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Impact of climaticfactors on yield quantity and quality of grain crops

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Abstract—Weather impacts may have direct or indirect influence on the performance of agricultural production and food industry. The present problems are various, however, they can be sorted into two major groups: (1) factors that can be related to climate change processes like water scarcity, drought, meteorological extremities (temperature anomalies – frost, heat days, duration of unfavorable periods; precipitation – heavy rains, hail storms, land slide; air – storms, high wind, alterations of radiation and its postulates, (2) economic, social, and policy problems, that may have negative impact on the adaptability to meteorological factors in general and climate change processes in particular regarding food and agricultural production.

Changes in temperature may be of less importance concerning agriculture. Apart from a wide range of physiological problems, warming may have beneficial impacts as well; 1 ^{o}C rise in mean temperature may induce some 7 to 9 days of increment of the vegetation period, which could give a chance to use a +100 FAO group in maize production. On the other hand, warming of the summer period can be considered unfavorable. That may result in deterioration of sexual reproduction of most annual plants.

Changes in precipitation have more severe and determining consequences for crop production. Limited availability to water in the vegetation period may cause various direct deteriorating effects in cropping. Also, mild and dryer winter periods can be harmful contributing to epidemics and gradations of pests and diseases. Weed cenoses are also affected by climate change processes.

Economic vulnerability of agriculture in general and that of crop production in particular can be detected in most fields of the food chain. It is hard to estimate losses, but trends and the magnitude of these can be assessed. Grain crops represent a major source of arable output in Hungary. Half of the arable land is used for wheat and maize cropping. The grain yield of these two crops range from 9 to 15 million tons annually due to weather influences of the very crop year. The gap between them represents some 270 billion HUF on today’s prices.

Key-words: climatic factors, crop production, yield quantity, yield stability

1. Introduction

Since the beginning of the human civilization, when man first tried to cultivate plants and recognized that crop plants do not give the same yield in each year, moreover, sometimes the differences could be very high, there is a profound interest to seek and learn possible reasons of that. According to the level of certain historical ages, this variance was explained by some supernatural forces. In accordance with the progress of society, more and more rational explanations were found up to now. On the basis of rationality, only scientifically approved causes could be accepted (*Jolánkai* and *Birkás*, 2007; *Jolánkai et al*., 2008). In this way, crop science and practice become reasonable gradually. There are numerous factors that are having effect on yield (*Tarnawa* and *Klupács*, 2006), and among them there are some that could be influenced by the farmer and also a few others that could not be. The first group is the set of elements of agronomic management, the second group is the set of factors of environment (*Várallyay et al.*, 1985). In the set of environmental factors, there are some with more or less impact on yield (*Klupács et al*., 2010), but according to former observations, weather plays a significant role (*Szöllősi et al*., 2004). Even because crop production is not an indoor practice but mostly outdoor; the weather and climate may have high impact on that (*Láng et al*., 2007). Weather impacts and climate change processes may have direct or indirect influence on the performance of agricultural production and food industry (*Veisz et al*. 1996; *Anda,* 2005; *Bozó et al.* 2010). Climate change impacts on crop production are due to weather anomalies and uncertain processes (*Varga-Haszonits,* 2003).

As the yields still show lower or higher fluctuation from the long term averages or trends, it should be more than useful to explore how they depend on each element of climate (*Pepó*, 2010). Certain crop species respond to climatic impact in different ways. The performance of maize crop is highly influenced by radiation and temperature (*Anda* and *Lőke,* 2004). The grain yield of maize is rather influenced by precipitation (*Anda et al.* 2002; *Lente* and *Pepó* 2009). Grain yield of wheat may vary in accordance with the weather conditions of the crop year. Yield stability depends on the optimum distribution of precipitation during the vegetative phenophases. Grain yield of wheat may vary in accordance with the weather conditions of the given crop year (*Bocz et al.,* 1983; *Pepó et al*., 1986; *Pepó,* 2010; *Pepó* and *Győri,* 2005).

Changes in temperature may be of less importance concerning agriculture. Apart from a wide range of physiological problems, warming may have beneficial impacts as well; 1 ^{o}C rise in mean temperature may induce some 7 to 9 days of increment of the vegetation period, which could give a chance to use a +100 FAO group in maize production. On the other hand, warming of the summer period can be considered unfavorable (*Ladányi et al.,* 2001; *ADAM,* 2008). That may result in deterioration of sexual reproduction of most annual plants. Climatic conditions may have an impact on the performance of crop production. Apart from the growth and development of the crop plant, water availability within the crop site may be responsible for various phytosanitary problems, such as weed infestation, disease infections, and gradations of insect pests (*Nagy* and *Ján,* 2006, *Ács et al.,* 2008; *Várallyay,* 2008; *Pásztorová et al*., 2011).

