**Theses of PhD thesis**

# Utilization possibilities of sorghum for energy purposes

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# 1. PRELIMINARIES AND OBJECTIVES OF THE DOCTORAL DISSERTATION

The production and use of bioethanol in public transport is a very important element to increase the proportion of renewable energies, so that the intensive spread of bioethanol utilization can be traced in the European Union. As a result of the EU legal harmonization and the common system of sanctions, bioethanol is already present in all of the Member States, which can be fueled on its own or in some proportions with gasoline. However, some countries produce and use this renewable energy in quite a large quantity. Occasionally, problematic sales opportunities of agricultural products allow the production of biofuels, while energy and environmental considerations provide a long-term professional justification for produce biomass liquid fuels. These processes are very effective in boosting production security, as they diversify the activity of farmers and produce products that are marketable and even suitable for their own use.

The application of first-generation biofuels will certainly be necessary and justified until the development of more efficient technologies and the expansion of transport policies, by the modification of transport policy. The use of bioethanol in public transport is considered to be a relevant solution by quantitative, technical, environmental aspects. Based on Hungary's experience, it can be stated that the barrier to spread bioethanol is typically due to some economic reasons, since bioethanol is on the boundary of economical profitability. In the case of second and third generation biofuels, the situation is even worse, because due to the negative economic indicators of the production technology, their production and wide application are still to be expected.

Although intensive developments are being made in relation with the production and use of biofuels in Hungary, the biocomponent content of fuels available at filling stations and the technological development of filling station systems are still justified. In the field of technological development, the efficient utilization of by-products can be an important factor, which can provide opportunities for second-generation bio-alcohol production and biomass firing as well.

The intellectual antecedent of my research was the research project "Biomass-based complex heat and power generation technology" conducted by Dr. István Balogh between 2006 and 2008, in which the energetic evaluation of the various silo sorghum hybrids was realized at the Karcag Research Institute. Based on the results and the experiences of the project, the aims of this writing were also formulated.

The overall objectives of the dissertation are:

The basic aim of the research was to quantify the bioenergy potential of sweet sorghum hybrids, as potential energy crops, by analyzing both biofuel production and biomass combustion aspects. A further aim was to develop the methodological development of the quantitative determination of complex carbohydrates which are important for the production of second generation biofuels, and to evaluate the potential of the hybrids as energy crops in a unit area. Further aim was to develop a spatial decision support methodology in order to obtain a numerically identify the size and location of areas suitable for energy-producing sorghum production.

Detailed objectives of the dissertation:

The aim of the dissertation was to study the maximum sugar content and sugar accumulation dynamics typical of sweet sorghum hybrids on the basis of six sweet sorghum hybrids. Further aim was to evaluate the calorimetric combustion heat of the compression residue (bagasse) which is produced by as a by-product of the sweet sorghum based bioethanol production. A goal was to quantify the amount of polysaccharides in the bagasses of the examined hybrids so as to clarify the potential role of these hybrids in the second generation bioethanol production. A methodological development of determination of these detergent fiber fractions using non-invasive spectroscopic methods was an aim as well.

Another objective is to quantitatively estimate the Hungarian sweet sorghum based bioenergy potential considering the climatic and edaphic conditions of Hungary based on map files of AGROTOPO, CORINE and CarpatClim which can form the basis of a regional level decision support system.

## 2. MATERIALS AND METHODS

2.1. Methodology for determining bioethanol potential

Field experiments were located at the University of Debrecen Agricultural Research Center Karcag Research Institute. During the experimental period, plots were placed on the Institute's B2, H2 and I2 marked arable lands, in compliance with the correct crop rotation rules. The experiments were made on a medow chernozem soil. The primary cultivation was ploughing in autumn in every case, which was further cultivated in spring with harrow, while the seedbed preparation was always done with a combined tillage equipment. The experiment was usually sown during the April 25 to May 5 period. Sowing had been done by 70 cm row spacing and 5 cm seed distance while the seedling depth was 4.6 cm. The sowing was done using a grain sowing machine (type: HEGE 95). In the experiments, ammonium-nitrate was used in equivalence with 100 kg/ha N active substance, which was managed into soil by the process of seedbed preparation. After sowing, the seedbed was closed in every case using a ring roller.

The biotanol potential measurements are focused on six sweet sorghum hybrids which are in the public cultivation and included in the National Variety Catalogue and the EU Field Plants List as well. Field experiments were sampled from mid-August until the harvest at an average of 10 days intervals. For the purposes of the tests, whole plants were collected from the 4 $m^2$ sample areas of the hybrids. Every sampling were done in two repetitions. The reduced number of repetitions was applied in order to avoid quality deterioration of the raw material. After sampling the mass of fresh samples was weighed and the plant samples were chopped with an AL-KO dynamic H1600 type chopper. From the chopped material samples were dried in a Nüve FN400 oven at 105 ° C till constant weight in four repetitions, so as to determine the moisture content of the samples.

The refractive dry matter content of the diluted phase of sorghum stems were determined by a refractometer which values are in a strong correlation with the actual sugar content (Kawahigashi et al., 2013). Thus the refractive dry matter content of the extracted juice determined in Brix% was defined as sugar content. The refractive dry matter contents were determined by four parallel measurements per sample. During the measurements, diluted phase of the samples, were originated from the internodium between the nodes 4 and 5, which method is in accordance with the measurement practice applied by the National Variety Experiments. Bioethanol potential calculations for the investigated hybrids were done by the calculation formulas published by Institution of Japan Energy (2006) using MS Office Excel software. For the preparation of the bagasse, the chopped sorghum samples were pressed by a Bologna S.T.M. AMP/E50/2 wedge press than the compression residue were dried in a Nüve FN400-type oven at 105°C till constant weight.

The lignocellulose content of the crushed samples with the size from 0,1 to 2 mm were determined by the analytical procedure developed by Georging and Van Soest (1975), which resulted the quantitative determination of Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF) and Acid Detergent Lignin (ADL) fractions (Figure 1).

