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GIS in the service of plant breeding in Karcag

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Abstract: Plant varieties bred by the Hungarian Breeding Institutes in different agro-ecological conditions can bear the unfavourable factors of the regions with greater tolerance, so they provide advantages and yield stability for the farmers who choose from these varieties. Farmers can contribute to the genetic potential of the planted seeds with the applied cultivation technology. The stable genetical background (the high quality pre-basic, basic and certified seeds) is provided by plant breeding to the farmers. Breeding is a long and tiring task: the classical breeding process, which usually takes 8–10 years, starts with selecting variety assignments and its growing. Finally new, stable varieties are produced which can provide balanced, high yield and also have good or significant qualitative features among extreme conditions. They can bear the unfavourable conditions of the region with greater tolerance, so provide significant yield stability for the farmers. Space technology supported IT solutions (remote sensing, precision farming and soil-friendly agro-technics) has been introduced into plant breeding methods in Karcag, which greatly support the aims of breeding. The main goal is to provide harmonical growing of the nursery, the large punctuality and to decrease the number and cost of agricultural operations. In this study, the new methods and technologies applied in plant breeding in Karcag are introduced.
Keywords: site-specific plant breeding, GIS methods, remote sensing, precision farming (PF), climate change
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Introduction

The aim of plant breeding is to create new crop varieties which have bigger productivity, increased disease-resistance and provide safe biological base for crop production (Braun et al., 1997). Breeding varieties which can adapt to the local agroecological conditions means the smallest environmental load, the land variety/race can be grown economically and with large stability. Breeding the land varieties which belong to a special landscape also contributes to the environmental sustainability. The comparative advantage of breeding and producing Hungarian wheat is that the growing conditions are appropriate for reaching high yields and good quality (Bedő & Láng, 2019). Globally, sustainable intensification is expected to spread, which reduces GGE[1] with the specific yield-growing because it contributes to the increase of biodiversity on the cultivated area (Popp, 2020). In the decades of climatic change, only the varieties with large plastic-

[1]GGE: Greenhouse Gas Emission

ity, high abiotic and biotic stress-resistance are perspective, so breeding such varieties is a big challenge of our present and must be the long-term aim of breeders (Á. Czimbalmos, 2016). The status of the Hungarian plant breeding and seed production has significantly changed in the last three decades. The seed production area was 313 thousand hectars in 1980, this decreased under 150 thousand hectars by the turn of the Millenium (Bedő, 2004). Although the area decreased, it is good that the share of the certified seed slightly increased, which indicates the quality improve of seed production and propagation. Preserving and improving seed sector is a national interest, it deserves high attention. The interoperability of the markets has extended the opportunities of this sector, but the competition has also grown. The multinational companies with their breeding farms and seed factories are strongly presented in our country. In this taut market situation only those Hungarian breeding houses and seed producers can remain on their feet which can use their comparative advantages well in the production of new varieties. The 21st century has also brought economic seed production and genetically modified plant varieties besides the traditional seed production. From these three tendencies, the genetically modified plant varieties is forbidden by moratorium in Hungary. This situation should be preserved for as long time as possible because the multinational companies can beat the Hungarian plant breeding and seed production industry with their GMO[2] maize and crop hibrides within some years (Heszky, 2008). If the living moratorium ends, only in the seed market of hibrid maize the sector can expect the loss of 300 billion forints (Balla, 2010). What are the comparative advantages which we must build upon? At first, the favourable ecological conditions, the land varieties, the Hungarian experiences and knowledge of breeders and farmers gained over centuries. There are also the latest production systems, geostatistics and GIS applications (Mesterházi, 2018) and Precision Farming (later PF!) and technologies in connection with this new tillage systems which preserve soil moisture (Berényi & Táncziné Óvári, 2018) and decrease drought damage (R. Czimbalmos, 2017; R. Czimbalmos & Kovács, 2017). Agriculture sector agrees that PF became unavoidable in plant breeding and plant production (Takácsné, 2015). The effect of climate change is more and more measurable for decades in our country too. Where does this lead to? The productivity of the soil injures (Stefanovics et al., 1999), our soil is eroded, wind storms erode the surface soil, the organic compounds of the soil decrease (Mátai, 2016). Besides fencing the negative effects of climate change, the role of precision methods, engineering solutions based on computers, sensors and drones will further increase (Szellő, 2018). Based on the satellite signals we can conclude the health condition of the plants from the changing chlorophyll content (NDVI[3]). From the satellite records after adequate transformations the expected product can be evaluated very punctually (Harangi, 2017). We must maximize the yield along the „golden rule"[4] 40–30–30 because the genetic potential of the valuable seed of a breeding variety can be approached only by this method. A breeding institute must also apply the GIS inventions from the last two decades for the complex breeding process (producing

