Long term experiments as a tool for solving current problems in agriculture – a case of Poland

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Introduction – long-terms experiments and current environmental problems

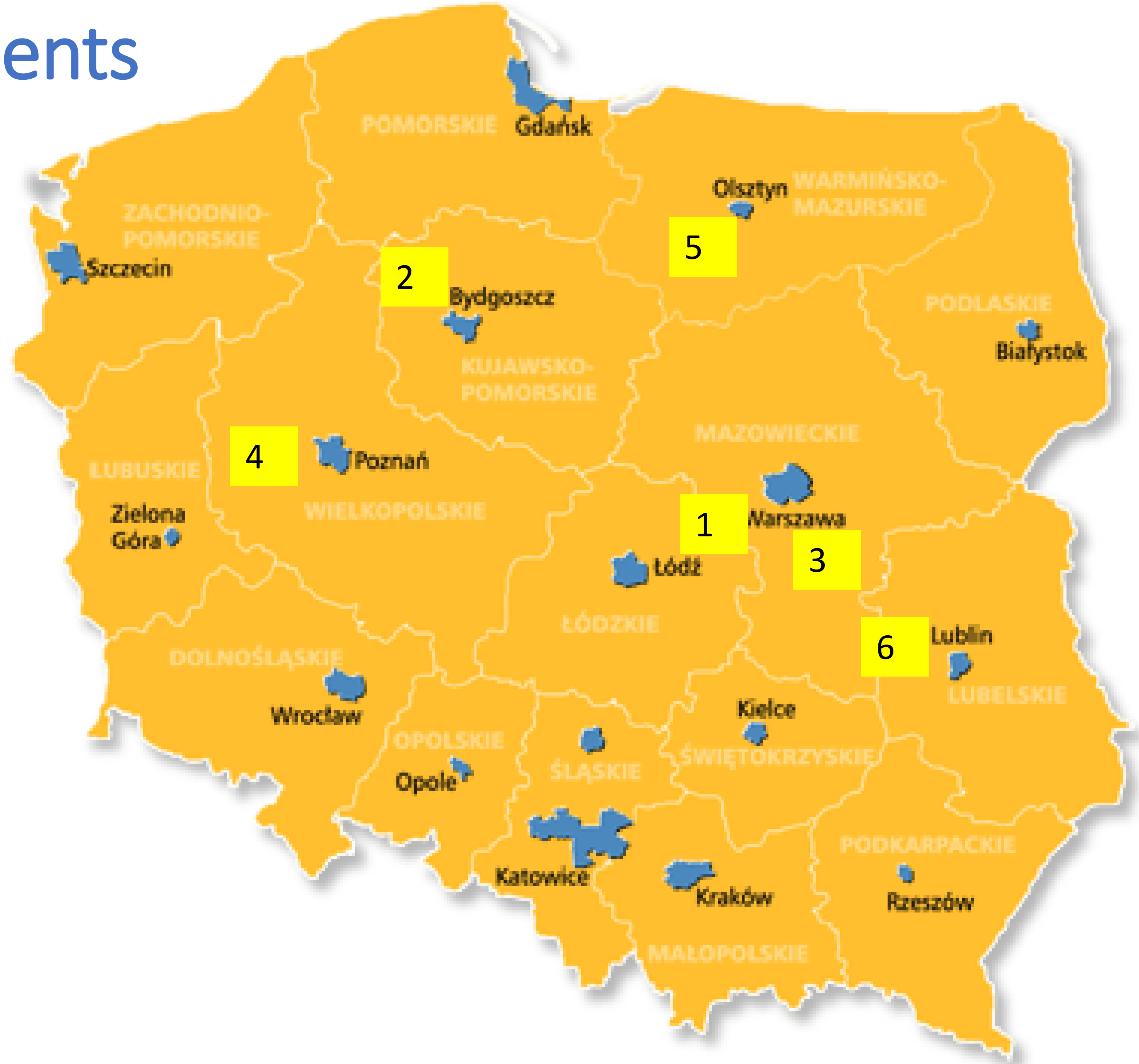
- Initially, the main objectives of the long-term experiments were to assess the effects of crops and fertilization on soil properties and plant yield.
- Currently, the aim is recognize long-term changes in the environment and to ensure the long-term sustainability of ecosystems, adaptation of agricultural practices to a changing climate, as well as to study negative effects of agricultural practices (e.g. nitrate leaching, greenhouse gas emissions)
- It is necessary to simulate models of nutrient cycling in agro-ecosystems, which can be used to predict the impact of global environmental (mainly climate) changes on soil quality and crop yield potential
- They are able to the identify the best agricultural practices that will help maintain soil fertility for decades and at the same time to facilitate the adaptation to the climate change
- The biggest challenges and problems related to: frequent droughts and negative water balance, low soil organic matter content; decreasing recycling of nutrients in manures, increasing soil acidity, high share of cereals in crop rotation; decrease in biodiversity, and low nitrogen use efficiency