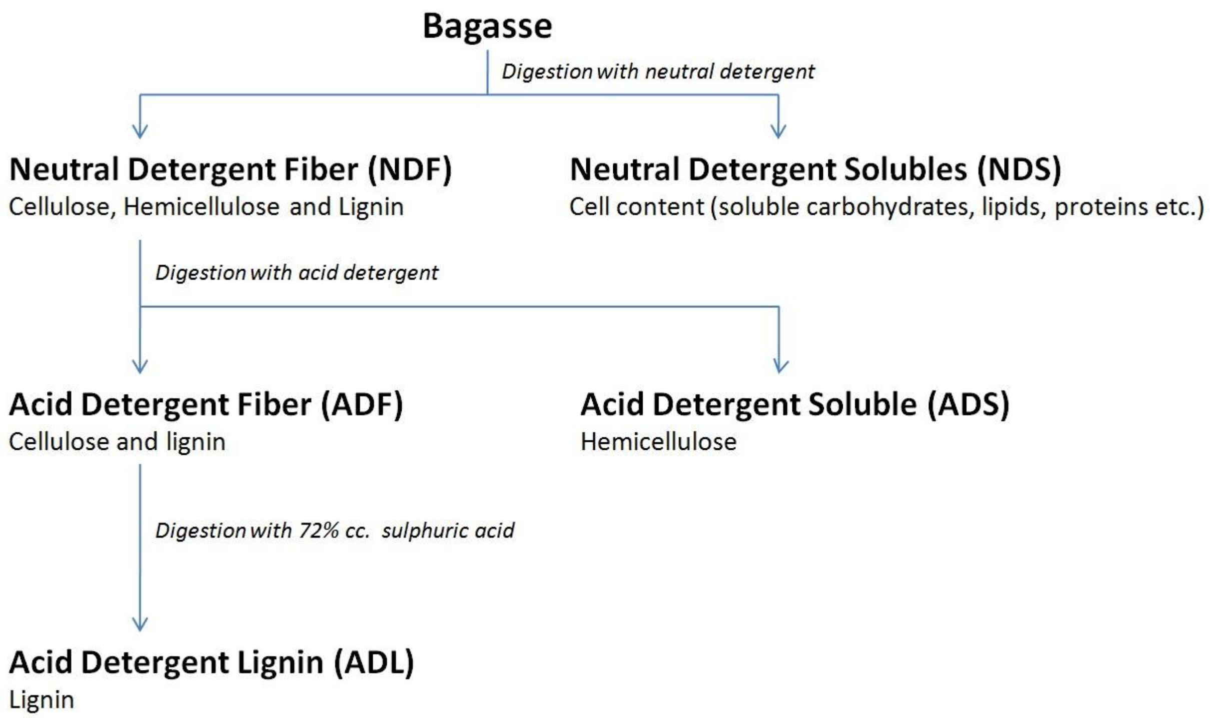



**Figure 1. Determination of detergent fiber fractions**

The NDF content of the samples is the sum of cellulose, hemicellulose and lignin, while the ADF contains cellulose and lignin molecules. ADL is equivalent with the lignin content of the samples. Based on the measurement results, the cellulose, hemicellulose and lignin content of the samples were calculated as follows:

NDF – ADF = hemicellulose

ADF – ADL = cellulose

ADL = lignin

Spectroscopic measurements of complex carbohydrate compounds were performed by using AvaSpec NIR256-2.5-HSC Fiber Optic Spectrometer in the range of 1000 to 2400 nm. During the measurements, the average class of wavelengths was 6.43 nm. To ensure the correct measurement accuracy, measurements were performed on a special "black box" in order to exclude external light. During the measurements, the end of the optical fiber was 5 mm from the surface of the sample. Spectral data was recorded by using AvaSoft 8.2 software. Recorded results reported an average of 30 measurements with triple pixel smooth of the spectral curves. Spectral data was exported as an .xls file and spectral features were carried out with MS Office Excel software.

Since cellulose sensitive to electromagnetic radiations between 2000 nm and 2200 nm (Nagler et al., 2003), it was possible to calculate the CAI (Cellulose Absorption Index), which is generally accepted method for distinguish dry senescent plant materials from soil surface (Daughtry et al. al., 2004). Based on the measured reflectance values, CAI was determined using the equation (1).

*Equation 1.*

$$CAI = 0.5\ (\rho 2000 + \rho 2200) - \rho 2100$$

where:

ρ: reflectance values of the current wavelength

2.2. Assessment method of combustion aspects of sorghum

In the case of sweet sorghum, for the determination of the calorimetric combustion heat, the dried and chopped plant samples were used. During the analysis further crop materials were used as winter wheat, maize and sunflower, while in the case of the examined tree species (poplar, alder, locust, willow), cube shaped plant materials were used as samples for the measurements. During each combustion heat measurement, 1.00 g samples were measured. The moisture content of the samples used for the measurements varies from 4-6%. For the calorimetric assays, the dried samples were cut with a Condux plant cutter of 1-2 mm and then a tabletting press were used to prepare tablets of 1.00 g. The moisture content of the tablets was determined by drying at a temperature of 45 ° C in a drying oven, which were ranging from 8 to 10%. The measurements were performed on an analytical scale with a precision of four decimal places, which is required for energetic determination.

The compost for calorimetric tests was derived from a biogas plant operating in the region where the biogas slurry from the fermenter was separated and the solid phase was composted while the oil cake samples came from an oil spraying plant operating in the region as well. To perform the measurements IKA C2000 Basic type adiabatic calorimeter was used. For perfect combustion, the calorimeter bomb was filled with pure oxygen at a pressure range of 20-30 bar.

The calorimeter I. system was formed by a specially designed calorimeter bomb, in which a well-prepared and tableted pattern was placed in a burning crucible. During the measurement, the samples were ignited in pure oxygen by cotton fibers. Heat Q released by System I. was recovered in its entirety by the known system of heat capacity C, which in this case was water. Due to the addition of heat Q, the temperature of the system II. was affected by ΔT. The disturbing heat streams need to be reduced to a negligible degree, which is ensured by the thermal insulation of the device from the environment. Due to the measurement of the ΔT, calorimetric combustion heat was determined based on the energy balance of *Equation 2.*

*Equation 2.*

$$Q = -C * \Delta \mathrm{T}$$

The calorimeter automatically calculated the value of the heat from the exact values of the sample mass and the ΔT, which is considered to be the general characteristic of adiabatic calorimeters (Erdey-Grúz and Prost, 1962). The software used in the measurement procedure was CalWin Version 2.00.030. version 1999. Each sample was measured by twenty parallel measurements for statistical reliability. Measurements were preceded by calibration by four measurements of known benzoyl acid tablets by calibration with the C value obtained from the mean of the four measurements (26470 KJ/kg).

For samples of crop and bioenergetic by-products, we measured the residual ash at four decimal places (g) after laboratory measurements. Controlled production of ash residue for the analytical examination was carried out in OM SÖV TypeOH 63 glow oven. For combustion in the furnace, an average of 6 g of well-known air-dry mass samples were measured into the ceramic vessels. The glow has been made in three steps to avoid slicing patterns.

First, the samples were incubated at ~ 257 ° C, then to 570 ° C, and finally to the heating phase at ~ 650 ° C in the third phase of the heating. The glow was done for 2 hours.

