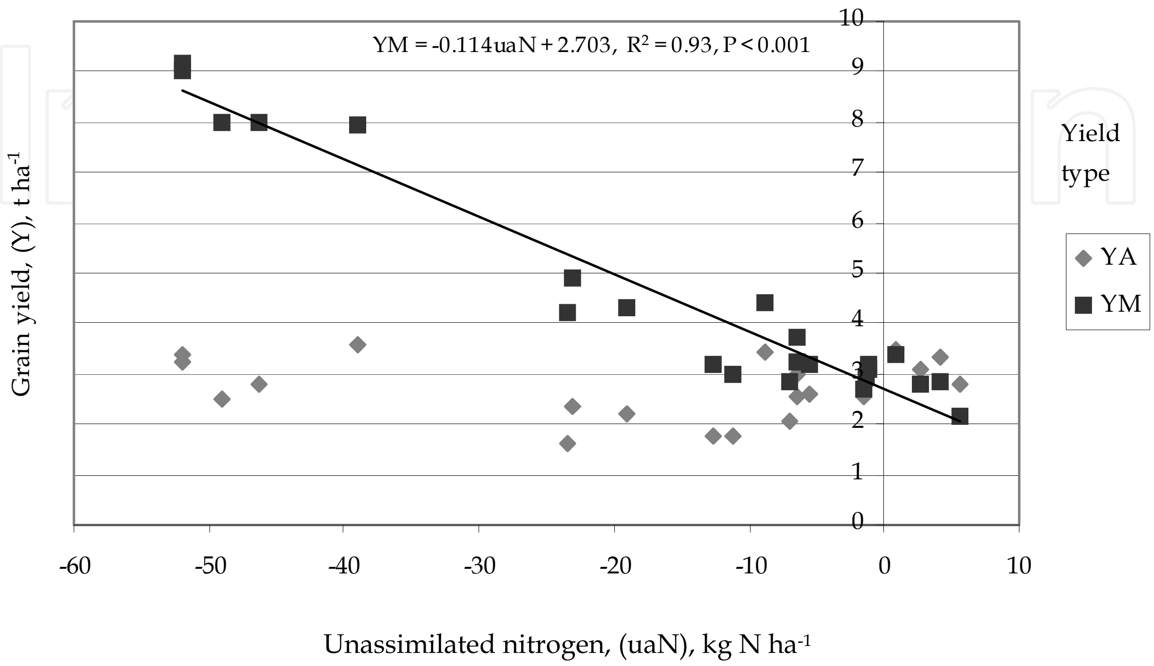


Fig. 7. Yield prognosis of winter wheat based on residual nitrogen - a case of Romania (RO). Significant (P<0.05) linear equation represents the trend for the attainable yields in the 1986-2008 period. Legend: Y_A – actual yield; Y_M – maximum yield.

Reliable yield prognosis can be performed, assuming a certain level of expected yield or by focusing any improvement of production technology on higher N use efficiency. The first approach can be best presented for wheat. The maximum attainable yield for this crop in Poland and the Czech Republic is fixed at the level of 6.5 t ha^{-1}, but for Romania at 4.5 t ha^{-1} (Rabbinge & van Diepen, 2000). The amount of $_{ua}$N required to be incorporated into grain yield was calculated by the models and amounted to 48, 27 and 33 kg ha^{-1}, respectively. It is equal to 58%, 27% and 100% of annual N rate applied in these countries, and does not seem a realistic approach. The same rules refer to other key crops in the study. Therefore, the second concept relying on the ability of currently cultivated crops to fix an extra amount of $_{ua}$N seems to be a more realistic approach for making any reliable yield prognosis (Table 7). This assumption is highly promising, especially for countries presenting an extensive type of agriculture production, for example, Romania. The expected wheat increase in response to the use of extra 20 kg N ha^{-1} is possible, considering the water limited yield, fixed at 4.5 t ha^{-1}. The prognosis for the Czech Republic is still below the water limited yield, being at 6.5 t ha^{-1}. In Poland, the calculated yields are at the same level as Romania, but soils are less suitable for wheat production. Therefore, any grain yield increase seems to be a great challenge for farmers in all countries of the CE. In the light of yields prognosis for sugar beets, the fixed level of $_{ua}$N at 20 kg N ha^{-1} is generally too low. The level of 60 t ha^{-1} of beets seems to be the most reliable short-term target. Thereby, the amount of $_{ua}$N successfully managed should be established at the level of 30 kg ha^{-1}.