Long-term experiments in Poland, the oldest and still functioning today

1. Experimental Station in Skierniewice (Warsow University of Life Sciences), exp. established in year 1923
2. Experimental Station in Mochełek (University of Technology in Bydgoszcz); since 1948
3. Experimental Station in Chylice (Warsow University of Life Sciences), since 1955
4. Experimental Station in Brody (Poznan University of Life Sciences), since 1957
5. Experimental Station in Bałcyny (University of Warmia and Mazury in Olsztyn), since 1967
6. Experimental Station in Grabów (Institute of Soil Science and Plant Cultivation (IUNG) in Puławy), since 1969

Location of experiments

Skierniewice, 51°58’N; 20°10’E	1
Mochełek, 53°13’N; 17°51’E	2
Chylice, 52°06’N; 20°33’E	3
Brody, 52°26’N; 16°18’E	4
Bałcyny, 53.66, 19.78	5
Grabów, 51°21’N; 21°40’E	6



Experimental Station in Skierniewice (Warsow University of Life Sciences) – basic information

- The oldest fertilization and crop rotation experience in Poland - established in 1923
- The experiment was continued even during the World War II
- Meteorological measurements have been carried out since 1921
- The experiment was established on soil: *Stagnic Luvisols* (according to WRB); texture in the topsoil – loamy sand
- The long-term experiment cover an area of approximately 5 ha, in 24 fields with a total of 588 plots

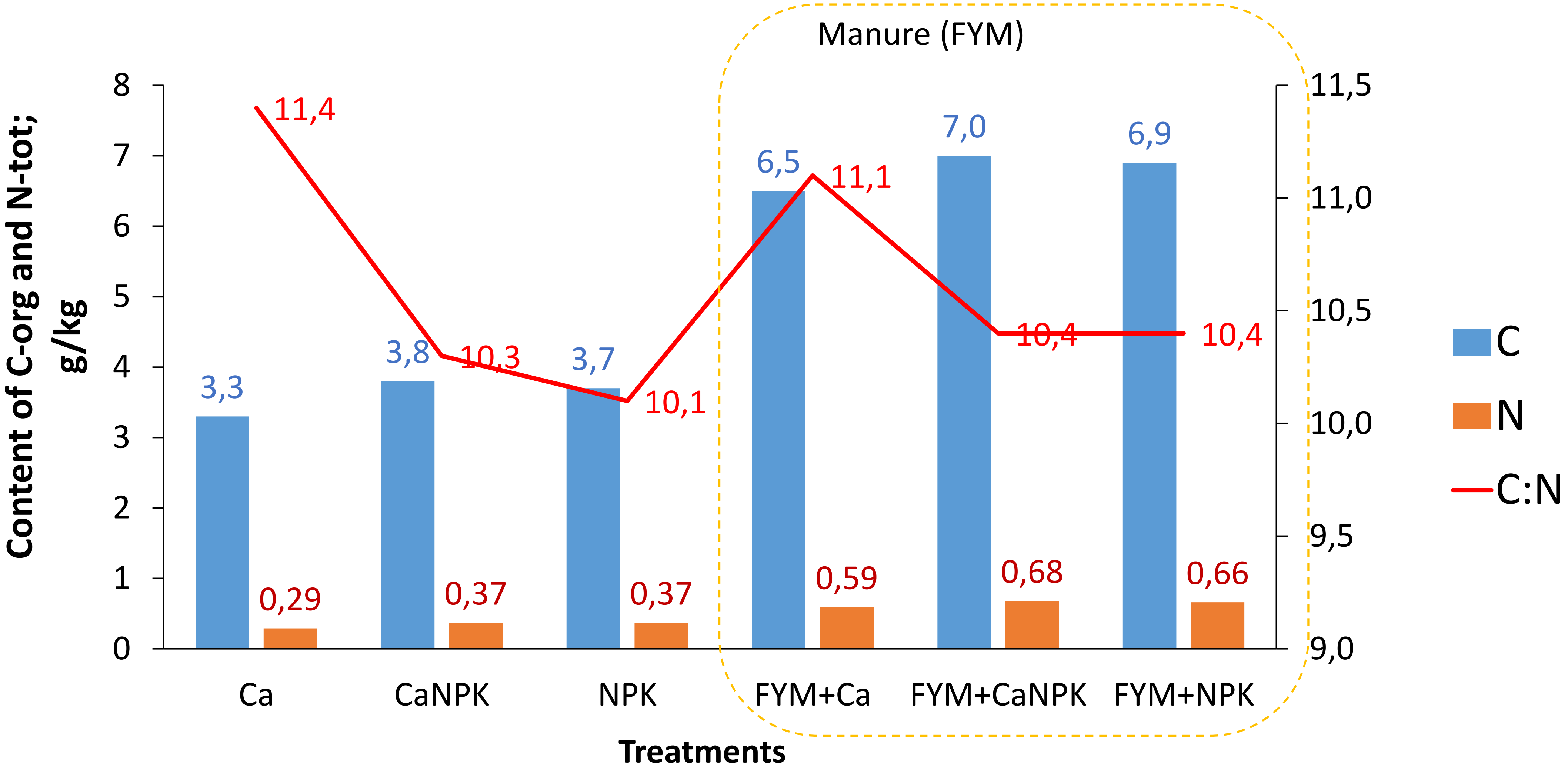
Fertilization treatments* and crop rotation in Skierniewicach