Ceramic vessels containing the ash residue were placed in a desiccator except for the furnace to protect it from any moisture or to allow the burning residues to absorb the ambient temperature.

The analytical assays were performed by four parallel measurements. For the quantitative determination of P, K, Na, Ca and Mg, 0.4 g of minced samples were destructured in DK-20 block decay (VELP Scientifica) at 360 °C, 4.0 cc. sulfuric acid for 40 minutes at atmospheric pressure in the presence of a selenium catalyst. The digestion residue was filled up to 100 $cm^3$ to do the measurements. The P content was determined spectrophotometrically with vanado-molibdenate (ammonium molybdate, ammonium metavanadate) with a Spekol 1100 Spectrophotometer (Carl Zeiss Jena) at 440 nm wavelength.

The K, Na, Ca and Mg content were determined by a flame photometer in air-acetylene flame using Spectra AA-10 Atomic Absorption Spectrophotometer (Varian).

For the Cu, Zn and Mn determination, 0.5 g of the samples were exposed in a mixture of $HNO_3$-$H_2O_2$ with microwave decoupling at 190 °C at 27 bar for 30 minutes in a MARS Xpress (CEM) type microwave decay. The element content of the samples was determined by a flame photometer in an air acetylene flame Spectra AA-20 atomic absorption spectrophotometer (Varian).

Using the measured results, we used the *Equation 3* (*Carillo et al., 2014*) to determine the alkali metal content of the ashes to quantitafy risks caused by slagging.

*Equation 3.*

$$Alcali\ content\left(\frac{kg}{GJ}\right)=\left(\frac{1*10^{6}}{100}\right)*\left(\frac{Ash\%}{100}\right)*\left(\frac{K\%*Na\%}{100}\right)$$

## 2.3. Methodology for assessing site risks

The data collection was carried out in Karcag, Karcag Research Institute of the University of Debrecen. The meteorological parameters were recorded using a VAISALA QLC-50 type meteorological meter, with a frequency of 10 minutes. From the measured data we selected the values and dates of the latest spring frosts and soil frosts, as well as the earliest fall frosts and soil frosts from 1995 to 2016. The given dates were sorted into 5-day classes and determined their incidence within 20 years, the likelihood of phenomena by which it was possible to evaluate the risks arising from the length of the growing season. For the 20-year time period the effective heat sum of the sorghum was calculated using different base temperatures.

The conventional formula for the calculation of the effective heat sum takes into account the daily minimum and maximum temperatures, calculating the average temperature and then decreasing its value with the base temperature characteristic for the plant (*Dorka, 2005*), so calculations were made by the formula of *Equation 4*.

*Equation 4.*

$$HU\,eff = i\sum_{1}^{n} \frac{(T_{i,MIN} + T_{i,MAX})}{2} - T_B$$

Where:

$T_{i,MIN}$: daily minimun temperature (°C)

$T_{i,MAX}$: daily maximum temperature (°C)

$T_B$: base temperature (°C)

n: legnth of phenophase (days).

The calculations were performed with the lengths of two cultivation periods (1 May to 30 September and 21 April to 10 October) using baseline temperatures of 8 ° C to 15 ° C. During the investigations, we identified the potential zones of sweet sorghum cultivation in Hungary, using different GIS databases. An important database of modeling was the land use map, which was provided by Corine Land Cover - CLC database. The national CLC map contains 29 land cover and land use categories, from which the non-irrigated arable land required for modeling was classified in the IDRISI Selva GIS environment. Since the agro-ecological potential of the country is well characterized by the Agrotopographical Database (AGROTOPO) of 1: 100000, produced in 1991 by the Institute of Soil Science and Agrochemistry of the Hungarian Academy of Sciences (MTA), this was the other main data of my analysis.

Sorghum cultivation is possible on several soil types, but it is worth considering that it is better to grow crops (eg maize, etc.) on some soil types. In the present paper we have therefore divided the sorted areas into two groups, such as "possible" for sorghum cultivation, and "preferred" for sorghum production. Areas in the "possible" category are suitable for the production of sorghum, but in these areas other arable crops can also be grown effectively, such as maize. The "preferred" category belonged to areas where, due to the soil parameter in the AGROTOPO database, the cultivation of the majority of arable crops can only be achieved by compromise or significant loss of yield, while the soil is the optimum of the demand for sorghum. Accordingly, the "possible" areas for sorghum cultivation are in this case the areas where sorghum can be integrated in crop rotation in terms of soil conditions under efficient cultivation conditions, while the "preferred" areas for sorghum cultivation form a narrower category where the soil species are expected a more competitive choice for maize.

In order to evaluate climatic conditions, maps of "possible" and "preferred" areas were created based on soil aspects provided with additional overlays. On the national scale, the index of the index elaborated by Ellenberg (1988) was mapped to the maps showing soil yields, which is the ratio of the monthly average temperature of July and the annual rainfall sum, multiplied by thousands, thus the probability of possible drought damages based on the temperature data of the July period. (*Equation 5*)

*Equation 5.*

$$EQ = (T_{07}/P_{ann})*1000$$

Where:

EQ: Ellenberg index

$T_{07}$: average temperature of July

$P_{ann}$: annual precipitation sum

The mapping overlays with the indexes were downloaded from the CarpatClim online database at 0.1 ° * 0.1 ° resolution for the 2001-2010 period, which is basically an in-depth study of the Carpathian basin climate based on a unified methodology.

In order to clarify the precise geographic conditions of the drought phenomena in the Great Plain, according to the data of CarpatClim, the precipitation data registered between 1991-2010 have been mapped, taking into account areas of cultivation risk due to rainfall, taking critical times of sorghum and maize water supply. In the case of maize, the period considered critical to water needs was the period of generative development of maize, that is, the months of July and August, while in the case of sorghum this was the period of grazing after sowing, which was May. By evaluating the overlapping of the soil and some climatic overlays we determined the specific cultivation characteristics of the given area unit for sorghum.

Since the AGROTOPO database stores the site specificities as vector files, and there are several attribute data for the given polygon, we first selected each of the soil parameters separately in the Global Mapper program. These polygons were used as a cutting area for the aforementioned Corine (raster-based) database. Since some soil parameters have covered several categories of land cover (eg, AGROTOPO based on chernozem soil, there may be forest, arable, urban environment, etc.), so the arable land was sorted by segmentation of the already cut land use category by map segmentation.

In the case of all the categories with the potential for modeling, we have done the sorting of the arable land. Next, we added the maps so that the areas where there are overlaps between the given soil parameters can be demarcated. For overlaps, the "AND" spatial logical operation was used, leaving out of the analyzes areas that did not meet the criteria for at least one parameter. In the following, overlays based on the CarpatClim data base were also combined with an "AND" logic operation, thus mapping over the "suitable" and "preferred" areas indicated the potential for cultivation of climatic hazards by precipitation quantities.

