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DOCTORAL (PhD) DISSERTATION

Development of measurement technique for GPS-aided plant production

by

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ABSTRACT

The author reports his research carried out in connection with measurement technique developments in the field of precision farming. The engineering and agronomic concerns of a three-year site-specific field trial involving soil sampling, yield monitoring and variable rate solid nutrient replenishment are covered. Design and build up of a continuous soil draft monitoring system is described; the measured data are compared with penetrometer-, yield- and soil data of the same field. Construction of a weed monitoring system based on CCD and infrared cameras or rather a special optical device with a horizontal view angle of 360° is also reviewed. Besides, the possibility of pest detection using infrared technique was examined. A file transformation method ensuring the compatibility of two precision farming systems and a higher level of data analysis was worked out and reported as well.

KIVONAT

A szerző ismerteti a precíziós növénytermesztés területén folytatott méréstechnikai fejlesztésekkel kapcsolatos kutatásait. Ezen belül, beszámol egy három éves szántóföldi helyspecifikus növénytermesztési kísérlet (talajmintavétel, hozammérés, tápanyag-visszapótlás) műszaki és növénytermesztési tapasztalairól. Ismerteti a kidolgozott folyamatos talajellenállás mérő rendszert és összeveti a mért adatokat ugyanazon területről származó penetrométeres mérési eredményekkel, illetve hozam és talaj adatokkal. Egy gyomtérképező rendszer szintén ismertetésre kerül a dolgozatban, melynek alapjául egy CCD és egy infravörös kamera, illetve egy speciális, 360°-os horizontális látószögű optikai eszköz szolgálnak. Kártevők és kórokozók infravörös technikával történő érzékelésének lehetőségét ugyancsak tárgyalja a szerző. A kidolgozott fájltranszformációs eljárás biztosítja két precíziós növénytermesztési rendszer kompatibilitását, valamint az adatok magasabb szintű elemzését.

1. INTRODUCTION

Precision farming is coming into general use all over the world and in Hungary as well because of its undoubted advantages. The greatest benefit of this technology is the possibility of making both economic and ecological trends meet. Using this farming system infield variability can be mapped and treated according to local conditions. In this way, the optimal amount of inputs (pesticides, fertilisers or even seeds) can be applied in each part of a field. While given parts of the technology become available for agricultural practice, further research is required in many aspects. Yield monitoring and solid fertiliser application are considered as well-elaborated applications. However, investigations might be necessary for their problem-free adaptation.

Site-specific weed- and pest management are matters of great importance and potential from both economic and ecological points of view. Machine vision based weed recognition is one of the most intensively investigated subjects in the field of precision agriculture. However, typical limitations – as inadequate efficiency caused by low operation speed and the restricted scanning area – still prevent this technology from becoming part of agricultural practice.

Similarly, site-specific soil tillage is hardly known in spite of the significant savings that could be achieved in this way. For its realisation reliable information are required about given soil parameters, such as soil draft, the direct and indirect measurement of which is still problematic.

In the frame of the presented research activity a field level site-specific trial was set up, involving yield monitoring, soil sampling and nutrient replenishment in order to model the actual practical circumstances and to test the capability and accuracy of the applied system under these conditions. The applied fertiliser advisory system was also examined in connection with the variable rate technology. The analysis of the recorded databases was also carried out.

In addition to the field trial, our aim was to develop the basis of a machine vision based weed-monitoring system avoiding the typical limiting factors and thus facilitating the practical application of this technology. The possibility of applying the system for pest management was also examined. Based on these measurements the fundamental system requirements (e.g. sensor sensitivity) were determined.

The design, evaluation and practical application of an on-line soil draft monitoring system, and the connection of the measured values with other data are reported too.

The field trial made possible further examinations as well. The question of proper sampling procedure has arisen in connection with soil sampling and mapping of soil physical properties. The advantage of point or continuous measurement and the effect of different sampling densities on the resulted maps were investigated as well.

The accomplished field trials revealed the lack of data transfer between two different precision farming systems (RDS and Agrocom ACT). The (manual) file transformation method worked out is presented together with the advantages derived from its application.

The accuracy of the RDS Marker Guide DGPS based navigation tool was also tested because of the experienced displacing of the guidelines during VRA (Variable Rate Application) of solid fertilizer. Our goal was at the same time to state whether such system is on the market can be used as a basis for autonomous guidance system.

During our research activity special emphasis was laid on practicability under actual field conditions.

2. LITERATURE REVIEW

Precision or site-specific farming becomes more and more well known not only within scientist circles but also by farmers. This process takes part in Hungary as well; nonetheless its expensive practical application is question of time, engineering and economic background as well. Despite the rapid development of this field differences can be noticed even in connection with the notion of this technology.

Regarding to Győrffy (2000) precision farming involves the followings: plant production taking into account the local conditions; variable rate technology; integrated pest management; high-technology; remote sensing; GIS; geostatistic; headway of electronic and information technology in agricultural machinery; soil supply and yield mapping; yield (plant) modelling; comparison of soil and yield maps; knowledge of pest and weed distribution within the field.

Referring to the approach reported in Neményi et al. (1998) precision farming means the complementation or rather the further development of modern agricultural machines. According to the authors the most important tasks are to make these machines able to sense, record and forward proper site-specific information and to ensure the automatic application of the decisions based on the gained information. The work out and application of continuous measurement of soil physical and chemical characteristics is urged by the authors. On the other side, the engineering background of the variable rate application should also be provided.

According to Blackmore (1999) precision farming is “the management of arable variability to improve the economic benefit and reduce environmental impact.” In the author’s opinion it is not a technology rather is to be considered as a management process. Some examples are mentioned, which represent that precision farming may be realised without applying new technique or elements. The cited precedents of site-specific management of tea and dates carried out solely manually justify the above-mentioned idea. Based on these facts the author express that “precision farming is now having an impact on agriculture throughout the world.”

In Jürschik’s (1999) opinion the primary goal of the site-specific plant production system is to help the farmers to reduce the amount of inputs and to increase the crop safety and likely the yield. However, we strongly believe that the environmental concerns are at least as important because of the direct and indirect effects. This belief is supported by Pierce and Nowak (1999) who express that “the main objectives of precision agriculture are to increase the profitability of crop production and reduce the negative environmental impact by adjusting application rates of agricultural inputs according to local needs”

What is more, referring to Győrffy (2001) „precision agriculture is the only solution for both ecological and economic problems”.

2.1. Soil sampling

Proper soil information is required in order to reasonable nutrient replenishment. Its importance is reflected by the statement that “Fertile soils are one of the most important resources on Earth” (Schnug and Haneklaus, 1997). Since the treatments took part taking into account the within field variability the sampling should sound this heterogeneity. The requirements of the advisory systems differ from each other country by country. These differences tell so much about how close or far the practical realisation of precision agriculture (PA) is in the given countries.

According to the referring directive the standard soil sampling method is the following in Hungary: "In case of field crops, each approximately 12 ha part of a field should be described with a bulked sample of at least 20 point samples taken along with the diagonals from the 0-25 cm layer. If approximately the 10% of the field is spotty these areas are required to be sampled individually. If the size of a spot exceeds the 30-35 ha differentiated fertilizer application is needed." (Debreczeni, 1993). Based on the referred description it can be declared that the traditional soil sampling method is entirely insufficient for the variable rate technique (VRT).

In case of Austria „soil samples should be taken from uniform areas with identical vegetation respectively from the same land use units. If there are differences in soil types or soil textures on the site, separate sampling has to be done. Border areas or untypical parts must not be sampled. One composite sample is usually representative for 1–2 ha, but for larger areas more composite samples are necessary." „According to the size of the area and variability on the site 15–25 subsamples (single samples or auger cores) should be distributed over the area of investigation. The distribution pattern of the subsamples should be even, following an imaginary zig-zag line, a wavelike line or the diagonals of the area. Sampling can also be done with respect to a systematic grid. All subsamples are normally combined and mixed to a composite sample of 500–1000 g." Sampling depth for top soils varies between 5 and 30 cm depending on land use (Aichberger and Bäck, 2001). Based on their investigation the authors concluded that the applied method of composite sampling of representative areas is exact and reliable.

The standard soil sampling procedure in Spain is described by Barahora and Iriarte (2001). „The sampling area should be homogeneous and no larger than 5 ha. The subdivision of fields in homogeneous zones is made on the basis of physiography, soil colour, stoniness, drainage class and plant development.” „A total of 12–20 subsamples are taken along a W-shaped transect or in a regular grid within a circular area of 6–8 m diameter. The subsamples are mixed in a bucket and a composite sample of approximately 500 g is taken and stored in a plastic bag.” „Sampling depth: 0–5/10 cm in pasture land; plough layer in arable land; plough layer, subsoil and deep rooting zone in tree orchards.” Sampling intensity is at least one sample per homogeneous zone.

Fernando et al. (2001) expounded the Portuguese scheme. If the sampling area is not homogeneous, the area should be divided into homogeneous units according to the colour, texture, slope, drainage and feature of the crop. In each plot a composite sample is prepared by mixing individual samples randomly collected. The number of individual samples should be decided according to the area of the plot but must not be less than 3–4 samples/ha.

Referring to Brouder and Morgan (2000) in the USA a soil sample should be composed of at least 5 to 8 cores even if the sample area is smaller than 2 acres (app. 0.8 ha) but 8 to 12 is considered optimal. In case of grid sampling the size of 2.5 acre (1.45 ha) is declared as the upper limit.

The above-mentioned examples show that the resolution of the traditional sampling is 1 ha in the most optimal case. It is still far worse than the scale of variation what can effective be handled in VRA (variation rate application) mode. What’s more, Murphy et al. (1994) emphasise that (soil) sampling intensity must conform not only to the soil heterogeneity but to the characteristics (e.g. working width, reaction time in case of volume change) of the application machinery as well. Consequently application of a “non-plastic” method may lead to information loss or causeless cost.

Therefore, specific soil sampling method or methods are required, which can totally harmonise with the special requirements regarding to the sample density and distribution. Several methods are known for this purpose. Referring to Pecze (2001) the most common methods for marking out the sample points are the followings:

- following the pattern of the yield map,
- over existing soil maps,
- based on remote sensing information,
- grid sampling.

Auernhammer (2001) also provide a review about the soil sampling methods, which are supported in case of the precision farming technology.

As it showed, in case of point sampling the pattern of a given parameter is taken into account. The number of points is determined by the size of the concerning sub area. On the other side, grid sampling is employed in order to gain adequate dens and evenly distributed measured data. Lund and colleagues (1999) expressed that grid sampling has become a common method in precision farming. However, they also emphasise that using very small grid size this practice may became wasteful. But the optimal grid size is still an open question.

The literature concerning to this subject is not entirely uniform. Stafford (1999) for example applied a 100 m sampling grid during the site-specific field trials in connection with the yield quality. Godwin and Miller (2003) did it as well, however they sate, that this sample intensity provide information about the major soil types, but inadequate for VRA applications. This value was 50 m in case of Earl et al. (2003) examining the spatial variation in the nutrient status.

Since the accuracy of the gathered information is strongly influenced by the sampling intensity the increase of sample number could be a solution. An agro-economic analysis of automated soil pH mapping carried out by Adamchuk et al. (2003) has shown that higher resolution maps can significantly reduce estimation errors. But it has consequences as well: “The adoption of precision farming methods, however, necessarily involves spatially extensive data collection or sampling strategies with a consequential increase in the volume of data that are required to be stored, processed and manipulated.” (Earl et al., 2000). It means not only huge time and labour demand but also extra expenditure, which are in most case not available or not affordable in the practice. A similar opinion is expressed by Frogbrook (1999) who believes that the major limiting factor linking to the commercial application of precision farming is the cost of sampling data with sufficient intensity. This way of sampling is taken impractical as well for the practice (McCormik et al., 2003).

In Oliver’s (1999) opinion, soil properties vary at a range of spatial resolutions from millimetres to hundreds of kilometres, which is caused by the interaction of given soil-forming processes. Consequently, the in-field variability of the fields according to the soil parameters is so complex that the accurate prediction of them at places where no measurement was done is very difficult. Besides, the author states that the less variable the soil is or the denser the sampling is, the more accurate estimation is achievable.

Frogbrook (1999) also studied the effect of sampling intensity on the predictions and maps of soil properties. In this case a 20 m square grid sampling was applied thus the 15.27 ha field was divided into 182 sample sites. At each grid 10 samples were taken in a range of 10 m^2, to a depth of 15 cm. These bulked samples were analysed for K, Mg, P and organic matter. For the prediction of the non-measured values the kriging method and a stochastic simulation, the sequential Gaussian simulation were applied. Maps were also created by using grid points belonging to 40, 60 and 100 m grids. The author states that kriging is likely smooth the variation by overestimating the small and underestimating the large values. And even, this smoothing is not uniform at different locations. Consequently, the maps created this way may be unreliable representations of the in-field variability. However, finally it is advised to use kriging to achieve precise prediction and simulation to preserve the variability.

Not only the sampling itself but also the processing of them raises several questions. Our experiences confirm the opinion of Yao et al., that in case of any interpolated map, the result is affected by the interpolation method and the sample density (Yao et al. 2003). Maniak (2002/2003) also made examinations in this field.

Söderström (1999) mentions also the question of interpolation. In his opinion an automated technique is required because of the lack of special knowledge of the users.

The observations made by Nissen and Söderström (1999) concern the mapping process and the problem of different interpolation techniques. They write that a few changes of the mapping parameters can result in an entirely different (yield) map in case of the same data set. Again, we have the same experiences in case of yield and soil draft maps. Larscheid and Blackmore (1996) also emphasize the importance of this fact since “a great deal of the analysis of spatial yield data is mainly based on a visual investigation”.

Brenk et al. (1999) announced that using different 1 ha-size grids may cause distinct differences in the resulted nutrient content maps. This voice draws our attention to a very complex stickler. First of all, as it was above alluded every changes in the setup of the mapping software (interpolation method, resolution, searching radius etc.) has an affect on the result. It is exactly the same situation with marking out the sample points. The density and the pattern of sampling play also a key role in this matter. These factors should be fitted to the actual circumstances. But how can we define it without the knowledge of the soil heterogeneity? Regarding to the literature, yield data, EC (electric conductivity) or NIR (near infrared) measurements are declared to be the most effective ways to mark out the management zones.

In spite of its above-mentioned disadvantages, grid sampling is widely applied first of all for research purpose as objective picture can be gained about the field choosing an adequate dense grid. The other reason for its popularity is undoubtedly the fact that no better solution is available at the moment. Having a look at the international literature there are two main trends regarding to this question. On one side the further development of the grid sampling and on the other side the working out of a new method for determine the optimal sampling scheme.

Intensive research can be observed in connection with the mathematical and geostatistical backgrounds of soil sampling in order to define the number and position of required sample points. The aim is to balance the inaccuracy origin from the disadvantageous nature of point sampling. (Lark, 2000; Papritz and Flühler, 1994; Kulmatiski and Beard, 2003).

Kozar and his colleagues (2002) examined whether grid-sampling efficiency can be improved using cokriging estimates with slope gradient as a secondary variable, which is easily obtained from high-resolution digital elevation models. It was found that the average estimation variance for cokriging compared to kriging was reduced for all values of the correlation considered. The authors also expressed that grid soil sampling is often too expensive to provide spatial information about soil nutrients at the scale of precision fertilizer application. The ascertainment is entirely consonant with our opinion regarding to practical farming, however for experimental purpose it is assumed to keep its importance as data mining method till the initiation of a reliable continuous measurement technique.

An interesting approach is drawn up by Schnug et al. (1998) who proposed to measure such easy-to-determine parameters, which are in correlation with the soil nutrient supply instead of the time and labour intensive direct measurement. This kind of principle exists in connection with weed mapping as well. Similarly, Machado et al. (2002) mention that information on seasonally stable factors like elevation and soil texture can be used for identifying management zones for water and fertiliser application. We agree with this establishment with the expression that other parameters may also play important role in this concern. Consequently, they also should be taken into consider.

According to Godwin and Miller (2003) yield heterogeneity is hardly affected by the variation in available water content in the soil. Available water content is a function of soil texture, therefore, an understanding of soil textural distribution is essential when considering precision farming.

The information achieved by yield monitoring can also be a marker as plant stand reflects the effects of the differences in chemical and physical soil characteristics and other parameters on each other and on plant growth (Kalmár and Pecze, 2000).

Despite there are many publications concerning to the non on-line surveying and mapping of soil properties on given measurement points (Fekete et al. 1995; Hoskinson et al. 1999; Lund et al., 1999; Fekete et al., 2001) "there is still a serious lack of site-specific data about physico-chemical topsoil characteristics for precise and spatially variable management" (Selige et al., 2003). We entirely agree with this comment and in our opinion the working out of the continuous measurement of the physical and chemical soil properties is required.

This idea is supported by Earl et al. (2000) who concluded that the monitoring of ambient field conditions at fixed locations, including soil moisture and micrometeorological parameters is possible using direct sensing technology. However, to be able to provide sufficient information for site-specific management, the sampling density should sound the scale of variability and even the continuous measurement may be desirable.

Hummel et al. (2001) subscribe to this view as well. According to him changes in soil parameters may occur on a finer spatial resolution than can be documented with manual and/or laboratory methods due to the cost of sampling and analysis procedures. Therefore, there is a need for the development of sensors to more accurately characterize within-field variability.

Thomasson et al., (2001) stated, that the spectral regions from 400-800 nm and from 950-1500 nm are sensitive to soil nutrient composition.

Selige et al. (2003) examined the possibility of topsoil clay- and organic matter content mapping by field-spectroscopy and hyperspectral remote sensing. The topsoil reflectance was measured in a range of 330-2500 nm in case of field measurement, and 420-2480 nm in case of remote sensing, respectively. As a control, the total amount of organic nitrogen, the total amount of carbon and thus the total organic matter content (OMC) was determined. In addition, the organic matter composition was characterised as aliphatic and aromatic compounds. The iron oxide content and the wetness condition (by means of an adapted topographic wetness index, TWI) of the topsoil were also taken into account. The authors found a close relation between clay and iron oxide amounts ($r^2 = 0.90$), whilst significant correlation with clay content could have been observed only in the spectral range >2300 nm. The OMC correlated most strongly in the range of visible and near infrared wavebands. The researchers pointed out furthermore that higher TWI and aromatic fraction in the OMC, respectively cause lower reflectance value.

Adamchuk et al. (2003) stated in connection with the investigated soil properties monitoring system based on ion-selective electrodes that more research is required both in terms of improving sensor performance and interpretation of the results. Therefore, this kind of solutions at the present can be useful tools for relative measurements, but not for absolute measurements.

Regarding to the on-line sensor-based soil chemical mapping it can be declared that in spite of the promising and foreshadowing results further development is required. On one side the way of on-line measurement should be ensured for each important soil property and on the other side the enhancement of the accuracy is needed.

The accuracy of the laboratory analysis can also be questionable (Brenk et al., 1999). The authors appointed that the same analysis carried out by different laboratories may provide different results. According to the article, the coefficients of determination (r^2) between the results were 0.81 and 0.74 for P_2O_5 and K_2O, respectively. It may lead to inaccuracy.

2.2. Yield monitoring

Adequate number of measurement points is required in order to generate reliable maps about any field. Probable the most obvious way for this purpose is yield monitoring as 500-600 measured points per hectare may be recorded in an economic way. Furthermore, yield is the major indicator of the success of the plant production since the effect of every influencing factor is manifested in it Dampney (1999). Additional benefit of this measurement is that the yield integrates the effect of soil properties throughout the rooting depth of the crop, whereas other methods such as EMI (Electro Magnetic Induction) interact with soil independently of the growing crop. Thus the advantage of yield map analysis is that there is very little extra cost to obtain this information (Dampney et al., 2003). At the same time, Blackmore (1994) warns to not overestimate the value of yield data. Respecting to the author's mind the observed yield heterogeneity is appropriate for the classification of the field regarding to its fertility but does not provide detailed information about the reasons for the variability.

Yield monitoring is then probable the most widely applied and most obvious step of the PF (precision farming) technology first of all in case of cereals. The available yield sensors were reported by many authors (Borgelt and Sudduth, 1992; Auernhammer et al., 1993; Murphy et al., 1995; Perez-Munoz and Colvin, 1996; Reyns et al., 2002; Takátsy, 2000; Tóth, 2002).

It is to be mentioned that yield-monitoring devices appeared in the early 80s with the aim of measuring the total yield of the field. Later, together with GPS their function changed and the primary goal has been the geo-referred monitoring of the yield heterogeneity (Murphy et al. 1995).

Real practical applications are also took part even in Hungary. Neményi et al. (1998) report their experiences in connection with yield monitoring with RDS system. The total error of the measurement was over 30% in case of winter wheat opposite to the 1.89% error of the area measurement. The yield map was corrected as post processing by means of RDS PF software. The authors set themselves the task of increasing the accuracy of the yield monitoring. However large the reported inaccuracy is, be it remembered that it was probable the first practical application of any yield mapping system in Hungary.

Beside the quantity measurement there are efforts in order to ensure the grain quality monitoring during harvest as well. The infield variability of grain nitrogen content and bulk density was mapped by Stafford (1999). The plant sampling was done by a 25 x 25 m grid and the nitrogen content was determined with laboratory measurement.

Reyns et al. (1999) carried out examination during which the yield and straw flow of winter wheat were measured continuously together with point measurements of grain protein and moisture content by means of near infrared reflectance (NIR). According to the researchers a weak relationship could have been observed - first of all visually - between the yield and the protein content. They stated that the monitoring of both grain yield and protein content might provide valuable information about N uptake of the plant stand. The applied straw flow sensor detects the torque on the auger in the header of the harvester. The measurement was carried out by gauging the tension of the drive chain with a small hydraulic cylinder and a pressure transducer.

There are efforts even to use X-rays for grain flow measurement. Arslan et al. (2000) carried out investigation with low energy X-rays densitometry under laboratory circumstances. The correlation coefficient between the mass flow rates of maize and C-ray intensity was 0.99 for flow rates ranging from 2 to 6 kg/s. Measurements were done in real time at a 30 Hz sampling rate. As one of the major advantages of the examined manner the authors emphasize that it is relatively independent of grain moisture due to a negligible change in the X-ray attenuation coefficients at typical moisture content values from 15 to 25%. Furthermore, biological shielding can easily be accomplished due to the low energy of the X-ray photons. The exploit of this solution can be especially hopeful in case of oil-seeds where notably influence of the oil content on both the yield and grain moisture measurements were observed during our trials using optical yield- and conductive moisture sensors. Besides, the X-ray technique may suitable for yield measurement even in case of root crops; nevertheless health and environmental reasons may impede its spreading.

The demand of yield monitoring however exists in case of root-crops and rough fodder as well. (Demmel and Auernhammer 1998; Demmel et al., 1999; Jürschik 1999; Hennens et al., 2003).

Snell et al. (2002) examined the possibility of on the go measurement of dry matter content of chopped maize using electromagnetic field. The authors stress that the effects of different sample weights and densities should be taken into account.

Wild and Auernhammer (1999) published a yield monitoring system for round balers using a load cell in the drawbar coupling and strain gauges in the axle. The average error of weight measurement was under 1% in static mode but reached 10% in dynamic mode. These results are pointing ahead especially taking into consideration that the trial took place under practical circumstances.

Hammen and Ehlert (1999) report their experiences with their pendulum-meter applied for fresh plant mass measurement in Italian ryegrass.

Kuhar (1997) gives an overview of the yield monitoring development for non-grain crops (Table 2.2.1.).

Table 2.2.1. Yield monitors for non-grain crops (Kuhar, 1997)

Crop	*Measurement method*	*Development status*
Potatoes	Load cells	Commercially available
Tomatoes	Load cells	Experimental
Sugarbeets	Load cells	Experimental
Peanuts	Load cells	Experimental
Cotton	Load cells	Experimental
Forage crops (baled)	Load cells	Experimental
Forage crops (chopped)	Shaft torque sensing	Experimental
Forage crops (chopped)	Radiometric sensor	Experimental

Ehlert (1999) describes his examinations in connection with mass flow of potatoes for yield mapping. The trial was carried out under laboratory conditions and the results show, that the determination of the mass flow is possible by measuring the resulting impulse in the discharge trajectory of conveyor belt with a rubber coated plate.

Demmel et al. (1999) give a review about the possible methods of yield monitoring in case of potato and express that the measurement system suggested to be located at the end the material stream because of the presence of haulm, clods, stones etc.

According to Jürschik (1999) the yield monitoring of potato can be carried out using load cells in the chain-grate or in the axle of the elevator. In the author’s opinion this solution could be applied in case of sugar beet as well.

Several studies were executed concerning to the belt weighting as a mode of yield monitoring of non-cereal crops. A three-roller continuous belt-weighing type load monitor was developed by Pelletier and Upadhyaya (1999) for this purpose (Fig. 2.2.1.).

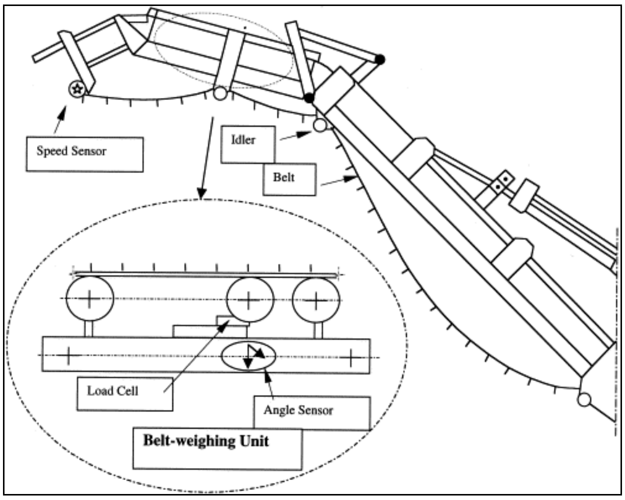


Figure 2.2.1. A schematic diagram of a three-roller, continuous belt-weighing type load monitor mounted on the boom elevator of a tomato harvester (Pelletier and Upadhyaya, 1999)

Despite the remarkable results and research activity it should be mentioned that further research is still required according to yield monitoring. One of the most critical factors is the question of automatic cutting width measurement. As this value together with the forward speed determines the actual area which to the actual yield is concerning its accurate knowledge is essential. Nissen and Söderström (1999) opinion is entirely agree with our judgement in connection with this problem: it is difficult for the driver to estimate it. And since no available automatic tool is on the market, manual method is applied, which may cause incorrect data logging. Reitz (1992) also emphasises the importance of automatic cutting width measurement and reports two solutions. In case of the spring-loaded drop arm the deflection angle is proportional to the width of the inactive part of the cutter bar. A potentiometer transforms the deviation into electric signal. However, because of practical reasons the possible length of this arm may be a limiting factor. The ultrasound distance measurement can also be applied. The distance is calculated by the time delay between the signal emitted and absorbed by the detection head. Both devices are big step forward comparing to the manual adjustment. The possibilities for on-line cutting width measurement are reported by Kuhar (1997) as well (Fig. 2.2.2.). According the author these sensors have not performed flawlessly, but have shown promise for widespread commercial adoption.

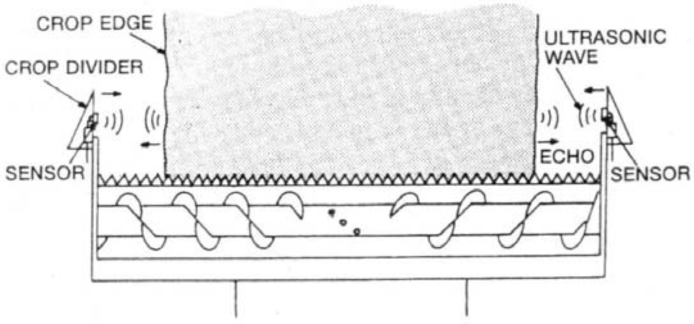


Figure 2.2.2. Automatic cutting width measurement (Kuhar, 1997)

Murphy et al. (1995) summarize the most typical problematic points during yield monitoring:

- Zero or near zero recorded values at the start.
- Periods with data logging but without incoming crop.
- Sudden changes in the forward speed between the cutting and the measurement of the crop. The abrupt alteration of the forward speed may cause that the measured value is calculated taken into account an incorrect

speed, thus the measured yield is referred to an incorrect area (defined by the cutting with and the forward speed).

Indistinctness however exists in connection with the process of the yield data as well. The harvest row data file may contain unreliable values, because of given reasons. Blackmore (2000) stated that yield maps play an important part in the decision making process for farmers adopting precision farming practices. But these data sets and the maps created from them may contain systematic errors, which are mainly caused by the harvester or the way in which that was used (Blackmore and Moore, 1999). According to Nissen and Söderström (1999) one of the most typical sources of these errors is the incorrect time delay of the yield monitoring system (the time, during which the crop mass get to the yield sensor from the cutting bar). Therefore, it is suggested in the article that the first few data records for each transect should be deleted. Our experiences show a different picture. During the field-scale yield precision farming trials our institute applied both the RDS (installed on a Claas 204 Dominator) and the Agrocom ACT (installed on a Deutz Fahr M 62.80) systems. In case of both combinations the 10 s delay proved to be accurate. On the contrary, Reyns et al. (1999) experienced average delay times of 20.3 and 29.5 s entering and leaving the field, respectively in case of a New Holland TX 64 harvester. Come up so the question that which is the better solution: to delete measured values because of a suspicion of error or to use the recorded value. In other words: waste the yield data of a given area – 30 m long part according to Nissen and Söderström (1999) – or describe that area with the possible erroneous data? Do we use data, which are not 100% reliable or do we use no data at all from the first 30m of each transect? In our opinion, even based on our above-mentioned examinations to delete the data is not the proper way. It is much more desirable to work out a controlling method to define the exact trashing time. The way of the grains could be monitored with some sensors built in given places of the trashing system.

Arslan and Colvin (2002) also propose a solution based on their research focusing on yield sensing methods, yield reconstruction, mapping, and errors. It was concluded that with proper installation, calibration, and operation of yield monitors, sufficient accuracy can be achieved in yield measurements to make site-specific decisions. Nevertheless, attention must be paid when interpreting yield maps since yield measurement accuracy can vary depending upon the measurement principle, combine grain flow model, size of management area chosen, and the operator's capabilities and carefulness in following instructions to obtain the best accuracy possible under varying field operating conditions. According to the authors a yield reconstruction algorithm, which effectively handles non-linear combine dynamics has not been developed by researchers yet. More efforts towards yield reconstruction should be encouraged.

Nissen and Söderström (1999) mention furthermore that all point without DGPS signal should be deleted. We also faced with the lack of differential signal. It may occur a few times, however it typically lasts for some seconds. During these periods the information stored in the almanac of the DGPS receiver ensures the accurate positioning.

Irrespective to the applied yield monitoring system a regular grid of data should be generated from the irregular data of the recorded yield file. For this task geo-statistical methods are employed. The smoothness of the resulted contour map depends on the input data, the grid density and the selected gridding algorithm. As yield data may show erroneous fluctuation smoothing can also be an important parameter. Probable the most common methods are the inverse distance and the kriging – write Murphy et al. (1995).

A very considerable way of thinking appears in the study by Balckmore (2000). The researcher warns of the importance of trends can be observed in yield data. A technique and an example published to characterise the spatial and temporal variability and to create classified management map in the basis of yield data over six years. As a first step, a so-called spatial trend map is created by calculating the mean yield at each point of a regular grid (in case of single crop, i.e. no rotation) or the relative percentage yield compared to the field average as 100% (multiple crops, i.e. with rotation). Similarly, temporal stability maps may also be produced taken into account the coefficient of variation at each point. The management map may be achieved as a combination of the spatial variability and the temporal stability. Based on these calculations and combinational logical statements the classification of the characteristics can be carried out as higher yielding stable, lower yielding stable and (temporally) unstable. In this foundation, the gross margin map can also be generated as well as the management decisions may be made. The author mentions at the same time that these trend maps tend to be more sensitive to extreme values than to "subtle consistent changes, which is of course, a characteristic of the average function."

Other scientist also investigated the relation between the subsequent crops. Demmel and colleagues (1999) e.g. found no correlation among the successive yield data of potato and combinable crops from the same field. Our experiences show moderated correlation between the yield of maize and spring barley as well. These facts draw our attention into the question whether soil sampling based on yield information is a proper solution when different crops follow each other. Even if it is well known that other factors may also have an effect on the yield.

Referring to Godwin and Miller (2003) topography is one of the most obvious causes of variation found in field crops both from its direct effect on micro-climate and related soil factors such as soil temperature, which influences germination, tiller production and crop growth. In this concern we have to emphasise the importance of the height information may be recorded during harvest (if the system supports it, unlike e.g. the AgroCom ACT). Based on these data the relief model of the field can be constructed and thus the effective analysis of its influence is available. An example presented by Nugteren and Robert (1999).

2.3. Site-specific nutrient replenishment

The goal of nutrient replenishment in general can easily put into words. The aim is to provide an optimal nutrient supply taking into account the given conditions, the demand of the plant and the planned yield. The situation is exactly the same in case of site-specific farming, however the circumstances changing through the field.

Similarly, Marquring and Scheufler (1997) state that in the frame of nutrient management the applied amounts should be harmonised to the uptake of the plants. This attitude also has a positive effect on the environmental conservation. We entirely agree with the sentence expressed by the authors whereas beside the yield increase the quality improvement is also expected.

The importance of sub area management is emphasised by Schnug and Haneklaus (1997) as well: "… as soils are neither static nor homogeneous in space and time, the common way of uniform application rates always results in a side by side of over and under supply."

Jürschik (1999) takes this viewpoint as well. According to the author, dozing taking into account the local circumstances is especially important in case of nutrient replenishment and pest management.

Schmidhalter et al. (2003) also believe that heterogeneous fields require a targeted, site-specific application of nitrogen.

The idea reflected by Selige et al. (2003) is entirely coincide with the above-mentioned statement. According to their study, significant heterogeneity in topsoil can be observed within the fields, what causes differences in crop nutrient and water uptake and consequently influences the crop growth.

Beside the spatial- and the temporal- variability Blackmore (1999) defines a so-called predictive variability as the difference between the prediction and the reality. Besides, the author takes the viewpoint that most traditional systems over-apply inputs such as seed, spray and fertilizer to reduce the risk of crop failure. With better assessment techniques, the inputs can be reduced or redistributed to optimal levels and the risk of failure can be managed. This will result in making the system more efficient. Our experiences confirm this latter establishment.

Hungarian researchers also made investigations concerning to the relevant subject. Based on their experiences they state that using this technology it is possible to provide the optimal or near optimal nutrient (Csizmazia, 1993) and chemical (László, 1992) amounts and even the proper cultivation for each part of the field (Jóri and Erbach, 1998). Consequently is it possible to save money and to prevent the environmental pollution caused by the leaching out of the nutrient and by the overuse of chemicals (Pecze et al., 2001).

At the same time, Neményi et al. (2001) warn that despite several systems are in the market to attain this technology their reliability is poorly known by users and even by researchers in Hungary and abroad as well at the present. This problem is undoubtedly caused by the lack of practical tests and even by the insufficient communication between producers and users.

This point of view is partly reinforced by Person and Bangsgaard (1999). The Danish researchers made tests to study the effect of variable rate application on spreading pattern in case of disc spreaders. In the frame of the trial different combinations of fertilizers and spreaders were applied. They found, that the spreading pattern varies with varying flow rate; consequently the application differs from the plan. The authors suggest that other parameters such as vane position, drop point, inclination, etc. should be automated adjusted during the application. They expedite the working out of algorithms for each individual combination of spreader and fertilizer. The article deals with a problem, which is affected by several factors even in a test hall (like in this case). Nevertheless, the practical circumstances are even more complex: factors such as relief, airflow, humidity or temperature cannot be regulated. To be able to take into account all these aspects and even the type of fertilizer a more complicated control system is assumable required. However, it should remembered, that one of the main goals of this technology is to make the farming more (cost) effective. Moreover, our field experiments show that accurate application can be carried out without the above-mentioned solutions. The algorithm for each fertilizer and spreader seems now unnecessary, because in case of every VRA the first step must be the calibration of the system with the actual agent. And the scale of required accuracy is also a question. The applied fertilizer granule is effective not in a point but in a spot due to its solving consequently a certain smoothing stands out.

According to Lütticken (1999), the most important criteria regarding spreader technology are dose rate accuracy, part width options and short response times to vary fertilizer rates.

Considerable developments according to the distribution accuracy of disc spreaders were achieved even in Hungary (Csizmazia, 1986; Csizmazia, 1990; Csizmazia, 1993; Fekete et al., 1996).

Nevertheless, a serious limitation still exists with respect to VRA fertilizer application using spin disc spreaders. It is that only one agent can be applied at the same time as not only the amounts but also the ratio of the given agents change through the field. However, most of the control systems are also unable to direct this process.

Fortunately, there is an example on simultaneous site-specific distribution of several agents. The SOILECTION™ system has the capability of variable rate application of both dry and liquid products. A pneumatic system is applied to deliver dry materials across the width of a 70-foot (app. 21 m) boom. The system is equipped with four individual fertiliser bins, two bins for micronutrients or herbicides and two tanks for chemicals. Up to eight different agents can be blended and applied at one time (Kuhar, 1997). The capacity of the system is very remarkable, however, no further operation parameters are presented.

In case of the so-called map-based VRA the decisions are made prior to the application. For this purpose different advisory systems are available. In this concern a Hungarian example is mentioned. Csathó and his colleagues (1998) worked out an environmentally friendly fertilizer advisory system, which philosophy is in harmony with the basic principle of PA. The model mentioned under “Materials and Methods” as well.

The Institute of Agricultural, Food and Environmental Engineering have been applying the above mentioned recommendation system under real field conditions, and reports the experiences regularly (Pecze et al., 2001; Neményi and Mesterházi, 2003; Mesterházi et al., 2003/d).

Czinege and his co-authors (1999) return the elaboration of a GIS based site-specific fertilization recommendation system, which can take into account the in-field heterogeneity.

Alternative initiations come also to light. Contrasted to the map-based approach the required fertiliser amount is defined and applied on-line based on the signal of a proper sensor. In most case, the nutrient demand of the plants is determined in the basis of their spectral characteristics.

Yao et al. (2003) studied the application of HRSI (hyperspectral remote sensing imagery) for soil nutrient management zone mapping. The spectral information was collected in the range of 470 to 826 nm

An active sensor was developed by Schächtl et al. (2003) to measure the laser induced chlorophyll fluorescence. The method is based on the idea, that the intensity of fluorescence at 690 nm and 730 nm is dependent on the chlorophyll content, which is related to the nitrogen content (decreasing ratio with increasing N uptake). Therefore, the vegetation index ratio (690/730) can be applied to determine the nitrogen uptake of the plants. Field trials were carried out in case of five wheat cultivars and different nitrogen supply. The results show, that the affect of soil background, irradiance or cloudiness on the above mentioned ratio is negligible. However, differences caused by the N fertilizer treatments and different cultivars can be identified.

Schmidhalter et al., (2003) report their experiences in connection with their multispectral crop scanner. The device is designed to detect differences in biomass, nitrogen content and nitrogen uptake. The light is collected from four sources by a two-diode array spectrometer and optically averaged by a four-split light fibre in order to minimize the effect of different incoming (solar) radiation.

Measurements are made in five wavelengths (550, 670, 700, 740 and 780 nm) and the following spectral reflectance indices are calculated:

Red edge inflection point: REIP = $[700+40((R_{670}+R_{780}/2-R_{700})/(R_{740}-R_{700}))]$,
Soil adjusted vegetation index: SAVI = $[1.5(R_{780}-R_{670})/(R_{780}+R_{670}+0.5)]$,
Normalised difference vegetation index: NDVI = $[(R_{780}-R_{670})/(R_{780}+R_{670})]$,
Green – red ratio: G/R = $[R_{550}/R_{670}]$,
Infrared – green ration: IR/G = $[R_{780}/R_{550}]$,
Infrared – red ratio: IR/R = $[R_{780}/R_{670}]$.

