**IDŐJÁRÁS**

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# Impact of precipitation on yield quantity and quality of wheat and maize crops

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**Abstract**—Yield samples of winter wheat *Triticum aestivum* L. and maize *Zea mays* L. taken from consecutive series of crop years at the Nagygombos experimental field of the Szent István University have been evaluated. Impact of precipitation on yield quantity and quality was studied. In case of wheat protein, wet gluten, farinographic value, and Hagberg sedimentation, while in case of maize, protein, starch, oil, and fibre content were examined.

Yield performance of wheat and maize varieties has been highly variable regarding crop years. Wheat was less affected by precipitation in general, however, extremely high precipitation as well as drought caused yield depression. Water demand of yield formation was in accordance with that of C3 – C4 physiological patterns. Yield quality was highly influenced by different crop years. In case of wheat, wet gluten content proved to be a most stable characteristic. Protein, farinographic values, and Hagberg sedimentation figures were more variable in relation with the precipitation of crop years. Yield quantity of maize crop proved to be more variable than quality parameters. Protein values were smaller, and starch values higher in rainy years. Other parameters, like oil and fibre have shown no consequent changes that could be related to the amount of annual precipitation.

*Key-words*: Precipitation impacts, grain crops, yield, grain quality.

## *1. Introduction*

Water availability profoundly influences all physiological processes of plant life. Water transport of individual plants as well as water budget of the crop site determine growth and development, and finally, quality.

Crop water use, consumptive use, and evapotranspiration are terms used interchangeably to describe the water consumed by a crop. This water is mainly used for physiological processes; a negligible amount is retained by the crop for growth. Water requirements for crops depend mainly on environmental conditions. Plants use water for cooling purposes, and the driving force of this process is prevailing weather conditions. Different crops have different water use requirements, under the same weather conditions (*Várallyay,* 2008; *Pepó,* 2010). Crops will transpire water at the maximum rate when the soil water is at field capacity. When soil moisture decreases, crops have to exert greater forces (energy) to extract water from the soil. Usually, the transpiration rate does not decrease significantly until the soil moisture falls below 50 percent of available water capacity.

Information regarding seasonal crop water requirements are crucial for planning crop species planting especially during drought years. For example, in Hungary, the seasonal water use of maize crop is 550 mm, while wheat crops use some 400. These water requirements are net crop water use or the amount a crop will use (not counting water losses such as deep percolation and runoff) in an average year, given soil moisture levels do not fall below critical levels. Under ideal conditions, this net water requirement is reduced by the effective rain (*Muchová* and *Fazekašová,* 2010; *Führer et al.,* 2011; *Pásztorová et al.*, 2011).

Availability of water is a major stress 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 values of the crop are highly affected by climatic conditions, 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 (*Pollhamer,* 1981; *Nagy* and *Jan,* 2006; *Varga et al*., 2007; *Vida et al.,* 1996). The aim of this study was to determine the role of water availability impacts on wheat quantity and quality. Since main quality indicators – protein, farinographic value, gluten content, Hagberg falling number for wheat, as well as protein, starch, oil, and fibre for maize – have a rather diverse manifestation, there is a need to gain more information concerning the behavior of them.

## 2. Materials and methods

In long term field trials, a wide range of high milling and baking quality winter wheat *Triticum aestivum* L. varieties were examined under identical agronomic conditions during a 15 years period in the experimental years of 1996–2010, and high starch maize (*Zea mays* L.) hybrids were tested in a 9 years period of 2002–2010. The small plot trials were run at the Nagygombos experimental field of the Szent István University, Crop Production Institute, Hungary. 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 (*Fig. 1*), while the average depth of groundwater varies between 2 to 3 meters (*Fig. 2*).

