Predicting sugar beet yield variability using yield maps of combinable crops and the 'monitor pedo cell' approach

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Summary

Yield maps of combinable crops are often used to gather spatial variable data for Precision Agriculture. Yield mapping systems for root crops are under construction, but until now they are not commercially available. Aim of the presented field experiment was to determine if existing yield maps of combinable crops can be used to predict sugar beet yield and therefore can also be used as a base for variable field operations. Four yield maps (1995-1998) were available for an experimental field (7.9 ha) in Mariensee (Northern Germany) which were used to create a combined yield map. Sampling locations for collecting plant, soil and root samples were chosen by following the 'directed sampling' strategy. Sugar beet yield was determined manually at 33 sampling locations. 49% of the sugar beet yield variability and 57% of the sugar yield variability could be explained by the grain and legume yield variability of former years. For further investigations on yield influencing parameters, a reduction of the 33 locations to 16 'monitor pedo cells' (MPC) was accomplished. A soil texture analysis result of the reduced number of deep soil samples showed a high relationship with grain and sugar beet yield and indicates that water availability is the main yield limiting factor. Considering the results it can be concluded that the discovered reason for yield variability will be valid for all crops in the crop rotation and can therefore used to develop fertiliser strategies, especially for nitrogen.

Key words: *Precision Agriculture, sugar beet, yield mapping, yield variability*

Zusammenfassung

Ertragskarten von Mähdruschfrüchten bilden seit vielen Jahren die Basis für die Erfassung von räumlicher Variabilität in Precision Agriculture. Ertragskartierungssysteme für Hackfrüchte stehen in der Entwicklung, sind aber zur Zeit auf dem Markt noch nicht erhältlich. Aus diesem Grund wurden in einem Versuch die Möglichkeiten zur Prognose der Ertragsvariabilität von Zuckerrüben anhand vorhandener Karten von Mähdruschfrüchten geprüft. Für eine Versuchsfläche (7,9 ha) des Instituts für Tierzucht der FAL in Mariensee lagen Ertragskarten der Jahre 1995-1998 vor, die in relative Ertragskarten umgewandelt wurden. Nach dem Verfahren des ‚directed sampling' wurden zur Zuckerrübenernte 1999 33 Messungen der Zuckerrübenerträge durchgeführt, sowie Boden- und Pflanzenproben genommen. 49% der Variabilität der Zuckerrübenerträge und 57% der Zuckererträge konnten durch die Variabilität der Getreide- und Leguminosenerträge in den Vorjahren erklärt werden. Für weitere Untersuchungen zur Ursache der Ertragsunterschiede wurden die 33 Probenpunkte nach dem 'monitor pedo cell' (MPC) Verfahren auf 16 reduziert. Texturanalysen der auf 16 reduzierten Bodenproben zeigten einen starken Zusammenhang zu Getreide- sowie Zuckerrübenerträgen. Aus den Ergebnissen läßt sich schliessen, dass die Wasserverfügbarkeit der wesentlich ertragslimitierende Faktor ist. Somit kann in diesem Fall die relative Ertragskarte von Mähdruschfrüchten auch zur Ertragsabschätzung von Zuckerrüben und damit als Grundlage für die Düngeplanung eingesetzt werden.

Schlüsselwörter: *Ertragskartierung, Ertragsvariabilität, Precision Agriculture, Zuckerrübe*