The size of the scanned area is 2-18 m^2, according to the sensor's position. Field trials were carried out with two wheat species beside variable rate nitrogen application in two fields. The results show that the best outcome was achieved with REIP, IR/G and IR/R. However, the authors emphasizes, that in general, with a higher level of N fertilization or N uptake, the relationship flattens between reflectance and the investigated parameters.

Bradow and his colleagues (1999) investigated the correlation among spatial variation in fibre properties of cotton, soil pH, levels of phosphorus, sodium, calcium, magnesium, cation exchange capacity and organic matter content. The cotton fibre samples were collected by hand. It was found, that no cause and effect relationships could have been unequivocally demonstrated however, the fibre quality seemed to be affected by the phosphorus level and soil pH.

Variable rate application of given inputs can be the solution to handle the in-field heterogeneity. In this concern the site-specific distribution of fertilizers and other chemicals seems to be evident. However, variable rate seeding (VRS) is also known. In this case the plant stand is to match to the local circumstances. It may take part with or without VRA nutrient replenishment that is why it mentioned here. Welsh et al. (1999) found in connection with it that the most effective strategy is applying more fertilizer to areas of low tiller density and less to areas of high density.

Considering to Bullock et al. (1999) the VRS can be profitable only if the relationship between yield and seeding rate for each part of the field is known. In their opinion, there are two possible ways to get the required information. The first way would be to parcel of each field into small plots with different plant densities and different fertilization. In this way it would be possible to define the response function and estimate the economically optimal seeding rate for each spot in each individual field. As an alternative solution, scientists are suggested to label the affecting factors on yield and seeding rate. According to the author, only a small part of this work has been completed. For us, the second approach seems to be evident. The first idea is far from the practice and appears to be completely unaccomplishable. As it is published, these statements are based on the economic analysis of two agronomic data sets (Pioneer Hi-Bred International Data Set and the University of Illinois Data Set). In our view, to discover biological and agronomic connections first of all a professional (agricultural, biological, genetic etc.) investigation of such databases is required. And what more, this questions must have been already studied. In this point we have to mark that trials in this field took part in Hungary as well. Besides, we firmly believe, that the mentioned small and large plot examinations are far not the same as a real field trial from several point of views. However important measurements these are from agronomic side, they differ from the real practice concerning to engineering factors, for example (different machinery, DGPS, variable rate technique etc.) and thus regarding to the economy (e.g. machinery cost and effectiveness) as well.

Finally, the authors state that according to the above-mentioned difficulties the VRS on its own is of no economic benefit to farmers.

Brenk and his co-authors (1999) report their experiments regarding to site-specific nutrient application. Studying the relation between the spatial distribution of soil nutrients and the crop yield they found no correlation. Yield increase due to the variable rate P and K supply was not demonstrable. At the same time, the studied elements showed temporal variability within two subsequent years. Therefore, the authors state that „the use of site-specific soil test data for the planning of variable-rate application of P and K appears not to be economically justified”. We cannot agree with this sentiment. The yield increase is an important aspect but it cannot be the only one. The principle of precision farming rather suggests us a way of farming, which makes possible to meet both ecological and economic trends meet (Mesterházi et al., 2001). In this way, to keep the same level of yield applying less fertilizer can be at least as valuable step forward as achieving a higher yield. And even, there are other soil properties, which may show stronger correlation with the yield (e.g. humus content). And what’s more, we have to refer to the well-known minimum low of Leibig. As regard the temporal variability of given elements, in our opinion it is a fact, and the main reason might be the uptake of the plants. However, it must be in correlation with the yield, thus it can be taken into account.

Hoskinson and his colleagues (1999) also made examination in connection with this phenomenon. This investigation covers a four-year period in a 72.4 ha field. Soil samples were collected in a 3.5 ha grid, from a depth of 30.5 cm. A composite sample consisted of about 10 single samples taken within a 1 m area at each location. Potato petiole samples were also gathered in a 3 m range at each location two times both in 1995 and 1998. From 1995 to 1998 uniform fertilizing was applied. As an effect of homogenous nutrient replenishment the soil phosphorus content showed a non-uniform increase. This phenomenon was observed even without fertilizing. The changes of nutrient content of the soil and the petiole often showed no correlation. The authors found also that the soil fertility parameters changed in a spatially non-uniform manner. In 1995 a soil microbiological analysis was also carried out and the consequence was drawn that the changes in soil organic nitrogen is affected by the microbial activity.

2.4. Measurement of soil physical parameters

Soil compaction is one of the most typical soil problems, which is mainly caused by technological/cultivation faults. However, it has typical signs, soil compaction is observed generally by means of plant symptoms, in this way too late (Mesterházi et al., 2003/c).

Birkás (2002) provides a very comprehensive analysis of the possible reasons of soil compaction. The prevention and the ways of elimination of it are discussed keeping in eye the practical conditions.

Dampney et al. (2003) also believe that the in-field variability of soil physical properties is of key importance when assessing the justification of any VRA in case of a given field and for marking out within-field management zones. We are on the same mind even in case of their pronouncement that yield maps are useful for identifying potential management zones based on soil physical characteristics.

The importance of the knowledge of the soil conditions is emphasised by Sudduth et al. (2002) as well: “Yield monitoring has demonstrated to farmers that much of the yield variability within fields is associated with soil and landscape properties, and in many cases these properties are water-related." Furthermore, since the location and degree of maximum compaction are important information for site-specific tillage or other compaction amelioration techniques, being able to estimate these parameters has potential benefits for site-specific compaction management.

Beside the agronomic consequences soil compaction has engineering concerns as well. Yule et al. (1999) pointed out significant increase of engine power utilisation and thus cost in case of compacted soil.

For the measurement of the soil compaction the penetrometer measurement is the most common method. Even if the information gathered in this way doesn't suit entirely for the agricultural practice (Sirjacobs et al., 2002): the field is described with point measurement (among the points only calculated values are available) and only a static, vertical force can be measured contrary the dynamic forces are present in the surface of any cultivator unit (Neményi and Mesterházi, 2002). Our experiences confirm furthermore the opinion reflected by Verschoore et al. (2003), that the accuracy of soil maps based on discrete penetrometer measurement points depends on the density of sampling points, thus it is limited in many cases. And this appointment warns again of the importance of the sampling method and data processing was negotiated in chapter 2.1.

An investigation is reported by Sudduth et al. (2002) in the frame of which the relationship of cone penetrometer index (CI) and other soil and landscape characteristics (result of profile analysis, soil texture, organic C content, bulk density, water content and electric conductivity) were examined. According to the results CI showed correlation only with the measurement depth but not with the examined soil properties in the layer of 0-15 cm. At deeper layers, it was in correlation with soil texture, soil water content and depth as well. However, there was no correlation between CI and bulk density, despite bulk density is considered as one major factor affecting CI. An interesting observation was that correlations of CI with clay content were negative in one field but both negative and positive in the other. These observations are really thought-provoking and question the accuracy and importance of the penetrometer measurement. However, to replace this method a better one is requires.

The demand of continuous measurement was phrased by several researchers (e.g. Neményi et al., 1998; Pecze et al., 1999) in order to eliminate the existing defectiveness of the penetrometer measurement.

The need of continuous measurement of the physical soil properties is emphasized also in Sirjacobs et al. (2002) where it is expounded that the measurement of soil resistance with penetrometer provides only discontinuous field information, and also that this technique together with the laboratory analysis do not fit for soil mapping. Others make mention of the inadequate speed of site-specific data collection with single-shaft penetrometer (Sudduth et al., 2002).

A very vivid research activity can be noticed in the field of continuous soil physical property mapping. One of the major trends is the on-line draft measurement.

Kushwaha and Linke (1996) make perceptible the complexity of the process takes place during the interaction of the soil and any tillage tool. According to them, the normal stress present at the soil-tool interface always deforms the soil a little and rearranges the soil particles. Consequently, beside the friction force, an additional force for soil deformation is also present. On the other hand, as an effect of the normal stress water may be pressed out of the soil pores. This water reduces the friction coefficient corresponding the surface, however if this water is under suction it provides another effective stress.

Reviewing the literature Kushwaha and Linke (1996) pointed out that the draft of mouldboard and disc ploughs increased as the square of speed while this increase was linear in case of many other implements. Based on their examinations the researchers stated that a critical speed range is exists at which the relationship between draft and speed changes (i.e. the draft increased less with speed above the critical speed). This range was found between 3 and 5 m s^{-1}, and was almost independent of soil properties, operating conditions and tool size. Corresponding to the authors, the decrease of soil deformation can also be expected above the critical speed.

Mouazen and Neményi (1995 and 1998) applied finite element modelling for describing the interaction between soil and the applied tillage tool. The same technique was than applied for simulation cutting homogeneous (Mouazen and Neményi, 1999/a) and non-homogeneous materials (Mouazen and Neményi, 1999/b).

Verschoore et al. (2003) introduce a self-developed tool for draft measurement. Its chisel is equipped with several wings with a height of 0.05 m, which cover a total depth of 0.3 m. The bending moment on the wings is measured and correlated to the soil resistance. The instrument was tested both in soil bin and under field circumstances. A poor r^2 value (0.4061) was found between the soil resistance measured this way and the classic vertical resistance.

Sirjacobs et al (2002) describe a system for continuous measurement of soil mechanical resistance. Its operation is based on three Wheatstone bridges measuring the draft force (F_x) the vertical force (F_z) and the moment (M_y) are present at the surface of the applied horizontal cutting blade. An octagonal ring transducer is installed between the tractor and the beam supporting the blade. Two parallel but independent logger applications were employed to record the soil and position information, respectively. The synchronization of these data took part in post-processing mode, analogous with the transformation of the voltage values of the sensors. During the field trials several soil properties and indicators (moisture content, bulk density, plasticity- and consistency indexes, granulometry, penetrometer resistance, cohesion- and internal friction angle, pF curves) were examined simultaneously with the continuous measurement. However, no significant relation was found between the sensor's main signal and the given soil physical properties. Based on the assumption that the high compaction may modify the mode of interaction between the soil and the blade and consequently relationships may be masked data from those areas were left out of consideration. After this significant relationships ($r^2 = 0.807$) were found between the global penetrometry index and F_x and M_y; and between the gravimetric water content and the vertical force (F_Z) ($r^2 = 0.779$). The authors appreciate the results as promising perspective of a solution allowing on-line characterisation of soil physical state. We also believe that these results and the applied device are pointing ahead in many concerns, however some questions still arise. On one hand, neglecting the data from the areas with significant compaction seems questionable even taking into account the fact that the primary goal of these soil-mapping systems is to identify just these parts. On the other hand, in our opinion it is not suitable to call the described tool as an on-line one taking into consider the need of post processing and the separated logging of position and soil data. Otherwise, we entirely agree with the followings: “the knowledge of soil properties and especially of soil strength is one important aspect of precision agriculture to perform soil variability maps and to regulate soil tillage and sowing machines” (Sirjacobs et al., 2002).

Mouazen et al. (2003) however stated that soil draft cannot be related directly to soil compaction ignoring the affecting factors such as soil type, soil moisture content and working depth. According to Mouazen and Ramon (2002) soil draft is in direct ratio to working depth and in inverse ratio to soil moisture content. According to this latter statement it should be mentioned that the soil in its natural state far not homogeneous corresponding to the depth. Compacted layers may occur even in the surface thanks to the field traffic.

Mouazen et al., (2003) measured the soil draft and the cutting depth of the applied subsoiler. On the basis of a previously developed formula, dry bulk density indicating soil compaction was estimated as a function of the measured horizontal force, cutting depth and moisture content. Moisture content and bulk density was simultaneously determined during the texture and mechanical analysis. The model-based bulk-density showed an average underestimation of 14%, however the spatial distribution was similar to the measurement-based one. The map generated from the directly measured soil draft showed a different spatial pattern comparing to the maps based on the data of the estimation and the measurements, respectively. The applied speed of 0.9 km h^{-1} is far from the normal operation value. It is well known, that operation speed also influences the draft. There is no reference in the article if this effect was examined or any explanation that why this value was selected. Referring to Kushwaha and Linke (1996) the extent of soil deformation caused by tillage would decrease above the critical speed range (3-5 m s^{-1}). Therefore, according to the authors it is important to examine the dynamic effect of tillage at higher operating speeds, which were presumably neglected by Mouazen et al. (2003).

Al-Jalil et al. (2001) also describe a self-developed three-point hitch dynamometer and the investigations were carried out with that. An increasing draft was observed according to increasing working speed (approximately 1.4, 2.3 and 4.8 m s^{-1}) and depth (10, 20 and 30 cm). The published figure showing draft vs. speed confirms Kushwaha's and Linke's (1996) observation: above the applied velocity of 2.3 m s^{-1} the rise of the curve decreases significantly.

McLaughlin et al. (2002) carried out investigations in connection with the effect of the organic and inorganic nitrogen replacement on mouldboard plow draft. The measurements were carried out by means of an experimental tractor of which operation parameters including fuel consumption, engine and ground speed, axle torques and forces in the three-point hitch linkages (in order to calculate implement draft) were recorded. The results show that fuel consumption is highly correlated with implement draft, but not in a linear form since the engine efficiency changes with changing load. Based on the draft-speed equation it was made appear that 1% increase in a nominal forward speed of 5.7 km h^{-1} would increase draft by about 0.3%. It was also observed that applying organic manure for 8 years in an amount of 100 kg/ha wet weight the plow draft reduced with 27-38% as well as the fuel consumption with 13-18%. These numbers are really noticeable, and as a possible solution to reduce the input demand and the environment load, this way of thinking may be considered to be similar with the basic principle of precision agriculture. Research regarding to on-line soil draft measurement is reported by further authors as well (e.g. Clark, 1999; Desboilles et al., 1999; Lund et al., 1999).

As soil moisture content is considered as a significant influencing factor on soil draft, the study executed by Hummel et al. (2001) has an importance from this point of view. Regarding to the described method soil moisture and organic matter prediction was carried out by means of a NIR sensor. In the frame of this trial soil samples were taken from 16 sites with natural grass surface across a

144000 km^2 area of the US Cornbelt. The samples were divided into layers of 2.5 cm and analysed for bulk density, volumetric water content and soil organic matter by laboratory methods. The spectral reflectance measurements in a range of 1623 to 2467 nm were carried out in instance of defined levels of moisture content. The data were normalized, transformed to optical density [$OD=\log_{10}(1/\text{normalized reflectance})$], and analyzed using stepwise multiple linear regression. Standard errors of predictions for organic matter and soil moisture were 0.62 and 5.31 %, respectively. However, the measurements took part under laboratory circumstances, the results are encouraging for the practical implementation.

Shibushawa et al. (2003) describe a complex system for monitoring the temporal changes in spatial variability of soil parameters. The reviewed device is equipped with a real-time spectrophotometer, which collects information in the range of 400 – 1700 nm; an EC electrode and a load cell is also part of it. It was noticed, that soil organic matter (SOM), EC and pH showed temporal stability unlike NO_3-N and soil water content. The authors appreciate the real-time soil spectrophotometer as it suffices for its purpose.

Electric conductivity (EC) measurement is also a very popular fashion for gathering continuous measured soil information. Some of the large number of example is reported hereby.

According to Smith (2001) the electrical conductivity mapping distinguish between different levels of soil compaction.

McCormic et al. (2003) carried out an investigation in connection with soil electrical conductivity (EC) in case of grasslands in Ireland. They observed that EC was predominantly moderately and negatively correlated ($r^2 = 0.54$) with sward N offtake and weakly with soil P and Mg content. It was also pointed out, that almost 40% of the heterogeneity in soil EC was caused by the differences in soil moisture variation. According to this fact the authors guess EC to have a potential for mapping areas with risk of drainage or drought problems.

Results published by Lund et al. (1999) show in part similar picture as the correlation of soil EC and yield has a high potential first of all when yields are influenced by water-holding capacity.

However, be it remembered, that by means of the EC measurement a summarized habit of several different soil factors (e.g. soil profile; bulk density; soil structure; water potential, water content; clay-, organic matter, mineral matter content; stone content and salinity) is reflected. Consequently, to be able to achieve a prediction of any of these properties with adequate accuracy, other attributes also have to be measured. However, continuous measurement of parameters such as soil profile, bulk density, stone content or even water content is problematic or even impossible in the practice yet.

Frogbrook et al. (2003) state based on their examination that the strength of the relation among the soil electrical conductivity (EC_a) and soil properties such as clay and water content seems complex; consequently EC_a mapping is not a substitute for sampling the soil.

2.5. Investigations with optical device based system

The gained spectral or rather optical information describing the vegetation serves more purposes: it is used for weed (e.g. Hemming and Rath, 2001; Oberti, 2002), plant diseases or perhaps for pest monitoring. Beside the possible saving of applied chemicals and consequently achievable cost reduction the main task is to ensure the healthy food production. Healthy food without natural (under dosing) and artificial (overdosing) toxins.

According to Hummel and Stoller (2002) the herbicide application reach the 12,600 t (2.8 kg/ha) in case of maize, and the 4500 t (1.1 kg/ha) in case of soybean in Illinois alone. These numbers reflect the importance of site-specific weed control. Corresponding to the authors the use of the under-hood sensor-controlled application technology can result in significant savings (up to 80%) in the amount of glyphosate used to control weeds in corn and soybeans in the upper US Cornbelt.

Results reported by Secher (1997) suggested that significant increases in yield of winter cereal crop could be achieved by distributing the dose of fungicide in relation to crop canopy characteristics as measured using boom mounted radiometers. Miller et al. (2000) describe a system, which has the capability of matching the delivered dose of any chemical to the leaf area of the crop canopy to be treated. These conclusions were not supported by Bjerre (1999) with an indication that penetration of spray into areas of high foliage density may have been limiting factor in the work.

Jurado-Expósito et al. (2003) expressed, site-specific weed management is recommended only in case of patched weed distribution. In our opinion the limiting factors are in this concern the resolution of the sensing and the application.

Gerhards and his co-authors (1999) carried out a four-year study on site-specific weed control. In its frame, the weed seedling distribution was mapped manually within a 5.1 ha field with a crop rotation of maize, sugar beets, winter wheat and winter barley. The treatment plans were worked out based on the collected information and the variable rate application took part by means of a patch sprayer with a 15 m boom divided into 5 sections. According to the authors, in case of winter wheat the 72% of the area was infested, and the herbicide use managed to be reduced almost 70%. In case of maize and sugar beets 52% of the area required the full dose of herbicide and 48% received only the half rate.

Danish researchers carried out field-level site-specific weed management experiments using patch spraying. Weeds were manually counted in a regular 20 m x 20 m grid in two spring barley fields. The Decision Algorithm for Patch Spraying (DAPS) was used to calculate the potential yield loss using weed density and the species competitiveness and than to define the optimal herbicide doses. The results show 62% and 47% reduction in herbicide use in the two fields, respectively. There are announcements in the article, which are entirely coinciding with our thinking. According to these, it can be assumed that crop competitiveness is related to crop yield so previous yield maps may be taken into account during this kind of decision-making. And, they also write about the problem of interpolation among grid points so again, the lack of continuous (automatic) weed identification (Heisel et al. 1999).

In case of weed detection some typical trends can be observed. These methods can be separated basically as spectral characterisation and shape or texture analysis. And a distinction can also be made corresponding to the place of detection, namely local and remote sensing. Earl et al. (2000) provide an evaluation of the achievable resolution of these sensing methods. Referring to the authors remote sensing systems based on satellite imagery are capable of cell size of 20-30 m whilst the same value is 1-0.15 m in case of airborne digital photography, and this resolution may be even much better using machine mounted systems. This difference determines at the same time the potential use of the given methods.

Weed control based on machine vision and spectroscopy is a very popular but complex research field with special limiting factors, thus more and more new experimental tool came in to light, but still there is a huge gap between research and the practice. Under field circumstances, cultivated plants and a wide variety of weeds are mixed present. Therefore, the first step must be the separation of plants and soil. In the most case it can be done with high confidence by means of the reflectance differences.

Jurado-Expósito and his collages (2003) used near infrared reflectance spectroscopy for weed identification in no-till sunflower field. They found that the spectral range from 750 to 950 nm is the most effective for the separation of weeds, sunflower and wheat stubble. The examinations were carried out in laboratory using small pieces of plant parts. The authors state that under field conditions factors such as phenologic state or spatial leaf structure may have effects on the spectral characteristic of the plants. We agree with this opinion, however in this concern the lighting condition and a possible surface humidity also have to be mentioned.

Nielsen and Henriksen (1996) carried out research on developing a method, which use both spectral and spatial information provided by the electromagnetic radiation reflected by crop and soil. The applied experimental system consists of two linear spectrometers (380-770, and 660-1000 nm), a controller unit and a portable computer. Based on their examinations the authors corroborate that due to the difference between the red and infrared reflectance the localization of green plants can be carried out. It is reported also that a significant difference in the reflectance characteristic of photosynthetically active plants and soil or defunct plant parts can be observed. These latter objects have reflectance with low linear increase with the wavelength, while in case of green plants exists an increase in reflectance with low value in the red wave band to an approximate value of 0.5 in the near infrared.

The Weed Seeker™ PhD600 (Patchen Inc.) VRA spraying system determine the chlorophyll content of the plant parts taken into account the reflected light of a LED (Light Emitting Dioda) in order to make distinction between weeds and field crops.

To dissociate the green part into weeds and cultivated plants the reflectance properties can be taken into account too, but in the most case other techniques are (also) required. Shape- and texture analysis is also known methods for this aim

The most shape analysis based system working with predetermined parameters, thus they can – theoretically – identify the weed species, which they have information about. But not any other. To increase the capability of these systems, there are efforts to employ spectral features together with shape- and texture analysis (Zhang and Chasaittapagon, 1995). Perez et al. (2000) also introduce a near-ground image capture and processing system using the colour information to distinguish the vegetation from the soil and shape analysis to discriminate the weeds. Based on this information the relative leaf area of the weeds is calculated.

As an advanced form of this method such experimental recognition system is also under development, which takes into consideration not only the characteristics of the leaves but also their relative spatial position (Manh et al., 2001). Hemming and Rath (2001) reported their system using statistical analysis and fuzzy logic. In the frame of the filed trial, the morphological and colour features were calculated for each single object to build a joint feature space. Using statistical analysis and fuzzy logic the accuracy of weed identification was between 51 and 95%, according to the circumstances. This level of reliability is remarkable, however, it is to notice that the image processing take part off-line, consequently the prompt real-time weed control cannot be realised, in this case. According to the authors one of the most typical difficulty is separating and allocating single plants in plant stands where the plants are together.

An on-line weed monitoring and VRA system was developed by the California University for tomato and cotton. The distinction is based on shape analysis taking into account among others the leaf area, the ratio of the leaf diagonals, the length and curvature of the leaf edge. Despite the average time demand of the image processing is about 0.34 s the reachable working speed is 1.2 km/h as the scanned area is only 11.43 x 10.16 cm. (Lee et al., 1999).

Pomar and Hidalgo (1998) write about the importance of early weed detection. In their opinion the seedling stage is the most appropriate time for this task. The reasons are that there is no significant yield loss caused by the seedlings and that weeds are more sensitive for herbicides in early growing stages. The authors describe a weed identification tool, which consists of an image approximation key, an intelligent identification aid, a navigation multimedia system and a plant database. The image approximation key consists of a “set of different abstraction level images and their logic sequence.” The identification process moves on from the poor to the best resolution images, till the weed is identified by means of a so-called “matrix of analogies”. By means of the plant (weed) database and the multimedia navigation part, the system functions as a “semi-automatic botanic book”. The device requires the user’s co-operation during the identification to select which parameters are to be taken into account. Consequently, this tool is not feasible for on-line VRA application, and its operation speed may be the bar even of the off-line application. In our opinion, it is not the image but the information of weed presence what is required for the practice. In other words, the user does not have to see – or even to know anything about – the weed species are occur at the field in the agricultural practice. In the future, the farmer has to drive trough the field and an autonomous system identifies the weeds and applies the proper mechanical or chemical treatment. However, the friendly-to-use surface and the accuracy (85.7%) of the mentioned device are remarkable. Finally, the authors have some relevant remarks concerning to the difficulties of weed monitoring using predetermined datasets. On one side, the reliability of discrimination depends on the key designer's ability and experience. On the other hand, modification or extension of the data set may be a heavy job because of the dependent relationship of given parameters.

However much pointing ahead these systems in many cases the low working speed and consequently poor efficiency restrain the real field application. This goes among others for the robotic weed control system elaborated by Slaughter et al. (2000) too, which has the capability of on-line operation at a speed of only 1 m/s.

S⌀rensen et al. (2002) report an autonomous DGPS navigated vehicle for weed inspection. The authors analyse the advantages and disadvantages of both on-line and off-line solutions. In this case, the off-line method was favoured in contrast to the on-line one, which was blamed on being extensive because of the big number of cameras and image processing units. The possibility of using algorithms requiring "heavy and time-consuming computations" is declared a further advantage of the off-line system. Despite the described device does not use on-line image processing an operating speed of only 1 m/s was achieved. Taking into consideration the complexity of the reviewed system and its hardware and software parts (computers, internet, phone interfaces and modems, LAN, MatLab etc.) the promised inexpensive operation is questionable. And again, the question arises whether can this technology under practical circumstances be realized. As a normal operation, not a continuous measurement is applied, but a predetermined grid is followed. In our opinion it may decrease the accuracy of the weed mapping since among the measured values only estimated ones are available and even, the contiguous mapping should be applied when possible.

For reaching a satisfactory on-line operating speed, a sufficiently powerful computer system is requested (Philipp and Rath, 2002). In many cases controlled lighting conditions are also required to eliminate the effect of the varying ambient illumination.

Problems may arise from the overlapping of certain plant parts (Hemming and Rath, 2001) and from their movement too; or even from the limited view angle of the applied optical devices (Mesterházi et al., 2003/a.).

The efficiency of the map based variable rate pesticide application can be limited because of the mobility of given pests. Nevertheless, it seems to be a promising solution in case of soil-based pest, such as potato cyst nematodes, where the information is gathered by means of soil sampling (Evans et al., 2000).

Despite the intensive research and new experimental results, several experts are sceptic corresponding to the practical application of this technology.

We can agree with Gerhards et al. (1999) that sampling and mapping of weed seedling distribution in the field is very time consuming. In the same time, it reflects the complexity of the automatic weed detection, that they statement is basically still up-to-date, that: “So far, real-time sensors do not allow a clear discrimination between weeds and crops and digital image analysis systems are not fast enough to identify plant species in real-time”.

Referring to Manh et al. (2001) in spite of using more and more sophisticated systems taking into account more and more parameters weed identification still remains difficult. According to the authors, the complexity of the real field conditions and the morphological variability of the plants are mainly to be blamed for it.

A very consonant viewpoint is expressed in Feyaerts and van Gool (2001) as well; they also state that the techniques based on shape and texture analysis are currently too slow to be implemented in a real-time evaluation system, due to the mathematical complexity to characterize and recognize the plants.

Miller et al. (2000) take also a similar viewpoint mentioning that the complexity of images and the computing power needed for weed/crop discrimination means that any such systems are currently a long way from commercial development.

Similarly, Auernhammer (2001) expounds in connection with precision plant protection applications that both map and sensor based approaches have been put to very limited use. The author states that one of the major limiting factors is still the extensive computation requirement for on-line application.

Godwin and Miller (2003) also believe that the automated weed monitoring systems based on either spectral reflectance characteristics and/or image analysis methods will not be available for the agricultural practice within the foreseeable future.

What can be the solution than? A compromise or a breakthrough is required. As a compromise, devices, which discriminate only the soil and plant parts, may be fast enough for the practice. The provided information may be considered less valuable, however it is still adequate for weed control between the rows or for stubble analysis. The principle of recognition may also be altered – it is probable the field crop(s), which is to be identified and everything else should be handled as weed. Particular solution should be needed only in case of weed species requiring specific (herbicide) treatment.

The remarkable alternative approach reflected by Nordmeyer and Dunker (1999) joins to this way of thinking. The German researchers examined the correlation between soil structure, soil pH, organic carbon-, total nitrogen-, P_2O_5-, K_2O-, Mg content and the occurrence of different weed species. According to the authors *Alopecurus mysoroides Huds.* and *Viola arvensis Murr.* showed positive correlation with the Mg content of the soil. The presence of *Poa annua L.* is possible beside lower Mg, K_2O, total N, organic C and clay content. However, in case of e.g. *Bromus sterilis L.* no correlation was found. However, the main benefit of such solutions is that a reliable prediction of the weed or even pest presence would be available.

The other possibility is to break through the limiting factors such as the slow operation and low efficiency. This development may – theoretically – be achieved by speeding up the recognition process and/or by enlarging the observation area. Unfortunately, the speed increase has been proved to be unaccomplished yet.

The other way is to use special optical devices in order to enlarge the scanning area of the system. A possible solution is described by Klotz et al. (2003) where a ground-operated visible and near infrared (NIR) imaging spectrometer is applied to collect information about the condition of the vegetation. To eliminate the problem of limited view angle of the optical devices, a fibre-optic system consists of 16 lenses is applied. The light collected by the fibres enters into a spectrograph, which projects it on the CCD of a camera. In this way, the recorded image consists of 16 hyperspectral stripes from the operation width of 12 m. The spatial resolution of the system is 0.9 m per lens, while the optical resolution is about 8 nm. For the accurate calculation of the reflected light, the knowledge of the incoming radiation is essential; therefore a so-called reference panel (grey-coated, matt-finished aluminium with known reflectance properties) is installed. During the data processing vegetation indexes, such as NDVI (Normalised Differential Vegetation Index), CAI (Clorophyll Absorption Integral), REIP (Red Age Inflection Point) and OSAVI (Optimised Soil-adjusted Vegetation Index) were calculated. The system was tested in sugar beet, under field circumstances. The authors found, that the CAI showed strong relation ($r^2 = 0.89$) with the Yield, whereas in case of the OSAVI and REIP it was significant lower (0.47 and 0. 57, respectively).

2.6. Data transfer among precision farming systems

Söderström (1999) describes a conceptual model of a precision farming support database and web GIS application. The author emphasises among others the need of user friendly surface.

Nissen and Söderström (1999) compare the yield monitoring systems are applied in Sweden (Massey-Fergusson, LH-Agro, Claas and RDS). They state that all these yield monitors record the position and yield data, however, the registration procedures differ. Our experiences conform to this (Neményi et al. 2002; Mesterházi et al. 2002/a and b).

File and data formats have been standardized in ISO 11787 (referred to as ‘ADIS’ – Agricultural Data Interchange Standard) and are in use by some manufacturers (Stafford, 2000). By the way, in many cases the problem of incompatibility still exists.

Auernhammer (2001) also evaluates the state of the standardisation process. The author notes that LBS (Landwirtschaftliches BUS-System) functions as a basis for the ISO 11783 standardisation process. It is also stated that with identical physical components and data structure as well as an identically structured virtual terminal, software updates from LBS to ISO cause few problems. However it is emphasised that there are no uniform electronic communication systems available for agricultural application at the present. Significant problems still exist regarding to the implementation, which for the lack of know-how of the manufacturers and the different possible interpretation of the standards are blamed.

During our investigations we faced with several incompatibility problems. It is an essential requirement to solve these problems in order to the spreading of this technology, and to its perfect integration into the agricultural practice (Mesterházi et al., 2002/a).

The comparison of the Agrocom ACT and RDS systems is carried out by Mesterházi et al. (2002/a and b) and Maniak (2001; 2003 and 2004). The authors introduce a procedure to transfer the yield data between the examined systems providing a wider range of possibility for data analysis and visualisation.

The work out of a so–called GIS Exchange Format is reported by Maniak (2002/a). Publications mention the application of data transformation modules supporting several file formats involving the GIS Exchange Format. (Maniak 2002/a and b; Mesterházi et al.,2003/a and b).

2.7. Investigations in connection with machine guidance

The demand of automatic vehicle steering dates back many years. Russian literature from 1959 presents a detailed study of this subject. The authors discuss several methods.

Navigation following the furrow. A mechanical or electro-pneumatic device ensures the copying of the direction of the furrow created in the previous run.

Electric or electro-mechanic control system. The system consists of a central unit positioned in the middle point of the field, the control unit of the steering system of the tractor and a connecting cable (Fig. 2.7.1.). The vehicle drives around the central unit. According to the authors human intervention is required only during the set up of the central unit and to cultivate the corners and the middle of the field.

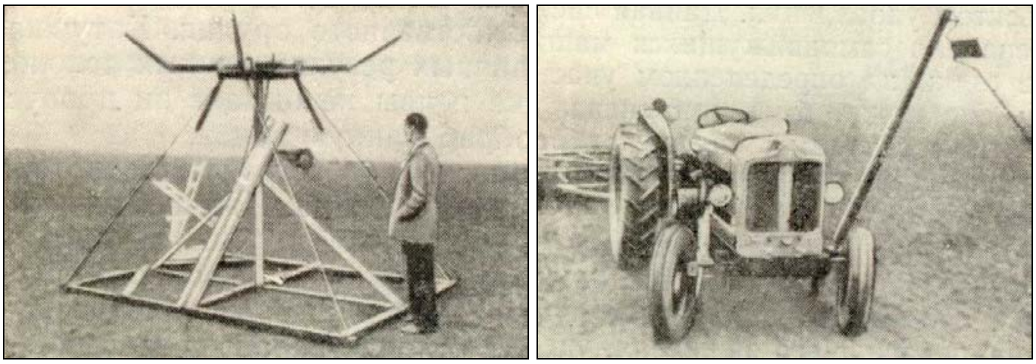


Figure 2.7.1. Central electro-mechanic steering of a tractor
(Rusilov and Popov, 1959)

Electromagnetic vehicle guidance (Fig. 2.7.2.). In this case the tractor is guided along with a wire laid down under the soil surface. Electric current is inducted in the coins mounted in the two sides of the sensor head. The currents of the two sides are in balance when the wire is exactly in the middle of the sensor head.

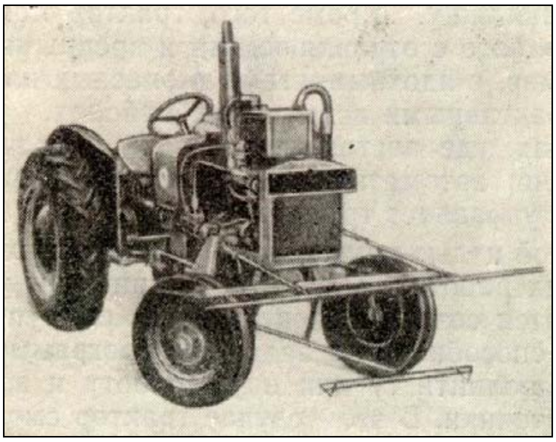


Figure 2.7.2. Electromagnetic vehicle guidance (Rusilov and Popov, 1959)

Because of the need of implanted wires this method in its published form does not have reason for the existence.

Using photo-electric guidance the guideline may be the edge of the harvested plant stand. This borderline is detected by two couples of light-source and photocell one of them which is directed to the harvested part and the other to the non-harvested one. Navigation following visible or infrared light is also reported.

Guidance using high-frequency positioning and based on pre-programmed rout planning also published by the authors (Rusilov and Popov, 1959). These ideas are indeed noteworthy even taking into account that the above-mentioned infrared light-based navigation was traced back to 1944! Some of the cited ideas or similar ones are (re)appear in the latest developments as well.

Earl et al. (2000) believed that "two issues of increasing importance in agriculture are the targeted approach to managing field operations, or precision farming, and the development of automated guidance systems."

According to the opinion of Earl et al. (2000), to realize any autonomous field operation, the following steps are required to be accomplished:

- asset survey: mapping of permanent spatial attributes of the field (e.g. filed boundaries, topography, trees, ditches);
- monitoring of transient data: attributes of a field, which change during the growing season (e.g. soil and crop status, incidence of pests and diseases);
- mapping and interpretation of individual transient data sets;
- combination of different transient data sets – in order to study the temporal stability of the spatial patterns;
- creation of field operation map.

Reid et al. (2000) gives a very comprehensive study regarding to the agricultural automatic steering studies in North America.

Bell (2000) applied Carrier-Phase Differential GPS for automatic steering of agricultural machines resulting an uncertainty up to 4 cm. The GPS positioning system used in this research measured the position of one of the tractor's GPS antennas *relative* to a fixed reference station antenna. The *absolute* position of the tractor could be measured only if the absolute position of the reference station antenna was known. The author concluded that accurate position information is not the only key factor regarding to the guidance accuracy. Nevertheless, the occurrence of commercial automatic tractor control is declared only a matter of time.

An autonomous machine guidance system based on predetermined guidelines was reviewed by Stoll (2000). The rout was planned using the DGPS coordinates of a previously recorded application. The guidance of a forage harvester was carried out using DGPS navigation coordinating the hydraulic steering. The deviation from the planned direction was within 10 cm beside an operation speed of 0.9-2 m/s. This result is remarkable and the achieved accuracy can be considered to be sufficient for the mentioned purpose.

S⌀rensen et al. (2002) also report an autonomous DGPS navigated vehicle for weed inspection.

In the frame of the examination was carried out by Schwenke and Auernhammer (1999) commercially available microwave velocity sensors were applied for eliminating the positioning problems caused by shading, signal refraction and reflection, etc. The idea was to ensure an accuracy of 1 m by measuring the forward speed from a known GPS coordinate. It was made appear that the signals of microwave sensors were continuous and free of such errors, which were present in the DGPS signal. Nevertheless, the cross sensitivity of the sensors caused accuracy problems. Our experiences show that by now the positioning have been made more reliable. The lack of differential signal may still occur, however, as we mentioned before by means of the information stored in the almanac of the DGPS receiver the positioning keeps accurate. Regarding to the display of on our receiver (CSI-Wireless DGPS MAX) the typical horizontal error is about 0.2-0.3 m in real time kinematical mode. In our opinion, this level of accuracy must be enough for yield monitoring and for most of VRA in the practice. However, this kind of solutions may be important in case of actions which require more precise positioning e.g. variable rate seeding, DGPS aided mechanical plant protection or automatic machine guidance.

During our research activity we also faced with a problem of the positioning system, however it differs from the above-mentioned ones. During precision fertilizer distribution two rounds followed each other with 5-6 hours difference. In order to achieve the most possible accurate treatment, the RDS Marker Guide (with CSI Wireless, DGPS Max sub meter accurate receiver) was applied to provide directional guidance. Following the displayed guidelines an approximately 1.5 m constant dislocation was observed according to the previous run. The examination carried out is detailed in Chapters 3.7 and 4.7.

Exactly because of the possible inadequate accuracy of the positioning it seems obvious to use the plant rows as guidelines. Such solution is reported by Toda et al. (1999) where sonar based crop row mapping and fuzzy logic steering control was applied. This kind of approach has economic benefit as well since it can be realised without the extra cost of positioning with cm accuracy.

A method for determination of crop rows using machine vision was presented also by S∅gaard and Olsen (2000) and similar research was carried out by Láng and Molnár (2000) as well.

As the presented literature review reflected intensive, wide-ranging research work are present in many fields of PF. According to this activity promising results are published all over the world. Nevertheless, in many concerns there are still open questions, further problems to solve. Let some citation stay here as closing statements, which reflect perfectly our point of view.