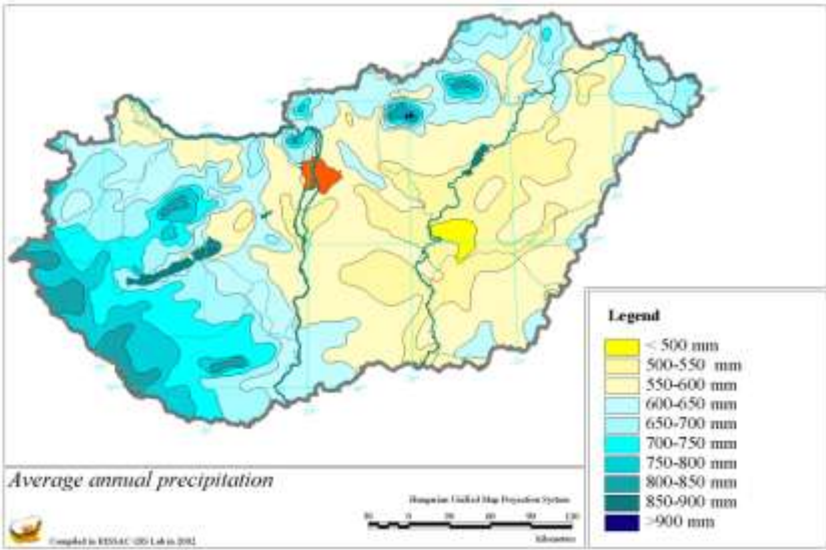


*Fig. 1*. Spatial distribution of average annual precipitation in Hungary (Source: RISSAC, 2002).

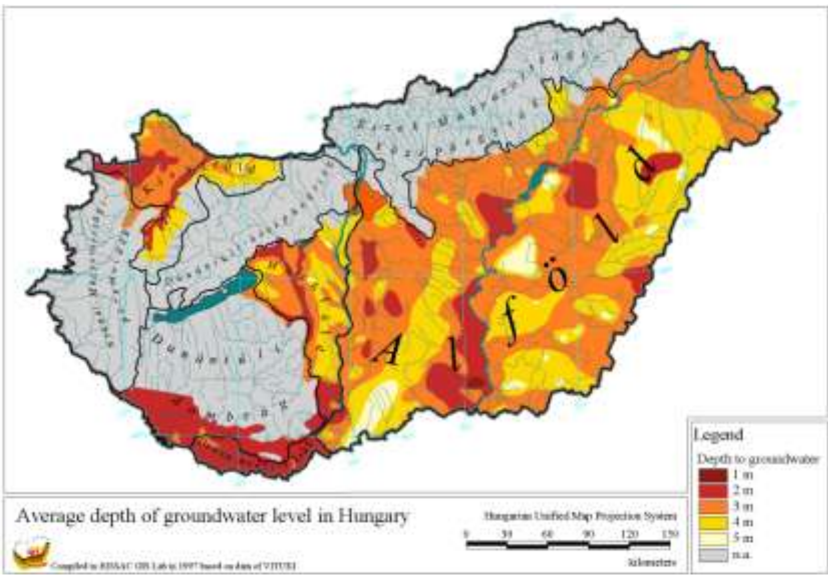


*Fig. 2.* Average depth of groundwater level in Hungary (Source: RISSAC, 1997).

Experiments were 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, wet gluten content, and Hagberg falling number results were processed, as well as maize quality parameters: protein, starch, oil, and fibre content. According to the specific harvest conditions of 1999 and 2010 crop years, Hagberg figures were not applicable. In case of maize trials, oil values have been analyzed from 2006 only. Quality characteristics were processed at the Research Laboratory of the SIU Crop Production Institute, according to Hungarian standards (*MSZ 6383,* 1998). Grain yield samples and quality figures were correlated with water availability parameters. Analyses were done by Microsoft Office 2003 statistical programmes with respect to the methodology of phenotypic crop adaptation (*Eberhart* and *Russell,* 1966; *Finlay* and *Wilkinson,* 1963; *Hohls,* 1995).

## *3. Results and discussion*

Annual amounts of precipitation and winter wheat yields have been examined in a 15 years time range, while that of maize in a 9 years period at the Nagygombos experimental field of the Szent István University, Gödöllő. *Tables 1* and *2* illustrate the annual changes of yield and precipitation mean values. Yields have been correlated with water availability.

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

*Table 1*. Annual precipitation, yield and quality figures of a winter wheat trial (Nagygombos, 1996–2010)

| Year | Precipitation, [mm]* | Yield [$tha^{-1}$] | Protein, [%] | Farinographic value | Wet gluten [%] | Hagberg Falling No |
|---|---|---|---|---|---|---|
| 1996 | 544 | 4.08 | 15.8 | 89.7 | 37.8 | 339 |
| 1997 | 407 | 2.88 | 13.2 | 50.4 | 30.5 | 213 |
| 1998 | 725 | 6.21 | 11.5 | 70.7 | 27.4 | 278 |
| 1999 | 837 | 2.87 | 14.3 | 47.4 | 32.2 | – |
| 2000 | 344 | 3.32 | 11.6 | 44.4 | 28.3 | 188 |
| 2001 | 706 | 5.28 | 12.0 | 51.6 | 27.5 | 295 |
| 2002 | 426 | 4.34 | 17.2 | 62.4 | 38.4 | 362 |
| 2003 | 442 | 3.47 | 17.6 | 63.3 | 36.8 | 370 |
| 2004 | 463 | 6.06 | 15.3 | 58.8 | 29.9 | 296 |
| 2005 | 705 | 5.72 | 14.3 | 50.9 | 30.1 | 282 |
| 2006 | 593 | 7.11 | 15.4 | 54.8 | 33.7 | 346 |
| 2007 | 545 | 5.21 | 18.1 | 62.6 | 38.8 | 420 |
| 2008 | 612 | 7.82 | 13.2 | 54.1 | 28.8 | 349 |
| 2009 | 623 | 6.55 | 12.2 | 58.3 | 32.7 | 293 |
| 2010 | 847 | 3.87 | 14.5 | – | 32.3 | – |

