SZENT ISTVÁN EGYETEM

Analysis of coherency between the quality and quantity characteristics of wheat *(Triticum aestivum L.)* and site-specific nutrient supply

PhD thesis

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1. melléklet

1. INTRODUCTION

In the beginning of the 21st Century most of the scientific papers related to agriculture are concerned with the new challenges with which farmers and producers have to face. In point of the challenges and their ranking the opinion of authors is very varied, however the sustainable production, environmental protection, innovation the increase of production efficiency and profitability appear among the tasks for the future. Nowadays environmental protection and sustainable production are obligatory for all producers. With precision agriculture it is possible to meet all the requirements of sustainable production. The satellite-based positioning is the main element of precision agriculture because the entity of agricultural production - the land - can be handled based on its heterogeneity. By the utilization of agricultural GIS the cognition of land - the basic tool of agricultural production and the monitoring of running processes become possible. The data assessed by remote sensing technologies is expanded and their use gives new solutions for the practice of site-specific technologies. The spread of remote sensing data is affected by its price and the time of assessment. IF there is available information about the yield before harvest there is still possibilities for farmers to encroach and increase yield.

The main goal of my research was to analyse if the large varieties of yield quality and quantity can be moderated with site-specific nutrient supply. The aim of my suggestions is to promote the farmers to a more economical and sustainable production.

My research hypotheses are the following:

H1: In the case of a land with heterogenic soil characteristics the average yield of wheat can be increased with site-specific phosphorus fertilizing and the standard deviation in the parcel decreases thanks to the treatment.

H2: In the case of a land with heterogenic soil characteristics the values of composition parameters of wheat can be increased with site-specific phosphor fertilizing and the deviation in the parcel decreases thanks to the treatment.

H3: The effects of climate can be moderated by site-specific nutrient supply.

H4: By the use of remote sensing technologies the spatial distribution of the area can be represented with contributes to explore the relationship between the yield and production site.

H5: The yield map and the map of normalized difference vegetation index (NDVI) is in correlation which indicates that the map of vegetation index is applicable for yield assessment.

2. MATERIALS AND METHODS

Circumstances of experiment setting

Gyöngyöspata is located on the North-East part of Hungary at West Mátra in the Valley of Tarna and Zagyva rivers. The study site is located between Gyöngyös and Gyöngyöspata, 1 km far from Gyöngyöspata. The study site is selected from a 160,88 ha field and it is divide to two parts. The treated area is 20,2 ha and the untreated is 21,6 ha. The study side is bordered by road on the East and North side and by watercourse on the South. On West side the site is surrounded by higher flat land which indicates that the processes of the area (movement of water and nutrients, erosion) are not affected by external factors. The soil characteristics of the study area and the surrounding lands are composed because the rock quality, the relief, the macro- and mezo-climate, the evaporation and runoff conditions and the vegetation are very varied.

On the study site soil samples were taken in 2006. Based on that the nutrient map of the area has been done including the elements of complex soil analyses. Based on the soil analyses the phosphor content could appear as limitation factor of the quality and quantity of yield. The used type was MV Magdaléna. In the farmland mulch technology is preferred - the cultivation is without turning and short rigger is applied.

The first yield map was formed in 2007. We concluded that the average amount of yield and the quality is very heterogeneous on the study site. Samples were taken by hand from points that were previously set by GNSS to determine the quality parameters of yield and the amount of yield connected to the points were collected during harvest based on the data of the harvester. Each year samples were collected from the sample points which gave the possibility of continuous data collection and analysis. According to the methodology of precision nutrient supply the phosphor fertilizer, as monophosphate was spread site-specific way to the treated area and in the case of the control area traditional fertilizing was used. Phosphor fertilizer was applied as basic fertilizer during autumn. Nitrogen was applied as 27% calcium ammonium nitrate (CAL) in 220 kg/ha dose, with 59,5 kg/ha effective nitrogen content. The areas are well-supplied with potassium. Due to the recommendation of the Institute for Soil Science and Agricultural Chemistry, Centre for Agricultural Research, Hungarian Academy of Sciences potassium was not supplied only in the case of row crops. During spring fertilizer supply is divided into two outing as CAL 27 nitrogen. In both cases 200 kg/ha amount with 54 kg/ha effective nitrogen content was spread.
Yield maps were formed (with the use of KITE and IKR precision systems) in 2008 and 2011. The map of 2008 is imperfect due to technical issues. In 2010 the yield map for technical reasons was not copied to the storage, there is no yield map from this year. During harvest, based on the collected data of the

harvester the average yield for each point was observed manually and further calculation were done using this data in those years when technical problems appeared.

Harvest was fulfilled in the first decade of July 2007, in the second decade of July 2008 and in the third decade of July on 2010 and 2011. During harvest first samples were collected from the sampling points. Other areas were harvested after sampling to ensure the collection of samples in the same time and avoid the effects of disadvantageous weather. Samples were analysed in the accredited laboratory of SGS and I used their data during my data evaluation. Laboratory analyses in 2007 were: moisture content, gluten content, protein % and Zeleny index. From 2008 analyses were completed with kernel weight and falling number. The analyses of samples were done according to the Hungarian Standards.

The analyses of annual effects were based on Harnos (1993) and annual quality was determined. The year was handled as droughty if the precipitation between September and June was lower with 20% than the yearly annual. In the case of summer (April-June) it was draught if the precipitation was lower with 30% and in the case of winter (October-March) if the precipitation was lower with 50% than the annual average. In the case of annual effects of wheat time period between September and June was handled as deterministic. During the determination of dry period I used the parameters of Gyuricza - Birkás (2000) - if the preicpitation of the given period is lower with 20% as the annual average the period is dry. In 2010 and 2011 the amount of precipitation was average - comparing with the average of the last 25 years, 2008 was droughty year, meanwhile, in 2007 the annual precipitation (424 mm) approximates 421 mm that is handled as droughty.