# 3. RESULTS

## 3.1. Results of bioethanol potential determination

Sugar accumulation curves typically have a bell-curve character, which reach the peak point when the plant's reached waxing maturity state, so the time to reach the maximum sugar content of the hybrid is closely related with the length of vegetation period of the hybrid. The results are in coherence with this assertion because Hybrid 1 as a middle maturity hybrid was the peak of the sugar accumulation curve at the earliest, while in the case of other hybrids with longer vegetation period, this maximum value could be determined only at later times. (Figure 2). This phenomenon was particularly emphasized in the case of hybrid 2, hybrid 5 and hybrid 6 species, where the bell shape curve could not be modeled due to the length of the growing season, which is also due to the climatic characteristics of the site. Thus the test hybrids due to the temperature of autumn, the phenological development was only possible to the stage of waxing. In addition to the curve characteristics, there were differences in the values of the maximum sugar content. For Hybrid 6, the maximum sugar content was 15.25 Brix%, while for Hybrid 4 it was 14.5 Brix%. For all other hybrids, I determined a sugar content of over 15 Brix%. On the basis of the measured values of the accumulation curves I found that the average maximum sugar content for Hybrid 1 was 17.8 Brix%, while for Hybrid 5 this value was 19.1 Brix%. Based on the variances analysis, it can be concluded that there is a significant difference between the hybrids under consideration and the potentially bioethanol produced at the peak of the sugar accumulation dynamics where the least significant difference was 745 l/ha.

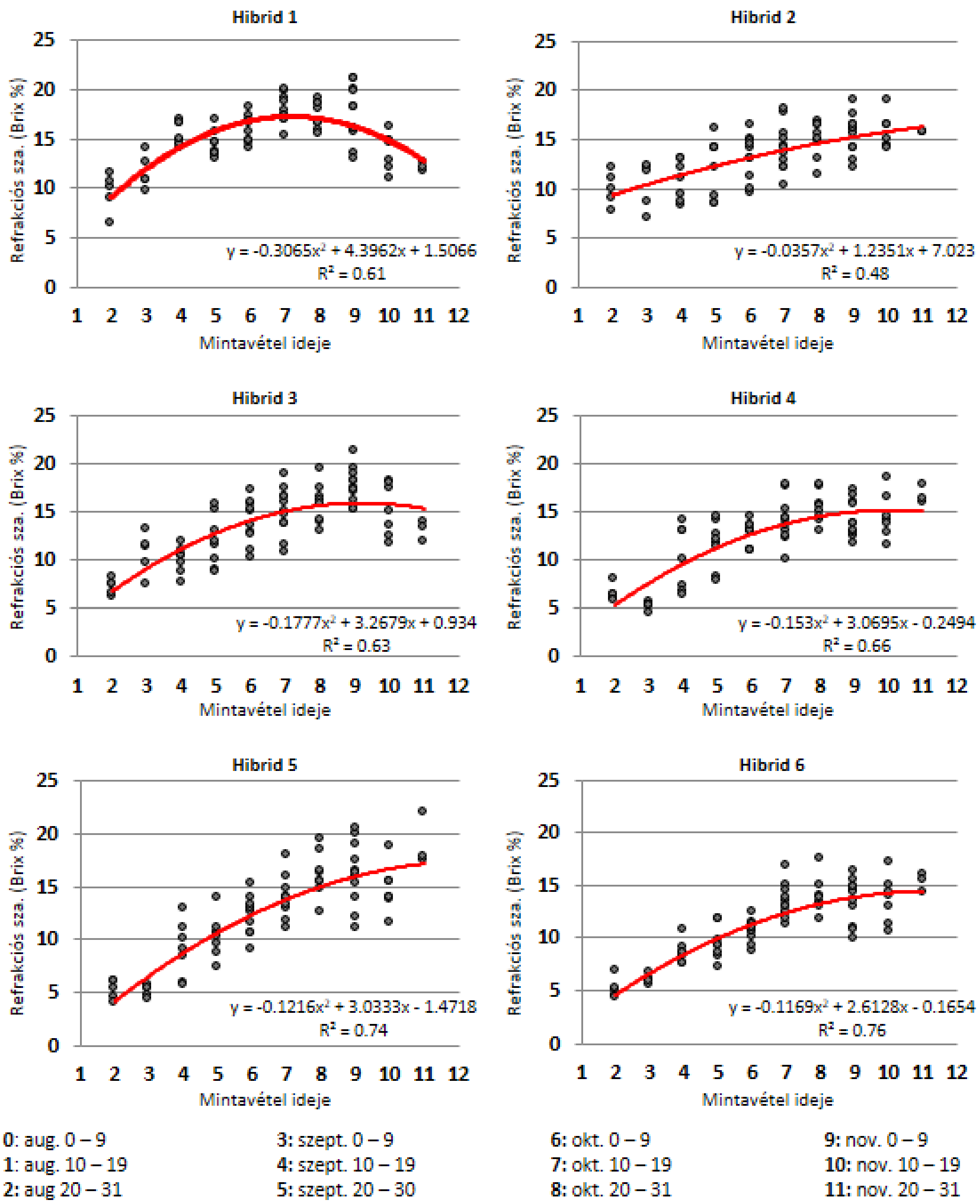



**Figure 2. Sugar accumulation curves in case of the investigated hybrids**

Based on the calculated bioethanol potential, I found that this value shows a strong correlation with the yield of the given hybrid, while the correlation with the sugar content was negligible. The finding was based on the determined Pearson's correlation coefficient, which showed a significantly stronger linear relationship between bioethanol potential and green yields (R=0.73) than the bioethanol potential and the sugar content ratio, where this coefficient was R=0.38.

On the basis of a cumulative assessment of the compression residues of the examined plant samples, it was found that the neutral detergent fibers (Neutral Detergent Fiber - NDF) fractions produced by cellulose, hemicellulose and lignin were on average 72% in the samples. It was also found that 32% of the dry matter content of the samples is hemicellulose, 36% cellulose, 4% lignin, and 28% on average other components present in the dry matter of the plant samples. Given that the NDF content consisted of an average of 50% cellulose and 45% hemicellulose, it was found that the compression residue of sorghum is a very good source of substance for second-generation bio-alcohol production. Based on the results of ANOVA I found that there is no significant difference among hybrids for hemicellulose and lignin content, while for the cellulose content there is a significant difference among the hybrids ($LSD_{5\%}$ = 4.9%). Based on the cellulose and hemicellulose-based bioethanol potential it has been found that compression residues of sweet sorghum hybrids are very important for the production of biofuels. This is supported by the fact that the average theoretical second generation bioethanol potential was above 900 l / ha for each hybrid tested, and even for some hybrids (Hybrid 1, Hybrid 5, Hybrid 6) this value was more than 1000 l/ha.

