Cereal Research Communications 42(4), pp. 710–720 (2014)
DOI: 10.1556/CRC.2014.0009
First published online June 15, 2014

Effect of Production Factors on Maize Yield and Yield Stability

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(Received 18 October 2013; Accepted 27 January 2014;
Communicated by J. Kubat)

Different long-term experiments were carried on chernozem (Debrecen) and loamy (Hajdúböszörmény) soils. They included the most important agrotechnical, biological (hybrid) and agroecological (crop year, soil) factors in maize production. This paper evaluated the results of polyfactorial long-term experiments. For the maize the most favourable crop rotation was winter wheat (in a tri-culture) with an N 60–120, P_2O_5 60–70, K_2O and 90–110 kg ha^{-1}, and a density of 75–90,000 plants ha^{-1}. The different input levels of maize crop management systems can modify an adaptive capacity to ecological conditions and the resilience of agro-ecosystems. The optimalization of agrotechnical elements reduces the harmful climatic effects. The yields of maize varied between 2–11 t ha^{-1} in extensive and 10–15 t ha^{-1} in intensive crop management systems, respectively.

Keywords: maize, crop rotation, fertilization, plant density, hybrid

Introduction

The cultivation of maize is currently going through significant changes, both in Hungary and in the wider world.

In global terms, the greatest change is that the area under production exceeds 170 million hectares, of which 55 million GMO hybrid cultivation. A significant proportion of the maize produced is used for industrial purposes (bio-ethanol) as well as for food and animal feed.

In Hungary, up-to-date hybrids have been cultivated. Ninety per cent of the hybrids produced are single cross hybrids (SC) and 90% FAO 300–400 hybrids, which have good productive capacity and an early harvesting period.

Fundamental changes in the cultivation of maize in Hungary have been underway since the beginning of the 1990s. As a result of the financial and economic difficulties the quantity of inputs and the level of resources invested have decreased. An extremely disadvantageous factor is the reduction in the amount of organic fertiliser used, from 22–24 million tons year^{-1} to 3–4 million tons year^{-1} (Pepó et al. 2006).

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The largely dry, continental climate in Hungary demands an appropriate crop rotation. The forecrop also has an effect on the spread of pathogens and pests, the amount of weeds and the NPK demands as well (Pepó et al. 2008).

The NPK fertilisers and the soil's AL-soluble, P, and K content are not only affected by the intensity of the fertilization, but also by the crop rotation and the agro-techniques applied (Andersson and Hermann 1992; Liang and MacKenzie 1994; Kovacevic et al. 2006).

There is a close relationship between the crop yield and water supply to the crop (Plavsic et al. 2007). Over the past decades climate change has increased the extremes in the weather. Between 1860 and 1900 the frequency of dry and wet years was equal (22.5%), and more than half of the years were characterised as having a typically average pattern (55%). In the period between 1980 and the 2000s the frequency of dry years increased significantly (52.6%), at the expense of years with an average pattern (26.3%) (Brown and Rosenberg 1999; Olesen and Bindi 2002).

A significant factor in the doubling of average yields was the use of a higher plant density (Carlone and Russel 1987). Without appropriate nutrition, fertilization the number of plants cannot be increased continuously (Russel 1991; Nagy 1996).

Materials and Methods

The long-term experiments were carried out on chernozem (Debrecen) and loamy (Hajdúböszörmény) soils. The long-term experiment in Debrecen was set up in 1983 year and in Hajdúböszörmény in 1967 year. The chernozem soil of Debrecen long-term experiment can be characterized by the following most important parameters: humus content 2.76%, depth of humus layer 0.8 m, AL-soluble P_2O_5 130 mg kg^{-1}, AL-soluble K_2O 180 mg kg^{-1}, $pH_{(KCl)} = 6.4$. Chernozem soil has good nutrient and water husbandry which are very favourable for maize production.

The long-term experiment in Hajdúböszörmény has loamy soil with special physical and chemical traits. Its humus content is 4.51%, the depth of humus layer is 0.4 m, AL-soluble P_2O_5 180 mg kg^{-1}, AL-soluble K_2O 240 mg kg^{-1}, $pH_{(KCl)} = 6.2$.