Recently, one of the most severe harm induced by insects may be related to the spread of western corn rootworm *Diabrotica virgifera virgifera* Le Conte (*Kiss* and *Edwards,* 2003). Spread of this insect species has been recorded since 1992 in Central Europe due to an anthropogenic failure. The pest has been imported from overseas during the Yugoslav war with a humanitarian aid transport to Europe. This insect has conquered gradually the whole territory of the Carpathian Basin in recent years. The gradation of Diabrotica in Hungary has started in 1996 and has been completed by 2002 (*Zsellér Hatala* and *Széll,* 2001; *Vidal et al.,* 2005; *Jolánkai et al.,* 2006).

Availability of water is a major stressor in relation with yield quality and quantity performance of winter wheat. Cereals represent a most plausible source of human alimentation in the world. Wheat provides a basic staple for mankind. This crop is one of the most important cereals in Hungary with a high economic value. Utility, market, and alimentation value of the crop is highly affected by climatic conditions and within that annual weather performances, as well as soil moisture conditions (*Ács et al.*; 2008; *Koltai et al*., 2008; *Skalová et al*., 2008; *Várallyay*, 2008). The aim of wheat production is twofold; to provide quantity and quality. Milling and baking quality of wheat is mainly determined by the genetic basis, however, it can be influenced by management techniques (*Pollhamerné,* 1981; *Nagy and Ján*., 2006, *Varga et al*., 2007; *Vida et al.,* 2005). In our previous studies, we have reported results regarding the role of water availability impacts on the quantity and quality of grain crops (*Gyuricza et al.,* 2012; *Horváth et al.* 2014; *Jolánkai et al.,* 2014). Since main quality indicators – protein, farinographic value, gluten content for wheat, as well as protein, starch, and fibre for maize – have a rather diverse manifestation, extensive studies were performed to gain more information concerning the behavior of them.

The present paper is intended to provide some information on the performance of wheat and maize, the major grain crop species produced in Hungary. The work of the research team was based on two sources, once on the results of long term small plot field experiments, while on the other hand, on the use of national databases of meteorology and agriculture.

2. Materials and methods

The materials and methods of the present study cover a rather broad field, since there are three slices of the research work done by the Szent István University, Crop Production Institute, Hungary (hereinafter SIU). Most of the results are based on experimental research, however, some evaluations were implemented by using national public data, or observation results published.

In long term field trials, a wide range of winter wheat *Triticum aestivum* L. varieties and maize *Zea mays* L hybrids were tested. The small plot trials were dirun at the Nagygombos experimental field. The soil type of the experimental field is chernozem (calciustoll). Annual precipitation of the experimental site belongs to the 550–600 mm belt of the northern edges of the Great Plain in a 40 years average, 1961–2000, while the average depth of groundwater varies between 2 and 3 metres.

Experiments have been conducted in split-plot design with four replications. The size of each plot was 10 m^2. Plots were sown and harvested by plot machines (standard Wintersteiger cereal and maize specific experimental plot machinery series). Various identical agronomic treatments were applied to plots. Plant protection and plant nutrition applications were done in single and combined treatments. All plots were sown with identical series of wheat varieties and maize hybrids for studying their performance in relation with agronomic impacts. Regarding water availability impacts, experimental mean values of respective treatments and homogenized bulk yield samples were used only. Precipitation records have been evaluated in relation with yield quantity and quality. Wheat grain quality parameters like protein, farinographic value, and wet gluten content were processed, as well as maize quality parameters; protein, starch, and fibre content. Quality characteristics were determined at the Research Laboratory of the SIU Crop Production Institute, according to Hungarian standards (*MSZ,* 1998). Grain yield samples and quality figures were correlated with precipitation parameters. Analyses were done by statistical programmes with respect to the methodology of phenotypic crop adaptation (*Eberhart* and *Russell* 1966; *Finlay* and *Wilkinson* 1963; *Hohls,* 1995).