CAI was not directly developed for the spectral properties of cellulose, but for the quantitative estimation of high cellulose content, hence the cellulose content of the samples in this case changed too narrowly, which did not allow the possibility to emergence of possible widespread correlations. Calculated CAI values were on average 0.069 ± 0.013, a phenomenon which supports the assumption of a narrow interval of cellulose content, considering the fact that the values of this index are typically between -2 and 4, where the negative values indicate the absence of cellulose in the test (Daughtry et al., 1996). Nevertheless, results showed that there is a close correlation between CAI and the cellulose content of the bagasse (Figure 3).

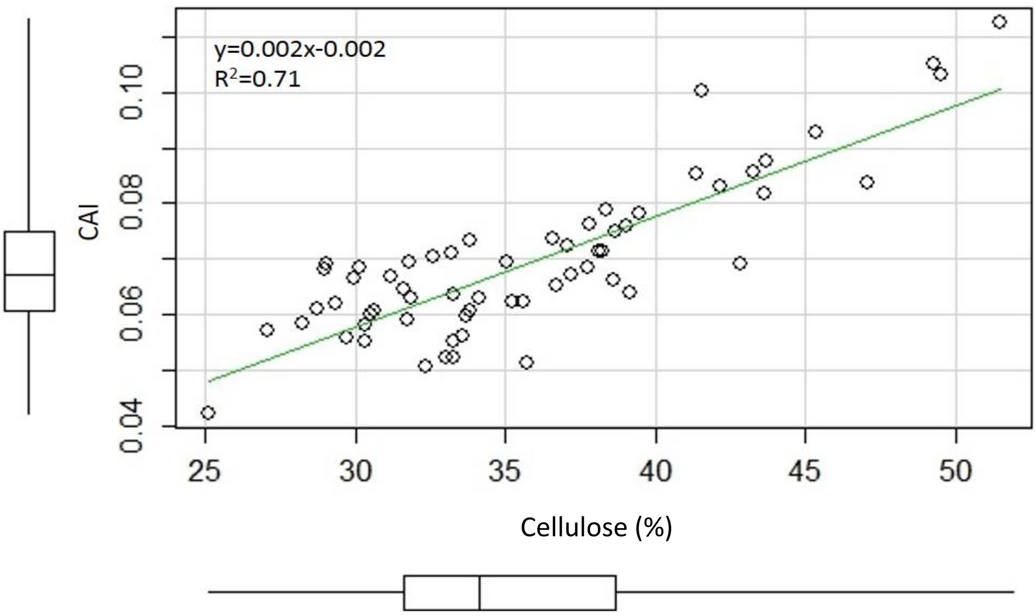



**Figure 3. The correlation of CAI and cellulose content**

Compared to the first generation bioethanol potentials, the average second generation bioethanol potentials show that there are significant differences between the hybrids for the total bioethanol potential. The most prominent results were registered in case of Hybrid 1 (3567 ± 1092 l / ha) and Hybrid 5 (3538 ± 864 l / ha), while Hybrid 2 (2030 ± 776 l / ha) had the smallest aggregate bioethanol potential. The results show that Hybrid 1 and Hybrid 5 varieties are the most promising for the production of bioethanol, but it is important to note that there is a significant difference in time between the measured parameters.

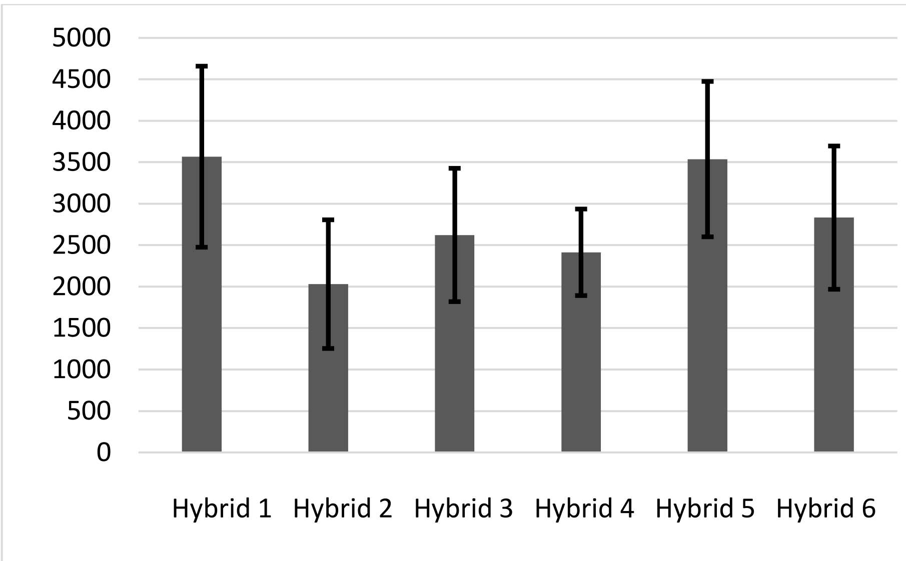



**Figure 4. Bioethanol potentials of the investigated hybrids**

3.2. Results of the calorimetric measurements of sorghums

Based on the results of the combustion heat of the investigated energy by-products, I have determined that the oil cake has the highest average combustion heat value of 20577 KJ / kg, while the average combustion heat of 15515 KJ / kg was lower for compost. The results of the test material are very distinct from each other, the difference between which is significant. The groups of test substances also differed in terms of the percentage by mass of ashes remaining in the firing. Most of the ash produced in the case of compost, which was characterized by an average ash content of 14.42%, while that of the oil cake was 0.86%. The difference between materials in this respect was also significant.