The polyfactorial long-term experiment of Debrecen has split-plot design with 4 replications. Area of each plot is 46 m^2. The total number of plots is 1080. The structure of polyfactorial long-term experiment is the following:

– crop rotation	monoculture (maize) biculture (wheat–maize) triculture (pea–wheat–maize)
– fertilization	control (without fertilizers) basic dose N = 60 kg ha^{-1}, P_2O_5 45 kg ha^{-1}, K_2O 45 kg ha^{-1} 5 treatments (control + fertilization 1-, 2-, 3-, 4-fold doses)
– plant density	40, 60 and 80 thousand plants ha^{-1}

– water supply rain-fed treatment (non-irrigated)
irrigation (50% of maize water demand in the vegetation period)
irrigation (100% of maize water demand in the vegetation period)

Our polyfactorial long-term experiment gives a possibility to built up different crop management systems (including crop rotation, plant density, nutrient and water supply) on different input levels (from extensive to intensive).

In years of average precipitation the under surface water level is at a depth of about 2.0–2.5 metres. The cultivated levels of the soil are susceptible to silting away when wet, and to severe cracking when dry (loamy soil in Hajdúböszörmény).

The 30-year average annual precipitation in Debrecen is 585 mm, and in the maize growing season (from April to September) it is 345.1 mm. The average annual temperature is 10ºC.

Climate change can be felt in the fact that over the past 120 years, the amount of precipitation has significantly decreased by 1 mm $year^{-1}$.

The amount of precipitation in the last three years (2010–2012) and the changes in the monthly mean temperature in relation to the 30-year average clearly show the unfavourable changes in climate factors (Table 1, Fig. 1).

Table 1. Deviation of rainfall and temperature in 2010–2012 crop years (Debrecen)

Years	Precipitation (mm)	Deviation from the 30-year average (mm)	Annual mean temperature (°C)	Deviation from the 30-year average (°C)
2010	987.8	422.5	10.3	0.5
2011	448.9	–116.4	10.2	0.36
2012	271.2	–136.6	10.4	0.7

In 2010 there was 422.5 mm more precipitation, while in 2009 there was 116.4 mm less, and in 2012 136.6 mm less than the 30-year average and during this period the monthly and annual mean temperature exceeded the 30-year average.

The crop rotation used in the experiment of Hajdúböszörmény:

– triculture (pea–winter wheat–maize)
– biculture (winter wheat–maize)
– monoculture maize (1973–1994).

The fertilization treatments on loamy soil long-term experiment are the following:

– control
– basic fertilizer dose N = 40 kg ha^{-1}, P_2O_5 = 25 kg ha^{-1}, K_2O = 30 kg ha^{-1}
– and 2-, 3-, 4- and 5-fold of basic dose.