<table>
<tr><th>Field no.</th><th colspan="2">Crop rotation, form of nitrogen fertilizers</th><th>Treatments</th></tr>
<tr><td>A_{1-4}</td><td colspan="2">acid soil; various rotations of plants, without of manure, and without fabaceae; NH_4NO_3</td><td rowspan="2">O
CaNPK
NPK
PK
NP
NK</td></tr>
<tr><td>AF_{1-3}</td><td colspan="2">very acid soil; various rotations of plants, without of manure, and without of fabaceae; NH_4SO_4</td></tr>
<tr><td>A_{5-8}</td><td rowspan="2">various rotations of plants, without of manure</td><td>without fabaceae</td><td rowspan="5">Ca
CaNPK
NPK
CaPK
CaNP
CaNK
Manure</td></tr>
<tr><td>A_{9-11}</td><td>with of fabaceae</td></tr>
<tr><td>E_{1-5}</td><td colspan="2">5-field rotation: potato + 30 t/ha manure; spring barley; red clover (or lupine); winter wheat; rye; NH_4NO_3</td></tr>
<tr><td>D_5</td><td colspan="2">potato continuous monoculture, NH_4NO_3</td></tr>
<tr><td>D_6</td><td colspan="2">rye continuous monoculture, NH_4NO_3</td></tr>
</table>

* **Since 1976**: 1,6 t/ha CaO every 4-5 years; 90 kg N; 26 kg P; 91 kg K na 1 ha.