Introduction

Despite all critical aspects of yield mapping, like the correct allocation of GPS coordinates to the actual yield data or the internal grain flow in combines (Blackmore & Marshall, 1996; Panten et al., 2002a), yield maps are usually the first and most common tool to determine in field variability. But recording variability is only the first step of Precision Agriculture management strategies which further imply spatial data analysis and finally variable field management actions (Schnug et al., 1993). Especially nitrogen (N) fertiliser applications are often based on yield expectations. Most advisory service guidelines are calculating optimum fertiliser rates in their codes of practice using the expected crop productivity and soil analysis data (Fruechtenicht et al., 1993). If yield maps of more then one year are available, these maps can be combined into an average yield map after the transformation from absolute into relative maps. Combined grain yield maps offer a good base for decision making processes by reflecting good, medium and bad performing areas in the field. Variable yield expectations can be derived using these maps assuming average climatic conditions. Combinable crop yield monitors are commercially available in contrast to yield monitors for sugar beet (*Beta vulgaris* L.), a highly intensively managed and economically beneficial crop for farmers. Yield monitors for sugar beets are under construction and some prototypes are already running under test conditions (Walter & Backer, 2003; Hall et al., 2003; Isensee, 2003). For farmers collecting grain yield maps since several years the question arises how to take advantage of these yield maps not only for the variable application of fertilisers to grain crops, but also for sugar beet.

Combined yield maps may be used for the determination of yield variability and thus the spatial variation of nutrient off-takes, but also proved to be an efficient source for identifying in field heterogeneity by applying sophisticated sampling strategies. Many approaches for effective sampling strategies in Precision Agriculture were published during the last years. Some examples are 'self-surveying' (Haneklaus et al., 1998), 'directed sampling' (Schnug, et al., 1994; Pocknee et al., 1996; Mulla et al., 2000), 'variance quad-tree-sampling' (McBratney et al., 1999) or 'Monitor Pedo Cells (MPCs)' (Panten et al., 2002b). Based on the 'directed sampling' method, MPCs are derived using so-called 'equifertiles' representing areas with similar crop productivity to define sampling positions which reflect the whole range of variation of soil and plant parameters in the field. For the definition of the final MPCs the number of directed sampled points in the field will be reduced over time until a minimum set of representative sample locations remains. These positions will be used to monitor soil parameter changes over long periods by regular sampling campaigns. Combined yield maps of combinable crops may be used for establishing 'equifertiles' as they are the sum of all factors influencing the yield heterogeneity (Schnug, et al., 1994). The analysis of soil and plant samples can then be used to identify factors controlling yield. This might be an iterative process, starting with standard analysis followed by further investigations on more parameters if necessary. For the decision process about sensible parameters for analysis, local knowledge of farmers will be essential as in most cases fundamental ideas about yield limiting factors exist.

Materials and Methods

Precision Agriculture was introduced on the experimental farm of the Institute of Animal Breeding of the FAL in Mariensee in 1994. Geo-coded yield mapping of combinable crops has been carried out since then by a flow meter sensor mounted on a Massey Ferguson combine harvester equipped with a DGPS system. After harvest in summer 1998, 4 yield maps were available for the field 'Grosser Fuchsberg' (9.4717° E; 52.5765° N; Tab. 1). All erroneous yield data were extracted employing the routines described by Haneklaus et al. (2000a). These data sets were transformed into relative yield maps using the mean yield of the year. Then the 4 maps from 1995 to 1998 were combined (Fig. 1) and 5 yield classes, < 80%, 80-90%, 90-100 %, 100-110 % and > 110 % established.

Tab. 1: Descriptive statistics for yield data of the field 'Grosser Fuchsberg' (1995-1999)

Year	Crop	Yield t ha^{-1}			
		Min.	Max.	Mean	CV%
94/95	Oats	3.0	6.2	5.0	14.5
95/96	W-barley	3.4	8.0	6.5	15.2
96/97	Peas	2.0	6.5	5.0	19.6
97/98	W-barley	5.5	9.5	8.3	9.6
98/99	S-beet	29.8	92.0	59.1	28.3

In order to evaluate the suitability of yield maps of combinable crops to predict sugar beet yield, 33 sampling locations were allocated on basis of the combined yield map (Fig. 1) employing the directed sampling approach. At sugar beet harvest in October 1999 2 m^2 of sugar beets (*Beta vulgaris*, var. Helix) were harvested and topsoil samples were taken on each location.