The gradation of the western corn rootworm was analyzed from a point of view of crop production. The beetle has conquered within almost ten years the whole territory of the Carpathian Basin. The spread of Diabrotica in Hungary has started in 1996 and has been completed by 2002. Climatic factors of the gradation were evaluated. The meteorological database of the research referring to precipitation as well as temperature data was provided by the Hungarian Meteorological Service (OMSZ). Yearly and monthly data of precipitation and temperature of the respective years have been used during the evaluation. The spreading of the insect was recorded by digital mapping with the use of planimeter. Distances have been determined by GPS coordinates of the locations. Gradation reports and data of the spreading were obtained from the Ministry of Agriculture of Hungary as well as that of the phytosanitary authorities (NÉBIH). In the study, there were no entomological evaluations. All information regarding entomological aspects were adopted from specific reports on Diabrotica (*Kiss* and *Edwards,* 2003; *Zsellér Hatala* and *Széll,* 2001). Statistical evaluations, crop ecological model adaptations, and correlation calculations were done by regular methods (*Sváb,* 1981; *Finlay* and *Wilkinson,* 1963).

The present paper produces three slices of the results of the ongoing research in relation with weather impacts on grain production. Such an assessment has a diverse nature. Once, it is beneficial regarding the abundance and the duration of baseline data. On the other hand, it is restricted to the available structure, moreover, it is bound mainly to annual figures giving less chance for deep layer evaluations. However, the study could provide some novel specific information on crop performance.

3. Results and discussion

3.1. Yield stability

Hungarian agriculture is run mainly by rainfed technologies regarding field crops, since less than 7 percent of the arable land is equipped for irrigation. Changes in precipitation have more severe and determining consequences for crop production. Limited availability to water in the vegetation period may cause various direct deteriorating effects in cropping. Economic vulnerability of agriculture in general and that of crop production in particular can be detected in most fields of the food chain. It is hard to estimate losses, but trends and the magnitude of these can be assessed. Grain crops are a major source of field crop output. Half of the arable land is used for wheat and maize cropping. The grain yield of these two crops range from 9 to 15 million tons annually due to weather influences of the very crop year as it is indicated in *Figs. 1* and *2.* The gap between the total yield of the two crops represents some 230 billion HUF on today's prices (an estimated value of 386.6 billion HUF for the minimum and 616.2 billion HUF for the maximum within the time range).

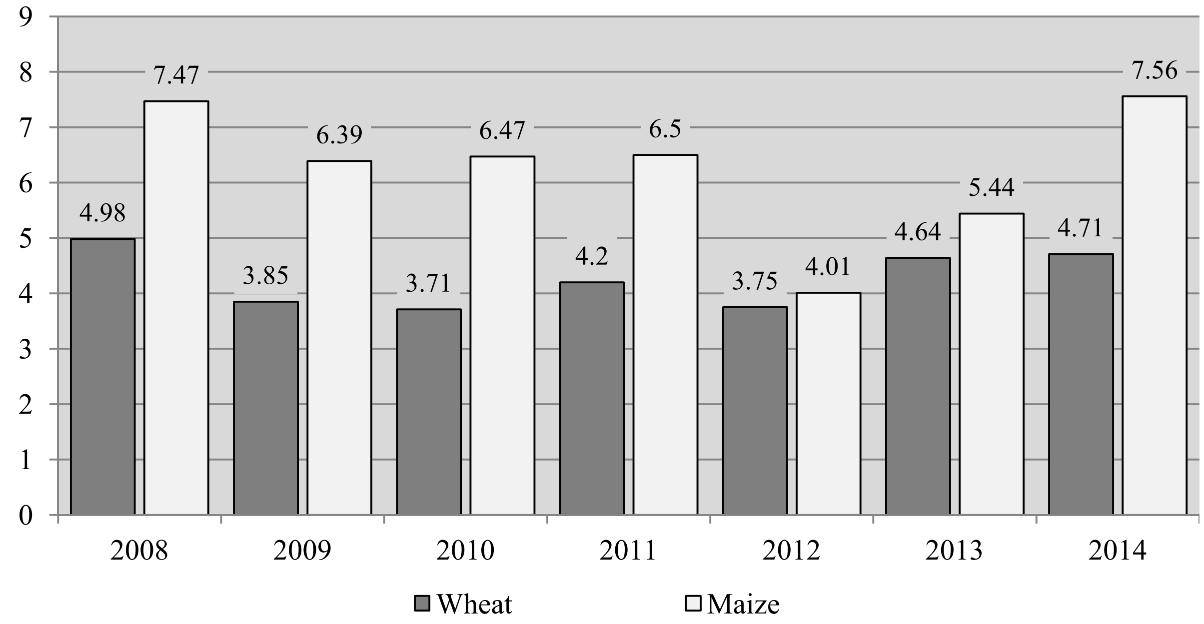

Fig. 1. Wheat and maize yield averages in Hungary, t/ha. (Source: KSH, 2008–2014)