The so-called fleet management mentioned by Auernhammer (2001) draw the intention to the rationalisation of the whole precision farming circle. Making e.g. the field traffic more reasonable may help avoid soil compaction; consequently a higher yield is achievable without the demand and cost of loosening. In case of a plant stand growing under (near) ideal conditions involving soil status a lower cost of plant protection can also be expected. In our opinion, this kind of approach may provide more additional economic and ecological benefit without extra cost comparing to the advantage can be achieved by significant investment on e.g. optical based weed monitoring systems (with respect to their present capability). The author warns at the same time of the risk of “l’art pour l’art” development: “With the integration of information technology, precision farming requires more and more comprehensive technology, which, while performing better, is also more cost-intensive. However, potential savings are relatively small if operations are already running close to optimal capacity without the technology. … Additional costs, therefore, may only be recovered by new management options and reduced environmental impacts, resulting from higher quality information.”

And finally, it should be remembered during every engineering development that “despite all the engineering and technological development the substantial determinants are the living organisms” (Dudits, 2001), as both the subject and the environment of the agricultural production is a living biological system.

3. MATERIALS AND METHODS

The investigations in connection with precision farming were carried out in two study sites. Both research fields are situated in the area of Mosonmagyaróvár, in the North-Western part of Hungary. The majority of the investigations took part in the field No. 80-1, which is a 15.3 ha part (green) of a 23.9 ha field (blue) (Fig. 3.1.). The field belongs to the study farm of the University of West-Hungary, Faculty of Agricultural and Food Sciences. The direction of the cultivation is parallel to the shorter side of the field. For detailed information about the soil chemical parameters, the phases of the cultivation and the grown plants see Appendix 2-4.

Figure 3.1. Experimental field no. 80/1 Mosonmagyaróvár

The other site is an experimental plot of 1 ha belonging to the Institute of Agricultural, Food and Environmental Engineering. The area was a fallow with a (natural) heterogeneous coverage of weeds, which are parts of the typical field flora and used for practical education of tillage. Thus, the soil was frequently cultivated with plough, hoe and disc harrow. Therefore, a significant soil compaction would have been assumed. The soil surface was also heterogeneous, the clod size varied from 0.5 to 10 cm. This area was the primary study field for the soil compaction- and weed monitoring systems.

3.1. Soil sampling

Site-specific soil sampling was carried out on a 50 x 50 m grid dividing the 15.3 ha field into 63 management units with an average size of 0.25 ha. Nonetheless, according to the local conditions the grid shows irregularity in given sections (Fig. 3.1.1.).

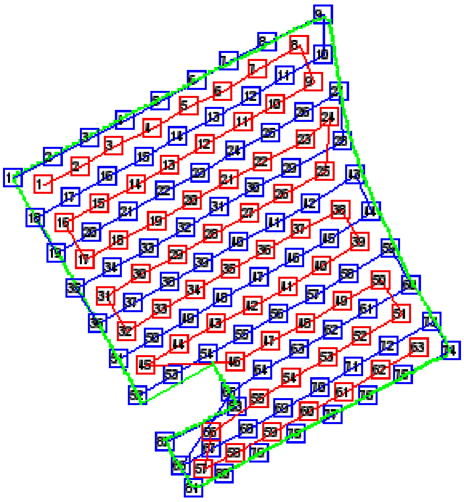


Figure 3.1.1. The soil sampling grid (blue) and the number of management units (red)

The sampling plan was created by Agrocom Agromap Basic 4.2. However, the mentioned planning application provides the possibility of creating grid sampling plan, it is impossible to turn the management grid. In other words, the grid cannot be made parallel to the borderline of the field. To solve this problem, the plan showed in Figure 3.1. was made as point sampling. To find and mark out the node points the Agrocom Soil software running on the ACT unit (Agrocom Computer Terminal) was employed. Directional guidance with sub-meter accuracy was provided its built-in DGPS receiver and an external antenna.

Sampling took part in November 2001. Samples were taken manually by means of a hand probe at each 5-6 m along the diagonals of each cell in a depth of 25 cm. Samples were than bulked and analysed according to the input requirements of the applied fertilizer advisory system. The laboratory methods used conform the concerning directives (TVG, 1978; Gerei, 1978; Koplonyi, 1962; Buzás, 1988; and Buzás, 1993).

The sampling method and distribution was chosen in co-operation with Dr. Péter Csathó, a researcher of the Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences (RISSAC-HAS). The defined soil characteristics were mapped by the Agromap Basic 4.2. For a more equable distribution 4 reference points were marked out in each of the 63 treatment units (Fig. 3.1.2.), expect for number 24, 57, 58, 59 where only two and number 56 where three were applied according to their different shape.

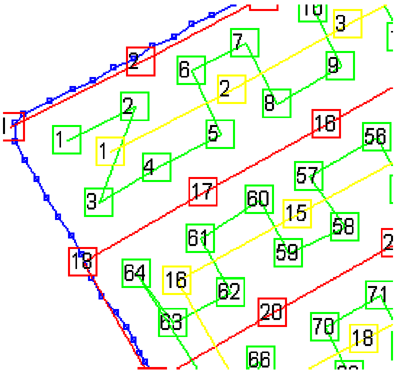


Figure 3.1.2. The reference points (green) in the treatment zones

3.2. Yield monitoring

Yield monitoring was conducted yearly from 2001 after some test runs in other fields. The harvested plants were maize (2001 and 2002) and spring barley in 2003. The employed system was the Agrocom ACT installed on a Deutz Fahr M 35.80 combine harvester.

3.2.1. The build up of the applied yield monitoring system

Ceres opto-electronic volumetric yield sensor

The sensor is equipped in the elevator (Fig. 3.2.1.1.). The emitted light signal is interrupted by the elevator elements. The period of interruption is in ratio with the yield.

Continuous grain moisture content sensor

The operation of the sensor mounted in the exit of the clear grain auger is based on the principle of conductivity (Figure 3.2.1.1.).

Figure 3.2 1.1. Yield and grain moisture sensors built in the harvester

Speedometer

Magnetic speed sensor installed in the front shaft of the harvester (Fig. 3.2.1.2.). The sensor provides electric signal in the ratio to the impulses indicated by the magnet situated in a distance of 3-5 mm from the sensor. This device provides a simple and robust way of speed measurement, however slip may influence its accuracy.

Inclinometer

The inclinometer is situated in the front axle housing in the centre line of the harvester (Fig. 3.2.1.2.). A pendulum in high viscosity oil deviates according to the rake and a potentiometer installed on the shaft of the pendulum provides electric signal in the ratio to the degree of incline.

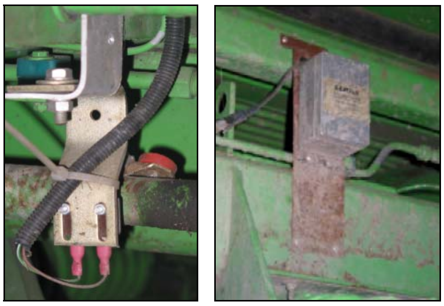


Figure 3.2.1.2. The speedometer and the inclinometer

LEM module

LEM module is an electric unit, which combines the signals of the above-mentioned sensors. Its signal is passed on to the ACT unit (Fig. 3.2.1.3.)

Cutter bar positioning sensor

A simple electric switch is mounted in the bottom of the cabin and connected to the cutter bar with a chain (Fig. 3.2.1.3.). Lifting up the cutter bar the switch stops the data logging. Its importance appears at the turns in the end of the rounds. The chain makes the switching height adjustable.

Figure 3.2.1.3. The LEM module and the cutter bar positioning sensor

ACT unit (Agrocom Computer Terminal)

The ACT unit is a board computer with built-in DGPS receiver, which is used for soil sampling, area measurement, yield monitoring, and VRA (Variable Rate Application) e.g. nutrient replenishment. A DOS and given application software are installed. In case of yield monitoring the Agrocom Mega program is to run. The yield monitoring process can be followed in the colour monitor: the actual speed, yield, grain moisture, cutting width and the summarised yield and harvested area are displayed. The setup and the calibration of the system can also be done through the ACT. Since there is no cutting width measuring sensor belongs to the system, it has to be adjusted manually with the switch of the ACT. Due to its socket the ACT can easily be removed and placed to other machine. The accuracy of its DGPS receiver is better than 1 m. The position information received at each 2nd seconds is recorded together with the signals of the sensors to a standard PCIMCIA card.

DGPS antenna

A common DGPS antenna mounted at the top of the harvester's cab in the centreline was connected to the ACT unit.

<u>3.2.2. The set-up and calibration of the yield monitoring system</u>

The set up of the yield monitoring system was carried out is presented in Appendix 13.

3.3. Site-specific nutrient replenishment system

Fertilizer spreading was conducted with the Agrocom ACT system jointly with the Amazone ZA-M Max Tronic disc spreader.

<u>3.3.1. Description of the system applied for nutrient replenishment</u>

Speedometer

Similarly to yield monitoring, the covered area is defined by the working width and the forward movement. A magnetic speedometer is applied in this case as well; however the magnets are fixed in the screws of the rear tyre of the tractor. The sensor is situated in a distance of 2-4 mm (Fig. 3.3.1.1).

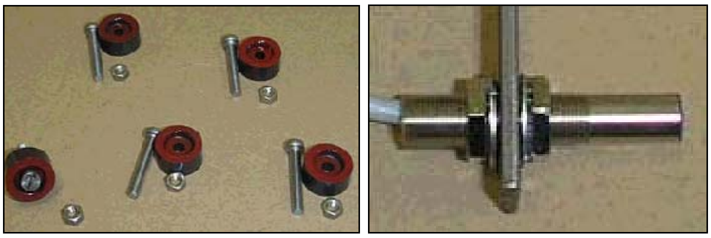


Figure 3.3.1.1. The magnets and the sensor of the speedometer

Rev sensor of the PTO

During the spreading the revolution of the PTO should be 540 1/min in order to achieve the desired working width. If the actual rpm differs more than 10% the driver is warned. This sensor is also a magnetic (inductive) one (Fig. 3.3.1.2.). The magnets are mounted in the plastic ring, which is fixed on the shaft.

LBS unit (central communication unit)

The signals from the above mentioned sensors are forwarded through the LBS unit (Fig. 3.3.1.2.) towards the ACT unit. The ACT sends the orders to the actuator in this way as well.

LBS connector

The LBS connector (Fig. 3.3.1.2.) provides the connection between the LBS unit and the job computer mounted on the disc spreader. The LBS connector designed in accordance with the LBS standard.

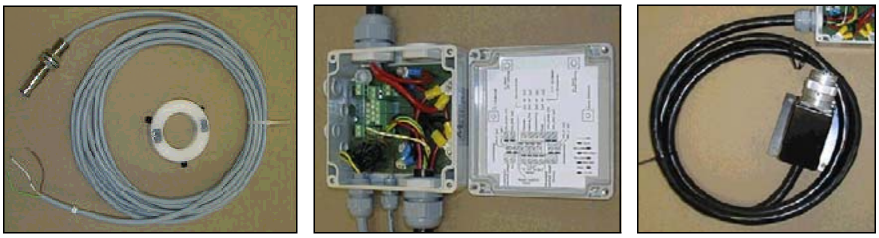


Figure 3.3.1.2. The rev sensor of the PTO, the LBS unit and the LBS connector

Job computer

The job computer is installed on the disc spreader. This part receives the commands of the ACT through the LBS and LBS connector and directs the electrical double shutter system of the spreader (Fig. 3.3.1.3.). A sensor sends information about the status of the shutters as well through the LBS connector towards the ACT.

Figure 3.3.1.3. The job computer and the electric double shutter system on the disc spreader

ACT unit

The ACT receives the position information and the signals of the sensors and reads the actual value of the given application plan from the PCMCIA card. Then, the momentary applied and the required values are compared and an order is sent to the job computer via the LBS in case of need. (The ACT has the capability of control any application according to the RS 232 protocol as well, but in our case the LBS was applied.)

For site-specific application two programs should be installed on the ACT. The advanced set up of the system may be accomplished in the SMGR. In that menu the type of the sensors were defined and calibrated. The ZUG_AM is the control software of the VRA. It was applied for the calibration of the quantity regulation as well (Appendix 13.).

During the fertiliser spreading the application plan is reflected together with the actual position, fertiliser amount and speed and the rev of the PTO (Fig. 3.3.1.4.). The driver is warned in case of low PTO rev (deviation of more than 10%) or lack of differential signal. By means of the information provided by the sensor controls the state of the shutter system the distributed amount can also be mapped. It is however also volumetric measurement and its accuracy depends also on the calibration. This function makes possible the warning in case of low fertiliser level.

Figure 3.3.1.4. The Zug_AM menu on the ACT

RDS Marker Guide System

Since the Agrocom ACT system provides guidance only in AgroSoil menu (for soil sampling) for VRA it had to be completed with the RDS Marker Guide instrument. This tool provides directional guidance along strait line by means of DGPS navigation, and warns driving in areas, which has already been treated or are out of the borderline. Parts of the system:

- navigation module;
- CSI Wireless DGPS-Max DGPS receiver with sub meter accuracy;
- DGPS antenna and cable;
- navigation screen and user surface (Fig 3.3.1.6.);
- mounting frame.

Driving around the field, the navigation module recorded the borderline. After setting the working width the guideline to follow during fertilising was marked out. In order the accuracy, the starting and end points of the first line were pointed out in the AgroSoil as sample points, thus the ACT provided navigation while marking out the guide line in the Marker Guide. The navigation started after driving approximately 25 m. Loading the fertilizer order into the ZUG_AM menu of the ACT the distribution started. The sensitivity of the system is adjustable. In our case the finest regulation was applied – over a deviation of 0.1 m the driver was warned. In normal operation mode the distance from the guideline (Fig. 3.3.1.5.), in the turns the distance from the next row was displayed. Crossing the borderline a massage was displayed to close the shutters to stop the distribution as the actual position is out of the field.

Figure 3.3.1.5. The RDS Marker Guide System

3.3.2. The planning of the nutrient replenishments

Site-specific fertiliser spreading took part according to Table 3.3.2.1.

Table 3.3.2.1. The schedule of site-specific nutrient replenishments

	dat	**agent**
Spring 2002	04 April	N 34%
		K60%
Autumn 2002	04 November	K 60%
		P 18%
Autumn 2003	10 September	K 60%
		P 26%

In the basis of the soil analysis results and the measured yields the required amounts of fertilisers were determined for each treatment units using the Fertiliser Advisory Model of the Research Institute for Soil Science and Agricultural Chemistry and the Research Institute for Agronomy of the Hungarian Academy of Sciences (RISAC-HAS and RIA-HAS). (See description of the model under Chapter 3.3.3.). Two different methods were applied for generating plans (orders) using the determined values. In 2002 (spring and autumn) the planned values were joined with the proper co-ordinates, and a so-called interpolated "base map for planning" was generated with the AgroMap Basic 4.2 software. For the proper distribution the same reference point system was applied as in case of soil property mapping (Fig. 3.1.2.). An example of these planning base maps is shown in Fig. 3.3.2.2.

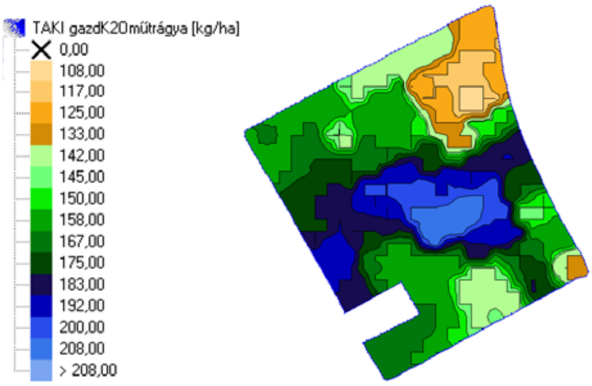


Figure 3.3.2.2. K_2O fertilizer planning base map 2002 spring

Since the fertilizer distribution system handles only raster maps, the real application orders were created following the pattern of these interpolated maps. The fertiliser orders edited this way are presented below (Fig. 3.3.2.3. and 3.3.2.4.).

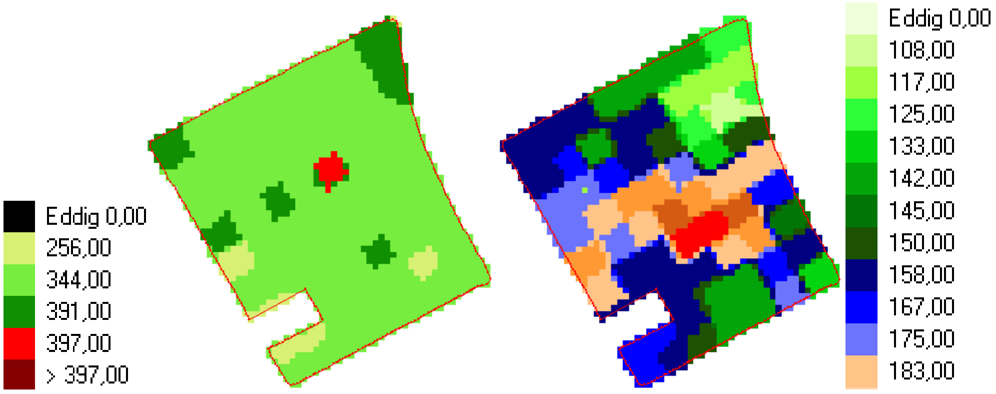
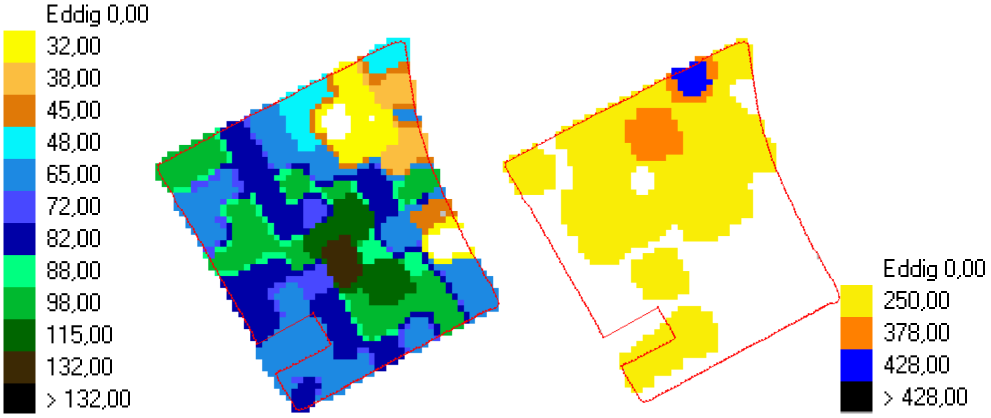
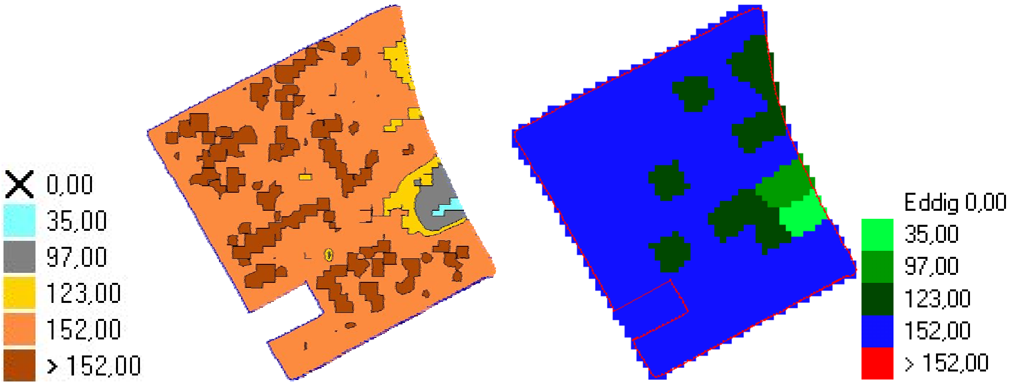


Figure 3.3.2.3. N and K_2O fertilizer application plan 2002 spring

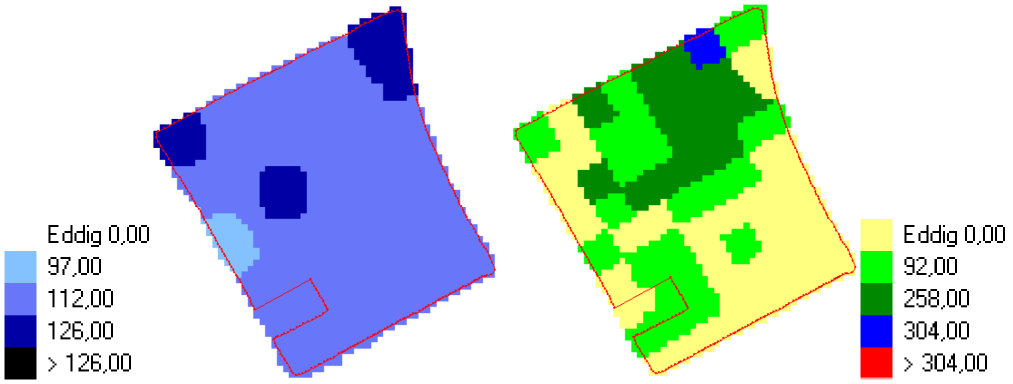


3.3.2.4. K_2O and P_2O_5 fertilizer application plan 2002 autumn

In case of the fertiliser plans in 2003 a different way of mapping was applied. The planned values were concerned to the proper management unit without interpolation unlike in the previous years. This change was required, because of the high level of heterogeneity was present on the interpolated map, which would have masked the real pattern of the application plan. An example of this phenomenon is shown in Figure 3.3.2.5.



3.3.2.5. Planning base map and the real fertilizer application plan of K_2O 2003



3.3.2.6. N and P_2O_5 fertilizer application plan 2003

Belonging data are in Appendix 5.

(The 0.5 ha recess near to the southern corner of the field was used as experimental area of another trial therefore was left out. As it was finished meantime, the whole field was fertilized later but the data from this area were left out of consideration during the trial.)

3.3.3. The applied fertilizer advisory system

The environmentally friendly fertilizer advisory system developed by the Research Institute for Soil Sciences and Agricultural Chemistry and the Research Institute for Agronomy of the Hungarian Academy of Sciences (RISSAC-HAS, RIA-HAS) was used to determine the required fertilizer amount in each management unit,

The basic philosophy of the model is the following:

- efforts for economic level;
- the aim is “plant nutrition” (do not accumulate store in the soil);
- to achieve and sustain moderate soil PK supply;

- slow soil PK build-up;
- PK fertilisation of the rotation;
- PK fertilisation only at moderate or poor soil supply levels;
- lower limit values for soil nutrient supply categories;
- lower specific crop nutrient contents;
- specific crop nutrient contents dependent of the planned yield level (because of the nutrient dilution-effect in crops).
- Mineral soil N-content is taken into consideration only in the case of the most important crops (Csathó et al., 1998).

3.4. Measurement of soil physical parameters

3.4.1. Site-specific penetrometer measurements

Cone penetrometer measurement is the most common method to get information about the soil compaction or about the force is required for the cultivation of the soil. As a first step, this method was applied to acquire site-specific information about the 1 ha experimental field belongs to the Institute. The applied instrument was a 3T (manual) vertical penetrometer whit DGPS navigation provided by the Agrocom ACT.

As sample density and distribution is always a crucial question in case of point measurements, the need of continuous measurement has appeared concerning to the soil physical parameters as well. An on-line draft measurement system was designed in order to obtain continuous information about the dynamic forces, which act on the surface of any cultivator.

3.4.2. Continuous soil draft measurement

The build up of the system is showed in Fig. 3.4.2.1.

Steyer 9078/A tractor

The Electro-Hydraulic System (EHS) of the tractor and the load cells are installed on it consist the fundament for the measurements. The cultivator tools were mounted in the rear three-point hitch of the tractor without any special mounting frame.

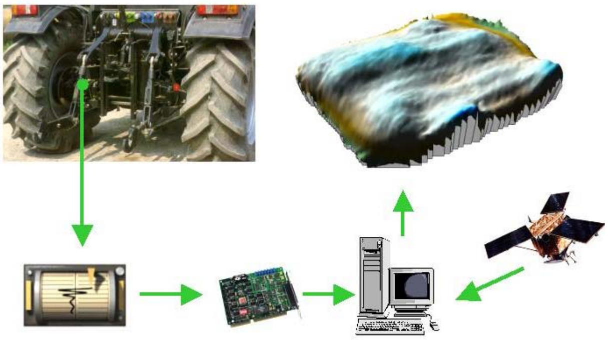


Figure 3.4.2.1. The scheme of the on-line soil draft measuring system

Load cells

The load cells are part of the EHR provide electrical signal pro rata the forces affect the hydraulic system. The characteristic of the load cells is showed in Fig. 3.4.2.2. According to this, dU=5 V in case of 2 x 40 kN, thus 1V change in the signal of the load cells means 16 kN.

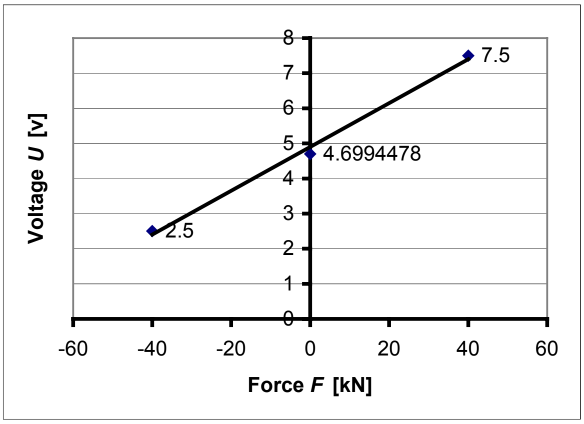


Figure 3.4.2.2. The characteristic of the load cells

In spite of the known factory characteristic of the load cells an evaluation measurement was executed. The hydraulic system was loaded with different forces exerted by a hydraulic lever was fixed on a stand. The inducted voltages of the internal load cells were measured by the on-line system using a data acquisition board and a portable computer described below. Simultaneously, the signal of an external load cell built in between the lever and the drawbar of the tractor was measured. Taking into account its calibrated parameter (50 kN = 1 mV/V) and the conditions of application (power supply10 V, amplification 92.9 x) the performance of the external load cell can be described as 92,9 mV= 50 kN. The measured characteristic of the internal load cells is represented in fig. 3.4.2.3. The found load cell signal vs. load relation is shown by Fig. 3.4.2.4.

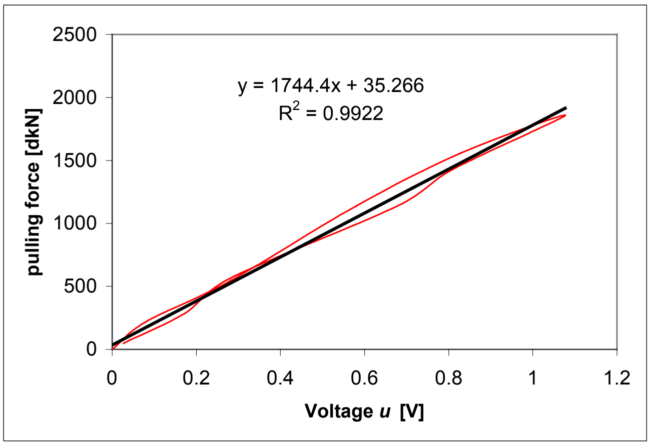


Figure 3.4.2.3. The measured characteristic of the load cells of the EHR

Using the equation displayed on Fig. 3.4.2.4. the electric signal can be transformed into force value.

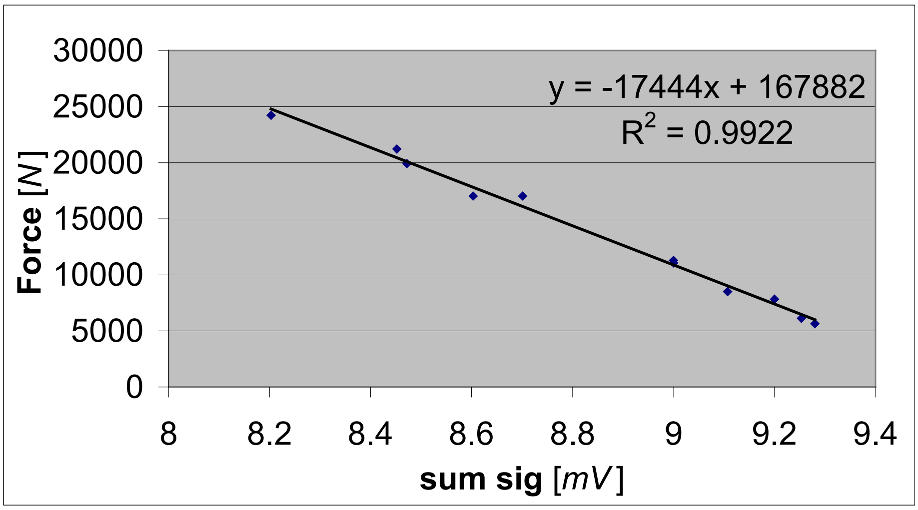


Figure 3.4.2.4. The summarised signal of the load cells corresponding to different loads

ICP DAS A-822 PGL data acquisition board

Analogue – digital I/O board. (For details see Appendix 12.)

KP5212TS field computer and capture software

A robust portable computer with 800 MHz CPU, 256 MB RAM and Windows NT 4 OS. Software developed by S. Maniak records the digitised summarised signals of the load cells and writes on the hard disk together with the position information. The file transformation module developed previously by the institute was also built into the data logger software; in this way the transformation of the recorded file was ensured into several formats (*.xls, *.txt, RDS and Agrocom ACT, etc.).

DGPS receiver

The capture application has the capability of receiving position information from both of the above-mentioned DGPS receivers using different message structures.

RDS Marker Guide

The RDS-made navigation instrument was applied in this case as well.

Cultivators

The applied tools were cultivator with eight tools and a single loosener in separate run, in a depth of 25 and 40 cm, respectively. Thanks to the time gap and building-up of the loosener the effect of the cultivator application to the second treatment can be considered to be negligible.

The investigations took part in a few steps. Measurements were carried out in the 1 ha experimental ("exercise") field in April 2003, with penetrometer and the on-line system using field cultivator or rather loosener in 40, 25 and 40 cm, respectively. The penetrometer measurement was done following a 20 x 20 m grid (Fig. 3.4.2.5.). Similar trials were done in the 15.3 ha field No. 80/1 in June 2003. The penetrometer-sampling plan is showed in Fig. 3.4.2.5. Twenty sampling points were distributed taking into account the pattern of the map generated from the continuous measurement. The plans were created by Agromap Basic.

Since data origin from two different measurement methods (point- vs. continuous measurement; vertical non-dynamic force vs. complex dynamic force) are to be compared the choice of the proper data is essential. For this purpose theoretically four methods were given: compare point data with point data, point data with interpolated data (and vice-versa) or two interpolated data sets with each other. Since penetrometer measurement was carried out as point measurement it seems evident to handle it in this way.

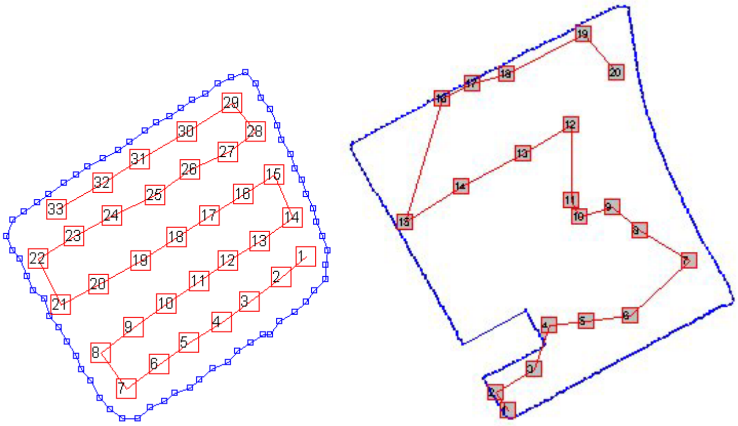


Figure 3.4.2.5. The penetrometer-sampling plan on the 1 ha experimental area and field No. 80/1

The on-line data set involves a large number of data, thus the choice of the exact value is elusive. Consequently, the average of a given area is required to be taken into account. To get these data an interpolated map should have been produced together with the borderlines of each treatment units in the Agromap Basic (Fig. 3.4.2.6.). (The average of an encircled area can be reported in the software.) The same method was applied to gain information about the average yield or the distributed fertiliser amount in the management units for statistical analysis as well.

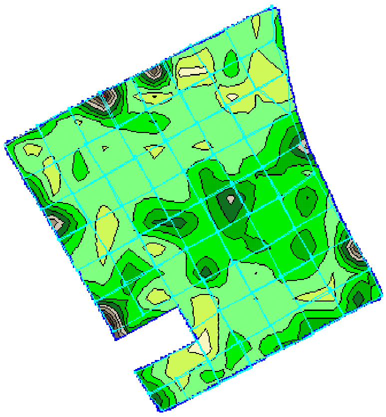


Figure 3.4.2.6. Interpolated map with the borderline of the treatment units for data reporting

3.5. Investigations with optical device based system

3.5.1. Weed monitoring

Investigations in the field of machine vision based weed monitoring started in 2002. As a result of this research an optical weed/plant monitoring system has been established. The build up of the system is the following.

CCD camera

A Hitachi KP-C550 CCD camera was applied as a primary device to capture colour (red, green, blue and NIR) images. The camera was mounted at a height of approximately 3.5 m on a holder fixed to the front three-point hitch of the tractor. The main features of the camera are detailed in Appendix 12.

Infrared camera

The system was completed with FLIR ThermaCAM PM 675 infrared camera to take the possible advantage of taking into consideration the information gained in infrared range. The thermal sensitivity of the camera is 0.1 °C. Further description can be found in Appendix 12. The evaluation of the recorded images was done by means of the Therma Cam Reporter 2000 software.

PCI Frame Grabber card

A “Hauppauge WinTV Go” capture card installed on the portable computer was applied for on-line image capturing. The card has the capability of capturing images or video in on-line mode. The resolution of the captured images was 721 x 584. During the capture process the RGB mode was applied.

KP5212TS field computer and capture software

The same computer used for draft measurement. Software developed by Maniak was used to record the captured images on the hard disk together with the position or even to process them on-line. Based on the analysis of captured images and their histograms an algorithm for weed density calculation was developed. Figure 3.5.1.1. shows an average histogram of 50 CCD images with two conspicuous minima at 127 and 169 in the histogram.

The weed density of a set of captured images were measured manually in order to find the optimal threshold for dividing ground from plants, The result of this reference measurement was compared with computer measurements by using all thresholds from 0 to 255 of all the three colour components (R, G, B). As expected, the best threshold for dividing weed from ground was discovered at 127. Each pixel in the blue colour component of the captured image is scanned and compared with the threshold. The ratio of the number of pixels that are lying under the threshold and the total number of pixels results in the weed density in percent.

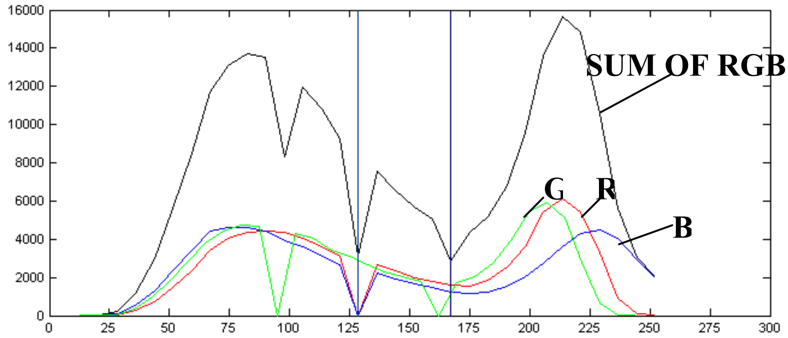


Figure 3.5.1.1. Average histogram of 50 CCD images (Mesterházi et al., 2003/c)

In case of the infrared camera the algorithm for weed recognition had to be altered because of the different input range. Here a threshold at 45 was used in the red colour component. (Maniak et al., 2003).

The software provides the opportunity of capturing images with adjustable regular time gap or in distance dependent way. In this latter case, the forward speed is calculated by means of the information provided by the DGPS signal. Knowing the scanning area of the applied optical device, the whole area can be covered without any skip or with a required overlapping in this way even in case of fluctuating operation speed.

DGPS receiver

The capture application has the capability of receiving position information from both of the above-mentioned DGPS receivers using different message structures.

Humanoid Machine Vision System (HMVS)

To break through the limitation caused by the limited view angle of the optical devices described above a special lens with a horizontal view angle of 360 degrees and a vertical view angle from –15 to 20 degrees was applied. (This lens system has developed by Prof. Dr. Pál Greguss, and is employed world-wide in several areas, from robotics to space research, among others by the NASA.) This imaging device, called Humanoid Machine Vision System (HMVS) consists of two main parts (Fig. 3.5.1.2): an imaging block such as the Panoramic Annular Lens (PAL) that renders omnidirectional panoramic view and a collector lens (Greguss, 2002). The PAL optic is a piece of glass that consists of a 360-degree circular aperture A1, a rear aperture A2 connecting to the collector lens, a top mirror S1 and a circular mirror S2 (Fig. 3.5.1.2.).

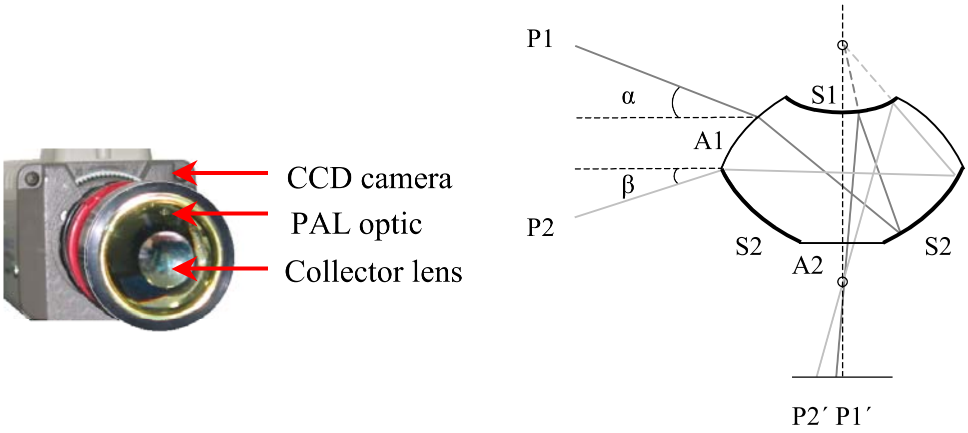


Figure 3.5.1.2. The Humanoid Machine Vision System (Maniak et al., 2003).

3.5.2. Pest monitoring

During the base measurement according to pest monitoring the infrared camera (FLIR ThermaCAM PM 675) and the software (Therma Cam Reporter 2000) belongs to that were applied. The investigation focused primary on virus and Colorado beetle (*Leptinotarsa decemlineata Say*) infection on potato (*Solanum tuberosum L.*). As this research is in initial phase, the infrared camera was applied without the hardware and software components including positioning described in Chapter 3.5.1. The captured images were stored in a flash memory card. The study field is situated in Kóny, about 40 km south from Mosonmagyaróvár, in the North-West part of Hungary.

The measurements took part in July and August 2003. In July the images were taken midday, while in August it was done in dawn to avoid the potential effect of sunshine on the images.

The investigations in connection with pest management were carried out in cooperation with the Department of Plant Protection of the University of West-

Hungary. Consequently, the results belong to Prof. Dr. Géza Kuroli DSc and his colleagues as well as the Institute of Agricultural, Food and Environmental Engineering.

3.6. Data transfer among precision farming systems

In the frame of the precision farming experiments carried out previously by our institute the RDS (yield monitoring) and the Agrocom ACT (soil sampling, yield monitoring and solid fertiliser distribution) systems were applied. Each system has special file types with special extensions.