Based on summer period in 2007 the summer can be characterised as draught because the precipitation was only 145 mm. In 2008 the precipitation during the summer was 30% lower than the 25 years average (154 mm) - can be handled as draught. In the case of winter periods between October 2009 and March 2010 the precipitation was 30% higher than the yearly average. During other years the precipitation of winter was average.
Weed flora would appear as limitation factor during production and increase the heterogeneity. Due to this weed assessment was done based on Balázs - Újváry (1973) in April 2011. I concluded that the number of weed species is very low and not relevant in my research.

For the statistical evaluation of data during my research I used IBM SPSS Statistics 18 software. For the analysis of quality and quantity parameters of yield and annual effects I used variance analysis. Next to the descriptive statistics Levene-test, variance homogeneity analysis and variance analysis were used to evaluate the quality and quantity parameters of yield. To determine the identical annual effects Tukey-b probe was used. To represent the distribution of samples BoxPlot graphs were used.

Remote sensing applications during research

For hyperspectral data acquisition push-broom type AISA Eagle II sensor was used (equipped into a Piper Aztec). To evaluate the geometry of the terrain Leica ALS-70 HP airborne laser scanner was used.

The hyperspectral data acquisition with the AISA Eagle II hyperspectral sensor was fulfilled in the visible and near infrared (VNIR) spectra. Assessment was done in full spectral width (400-1000 nm) with 4,5 spectral resolution- each pixel contained 128 spectral bands. Navigation data was collected with and OxTS 3003 high precision GNSS/INS system.

Data assessment was done in 20. August 2012 with the following parameters

- altitude above ground level (AGL): 1500 m
- flight speed: 55 m/s
- spectral width: 400-1000 nm
- overlay of flight lines: 30%
- ground resolution: 1,5 m

In the same time with the flight on-field survey was done with ASD FieldSpec3 spectrophotometer on various homogenous surfaces and on reference tarp. This data was used for calibration and atmospheric and radiometric correction. The preprocess of hyperspectral data (geometric and radiometric correction) was done with CaliGeoPro software by Specim.
Airborne laser scanning was fulfilled with Leica ALS-70 HP sensor. The horizontal accuracy of the digital terrain model (DTM) based on ALS data was 20 cm. The vertical accuracy was approximately 5-10 cm. The used ALS technology is a full waveform data collecting and processing platform. The effective flight altitude is 200-3500 m (AGL), the effective impulse frequency is 500 KHz. The equipment is capable to detect and store minimum 4 reflections of each pulse and store the intensity of minimum 3 reflections. The aerial laserscanning was taken place in spring 2014. The average point density of the point cloud was 10 point/m2, the overlap was 20%, the flight altitude was 800 m and the field of view was 50°.
The used geographic reference system were UTM 34N and Hungarian Spatial Reference HD72/EOV.
The hyperspectral images were processed with ENVI/IDL 5.0. The further investigation of vegetation indices was done with ArcGIS 10.1. The DTM generated from ALS data and the further process of yield map were done with ArcGIS 10.1.

To determine the mass of moist biomass on-field sampling was done in the same time with the hyperspectral data acquisition. The sampling points were stored with RTK GPS and the biomass of 1 m2 was measured. The given data was applied during the classification of hyperspectral images.
Sampling points were visualized on the DTM. During NDVI calculation the combination of red and infrared bands were use. To compare the NDVI data and the samples collected on field IBM SPSS Statistics 18 software was used to calculate regression.

3. RESULTS

Analysis of annual effects

The average yield of 2007 was 3,64 t/ha which was the lowest considering the examined years. The minimum and maximum values varied between 3,26-4,02 t/ha, the standard deviation was 1,05 t/ha. The time period is close to droughty which indicated yield loss comparing with average years but the quality was prominent.

The highest amount of yield was measured in 2008, 4,48 t/ha. 2008 is counted as droughty year because the least amount of precipitation. In spite of this, the largest yield was produced in this year. In March and April 2008 the total precipitation was 111 mm. In the same period of average years the amount of precipitation has never reached the data of 2008, furthermore this values is higher with 44% comparing with the 25 year average. The large yield of 2008 was determined by the precipitation of March and April - in spite of it was a droughty year. This is verified by the work of Szabó et al. (1996) which discusses that the plant requires 40% of of optimal precipitation from March, the highest water consumption is between 10. April and 10. May.

2010 and 2011 can be handled as typical year. In these years there was no significant difference between average yield because in 2010 4,03 t/ha, in 2011 4,00 t/ha yield was measured with similar standard deviation. The highest standard deviation of yield was calculated in 2007 (1,0490) and in 2008 (1,0719) which indicates that the in droughty and dry years the standard deviation of yield is larger than in typical years. Both years were close to droughty (2007) or droughty (2008), dry periods characterised the summer period. The lack of precipitation may cause plant stress which can be more highlighted in the case of heterogeneous soils through the water restore and supplying capacity of the soil. Based on this, extreme years considering precipitation may cause changes in the water storage capacity of soil that can be realized through the decrease of yield.

There was no difference between the value and standard deviation of kernel weight, the value varied between 40,30 g and 41,72 g with 1,8-1,44 standard deviation. The moisture content was the lowest in 2007 and 2008 - at harvest 13,53% in 2007 and 11,98% in 2008, in typical years this value was higher (14% in 2010 and 13,83% in 2011).