Crop/Country	Linear regression model	Yield at 20 kg $_{ua}$N t ha^{-1}
Wheat		
Croatia	$Y_M = -0.064\ _{ua}N + 3.989$ for $R^2 = 0.96$	5.27
Czech Rep.	$Y_M = -0.063\ _{ua}N + 4.777$ for $R^2 = 0.88$	6.04
Poland	$Y_M = -0.060\ _{ua}N + 3.623$ for $R^2 = 0.92$	4.82
Romania	$Y_M = -0.114\ _{ua}N + 2.703$ for $R^2 = 0.93$	4.98
Maize		
Croatia	$Y_M = -0.069\ _{ua}N + 4.852$ for $R^2 = 0.86$	6.23
Czech Rep.	$Y_M = -0.064\ _{ua}N + 6.470$ for $R^2 = 0.69$	7.76
Poland	$Y_M = -0.085\ _{ua}N + 5.431$ for $R^2 = 0.83$	7.13
Romania	$Y_M = -0.121\ _{ua}N + 3.348$ for $R^2 = 0.94$	5.78
Sugar beets		
Croatia	$Y_M = -0.605\ _{ua}N + 40.677$ for $R^2 = 0.89$	52.78
Czech Rep.	$Y_M = -0.458\ _{ua}N + 45.872$ for $R^2 = 0.76$	55.03
Poland	$Y_M = -0.609\ _{ua}N + 39.801$ for $R^2 = 0.81$	51.98
Romania	$Y_M = -0.822\ _{ua}N + 24.046$ for $R^2 = 0.93$	40,49

Table 7. Yield prognosis based on the unassimilated quantity of nitrogen ($_{ua}$N)

5. Soil productivity improvements: The concept of N:P:K fertilizers balance

The simple comparison of CE countries with respect to nutrient management clearly shows, that annual inputs of nitrogen are too high with respect to phosphorus and potassium. Therefore, the main reasons of general yield stagnation in most of the CE countries are long-term negative balances of P and K, caused by low input of both mineral and organic fertilizers. As a consequence of soil P and K long-term mining, the percentage share of soils rich in both nutrients declined in the last two decades below the sufficiency level, which was achieved in many countries in 80s (Csatho at al., 2007; Grzebisz & Fotyma, 2007).

It has been clearly stressed that in *the transition phase of yield development*, the PFP_N indices reached the highest values, resulting in yield gain. This phenomenon emerged in years 1990, 1991 for Poland and Hungary and in 1991, 1992 for the Czech and Slovak Republics. In all these years, the supply of P and K fertilizers was low. In the Czech Republic, ratios between amounts of applied N-P-K fertilizers, expressed as $N:P_2O_5:K_2O$ was 1:0.25:0.25 on average. This structure, in spite of decreased fertilizers' consumption, allowed farmers to achieve the same yields of all crops as in the period 1986-1990. The present structure of nutrient use is as 1:0.15:0.15 for the Czech Republic, and 1:0.4:0.4 for Poland. These disparate nutrient ratios stress the importance of N:P:K balance for high crop production. The proposed N:P:K ratio for the Czech Republic, based on the $cPFP_N$ index, can be established at the level of 1:0.25:0.25 in *good years*, i.e., under ample water supply or 1:0.25:0.50 in *unfavorable years*, i.e., under expected water stress. Hence, keeping the current level of fertilizers' consumption on arable land, *ca* 130 kg ha^{-1}, one can predict the right amount of nutrients to apply. In Poland, the total amount of currently consumed fertilizers is almost the same as in the Czech

Republic. Unfortunately, soils in Poland are much poorer in potassium and also in phosphorus, being therefore, highly sensitive to external supply of nutrients. This conclusion is corroborated by positive trends of yields in response to P and K fertilizers application, as found for all crops since 1991 onwards. Consequently, under favorable weather conditions, or on soils naturally rich in potassium, the suggested formulation of N-P-K fertilizers is as follows: 1:0.33:0.66, but in years with high probability of drought or on areas sensitive to drought, a slightly different formulation is recommended, namely 1.0:0.5:1.0.