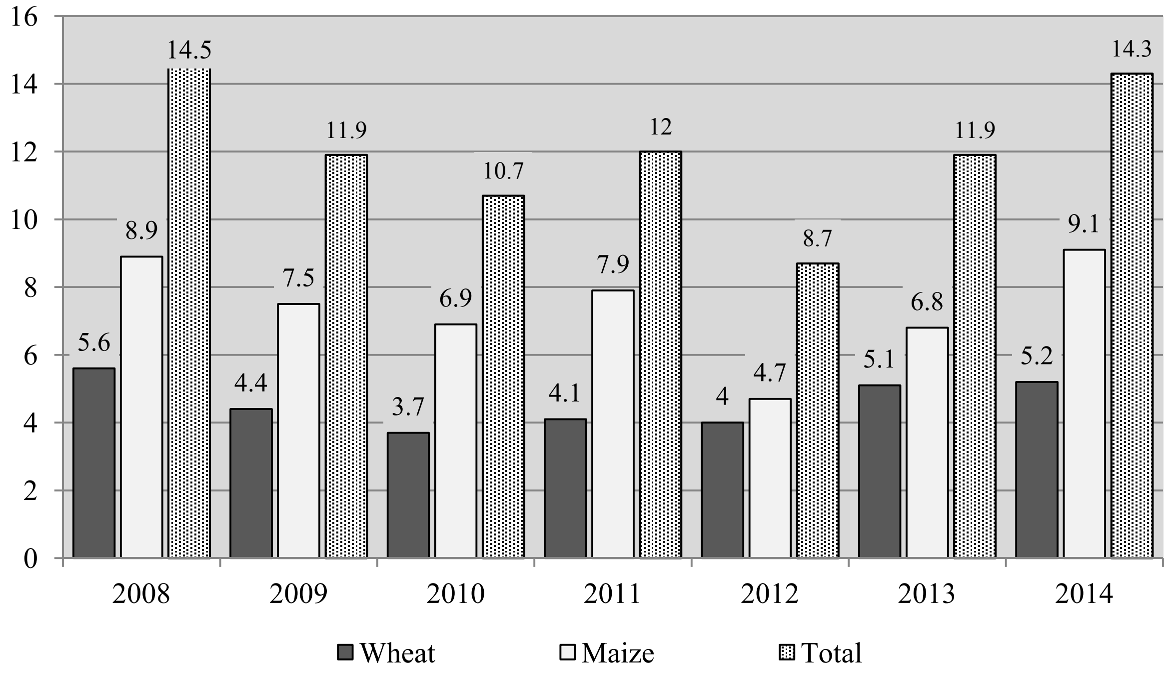

Fig. 2. Wheat and maize yields in Hungary, million t. (Source: KSH, 2008–2014)

3.2. Insect pest gradation

Availability to water during the vegetation period may cause various direct deteriorating effects in cropping. Also, mild and dryer winter periods can be harmful contributing to epidemics and gradations of pests and diseases. Weed cenoses may also be affected by climate change processes.

The basic hypothesis of the work was related to the performance of maize crop of the respective periods. Since all live populations in general and the reproductive activities of them in particular depend on the food availability, an assessment was implemented to find correlating factors. *Fig. 3* presents data on the annual spread of the insect pest with the maximum distance of migration of the respective crop year and the maize kernel yield. It has been observed that the magnitude of gradation was usually bigger in crop years with high grain yield. This phenomenon may be explained by the better habitat conditions of the actual crop year provided by the good plant performance. The trend of gradation has similarities with that of the maize kernel yield of the respective years, however, various other factors had to be evaluated as well. For example, there were crop years with 2 t yield differences when the gradation maximum distance was identical.