Considering the annual effects 2007 was crucial when the parameters that determine the quality for baking were higher comparing with other years.
The average of Zeleny-index in 2007 was 69,49 with 3,44 standard deviation. The high value was resulted by the dry climate which decreased the amount of

yield. The decreased yield was connected to prominent quality. Next to the Zeleny-index the gluten % and the protein % were the highest in this year as well. The gluten content was averagely 33,83% (standard deviation: 3,69; minimum: 32,50; maximum: 35,16). The highest protein value was measured also in 2007: 17,17% (standard deviation: 1,21).

Considering every quality parameters 2008 (droughty year) produced the highest values after 2007. The lack of precipitation had a positive effect on the quality. However, both years were droughty or close to droughty but in my opinion higher quality in 2007 was indicated by the distribution of precipitation. In March-May 2008 the precipitation was 141 mm which positively affected the yield. In 2007 this period was dry, the average yield was lower (3,63 t/ha). The lower amount of yield made possible the more effective utilization of fertilizer and the infiltration of nutrients.

Based on the variance analysis we can conclude that in each year the data (using control data and the data of treated area) is significantly varied. In the case of moisture content, protein %, gluten %, and Zeleny-index the significant difference value is ≤0,001; while in the case of yield, kernel weight and falling number the significant difference is ≤0,01.

The results of Tukey-b probe for average yield showed that 2007 and 2008 is significantly different. 2011 and 2010 showed intermediate values and there was no significant difference, the annual yield was similar. Considering moisture content the Tukey-b probe showed significant difference in each year. The moisture content of the yield can be very varied depending on the annual precipitation, its distribution especially the amount of precipitation before harvest. The moisture content of wheat was the lowest in the droughty or close to droughty years (2008, 2007) which was resulted by the dry period before harvest. In the case of protein % each year was significantly varied, Analysing gluten %, 2007 and 2010 significantly varied but 2008 and 2011 showed intermediate values. The year had the strongest effect in the case of Zeleny-index. The droughty year 2007 resulted extremely high value and significantly different from the other years. 2010 and 2011 were typical years, the Zeleny-index was similar. 2008 was rainy and it is significantly different comparing with 201-2011 and 2007.

Analysis of experiment year 2007

In 2007 the treated and control parcel have been selected but the treatment has not been started. The data of this year gives information about the starting state of the study site. The changes in quality and quantity parameters of samples were affected by soil characteristics (nutrient supplying ability, physical characteristics, water balance) because annual effect and technology can be handled as constant values. With base sampling the main goal was to get an overview about the soil-plant connection system before treatment through the yield.

Based on the results of 16-16 samples taken on the treated and control sites the amount of yield of control site (4,00 t/ha) was 12% higher comparing with the site selected to be treated (3,27 t/ha). The standard deviation of control site was 1,10 and 0,89 in the case of treated site. We can conclude that however the two sites are selected on the same parcel the yield varied in the case when the same cultivation and agricultural technology was used as well. There was no significant difference between the data of the two sites considering the moisture content. On the treated site the value was between 12,9 % and 14,3%. The value on the control site was between 12,9% and 14,1%. In the case of protein the treated parcel had a value of 17,44% (with 1,09 standard deviation) and the control parcel had 16,9% average (with 1,30 standard deviation. Considering the quality parameters (protein %, Zeleny-index, gluten-content) was higher in the case of selected study site for treatment but with larger standard deviation. The summer of 2007 can be handled as droughty because comparing the 25 year average the 67% of precipitation fell down in April-June and negatively affected the amount of yield. The droughty summer and the lower yield altogether caused the high quality of the yield comparing with the other years. Based on the results of variance analysis significant difference were only between the amount of yield and gluten-content. In the case of moisture content, protein % and Zeleny-index the results of selected and control site are homogenous.

Analysis of experiment year 2008

The first year of treatment can be handled as droughty year because the amount of precipitation was 30% lower than the 25 year average. The fallen precipitation in March and April which was 144% of the average and positively affected the amount of yield is in contradiction with the conclusion that 2008 was a draughty year.

Examining the average yield we can say that the average yield of the treated parcel was 4,55 t/ha (min.: 3 t/ha, max.: 6,8 t/ha). The average yield of the control site was lower, 4,40 t/ha (the minimum and maximum values varied between 3,94 t/ha and 4,86 t/ha with 95% confidence interval). There was no

significant difference between the treated and control sites in the case of kernel weight. The moisture content was 12,06% in the case of control parcel and 11,91% in the case of treated parcel. There was no difference between the two sites in the case of protein content.
The quality parameters are more varied. In each case the values of treated site were higher. The gluten content was 30,24% at the treated parcel and 29,46% in the case of control site. The values varied between 29,52% and 30,96% in the case of treated site and between 28,65% and 30,28% at the control site with 95% confidence interval. The Zeleny-index was more sensitive to the treatment. The 52,13 value of the treated parcel with 5,4 standard deviation confirms this. The values varied between 49,2 and 55,01 with 95% confidence interval. In the case of control parcel the Zeleny-index values varied between 47,95 and 50,92 with 95% confidence interval. The average value of control site was 49,49 which is 5% lower than the average Zeleny-index of treated site. The standard deviation of the values at the control parcel was 2,79. However, there is no significant difference between the control and treated sites but it can be concluded based on the standard deviations that in the case of the treated parcel the standard deviation was higher comparing with the control site - the standard deviation was increased by the treatment. Considering the falling number higher number was accomplished by the treated parcel (292,19) with 10,83 standard deviation. The control parcel showed 279,50 average falling number with 22,39 standard deviation. The higher falling number was reached with lower standard deviation on the treated site. The values varied between 286,41 and 297,96 with 95% confidence interval in the case of the treated site., while the values were between 267,57 and 291,43 at the control site. Based on the variance analysis we can conclude that there was significant difference between the control and treated parcel after the first-year site -site specific phosphor output (at 0,05 significant level) in the case of moisture content, protein % and falling number. There was no significant difference between the two sites considering average yield, kernel weight, gluten % and Zeleny-index.