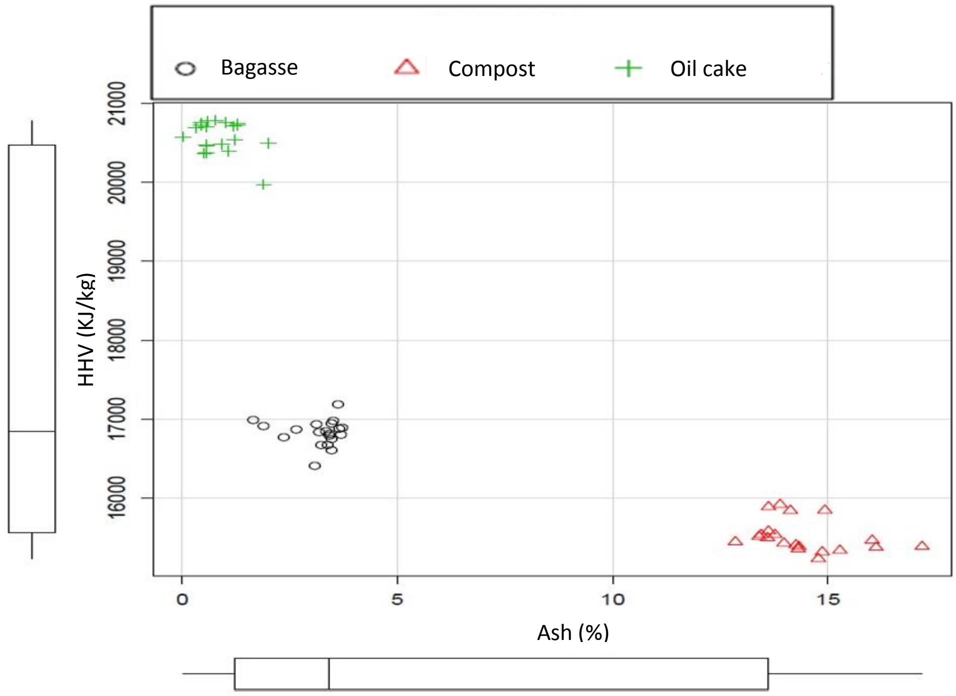



**Figure 5. Higher heating values and ash amounts of the investigated by-products**

Ash deposits are good phosphorus and potassium sources, however, they contain a sufficient amount of Ca and Mg that can be important in improving the soil structure. When applied to the soil, P and K are the most important nutrients in the two largest proportions, given that the P and K content of these ash amounts is equivalent to the active substance content of phosphorus and potassium fertilizers. For the phosphorus content, the three bioenergy by-products showed significant differences. The compost had an average phosphorus content of 10.57%, the oil cake was 34.53%, while for the bagasse it was only 2.93% (Figure 6). With 27.2% of the average potassium content in this respect the oil cake proved to be the most prominent, while in case of bagasse this value was 18% and for compost 9.53%. To the greatest extent these elements are contained in the oil cake, which is attributable to the nutritional value of the sunflower seed. As for the K content, the value of bagasse was outstanding.

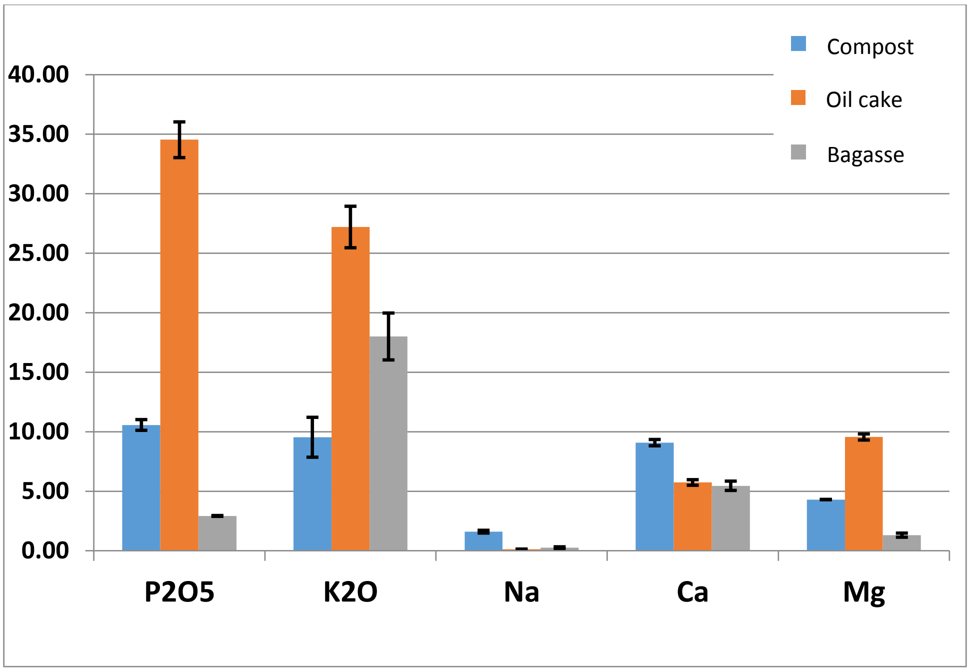



**Figure 6. The amount of the investigated elements in the ashes (%)**

Ca and Mg elements can play a role in improving soil porosity, especially when the Na content of the soil is high. All these three types of raw material contain very high proportions of these elements. For the Ca content 9,08% for compost and 9,56% for Mg for oil cake was the highest common occurrence rate.

The Na content in the case of oil cake and bagasse was low, only compost was found to have a 1.6% sodium content, which may be related to the fertilizer content of compost given that compost was made from a solid phase of a biogas processing plant. Regarding the risk of slagging, the compost was characterized by 1.04 Kg/GJ of alkali metal content at a level of 0.16 Kg/GJ, which was the highest among bioenergy by-products. For bagasse, this value was 0.34 ± 0.07 Kg/GJ, while for oil cake 0.11 ± 0.07 Kg/GJ. According to Miles and Miles (1995), the alkali metal content above 0.34 Kg/GJ may lead to slagging problems in sustained biomass for combustion purposes, in order to avoid risk mitigation interventions can be needed. Based on these results, the burning characteristics of compost and bagasse requires the treatment to mitigate slagging potential. Mitigating risks can be achieved by washing,  mixing with low-alkali metal fuels or by lowering the amount of high alkali metal containing components if the combustion process use more than one feedstock component.