*Source: OMSZ

*Table 2*. Annual precipitation, yield, and quality figures of a maize trial (Nagygombos, 2002–2010)

| Year | Precipitation* [mm] | Yield [$tha^{-1}$] | Protein, [%] | Starch [%] | Oil [%] | Fibre [%] |
|---|---|---|---|---|---|---|
| 2002 | 426 | 5.44 | 9.2 | 63.5 | – | 4.4 |
| 2003 | 442 | 4.12 | 7.63 | 72.2 | – | 4.35 |
| 2004 | 463 | 5.60 | 8.43 | 68.8 | – | 4.87 |
| 2005 | 705 | 5.22 | 7.1 | 74.5 | – | 3.96 |
| 2006 | 593 | 7.40 | 6.7 | 74.1 | 4.6 | 3.84 |
| 2007 | 545 | 8.24 | 8.5 | 65.8 | 4.7 | 5.8 |
| 2008 | 612 | 6.28 | 7.9 | 64.3 | 4.6 | 3.4 |
| 2009 | 623 | 7.34 | 6.8 | 63.3 | 4.2 | 2.1 |
| 2010 | 847 | 4.09 | 8.2 | 70.5 | 4.4 | – |

*Source: OMSZ

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). *Table 1* provides a summary of changes in yield quality characteristics. Apart from grain yields, protein, farinographic value, wet gluten, and Hagberg falling number records have also been evaluated all along the experiment. Yield figures were in accordance with annual amounts of precipitation with two exceptions regarding the 1999 and 2010 crop years.

Wet gluten content of grain samples proved to be a most stable quality characteristic. Annual changes of protein figures were significant. Farninographic values and Hagberg falling number figures were affected by precipitation. In some dry years like 2002 and 2003, baking quality was far better than in moist years, however, it was escorted by low yield figures as well. The manifestation of the Hagberg falling number was due to the rain conditions of the harvest and post-harvest periods. Re-moistening of ripen dry grain may result in alterations of the α-amylase activity, thus, it may have an impact on rheological characteristics of dough.

Results of maize experiments are summarized in *Table 2*. Yield quantity of maize crop proved to be more variable than quality parameters. Protein values were smaller, and starch values higher in rainy years. Oil values have shown no major changes. Fibre content values in certain crop years were randomly changing, however, no systematic trends could be observed.

## *4. Conclusions*

Water availability can be considered as a basic factor related to yield quality and quantity performance of grain crops. In an agronomic long term trial run at the Szent István University's Nagygombos experimental site, the impact of water availability on wheat and maize crops have been evaluated. Correlation tables are presented in *Tables 3* and *4*. Various crop years have had different impacts on crop yield quantity. Yield figures were not in correlation with annual precipitation in general. However, with an exception of two years of extremely high precipitation, yield figures were in accordance with that the annual precipitation. Moisture availability had diverse influence on quality manifestation. High precipitation has often resulted in poorer quality, especially gluten and Hagberg values have been affected by that. Protein and gluten values proved to be the most stable quality characteristics in this study. Drought stress reducing the amount of yield has induced quality improvement in a few cases. Maize yields were more variable than that of wheat. Maize quality parameters proved to be more stable than yield figures except for fibre content values (*Fig. 3*). In *Fig. 3*, maize yields and quality parameters are displayed on a 9 years basis, while wheat yields and quality parameters are displayed on a 15 years basis. Both yields are clustered into three groups representing dry (<500 mm), normal (500–700 mm), and moist (>700 mm) crop years, and the range of stability is expressed in % of respective X value deviations.