Based on the results of experiment year 2008 in the case of draughty year the quality parameters are similar comparing the control and treated sites which is also confirmed by the low F value.

Analysis of experiment year 2010

2010 was the second year of the treatment and can be handled as a typical year according to the yearly precipitation. The yield was higher comparing with the production of 2007 and 2008, on the treated site it was 3,98 t/ha with 0,71 standard deviation. On the control site the average yield was higher with 0,34 standard deviation. There was no significant difference between kernel weight - 41,81 on treated site and 41,63 on the control parcel. There was no variety of moisture content on the treated site. The average moisture content of yield harvested on the treated site was 13,85% with 0,24 standard deviation; in the case of control site it was 14,16% with 0,23 standard deviation. Examining the values of protein% the values of treated parcel showed higher values (12,38%) and varied between 11,95% and 12,80% with 95% confidence interval. These values varied between 11,25% and 12,25% in the case of control site. The average gluten % was higher in the yield of treated parcel like the protein - 27,76%. The average gluten content of produced yield on control site was 26,70%. The difference between the two values are not significant. The performance of the two sites in the case Zeleny-index were similar. The result of treated parcel varied between 42,67 and 45,67 with 95 confidence interval. At the control site these values varied between 40,93 and 44,3. In a typical year with average precipitation there was no significant difference between the treated and control sites. The falling number was higher on the treated site like the other quality parameters. The average value was 271,81 on the treated site and 268,13 on the control parcel.

Based on the results of experiment year 2010 we can conclude that there was difference between the treated and control site in moisture content and some quality parameters. The average precipitation compensated a part of the quality parameters, however the average yield was lower on the treated parcel but the protein %, the gluten %, the Zeleny-index and the falling number was larger. The variance analysis resulted that there is significant effect of treatment on the moisture content and protein % (at 0,05% significance level). In the case of average yield, the kernel weight, the gluten %, the Zeleny-index and falling number there was no significant difference.

Analysis of experiment year 2011

The last year of research (2011) - as year 2010 - was typical considering the annual precipitation. In the case of average yield the production on treated parcel was lower comparing with the control site. In 2011 the average yield of treated parcel was 3,78 t/ha and 4,22 t/ha of control site. The values varied between 3,39 t/ha and 4,16 t/ha with 95% confidence interval on the treated site and between 4,08 t/ha and 4,36 ha on the control site. There was no difference between the two sites considering the kernel weight. This can be said in the case of moisture content where the treated parcel showed 13,74% and the control site 13,93% average with similar standard deviation. The protein content was larger on the treated site - 13,71% with 1,23 standard deviation. The values varied between 13,57% and 13,91% with 95% confidence interval. The average protein value of control site was 12,58% with 0,44 standard deviation and the values varied between 12,34% and 12,81% with 95% confidence interval. In the case of gluten % the values were similar on both parcels, The average gluten content of the treated parcel was 29,48% while on control site it was 28,23%. The standard deviation was higher again on the treated site (1,47). If the variation of values is examined with 95% confidence interval it is shown that it was moving between 28,70% and 30,27% (treated site) and between 27,83% and 28,63% (control site). Considering the Zeleny-index the treated parcel performed 45,76 average with 2,22 standard deviation comparing with the 43,54 value of the control parcel. The standard deviation of the control site was 2,58, there was no large difference between standard deviations. Most sensitively the falling number reacted to the treatment as in the other years. The average falling number of treated parcel was 258, while it was 247,50 on the control site. There was significant difference between the standard deviations. The standard deviation of the treated parcel was 9,3 while this value was 34,17 in the case of the control site which indicates the heterogeneity of the control site considering the falling number. This is confirmed by the 229,29 minimum and 265,71 maximum values with 95% confidence interval.

Based on the variance analysis we can conclude that in 2011 (at 0,05 significance level) there was significance difference between the treated and control parcel considering average yield, moisture content, protein %, gluten %, Zeleny-index and falling number but there was no difference in the case of kernel weight.

Effect of treatments

The effect of site-specific phosphor fertilizer output on average yield is not unambiguous. In the droughty year 2008 the average yield of the treated area was 4,55 t/ha with 1,27 standard deviation. Meanwhile on the control site the measured average yield was 4,40 t/ha with 0,87 standard deviation. The difference between the two yield averages is only 2%. Analysing the standard deviation we can conclude that with the site specific output of phosphorus fertilizer the standard deviation of average yield is not decreasing. The spatial variety of average yield is determined by soil characteristics, the water balance conditions of the soil are the most deterministic factors. It is confirmed by the lower average yield on the treated area in typical years with average precipitation. In 2010 the average yield was 3,98 t/ha, in 2011 it was 3,78 t/ha on the treated site and 4,09 t/ha in 2010 and 4,22 t/ha in 2011 on the control site. Examining the differences we can conclude that there are no large variety considering the average yield in typical years as well. Comparing the three year averages the yield was 4,10 t/ha with 0,97 standard deviation on the treated site and 4,24 t/ha with 0,56 standard deviation on the control site. If analyse the base sampling of 2007 we experience that average yield of the control parcel was 31% higher and the standard deviation of the treated site was 0,89 comparing with the 1,10 standard deviation of the control site. Correlating with the average yield of 2007, after the site-specific output of phosphorus fertilizer the difference in the yield of treated and control sites decreased. Next to this we can conclude that by the treatment the standard deviation has not changed

considering the average yield but increased comparing to the control parcel. This means that there are soil patches in the area where the soil characteristics and the micro-relief make possible to increase the yield, but there are parts where the site-specific phosphorus fertilizer output is not reasonable because the plus costs not returns through the yield. More investigations are needed to explore the reasons of this issue.
The results of sampling points showed that the results were more homogeneous in the case of sample point 17,18,19 and 20 considering the yield comparing with the other sections of the site. This conclusion is really significant in 2008. Because the year, the technology and the species can be handled as constant probably the soil characteristics (micro-relief, physical characteristics) influence the produced yield.