It is not easy to formulate any efficient fertilizing strategy for Romania. Since mid- 90s, maize and wheat have shown yield stagnation at a very low level. The main factors responsible for this situation are i) low N fertilization rates, ii) imbalanced use of P and K fertilizers. Therefore, yields of these two crops are, in fact, dependent only on the seasonal weather course, fluctuating for *ca* 100% on a yearly scale basis. The main reason is unbalanced consumption of basic fertilizers, which leads to permanent soil mining, especially potassium. The $N:P_2O_5:K_2O$ relationships, averaged for the period 2004-2008, as 1:0.27:0.09 is not sufficient to get any yield increase or even its stabilization. Potassium accumulates in plant tissues in much higher amounts and is considered as useful nutrient in water management (Cakmak, 2005). Thereby, this nutrient seems to be crucial for crop production in Romania, even taking into account, that almost 50% of land area is covered by soil naturally rich in minerals containing K. In spite of low N consumption, but unbalanced nutrient management, there is still a space for an extra N loss for both key crops, i.e., wheat and maize (see Fig. 7). Therefore, it could be concluded, that any yield increase depends on both significant N rate rise and simultaneous change of fertilizer formulations. The operational N-P-K fertilizers ratios suggested for Romania are as follows: 1:0.33:0.17 in *favorable* and 1:0.4:0.4 in *unfavorable* years. The second scenario should aim at increasing plant survival under drought conditions.

6. Thoughts and prospects

The new era of agriculture development in the Central Europe revealed how actual agriculture outcomes in this region depend on three key factors, presented in descending order: i) weather conditions during the growth season, ii) inherent soil fertility, iii) nitrogen fertilizer consumption. At present, the first factor is decisive for crop production. High year-to-year yield variability reflects the imbalanced use of soil and external resources such as fertilizers. Therefore, maximum attainable yields, i.e., limited by water supply, for example for wheat, are not attainable in all countries of the region. In Germany, also part of the Central European region, actual yields are above the "water limited" level (Rabbinge & Diepen, 2000; Supit et al., 2010).

Inherent differences in the nature of soil quality between the CE countries, as a background of nutrient management, are strictly related to the soil origin (Plant et al., 2005). Except for Poland, all other countries are relatively rich in soils originated from loams (Cambisols) and loess (Chernozems). These soils exhibit a high inherent potential for supplying K and other cations, such as calcium and magnesium (Nikolova, 1998).

However, at present nutritional requirements of high yielding crops, most of the CE countries are almost entirely oriented on the third yield forming factor, i.e., nitrogen fertilizer use. It has been well recognized, that a balanced supply of external sources of slowly mobile elements, such as phosphorus and potassium is broadly expected (Atkinson et al., 2005; Struik & Bonciarelli, 1997). Consequently, the average actual and attainable yields of main crops in CE countries are much more related to the soil-adjusted potential, than to amounts of currently applied fertilizers. As a result, CE countries show at present much greater differences in agricultural production than at the end of the 80s.

The observed unfavorable patterns of N fertilizer long-term consumption creates problems not only for agriculture production, but are also potentially dangerous for the environment as a potential source of *reactive nitrogen* (Roberts, 2006). There are three main questions to be urgently answered by specialists in all countries of the CE region: i) do farmers really recognize an increasing yield gap?, ii) what is the reason for farmers and their advisory services to tolerate low efficiency of nitrogen? iii) do farmers and advisory services recognize environmental aspects of the increasing amount of residual nitrogen?! In order to get answers to these questions one has to be familiar with factors contributing to the improvement in N fertilizer use efficiency:

1. Farm management of N in terms of i) N rate quantification, ii) time of N fertilizers application and iii) method of N fertilizers application.
2. Management of nutrients responsible for the efficiency of N uptake and it in-plant transformation;
3. Management of production factors other than N.