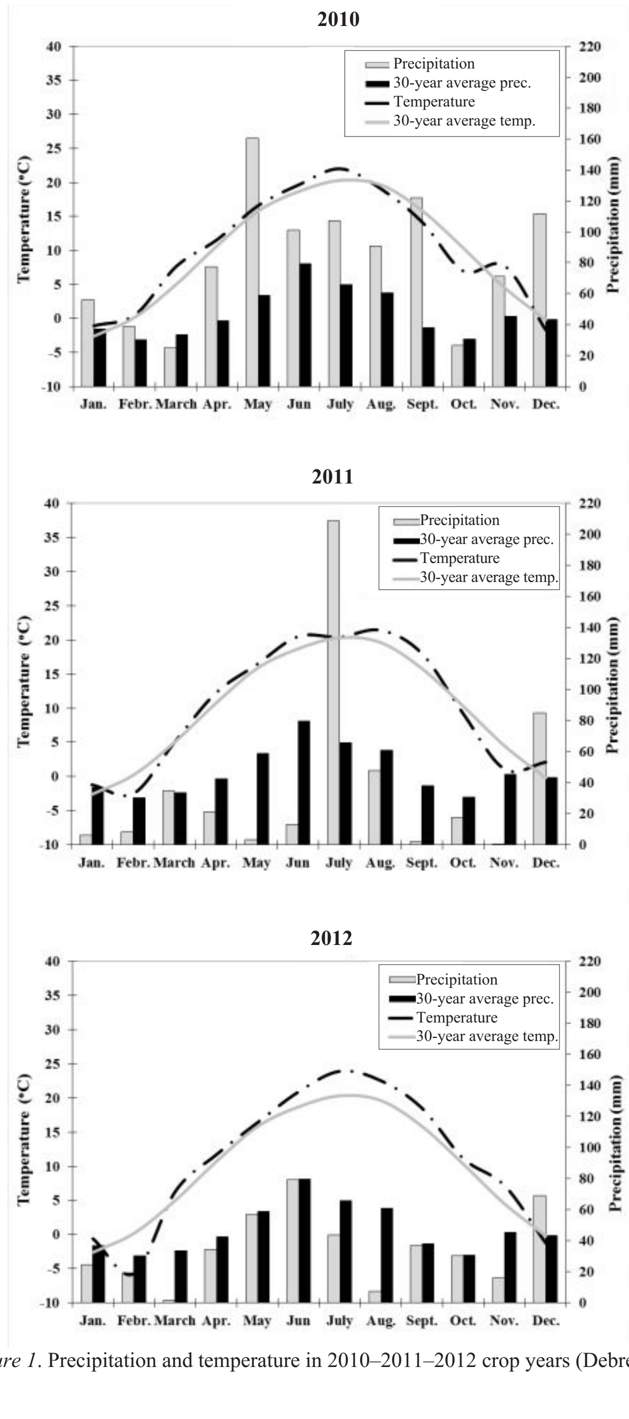

Figure 1. Precipitation and temperature in 2010–2011–2012 crop years (Debrecen)

The numbers of plants were 45,000, 60,000, 75,000 and 90,000 ha^{-1}.

The studied hybrids tested in long-term experiment of Hajdúböszörmény had different genetic background. Experimental data were evaluated by SPSS 13.0 statistical programme (variance and parabolic regression analyses).

Results

The different agrotechnical elements can hugely modify the yield of maize hybrids, especially important elements the crop rotation, fertilization and plant density among them.

The appropriate fertilization needs to take into consideration a lot of agrotechnical factors and other ecological circumstances (NPK contents of soil, weather condition, water supply, water reservoirs of soil etc.) and biological factors (genotypes). The optimum NPK doses of maize can modified the crop rotation. According to our experimental results we can state that the triculture crop rotation (peas–wheat–maize) increased the yield of maize by 1.31 t ha^{-1} and biculture crop rotation (wheat–maize) also increased by 1.58 t ha^{-1} comparing with maize monoculture 7.39 t ha^{-1} in our long-term experiment on loamy soil.

Our long-term experimental results proved that the plant density of maize was a decisive agrotechnical element, too. The optimum plant density was determined by genotype. Every maize hybrid had a special optimum plant density value (between 68–82 thousand plants ha^{1-}) and a special width of optimum interval (between 5–20 thousand ha^{-1}). The hybrids with wide optimum interval were more favourable ones for better adaptation to the different agroecological conditions.

Our long-term experiments proved that we have to use hybrid-specific technology (fertilization, planting technology, etc.) in the maize production.

The nutritional requirements for 100 kg of main and side crop products are of N 2.5, P_2O_5 1.1, K_2O 2.2 kg ha^{-1}. Twice as much potassium is needed as phosphorous, even if 70–75% of the potassium migrates not to the grain production but to the leaves and stalk. The NPK nutritional requirements for maize, depending on the forecrop, the crop year and the hybrid, are N 60–120, P_2O_5 60–70, K_2O 90–110 kg ha^{-1} (Fig. 3).

In the control treatment (without chemical fertiliser) the average yields varied 3–4 t ha^{-1}. In comparison with the control, we achieved the highest growth in yield with of N 40, P_2O_5 25, K_2O 30 kg ha^{-1}. Although in most cases the yield increased up to an level of N 200, P_2O_5 125, K_2O 150 kg ha^{-1}, this did not reach a level of reliability in each case.

An important agro-technical factor in increasing maize yields is to apply the optimum plant density (Fig. 4).

Maize hybrids can be divided into four types according to responses of plant density:

1. Hybrids with a wide optimum plant density, which can be planted densely.
2. Those which do not demand a high plant number, but which give good individual production.
3. Flexible cob types. In good years the cob extends.
4. Hybrids sensitive to an increase in density, with a relatively restricted optimum plant interval (Fig. 5).