According to the results of variance analysis in there was no significant difference between the years considering the average yield and the kernel weight neither in the case of treated parcel or the control site. There was significant difference when moisture content, protein %, gluten %, Zeleny-index and falling number were taken into consideration either on treated site or on control parcel. The significant differences and their level indicates that the three year effect of treatment has a deterministic role on the quality parameters of wheat. Examining each year the significant differences of quality parameters are not as deterministic.

Considering the average yield there was no significant difference between the years neither in the case of treated site or the control site. Each year of the treated parcel (2008, 2010, 2011) was homogenous considering kernel weight. Examining the control site related to the moisture content there were significant differences between the three years. In the case of the treated site the data of 2010 and 2011 was similar but significantly different comparing with 2008. Evaluating the protein values we can conclude that the three years were significantly different at the control parcel. There was no difference between 2011 and 2008 in the case of the treated site but there was significant difference between 2008 and 2011, and 2008 and 2010. Gluten % values performed the same results as given by protein %. The control site showed significant difference in each three year (2008, 2010, 2011). meanwhile there was no difference between 2011 and 2008 in the case of the control site but there was significant difference between 2008 and 2010, and 2010 and 2011. The values of Zeleny-index was similar in 2010 and 2011 on both sites but there was significant difference between 2008 and 2010 and 2008 and 2011. The values of Zeleny-index of the treated and control sites give the conclusion the treatment increase the quality but the annual effect has a great role on Zeleny-index. The Tukey-b probe on falling number resulted that the values of treated area are higher than the control site. There was no significant difference between 2010 and 2008 on the control site but 2011 significantly differed from 2008 and 2010.

Evaluating the falling number that we get on the treated site there was no difference between 2011 and 2008 but 2010 was significantly different. On both sites the dry annual effect gave the best falling number result, there was difference between the two sites in years with typical precipitation.
There was no unambiguous positive effect f the treatment on the yield - lower average yield was measured in typical years. Considering the standard deviation we can conclude that the standard deviation of average yield was not decreased by the treatment but increased comparing with the control site. The differences between the yield of control and treated sites moderated.
Comparing the moisture content values of the treated site and control site we can conclude that the values were low in 2008. The control site showed 12,06 %, the treated site 11,91%, thanks to the dry period before harvest. In years with average precipitation the yield was harvested with higher moisture content but the standard deviation was larger on the treated site. The standard deviation of moisture content was probably caused by that during draughty years the micro-relief characteristics of the area affect the moisture content of yield at harvest.

The protein content after the site-specific phosphorus fertilizer output on the treated site had higher value in each year comparing with the values of control site. In dry year (2008) the standard deviation of samples was almost equal (control site: 0,48; treated site: 0,58). In years with average precipitation there is no unambiguous relationship between the annual effect and the standard deviation of samples. The gluten content had the highest value in 2008 in both cases (control site: 29,46%; treated site: 30,24%). After the site-specific phosphorus output the treated site reached higher gluten value than the in each case but with higher standard deviation. The increase of standard deviation indices the changes of soil characteristics which means there are areas where the phosphorus is well used and increases the value of quality parameters.
Based on the analysis of Zeleny-index we can conclude that the Zeleny-index of treated parcel was larger in each year. We can say in the case of Zeleny-index too that as all of the quality parameters the Zeleny-index is sensitive to the amount and the distribution of precipitation. More significantly the falling number reacted to the nutrient treatment. In each experiment year (2008, 2010, 2011) the value of treated site was larger than the control's.
The standard deviation of protein %, gluten % was higher thanks to the treatment comparing with the control site and the averages of quality parameters were higher as well. There was no obvious decrease of standard deviation of quality parameters after the site-specific treatment but the average of quality parameters was higher in each year on the control site. This means that the site-specific phosphorus fertilizer output in at some locations of the site affected the quality parameters positively but there were some patches where probably the soil characteristics (water balance characteristics, compactness, micro-relief) prohibited the infiltration to yield. We can sum up that on heterogeneous site the site-specific phosphorus supply do not decrease but increase the average value

of protein % and gluten % and their standard deviation comparing with the control parcel where traditional fertilizing technologies was applied. We can conclude that the utilization of fertilizer is affected by other soil characteristics which's investigation needs further researches. The nutrient supply maps can be refined by using the research results.