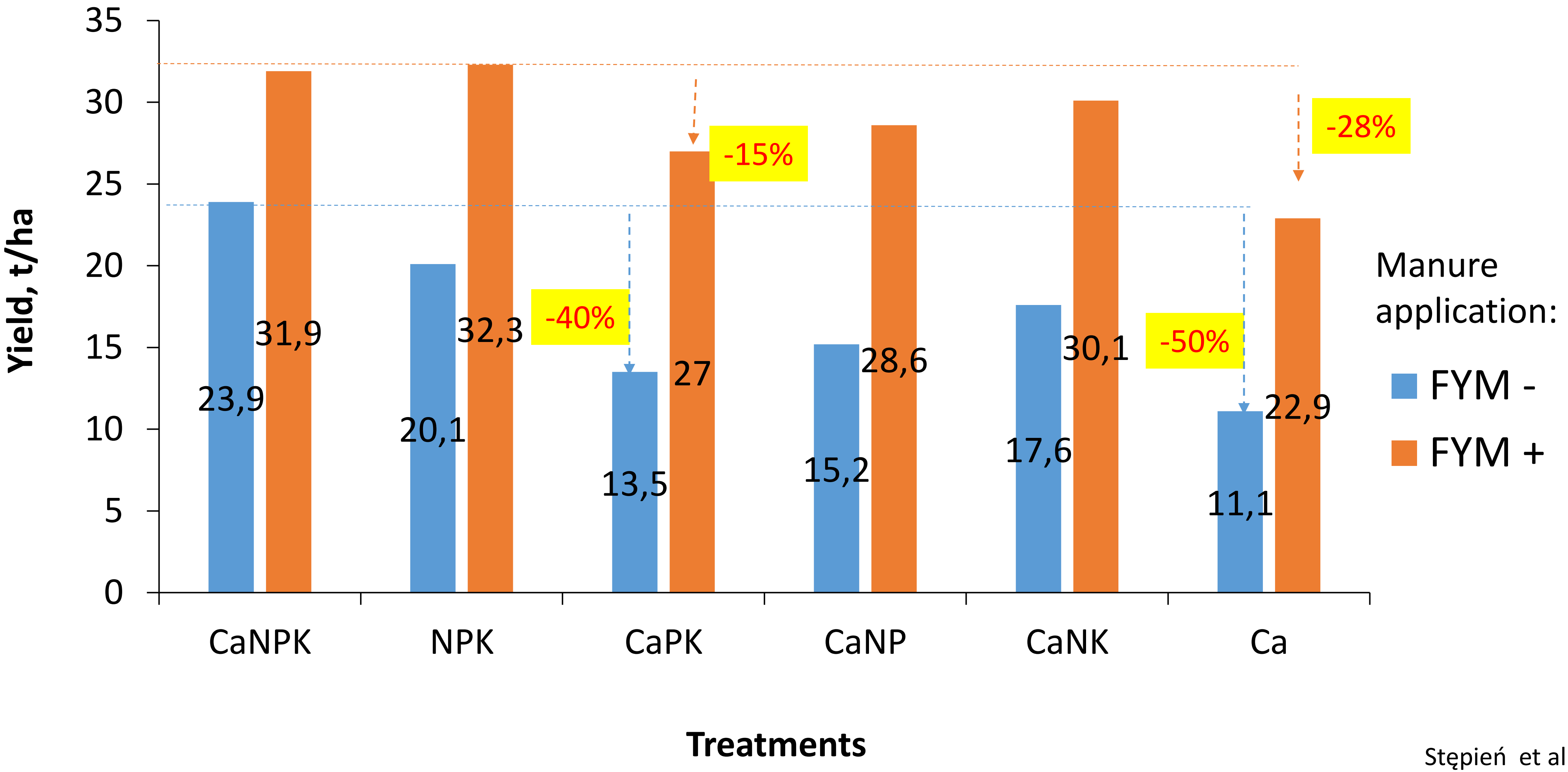
Stępień et al. 2018

Skierniewice: C_{org} and N_{tot} content in the topsoil and the C: N ratio; after 90 years of experience



Stępień et al. 2018

Skierniewice: Effect of fertilization treatments on potato yield (1995-2015) and decrease in yield as compared to CaNPK



Stępień et al. 2018

Chylice (Warsow University of Life Sciences) – basic information and purpose of research

- The experiment was established in 1955
- Gleba: *Endogleyic Phaeozem**; humus horyzont 30-35 cm; texture - sandy loam; a good quality (class IIIa)

- Assessment of the effect of mineral fertilization, manure and mineral fertilization + manure used in two crop rotations on:
  - Physical, chemical and microbiological properties of soil
  - The number and weight of weeds
  - Plant growth and yield

*the share of black earth (*Endogleyic Phaeozem*) in Poland is small, only 1%

Chylice – experiment disign

Factor I. Crop rotation:

a. with Fabaceae (od 1990: sugar beet – spring barley – red clover – winter wheat)
b. without Fabaceae (od 1990: sugar beet – spring barley – winter oilseed rape– winter wheat)

Factor II. Fertilization treatments:

a. Mineral fertilization, NPK*
b. Manure in autumn (40, 20, 0 lub 20, 20 t/ha, for successive plants in rotation)
c. ½ manure + ½ NPK
d. Control (without fertilization)

*NPK = 200/100/0 lub 100/100; 56/36,5/36,5/36,5/; 200/91,5/91,5/91,5 for successive plants in rotation

Chylice - the most important conclusions *

1. After 40 years, it was found that a Norfolk rotation with a legume plant increased the C-org content by 40% compared to a rotation without a legume plant
2. In recent years, the content of C-org in variants with FYM and FYM + NPK did not change compared to 1989 or only slightly increased
3. Only NPK fertilization decreased the C-org content
4. Manure fertilization and Norfolk crop rotation had a positive effect on soil structure, soil aggregate stability and water-air properties
5. The highest yields were obtained in NPK or FYM + NPK treatments, despite the fact that FYM positively influenced soil properties. This is due to: slower release of N_{min} from the manure; and NPK fertilization ensured a good supply of plants with P, K, Mg with a relatively small decrease in soil pH

*Source: Suwara et al. 2018

Mochełek – University of Technology in Bydgoszcz – basic information

- The static experiment was established in 1948
- Soil: *Haplic luvisol*, loamy sand in the arable layer, deeper → loam
- Generally the experiment is 1 factor with 14 treatments, and with 5 repetitions
- During the experiment, the fertilization treatments were modified, for example in the years 2001-2010, the second factor was additionally assessed - the intensity of NPK fertilization (see Table)
- The species of cultivated plants also changed, depending on changes in agricultural practice

Mochełek – experimental design (Jaskulska and Urbanowski 2018)