The gathered information can be loaded into the specific software and by means of certain functions maps can be created. Both the RDS PF and the AgroMap Basic (Agrocom ACT System) programs have advantages and disadvantages. From our point of view the Agromap Basic software has two important advantages, which are the followings:

- there is an opportunity to edit the row data, consequently it is possible to divide and analyse separately any given part of any yield map;
- by means of the AgroMap Basic data from each column of a given data file may be mapped, while due to the RDS PF program only yield map may be created.

These functions are not available in the RDS PF software.

3.6.1. File structures

Description of the RDS yield files

In case of the RDS system, the information gathered during the harvest is recorded in ADIS (Agricultural Data Interchange Syntax) format, which conforms with the Draft International Standard ISO/DIS 1187. The file is structured in columns of data fields separated by an @. Lines are prefixed with first column entry identifying the type of data and job number xxxxxx, with further column entries of data fields, and grouped as follows (RDS, 2000):

- header data;
- supplementary data (parameters defined by the Ceres 2 F1 – F12 fuction keys);
- yield data;
- summary data;
- end of file (EN, EZ).

This structure is shown in case of a yield file recorded by the Institute of Agricultural, Food and Environmental Engineering in Appendix 14.

Description of the Agrocom ACT yield file

In case of the Agrocom ACT system yield data are recorded in files with “gpc” extension together with a “card.out” file. These files can be read back into the AgroMap Order module and with this a file with “aft” extension will be created. This file can be opened, edited and processed in the AgroMapBasic software. The structure of the aft yield file (Agrocom, 1998) is presented in Appendix 14.

Unlike the RDS data the aft yield file does not involve supplementary data end label and height information.

3.6.2. Agrocom ACT data import into the RDS PF program

The RDS PF software provides import functions for external data (recorded by other yield-monitoring systems). In this way it is possible to read the Agrocom ACT yield files in it as well. The problem is that to create this yield file (processed row yield data) the AgroMap Basic is required (see Chapter 3.6.3.). From this point it makes no sense to import these data into the other system's software even taking into consideration the difference between the capabilities of the given programs.

3.6.3. RDS data import into AgroMap Professional

This software provides import function with much more possibilities comparing to the other program. At the first step, the "row yield data" recorded by the yield monitoring implement (with .gpc extension) should be read into the Agromap Order module. During this process the measured data are going to be written to the AgroMap Basic as "measured yield data" (with .aft extension) (Fig. 3.6.3.1.).

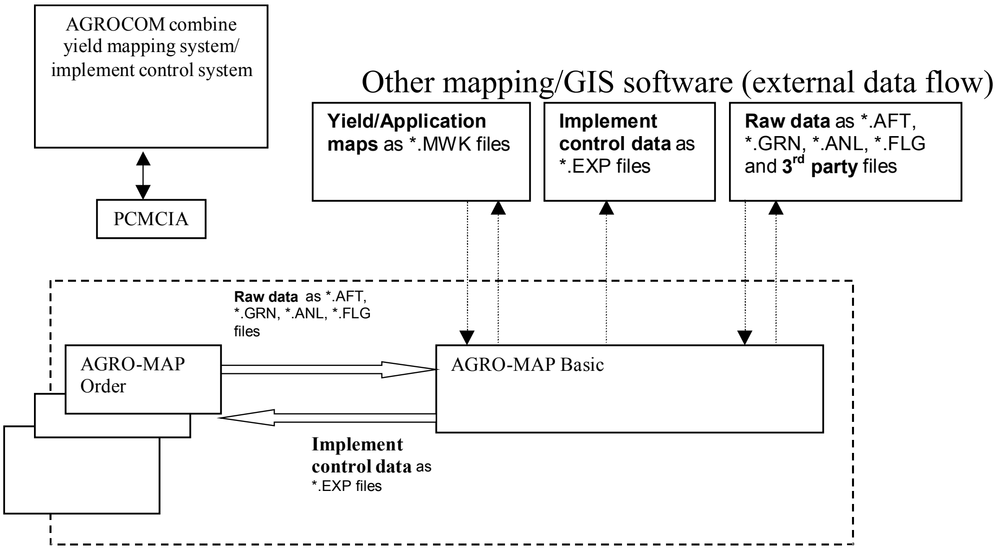


Figure 3.6.3.1. AGRO-MAP Basic Software Package (internal data flow) (Agrocom, 1998)

Yield files (with ".aft" extension) can be efficiently edited, and all of its information can be visualised in map form.

Despite the wide range of import possibilities it is impossible to read the RDS yield files directly in. To be able to do it, the conversation of the RDS file is required. By extracting and editing the data from the proper columns of the RDS yield file a tab delimited text file can be built (Fig. 3.6.3.2.). A header consisting of the title of each column should be included.

For transformation purpose, software has been developed based on partly the above-mentioned principle (Maniak, 2002/a and b). This transformation function has been built into the soil draft- and weed monitoring system's software.

Yield	Moisture%	Y	X	Height
0	0,5	47,68296	17,95825	121
1,12	0	47,68301	17,95821	121
0,14	0	47,68305	17,95819	122
0,6	4,5	47,68309	17,95816	122
5,2	8	47,68324	17,95808	123
5,31	10	47,68328	17,95805	123
5,03	12	47,68333	17,95802	123
5,03	12	47,68338	17,95799	123
5,97	12,5	47,68341	17,95798	124

Figure 3.6.3.2. The transfer file (tab delimited text) created from the RDS yield file for the AgroMap Basic (Mesterházi et al. 2002/a and b)

3.7. Investigations in connection with machine guidance

Guidance tests were carried out in the 1 ha practice field during which a predetermined pathway was followed in 3-5 repetitions. The test runs were repeated at different times of subsequent days in January 2003. The pathway was planned in Agromap Basic as point sampling order. Navigation provided by the ACT was used for marking out the guideline for the RDS Marker Guide. The actual position was recorded with a frequency of 2 s by the Agroline program running on the ACT. The working width was set for 18 m

4. RESULTS

4.1. Soil sampling

The results of soil sampling and analysis are reported in Appendix 2. Some of the created soil property maps are presented in Figs. 4.1.1. and 4.1.2.

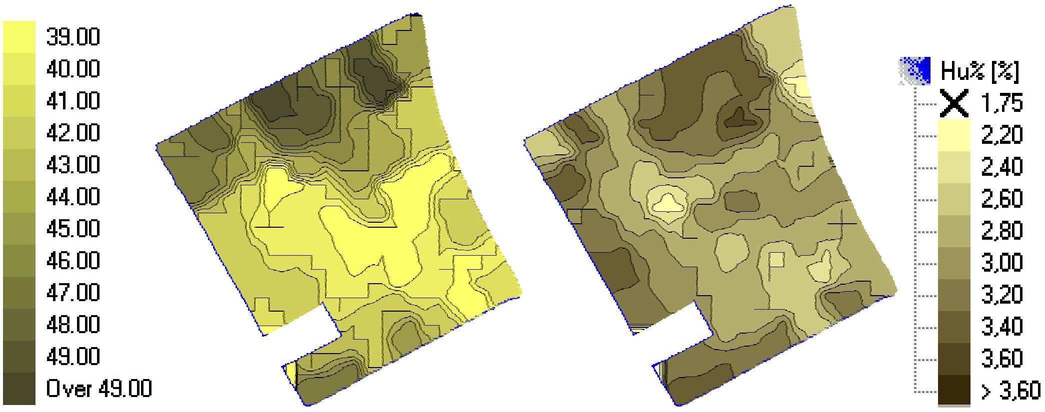


Figure 4.1.1. K_A and humus supply maps of the experimental field 80/1

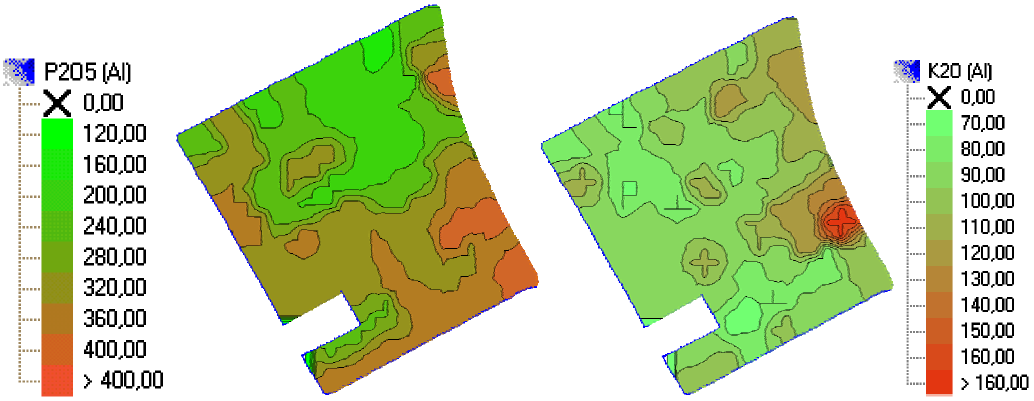


Figure 4.1.2. P_2O_5 and K_2O supply maps of the experimental field 80/1 (ppm)

The soil supply maps according to the applied fertiliser advisory system were also compiled (Fig. 4.1.3.).

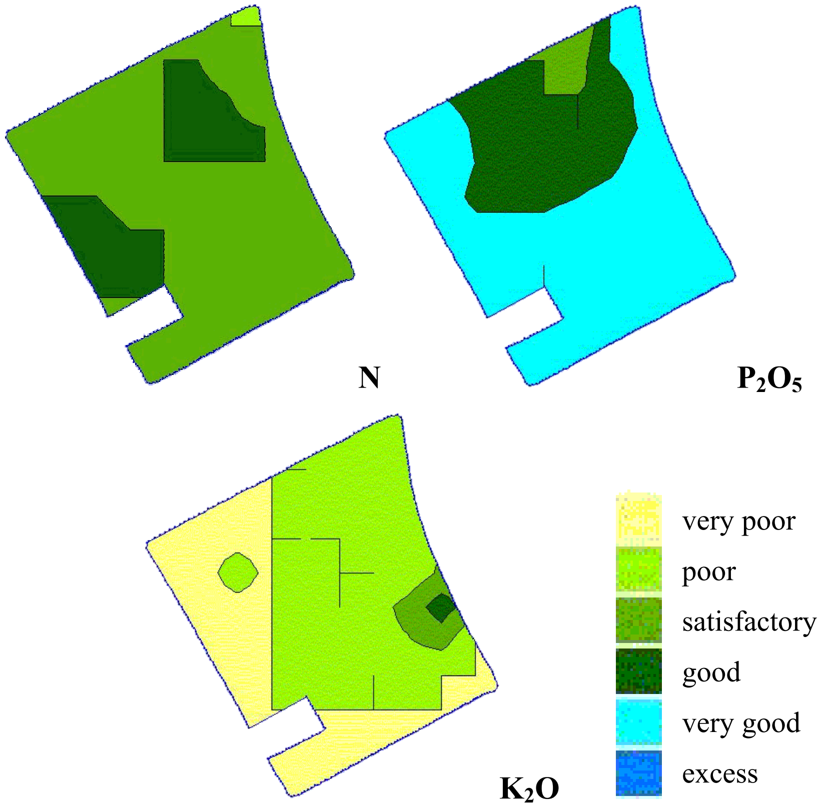


Figure 4.1.3. The level of N, P_2O_5 and K_2O supply according to the RISSAC – HAS – RIA - HAS fertiliser advisory system in case of spring barley in 2003

Further maps of soil supply are published in Appendix 1. and 11. The statistical analysis of the measured parameters was carried out. The table of correlation coefficient is presented in Appendix 6.

According to Appendix 6. K_A showed significant correlation with hu%, Na and Mg content on a level of P = 0.1%. A similar significance was presented by hu% with Na, Mg and Cu content (in addition to K_A); and with total N% on a level of P = 1%. Further definite connection (P=0.1%) was found between $CaCO_3$ and Mg; P_2O_5 and Zn; Na and Mg; Zn and Mn; Zn and Fe; Cu and Fe and Mn and Fe contents. Additionally, a P = 5% correlation was present between pH_{KCl} and P_2O_5; hu% and total N%; total N% and Na content as well as between Cu and Mn contents. pH_{KCl} showed correlation on a level of P=5% with pH_{H_20}, P_2O_5 and Zn contents. A similar connection manifested between pH_{KCl} and Zn content; salt% and Cu content; total N% and Cu content; K_2O and Zn; K_2O and Fe furthermore between Mg and Cu and Zn and Cu contents.

4.2. Yield monitoring

The yield and grain moisture content maps based on the collected data are presented below.

4.2.1. Year 2001

The yield- and grain moisture maps (Figs. 4.2.1.1. and 4.2.1.2.) of 2001 show the in-field heterogeneity after homogeneous nutrient replenishment thus are considered to reflect the variability in fertility.

The area with extremely low moisture content marked with green in the right side of the map (Figure 4.2.1.2.) is caused by the dysfunction of the moister sensor. After observing and fitting the problem, the moisture content measurement proved to be accurate.

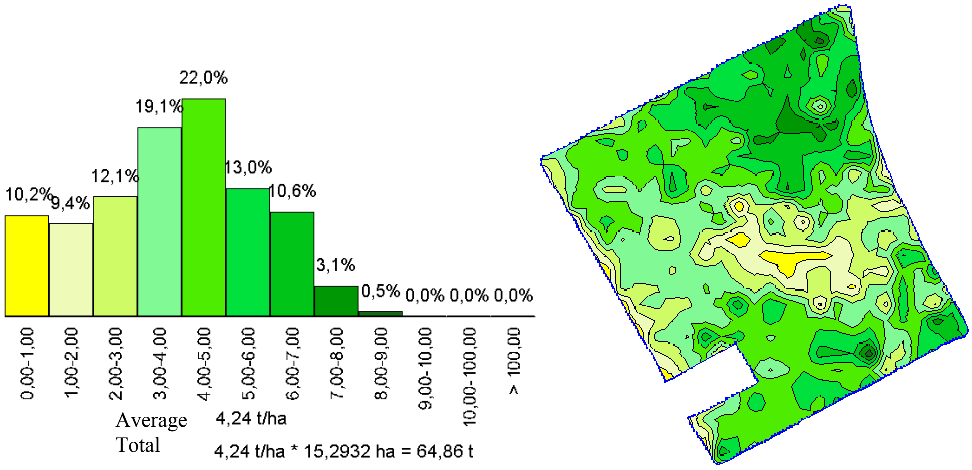


Figure 4.2.1.1. Yield map of maize in 2001 after homogeneous nutrient replenishment

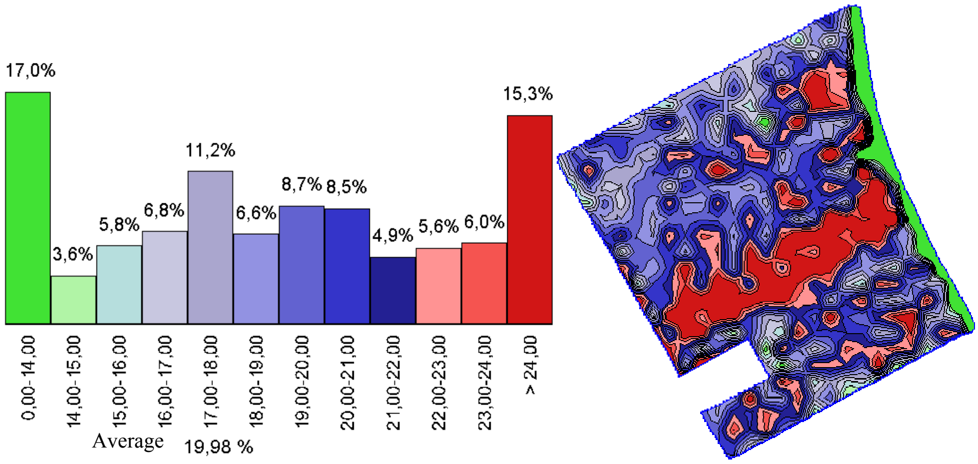


Figure 4.2.1.2. Grain moisture map of maize in 2001

The high moisture content area (red) situated in the middle of the field shows a more or less regular shape. Should this phenomenon appear in the subsequent years, this part of the field might be harvested separated a given time later than the rest saving money by the decreased demand of drying. It may ensure the problem free drying and the steady quality as well.

4.2.2. Year 2002

These maps – like the maps of year 2003 (Figs. 4.2.3.1. and 4.2.3.2.) - are generated after VRA fertiliser distribution.

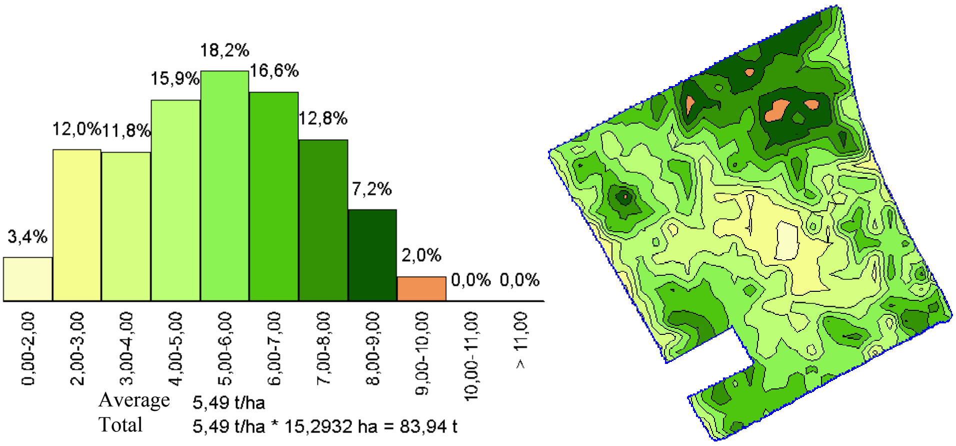


Figure 4.2.2.1. Yield map of maize in 2002

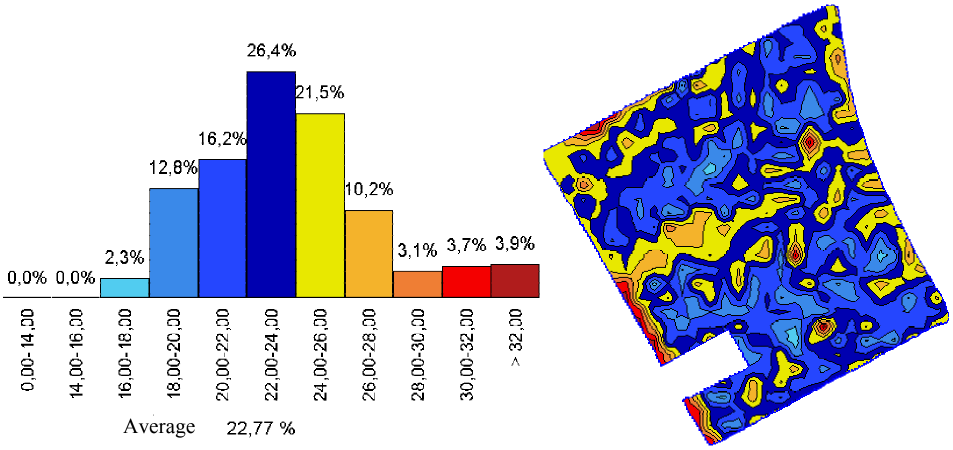
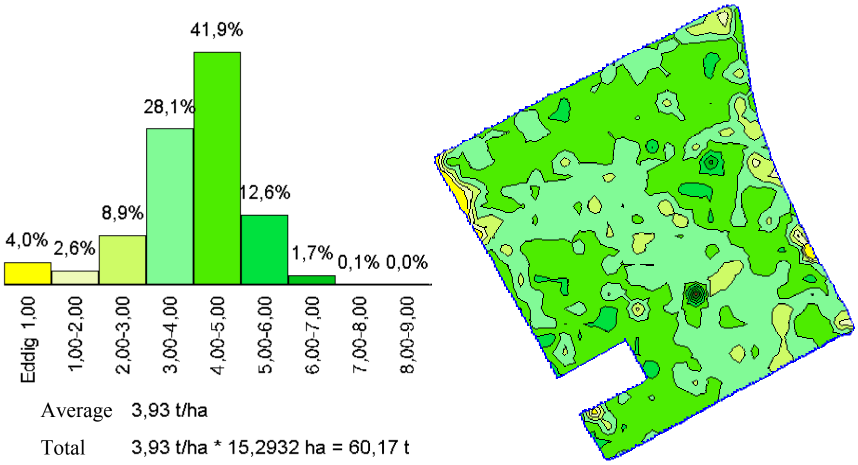


Figure 4.2.2.2. Grain moisture content map of maize in 2002

As it was presumed the high moisture content area in the middle is present in the map from 2002 as well.

4.2.3. Year 2003

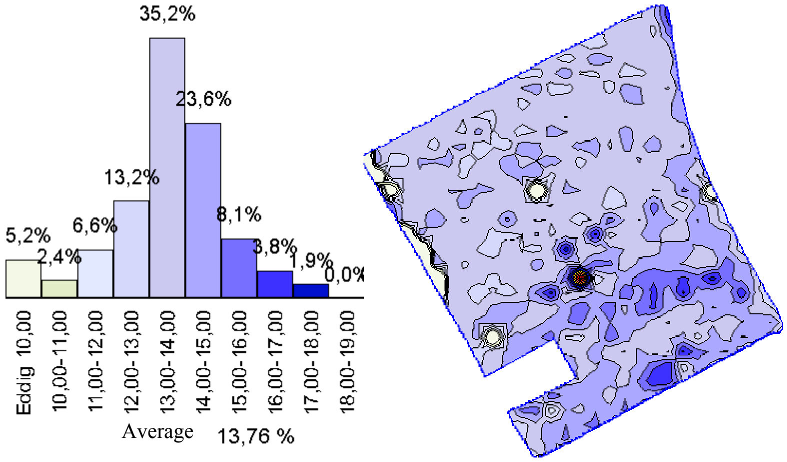
Figures 4.2.3.1. and 4.2.3.2 show the results of 2003's harvest.



Average 3,93 t/ha

Total 3,93 t/ha * 15,2932 ha = 60,17 t

Figure 4.2.3.1. Yield map of spring barley in 2003



Average 13,76 %

Figure 4.2.3.2. Grain moisture sensor of spring barley in 2003

After the visual evaluation of the maps it can be declared that the pattern of the yield maps show similarity. It affects especially the low yielding area in the middle of the field, which appears in all three years, however slightly dissolved in 2003. The big high yielding spots in the right upper and left bottom corners may be stated to be temporally stable similarly to the small spot in the right bottom corner. Some equalisation can also be noticed.

In case of the grain moisture maps similarity may also be found. First of all, the above-mentioned strip, which manifest itself strongly in 2001 and 2002 but appears with displacement in case of the winter barley in 2003.

According to the statistical analysis of the recorded data a strong relationship exists between the yield of 2001 and 2002. The coefficient of determination is 0.84 ($P = 0.1\%$), whereas between year 2001 and 2003 or rather 2002 and 2003 it is only 0.25 and 0.28, respectively on a probability level of 95%.

The effect of the soil characteristics on the yields and grain moisture contents were also investigated. Based on these calculations it can be declared, that in 2001 the yield variance was caused in 50% by the variance of the soil parameters, on a probability level of 99%. In 2002 it was 65% and $P = 0.1\%$, whereas in 2003 it was slightly lower comparing to the initial year with 46% and $P = 1\%$. Corresponding to the grain moisture content it was found, that its variance was 58% determined by the variance of the soil properties in 2001, on a probability level of 99.9%. In case of the other years, this effect decreased significantly; in 2002 no significant correlation was found, and r^2 was 0.42 in 2003 on a probability level of 95%.

As a next step, the relative importance of the investigated soil parameters was determined (Table 4.2.1.). It is remarkable that the Cu content of the soil turned out to be an important factor corresponding to the yield showing positive correlation all three years. It had a definite effect on the grain moisture content as well in 2002 and 2003 however it was in negative correlation in 2002 unlike the positive effect in 2003. On the contrary, Zn showed negative correlation on yield, except for 2003. The calculation reflects correlation between K_A and yield in 2001 and 2003, whereas its effect seems negligible in 2002. Mn also seems to be a significant influencing factor on yield with a positive correlation in case of maize (2001 and 2002) and a negative one in case of barley (2003). Fe proved to be a rather positive effecting factor on yield in case of maize and a negative one in case of barley. In connection with grain moisture it had a slighter negative effect. The K_2O content of the soil is marked as positive influencing factor in case of maize, but in case of barely its impact is moderated. The effect of the humus content is changeable both on yield and grain moisture. The influence of P_2O_5 on yield seems negligible all three years, but seems to be a negative one corresponding to grain moisture of maize. Other factors such as pH, Na and NO_3 content seem to play variable role in connection with yield and moisture content.

Table 4.2.1. The relative importance of the B values of the standardized equations in decreasing order

The relative importance of the B values of the standardized equations in decreasing order															
	Cu (EDTA)	K_A	Mg(KCl)	Al K2O5	Fe (EDTA)	Al Na	CaCO3%	total N%	pH KCl	Al P2O5	NO_3	pH H2O	salt%	Mn (EDTA)	humus%
yield 2001	0,3018	0,2923	0,1202	0,1077	0,0665	0,0485	0,0431	-0,0018	-0,0065	-0,0128	-0,0607	-0,0805	-0,1054	-0,1640	-0,2362
relative value	1,00	0,97	0,40	0,36	0,22	0,16	0,14	-0,01	-0,02	-0,04	-0,20	-0,27	-0,35	-0,54	-0,78
	Cu (EDTA)	Fe (EDTA)	CaCO3%	Al K2O5	Mg(KCl)	Al Na	Al P2O5	K_A	összN%	humusz%	só%	pH KCl	pH H2O	NO_3	Mn (EDTA)
yield 2002	0,3007	0,2111	0,1384	0,1311	0,1167	0,1040	0,0265	0,0227	0,0182	-0,0322	-0,0645	-0,0953	-0,1267	-0,1439	-0,2897
relative value	1,00	0,70	0,46	0,44	0,39	0,35	0,09	0,08	0,06	-0,11	-0,21	-0,32	-0,42	-0,48	-0,96
	Cu (EDTA)	K_A	Mn (EDTA)	pH KCl	összN%	Al K2O5	só%	NO_3	Mg(KCl)	CaCO3%	Zn (EDTA)	pH H2O	Al P2O5	humusz%	Al Na
yield 2003	0,6906	0,4938	0,3772	0,3066	0,1789	0,1100	0,1012	0,0807	0,0689	0,0654	-0,0145	-0,0422	-0,0539	-0,2227	-0,2618
relative value	1,00	0,72	0,55	0,44	0,26	0,16	0,15	0,12	0,10	0,09	-0,02	-0,06	-0,08	-0,32	-0,38
	Mn (EDTA)	pH KCl	Al Na	NO_3	humusz%	Zn (EDTA)	összN%	só%	Cu (EDTA)	CaCO3%	Mg(KCl)	Al K2O5	pH H2O	K_A	Fe (EDTA)
moisture 2001	0,5877	0,3606	0,3207	0,1591	0,1448	0,1402	0,0845	0,0174	0,0173	-0,0301	-0,0393	-0,0478	-0,1224	-0,1340	-0,1348
relative value	1,00	0,61	0,55	0,27	0,25	0,24	0,14	0,03	0,03	-0,05	-0,07	-0,08	-0,21	-0,23	-0,23
	összN%	NO_3	K_A	pH H2O	Zn (EDTA)	só%	Mn (EDTA)	Al K2O5	Mg(KCl)	Al Na	humusz%	Fe (EDTA)	Al P2O5	CaCO3%	pH KCl
moisture 2002	0,3771	0,3761	0,2283	0,2123	0,1801	0,1784	0,1031	0,0954	0,0695	-0,0939	-0,1455	-0,2034	-0,2190	-0,2221	-0,3271
relative value	1,00	1,00	0,61	0,56	0,48	0,47	0,27	0,25	0,18	-0,25	-0,39	-0,54	-0,58	-0,59	-0,87
	pH KCl	Cu (EDTA)	pH H2O	Al K2O5	humusz%	Al P2O5	CaCO3%	Al Na	Zn (EDTA)	összN%	K_A	Fe (EDTA)	Mg(KCl)	só%	NO_3
moisture 2003	0,6270	0,4125	0,1572	0,1397	0,1203	0,0654	0,0552	0,0415	0,0127	-0,0577	-0,0919	-0,1051	-0,1331	-0,1501	-0,1601
relative value	1,00	0,66	0,25	0,22	0,19	0,10	0,09	0,07	0,02	-0,09	-0,15	-0,17	-0,21	-0,24	-0,26

Finally, the real values of correlation and the level of significance were determined. According to this analysis the following statistically justifiable regressions were found:

- The yield of maize increased with 1.25 t/ha from 2001 to 2002. The average yield was 5.48 t/ha in 2002 after the 4.24 t/ha in 2001. The same value was 3.93 t/ha in case of spring barley in 2003. (Because of the complicated structure of the experimental field – part of a larger area, which was divided several ways – there is not reliable information about the previous yields available. For informative purpose: the Hungarian country averages for the same periods are 5.05 t/ha, 6.22 t/ha and 3 t/ha, respectively. However, the meaning of this comparison is restricted taking into account the short period, the different circumstances and the significant soil compaction in the middle of the field was explored later.)
- Equalization, the decrease of the deviation of the yield took part. From 2001 to 2002 the CV% decreased from 31.79 to 27.26 (P = 5%).
- The yield variance in 2001 was mainly affected by K_A (R = 0.5927) P = 0.1%. Na and Mg contents proved also to be significant factors on a probability level of 99% (R = 0.34 and 0.35, respectively).
- Yield was influenced by the same factors in 2002 as well, however a slightly more decidedly; the statistical correlation is justifiable on a level of 99.9%. Besides, the effect of the humus and Cu contents also turned out to be significant (P = 1% and 5%, respectively).
- In 2003 significant correlation on a probability level of 99.9% was found only with Cu content. The effect of Mg was like in 2001. The salt and total N content proved out also to be determinative on a probability level of 95%,

however humus content showed significance only on a level of 90%, just like K_A.

- The variability in grain moisture content in 2001 was mainly affected by two factors: Mn and Zn contents (P = 0.1%). The influence of the Fe content and pH_{KCl} is justifiable on a probability level of 99%. In case of the NO_3 content a significance of P = 95% was found.
- No significant correlation was found between the soil characteristics and the grain moisture content.
- In 2003 the influence of pH_{KCl} was repeated, but this time on a probability level of 99.9%. P_2O_5 content and pH_{H_2O} also affected the grain moisture (P = 1% and 5%, respectively). The entire data sheet is presented in Appendix 7.

4.3. Site-specific nutrient replenishment

The amount of applied fertiliser was recorded and mapped due to a sensor is mounted in the quantity regulator of the disc spreader. In this way, the planned and applied nutrient replenishments are comparable.

4.3.1. Spring 2002

In case of the N fertilizer the data logging has been started with a considerable delay. Consequently, the map itself does not allow the direct comparison (unreliable information is present on the map because of the interpolation with too many missing measured data). However, by means of the recorded data it is still possible (Fig. 4.3.1.2.). This comparison shows significant faults in the treatment units 1, 2, 3, 16, 17, 24, 31 and 32, which are marked in Figure 4.3.1.1. It is remarkable that all these units are situated beside the borderline. The management unit 24 seems to be an exception as it is situated in the opposite site comparing to the other ones.

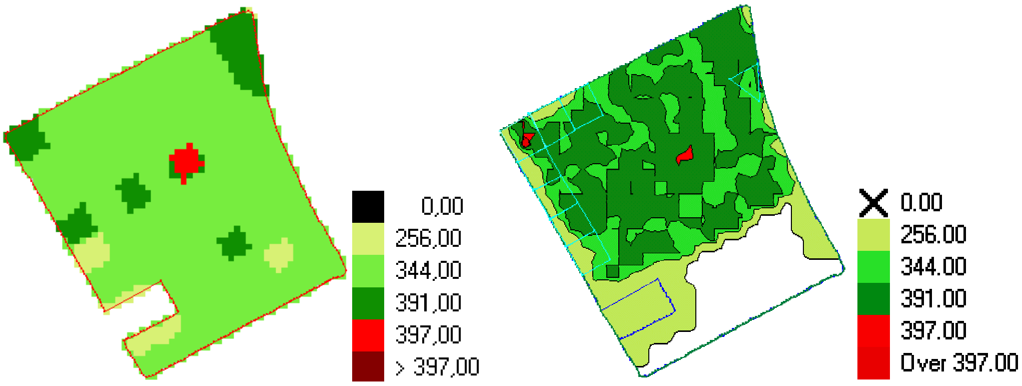


Figure 4.3.1.1. Maps of planned and applied N fertilizer amounts (kg/ha) in spring 2002

These errors and the deviation of the applied amounts are the reasons for the low r^2 value presented in figure 4.3.1.3.

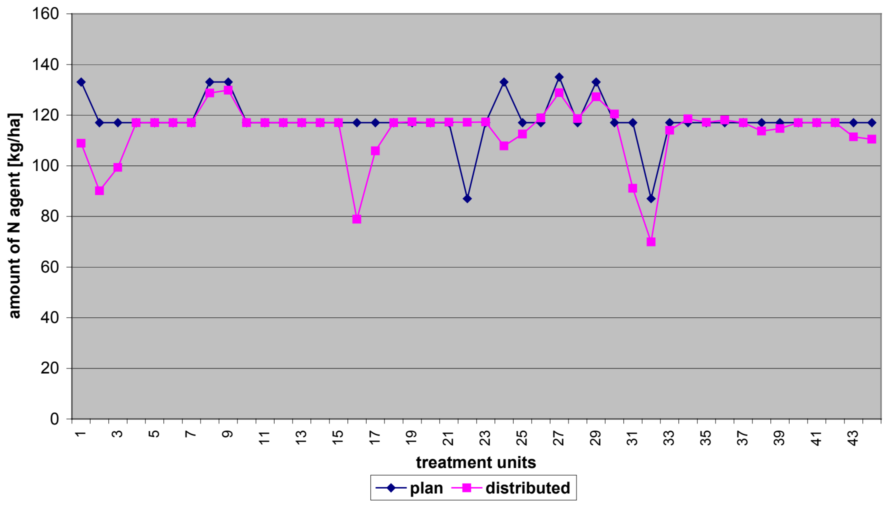


Figure 4.3.1.2. Comparison of the planned and applied N agent in the treatment units in spring 2002

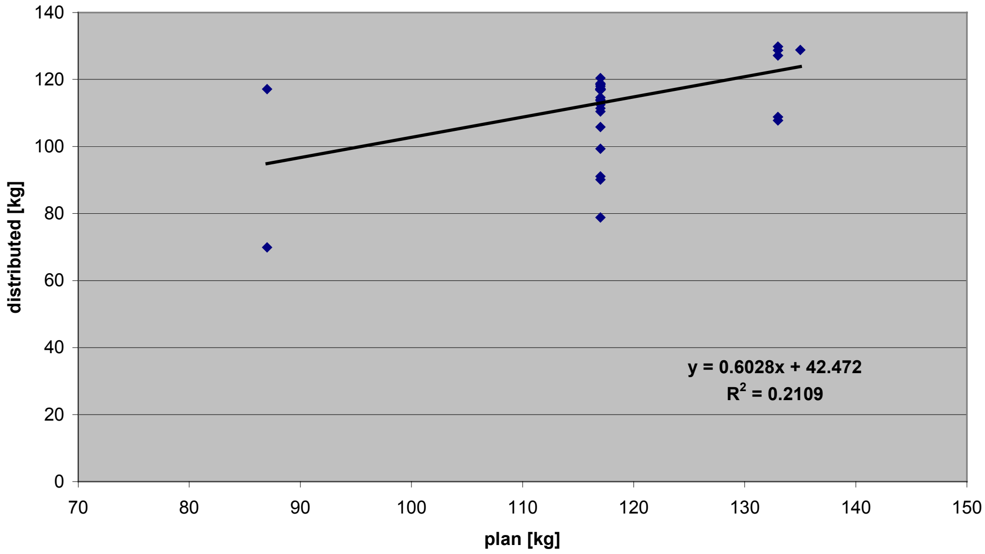


Figure 4.3.1.3. Correlation between the amounts of planned and applied N agent in spring 2002 (kg)

The recorded K_2O application map (4.3.1.4.) makes possible both the visual and statistical evaluation.

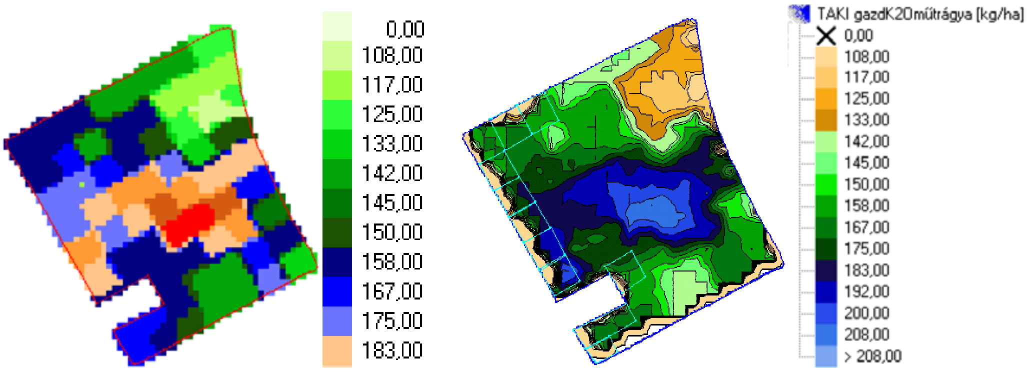


Figure 4.3.1.4. Maps of planned (left) and applied (right) K_2O fertilizer amounts in spring 2002 (kg/ha)

Based on visual inspection, the map shows significant similarity to the plan and even to the so-called fertilizer planning base map (3.3.2.2.). However, Figure 4.3.1.5. reflects faults in given treatment units again, and these units are the followings: 1, 2, 3, 16, 17, 24, 31, 32 45 and 46 (marked). It is remarkable, that except for the latest two, these are exactly the same as in case of the N application. As this phenomenon occurred in both cases it is supposed to be caused by the same reason. Since the spreader was loaded every time beside the left side of the field and the majority of the faults is situated there as well it is supposed to be the reason for the errors or rather the unsuitable infield rout. The lack of recorded value on the bottom line of the field is caused by a little delay of data recording. These errors together are blamed for the decreased correlation marked in Fig. 4.3.1.5.