Analysis of applicability of high resolution aerial remote sensing data

For effective comparison the yield map of 2011 had to be transformed to the same format as the high precision LiDAR data assesses in 2011. The resolution of the raster was 10 x 10 m. The size of the raster was determined by the sampling area of the harvester equipped with yield mapper. Each raster contains the values of average yield. The average yield that was calculated to the 10 m resolutian varied between 1,1 and 6,3 t/ha. The GNSS system of the prime mover generated a 1,5 m resolution terrain model which shows the relief characteristics of the area but not as accurate as the digital terrain model (DTM). Because of this, this data was excluded from the further analyses.
From the classified laserscanned point cloud digital terrain model was interpolated to investigate the micro-relief of the area. The original data which was in UTM34N reference system and elevation above ellipsoid was calculated to elevation above sea level (Baltic-sea). The elevation values on the DTM varied between 155,82 and 190,44 m.
The slope characteristics calculated from the DTM highlighted the areas with larger slopes. To calculate the angle of slopes bilinear interpolation was used. During the selection of resolution various settings were tested from 0,2 m to 5 m. For further investigations 1 m resolution was selected because higher resolution resulted too "noisy" because of roughness and the deviation of point cloud (averagely 2-6 cm). In the case of lower resolution than 1 m the important relief forms disappeared. Accumulation shows those areas where the fallen precipitation converges and the angle and length of runoff. The situation of runoff channels on the study site showed that there are less accumulation zones on the North-East part - the precipitation do not run down to the lower areas which makes possible to store the water and indices less nutrient loss.

On those soil patches where the elevation is higher are less accumulation zones and less sensitive to drought comparing with other parts that are downhill and contains more accumulation zones. In this case the coming water runs off and cannot be stored. In years with large precipitation - depending on soil characteristics - at higher areas with areic sites the possibility of inland water formation is larger.

To calculate heterogeneity 10*10 m resolution layer was used. The resolution of the calculated layer is the same as the map given by the collected data of the harvester. Average (x) and standard deviation (y) were calculated to each pixel.

The common analysis of the estimated yield and standard deviation we can determine those area where the spatial heterogeneity is larger. We were looking for the reasons for how the varieties of relief characteristics determine the spatial differences of the average yield. We examined that what is the statistical relationship between the calculated layers from the DTM (10*10 m resolution) (slope average and deviation, flowacc average and deviation) and the average yield. If only one independent variable was used the relationship between the average slope values and yield was weak (R2 = 0,51). During the calculation of linear model with common use of flow accumulation and slope values (as independent variables) the relationship between the yield map was a bit stronger (R2 = 0,56) but the results did not change deterministically. By the analysis of high resolution remote sensing images it became possible to estimate the spatial heterogeneity on the site. With the model generated from the high resolution hyperspectral images (1 m) the spatial distribution of yield of wheat could be estimated. Due to the accuracy of sampling the erosion dikes formed on the vegetation map. The 1 m resolution hyperspectral images are applicable to analyse the characteristics of the area. By using LiDAR data and generated slope map we can determine those areas where nutrient loss and disadvantageous water balance appeared because of the effects of erosion. The effects of slope could be demonstrated comparing with the biomass map.

The accumulation zones show the direction and length of water flow from which erosion dikes can be determined. Relief and soil characteristics have a deterministic role in drought sensitivity. During the determination of drought sensitivity the water storage ability of the soil has a great importance. However, the water storage capacity of the soil van be improved with cultivation but the effect of the relief cannot be eliminated. The yield security may keep its variety next to varied relief characteristics and adequate agrotechnology. Through drought sensitivity we can determine those patches where ecological conditions do not make possible the adequate utilization of nutrients. The relationship of these zones with yield security may varied according to the annual effect because the water stock of the soil and the water flow dynamics are varied during years. The site-specific know of draught sensitivity modifies the determination of the amount of nutrient supply.

Calculation of biomass map based on hyperspectral vegetation index

The analysis of the relationship between the yield and vegetation map means that by the use of aerial remote sensing technologies we can get information about the heterogeneity of yield on the field before harvest. Because there are several available vegetation indices our first goal was to determine which vegetation index is the most effective during the process of remote sensing data.

During our research the normalized different vegetation index (NDVI) was found the most applicable. During the determination of NDVI values we used the combination of NIR and red bands. With regression model we revealed the relationship between the NDVI values and the samples taken on-field. The strongest relationship was found between NDVI and biomass at 625 nm and 720 nm (n=9; R2=0,762; p<0,05). With regression calculation further less strong relationship was found between the red edge position and biomass (n=9; R2=0,668; p<0,05). With the use of regression model wet biomass map was formed. The mass of wet biomass is (kg/m2) = 52.317eNDVI(625,720).
The precision technology requires spatial information about the state of vegetation, the changes of biomass and average yield which can be varied through years. The relationship between the wet biomass and yield is applicable during the yield estimation before harvest.

Results of hypothesis analysis

Research hypotheses	Results of hypothesis analysis
H1: In the case of a land with heterogenic soil characteristics the average yield of wheat can be increased with site-specific phosphorus fertilizing and the standard deviation in the parcel decreases thanks to the treatment.	partly confirmed
H2: : In the case of a land with heterogenic soil characteristics the values of composition parameters of wheat can be increased with site-specific phosphor fertilizing and the deviation in the parcel decreases thanks to the treatment.	partly confirmed
H3: The effects of climate can be moderated by site-specific nutrient supply.	not confirmed
H4: By the use of remote sensing technologies the spatial distribution of the area can be represented with contributes to explore the relationship between the yield and production site..	confirmed
H5: The yield map and the map of normalized difference vegetation index (NDVI) is in correlation which indicates that the map of vegetation index is applicable for yield assessment.	confirmed

New scientific results

During my research I received the following new scientific results:

T1: Comparing the years and annual effects we concluded that the differences between the examined yield quality parameters were smaller in dry years and higher in years with larger precipitation.

T2: I confirmed the research results of Szabó et al. (1996) in the case of yield maturation - the plant requires t40% of the optimal precipitation from March. The largest water consumption is between 10. April and 10. May. The precipitation of this period determines the amount of yield.