The first problem is not only of technical nature, because it affects in-season nitrogen use efficiency, and in turn actual yields' variability. However, CE countries representing the restoration type of yield development, but at the same time unbalanced pattern of consumed fertilizers do not indicate needs for increasing actually applied N rates. This strategy is, to some extent, the core of yield improvement in countries presenting stagnated type of fertilizers' management, provided that any increase in N use will be compensated by adequate amounts of applied phosphorus and potassium.

It could finally be concluded, that the realization of both goals of agricultural production in the CE countries, i.e., i) long-term yield stabilization and even its increase and ii) unit productivity of the applied fertilizer N increase, in turn decreasing amounts of the residual N, requires in the coming future changes in the structure of fertilizers' consumption, keeping in the Unbalanced group of countries the same level of applied fertilizers. The problem of nutrients supply to a growing plant does not however refer only to the balanced amounts of the applied fertilizers, but also to the crop accessibility to soil natural nutrient pools. This problem is inherently related to conditions of root system growth in the soil body. There are a lot of factors limiting roots accessibility to water and nutrients, even in soils of high natural fertility, which have been forgotten in the last 50 years, but the most important is soil acidy and related toxicity of aluminum (Atkinson et al., 2005; Diatta et al., 2010; Marschner, 1991; Struik and Bonciarelli, 1997). The key strategic target for farmers is to increase soil volume directly occupied by plant roots in order to improve their access to unavailable pools of nutrients. Three main areas of soil productivity improvement *via* increasing crop plants accessibility to nutrients in the subsoil, at least may be considered: i) regulation of soil reaction ii) increase of organic matter content iii) removing of any kind of hardpans. It seems highly probable, that in the case of Poland all three groups of measures are important. In other countries of the CE soil acidity should be considered as an agronomical problem for farmers conducting production on Luvisols.

7. References

Atkinson, A.; Black, K. & Dawson, L. (2005). Prospects, advantages and limitations of future crop production systems dependent upon the management processes. *Annals of Applied Biology* Vol. 146, pp. 203-215, ISSN 1744-7348

Batjes, H. (2002). Carbon and nitrogen stocks in the soils of Central and Eastern Europe. *Soil Use Management,* Vol. 18, pp. 324-329, ISSN 1475-2743

Cakmak, I. (2005). The role of potassium in alleviating detrimental effects of abiotic stresses in plants. *Journal of Plant Nutrition Soil Science,* Vol. 168, pp. 521-530, ISSN 1436-8730

Catt, J. (2001). The agricultural importance of loess. *Earth-Science Reviews,* Vol. 54, pp. 213-229, ISSN 0012-8252

Cochrane, N. (2004). EU Enlargement: Implications for U.S._EU agricultural relations. *U.S.-EU Food and Agriculture Comaprison*/WRS-04-04, 78-86. Available online at: http://www.ers.usda.gov/publications/WRS0404/WRS0404.pdf (Access 2011.05.24).

Csatho, P.; Sisak, I. & Radimszky, L. (2007). Agriculture as a source of phosphorus causing eutrophication in Central and Eastern Europe. *Soil Use management,* Vol. 23 (suppl. 1), pp. 36-56, ISSN 1475-2743

Csatho, P. & Radimszky, L. (2009). Two Worlds within EU27: Sharp Contrasts in Organic and Mineral Nitrogen-Phosphorus Use, Nitrogen-Phosphorus Balances, and Soil Phosphorus Status: Widening and Deepening Gap between Western and Central Europe. *Communications in Soil Science and Plant Analysis,* Vol. 40, pp. 999-1019, ISSN 0010-3624

Diatta, J.; Bocianowski, J. & Skubiszewska, A. (2010). Sulphate-based aluminum phytotoxicity mitigation under strong soil acidification. *Fresenius Environmental Bulletin*, Vol. 19, No. 12b, pp. 3185-3192, ISSN 1018-4619