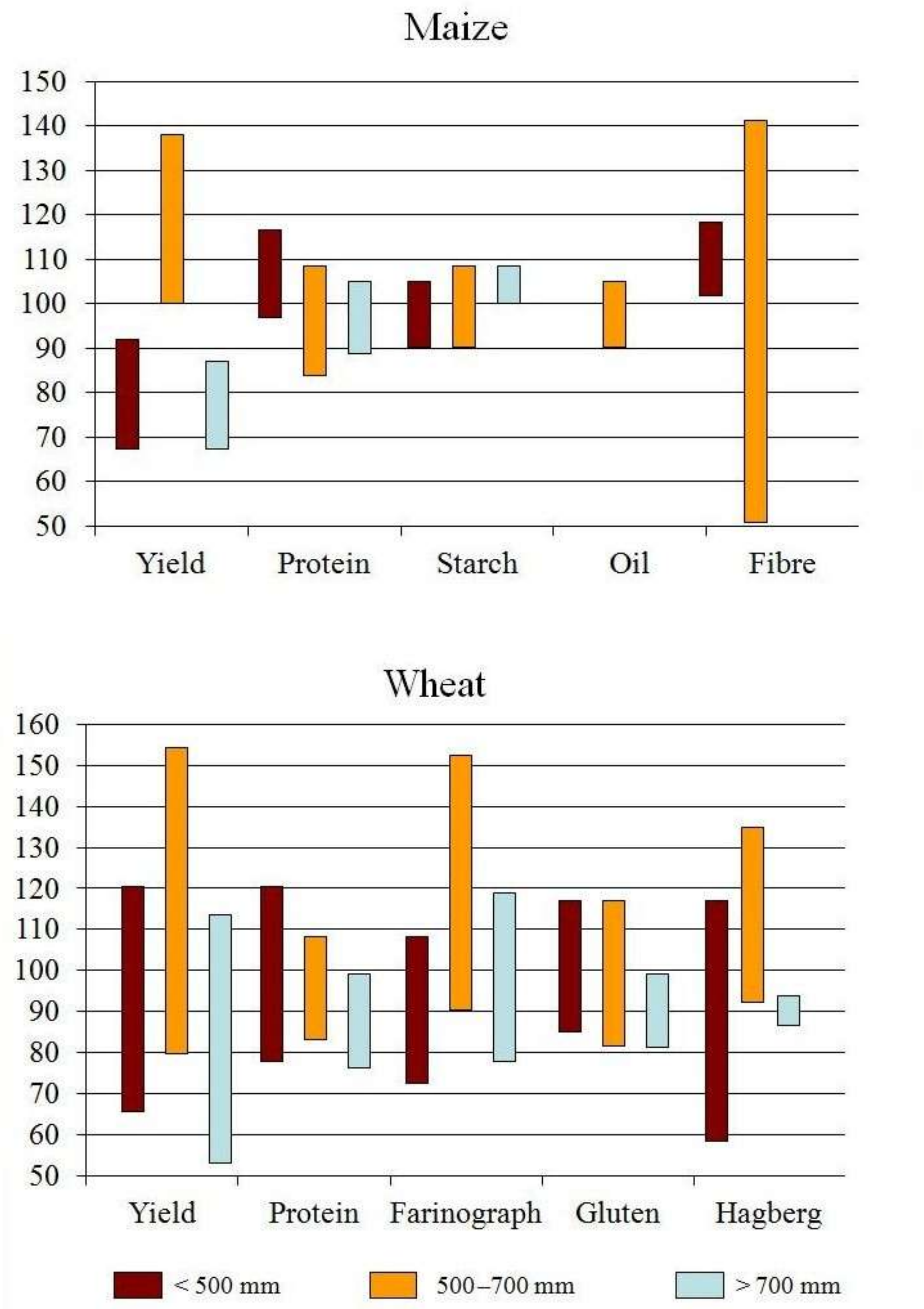


*Fig. 3.* Stability of yields and quality parameters of maize and wheat crops.
(Nagygombos, 2002–2010; 1996–2010)