T3: The site specific phosphorus fertilizer output - with the same nitrogen and potassium supply significantly increases following quality parameters: protein %, gluten %, Zeleny-index and falling number. I could not justify the effects of site-specific phosphorus supply on kernel weight and moisture content.

T4: I could not detect statistically verified relationship between the site-specific phosphorus fertilizer output and the increase of yield.

T5: During my work it is confirmed that by the precision supply the standard deviation of average yield, the protein %, the gluten , the Zeleny index and falling number has increased comparing with the control site.

T6: I detected verified relationship between the slope % of the area and yield which indicates that the utilization of fertilizer is affected by the slope characteristics of the area through the flow of the fallen precipitation.

T7: I detected verified relationship between the wet biomass and yield measured at the same points. I concluded at which spectral interval has the NDVI the strongest relationship with the yield.

CONCLUSIONS AND SUGGESTIONS

The determination of annual effect and the monthly distribution of precipitation has a great role during the evaluation of research results. The precipitation data of 2008 showed that in general the whole year was droughty but the fallen precipitation of March and April determined the 4,55-4,40 t/ha highest average yield of examined years.

The influence of site-specific phosphorus fertilizer output on yield is not unambiguous. The standard deviation on the treated site in 2008 was lower, in 2010 and 2011 were higher than the control site which indicates that the continuous treatment increased the heterogeneity of plants on the area.

The quality parameters in 2007 (close to draughty year) and on 2008 (draughty year) were the highest which means that draughty weather has a positive effect on the quality of yield. The quality of wheat was higher in each year on the treated side comparing with the control parcel, but with higher standard deviation values. The treatment was positive only on the area where the soil characteristics are optimal. On those patches, where the characteristics of the soil or the micro-relief limited the utilization of the nutrient the yield and quality parameters of wheat did not increase in spite of the optimal amount available nutrient.

Accordingly, the site-specific phosphorus fertilizer output did not increase the homogeneity of quality and quantity parameters of the stand. In economic point of view it is important to detect those patches where the plus investments do not return through the yield. The output of surplus amount of nutrient is considerable in economical and environmental protection point of view.

Based on the digital terrain model of the study site we can conclude that the elevation varied between 190,44 m and 155,822 m. The largest elevation difference on the study site is 34,618 m. The slope characteristics were determined from the digital terrain model and the optimal 1 m resolution was selected.

The identification of accumulation zones provides important information to the site-specific nutrient supply because with them the angle and length of waterflow can be determined. By using the model those soil patches can be classified where the soil and nutrient loss is higher. This information gives the possibility of further analyses considering annual effects and yield map and refine the map of site-specific nutrient supply.

The identification of accumulation zones gives the possibility to determine the site specific draught sensitivity of the area. De site-specific draught sensitivity index can be influenced by the elevation and relief characteristics of the site competing the yield map, the soil penetration map and the high precision soil map. Further research is needed to build up the practical model of site-specific draught sensitivity model.

The spatial distribution mapping of wheat yield on the site has been fulfilled with the use of high precision remote sensing data. From the vegetation indices the NDVI was used with combination of NIR and red bands. With regression we demonstrated the relationship between the NDVI values and collected samples. The strongest connection was found between NDVI and the biomass at 625 nm and 720 nm bands (n=9; R2=0,762; p<0,05). With regression calculation showed further less strong relationship between red edge position and biomass (n=9, R2=0,668, p<0,05).

With regression model the wet biomass map was worked out. The mass of wet biomass is (kg/m2) = 52.317eNDVI(625,720). The relationship between the biomass and NDVI confirms that the hyperspectral remote sensing technology is applicable to determine the yield before harvest and gives the possibility of agrotechnological interventions to increase yield.

PUBLICATION LIST OF AUTHOR

<u>*Scientific Journals papers in Hungarian language*</u>

Klupács H.; Tarnawa Á.; Szentpétery Zs.; **Ambrus A.**; Jolánkai M. 2010. Agrotechnikai elemek hatása az őszi búza (Triticum aestivum L.) vetőmagtermesztésére
NÖVÉNYTERMELÉS 59:(1) pp. 47-60.

Ambrus A.; Burai P.; Lénárt Cs.; Enyedi P.; Kovács Z. 2015. Estimating biomass of winter wheat using narrowband vegetation indices, Journal of Central European Green Innovation, HU ISSN 2064-3004

Jolánkai M. – Szentpétery Zs. – Tarnawa Á. – **Ambrus A.** – Kassai M.K. (2015): Evaluation of climate change impact by biological indicator. Acta Hydrologica Slovaca. 16. 2. 218-223 pp.

<u>*Book part*</u>

Ambrus A., Burai P., Bekő L., (2016): Hely-specifikus gazdálkodás bevezetése, mint döntési helyzet. In: Dr. Takácsné Prof. dr. habil György Katalin, XV. Nemzetközi Tudományos Napok „Innovációs kihívások és lehetőségek 2014-2020 között" Konferencia kiadvány, Gyöngyös, ISBN 978-963-9941-92-2 Konferencia ideje: 2016. március 30-31. pp. 59-66.

Fodor L.; Molnár Z.; **Ambrus A.** 2006. Őszi búza fajták minősége laboratóriumi vizsgálatok tükrében a gyöngyösi fajtakísérletben. In: Magda S. – Dinya L. (szerk.) X. Nemzetközi Agrárökonómai Tudományos Napok. A Tudományos Napok előadásai és poszterei. Károly Róbert Főiskola, Gyöngyös, CD kiadvány, ISBN 963 229 6230.