Dibb, D. (2000). The mysteries (myths) of nutrient use efficiency. *Better Crops,* Vol. 84, No. 3, pp. 3–5, ISSN 0006-0089

Dobermann, A. & Cassman, K. (2002). Plant nutrient management for enhanced productivity in intensive grain production systems of the United States and Asia. *Plant and Soil,* Vol. 247, pp. 153-175, ISSN 1573-5036

Evans, L. & Fisher, R. (1999). Yield potential: its definition, measurement and significance. *Crop Science,* Vol. 39, pp. 1544-1551, ISSN 1896-0782

Falloon, P. & Betts, R. (2010). Climate impacts on European agriculture and water management in the context of adaptation and mitigation – the importance of integrated approach. *Science of Total Environment,* Vol. 408, pp. 5667-5687, ISSN 0048-9697

FAOSTAT. Available online at: http://faostat.fao.org/default.aspx. (Access 2011.05.24).

Fixen, P. (2004). Phases in narrowing the yield gap. *Better Crops*, Vol. 88, No. 4., p. 3, ISSN 0006-0089

Fronzek, S. & Carter, T. (2007). Assessing uncertainties in climate change impacts on resource potential for Europe based on projections from RCMs and GCMs. *Climate Change,* Vol. 81, pp. 357-371, ISSN 1758-6798

Grzebisz, W. & Fotyma, M. (2007). Recommendations and use of potassium fertilizers in Central-Eastern Europe (CEE). In: *Proceedings International Fertiliser Society*, No. 621, York, UK, pp 24, ISBN 978-0-85310-258-8

Grzebisz, W.; Diatta, J. & Haerdter, R. (2010). Fertilizer consumption patterns in Central European countries – effect on actual yield development trends in 1986-2005 years - a comparative study of the Czech Republic and Poland. *Journal of Central European Agriculture,* Vol. 11, No. 1, pp. 73-82, ISSN 1332-9049

IFADATA Statistics online. (2011). www.fertilizer.org/ifa/statistics/ifadata /dataline.asp, (Access, 2011.05.24)

Jongman, R.; Bunce, R. & Metzger, R. (2006). Objectives and applications of a statistical environmental stratification of Europe. *Landscape Ecology,* 21, 409-419, ISSN 1572-9761

Karlen, D.; Ditzler, C. & Andrews, S. (2003). Soil quality: why and how?! *Geoderma,* Vol. 114, pp. 145-156, ISSN 0016-7061

Kelch, D. & Osborne, S. (2001). Crop production capacity in Europe" Economic Research Service/USDA, *Agricultural outlook*/March 2001, 19-23, ISSN 0099-1066

Marschner, H. (1991). Mechanisms of adaptation of plants to acid soils. *Plant and Soil,* 134, 1-20, ISSN 1573-5036

Neumann, K.; Verburg, P. & Stehfest, E. (2010). The yield gap of global production: a spatial analysis. *Agricultural Systems,* Vol. 103, pp. 316-326, ISSN 0308-521X

Nikolova, M. (1998). The soil potassium resources and the efficiency of potassium fertilizers in Bulgaria. Nikola Poushkarow Inst. of Soil Science and Agroecology, Sofia, Bulgaria. *IPI, Country Report,* 12, 39 pp.

Olesen, J. & Bindi, M. (2002). Consequences of climate change for European agricultural productivity, land use and policy. *European Journal of Agronomy,* Vol. 16, pp. 239-262, ISSN 1161-0301

Olesen, J.; Trnka, M. & Kersebaum, K. (2011). Impacts and adaptation of European crop production systems to climate change. *European Journal of Agronomy,* Vol. 34, pp. 96-112, ISSN 1161-0301

Plant, J.; Whittaker, A. & Demitriades, B. (2005). The geological and tectonic framework of Europe. *Geochemical Atlas of Europe*. Part 1. *Background Information, Methodology* Ed. Salminen R. Maps. GTK, FOREGS, 20 pp., ISBN 951-690-956-6