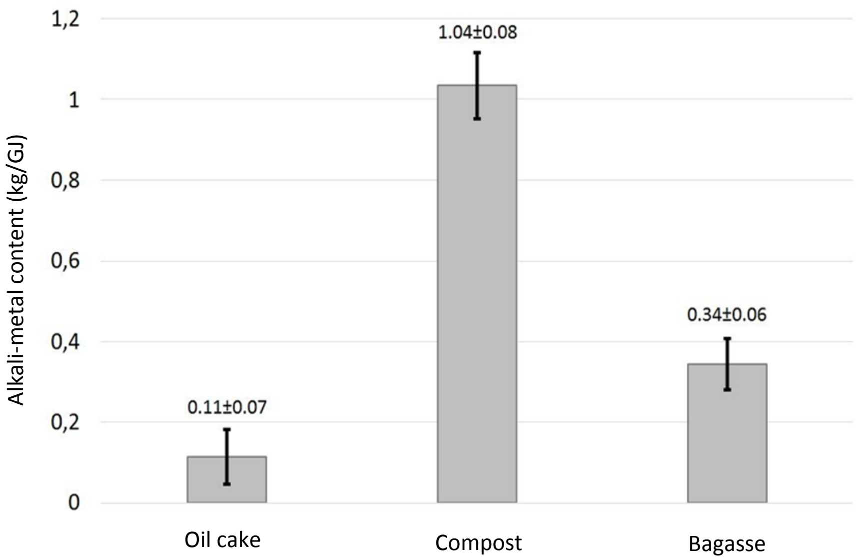



**Figure 7. Alkali-metal contents of the investigated ashes (mean±SD)**

<u>3.3. Results of the site specific risk assessment</u>

Since the base temperature value of the sorghum is typically higher than that of maize, so in Hungarian conditions, sowing is typically done later, usually in beginning of May. During this period the sorghum in the phase of germination and stage before sprouting of roots can be damaged by lack of precipitation. During the period 1991-2010, considering the possible lands for sorghum production by soil aspects on 698 968 ha less than 10 mm precipitation were registered once, while in the area of 71,160 ha fewer than 10 mm precipitation were registered twice in the beginning of May. This means that, based on the 1991-2010 period as a reference period, 33.96% of terrestrial areas suitable for sorghum cultivation can be expected to have a probability of 5% of the precipitation risk, while the 3.46% this probability is 10%. In the case of the Great Plain areas that are most preferred for sorghum cultivation, I found a probability of 5% for 2322 ha and 407 ha for 10%. (Figure 8)

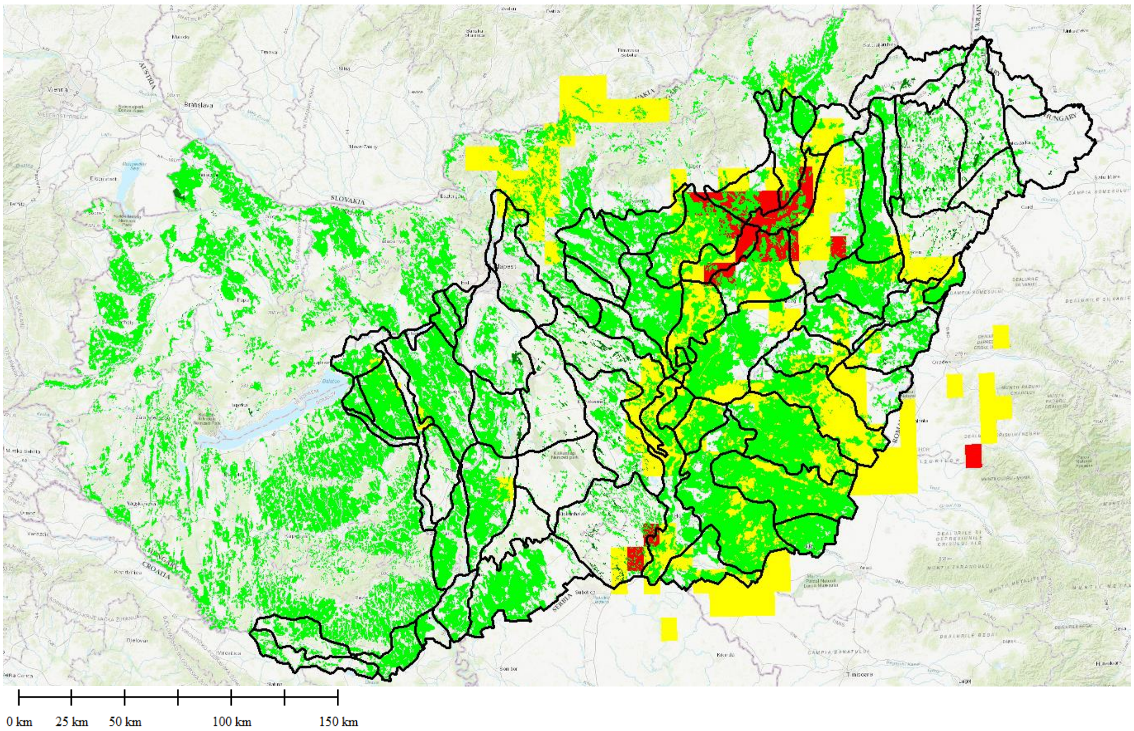
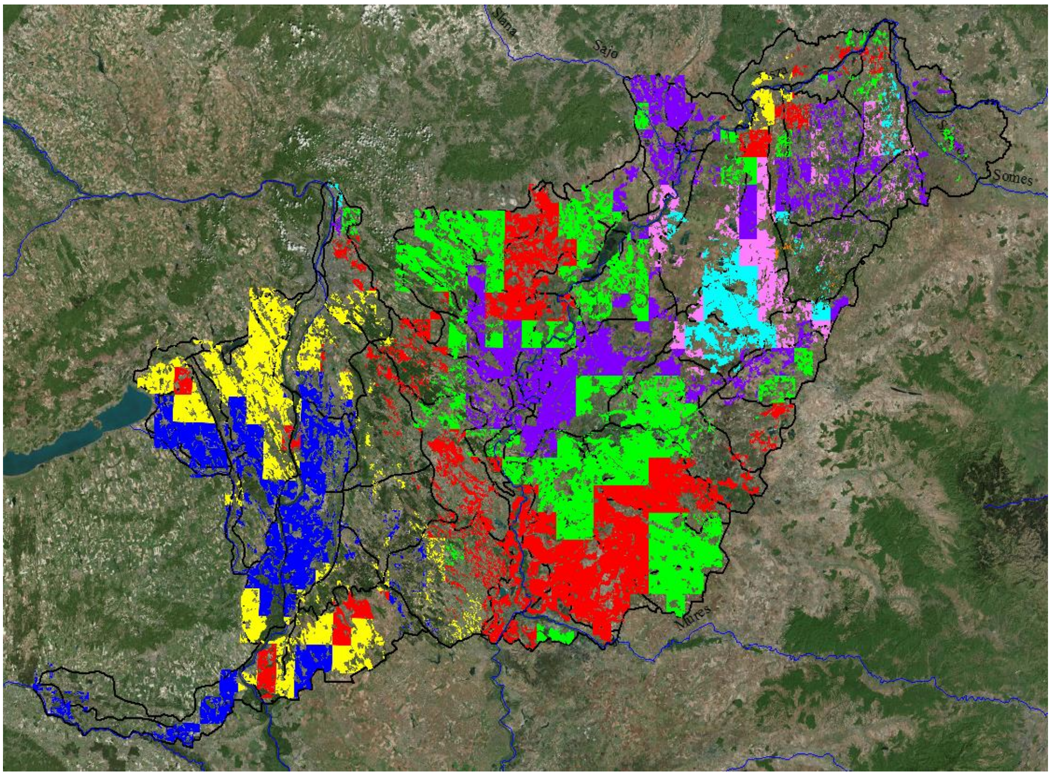



**Figure 8. The probability of precipitation shortage after sowing based on the period of 1990-2010**

The comparison of rainfall shortages in the July and August period, characterized by the generative development of maize, revealed that at 97% of the areas with sorghum production occurred at least one occasion of extreme rainfall deficiency in the maize generative development phase over the past two decades. In the 1082 ha area, a probability of 40% is likely to account for such a lack of rainfall, which clearly points to the thoughts of the representatives of conscious farming towards irrigation and drought-tolerant plant species. Based on the results it can be concluded that in the case of maize production, the critical probability of water scarcity may be present in the Great Plain during the generative phase in the Nyírség, Hajdúság, Midle Tisza and Northern Great Plain basins.