In the years 2001-2010			Since 2011	
Factor I	Factor II		Factor I	Cultivated plants
	level A	level B		
O – control	Liming 1,5 t CaO/ha A - intensive reclamation of nutrients in soil Manure (FYM) once in rotation P_2O_5 = 80 K_2O = 120 N = 30-150 kg depending on the crop	Liming 0,75 t CaO/ha B – not intensive reclamation of nutrients in soil – PK doses = 50% of full doses FYM once in rotation P_2O_5 = 40 K_2O = 60 N = 30-150 kg depending on the crop	½ NPK	Winter rape Winter wheat Pea Winter wheat Spring barley P_2O_5 = 80 K_2O = 120 N = 30-150 kg depending on the crop
Straw (5t/ha) + NPK			Słoma (5t/ha) + NPK	
NPKCa			NPKCa	
NPK			NPK	
FYM 30 t/ha			FYM 50 t/ha	
FYM + PK			FYM + PK	
FYM + NK			FYM + NK	
FYM + NKMg			FYM + NKMg	
FYM + NP			FYM + NP	
FYM + NPMg			FYM + NPMg	
FYM + NPK			FYM + NPK	
FYM + NPKMg			FYM + NPKMg	
FYM + NPKCa			FYM + NPKCa	
FYM + NPKCaMg			FYM + NPKCaMg	

Mochełek - the most important conclusions*

1) Taking into account both soil quality and crop yield, it is most advantageous to use manure in combination with NPK or NP mineral fertilizers, preferably with the addition of Mg and periodic liming. The positive effect of this fertilization system lasts for many years
2) The after-effects of many years of NK fertilization, despite the simultaneous use of manure and Mg, as well as the use of only NPK or NPK + straw, is unfavorable for plant yield
3) In a crop rotation with pea, it is possible to reduce the fertilization level without the risk of a decrease in the wheat yield, and at the same time to obtain grain of the good technological quality

* Source: Jaskulska and Urbanowski 2018

Bałcyny (University of Warmia and Mazury in Olsztyn) – experimental factors

Factor I. Crop succession system

- 5-field crop rotation (A - sugar beet - maize- spring barley - groch- winter whaet; B - potato – oats – flax – winter rye – faba bean – winter triticale)
- Continuous cropping of winter rye, winter wheat, spring barley, maize, sugar beet, faba bean, winter rape

Factor II. Cultivation of two varieties of each of the 12 species

Factor III. The level of chemical plant protection

- Control
- Herbicides
- Herbicides and fungicides

Bałcyny – the most important results*

- Decline effect – a rapid decrease in yields in continuous monoculture, and then stabilization of the yield level, but at a much lower level than in other crop rotations
- Continuous cropping of plants reduces their competitiveness against weeds for the uptake of macronutrients (NPKCa)
- Species tolerance sequences for continuous cropping were established, e.g. wheat is more sensitive among the cereals, followed by triticale, oats, barley and rye