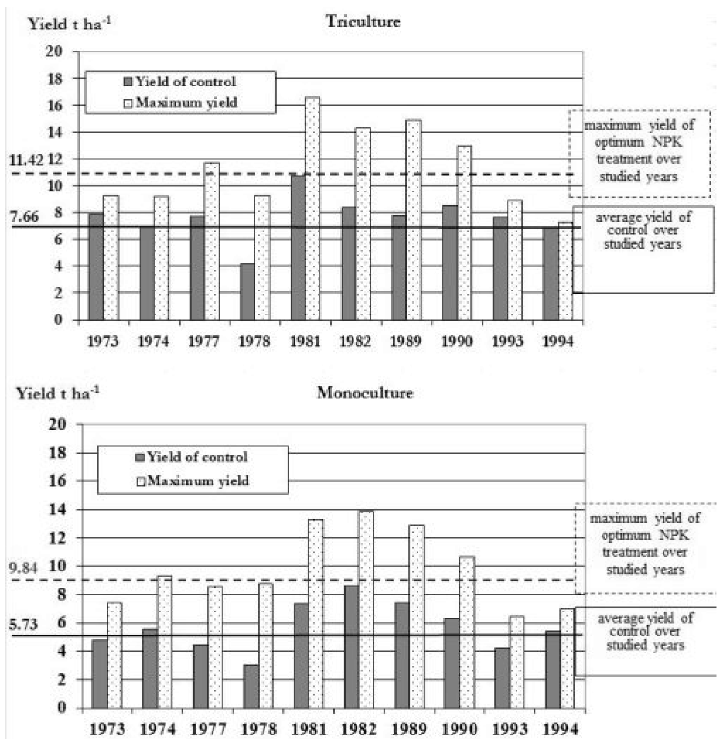

Figure 2. Effect of crop rotation and fertilization on the yield of maize
(Hajdúböszörmény, 1973–1994)
($LSD_{5\%}$: 1973 = 0.53 t ha^{-1}, 1974 = 0.44 t ha^{-1}, 1977 = 0.39 t ha^{-1}, 1978 = 0.58 t ha^{-1}, 1981 = 0.84 t ha^{-1}, 1982 = 0.66 t ha^{-1}, 1989 = 0.96 t ha^{-1}, 1990 = 1.09 t ha^{-1}, 1993 = 0.66 t ha^{-1}, 1994 = 0.52 t ha^{-1})

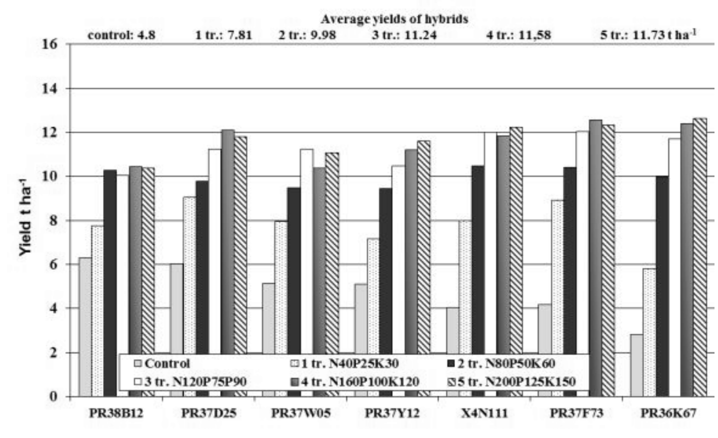

Figure 3. The effect of fertilization on hybrid maize yields (Hajdúböszörmény, 2006)
($LSD_{5\%}$ Hybrid = 0.54 t ha^{-1}; Plants = 0.53 t ha^{-1}; Reciprocal effect = 1.39 t ha^{-1})

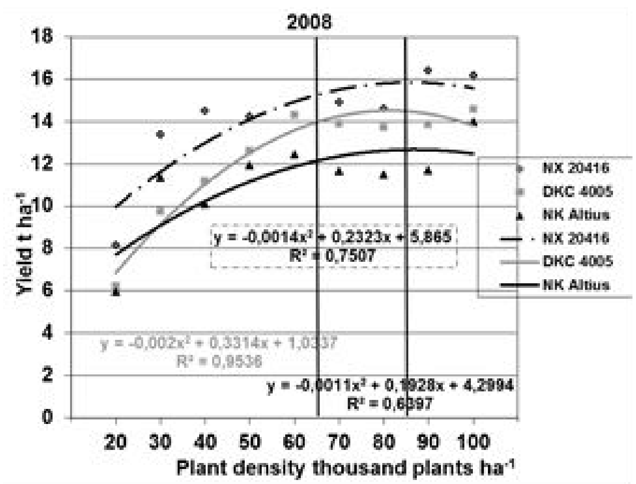

Figure 4. The effect of plant density on the yield of maize (Hajdúböszörmény, 2008)
($LSD_{5\%}$ Hybrid = 0.97 t ha^{-1}; Plants = 0.26 t ha^{-1}; Reciprocal effect = 1.26 t ha^{-1})