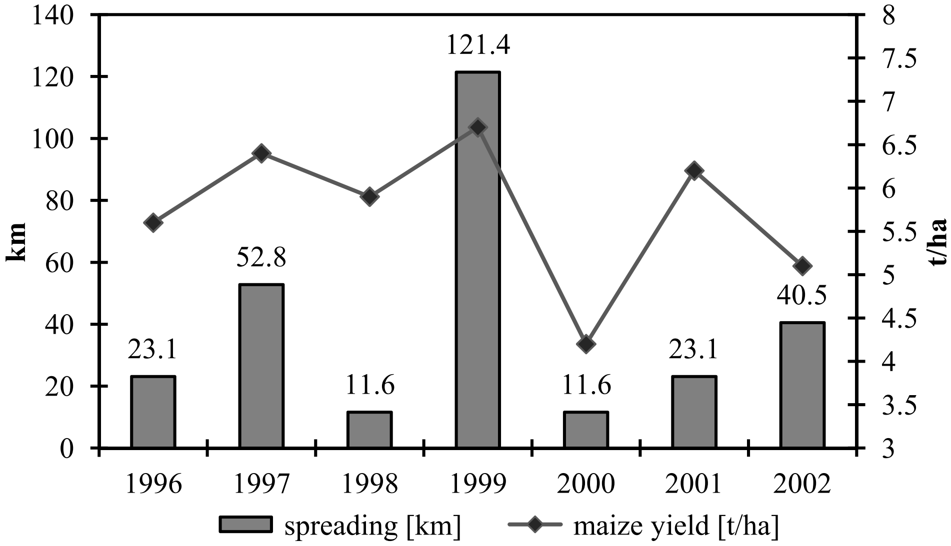

Fig. 3. The annual spread of *Diabrotica virgifera virgifera* and maize yields of respective years, 1996–2002.

In accordance with European entomological reports, the spreading of the insect has been performed by a pattern of concentric circles. The speed of gradation, the size and shape of the annually conquered area was different in each crop year observed. The correlation between maize yields and the magnitude of gradations indicated further studies in the field of meteorological data. In the study, precipitation of various periods within the crop year were evaluated in accordance with the life cycle information of the insect. Annual mean precipitation, the precipitation of the first six months of the year, and that of June month were checked. Temperature means of the respective periods were evaluated also. *Table 1* provides information on the correlation between the gradation and these meteorological data.

Table 1. Correlation between *Diabrotica* gradation and meteorological factors (1996–2002)

	r	***P***
Maize yield	0,683	0,95
Annual mean precipitation	0,248	ns
First 6 months' precipitation	0,236	ns
June precipitation	0,881	0,99
Annual mean temperature	–0,538	ns
First 6 months' temperarture	–0,604	ns
First 3 months' temperature	–0,196	ns

The research results of this study suggest that the amount of precipitation and temperature data had an indirect effect on the spread of the insect. Significant correlations were found in the case of annual harvested maize yields as well as the amount of precipitation of June month with the magnitude of the gradation of *Diabrotica virgifera virgifera* Le Conte. Since the study was based on crop production and geographic methodology using open access databases and observation results concerning gradation, further entomological studies are needed to clear the background of the results obtained.

3.3. Yield and quality of grain crops

Annual amounts of precipitation and winter wheat yields have been examined in a 15-year time range, while the same for maize has been investigated in a 9-year period at the Nagygombos experimental field of the SIU, Gödöllő. *Figs. 4* and *5* illustrate annual changes of yield and some quality parameters in accordance with the precipitation mean values. Yields and main quality characteristics were correlated with water availability.