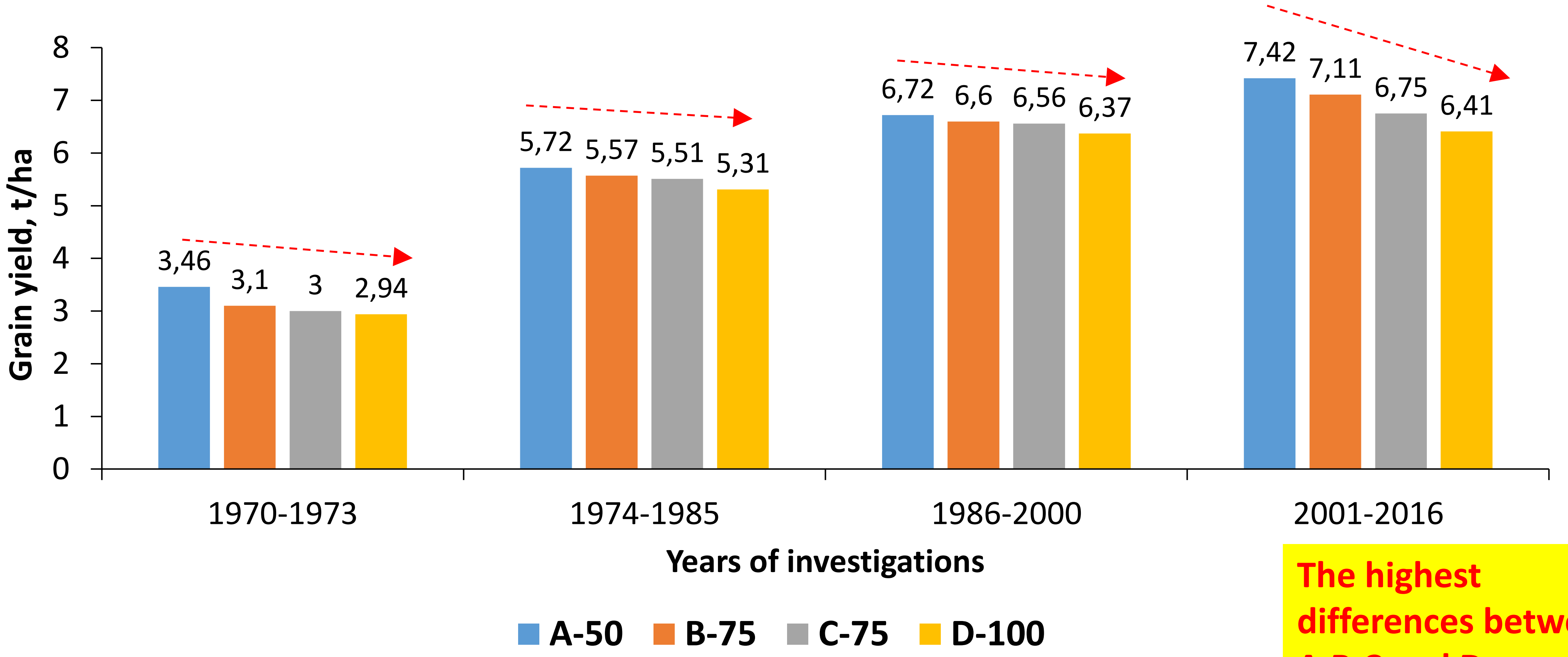
*Source: Marks et al. 2018

Grabów – Institute of Soil Science and Plant Cultivation (IUNG) in Puławy

- The experiment began in 1969
- Soil: haplic luvisols; texture – loamy sand / sandy loam
- 4 crop rotations are a permanent element of the long-term experiment:
  - **A** – participation of cereals in crop rotation = 50% (potato* - forage**- w. wheat - other cereals)
  - **B** – participation of cereals in crop rotation = 75% (potato*- w. wheat – cereal - cereal)
  - **C** – participation of cereals in crop rotation = 75% (forage***- w. wheat -cereal - cereal)
  - **A** – participation of cereals in crop rotation = 100% (oat – w. wheat - winter rye - cereals)
- Factor II. The level of plant protection (control and chemical plant protection)
- Factor III. Levels of mineral fertilization (180 and 160 kg NPK/ha, mean per year)

*FYM 30 t/ha; **forage – winter catch crop – rye or maize for silage; *** oat or fabaceae

Effect of 4-field crop rotations (% share of cereals 50, 75 i 100%) on winter wheat yield



The highest differences between A,B,C and D

*Source: Kuś and Smagacz 2018

Effect of 4-field crop rotations on soil organic matter content, pH and content of plant available P, K and Mg (topsoil)