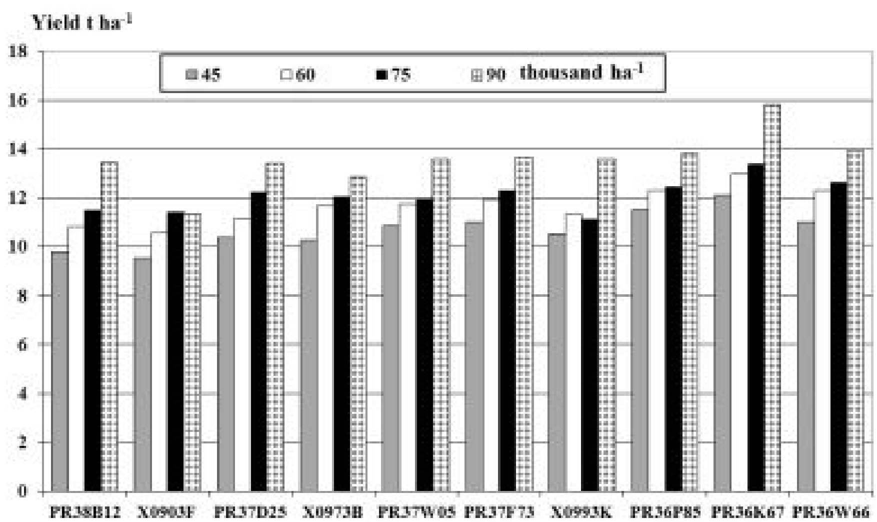

Figure 5. Effect of plant density on maize hybrid yields (Hajdúböszörmény, 2005)
($LSD_{5\%}$ Hybrid = 0.87 t ha^{-1}; Plants = 0.48 t ha^{-1}; Reciprocal effect = 1.51 t ha^{-1})

The results of polyfactorial long-term experiment in Debrecen allowed studying the interactions of weather factors and crop management systems characterized by different input level on chernozem soil. On the basis of our long-term experimental results we can build up different crop management systems which can fit to the agroecological and economical conditions. Our research data proved that in the extensive crop management system (rainfed, no fertilizers, low plant density) the yields of maize varied between 2,102 and 8,079 in monoculture, 6,032 and 11,328 kg ha^{-1} in biculture and 6,092 and 10,348 kg ha^{-1} in triculture (Fig. 6). The crop rotation had a fairly huge effect on the yield level in extensive crop systems. In an unfavourable crop year (2007) the yields of maize ranged between 2,000 and 7,000 kg ha^{-1} in the extensive crop management system depending crop rotation. On the contrary, in a favourable crop year (2008) with optimal water supply during the vegetation year of maize, the yields of maize varied between 8,000–11,000 kg ha^{-1} in the extensive system. It means that the crop year has a huge influence on the yields of maize in extensive crop system, it causes huge yield fluctuation. In the same crop years (2007 – dry and 2008 – optimum) the yields of maize were much higher and the yield fluctuations were moderate if we applied intensive crop management systems