[2]GMO: Genetically Modified Organisms

[3]In remote sensing the Normalised Vegetation Index (NDVI - Normalised Difference Vegetation Index) is a first generation index, shows the photosynthetically active vegetation. For spectral analyse of vegetation between 400 and 700 nm of the visible light and 700–1300 nm of infrared light are the most suitable because of the tissue features of the plants.

[4]The yields of a crop-growing farm are determined 40% by the ecological conditions, 30% by the genetic background of the seed used, and 30% by the applied agrotechnics.

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core material, variety-preserving, breeding, tillage and harvest, properly handling and storing of the core material and the candidate varieties, multiplication of core mixture, pre-basic and basic seed). A production supported by PF technology can lead to give 7-10% additional yield, and the properly chosen variety of seed can still bring additional 25-30% yield (Csurja, Zs., 2020). The proper expertise, knowledge is essential, the complex database of all the breeding varieties must be created, because breeding and cultivation success can depends on the skilled or unskilled humanside (Gönczi, n.d.). Despite the fact that for example in Jász-Nagykun-Szolnok County over one-fourth of the farmers have the workmachines and tractors for the introduction and application of PF and mulch cultivation method, they do not use these systematically (R. Czimbalmos & Kovács, 2017). Our aim is to introduce the primary and secondary data sources, GIS applications which we use and largely contribute to plant breeding, regarding the process of production of pre-basic and basic seed materials. Although the technical – software and hardware – background has been intensively developed for two decades, their explosive spread in daily implementation has not happened yet. The narrow section is not the entry value of these systems, but the lack of proper knowledge and targeted national and EU supports (Takácsné, 2015).

Materials and Methods

The nursery gardens of the plant breeding and variety maintenance department in MATE (Hungarian University of Agriculture and Life Sciences) Karcag Research Institute are found in the most extreme region of the Great Hungarian Plain, with highly dry climate, where the average yearly amount of precipitation is 400–550 mm. The maintenance and breeding of winter wheat, winter barley, winter triticale and alternative plants, production of core mixtures and seed with high productivity take place on the better quality plots (B-1, B-2, I-2, G-2, G-3 and G-4) of the institute, on solonetz meadow chernozem soil (Figure 1 and Figure 2). The area demand of breeding is about 10–12 hectars, beacuse of the isolation distance sorghum plants require larger area every year. The area demand of pre-basic, basic, and certified seed is bigger, between 5–30 hectars. Data collections took place between 2013–2016 (NDVI index) and 2018–2021. The primary aim of breeding is to achieve excellent adaptibility and favourable content parameters (high protein content, favourable amino acid- composition), untimeliness and an excellent drought- and freeze-resistance. Our breeding program is a pedigree selection based on ear selection.