Ambrus A. 2006. A precíziós növénytermesztés létjogosultsága a Mátra alján. In: Magda S. – Dinya L. (szerk.) X. Nemzetközi Agrárökonómai Tudományos Napok. A Tudományos Napok előadásai és poszterei. Károly Róbert Főiskola, Gyöngyös, CD kiadvány, ISBN 963 229 6230.

Ambrus A. ; Pethes J.; Bélteki I.; 2008. Ökológiai viszonyok és a minőség kapcsolata a Károly Róbert Főiskola őszi búza kisparcellás fajtaösszehasonlító kísérletében. In: Magda S. – Dinya L. (szerk.) XI. Nemzetközi Agrárökonómai Tudományos Napok, Napok előadásai és poszterei, CD kiadvány

Ambrus A.; Lénárt Cs.; Burai P. 2010. Az őszi búza piaci helyzetének értékelése és kihatása a jövedelmezőségre a Havas '92 Növénytermesztő Gazdaszövetkezetnél. In: Magda S. – Dinya L. (szerk.) XII. Nemzetközi Agrárökonómai Tudományos Napok, A tudományos napok előadásai és poszterei, ISBN 978-963-9941-09-0 (CD-ROM)

Lénárt Cs.; **Ambrus A.**; Burai P. 2010. GPS technológiák alkalmazási lehetőségei és vállalatirányítási rendszerben való szerepe a Havas '92 Növénytermesztő Gazdaszövetkezetnél. In: Magda S. – Dinya L. (szerk.) XII. Nemzetközi Agrárökonómai Tudományos Napok, A tudományos napok előadásai és poszterei, ISBN 978-963-9941-09-0 (CD-ROM)

Ambrus A.; Lénárt Cs.; Burai P. 2012. Precíziós és hagyományos technológiák alkalmazási lehetőségei az erózióval érintett területeken a Mátra-alján. In: Magda S. – Dinya L. (szerk.) XIII. Nemzetközi Agrárökonómai Tudományos Napok, A tudományos napok előadásai és poszterei, ISBN 978-963-9941-09-0 (CD-ROM) 1184-1189 p.

Scientific Conference papers in English language

Klupács H.; Tarnawa Á.; Szentpétery Zs.; **Ambrus A.**; Jolánkai M. 2008. Agronomic effects on production and quality of wheat seed In: Musilová J, Vozár I (szerk.) III.Vedecká konferencia doktorandov = Proceedings of the III. International Scientific Conference of PhD. Students. Konferencia helye, ideje: Nyitra, Szlovákia,2008. 11.28pp. 213-216.

Scientific Conference papers in Hungarian language

Ambrus A. (2007) Precíziós mezőgazdaság ökonómiai kérdései egy adott gazdaságnál. Tradíció és Innováció Nemzetközi tudományos konferencia, Szent István Egyetem, Gödöllő,

Bélteki I.; **Ambrus A.**; Pethes J., 2008. Korai éréscsoportba tartozó őszi búza fajták terméseredményeinek vizsgálata kisparcellás kísérletben. Georgikon Napok, Pannon Egyetem, Keszthely

Ambrus A.; Pethes J.; Bélteki I. 2008. Ökológiai viszonyok és a minőség kapcsolata a Károly Róbert Főiskola őszi búza kisparcellás fajtaösszehasonlító kísérletében. Georgikon Napok, Pannon Egyetem, Keszthely,

Holló S.; Pethes J.; **Ambrus A.**; 2009. A tartós szerves – és műtrágyázás hatása a talaj könnyen oldható foszfortartalmára Kompolton, csernozjom barna erdőtalajon. Tartamkísérletek jelentősége a növénytermesztés

fejlesztésében, Jubileumi tudományos konferencia, Martonvásár, 235-241 p.

Fodorné Fehér, E., Fodor, L., **Ambrus, A.**, 2009. Műtrágyázás hatása az őszi búza termelésére és minőségére, Tartamkísérletek jelentősége a növénytermesztés fejlesztésében, Jubileumi tudományos konferencia, Martonvásár, 95-100 p.

Other publications in English language

Ambrus A.; Hidvégi Sz.; Láposi R. 2008. Precision method's impacts on quality, quantity and soil in growing winter wheat. VII. Alps-Adria Scientific Workshop, Cereal Research Communication, Volume 36, 367 p.

Klupács H.; Tarnawa, Á.; Szentpétery, Zs.; **Ambrus, A.;** Jolánkai, M. 2008. Agronomic effects on production and quality of wheat seed. VII. Alps-Adria Scientific Workshop, Cereal Research Communication, Volume 36, 871 p.

Ambrus A.; Pethes J.; Fodorné Fehér E. 2009. The impact of precision nutrient supplementation on the quality and quantity of winter wheat and on the soil. Cereal Research Communications Vol. 37, 2009, Supplement. 249-252 p.

Ambrus A.; Burai P.; Lénárt Cs.; Enyedi P.; Tomor T. 2012. Potential applications of precision technologiesat erosion-affected areas. XI. Alps-Adria Scientific Workshop, Növénytermelés, Crop production, Volume 61, Supplement, 145-148 p.

Ambrus A.; Holló S.; Fodorné Fehér E.; 2010. Interaction of soil, fertilization, crop rotation and cropyear effect in the crop procuction. IX. Alps-Adria Scientific Workshop, Növénytermelés, Crop production, Volume 59, Supplement, 425-428 p.

Other publications in Hungarian language

Kerek Z.**; Ambrus A.;** Marselek S. 2007. Néhány, az őszi búza termesztését befolyásoló tényezők vizsgálata a precíziós gazdálkodás lehetőségei, Mag, kutatás, fejlesztés és környezet,21. évf. 4-5. sz. 49-55. p.