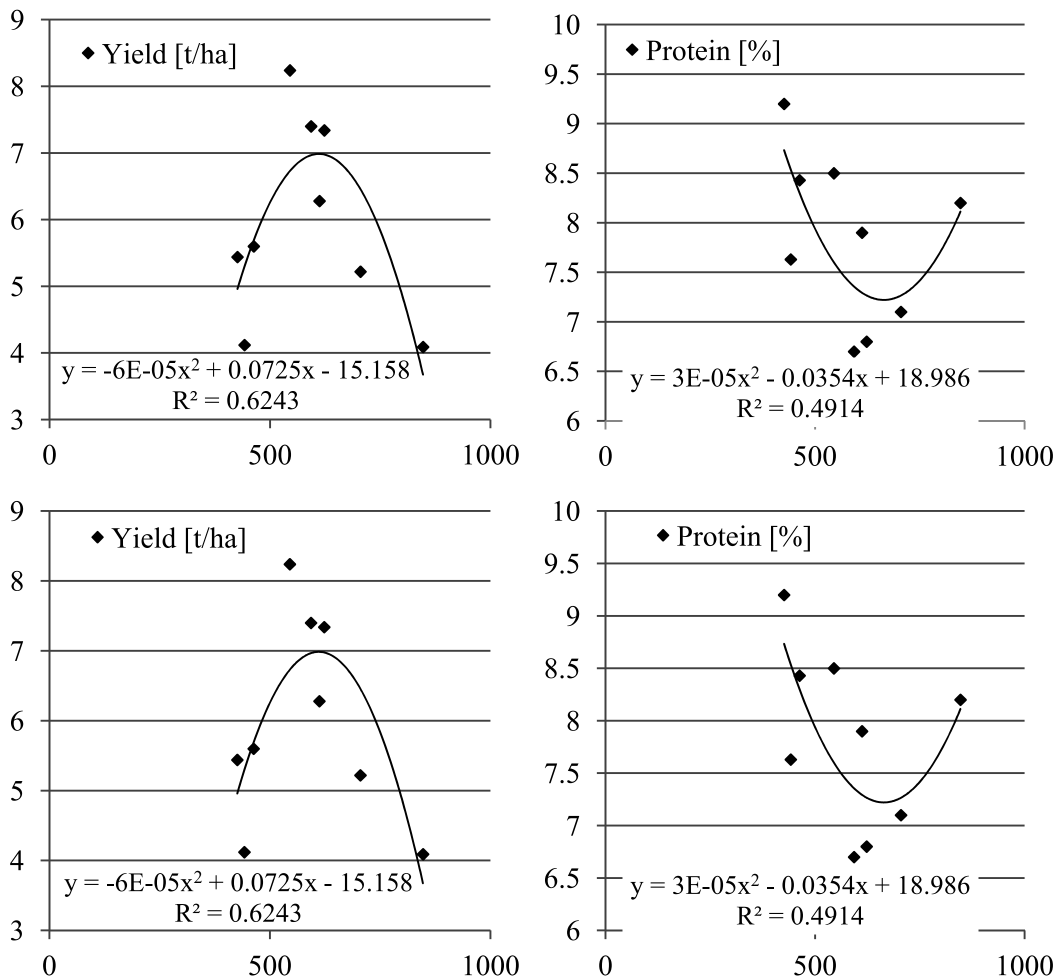

Fig. 4. The performance of grain yield, protein, starch, and fibre values of maize crop, Nagygombos, 2002–2010.

Yield quantity of maize crop proved to be highly variable. Years with low as well as too high precipitation had yield deteriorating effects. The highest yields were obtained in crop years of 600–700 mm. Protein values were smaller in rainy years. Starch values did not prove to have any correlations with precipitation. Fibre content values in certain crop years were randomly changing, however, no systematic trends could be observed.