5% probability for critical precipitation deficit
10% probability for critical precipitation deficit
15% probability for critical precipitation deficit
20% probability for critical precipitation deficit
25% probability for critical precipitation deficit
30% probability for critical precipitation deficit
35% probability for critical precipitation deficit
40% probability for critical precipitation deficit

**Figure 9. Extreme precipitation deficit in July and August**

Considering the fact that sorghums are significantly better in drought tolerance in these lands, in addition to the soil aspects, sorghum production is justified. Based on these, it can be concluded that the landscapes listed above can be considered the most ideal potential areas of sugar-based energy supply. If, in these areas, sorghums are integrated into the rotation, we can take serious steps to achieve the objectives set out in Directive 2009/28 / EC, which would be a very important step in the Hungarian renewable energy sector.

## 4. NEW RESULTS OF THE DOCTORAL THESIS

1. Based on the experimental results I found that the maximum value (14,5-19,1 Brix%) of the sugar content in the stems of the sweet sorghum hybrids may be significantly different ($LSD_{5\%}$=2,5 Brix%), which is a very important characteristic for the energetic sorghum production. It was found that the bioethanol potential of hybrids is more closely related to the yields at harvest (R=0,73), so one of the cornerstones of bioenergetic sorghum production is the green yield at harvest.

2. In addition to the maximum value of sugar content, sugar accumulation dynamics are also of a hybrid characteristic that is closely related to the growing length of the hybrid. Based on these, it can be stated that conscious selection of species can mitigate certain risks of energy production of sorghum.

3. The bagasse have a high complex carbohydrate content (32% hemicellulose, 36% cellulose, 4% lignin), thus enabling to enhance the potential bioethanol yields per unit area to be increased. By this opportunity the bioethanol potential can be increased (825-1126 l/ha). The cellulose content of the bagasse was closely related to the reflection characteristics of some of the nearby IR ranges. By the correlation between the Cellulose Absorption Index and the cellulose content ($R^2$ = 0.71), the cellulose content can be estimated noninvasively.

4. Bagasse are characterized by considerable calorimetric combustion heat values (16570-16876 KJ/kg), which results a significant amount of ash rich in nutrients, which may be beneficial in the nutrient supply of sorghum producing areas. In addition special attention must be paid to the high alkali metal content of ashes (in case of bagasse: 0,34±0,06 kg/GJ) which can cause long-term damage to combustion plants.

5. I have found that the benefits of cultivation of hybrids with longer vegetation period, with regard to yields and sugar content, involve climatic risks. In the case of early sowing, the probability of damage due to late cooling may increase significantly, while the risk of loss of yield and a significant reduction in sugar content may increase due to late harvests.

6. Using the databases issued by the Hungarian Academy of Sciences and the Hungarian Meteorological Agency, I developed a spatial decision support system that allows us to define the areas suitable for sorghum production. I determined the extent of certain climatic risks for suitable and preferred sorghum production areas based on soil aspects. Using the decision support system and other results of the dissertation, both the Great Plain and Hungary can be expressed numerically as a potential bioenergy potential for biofuel utilization, taking into account the energy potential in bagasse.

## 5. APPLICATION POSSIBILITIES OF RESULTS IN PRACTICE

1. I found significant differences in the maximum sugar content of sorghum hybrids that basically determine the potential bioenergetic use of a sweet sorghum hybrid. In order to maximize the potential of a hybrid, it is desirable to do the harvest at the time of the maximum of the sugar accumulation curve. I have found that attempts to maximize yields for energy production can not be subordinated to the sugar content targets.

2. The sugar accumulation dynamics curve - as a hybrid characteristic - is highly diversified, which is an important property during the selection of hybrids. Hybrids can reach their maximum sugar content at different times in the length of the growing season, this phenomenon may lead to the possibility of sowing hybrids with different sugar accumulation curves. This method will allow to expand the harvest period to maximize sugar yields.

3. By quantitative evaluation of the carbohydrate polymer content of bagasse, I found that the compression residue represents a significant bioethanol potential. Among the complex carbohydrates, only the cellulose was found to be significantly different considering the amount. However, the value of the least significant difference supported the hypothesis that regarding the amount of second generation bioethanol potential green yields are determinative factors. I also found that CAI as a remote sensing index may be suitable for the partial estimate of the potential of the second generation bioalcohol of the hybrids.

4. The utilization of the bagasse produced by pressing the juice extracted from sorghum may represent a very important step in the production of sorghum based bioethanol. High combustion heat values raise the potential for biomass fuel utilization, but in practice, the moisture content of the residual material should be took under further technical consideration. In the utilization of bagasse at plant-level utilization of biomass, attention should be paid to the alkali metal content, which is a predisposing factor in combustion to fade off the combustion plant and the resulting buildup of deposits.

5. Based on the data of the meteorological station in the Karcag area, I found that the base temperature development basically determines the potential growth period available for sorghum production. For sorghum production for energy purposes, the production of hybrids with low base temperature is an important aspect, which makes it possible to meet the heat sum

demands that achieve the maximum accumulation of sugar at a later stage. However, I have found that the probability of climatic hazards increases in spring and autumn, which may enhance risks.

6. Based on the AGROTPO and CarpatClim databases, I defined spatially the areas that could be suitable for the cultivation of sorghum, taking into account soil and precipitation distribution. By supplementing the model with additional aspects, it is possible to develop methodological bases for production-specific bioethanol based on the production of sorghum.

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# 7. Publication list

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Subject: PhD Publikációs Lista

Candidate: János Jóvér
Neptun ID: GNZ0PI
Doctoral School: Kálmán Kerpely Doctoral School
MTMT ID: 10032322

### List of publications related to the dissertation

Hungarian scientific articles in Hungarian journals (5)

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The Candidate's publication data submitted to the iDEa Tudóstér have been validated by DEENK on the basis of Web of Science, Scopus and Journal Citation Report (Impact Factor) databases.

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