The breeding aim is to create early, high yielded varieties with good stem strength and resistance to unfavourable climatical and soil conditions. With the use of excellent raw materials we create tribes which meet the requirements of the farmers (Á. Czimbalmos et al., 2019). In Karcag breeding the variety sortiment (14 species, 38 variety) is managed with traditional methods, modest area and human resources. High importance of good agrotechnique is given and it is also important to use the scarce resources as efficiently as possible. This is helped by besides breeding and the Accredited Laboratory of the Institute the special agrotechnique of seed production, and by GIS (remote sensing, PF) tools built up at the University of Debrecen. GIS applications and RTK-controlled tractors are the machine backgound which is suitable for GIS software in the office (ArcGIS 9.2, WayQuest, Digiterra Explorer v4, GoogleMaps), on the field, (Thales MobileMapper, Trimble RTK) and in the cultivation system without rotation in the Institute (R. Czimbalmos et al., 2017).

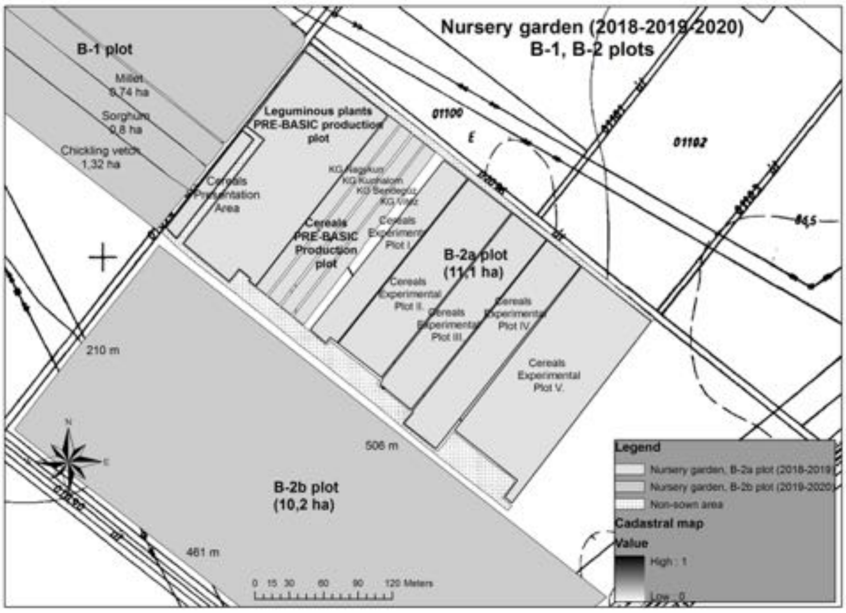

Figure 1: Nursery gardens in B-1, B-2 plots, 2018-2019-2020 (Source: own editing)

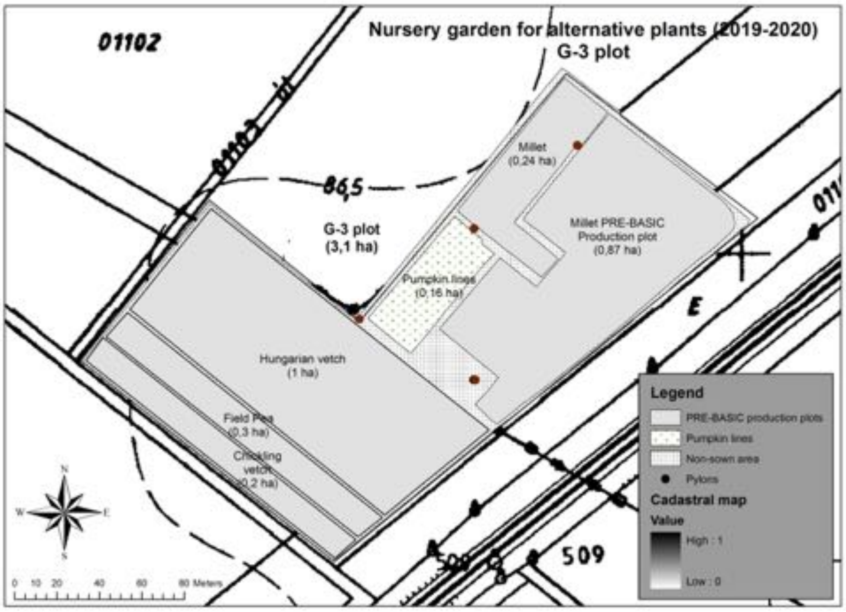

Figure 2: Nursery garden in G-3 plot, 2019/2021 (Source: own editing)