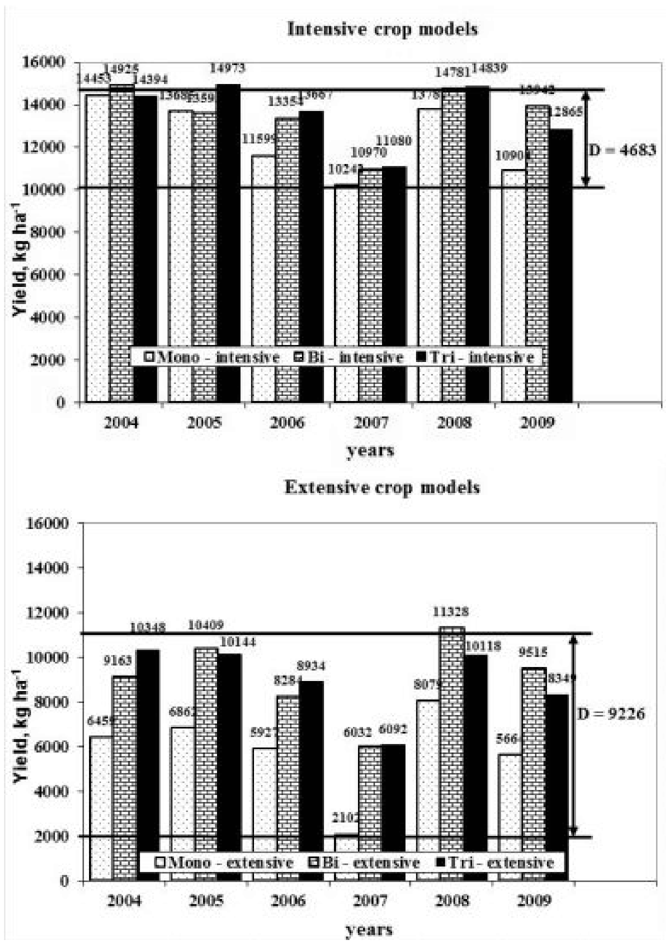

Figure 6. Yield and yield-stability of maize crop management systems (Debrecen, chernozem soil, 2004–2009)

(optimum fertilizer doses, optimum plant density, irrigation). In the intensive crop systems the maize yields ranged 10,200 and 14,400 kg ha^{-1} in monoculture, 11,000 and 14,900 kg ha^{-1} in biculture and 10,200–14,500 kg ha^{-1} in triculture. It means that the yields were higher by 4,000–8,000 kg ha^{-1} in the intensive crop management systems comparing with extensive ones, respectively. In the studied period (2004–2009 years) we obtained not only much higher yields in the intensive crop systems but we got lower yield fluctuations (in extensive 9,200 kg ha^{-1}, in intensive 4,683 kg ha^{-1}), too. Our polyfactorial long-term experiment proved that if we apply appropriate crop management system in the practice then we can get high yields (10,000–14,000 kg ha^{-1}) with a good yield stability (concerning the crop year effect) on chernozem soil.

Discussion

A rational crop rotation influences the effectiveness of the cultivation. The forecrops are largely decisive in establishing the planned quantity fertilization.

In Hungary problems are caused by the fact that the planting structure of the arable land is too simplified, the number of cultivated species has diminished and the proportion of cultivated legumes (e.g. pea, broad bean, alfalfa etc.) has fallen particularly sharply. At the same time the proportion of grain crops exceeds 70%.

An appropriate crop rotation is particularly important in maize cultivation, partly because crop rotation is the most effective defence against the larva of the American maize bug , and so the best way to protect against both the bug and its larvae. It is also important because with monoculture the soil's nutritional material can become over-restricted (e.g. zinc) and water use can cause a severe depression in yield (a reduction in yield) (Bernivolja 1976; Cramer 1989).

Furthermore, with a higher amount of NPK fertilizers during monoculture cultivation we achieve the same yield as with maize cultivated with crop rotation (Nagy 1996; Kovacevic et al. 2006).

The number of plants is a decisive factor on the yield. To establish the number of plants per hectare, the optimal plant interval for the given hybrid must be known, i.e. the interval which the hybrid can tolerate without a decrease in yield.

Modification of the optimal plant density:

– the genetic characteristics of the hybrid,
– the growing season of the hybrid,
– the nature of the planted area,
– the annual weather effect,
– the level of water and nutrition (Plavsic 2007).

In long-term experiments, we studied maize in crop models of different intensity on chernozem soil. From these models, we analyzed the yields of two crop models with very different inputs, the extensive and intensive models. In the agro-ecosystems, we included the same genotypes of maize in the studied years and the variables were the crop year and the weather factors (Pepó et al. 2006, 2008).

The resilience of the agro-ecosystem in its response to unfavourable weather conditions was essentially determined by the intensity level of the maize growing.

It can be established that the extremes in the weather caused by climate change have a great influence on the maize yield (Brown and Rosenberg 1999). There are up-to-date biological base materials (hybrids) in cultivation, but in order to reach a good level of production it is necessary to have the appropriate crop rotation and a harmonised NPK fertilization. Furthermore the planting time and the number of plants per hectare must also be adjusted according to the particular hybrid being planted.

Results of our long-term experiments proved that the equilibrium of different crop models and consequently, its productivity were greatly influenced by environmental, primarily weather factors. The application of input intensive technologies is also of favourable effect in maize production.

When applying an extensive technology in the period of 2004–2009, the yields of maize ranged from 2 to 7 t ha^{-1} and from 2 to 11 t ha^{-1}, respectively. By applying intensive technologies, yield stability could be improved significantly.

Acknowledgements

This research was realized in the frames of TÁMOP 4.2.4. A/2-11-1-2012-0001 "National Excellence Program – Elaborating and operating an inland student and researcher personal support system". The project was subsidized by the European Union and co-financed by the European Social Fund.

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