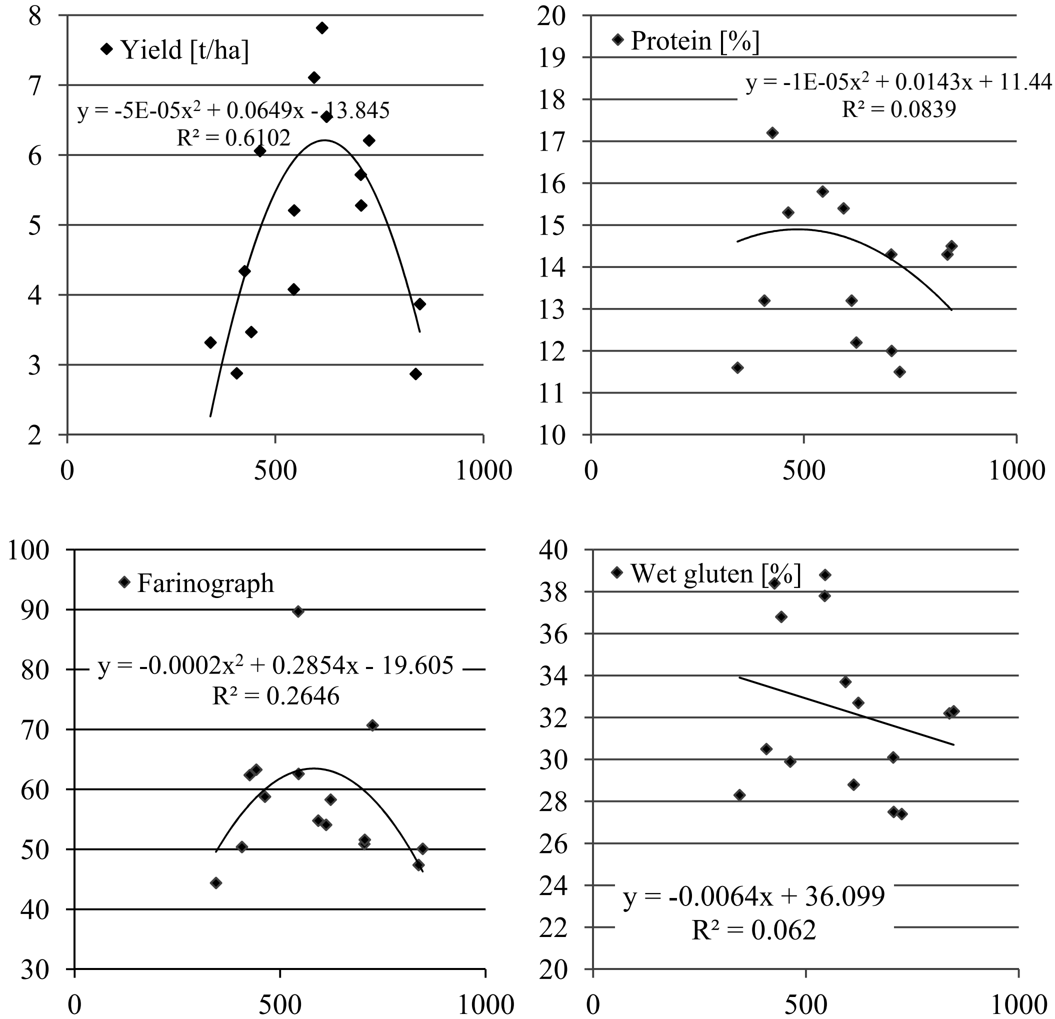

Fig. 5. The performance of grain yield, protein, farinographic value, and wet gluten % of wheat crop, Nagygombos, 1996–2010.

Yield figures were in accordance with annual precipitation patterns with an exception of some years when the distribution was irregular, e.g., in 1999 year, when 837 mm rainfall, one of the highest in the period examined was recorded, however, a severe drought spring was followed by an extreme moist summer obstructing the yield formation ripening, and harvest. Also, the year 2010 with the ever highest annual precipitation, 847 mm measured at the experimental site resulted in poor yield performance for both wheat and maize crops due long periods of water logging. Apart from these two years, the annual precipitation was in accordance with the water consumption of the respective crop species and their C3 and C4 physiological patterns.

Quality manifestation of winter wheat yields have been impacted by annual precipitation in general in accordance with previous reports (*Klupács et al.* 2010; *Pepó,* 2010). *Fig. 5* provides data regarding the changes in yield quality characteristics. Yield figures were in accordance with annual amounts of precipitation with two exceptions regarding the 1999 and 2010 crop years. Wet gluten, protein, and farinographic values had no significant relations with annual precipitation.

4. Conclusions

Weather impacts may have direct or indirect influence on the performance of agricultural production and food industry. Water availability can be considered as a basic factor related to yield quality and quantity performance of grain crops.

Yield stability of grain crops may be highly variable according to weather impacts. Yield losses may influence the whole of agricultural production. Grain crops are a major source of the output of field crops. Half of the arable land is used for wheat and maize cropping. The grain yield of these two crops range from 9 to 15 million tons annually due to weather influences of the very crop year. The gap between them represents some 270 billion HUF on today's prices.

The present study also summarizes results of an observation regarding the influences of climatic factors on the spread of an insect pest *Diabrotica virgifera virgifera* Le Conte. The research results suggest that the amount of precipitation and temperature data had an indirect effect on the spread of the insect. Significant correlations were found in the case of annual harvested maize yields as well as the amount of precipitation of June month with the magnitude of the gradation. Further entomological studies are needed to clear the background of the results obtained.

In an agronomic long-term trial, the impact of water availability on wheat and maize crop has been evaluated. Various crop years have had different impacts on crop yield quantity. Yield figures were not in significant correlation with annual precipitation in general. However, with an exception of two years of extremely high precipitation yield figures, they were in accordance with that. Moisture availability had diverse influence on quality manifestation. High precipitation has often resulted in poorer quality. Maize yields have been performing in a broader range than that of wheat. Maize quality parameters proved to be more stable than yield figures except for fibre content values.

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