Results

PF applies GIS, geostatistical and remote sensing innovative results in an adaptive way. The results of the research have been applied at operating level and appeared in breeding: very punctual (Differential GPS) soil sample taking, examinations, then the designed differentiated nutrient replenishment plan, within the plot heterogen periodical deep-cultivation, sowing supported with RTK, plant care, cultivation system without rotation (mulch cultivation). The paradigm shift of plant growing – cultivation technol-

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ogy change, digitalisation and PF– was not unexpected for GIS research of the Institute. Only with this complex technology the need of fuel, fertilizer, seed and live labor use for area unit can be decreased without yield and quality loss. Breeding starts with choosing the perfect nursery garden, then the demanding soil preparation considering the suitable isolation distances and pre-crops. During data collection and data processing we use the *primary* (own measurements, that are more expensive) and the much cheaper, *secondary sources* (GIS databases, satellite records, attributive databases). During design of nursery garden the field measures, measurement of parcels with traditional method are time-consuming besides local knowledge and observing professional aspects.

- This is specified – within *the primary data collection* – by the high-punctual hand GPS devices, which can do the following exercises: measure regular and irregular poligons, fixing corner points, measure field barriers, point-like establishments, control length- and area measures, survey of areas exposed by vis maior events, designing and fixing soil sample taking points, soil sample taking, making nutrient supply and other thematic maps, navigation onto specified points, yearly area measures etc. After submetre-punctual field measure, making the soil plans of the nursery gardens happens in the office with the use of field data with centimetre accuracy. At first, we make a digital sketch of the nursery gardens of all the species and varieties with field barriers, borders, cultivation roads and high-voltage columns. The cadastral map give the basic to create the map of the agricultural parcels, on which we overlay our own new thematic maps. Using ArcGIS, we edit the actual nursery garden with the correct size for the given year, the new thematic map (in this study the map and attributive database of the 2019/2020 and 2020/2021 growing season). After the official planning the thematic map is the raw material for the scientists and assistants, who measure the parcels on the field and do the breeding tasks. After the necessary soil tillage operation winter species are sowed with a special small parcel, computer-controlled, high-accuracy, self-propelled seeding machine. In the phenophase the corner points and poligons of the parcels are re-fixed with GPS, edited and we get the final thematic map databases of the nursery gardens (Figure 1). Here parcels, rotation areas, not cultivated areas, and the parcels of summer species, the poligons of the new experiments with necessary basic information (name, measure, treatments, databases of photos and videos, the primary data sources) appear in detailed and cm-punctual. The autumn and spring soil cultivation, soil preparation minimized turns of machinery use, according to the protocol of cultivation system without rotation (mulch cultivation).
- Within *the secondary data collection* in late-spring early-summer when the vegetative mass production are in the most intesive phase, we can start NDVI examination on the plots with LANDSAT satellite images. The aim of image analysis is to evaluate the amount of yield and the loss of yield. Rouse et al. (1973) developed an index, which characterizes the biophysical condition of plant cover (Gulácsi – Kovács 2015). NDVI correlates with the specific chlorophyll content of the plant cover on the area (Mika et al. 2011). The higher value of the index