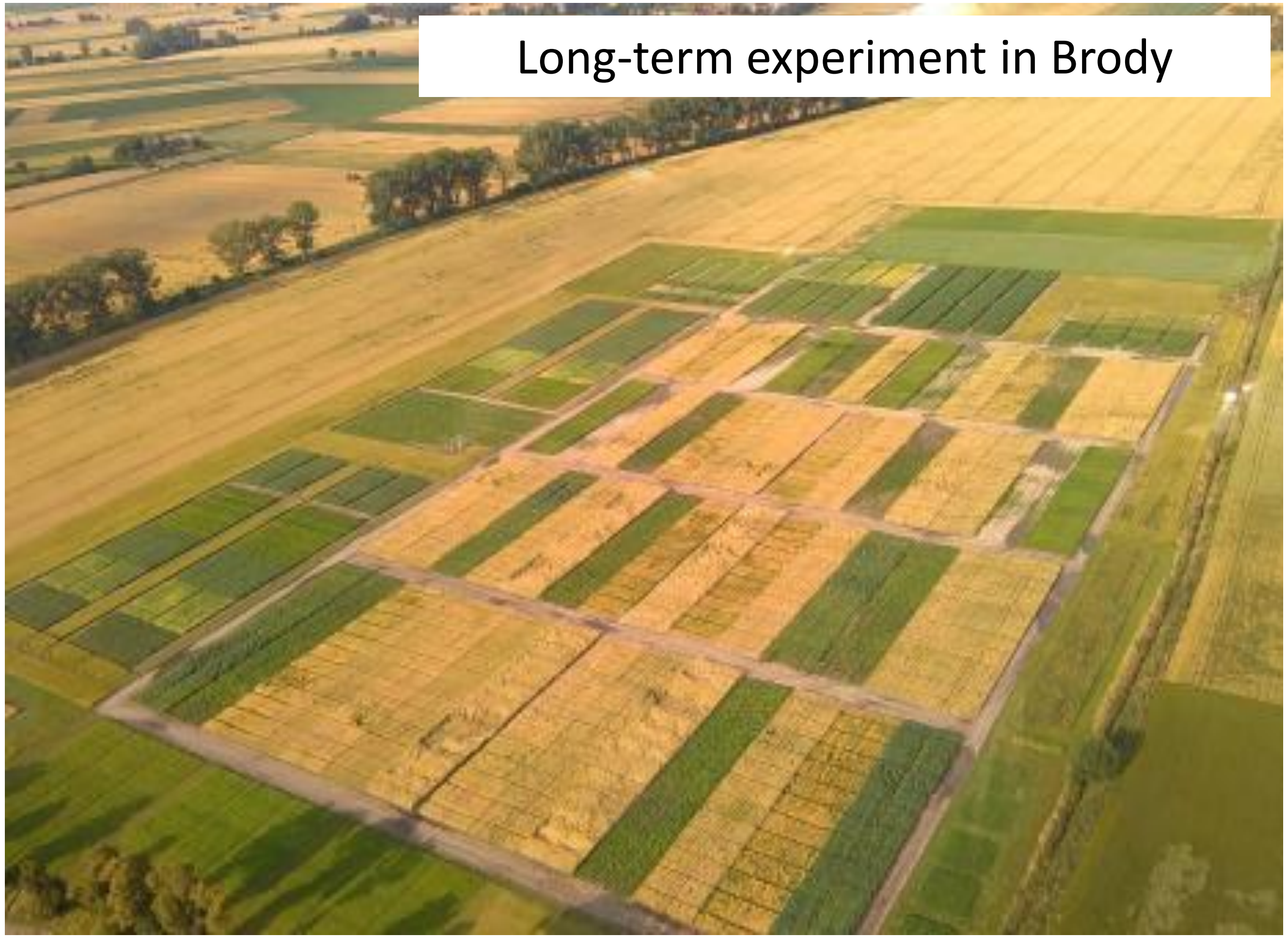
Crop rotation	Soil organic matter, g/kg	pH (KCl)	P, mg/kg	K, mg/kg	Mg, mg/kg
A	13,3	5,8	265	133	78
B	13,2	6,1	321	174	85
C	13,9	6,1	297	187	85
D	14,5	6,2	300	184	87
$LSD_{0.05}$	n.s.	0,29	21,2	21,0	8,4

Long-term use of cereal crop rotation did not adversely affect soil fertility. The low content of nutrients in the soil of system A was due to the cultivation of forage plants consuming large amounts of nutrients.

*Source: Kuś and Smagacz 2018

Brody – Poznan University of Life Sciences

- The experiment was founded in 1957
- Gleba: *Albic luvisols*; texture – loamy sand underlined by loam
- There was a significant increase in the mean annual temperature during the experiment: in the years 1961-1971 → 7,5 °C; 2001-2017 → 9,5 °C
- Precipitation: from 313 to 841 mm



Source: Z. Sawińska, UP Poznan, 2022

Brody – experiment disign

Factor I. Crop succession system

- A. 7-field crop rotation (potato, spring barley, triticale, winter wheat, faba bean, winter wheat, winter wheat, winter rye)
- B. Continuous cropping of winter rye, potato, spring barley, alfalfa(+others), and continuous fallow fields: mown and bare

Factor II. Different treatments of fertilization

- 11 treatments

Brody - fertilizarion treatments and fertilizers doses*

Fertilizers doses	Treatments
• N – 90 kg/ha • P_2O_5 – 60 kg/ha • K_2O – 120 kg/ha • CaO – 1 t/ha (calcium oxide, ground) • Manure – 30 t/ha • $MgO+SO_3$ – 25+50 kg/ha (kieserite)	• Control • Manure • Munure (every 4 years) + NPK • Ca (every 4 years) + NPK • NPK (since 1957) • NP. • NK • PK • N • NPK (since 2014) • NPK+Mg+S