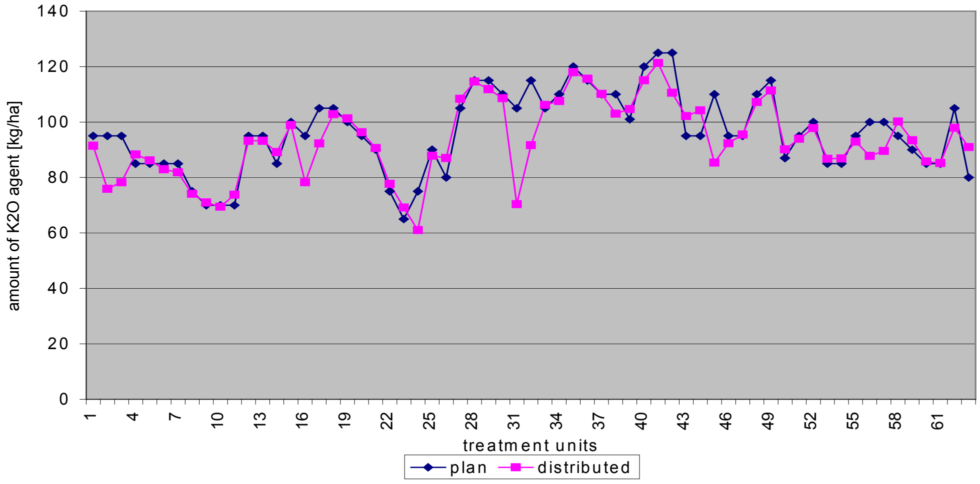


Figure 4.3.1.5. Comparison of the planned and applied K_2O agent in the treatment units in spring 2002

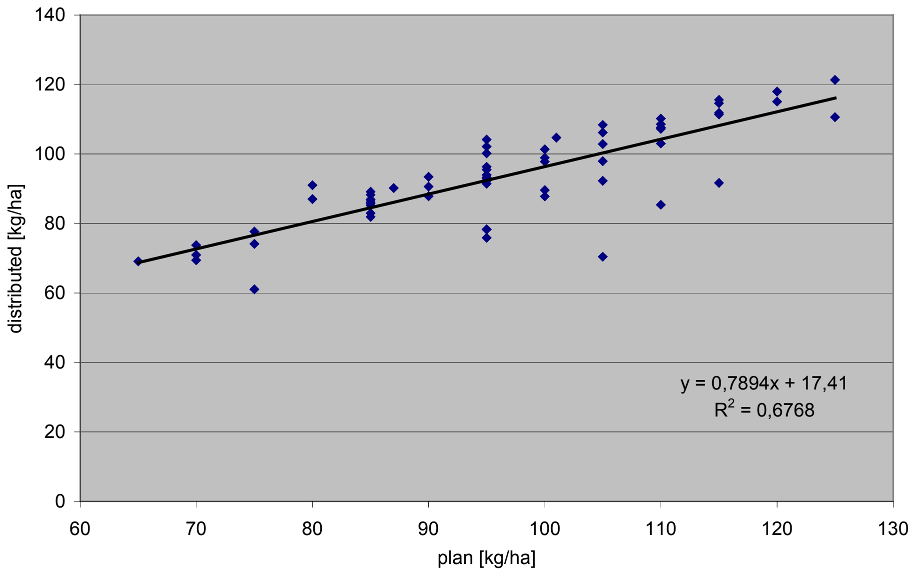


Figure 4.3.1.6. Correlation between the amounts of planned and applied N agent in spring 2002

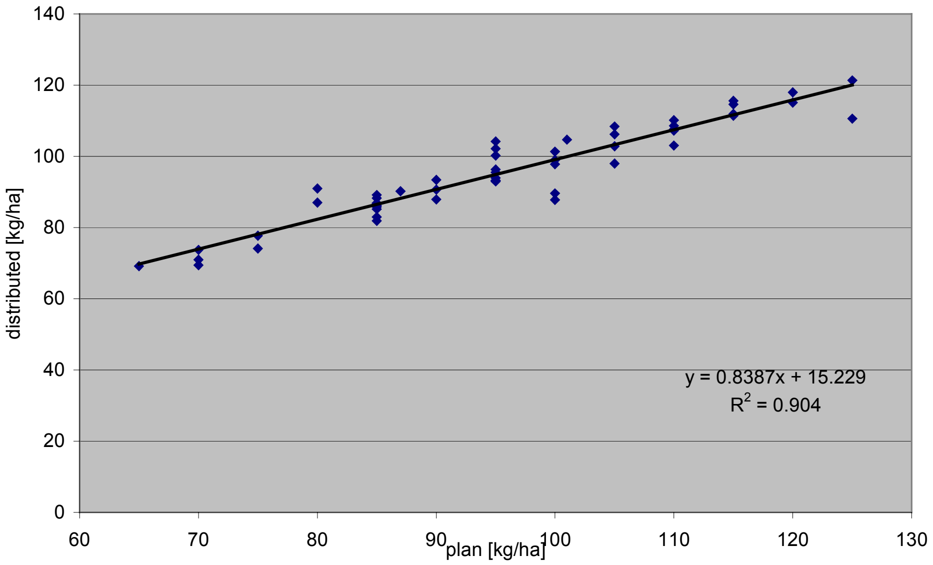


Figure 4.3.1.7. Correlation between the amounts of planned and applied N agent in spring 2002 after correction

After removing the erroneous data, the r^2 value increased significantly from 0.68 to 0.9 (Figs. 4.3.1.6. and 4.3.1.7).

Analysing the effect of applied fertilizer on the yield it was found that the variable rate application of the K_2O agent had 14.5 times as much impact on maize yield variance as in case of the N (leaving its sign out of consideration).

4.3.2. Autumn 2002

In autumn 2002 the site-specific application of K_2O and P_2O_5 took part.

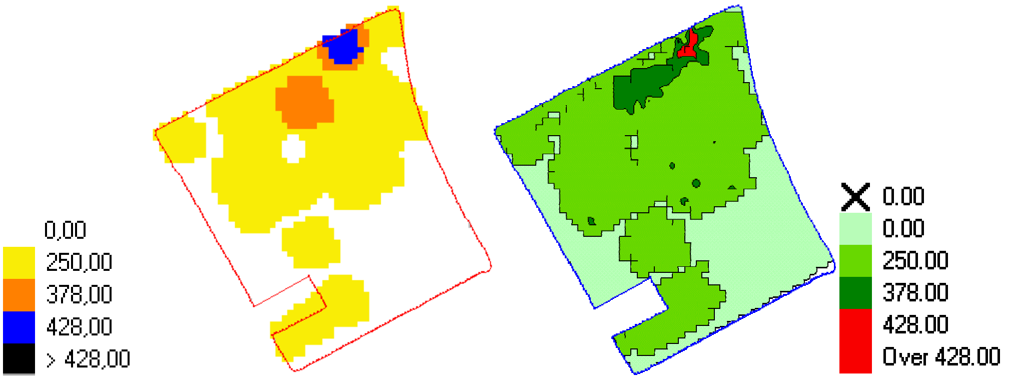


Figure 4.3.2.1. Map of planned (left) and applied (right) P_2O_5 fertilizer amounts in autumn 2002 (kg/ha)

It may be seen that the pattern of the application map in Figure 4.3.2.1. shows strong similarity with the application plan. Nevertheless, Figure 4.3.2.2. signs that the fertiliser distribution was carried out with significant errors.

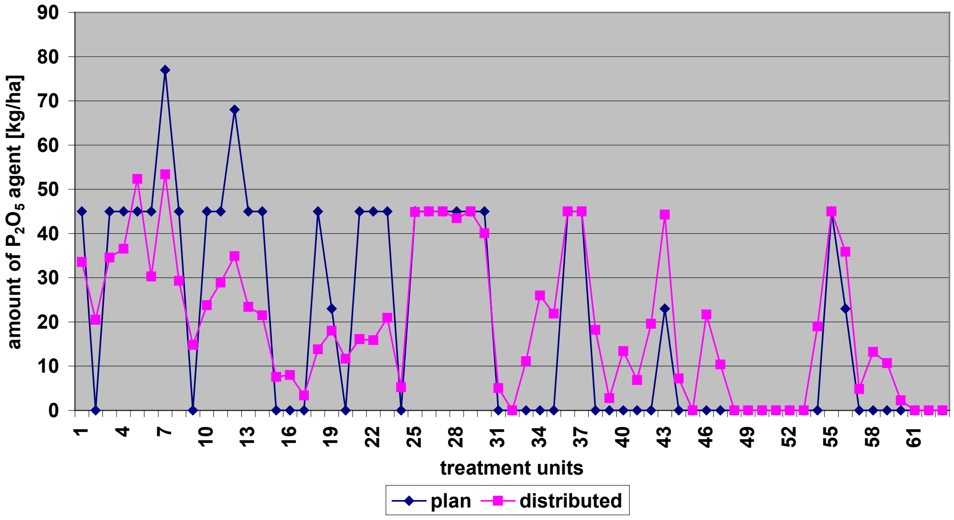


Figure 4.3.2.2. Comparison of the planned and applied P_2O_5 agent in the treatment units in autumn 2002

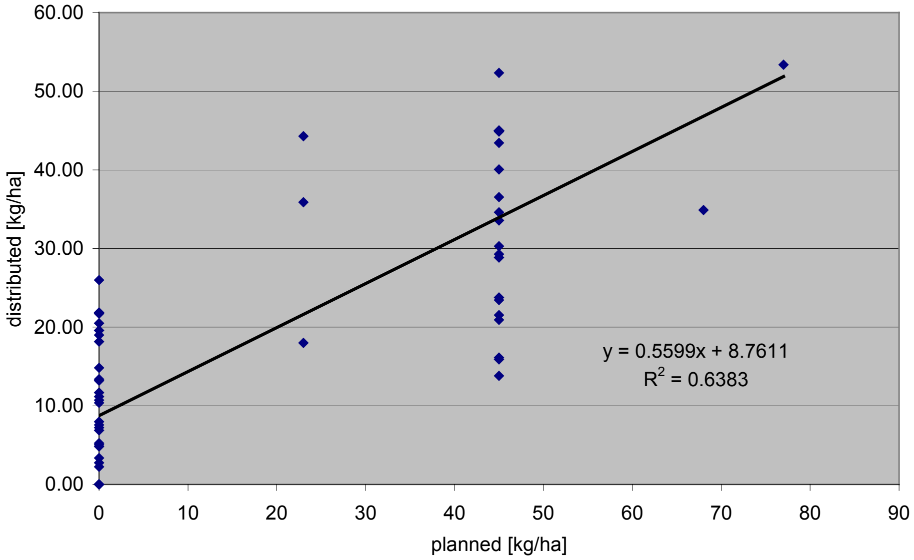


Figure 4.3.2.3. Correlation between the amounts of planned and applied P_2O_5 agent in the treatment units in autumn 2002

According to Figure 4.3.2.3. it can be stated that serious dosing problems occurred: the applied amounts varied in a wide range. It is confirmed by the poor r^2 value (0.63) as well.

The map of the applied K_2O (Fig. 4.3.2.4.) is visually similar to the concerning plan. Some lag may be discovered only along the western border of the field, what is caused probable by that the reload of the spreader took part there therefore the coverage was insufficient, as it was mentioned above. The statistical comparison backs up this idea. Based on figure 4.3.2.5. the application can be declared to be accurate. This statement is bearded out by Figure 4.3.2.6., which represents a strong relation between the plan and the realized treatment with $r^2 = 0.88$. The deviation of the applied values was also lower in this case.

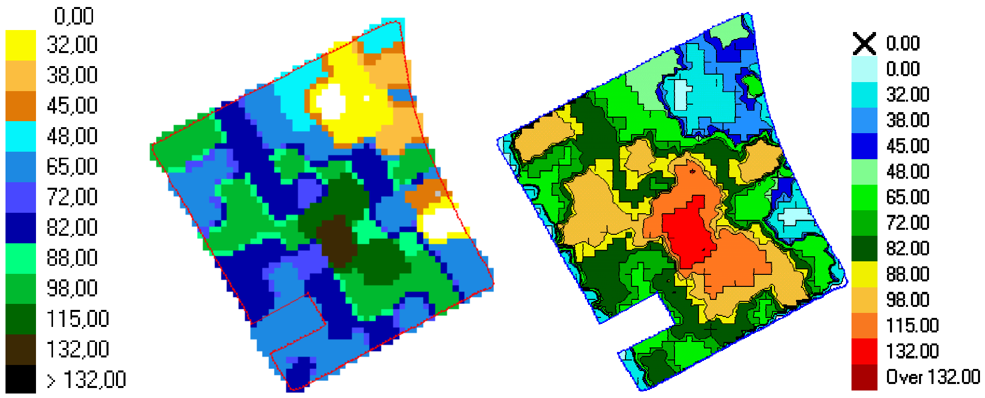


Figure 4.3.2.4. Maps of planned (left) and applied (right) K_2O fertilizer amounts in autumn 2002 (kg/ha)

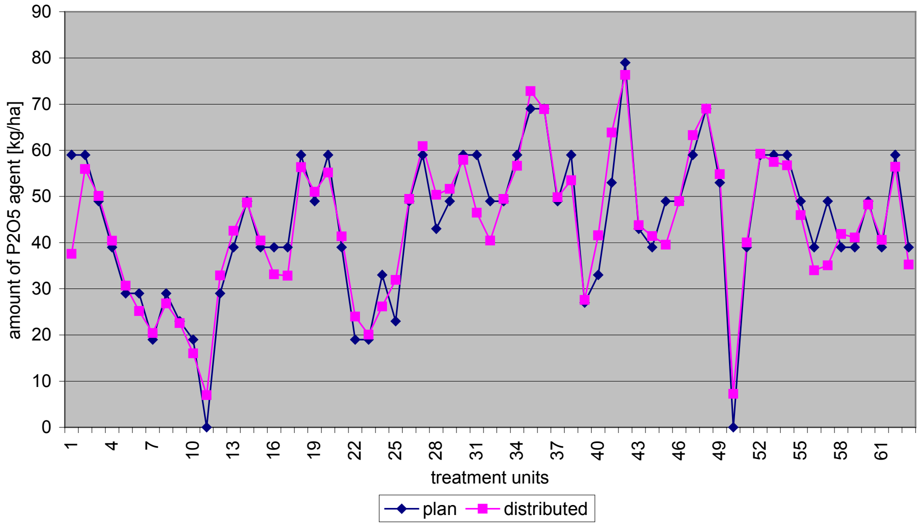


Figure 4.3.2.5. Comparison of the planned and applied P_2O_5 agent in the treatment units in autumn 2002

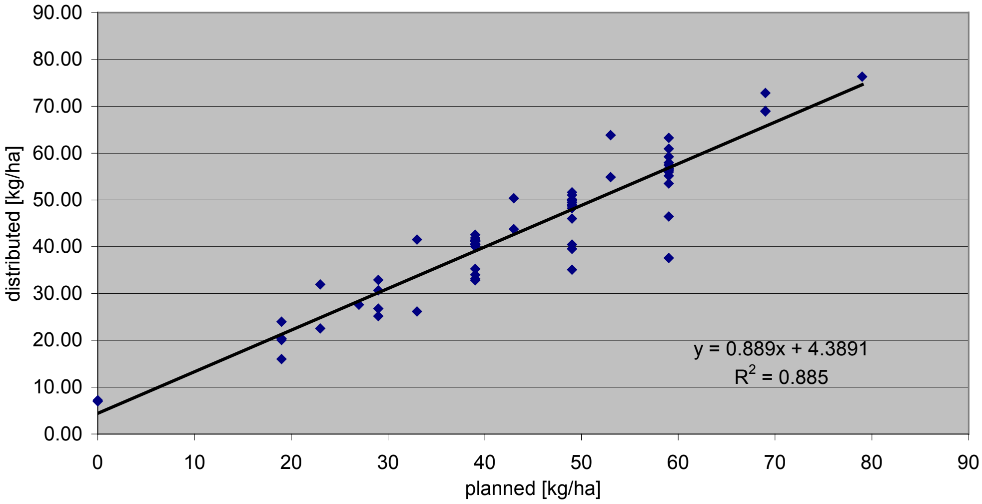


Figure 4.3.2.6. Correlation between the amounts of planned and applied K_2O agent in the treatment units in autumn 2002

This time, the effect of the variable rate application of P_2O_5 agent turned out to be 1.1 times more determinative on the yield variance of spring barley comparing to the K_2O agent application.

4.3.3. Year 2003

In 2003 P_2O_5 and K_2O fertilizers were distributed in variable rate. The map of applied P_2O_2 fertilizer amounts (Fig. 4.3.3.1.) shows significant differences corresponding to the plan. Having a look at the map containing the non-interpolated row measured data (Figure 4.3.3.1.) the pattern of the plan can be noticed. Nevertheless, the concerning values could have been polled from the interpolated map. The uncovered area in the southern part of the map has an effect on neither the nutrient supply nor the statistical analysis, since the applied amount was 0 kg ha^{-1} there.

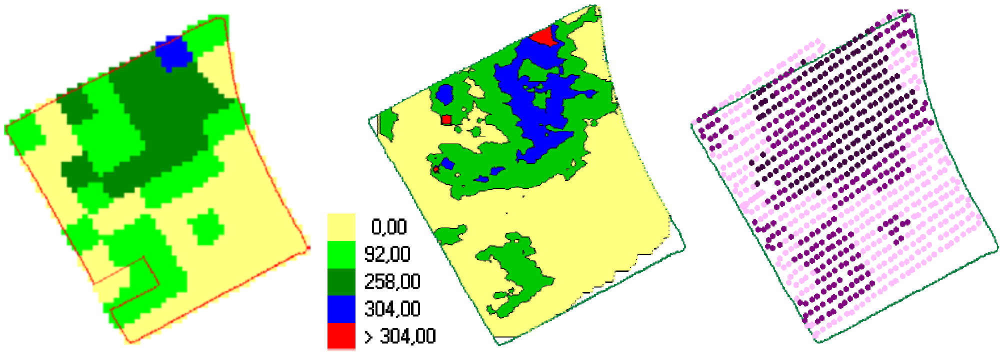


Figure 4.3.3.1. Maps of planned (left) or rather interpolated (middle) and row data (right) of applied P_2O_2 fertilizer amounts in 2003

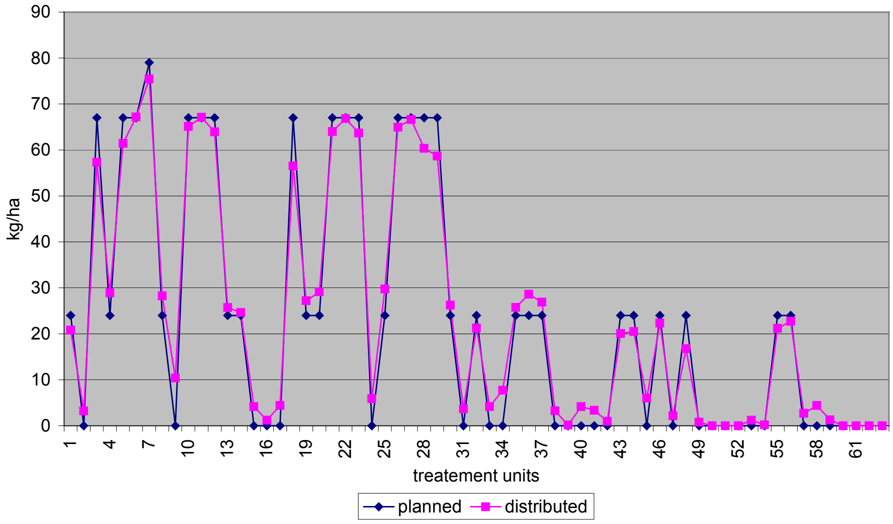


Figure 4.3.3.2. Comparison of the planned and applied P_2O_5 agent in the treatment units in 2003

The statistical analysis proves that the quantity regulation followed the plan very accurate (Fig. 4.3.3.2.) and the deviation was also within an adequate narrow range. Due to these facts a very strong correlation was found between the plan and the realized application (the coefficient of determination is 0.98; Fig. 4.3.3.3.).

In case of the K_2O fertilizing errors may be discovered concerning to the pattern of the heterogeneity regarding to the plan (Fig. 4.3.3.4.). Overdosing (red) is marked in many parts of the field. But it is not present in the row data map, which was created without interpolation. Nonetheless, a definite under-dosing may be observed in both maps parallel to the northern borderline of the field. The left side of the double shaft system of the spreader jammed during fertilizer distribution and consequently was not able to open entirely. Following repeated clearing, opening and closing the system seemed functioning well so distribution was continued. However, the trouble reappeared, thus the distribution ended after finishing the actual stripe. This is the line shown in the maps of the measured application (Fig. 4.3.3.4.) and presented also in the map with the concerning management zones (9, 10, 11, 12, 13, 14, 15, 16, 17 and 31) (figure 4.3.3.6.) created by averaging.

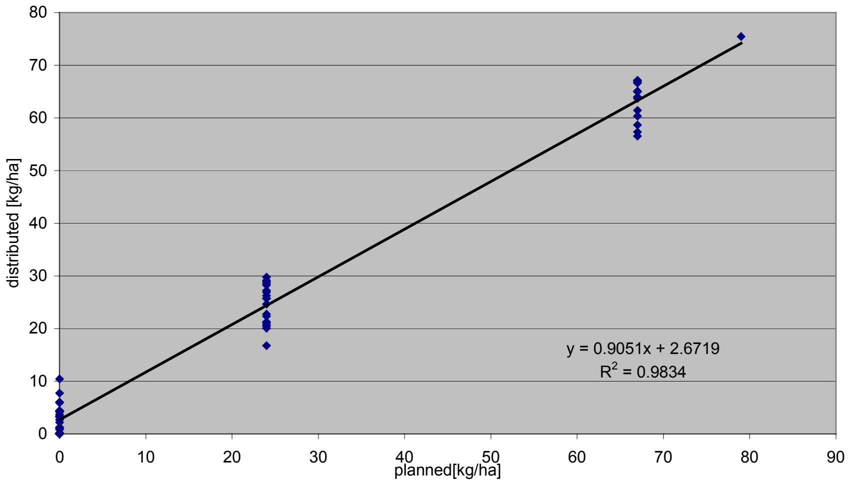


Figure 4.3.3.3. Correlation between the amounts of planned and applied P_2O_5 agent in the treatment units in 2003

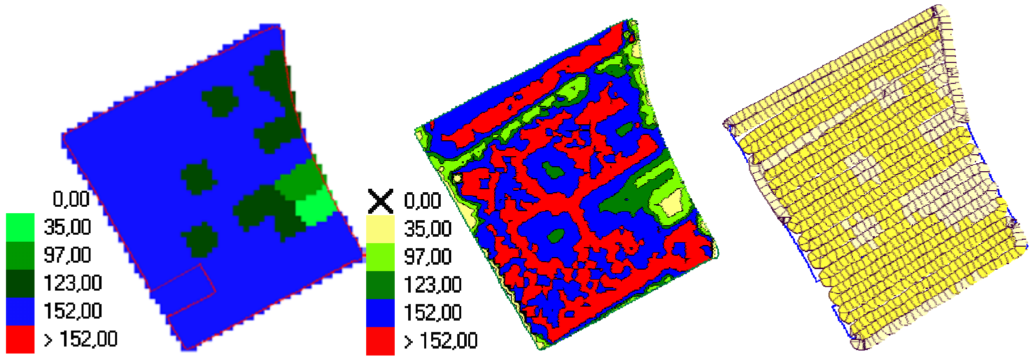


Figure 4.3.3.4. Maps of planned (left) or rather interpolated (middle) and row data (right) of applied K_2O fertilizer amounts in 2003 (kg/ha)

This latter fault unlike overdosing is reflected by the statistical analysis as well. According to Figure 4.3.3.5. the concerned treatment units are the followings: 1, 9, 10, 11 12, 13, 14, 15, 16, 17, 24, 31, 57, 61 and 63.

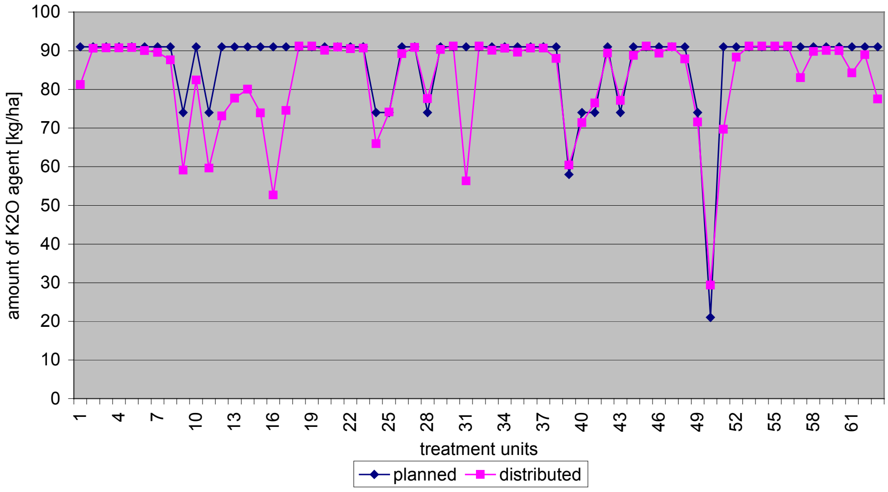


Figure 4.3.3.5. Comparison of the planned and applied K_2O agent in the treatment units in 2003

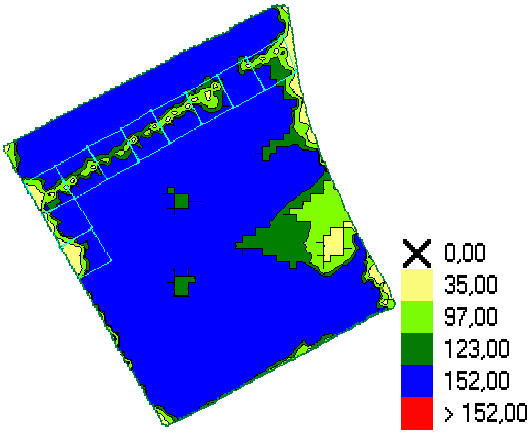


Figure 4.3.3.6. The map of applied K_2O amounts with the under-dosed area and the concerning treatment units

Further errors occurred in the treatment units 24, 57, 61 and 63, but these are situated out of the range of the observed problem. It might however be assumed that these were indications of the described problem. After stopping the fertilizer distribution the spreader was examined and it was stated that the problem was undoubtedly caused by the large amount of dust was present in the fertilizer. Figure 4.3.3.7. pictures that these errors decreased the accuracy of the fertilizer distribution. Eliminating the erroneous data caused by the known problem of the spreader the r^2 value increased significantly, from 0.56 to 0.86 (Fig. 4.3.3.8.). Be it remembered, that the data of the management zones 24, 57, 61 and 63 has not been removed, since their origin is unknown.

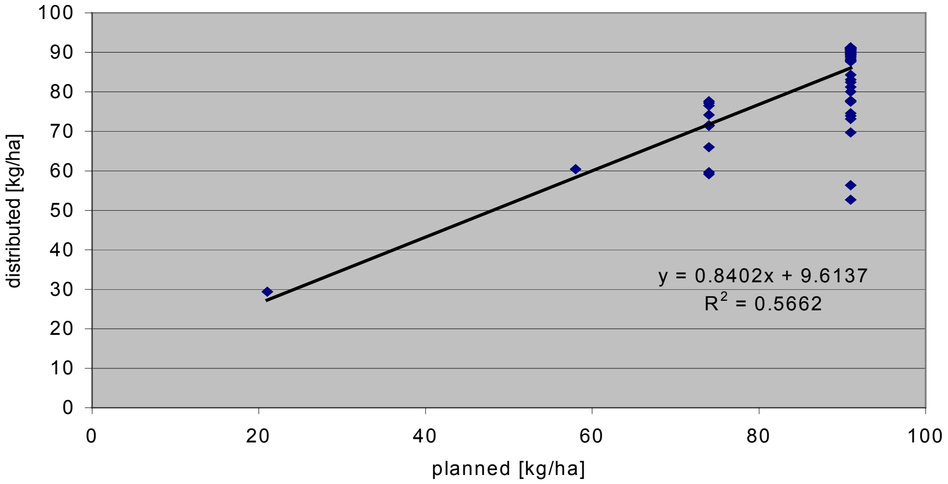


Figure 4.3.3.7. Correlation between the amounts of planned and applied K_2O agent in the treatment units in 2003

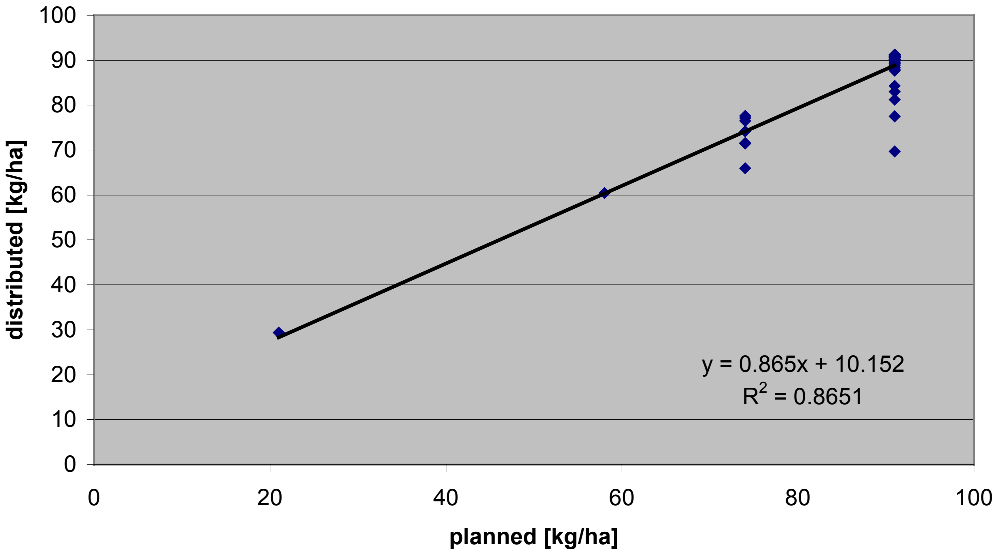


Figure 4.3.3.8. Correlation between the amounts of planned and applied K_2O agent in the treatment units in 2003 after correction

4.4. Measurement of soil physical parameters

4.4.1. Measurements on the 1 ha practice field

Based on the data collected by penetrometer measurement according to the plan presented in Figure 3.4.1.1. the soil compaction maps of given soil layers were generated (Figs. 4.4.1.1. and 4.4.1.2). It can obviously be seen that the position of the sampling points affects the generated maps. To demonstrate it the penetrometer sampling points are marked as well (red cross).

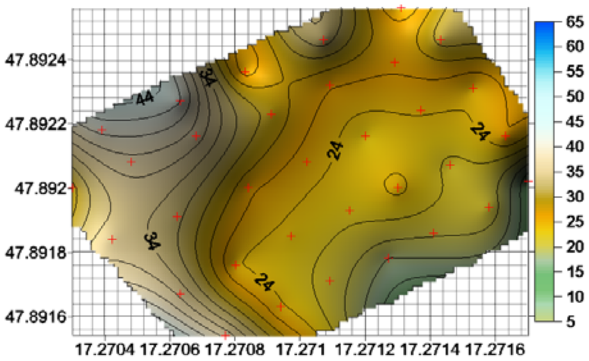


Figure 4.4.1.1. Penetrometer resistance map of the 20 cm soil layer with the measurement points (x100 kPa)

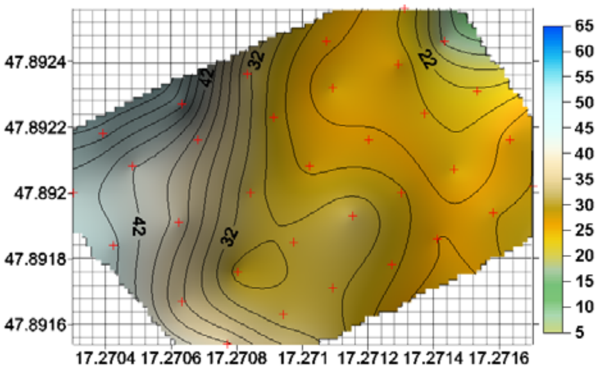


Figure 4.4.1.2. Penetrometer resistance map of the 25 cm soil layer with the measurement points (x100 kPa)

Analysing the data collected by penetrometer measurement, the position of the soil layer with critical soil compaction was also determined and simulated with the map presented in Figure 4.4.1.3. (Further maps are in Appendix 8.)

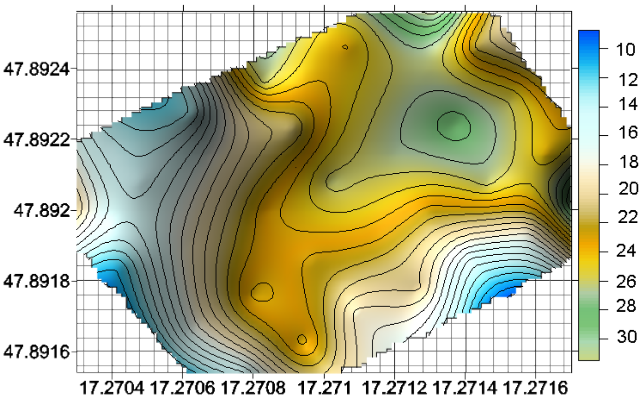


Figure 4.4.1.3. The situation of the soil layer with a compaction of 3 MPa or more (cm)

The data collected with the on-line system were processed in the same way. The image shows a partly different pattern comparing to the penetrometer maps.

Comparing the presented maps visually same observations can be made. The maps of the depths 5, 10 and 15 cm (Appendix 8.) show slightly the trend of the compaction. There are common points from where the compaction seems to expand. These points are situated in the northwest and southeast corner of the field and parallel to the northern borderline. On the contrary, in the eastern side an area with constant low compaction is present. Only the map of the 20 cm layer (Fig. 4.4.1.1.) differs in this concern. The map of the on-line measurement (Fig. 4.4.1.4.) reflects similarity in these characteristics. Nevertheless, other areas and deeper layers show different picture.

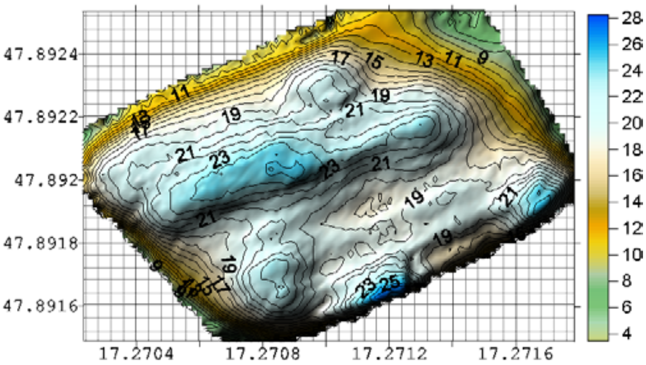


Figure 4.4.1.4. Map of the soil draft measured by the on-line system (kN)

In case of the penetrometer maps peaks can be noticed, and some continuous area of the on-line map appear in a less defined, discontinuous form. In our mind, these phenomena point out the difference between point-type and continuous measurement. For a better comparison of the measured parameters a map from the on-line measured data were produced taking into account only the values belonging to the penetrometer measurement points (Fig. 4.4.1.5.).

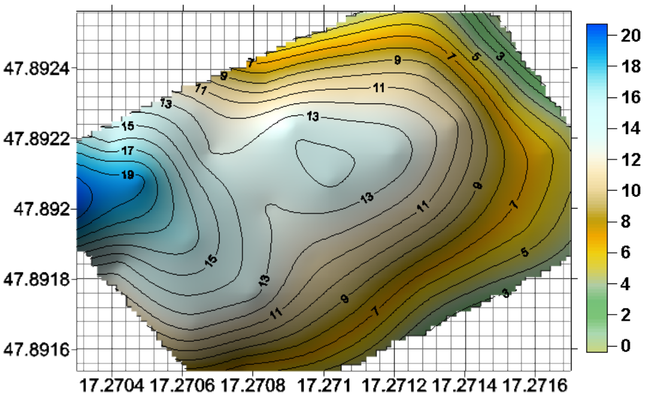


Figure 4.4.1.5. The map of on-line soil draft on the penetrometer measurement points (kN)

The pattern of the map shows similarity to those can be seen in Figure 4.4.1.4. however, in a more dissolved form. The positions of some measurement points are also visible.

Furthermore, the decrease of heterogeneity can be observed from the depth of 20 cm. The degree of compaction changes in a significantly narrower range than in case of the higher layers. This dual characteristics of the field is caused probable by the compacted layer is present under the typical depth of tillage. Nevertheless, significant statistical correlation between the results of the penetrometer and on-line measurement was not found despite some supposed visual similarity.

4.4.2. Measurements on the field no. 80/1

The above-mentioned dual characteristics reveals of this field as well. According to Figure 4.4.2.1. it can be declared that the layers from 5 to 20 cm and from 25 to 40 has different habits. This picture sounds entirely the typical field conditions arise in the lack of loosening. While, the compaction of the first 3 layers is under 2 MPa (except for point 2), down from 20 cm it tends to exceed this limit and with the increase of the depth it is over 3 MPa in the majority of cases.

The map from the data recorded by the on-line system using a loosener was generated (Fig. 4.4.2.2.). Since the penetrometer measurement points were marked out following the pattern of the on-line map as a control measurement its density is changing through the field and only 20 points were applied. This sampling intensity seems inadequate to provide entirely reliable image about the field however some maps were created.

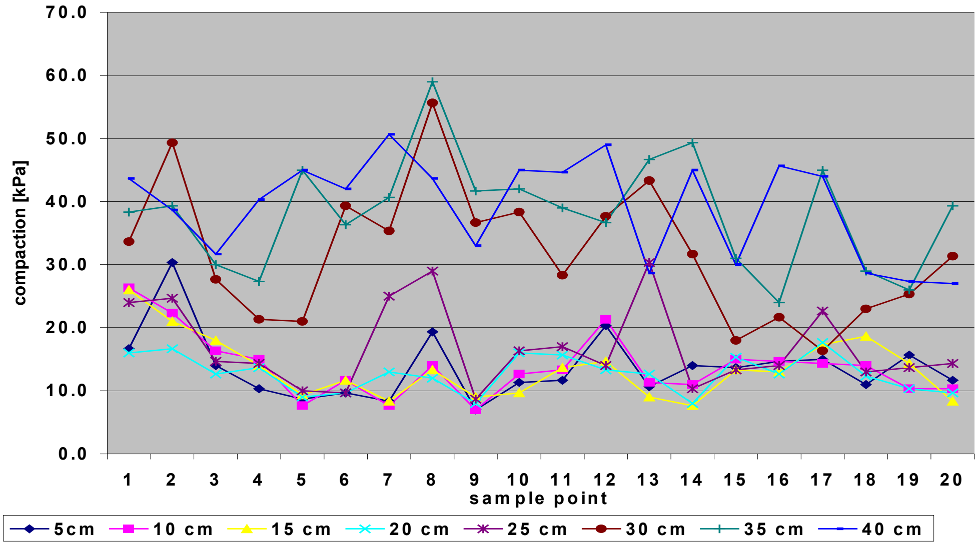


Figure 4.4.2.1. The level of compaction of the examined soil layers

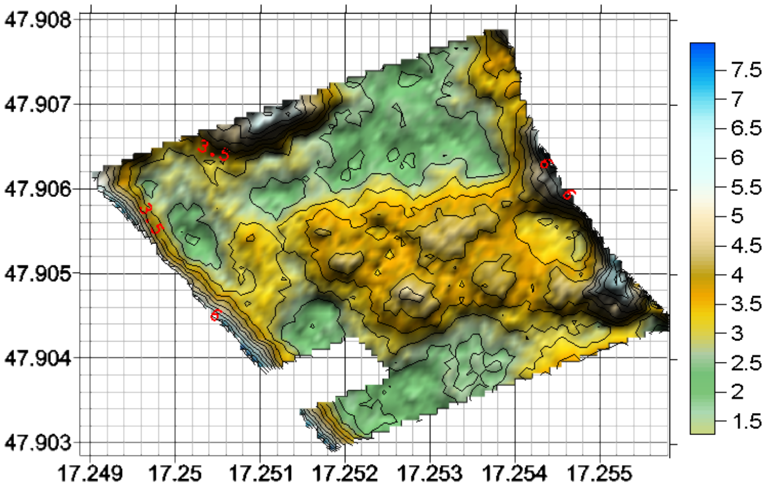


Figure. 4.4.2.2. Soil draft map of the field no. 80/1 (kN)

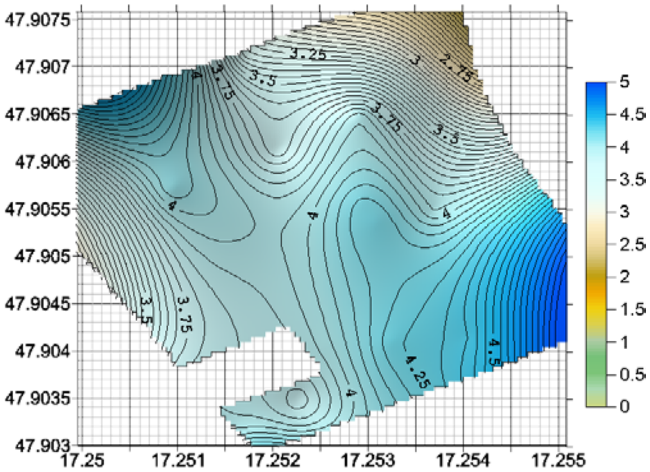


Figure 4.4.2.3. Penetrometer map of the 40 cm soil layer (MPa)

Similarity among the soil draft and penetrometer maps cannot be discovered by visual analysis. The patterns of K_A (Fig. 4.1.1.) and soil draft maps are resemblant. The connection between these two properties seems to be an inverse proportionality: the highest compaction values were measured on the area with low K_A, and vice versa. Besides, there is a very definite difference among the maps concerning to their resolutions. While the K_A map origins from 63 data and the penetrometer map is results of 20 measurements the on-line map is based on more than 3600 measured data (approximately 236 points per ha). Consequently, their comparison is a difficult task.