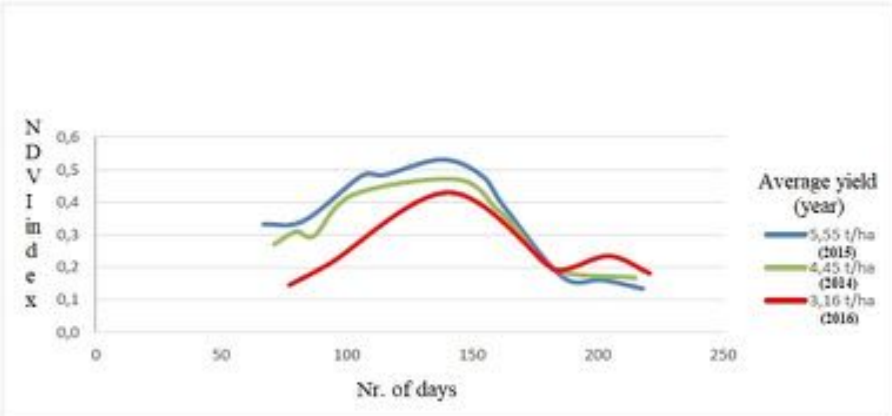

Figure 3: The correlation between different average wheat yields and yearly NDVI (Source: Harangi)

shows the higher vitality and photosynthetic capacity of the leaves, so the healthy, larger biomass vegetation has larger ratio between the near infrared and red reflectancy values than the smaller biomass vegetation (Burai – Tamás 2005). Accordingly this vegetation index can be used well for biomass examinations. This kind of research of our Institute – with the instructors of University of Debrecen – began in 2016 and mainly concentrated to the NDVI examination.

After processing wheat yield data between 2013-2016, the annual meteorological data, the processed satellite records, according to a method in a thesis (Harangi, 2017) there are the following results: we can follow the lifecycle of plants from stem grow to harvest with derived reflectance curves of NDVI values. The highest values of the wheat curves indicate the start of the total ripening phase, when plants have the highest water content. At this point the expected yield can be concluded. Decrease of the NDVI values on the day 150 of the year (the end of May – the beginning of June) shows the gradual reduction of the chlorophyll content, when the plant loses its moisture content. The curves are falling until the harvest, then after the harvest the different curves show similar values with some smaller differences. In the compared period the average yields of wheat varieties of our Institute indicate similarity to the measured NDVI values (Figure 3).

Discussion

During the classical breeding methods with the applied GIS methods, soil-friendly-, moisture retaining cultivation methods without rotation, plant breeding is done in better quality, with less human source and lower cost. Our conclusions:

- Besides good genetical seeds Precision Farming can increase the yield, crop safety, decrease producing costs and contribute to the long-term sustainable farming.
- The primary – more expensive, bigger human source-need – data collection methods are unavoidable, but these must be completed with secondary data collection methods.
- One of the secondary methods is to use satellite images for evaluating yield: before harvest the expected average yield can be evaluated with the unique NDVI reflectance curve which is specific for the plant species. The condition of the evaluation punctuality s

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to have weather data on the day of the orthoimagery. On the studied field the weeds and the amount of the precipitation can influence the reflectance curves of evaluation. Since the reflectance curves of the different plants are different, also the curves of the wheat and maize, besides the health condition of the plants we can determine what kind of plant can be found on the field.

- Within our class more data is needed for improving the reliability of GIS system, for doing more punctual measures, the sources can be provided by the secondary data collection methods. The Landsat system measures every eight days on the same area, and recordings of the Sentinel-2 system can be included.
- The right GIS human background with professional knowledge is needed for creating and operating GIS system, processing geometrical and attributive databases.

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Gallo-Roman harvesting machine, called Vallus. Source: U. Troitzsch - W. Weber (1987): Die Technik : Von den Anfangen bis zur Gegenwart

Rear cover:
Portrait of Columella, in Jean de Tournes, Insignium aliquot virorum icones. Lugduni: Apud Ioan. Tornaesium 1559. Centre d'Études Supérieures de la Renaissance - Tours

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Lucius Junius Moderatus Columella

(AD 4 – 70) is the most important writer on agriculture of the Roman empire. His De Re Rustica in twelve volumes has been completely preserved and forms an important source on agriculture. This book was translated to many languages and used as a basic work in agricultural education until the end of the 19th Century.