Rabbinge, R. (1993). The ecological background of food production. In: *Crop protection and sustainable agriculture*. Wiley, Chichester (Ciba Foundation Symposium 177, 2-29, ISBN 10 0471939447

Rabbinge, R. & Diepen, C. (2000). Changes in agriculture and land use in Europe. *European Journal of Agronomy,* Vol. 13, pp. 85-100, ISSN 1161-0301

Reilly, J., Fuglie, K., (1998). Future yield growth in field crops: what evidence exists? *Soil & Tillage Research* Vol. 47, pp. 275-290. ISSN 0168-1987

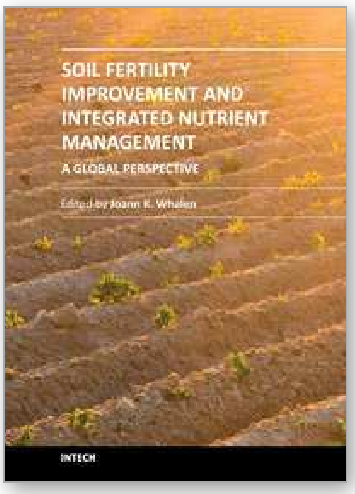
Roberts, T. (2006). Improving Nutrient Use Efficiency. *Proceedings of the IFA Agriculture Conference: Optimizing Resource Use Efficiency for Sustainable Intensification of Agriculture*, 27 february-2 March, 2006, Kunming, China, pp 8.

Rosegrant, M.; Paisner, M. & Meijer, S. (2001). Global Food Projections to 2020, Emerging trends and alternative futures. *IFPRI*, pp 206, ISBN 0-89629-640-7

Sinclair, T.; Purcell, L. & Sneller, C. (2004). Crop transformation and the challenge to increase yield potential. *Trends in Plant Science,* Vol. 9, No. 2, pp. 70-75, ISSN 1360/85

Struik, P. & Bonciarelli, F. (1997). Resource use at the cropping system level. *European Journal of Agronomy,* Vol. 7, pp. 133-143, ISSN 1161-0301

Supit, I.; van Diepen, C. & de Wit, A. (2010). Recent changes in the climatic yield potential of various crops in Europe. *Agricultural Systems,* Vol. 103, pp. 683-694, ISSN 0308-521X



Soil Fertility Improvement and Integrated Nutrient Management - A Global Perspective
Edited by Dr. Joann Whalen

ISBN 978-953-307-945-5
Hard cover, 306 pages
Publisher InTech
Published online 24, February, 2012
Published in print edition February, 2012

Soil Fertility Improvement and Integrated Nutrient Management: A Global Perspective presents 15 invited chapters written by leading soil fertility experts. The book is organized around three themes. The first theme is Soil Mapping and Soil Fertility Testing, describing spatial heterogeneity in soil nutrients within natural and managed ecosystems, as well as up-to-date soil testing methods and information on how soil fertility indicators respond to agricultural practices. The second theme, Organic and Inorganic Amendments for Soil Fertility Improvement, describes fertilizing materials that provide important amounts of essential nutrients for plants.The third theme, Integrated Nutrient Management Planning: Case Studies From Central Europe, South America, and Africa, highlights the principles of integrated nutrient management. Additionally, it gives case studies explaining how this approach has been implemented successfully across large geographic regions, and at local scales, to improve the productivity of staple crops and forages.

How to reference
In order to correctly reference this scholarly work, feel free to copy and paste the following:

Witold Grzebisz and Jean Diatta (2012). Constraints and Solutions to Maintain Soil Productivity: A Case Study from Central Europe, Soil Fertility Improvement and Integrated Nutrient Management - A Global Perspective, Dr. Joann Whalen (Ed.), ISBN: 978-953-307-945-5, InTech, Available from: http://www.intechopen.com/books/soil-fertility-improvement-and-integrated-nutrient-management-a-global-perspective/constraints-and-solutions-to-maintain-soil-productivity-a-case-study-from-central-europe

InTech Europe
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821