Statistical analysis was carried out in order to explore the correlation between the values measured by penetrometer and the soil draft monitoring system and even their relation to the K_A data determined by laboratory analysis.

The strongest relation between K_A and penetrometer resistance was found in a depth of 25 cm comparing the average values of the management units (compaction is reported from map). The r^2 value was 0.49 (Fig. 4.4.2.4.).

However, taking into account the point data of the penetrometer measurement the coefficient of determination decreases further ($r^2 = 0.21$).

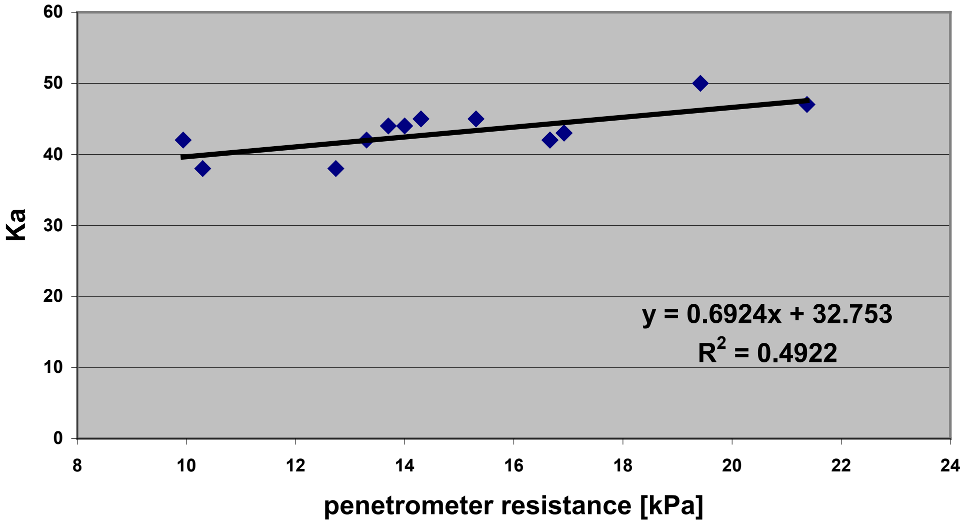


Figure 4.4.2.4. Correlation between K_A and penetrometer resistance (interpolated) in the depth of 25 cm

The connection between the on-line soil draft and the K_A showed neither significant correlation. Taking into account the point data of the on-line measurement, the correlation decreased further. Of course, different levels of compaction may occur in case of soils with the same K_A. It can be the situation in our case as well, because K_A changing in a narrow range while soil draft shows a higher scale of deviation.

Comparing the on-line soil draft and penetrometer resistance datasheets the strongest correlation was found in case of the 20 cm soil layer (between interpolated data sets) with a correlation of determination of 0.45 (Fig. 4.4.2.5.).

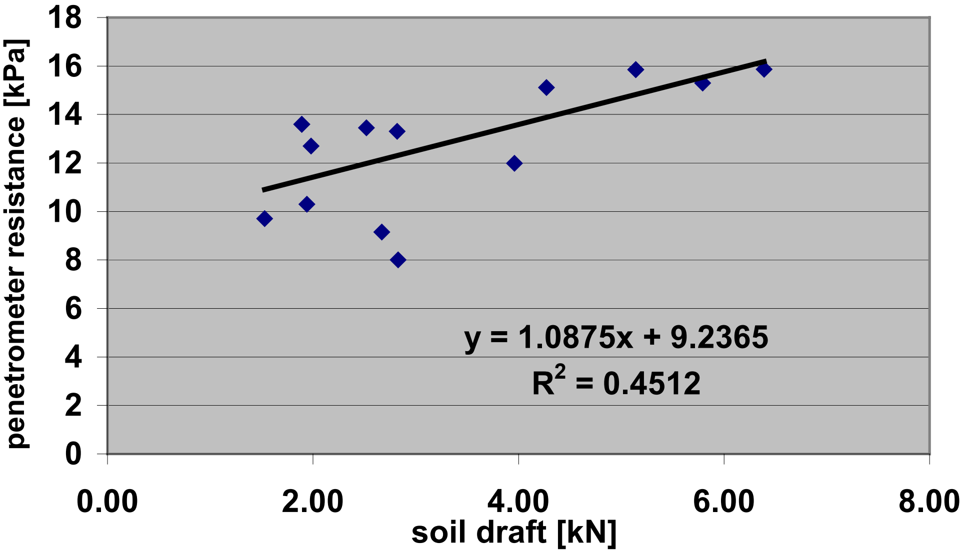


Figure 4.4.2.5. Correlation between interpolated on-line soil draft and interpolated penetrometer resistance in 20 cm

Again, taking into consideration the penetrometer resistance as point data the r^2 value reduced significantly (0.24). In the 25 cm depth no any correlation was found. But with the increasing depth a different tendency can be observed. Down from 30 cm, the comparison between interpolated values reflects weaker relationship than point-point or point-interpolation comparison. For example, by the 35 cm layer the r^2 value was 0.21 in case of interpolated-interpolated comparison, whereas it was 0.47 comparing point to point. In 40 cm depth there was not found correlation except for the one between the interpolated databases ($r^2 = 0.29$). The summary of the level of correlation is presented in Table 4.4.2.1.

Table 4.4.2.1. The summary table of the r^2 values between the measured penetrometer resistance and soil draft

	penetrometer / on-line			
depth	interp./interp.	point/interp.	interp./point	point/point
20	0.4512	0.2441	0.0414	0.0621
25	0.1483	0.1045	0.1799	0.0024
30	0.1754	0.1542	0.3511	0.2933
35	0.2155	0.1556	0.4068	0.4796
40	0.2917	0.0586	0.0273	0.1402

Based on the presented r^2 values and the deviation present in the data it can be declared that no clear significant statistical correlation can be demonstrated between the penetrometer resistance and the continuously measured soil draft in case of the described trial.

The effect of the measured soil physical parameters on the yields was also examined, but no statistically justifiable connection was found. However, the visual evaluation of the soil draft- and yield maps contradicts this statement. The pattern of the compaction map generated from the on-line data set (Fig. 4.4.2.2.) shows exact correspondence to the yield maps of three years (Figs. 4.2.1.1., 4.2.2.1. and 4.2.3.1.). Fig. 4.4.2.6. confirms this relation. Higher level of compaction is present on the lower yielding area, while higher yields are typically measured on the areas with lower compaction. The fitting was very similar in case of maize in 2002 and spring barley in 2003 but the demarcation could have been observed around 5 t/ha and 3.8 t/ha, respectively (Appendix 9.). This increase signs that the direct and indirect effect of soil compaction on yield was less explicit after site-specific nutrient application.

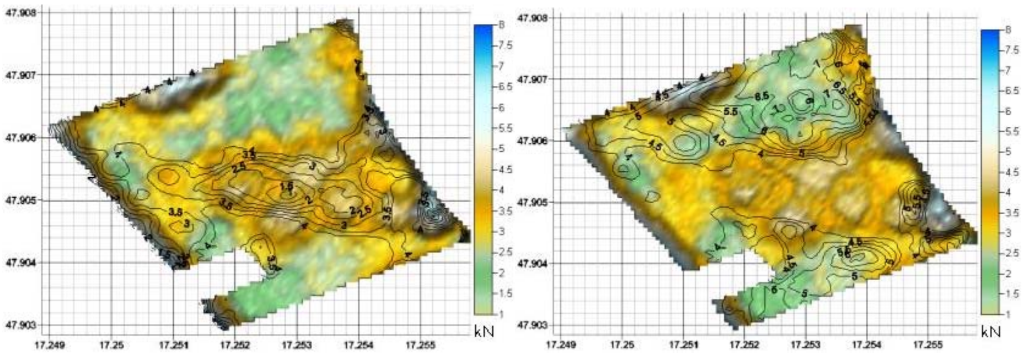


Figure 4.4.2.6. The on-line soil draft map with the contours of yield below (left) and above (right) 4 t/ha, respectively (maize, 2001).

4.5. Investigations with optical device based system

4.5.1. Weed monitoring

Comparing the reference measurement with the on-line computer measurements the best threshold for dividing weed from ground was discovered at 127 with an average error of 13 percent. In our opinion this error is mainly caused by lighting influence in the field. A weed (plant) coverage map of the 1 ha practice field was mapped as stubble analysis (Fig. 4.5.1.1.).

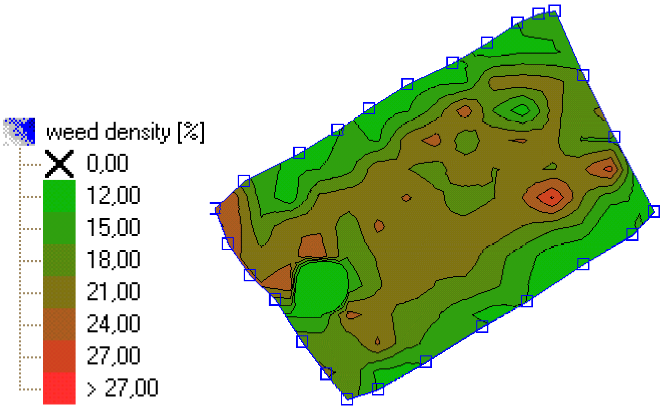


Figure 4.5.1.1. Weed (plant) density map

The image captured in infrared range provides more useful information. The infrared technology increases further the accuracy of plant and soil characterisation because the weed and ground characteristics are more explicit and it seems promising even for weed identification (Fig. 4.5.1.2.). In case of the infrared camera the average error between automatically analysed and manually measured weed density was only 1 percent.

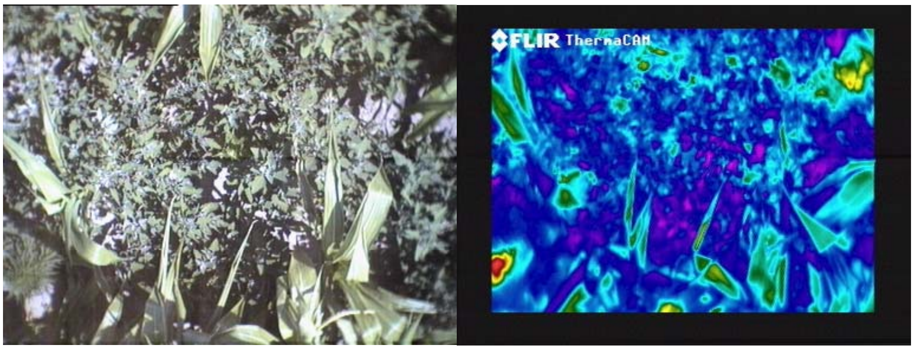
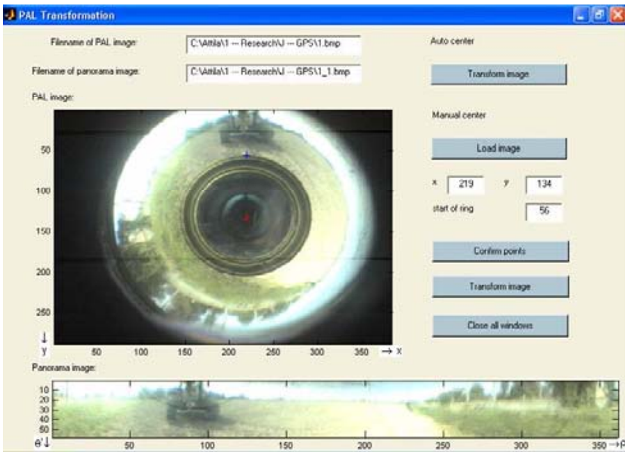


Figure 4.5.1.2. Images of mixed canopy of maize and weed provided by the CCD and the Infrared camera, respectively

The adaptation of the HMVS proved to be successful: the scanned area of the monitoring system has been significantly enlarged. Opposite to the 4 m^2 covered area of the CCD the 1 ha experimental field may be captured with a single image taken from a height of only 1,5 m. As the HMVS provides a special image a special transformation is required. For this purpose a Matlab application was developed by Maniak (Maniak et al., 2003). The surface of this application with the HMVS image and the transformed image is shown in Figure 4.5.1.3. For the poor image quality the limited resolution of the CCD and the PAL prototype are responsible. An advanced version of the HMVS module is available yet together with a 4 megapixel CCD. The significant increase of the resolution is expected.



Filename of PAL image: C:\Attila\1 --- Research\J --- GPS\1.bmp

Filename of panorama image: C:\Attila\1 --- Research\J --- GPS\1_1.bmp

x 219 y 134

start of ring 56

Figure 4.5.1.3. The PAL image and the transformed one in the Matlab application

4.5.2. Pest monitoring

The infrared technique proved to be an efficient tool in case of pest monitoring as well. The sensitivity of 0.1 °C turned out to be sufficient. Both the imagoes and the grubs of Colorado beetle (*Leptinotarsa decemlineata Say*) are sharply differentiated from the surrounding canopy. The temperature difference reaches the 1-1.5 °C (Fig. 4.5.2.1.).

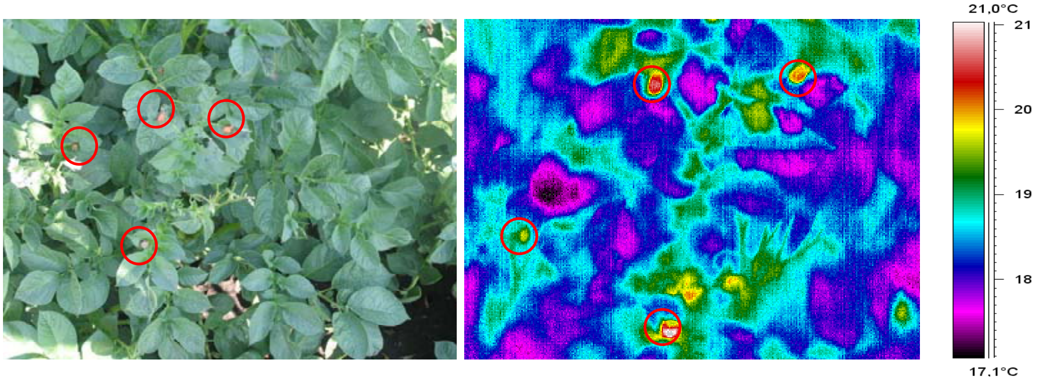


Figure 4.5.2.1. Imagoes and grubs of Colorado beetle on potato

Figure 4.5.2.2. shows that not only the insects directly but even the effect of the harm caused by them can be detected in this way. In this case the temperature of the champed plant parts was even 1.5-2.5 °C higher than the unharmed ones (Fig 4.5.2.2.).

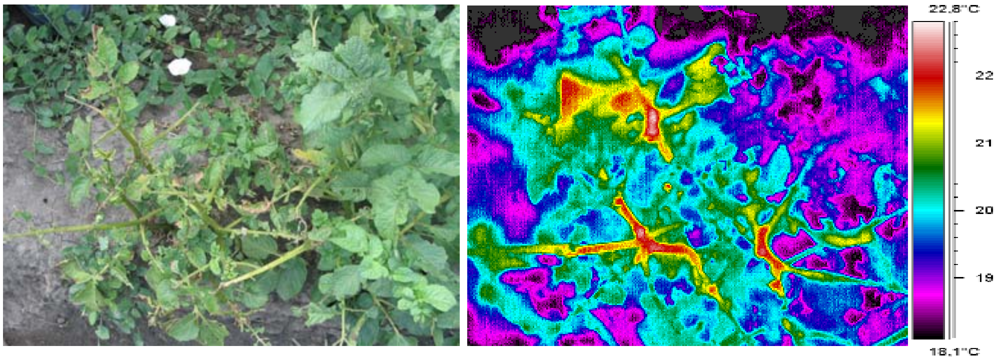


Figure 4.5.2.2. Temperature difference between champed (left) and unharmed (right) plants

Similarly, it was found that virus infection caused also a measurable (2-2.5 °C) temperature variance (Fig. 4.5.2.3.).

The assumed reason for the temperature distinction is the altered transpiration of the infected or harmed plants, what is caused by the changed metabolism or rather directly by the reduced transpiration surface.

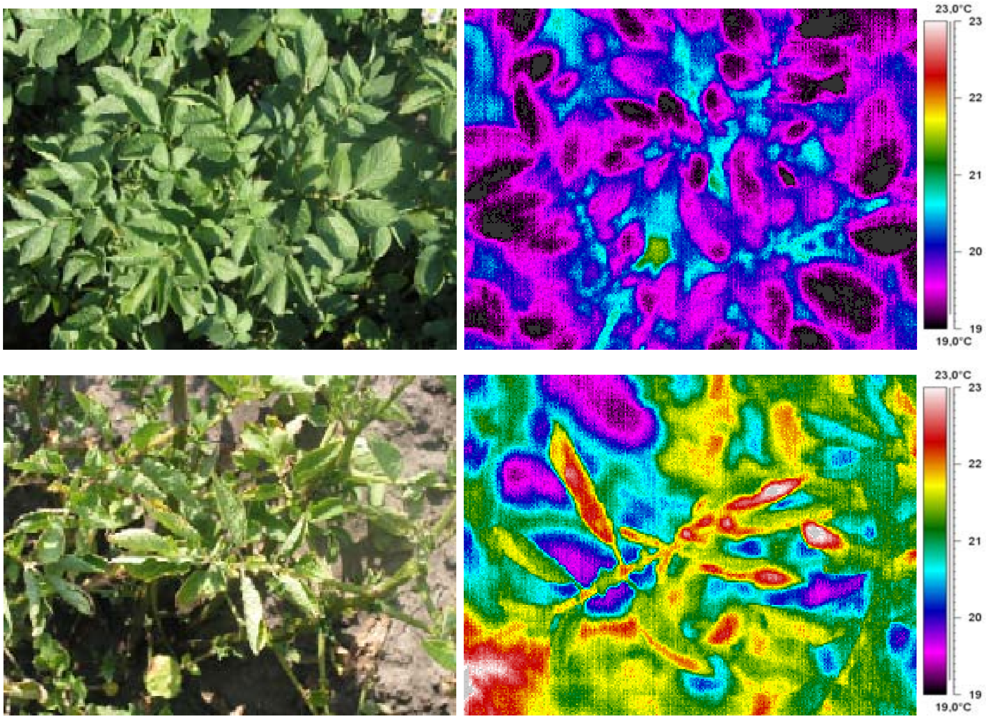


Figure 4.5.2.3. CCD and infrared image of healthy and virus infected potato

The investigation was carried out in dawn pointed out an equalised temperature distribution (Fig. 4.5.2.4.) – the above-mentioned temperature differences were eliminated. Only the soil surface was still warmer than the plant canopy. The difference between the damaged and unharmed plant parts was observable however, the temperature was equalised and some difference seemed to be caused only by the heat of the uncovered soil surface.

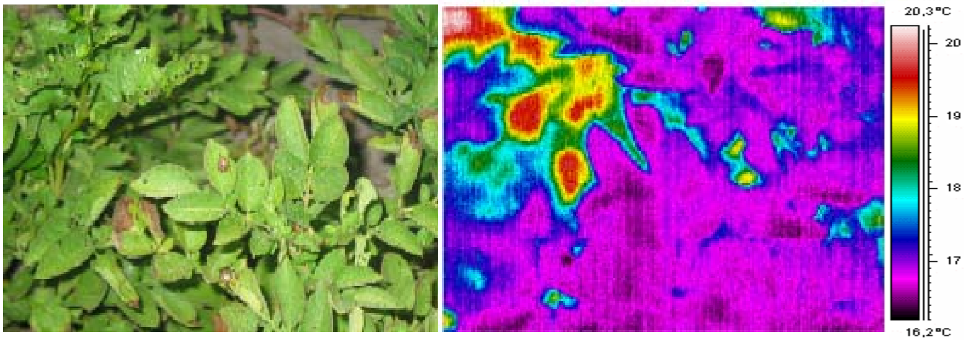


Figure 4.5.2.4. CCD and Infrared image of potato infected with Colorado beetle taken in dawn

4.6. Data transfer among precision farming systems

The transform file - created as “txt file” - can be chosen in the AgroMap Basic’s import menu and the custom import procedure can be applied. The information of the file can be reflected as row data map and it is possible to save it with “aft” extension. After that, it can be handled as the AgroMap Basic’s own row data. Since not only the yield and moisture but also the height data are involved a more complex view can be achieved about the field. Other geo-coded information can be imported in this way as well. It is also the key for using data origin from different sources and for applying different made of machines and precision farming systems together.

As a result, a yield map was created from the RDS yield data (Fig. 4.6.1.). (Yield data were collected by Pecze, Institute of Agricultural, Food and Environmental Engineering.)

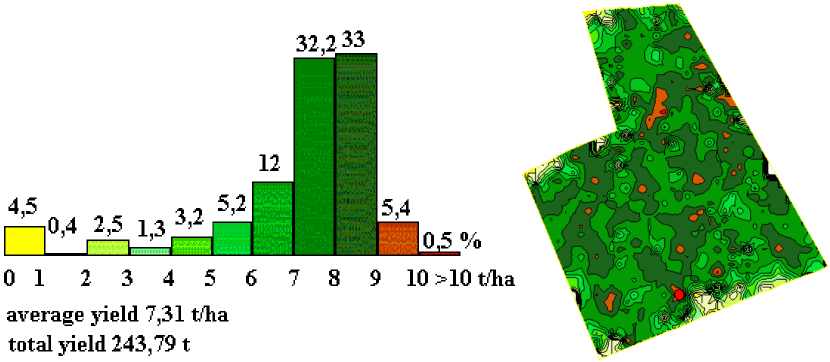


Figure 4.6.1. Yield map in Agromap Basic from RDS data

Similarly, grain moisture content was also transformed and mapped (Fig. 4.6.2.).

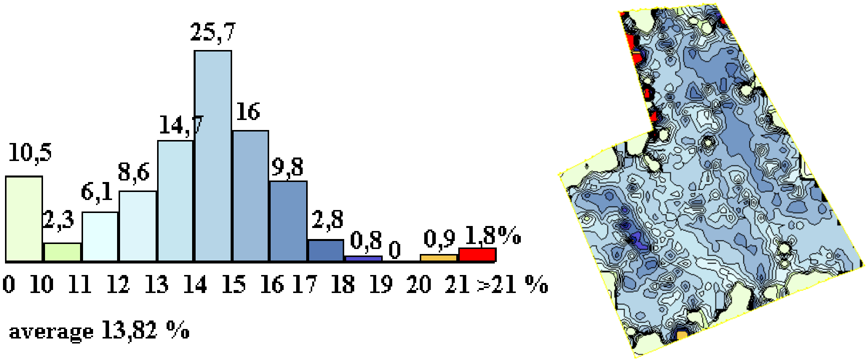


Figure 4.6.2. Grain moisture content map in Agromap Basic from RDS data

Using the same method it was possible to dissociate and evaluate separately any part of a given RDS yield map in Agromap Basic (Fig. 4.6.3.). This function is not available in the RDS PF software.

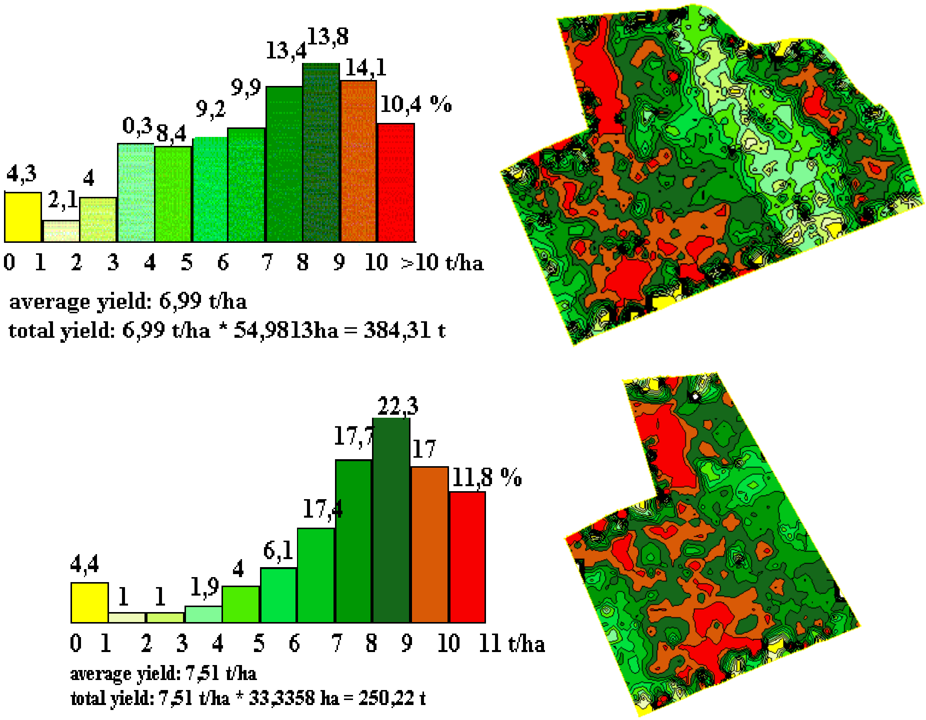


Figure 4.6.3. Dissociation and separate evaluation of an RDS yield map in Agromap Basic

Since “txt” format is widely supported, it is possible to read the recorded information into other software as well. Thus, additional presentments (e.g. three-dimensional relief model) are also available (Fig. 4.6.4.), which are not accessible in case of the above mentioned mapping programs. The relief and its effect can also be taken into account during decision-making in this way.

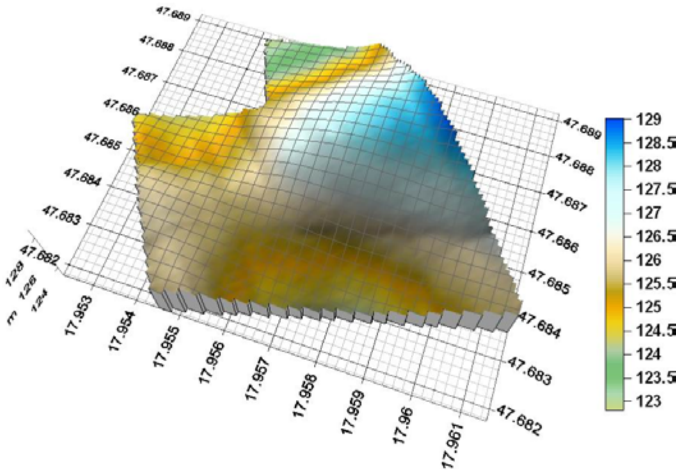


Figure 4.6.4. Three-dimensional relief model from RDS data in Surfer 8 (m)

Based on the reported idea data transformation software was developed by Stephan Maniak and has integrated into both the weed- and soil draft-monitoring program. By now, these applications have been combined in one program. As a result, all the gained information may be transformed into the required format (*.xls, *.txt, RDS and Agrocom ACT, etc.). It must be however mentioned that the referred application is a working computer program supporting a wider range of file formats comparing to the above-mentioned method.

4.7. Investigations in connection with machine guidance

Due to the RDS Marker Guide System it was possible to keep an even working width during any field job. Nonetheless, as it was mentioned in “Materials and methods” a consequent displacing of the guidelines was observed. The results of the trial were carried out in the 1 ha exercise field proved that it was not a one-time phenomenon. According to Figure 4.7.1. the measured average distance between two pathways (red) was 18.07 m. However, an overall deviation of 0.26 m was found among the subsequent runs (Fig. 4.7.1.). The blue line is the measurement tool of the software.

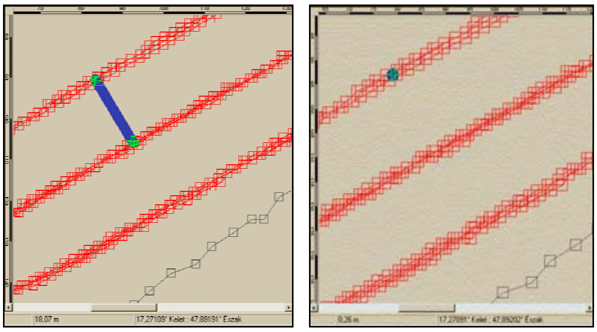


Figure 4.7.1. The analysis of the recorded DGPS data (Agromap Basic)

(Based on our experiments it can be stated that this deviation was caused mainly by the so-called human factor – the error of the driver – that happens under practical conditions as well.) It proved to be possible to drive the tractor several times on its own wheel-track. Nevertheless, repeating the runs with significant time gap the consequent displacing of the guidelines occurred again. The degree of this shift exceeded even the 3 m between extreme values (Fig. 4.7.2.).

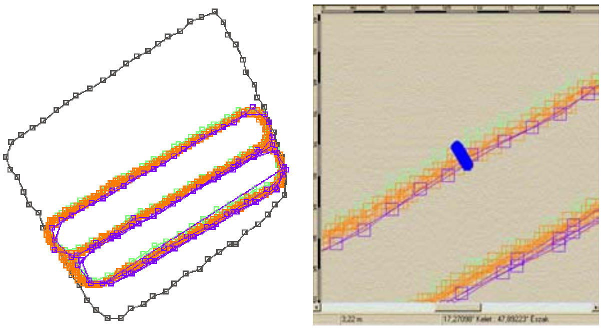


Figure 4.7.2. Displacing of the guidelines

5. CONCLUSIONS AND SUGGESTIONS

5.1. Soil sampling

Soil sampling can be applied for site-specific information gathering using positioning with adequate accuracy (1 m or better). The applied DGPS navigation proved to be a very easily usable and practical solution. The value of the gained information, however, is influenced by several factors. In addition to the so-called measurement error and human factor, from our point of view the sampling density and pattern seem to be among the most important elements. By the general principle these should be in accordance with the infield heterogeneity of the soil characteristics. But neither genetic soil maps nor soil sampling carried out in the traditional way provide enough detailed information. Therefore, grid sampling, one of the most common sampling methods for experimental purpose was carried out using a 50 x 50 m grid, which is considered satisfactorily dense in the international literature. The comparison of soil supply maps based on different grid sizes shows a decrease in resolution and consequently accuracy. This phenomenon occurred in case of mapping soil physical properties as well. These experiences drew our attention to the importance of continuous measurement. As the number of measurement points may be increased only within reasonable limits (time, labour and economic reasons) the accuracy of point measurements is always limited. In addition to measured values predicted values are present, which are dependents of the applied calculation method.

Therefore, it is required to work out the method and technique for continuous measurement of soil physical and chemical properties, as at present there is no available solution for each important soil property. (Some achievements in this field are referred to in Chapter 2.2.) An alternative may be the elaboration of a method to define the necessary sample intensity and likely the pattern as well, taking into account the available information. Yield data, EC- and spectral measurements are applied in order to define the management units within the field, however it should be remembered that these properties are influenced by many factors.

5.2. Yield monitoring

Yield monitoring is an obvious way of gathering a large number of site-specific data about a given field. In our case the 15.3 ha field was characterized with approximately 8200 measured values, meaning more than 500 measurements per hectare. The process does not require additional runs and gives an accurate picture of yield quantity and heterogeneity and of grain moisture content. In our case the returning yield pattern with the typically low yielding indicated that a factor was present throughout the trial period. By means of draft monitoring this correlation could be revealed.

The strip with high grain moisture content observed in 2001 recurred in 2002 as well, although in a less distinct form. This observation provides the possibility to harvest the given part separately. In this way, possible problems caused by grains with significantly heterogeneous grain moisture content can be avoided during drying and more uniform quality could be reached. On the other hand, the economic savings can be considered as well.

The application of the Agrocom ACT Yield monitoring system under practical circumstances proved to be successful. The investigations repeatedly confirmed that yield - just like other parameters - shows heterogeneity within the field. Consequently, site-specific (precision) technology has reason for existence.

In summary the following statements can be made related to the operation of the yield monitoring system:

- the yield monitoring system has basically no effect on the functioning of the harvester; but
- a consequent behaviour (the cutter bar has to be lifted up entirely at the end of the rows, no sudden changes should be made in forward speed) and additional attention (prediction and adjustment of the actual cutting width) are required during the operation;
- the yield-monitoring menu of the ACT can be used easily;
- yield monitoring can be carried out with high accuracy; the average (field) error was within 5%;
- the unfortunate attitude of the unreliable and incompetent Hungarian system distributor, however, retains the general use not only of this system in agricultural practice but the whole technology as well. For example, the reinstallation of the hardware parts of the system to maintain accurate operation, as well as the retuning of the DGPS receiver had to be carried out by ourselves. This kind of policy is unacceptable in practice.
- The high price of the differential signal is also disadvantageous.

Suggestions in connection with yield monitoring:

- the yield monitoring systems should be supplemented with an automatic cutting width sensor;

- in order to promote the success of the real potential of the site-specific technology an advisory-expert network should be developed;
- a special supported licence for farmers should be introduced, taking into consideration the periodicity of agricultural production and the ecological benefits of the technology.

5.3. Site-specific nutrient replenishment

Based on the field trials the following declarations are made:

- The applied disc spreader and VRA control system is capable of variable rate application of solid fertilisers with high accuracy under practical conditions.
- The user surface of the fertiliser application menu in the ACT is too complicated for practical use. The programs for the Amazone MAX-Tronic and Hydro-Tronic (hydraulic drive) are not separated, they are mixed. The software part of the Agrocom ACT system shows instability. The Agromap Basic installed into a PC tends to break down suddenly, without any previous sign. The ZUG_AM software in the ACT freezes several times when any application order is started. (German researchers also experienced such disorders.) The Agrocom Company checked the whole hardware and reinstalled the software, nonetheless, the problem still exists. On the other hand, it should be emphasized that data losing never occurred, and after starting the application the system was robust and reliable.
- During the planning of fertilizer distribution or even soil sampling the management grid cannot be turned, and in this way it cannot be made

parallel to the borders of any field. The software handles only the North-South directed grid. This feature is entirely incompatible with practice. The advantages of the software regarding the wide range of supported input format are discussed in Chapter 3.6.

- The system records the applied amounts as measured data and consequently the maps of applied fertiliser quantities can be produced. This function is very useful as the accuracy of distribution can be controlled even though it is not based on weight measurement but on the position information of the regulator of the spreader. This made it possible to use the actually applied amounts during statistical analysis even in case of application errors. It may help the user in getting a better understanding of the processes and correlations occurring on a given field. In this way the potential inadequacy of the applied practice can also be explored. An example is presented under Chapter 4.3. Similarly, the improper traffic during nutrient replenishment may be manifested in this form.
- Corresponding to the nature of the system only one agent can be applied at the same time. Not only the spreader, however, but the control system too means limitation in this respect.
- During spreading no directional guidance is available by the ACT, therefore there is a potential uncertainty of correct covering. Besides, the already treated area is not marked and repeated application is not prohibited.
- In order to eliminate these problems, the system was completed with the RDS Marker Guide System, which proved to be a reliable and accurate solution. The experienced guidance deviation was undoubtedly caused

by the GPS system itself. The tool does not function as an actuator, visual signs are given only, therefore both the directional correction and the stopping of spreading is done manually. In addition, the use of another DGPS receiver was required (the structure of the messages of the two DGPS receiver are different), which means additional cost.

- The technical problem occurring in 2003 was caused by the large amount of dust in the fertilizer despite it was packed in sacks and was not stored for a long time.
- The deviation of yield decreased, which is very likely ascribable to the more suitable nutrient supply.
- The nutrient replenishment advisory system developed by the RISSAC-HAS and RIA-HAS justified its potential even together with the site-specific technology. The reduced occurrence of low yielding categories shows that production safety has increased.

Suggestions concerning site-specific nutrient replenishment:

- The revision of the software part of the Agrocom ACT system is required, keeping in mind the above-mentioned problems (reliability, grid turning etc.). Regarding the practical establishment, e.g. the menu system of the RDS Pro-Series 8000 could be an example to be followed. In this case a three-level menu is applied. On the user level only those functions are available, which are essential for the given process (yield monitoring, nutrient replacement, etc.). The calibration and the fine tuning (e.g. applying the measured hectolitre weight contrary to the default value) of the system can be carried out in the technician menu, but the system parameters (e.g. DGPS settings) can be adjusted only in system administrator mode. The two latter menus are password protected.

- The directional guidance should be available for all applications not only in case of soil sampling.
- Besides the standardisation of file formats and signal protocols of the given control systems a uniform message structure for the output signals of the different DGPS receivers is required to make the different systems entirely compatible.
- The possibility of multiple treatment of the same area should be disabled.
- The elaboration of a control system capable of simultaneously regulating more agents is desirable (an example is described in Chapter 2.3.) In this way, the number of turns and, consequently, soil compaction could be reduced, and thus a restricted energy requirement of the agricultural cycle could be realised.
- Based on its capability the RDS Marker Guide System may be appropriate for autonomous machine guidance. The accuracy of its DGPS receiver does not allow its use in row cultivation, but it is satisfactory in case of the operations discussed in present study. As a first step the steering could be controlled by the electronics of the RDS Marker guide, thus eliminating the human error in this way.
- As regards dusty fertilisers, the evident consequence is that quality inputs are required by agricultural production.

5.4. Measurement of soil physical parameters

On the basis of the findings of the trials carried out the following conclusions can be drawn:

- The penetrometer resistance measurement with DGPS positioning is suitable for getting site-specific information on soil conditions. The recorded data make possible the mapping of the situation of the soil layer with critical compaction.
- However, this technique has certain limitations. As it is point measurement, sample density and consequently accuracy are restricted. The measured value is a static vertical (in our case) force, the character of which differs entirely from the complex dynamic forces acting on the surface of any tillage tool.
- Consequently, the penetrometer measurement does not provide appropriate information on the pulling force demand of tillage.
- The elaborated soil draft monitoring system provides the possibility of avoiding the above-mentioned imperfections. The measured property is described with a large number of data (depending on the working width and the adjustable logging frequency). In our case almost 3700 measurements were applied in the 15.3 ha (240/ha) field, and this can be further increased.
- No clear significant statistical correlation was found between the penetrometer resistance and the pulling force measured on-line.
- No significant correlation was justifiable between yield heterogeneity and the pulling force. On the basis of the exact similarity of the gained

maps, however, it can be said that yield was undoubtedly significantly influenced by soil compaction.