*Table 3*. Correlation figures of winter wheat trial. (Nagygombos, 1996–2010)

| **Correlation r value** | **Year** | **Precipitation [mm]** | **Yield [$tha^{-1}$]** | **Protein [%]** | **Farinographic value** | **Wet gluten [%]** | **Hagberg Falling No** |
|---|---|---|---|---|---|---|---|
| **Year** | 1 | 0.254 | 0.526 | 0.168 | –0.268 | 0.084 | 0.449 |
| **Precipitation [mm]** | 0.254 | 1 | 0.180 | –0.244 | –0.044 | –0.249 | 0.178 |
| **Yield [$tha^{-1}$]** | 0.526 | 0.180 | 1 | –0.165 | 0.058 | –0.246 | 0.308 |
| **Protein [%]** | 0.168 | –0.244 | –0.165 | 1 | 0.359 | 0.874 | 0.778 |
| **Farino-graphic value** | –0.268 | –0.044 | 0.058 | 0.359 | 1 | 0.513 | 0.453 |
| **Wet gluten [%]** | 0.084 | –0.249 | –0.246 | 0.875 | 0.513 | 1 | 0.716 |
| **Hagberg Falling No** | 0.449 | 0.178 | 0.308 | 0.778 | 0.453 | 0.716 | 1 |

| **Regression coefficient** | **Year** | **Precipitation [mm]** | **Yield [$tha^{-1}$]** | **Protein [%]** | **Farinographic value** | **Wet gluten [%]** | **Hagberg Falling No** |
|---|---|---|---|---|---|---|---|
| **Year** | 1 | 0.007 | 1.493 | 0.348 | –0.098 | 0.095 | 0.029 |
| **Precipitation [mm]** | 8.807 | 1 | 17.69 | –17.50 | –0.547 | –9.710 | 0.348 |
| **Yield [$tha^{-1}$]** | 0.185 | 0.002 | 1 | –0.121 | 0.008 | –0.097 | 0.007 |
| **Protein [%]** | 0.081 | –0.003 | –0.227 | 1 | 0.070 | 0.475 | 0.028 |
| **Farino-graphic value** | –0.733 | –0.004 | 0.415 | 1.833 | 1 | 1.425 | 0.081 |
| **Wet gluten [%]** | 0.075 | –0.006 | –0.619 | 1.610 | 0.185 | 1 | 0.048 |
| **Hagberg Falling No** | 6.786 | 0.091 | 12.82 | 21.28 | 2.530 | 10.65 | 1 |

There have been two parameters in this study with less chance to observe; once the soil impacts on water availability, since the trials were designed in a *ceteris paribus* agronomic layout. The other is the varietal differences between wheat cultivars and maize hybrids. These fields are to be evaluated in further studies.

*Table 4.* Correlation figures of maize trial (Nagygombos, 2002–2010)

| **Correlation r value** | **Year** | **Precipitation [mm]** | **Yield [tha$^{-1}$]** | **Protein [%]** | **Starch [%]** | **Oil [%]** | **Fibre [%]** |
|---|---|---|---|---|---|---|---|
| **Year** | 1 | 0.795 | 0.270 | –0.331 | –0.166 | –0.712 | -0.489 |
| **Precipitation [mm]** | 0.795 | 1 | –0.131 | –0.355 | 0.269 | –0.448 | -0.478 |
| **Yield [tha$^{-1}$]** | 0.270 | –0.131 | 1 | –0.223 | –0.363 | 0.316 | -0.024 |
| **Protein [%]** | –0.331 | –0.355 | –0.223 | 1 | –0.463 | 0.456 | 0.644 |
| **Starch [%]** | –0.166 | 0.269 | –0.363 | –0.463 | 1 | 0.263 | 0.169 |
| **Oil [%]** | –0.711 | –0.448 | 0.316 | 0.456 | 0.263 | 1 | 0.858 |
| **Fibre [%]** | –0.489 | –0.478 | –0.024 | 0.645 | 0.169 | 0.856 | 1 |

| **Regression coefficient** | **Year** | **Precipitation [mm]** | **Yield [tha$^{-1}$]** | **Protein [%]** | **Starch [%]** | **Oil [%]** | **Fibre [%]** |
|---|---|---|---|---|---|---|---|
| **Year** | 1 | 0.016 | 0.505 | –1.072 | –0.101 | –5.625 | –1.107 |
| **Precipitation [mm]** | 39.42 | 1 | –12.13 | –56.84 | 8.117 | –263.1 | –44.07 |
| **Yield [tha$^{-1}$]** | 0.144 | –0.001 | 1 | –0.385 | –0.118 | 2.531 | –0.031 |
| **Protein [%]** | –0.103 | –0.002 | –0.129 | 1 | –0.087 | 1.875 | 0.532 |
| **Starch [%]** | –0.273 | 0.009 | –1.117 | –2.461 | 1 | 6.000 | 0.742 |
| **Oil [%]** | –0.090 | –0.001 | 0.039 | 0.111 | 0.012 | 1 | 0.124 |
| **Fibre [%]** | –0.216 | –0.006 | –0.019 | 0.782 | 0.039 | 5.936 | 1 |

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