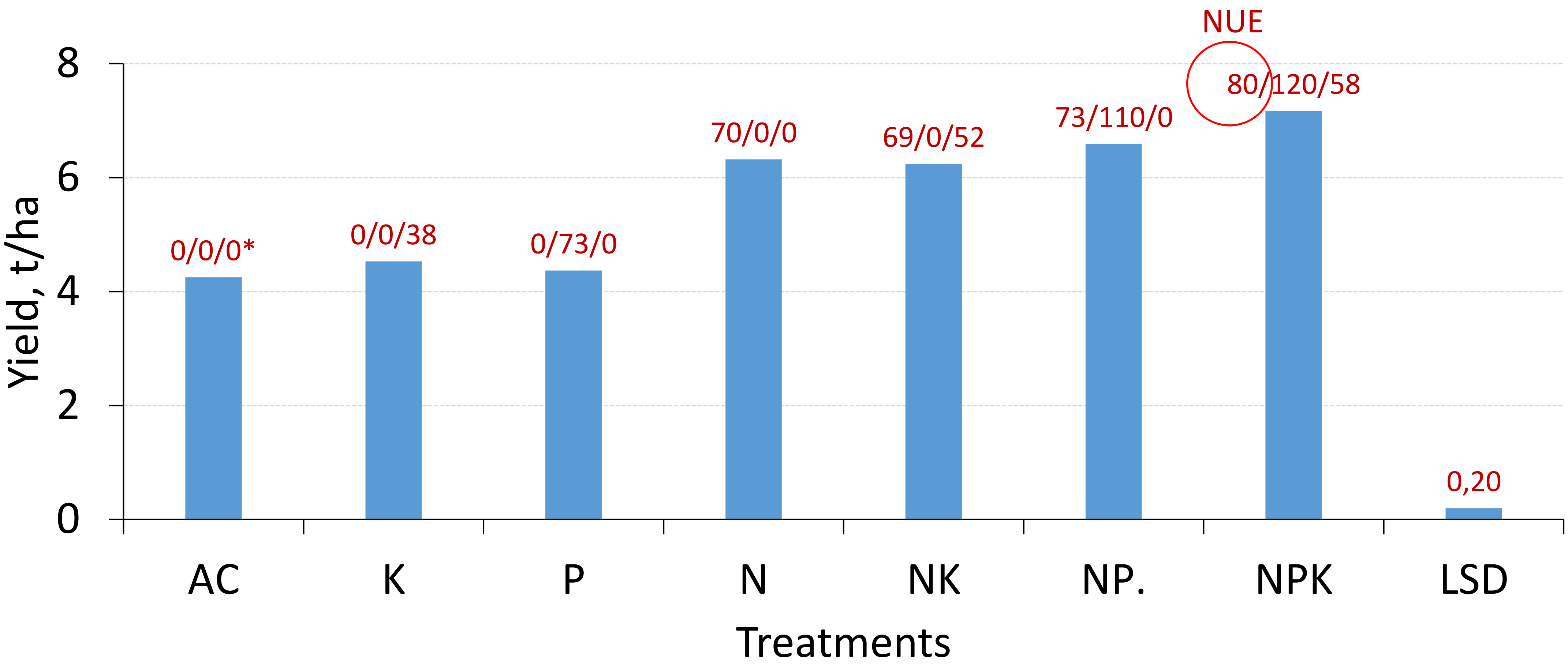
* Blecharczyk et al. 2018

Brody - the most important conclusions *

- Leaving the soil without vegetation (fallow bare) reduced by 50% the content of C-org and N-total
- The diversified system of fertilization and crop rotation resulted in the diversification of the C-org content in the soil
- Systematic fertilization with manure increased the content of C-org and N-total as well as plant-available forms of P, K, Mg
- The greatest reduction in C-org was recorded on plots in monoculture with potato, next spring barley
- Lack of liming increases soil acidification
- After 50 years, the number of weeds increased by 35% in monoculture rye compared to crop rotation, but the weight of weeds increased 9 times
- Continuous cropping of spring barley favors plant infection with *Gaeumannomyces graminis*

Source: Blecharczyk et al. 2018

Effect of long-term differentiated fertilization on yield of winter wheat, mean of 2005-2008 years (based on Blecharczyk et al. 2019)



Legend: AC – absolute control; K, P, N - experimental trials since 1957; LSD – Least Significant Difference; 0/0/0* - respective values of N, P, and K use efficiency

Summary and conclusion

1. Under continuous cropping of plants, the effects of using intensive agro-technics (plant protection chemicals and mineral-organic fertilizers) are largely dependent on changing meteorological conditions (climate)
2. The risk of the yield loss as a result of unfavorable changes in climatic conditions can be minimized by improving soil fertility, increasing N balance by P and K, increasing the number of beneficial soil microorganisms, and inhibition of weed development, pests and diseases
3. The benefits of differential crop rotation and balanced NPK fertilization are stronger in years with unfavorable weather conditions
4. Long-term experiments are enable the identification of best agricultural practices that will help maintain soil fertility for decades and while current data from experiments provide information of an immediate use to farmers

Thank you for your attention!