- Consequently the developed system can be considered as a proper draft-measuring tool under field conditions as well, even if the system does not take into account other influencing factors (e.g. soil moisture content). As a consequence of validation the equipment can even be used for absolute measurement, however its primary task is to define the real management zones within the field. Because of its low investment demand and the quite simple and reliable build-up of the system it can be qualified as a practice-matured device.

Suggestions in relation to the measurement of soil physical parameters:

- As the determinant effect of soil compaction on yield could be explored by means of the developed tool and as the continuous measurement proved much more advantageous in comparison to the penetrometer point measurement the practical use of the system is suggested.
- In spite of the promising results, further testing of the system is planned.

5.5. Investigations with optical device based systems

The following conclusions are drawn regarding the applied optical device based systems:

- The elaborated plant monitoring system is capable of defining plant density in on-line mode using CCD or infrared camera.

- In its present state the system cannot distinguish weeds from cultivated plants. It is suitable, however, for weed control between rows, or a stubble surveying can serve as the basis for pre-emergence treatment.
- The system's operation speed is not limited by the time demand of image analysis, consequently adequate productivity is provided.
- The application of the infrared camera improved the accuracy of plant density calculation and enhanced the differentiation of weeds and field crops.
- By means of the applied humanoid machine vision system the view area of the optical system has been enlarged significantly. The moderated resolution of the resulted image is caused by the prototype nature of the optic.
- The temperature of the *Leptinotarsa decemlineata* (*Say*) imagoes was 1-1.5 °C higher than that of the surrounding potato canopy. In case of plant parts harmed by the insects this difference reached 1.5-2.5 °C. Virus infection also manifested in a significant (2-2.5 °C) increase in temperature. Based on these observations it is said that the presence and the effect of the examined pests are detectable with a thermo-imaging system. As the required sensitivity is approximately one-tenth of the thermal resolution provided by the applied infrared camera, the cost of the system can be reduced significantly.

The following further developments in the system are planned:

- Elimination of the influence of sunlight.

- Integration of the panoramic image transformation module into the plant mapping software, and ensuring the positioning for each pixel of the recorded image.
- Site-specific application of the pest monitoring system in case of other vegetation using cheaper sensors.

5.6. Data transfer among precision farming systems

Conclusions drawn in accordance with data transfer:

- The transformation method worked out ensures the transfer of data between the software parts of the mentioned yield monitoring systems.
- Due to the data transfer the analysis and visualisation of the recorded information is available on a higher level.
- The export of the data into any GIS (e.g. ArcView) is also ensured in this way.

Suggestions related to data transfer:

- The standardisation should also include the file formats and extensions of the precision farming systems. A transformation method and a common format which to transform to is required. The use of the method and the GIS Export Format worked out by Stephan Maniak (2002) is recommended.

5.7. Investigations in connection with machine guidance

The following conclusions are made concerning the trials carried out with the RDS Marker Guide System:

- The RDS Marker Guide System proved to be an accurate, reliable and practical solution for directional guidance.
- Ensuring the even working width, the accuracy of any treatment (spreading, spraying) can be increased and can be applied during cultivation as well.
- Despite the sub-meter accuracy of its DGPS receiver a displacing of even 3 m of the guidelines may occur in case of a significant time lag between the subsequent runs. This error is caused by the GPS system itself. Consequently, it is stated that the applied system has the capability of being used as a basis of an autonomous machine guidance system in case of the field jobs studied in this work. However, this accuracy is not satisfactory for navigation between rows.

Suggestions regarding machine guidance:

- Regarding the advantages of the guidance tools on market, it can be recommended that these devices should become part of the variable rate machinery.
- The experienced displacing phenomenon should be taken into account during the design of any autonomous machine guidance system. At the same time it is an answer to the initiatives according to which the use of the GPS signal without differential signal is adequate and exemplary in practice. On the contrary, our examinations confirmed the view that in

case of given cases further enhancement of the accuracy is required (e.g. RKTF GPS technique).

- The standardization efforts should consider the signal structure of the DGPS receivers applied in agriculture as well. The compatibility of different systems cannot be complete without it.

6. NEW SCIENTIFIC RESULTS (THESIS)

1. On the basis of my measurements I state that although the number of sample points required to achieve the objective image of in-field heterogeneity can be defined, this sampling intensity is practically unachievable. Therefore, continuous (on-line) measurement of the mentioned properties is necessary. (The continuous soil draft monitoring method was developed for this purpose.)
2. The pattern of the compaction map generated from the on-line data set shows correspondence to the yield maps of three years, under the given circumstances.
3. Based on my measurements I declare that the vertical cone penetrometer resistance and the complex forces measured on the surface of the cultivator tools differ significantly. The (vertical) penetrometer measurement provides insufficient information about the energy demand of the tillage, especially in case of the sample density that can be achieved under practical circumstances.
4. Statistically justifiable equalization of the yield took place within the field after the applied site-specific nutrient spreading. Based on my investigations I declare that the effect of aridity on yield can be decreased by using the RISSAC-HAS - RIA-HAS (Research Institute for Soil Science and Agricultural Chemistry and Research Institute for Agronomy of the Hungarian Academy of Sciences) fertiliser advisory system, which can be successfully applied combined with VRA systems.
5. Based on the conducted examinations I express that the information provided by the established weed monitoring system is adequate for weed monitoring between plant rows or as stubble analysis.

6. The presence of insects as well as the harm caused by virus or insects are measurable by the temperature difference. Based on my investigations I pronounce that the degree of this temperature difference makes sensing possible with less sensitive (thus significantly cheaper) sensors as compared to the 0.1°C of the applied infrared camera.
7. The elaborated data transformation method ensures the data transfer between the Agrocom ACT and the RDS yield monitoring systems. Consequently, the joint application of the two systems and an advanced level of data analysis are ensured.

7. SUMMARY

This study intends to provide a review about the already achieved results and the running research project in the field of precision plant production. Focusing mainly on the further development of the sensing technology our primary goal was to develop practically realizable solutions with respect to the Hungarian agricultural conditions.

In the frame of the established field trial the engineering background of the site-specific plant production technology was investigated involving yield monitoring, soil sampling and solid fertilizer distribution. The soil analysis results and the soil supply maps are presented together with the yield and grain moisture maps of maize (2001 and 2002) and spring barley (2003). The Agrocom ACT yield monitoring system is declared to be suitable for gathering site-specific yield and grain moisture content information. The average error of yield measurement can be kept under 5%. The application of automatic cutting width measurement is urged at the same time.

The results of fertilizer application were also investigated. It was found that the examined Agrocom ACT – Amazone ZA-M Max Tronic system is capable of operating within an average range of error of 5%. Nevertheless, the recorded application maps pointed out that the rout and the quality of the fertilizer may significantly influence the application accuracy. It is stated that the revision of the software part is required keeping in mind the mentioned problems (software stability, turnable management grid). As directional guidance is available in the AgroSoil menu of the ACT the system has the capability of this task. With a more reasonable software structure this function should be ensured during any application (zug_am menu) as well. Similarly, the possibility of multiple treatment of the same area should be disabled. The development and application of a control system for simultaneous application of several agents are pressed.

The relation among soil parameters; soil parameters and yield data were analysed. It is remarkable that Na, Mg, Zn and Cu turned out to play important role regarding to the yield. The effects of the soil characteristics and the applied fertilizer replacement on the yields and grain moisture contents were investigated as well. Statistically justifiable equalization of the yield took part within the field. The assumed reason for this phenomenon is the more harmonic nutrient supply ensured by the Fertilizer advisory model developed by the RISSAC-HAS – RIA - HAS (Research Institute for Soil and Agricultural Chemistry and Research Institute for Agronomy) of the Hungarian Academy of Sciences). The model proved to be an effective tool even in case of variable rate application (VRA).

The question of optimal sampling method and density arose in connection with both soil sampling and soil physical property mapping. An example of the information degradation and distortion with decreasing sampling intensity is presented. The consequence drawn by the author that the continuous measurement of physical and chemical soil properties is desirable.

Investigations in connection with soil physical property mapping are also published. For this purpose, a self-developed continuous soil draft measurement system is described. The system measures the signals of the load cells built in the EHS of the tractor. The measured values are stored in the hard disc of a field computer together with the actual position. Due to the defined equation the measured voltage data can be transformed into force. Examinations with the on-line system took part simultaneously with GPS-aided cone penetrometer resistance measurements. Comparing the on-line soil draft and penetrometer resistance datasheets the strongest connection ($r^2 = 0.45$) was found in case of the

20 cm soil layer (between interpolated data sets). Nonetheless, the comparison of the different databases is difficult since their resolutions differ; and on the other hand the exact coincidence of the measurement points cannot be ensured. Nevertheless, the pattern of the compaction map generated from the on-line data set shows exact correspondence to the yield maps of three years. Consequently the developed system can be considered a proper draft-measuring tool even under field circumstances. Even if the system does not take into account other influencing factors such as e.g. the soil moisture content. As a consequence of the validation the equipment may be used even for absolute measurement, however its primary task is likely to define the real management zones within the field.

The established weed monitoring system has the capability for plant density monitoring with an average error of 13% or rather 1% using CCD and infrared, respectively. The provided information is adequate for weed monitoring between plant rows or as stubble analysis.

The integration of the PAL objective with a horizontal view angle of 360° into the precision plant production system was successful. The mentioned optic is an effective tool to enlarge significantly the scanning area of any optical device-based system.

The infrared technique proved to be an efficient tool in case of pest monitoring as well. The sensitivity of 0.1 °C turned out to be sufficient. Both the imagoes and the grubs of *Colorado beetle* (*Leptinotarsa decemlineata*, *Say*) are sharply differentiated from the surrounding canopy. The temperature difference reaches the 1-1.5 °C. Not only the insects directly but even the effect of the harm caused by them can be detected in this way. It this case the temperature of the champed plant parts was even 1.5-2.5 °C higher than the unharmed ones.

Similarly, it was found that a virus infection caused also a measurable (2-2.5 °C) temperature variance (Fig. 4.5.2.3.).

A data transformation method described, which ensures the data transfer between the Agrocom ACT and the RDS yield monitoring systems. Consequently, the joint application of the two systems and an advanced level of data analysis are ensured. It is emphasised however that the standardization efforts should consider the signal structure of the DGPS receivers applied in the agriculture as well. The compatibility of different systems cannot be complete without it.

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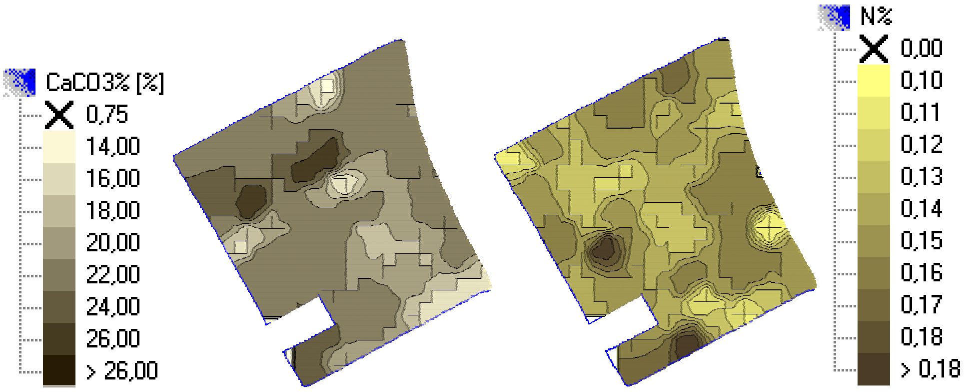
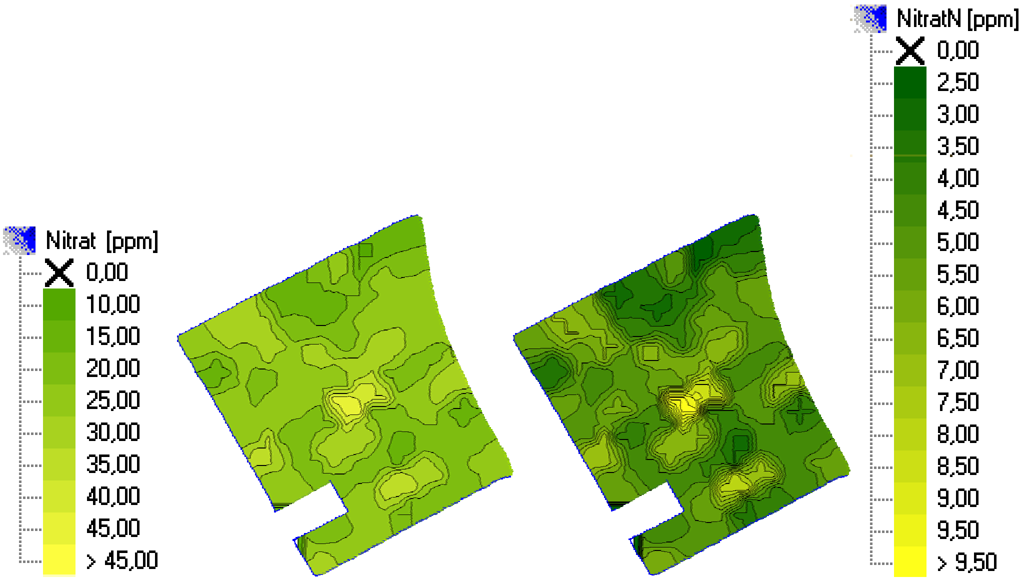
10. APPENDIXES

Appendix 1. *Soil supply maps*

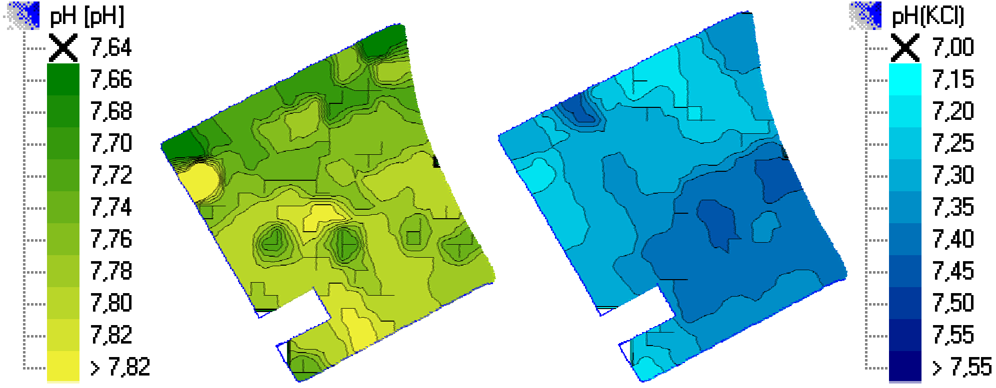


$CaCO_3$ and nitrogen supply maps of the experimental field 80/1

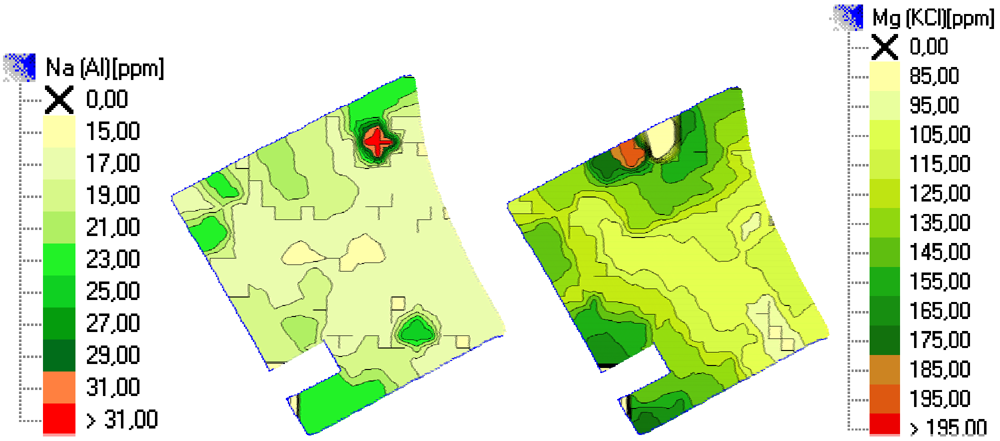


Nitrate supply and nitrate nitrogen supply maps of the experimental field 80/1

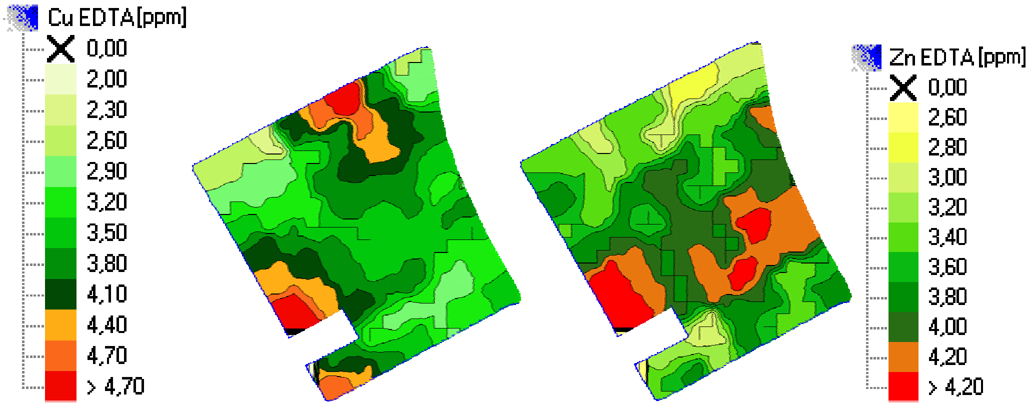
Appendix 1. (cont.)



pH $_{H_2O}$ and pH $_{KCl}$ maps of the experimental field 80/1

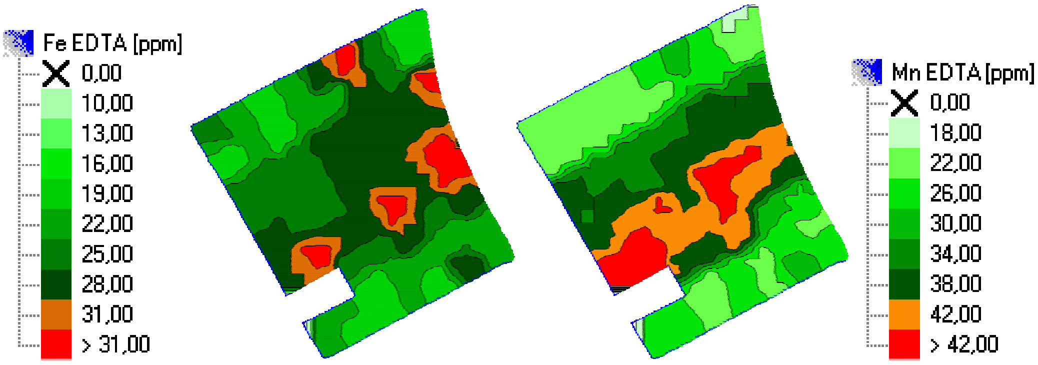


Sodium (Na) and magnesium (Mg) supply maps of the experimental field 80/1

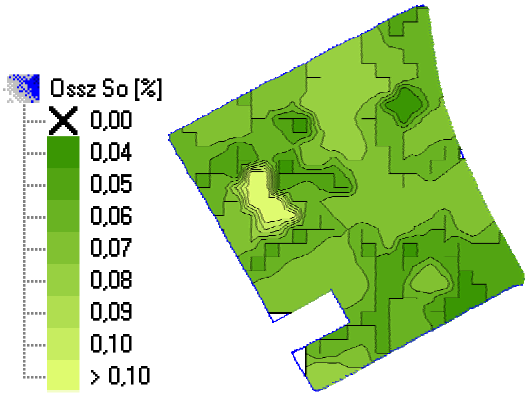


Cu and Zn (EDTA) supply maps of the experimental field 80/1

Appendix 1. (cont.)



Fe and Mn (EDTA) supply map of the experimental field 80/1

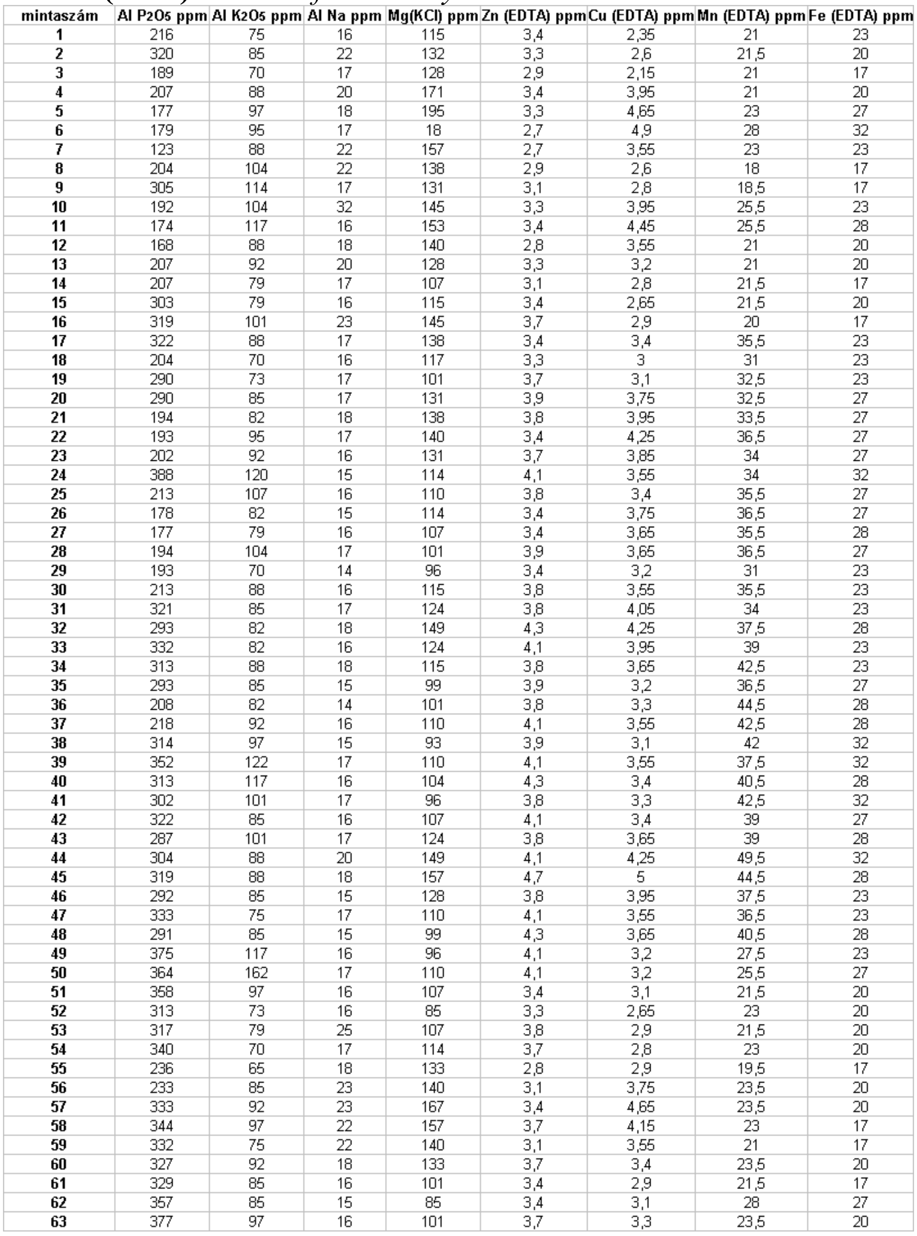


Salt content map of the experimental field 80/1

Appendix 2. *Results of soil analysis*

treatment unit	pH H2O	pH KCl	KA	salt%	CaCO3%	hu%	total N%	Nitrate ppm	Nitrate N ppm
1	7,63	7,29	46	0,06	21	2,5	0,11	23	5,17
2	7,69	7,24	48	0,07	22	3,3	0,15	29	6,52
3	7,72	7,42	45	0,06	22	2,65	0,13	26	5,85
4	7,71	7,23	50	0,07	20	3	0,15	13	2,92
5	7,69	7,15	48	0,07	18	3,25	0,16	15	3,37
6	7,69	7,17	46	0,08	14	3,25	0,15	21	4,72
7	7,76	7,24	49	0,07	21	3,25	0,17	10	2,25
8	7,62	7,33	44	0,05	22	2,5	0,15	13	2,92
9	7,78	7,32	45	0,06	22	2,5	0,14	16	3,6
10	7,7	7,21	50	0,07	22	3,3	0,15	22	4,95
11	7,68	7,2	46	0,08	22	3,1	0,13	15	3,37
12	7,78	7,25	49	0,08	22	3,25	0,15	13	2,92
13	7,76	7,3	48	0,04	22	3,25	0,15	16	3,6
14	7,71	7,28	43	0,06	22	2,75	0,13	27	6,07
15	7,73	7,26	45	0,04	22	2,85	0,13	23	5,17
16	7,93	7,18	47	0,05	24	3,3	0,15	14	3,15
17	7,74	7,23	42	0,06	22	3	0,15	23	5,17
18	7,76	7,26	41	0,11	26	2,65	0,13	18	4,05
19	7,74	7,31	38	0,04	22	2,5	0,12	21	4,72
20	7,73	7,28	44	0,07	25	3	0,12	27	6,07
21	7,74	7,27	46	0,08	25	3,1	0,14	17	3,82
22	7,75	7,2	44	0,06	21	3,45	0,15	23	5,17
23	7,75	7,23	42	0,03	22	3	0,13	22	4,95
24	7,71	7,28	42	0,06	20	2,15	0,12	24	5,4
25	7,75	7,25	42	0,07	22	2,85	0,15	22	4,95
26	7,74	7,26	44	0,06	19	2,7	0,13	28	6,3
27	7,77	7,29	44	0,07	14	2,75	0,14	26	5,85
28	7,74	7,26	40	0,04	19	2,5	0,13	24	5,4
29	7,8	7,31	40	0,06	22	2,15	0,15	22	4,95
30	7,8	7,28	39	0,11	18	2,7	0,13	25	5,62
31	7,79	7,23	42	0,07	16	3,2	0,16	21	4,72
32	7,79	7,28	42	0,05	22	3,3	0,14	31	6,97
33	7,7	7,26	40	0,05	22	2,95	0,19	17	3,82
34	7,82	7,32	40	0,05	21	2,6	0,15	18	4,05
35	7,83	7,35	38	0,07	22	2,95	0,12	43	9,67
36	7,75	7,4	42	0,07	22	3,05	0,13	36	8,1
37	7,8	7,36	38	0,06	20	2,95	0,16	18	4,05
38	7,79	7,4	38	0,05	20	2,6	0,16	19	4,27
39	7,79	7,42	41	0,07	22	2,95	0,16	29	6,52
40	7,77	7,37	38	0,07	19	2,85	0,15	22	4,95
41	7,79	7,42	39	0,07	17	2,7	0,13	17	3,82
42	7,7	7,36	38	0,05	20	2,45	0,13	27	6,07
43	7,78	7,38	40	0,07	22	2,8	0,14	28	6,3
44	7,8	7,33	42	0,07	22	2,9	0,15	19	4,27
45	7,78	7,26	41	0,07	22	3,1	0,14	23	5,17
46	7,8	7,35	40	0,07	20	2,8	0,14	19	4,27
47	7,76	7,38	40	0,05	20	2,8	0,16	17	3,82
48	7,8	7,4	38	0,04	18	2,4	0,15	13	2,92
49	7,74	7,34	40	0,05	18	2,65	0,16	20	4,5
50	7,78	7,36	42	0,07	20	2,6	0,1	14	3,45
51	7,72	7,38	39	0,05	21	2,65	0,15	19	4,27
52	7,78	7,4	39	0,04	18	2,35	0,16	18	4,05
53	7,8	7,4	40	0,07	19	2,5	0,15	30	6,75
54	7,78	7,36	42	0,05	22	2,6	0,11	35	7,87
55	7,82	7,37	42	0,05	21	2,7	0,13	23	5,17
56	7,79	7,25	43	0,05	24	3,05	0,15	18	4,05
57	7,72	7,19	47	0,08	24	3,25	0,17	26	5,85
58	7,79	7,26	47	0,07	18	3,25	0,17	22	4,95
59	7,83	7,31	42	0,05	20	3,1	0,19	22	4,95
60	7,8	7,31	45	0,06	20	3,1	0,13	15	3,37
61	7,79	7,34	42	0,04	16	2,5	0,11	17	3,82
62	7,77	7,32	38	0,04	16	3,1	0,13	19	4,27
63	7,78	7,36	41	0,05	16	2,8	0,15	23	5,17

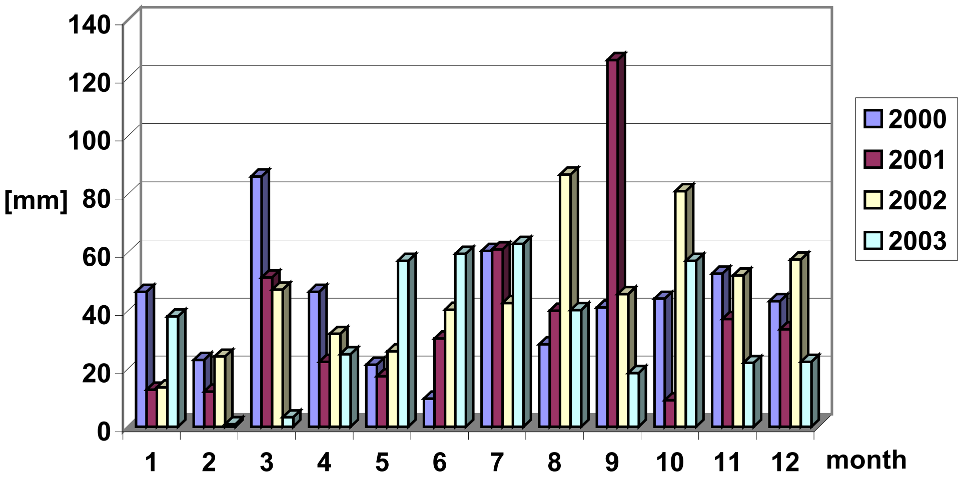
Appendix 2. (cont.) *Results of soil analysis*



mintaszám	Al P_2O_5 ppm	Al K_2O_5 ppm	Al Na ppm	Mg(KCl) ppm	Zn (EDTA) ppm	Cu (EDTA) ppm	Mn (EDTA) ppm	Fe (EDTA) ppm
1	216	75	16	115	3,4	2,35	21	23
2	320	85	22	132	3,3	2,6	21,5	20
3	189	70	17	128	2,9	2,15	21	17
4	207	88	20	171	3,4	3,95	21	20
5	177	97	18	195	3,3	4,65	23	27
6	179	95	17	18	2,7	4,9	28	32
7	123	88	22	157	2,7	3,55	23	23
8	204	104	22	138	2,9	2,6	18	17
9	305	114	17	131	3,1	2,8	18,5	17
10	192	104	32	145	3,3	3,95	25,5	23
11	174	117	16	153	3,4	4,45	25,5	28
12	168	88	18	140	2,8	3,55	21	20
13	207	92	20	128	3,3	3,2	21	20
14	207	79	17	107	3,1	2,8	21,5	17
15	303	79	16	115	3,4	2,65	21,5	20
16	319	101	23	145	3,7	2,9	20	17
17	322	88	17	138	3,4	3,4	35,5	23
18	204	70	16	117	3,3	3	31	23
19	290	73	17	101	3,7	3,1	32,5	23
20	290	85	17	131	3,9	3,75	32,5	27
21	194	82	18	138	3,8	3,95	33,5	27
22	193	95	17	140	3,4	4,25	36,5	27
23	202	92	16	131	3,7	3,85	34	27
24	388	120	15	114	4,1	3,55	34	32
25	213	107	16	110	3,8	3,4	35,5	27
26	178	82	15	114	3,4	3,75	36,5	27
27	177	79	16	107	3,4	3,65	35,5	28
28	194	104	17	101	3,9	3,65	36,5	27
29	193	70	14	96	3,4	3,2	31	23
30	213	88	16	115	3,8	3,55	35,5	23
31	321	85	17	124	3,8	4,05	34	23
32	293	82	18	149	4,3	4,25	37,5	28
33	332	82	16	124	4,1	3,95	39	23
34	313	88	18	115	3,8	3,65	42,5	23
35	293	85	15	99	3,9	3,2	36,5	27
36	208	82	14	101	3,8	3,3	44,5	28
37	218	92	16	110	4,1	3,55	42,5	28
38	314	97	15	93	3,9	3,1	42	32
39	352	122	17	110	4,1	3,55	37,5	32
40	313	117	16	104	4,3	3,4	40,5	28
41	302	101	17	96	3,8	3,3	42,5	32
42	322	85	16	107	4,1	3,4	39	27
43	287	101	17	124	3,8	3,65	39	28
44	304	88	20	149	4,1	4,25	49,5	32
45	319	88	18	157	4,7	5	44,5	28
46	292	85	15	128	3,8	3,95	37,5	23
47	333	75	17	110	4,1	3,55	36,5	23
48	291	85	15	99	4,3	3,65	40,5	28
49	375	117	16	96	4,1	3,2	27,5	23
50	364	162	17	110	4,1	3,2	25,5	27
51	358	97	16	107	3,4	3,1	21,5	20
52	313	73	16	85	3,3	2,65	23	20
53	317	79	25	107	3,8	2,9	21,5	20
54	340	70	17	114	3,7	2,8	23	20
55	236	65	18	133	2,8	2,9	19,5	17
56	233	85	23	140	3,1	3,75	23,5	20
57	333	92	23	167	3,4	4,65	23,5	20
58	344	97	22	157	3,7	4,15	23	17
59	332	75	22	140	3,1	3,55	21	17
60	327	92	18	133	3,7	3,4	23,5	20
61	329	85	16	101	3,4	2,9	21,5	17
62	357	85	15	85	3,4	3,1	28	27
63	377	97	16	101	3,7	3,3	23,5	20

Appendix 2. (cont.) *Amount of precipitation from 2000 to 2003[mm]*

Date	2000	2001	2002	2003
I.	46.4	12.7	13.5	37.9
II.	22.9	12.1	24.1	0.8
III.	86.1	51.3	47.1	3.2
IV.	46.4	22.3	31.9	24.9
V.	21.3	17.3	25.9	57.0
VI.	9.6	30.3	40.2	59.4
VII.	60.4	61.0	42.5	62.9
VIII.	28.3	39.9	86.7	40.1
IX.	41.0	126.1	45.6	18.4
X.	44.0	9.1	81.0	57.0
XI.	52.6	37.0	52.0	21.9
XII.	43.2	33.5	57.5	22.3
Total	502.2	452.6	548.0	405.8



**Data provided by the Meteorological Observation Station of the University of West-Hungary, Faculty of Agricultural and Food Sciences, Mosonmagyaróvár.*

Appendix 3. *The applied cultivation during the fleld trial*

year	**date**	**cultivation**
1999	11.1 .	disking
	23.1 .	ploughing
2000	11.04.	harrowing and levelling
	19.04.	seedbed combination 2x
	18.10.	conditionering
	20.10.	disking
	23.10.	ploughing
2001	27.03.	harrowing and levelling
	24.04.	seedbed combination 2x
	07.11	conditionering
	08.1 .	disking
	23.1 .	ploughing
2002	18.03.	harrowing and levelling
	22.04.	seedbed combination 2x
	28.10.	conditionering
	07.11.	ploughing
2003	17.03.	harrowing and levelling
		seedbed combination
	19.03.	rolling
	03.08.	disking
	11.1 .	ploughing
	06.10.	seedbed combination 2x

Appendix 4. Sowing *and non-VRA fertilising during the trial*

	fertilising*		**sowing**	
year	**date**	**agent**	**date**	**plant**
1999	11.11.	13:13:21 complex, 300 kg/ha		
2000	19.10.	N 34% 200 kg/ha	19.04.	Maize (Furio)
		15:15:15 complex, 100 kg/ha		
2001	17.04.	N 34%, 100kg/ha	25.04.	Maize (Furio)
	22.11.	N 34%, 150kg		
2002	04.11	N 34%, 100 kg/ha	23.04.	Maize (Furio)
2003	10.09.	N 34%, 100kg/ha	14.10	Winter wheat (Lupulus)

*Only the fertiliser distributions are marked, which were carried out not as VRA

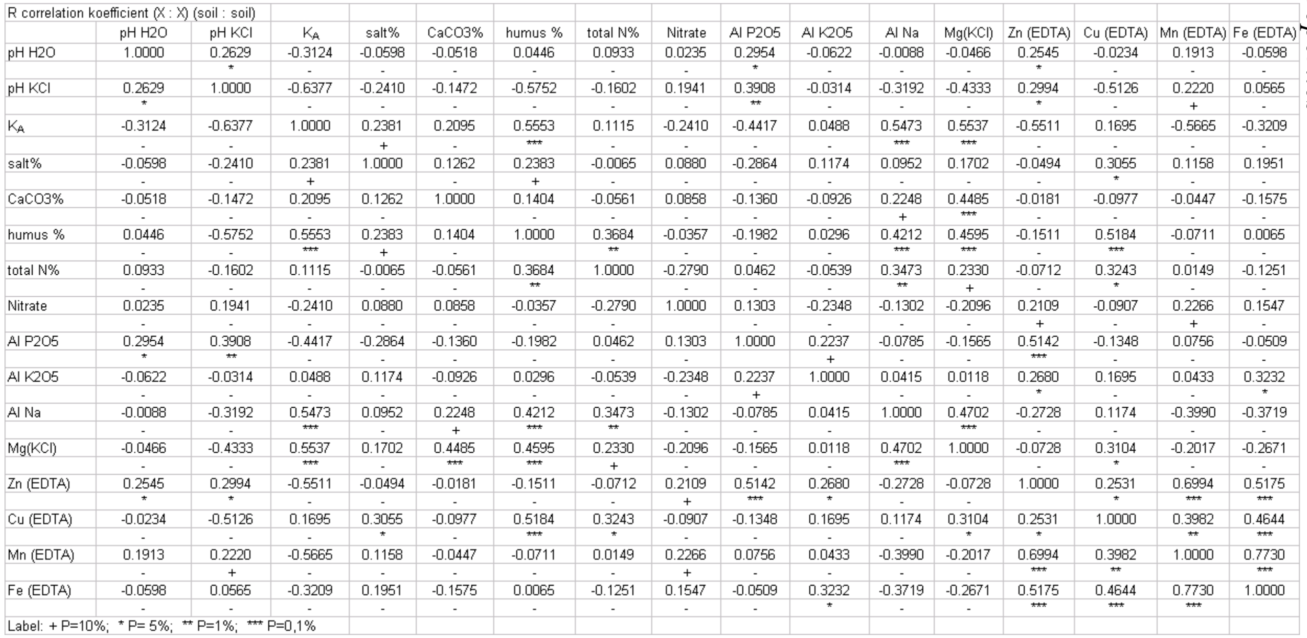
Appendix 5. *The amounts of fertiliser agents advised by the applied model (kg/ha)*

Management units	2002 spring		2002 autumn		2003	
	N	K_2O	P_2O_5	K_2O	P_2O_5	K_2O
1	133	95	45	59	24	91
2	117	95	0	59	0	91
3	117	95	45	49	67	91
4	117	85	45	39	24	91
5	117	85	45	29	67	91
6	117	85	45	29	67	91
7	117	85	77	19	79	91
8	133	75	45	29	24	91
9	133	70	0	23	0	74
10	117	70	45	19	67	91
11	117	70	45	0	67	74
12	117	95	68	29	67	91
13	117	95	45	39	24	91
14	117	85	45	49	24	91
15	117	100	0	39	0	91
16	117	95	0	39	0	91
17	117	105	0	39	0	91
18	117	105	45	59	67	91
19	117	100	23	49	24	91
20	117	95	0	59	24	91
21	117	90	45	39	67	91
22	87	75	45	19	67	91
23	117	65	45	19	67	91
24	133	75	0	33	0	74
25	117	90	45	23	24	74
26	117	80	45	49	67	91
27	135	105	45	59	67	91
28	117	115	45	43	67	74
29	133	115	45	49	67	91
30	117	110	45	59	24	91
31	117	105	0	59	0	91
32	87	115	0	49	24	91
33	117	105	0	49	0	91
34	117	110	0	59	0	91

Appendix 5. (cont.)

Management units	2002 spring		2002 autumn		2003	
	N	K_2O	P_2O_5	K_2O	P_2O_5	K_2O
35	117	120	0	69	24	91
36	117	115	45	69	24	91
37	117	110	45	49	24	91
38	117	110	0	59	0	91
39	117	101	0	27	0	58
40	117	120	0	33	0	74
41	117	125	0	53	0	74
42	117	125	0	79	0	91
43	117	95	23	43	24	74
44	117	95	0	39	24	91
45	117	110	0	49	0	91
46	117	95	0	49	24	91
47	117	95	0	59	0	91
48	133	110	0	69	24	91
49	117	115	0	53	0	74
50	117	87	0	0	0	21
51	117	95	0	39	0	91
52	87	100	0	59	0	91
53	117	85	0	59	0	91
54	117	85	0	59	0	91
55	117	95	45	49	24	91
56	87	100	23	39	24	91
57	117	100	0	49	0	91
58	117	95	0	39	0	91
59	117	90	0	39	0	91
60	117	85	0	49	0	91
61	117	85	0	39	0	91
62	117	105	0	59	0	91
63	117	80	0	39	0	91

Appendix 6. *Table of correlation coefficient (R) in case of the measured soil properties*



R correlation koefficient (X : X) (soil : soil)																
	pH H2O	pH KCl	K_A	salt%	CaCO3%	humus %	total N%	Nitrate	Al P2O5	Al K2O5	Al Na	Mg(KCl)	Zn (EDTA)	Cu (EDTA)	Mn (EDTA)	Fe (EDTA)
pH H2O	1.0000	0.2629	-0.3124	-0.0598	-0.0518	0.0446	0.0933	0.0235	0.2954	-0.0622	-0.0088	-0.0466	0.2545	-0.0234	0.1913	-0.0598
		*	-	-	-	-	-	-	*	-	-	-	*	-	-	-
pH KCl	0.2629	1.0000	-0.6377	-0.2410	-0.1472	-0.5752	-0.1602	0.1941	0.3908	-0.0314	-0.3192	-0.4333	0.2994	-0.5126	0.2220	0.0565
	*		-	-	-	-	-	-	**	-	-	-	*	-	+	-
K_A	-0.3124	-0.6377	1.0000	0.2381	0.2095	0.5553	0.1115	-0.2410	-0.4417	0.0488	0.5473	0.5537	-0.5511	0.1695	-0.5665	-0.3209
	-	-		+	-	***	-	-	-	-	***	***	-	-	-	-
salt%	-0.0598	-0.2410	0.2381	1.0000	0.1262	0.2383	-0.0065	0.0880	-0.2864	0.1174	0.0952	0.1702	-0.0494	0.3055	0.1158	0.1951
	-	-	+		-	+	-	-	-	-	-	-	-	*	-	-
CaCO3%	-0.0518	-0.1472	0.2095	0.1262	1.0000	0.1404	-0.0561	0.0858	-0.1360	-0.0926	0.2248	0.4485	-0.0181	-0.0977	-0.0447	-0.1575
	-	-	-	-		-	-	-	-	-	+	***	-	-	-	-
humus %	0.0446	-0.5752	0.5553	0.2383	0.1404	1.0000	0.3684	-0.0357	-0.1982	0.0296	0.4212	0.4595	-0.1511	0.5184	-0.0711	0.0065
	-	-	***	+	-		**	-	-	-	***	***	-	***	-	-
total N%	0.0933	-0.1602	0.1115	-0.0065	-0.0561	0.3684	1.0000	-0.2790	0.0462	-0.0539	0.3473	0.2330	-0.0712	0.3243	0.0149	-0.1251
	-	-	-	-	-	**		-	-	-	**	+	-	*	-	-
Nitrate	0.0235	0.1941	-0.2410	0.0880	0.0858	-0.0357	-0.2790	1.0000	0.1303	-0.2348	-0.1302	-0.2096	0.2109	-0.0907	0.2266	0.1547
	-	-	-	-	-	-	-		-	-	-	-	+	-	+	-
Al P2O5	0.2954	0.3908	-0.4417	-0.2864	-0.1360	-0.1982	0.0462	0.1303	1.0000	0.2237	-0.0785	-0.1565	0.5142	-0.1348	0.0756	-0.0509
	*	**	-	-	-	-	-	-		+	-	-	***	-	-	-
Al K2O5	-0.0622	-0.0314	0.0488	0.1174	-0.0926	0.0296	-0.0539	-0.2348	0.2237	1.0000	0.0415	0.0118	0.2680	0.1695	0.0433	0.3232
	-	-	-	-	-	-	-	-	+		-	-	*	-	-	*
Al Na	-0.0088	-0.3192	0.5473	0.0952	0.2248	0.4212	0.3473	-0.1302	-0.0785	0.0415	1.0000	0.4702	-0.2728	0.1174	-0.3990	-0.3719
	-	-	***	-	+	***	**	-	-	-		***	-	-	-	-
Mg(KCl)	-0.0466	-0.4333	0.5537	0.1702	0.4485	0.4595	0.2330	-0.2096	-0.1565	0.0118	0.4702	1.0000	-0.0728	0.3104	-0.2017	-0.2671
	-	-	***	-	***	***	+	-	-	-	***		-	*	-	-
Zn (EDTA)	0.2545	0.2994	-0.5511	-0.0494	-0.0181	-0.1511	-0.0712	0.2109	0.5142	0.2680	-0.2728	-0.0728	1.0000	0.2531	0.6994	0.5175
	*	*	-	-	-	-	-	+	***	*	-	-		*	***	***
Cu (EDTA)	-0.0234	-0.5126	0.1695	0.3055	-0.0977	0.5184	0.3243	-0.0907	-0.1348	0.1695	0.1174	0.3104	0.2531	1.0000	0.3982	0.4644
	-	-	-	*	-	***	*	-	-	-	-	*	*		**	***
Mn (EDTA)	0.1913	0.2220	-0.5665	0.1158	-0.0447	-0.0711	0.0149	0.2266	0.0756	0.0433	-0.3990	-0.2017	0.6994	0.3982	1.0000	0.7730
	-	+	-	-	-	-	-	+	-	-	-	-	***	**		***
Fe (EDTA)	-0.0598	0.0565	-0.3209	0.1951	-0.1575	0.0065	-0.1251	0.1547	-0.0509	0.3232	-0.3719	-0.2671	0.5175	0.4644	0.7730	1.0000
	-	-	-	-	-	-	-	-	-	*	-	-	***	***	***	
Label: + P=10%; * P= 5%; ** P=1%; *** P=0,1%																

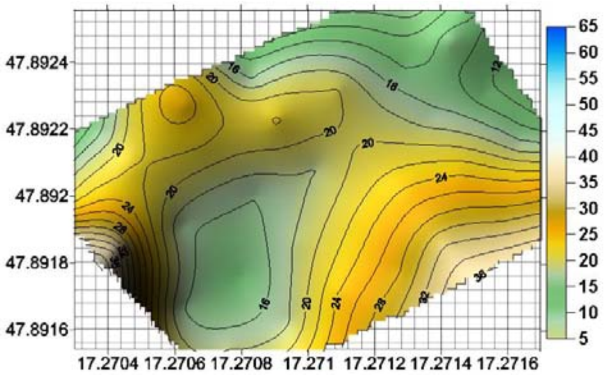
Appendix 7. *Correlation soil vs. yield and grain moisture data*

R correlation coefficient (X : Y) (soil : yield)

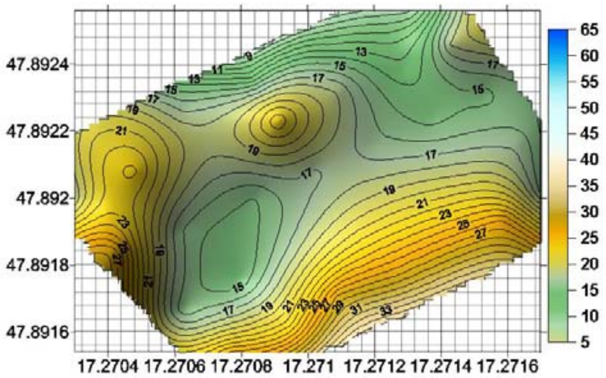
	yield 2001	yield 2002	yield 2003	moisture 2001	moisture 2002	moisture 2003
pH H2O	-0,3223	-0,3491	-0,0548	0,1348	0,1077	0,3222
	-	-	-	-	-	*
pH KCl	-0,4302	-0,5645	-0,2151	0,3465	-0,1416	0,4612
	-	-	-	**	-	***
K_A	0,5927	0,6403	0,2393	-0,4055	0,1628	-0,3027
	***	***	+	-	-	-
salt%	0,0579	0,1254	0,2709	0,0625	0,1802	-0,2554
	-	-	*	-	-	-
CaCO3%	0,0877	0,1553	0,0768	0,0019	-0,0283	-0,1622
	-	-	-	-	-	-
humusz %	0,2072	0,3801	0,2347	-0,0190	0,1034	-0,1517
	-	**	+	-	-	-
TotalN%	0,1010	0,1980	0,2887	0,1283	0,1754	0,0544
	-	-	*	-	-	-
NO_3	-0,3115	-0,3789	-0,0863	0,3221	0,1735	-0,1180
	-	-	-	*	-	-
Al P2O5	-0,3254	-0,3467	-0,1491	0,0615	-0,1260	0,3720
	-	-	-	-	-	**
Al K2O5	0,0981	0,1653	0,0259	-0,0979	-0,1033	0,1708
	-	-	-	-	-	-
Al Na	0,3446	0,4246	0,0749	-0,0283	0,1118	-0,0401
	**	***	-	-	-	-
Mg(KCl)	0,3523	0,4181	0,3544	-0,1292	0,0835	-0,1725
	**	***	**	-	-	-
Zn (EDTA)	-0,4812	-0,5060	0,0462	0,4472	-0,1245	0,1964
	-	-	-	***	-	-
Cu (EDTA)	0,1497	0,2737	0,4837	0,1586	-0,0760	-0,0868
	-	*	***	-	-	-
Mn (EDTA)	-0,4508	-0,4467	0,1309	0,6149	-0,1118	0,0221
	-	-	-	***	-	-
Fe (EDTA)	-0,2286	-0,1739	0,0274	0,3792	-0,1893	-0,0351
	-	-	-	**	-	-

Legend: + P=10%; * P= 5%; ** P=1%; *** P=0,1%

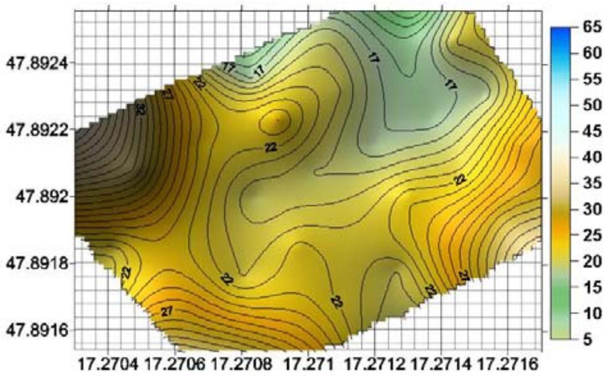
Appendix 8. *Maps of Cone penetrometer resistance and draft in the 1ha field*



Penetrometer resistance map of the 5 cm soil layer (x100 kPa)

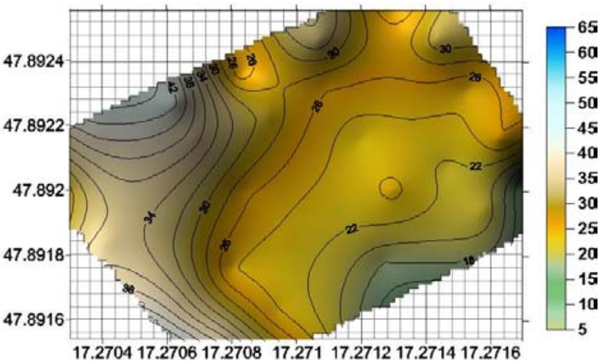


Penetrometer resistance map of the 10 cm soil layer (x100 kPa)

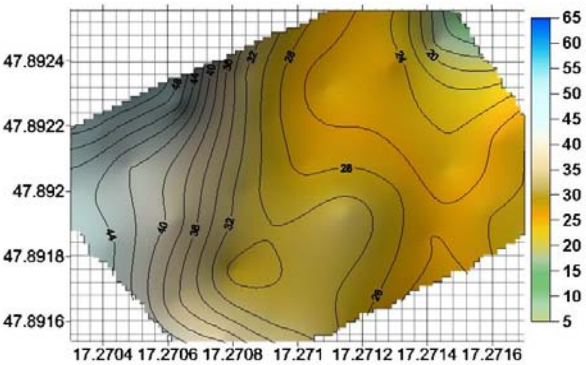


Penetrometer resistance map of the 15 cm soil layer (x100 kPa)

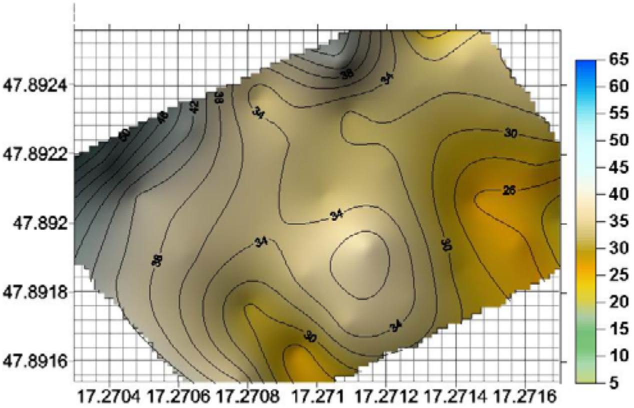
Appendix 8. (cont.)



Penetrometer resistance map of the 20 cm soil layer (x100 kPa)

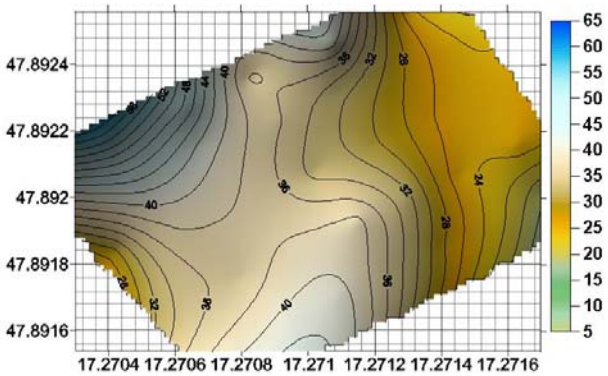


Penetrometer resistance map of the 25 cm soil layer (x100 kPa)

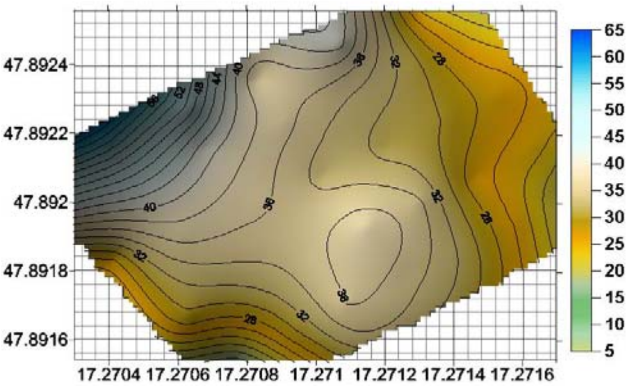


Penetrometer resistance map of the 30 cm soil layer (x100 kPa)

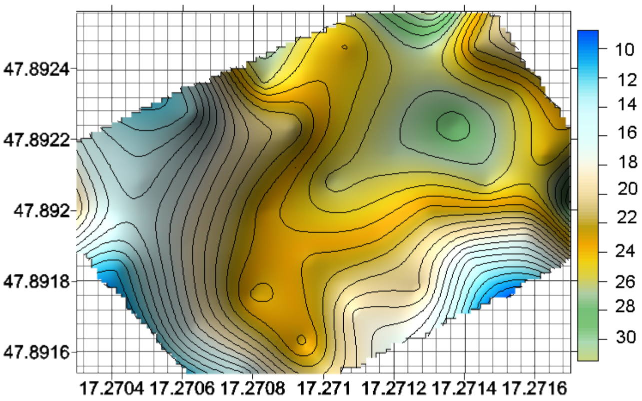
Appendix 8. (cont.)



Penetrometer resistance map of the 35 cm soil layer (x100 kPa)

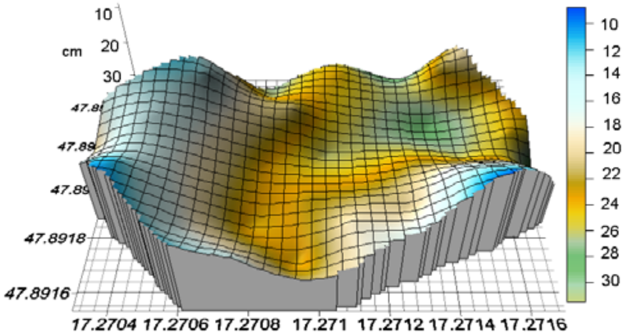


Penetrometer resistance map of the 40 cm soil layer (x100 kPa)

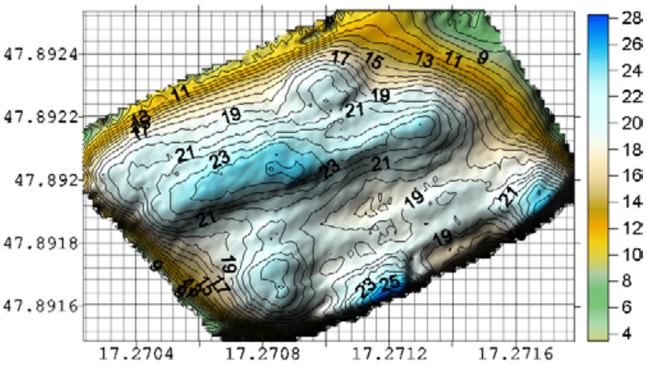


The situation of the soil layer with a compaction of 3 Mpa or more (cm)

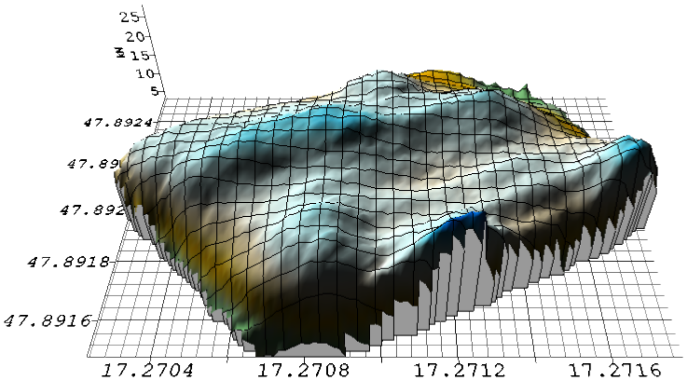
Appendix 8. (cont.)



Three-dimensional model of the soil layer with a compaction of 3 Mpa or more

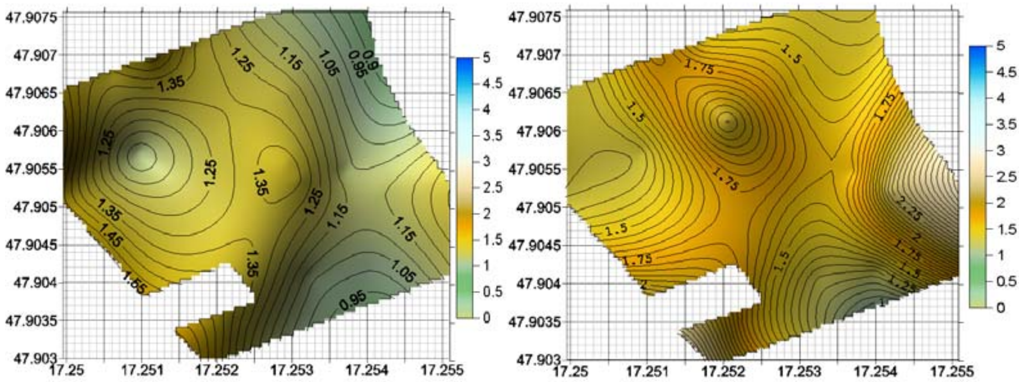


Map of soil draft measured by the on-line system (kN)

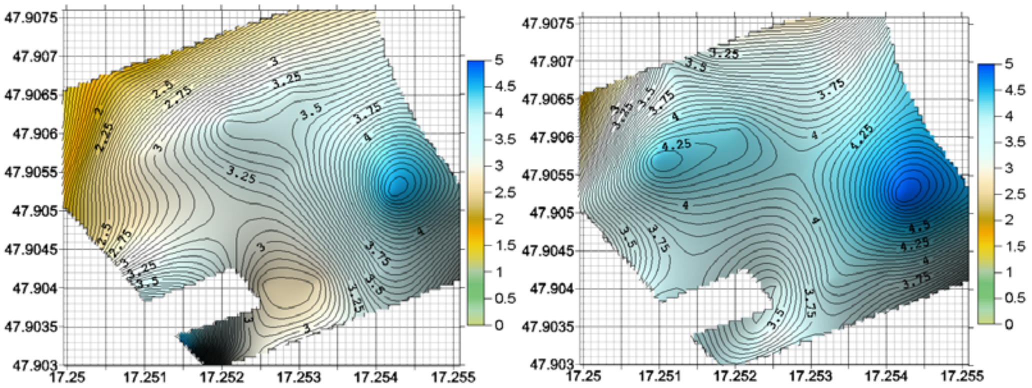


Three-dimensional model of the soil draft measured by the on-line system (kN)

Appendix 9. *Maps of Cone penetrometer resistance and draft in the field 80/1*

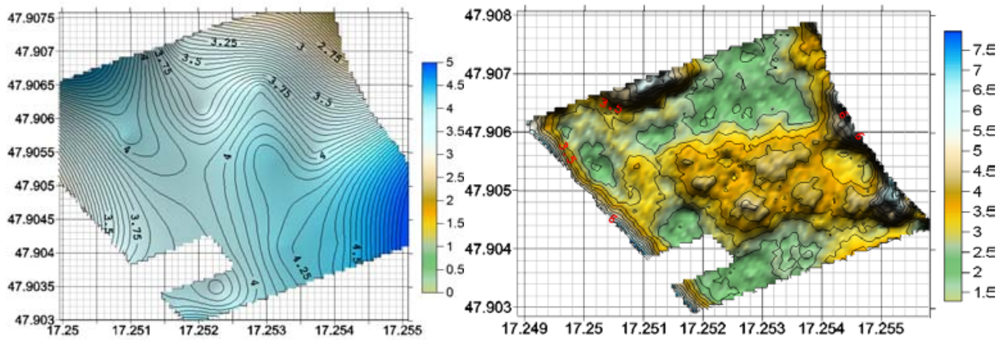


Penetrometer maps of the 20 and 25 cm soil layers (MPa)

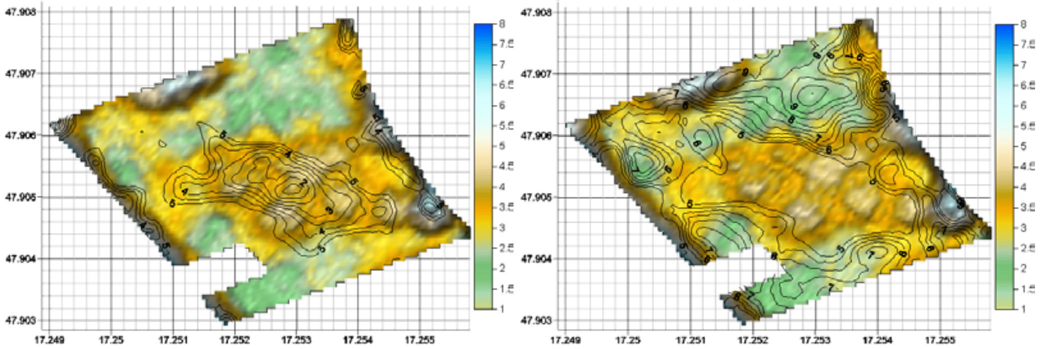


Penetrometer maps of the 30 and 35 cm soil layers (MPa)

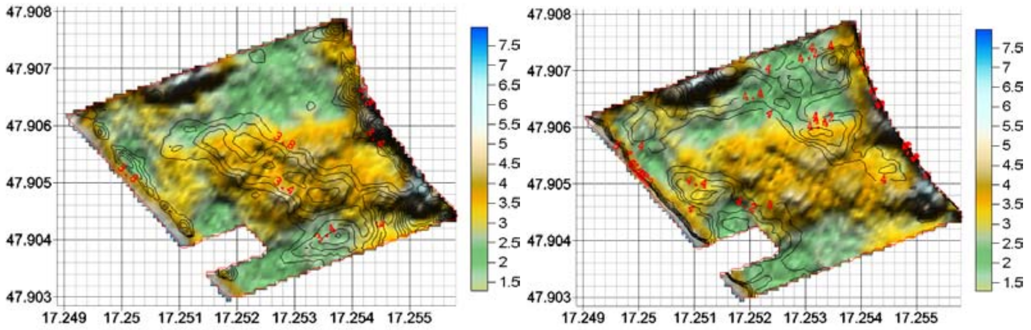
Appendix 9. (cont.)



Penetrometer map of the 40 cm soil layer (MPa) and soil draft map

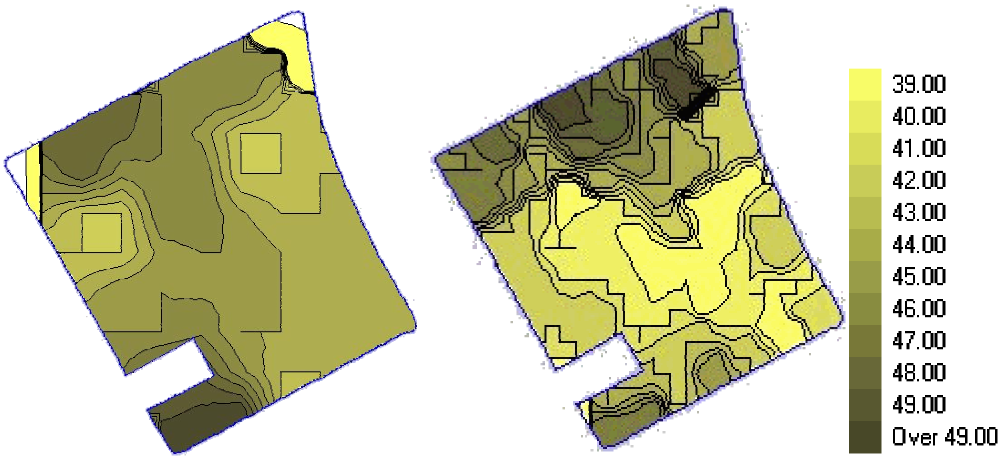


On-line soil draft map with the contours of yield below (left) and above (right) 5 t/ha, respectively (maize, 2002).

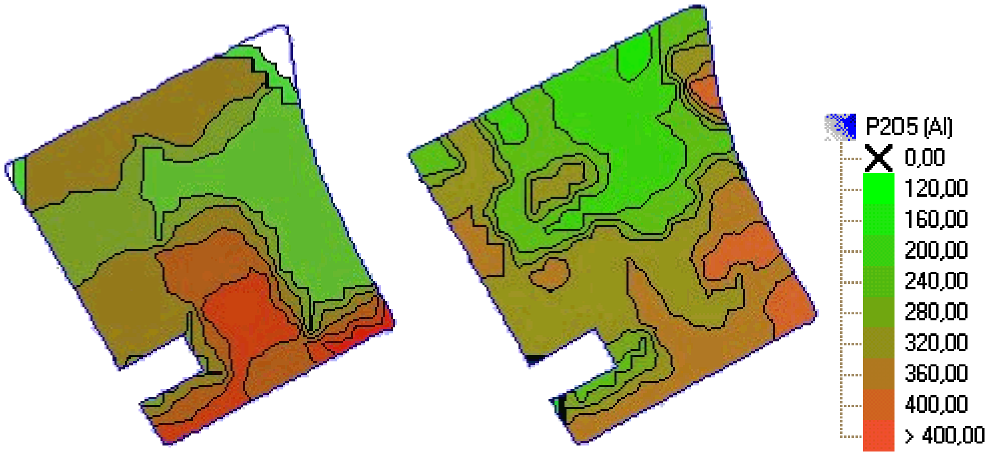


Soil draft map with the contours of yield below (left) and above (right) 3.8 t/ha (spring barley, 2003)

Appendix 10. *The effect of grid size on the resolution of the resulted maps*

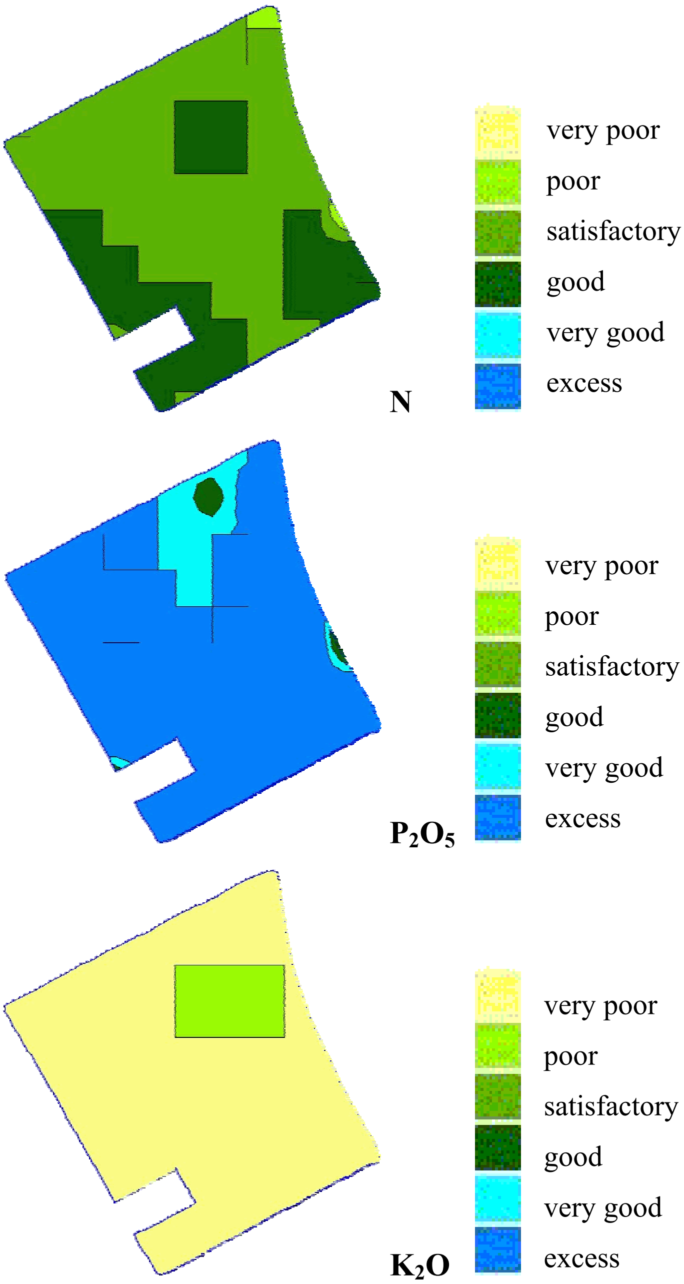


Map of K_A based on 100m and 50m grid, respectively



Map of P_2O_5 (ppm) based on 100m and 50m grid, respectively

Appendix 11. *The levels of N, P_2O_5 and K_2O supply according to the RISSAC-HAS – RIA- HAS fertiliser advisory system in case of maize*



Appendix 12. *Main features of the applied optical devices*

Features of the ICP DAS A-822 PGL data acquisition board

- approximately 100K sample/sec maximum sample rate;
- software selectable input ranges;
- 16 single ended or 8 differential analogue input signals;
- programmable low gain: 0.5, 2,3,4,8;
- interrupt handling;
- 8 μs conversion time in A/D mode;
- +/- 1 bit accuracy;
- 12 bit resolution. (ICP DAS A-822 PGL hardware manual)

Features of the Hitachi KP-C550 CCD camera

- 1/2" micro lens CCD 681 x 582 effective pixels;
- six step electronic shutter to 1/4,000 second;
- internal or external sync;
- 2:1 interlace;
- 430 TV lines horizontal resolution;
- 48 dB signal to noise ratio;
- 3 lux minimum sensitivity;
- real time auto or manual white balance;
- composite and Y/C video outputs.

Appendix 12. (cont.)

Features of the FLIR ThermaCAM PM 675 infrared camera

- object temperature range: -40 – 120 , +80 - 500°C;
- thermal sensitivity: 0.1 °C;
- field of view / minimum focus distance: 24°x18°/ 0.5m;
- detector type: Focal Pin Array (FPA), 320x240 pixels;
- spectral range: 7.5-13µm;
- video output: VHS or SVHS;
- 14 bit digital storage.

Appendix 13. *The set-up and calibration of the yield monitoring system*

- Calibration of the speedometer. The yield measured between two positions belongs to the area defined by the cutting width and the forward movement therefore it is necessary to measure the forward speed. The process can be started from the calibration menu of the ACT, which counts the number of impulses during driving 100 m. This number can however be set manually as well taking into consider the parameters of the wheel and the tyre of the harvester, and the number of the magnets.
- Learn elevator. The elevator and the trashing were run with full throttle in order to the computer be calibrated for the zero yield state. In this case the elevator is empty; the signal of the optical sensor is interrupted only by the elevator elements. This process takes approximately 30 s. If this value is out of the range of 0.7 and 1.3 the calibration process has to be repeated.
- Learn slope. The importance of this calibration derives again from the volumetric yield measurement method. It takes part with turned off trashing on a horizontal surface.
- Set the proper crop. Preprogrammed properties of several crops are stored in the computer. However, corresponding to the volumetric yield sensor, the measurement of actual grain bulk density is recommended. It was carried out with a commercial tool (Salter Abbey Super Samson).
- Evaluation measurement of the grain moisture was done by a Kelt PM 5029 digital instrument designed for this task in three repetitions. As an evaluation of the digital apparatus the moisture content was defined with oven method as well in the first some cases.

Appendix 13. (cont.) *The set-up and calibration of the yield monitoring system*

- Despite all above-mentioned set-up, the yield measured by the system may differ from the control weighted one. Therefore, the weighted value can be applied for the calibration of the weight measurement. However, if the calibration factor is out of the range of 0.7 and 1.3 the calibration process has to be repeated. The values resulted from the control measurements (grain moisture, bulk density, and weight) were used for correction in the ACT.

Calibration of the site-specific fertiliser spreader system

The rpm of the PTO was adjusted to 540 1/min, the left spreader disc was removed and both sides of the spreader were closed with the hydraulic shutter. In the calibration menu of the ZUG_AM software the average value of the plan was set. Opening the left hydraulic shutter the calibration procedure started automatically, the ACT started to measure the time. After 30 s the shutter had been closed, and the ACT reflected a predicted value of the fertiliser ran out from the left side of the spreader. The weighted value was typed in and the ACT computed a new calibration factor corresponding to the given fertiliser. (If this value is out of the range of 0.7 and 1.3 the calibration process has to be repeated.)

Appendix 14. *The structure of the RDS yield file*

Header data

DH000002@00001200@00002200@00003100@00004080@00005060

DHxxxxxx@ = Header Definition line

VH000002@ RDS Technology Ltd@ Ceres 2 Yield Meter@ NG406-543@19991027@085446

Job number @ Company @ Data logger@ software version number @ Date @ Time

Supplementary data

DN000002@00101073@00102073@00103073@00104073@00105073@00106073

VN000002@0000000@0000000@0003000@0000000@0000000@0000000

DNxxxxxx@ = Normal Definition line.

VNxxxxxx@ = Normal Value line. User defined functions(F 1-12) 1@2@3@4@5@6

DN000002@00107073@00108073@00109073@00110073@00111073@00112073

VN000002@0000000@0000000@0000000@0000000@0000000@0000000

DNxxxxxx@ = Normal Definition line.

VNxxxxxx@ = Normal Value line.

VNxxxxxx@ = Normal Value line. User defined functions 7@ 8@ 9@ 10@ 11@ 12 (F12 = field number, was not set)

DN000002@00006042@00016062@00012052@00017065@00201096@00202106@00204051@00203010@00301020

DNxxxxxx@ = Normal Definition line.

Appendix 14. (cont.) *The structure of the RDS yield file*

```
YIELD DATA
VN000002@0450@000881@01550@001821@+47684133@+017958769@001260@4@00
VN000002@0450@000865@01500@001726@+47684106@+017958791@001250@4@00
VN000002@0450@000779@01500@001610@+47684066@+017958826@001250@4@00
VN000002@0450@000747@01450@001522@+47684026@+017958858@001250@4@00
VN000002@0450@000842@01450@001674@+47684000@+017958881@001250@4@00
```

VNxxxxxx@ = Normal Value line

Job number @ working width @ actual yield t/ha @ moisture % @ accumulated yield kg @ lat. @ long. @ height @ GPS quality @ tag

In our case:

```
VN000002@0450@000814@01350@001679@+47683820@+017959026@001240@4@00
```

Job no. 2 @ 450 cm @ 8,14 t/ha @ 13,5% @ 16,79kg @ 47,683820° @ 17,959026° @ 124m @ 00

Summary data
DN000002@00007062@00008072@00009072 Normal Definition line.

VN000002@000911@0002254@0017189 Normal Value line.

Job no. @ duration @ area ha @ volume t

Job no.2 @ 91,1 h @ 225,4 ha @ 1718,9 t *

DN000002@00011073@00012052@00015010@00014071 Normal Definition line.

VN000002@0075500@01447@7@0000201

Job no. @ kg/hl @ average moisture cont. @ crop type index @ cal factor

Job no.2 @ 75,5kg/hl @ 14,47% @ 7 (maize) @ 20,1

(*The high value shows, that the data logger was not zeroed, the value is cumulated.)

Appendix 14. (cont.) *The structure of the RDS yield file*

File end

EN

ZN

The structure of the Agrocom ACT aft yield file

Header
AGRO-MAP.AFT,VERSION 01.04,01,<job number>,<name>,<field>,<crop>,<driver>,<machine>,
nein*,;;yield;;;;;;;;moisture;,<label, which shows weather the file was opened or not >,<field number >,
*fixed label

Recorded data
<lat.>,<long.>,<yield t/ha>,<local time>,<speed>,<heading>,<age of data>,<used satellites>,<GPS status>,<date>,<moisture>,<delimiter>

In case of the file recorded by us:

```
N47.89220,E017.25838,10.2,115947,000,000,01,8,2,12.07.01,16.3,
N47.89221,E017.25841,09.7,115952,000,000,01,8,2,12.07.01,16.3,
N47.89223,E017.25846,07.5,115957,000,000,01,8,2,12.07.01,16.3,
N47.89225,E017.25849,07.5,120002,000,000,01,8,2,12.07.01,16.3,
N47.89227,E017.25855,07.3,120008,000,000,01,8,2,12.07.01,15.2,
```

Unlike the RDS data the aft yield file involves no supplementary data and end label. The height information also misses from the file.