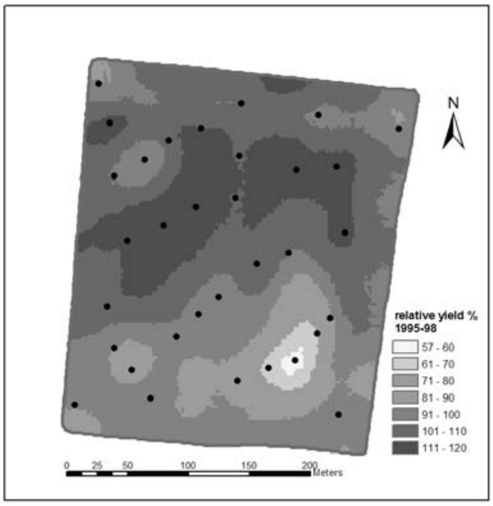

Fig. 1: Relative yield map of combinable crops (1995-1998) of field 'Grosser Fuchsberg' in Mariensee including 33 directed sampling points for the sugar beet harvest in 1999

After the evaluation of the plant and soil analysis results of 1999 the number of sampling locations was reduced from 33 to 16 following the procedure of Haneklaus et al. (2000b). The remaining 16 locations, so-called MPCs, were used for further investigations into the cause of the yield variability. After harvest of oats in August 2000, top- and subsoil samples (0-30, 30-60, 60-90 cm) were taken at exactly these 16 locations.

Soil samples of both sampling campaigns were air-dried and sieved to a particle size ≤ 2 mm. Soil pH was determined potentiometrically in a 0.01m $CaCl_2$ soil suspension (1:10) according to Schlichting and Blume (1966). The total carbon (C) content was determined by dry combustion using a LECO (EC-12, model 725-100) analyser. Plant available phosphorous (P) and potassium (K) contents were determined in the CAL extract according to Schueller (1969). Plant available magnesium (Mg) was extracted in 0.05 M $CaCl_2$ solution according to Schachtschabel (1954). Soil texture was analysed according to de Leenhear et al. (1955).

The determination of the sugar content was performed in fresh sugar beet samples in the laboratory of a sugar refinery using a polarimeter (Zuckerinstitut, 2001).

For statistical analysis of variance (F-test) the ANOVA procedure of the JMP software package was used. Geostatistical analysis was performed using the Variowin software (Pannatier, 1996).

Results and Discussion

In 1999, root sampling of sugar beet at harvest was carried out at the 33 sampling locations defined by directed sampling. Fig. 2 shows the variation of sugar beet yield superimposed on the combined yield map of combinable crops.

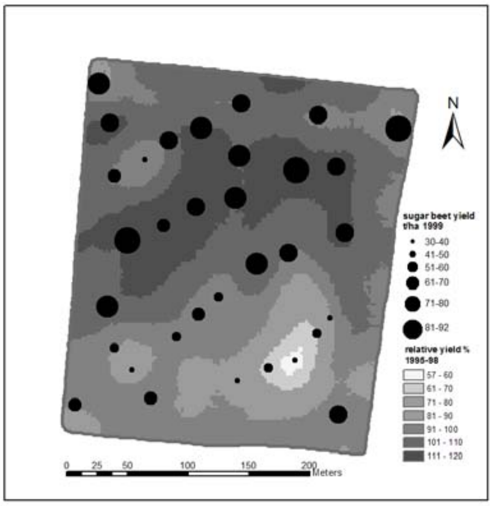

Fig. 2: Combined yield map of combinable crops (1995-1998) for field 'Grosser Fuchsberg' in Mariensee superimposed by sugar beet yield of 1999

A close relationship between sugar beet yield and relative yield classes of combinable crops is evident (Fig. 2). Regression analysis confirmed these results as 49% of the variation of sugar beet yield could be explained by variations of yields from combinable crops (Fig. 3).

One of the most important factors influencing the profitability of sugar beet cropping is the sugar content of the beets. Sugar beet prices are calculated under consideration of sugar, potassium, sodium and nitrogen content of the beet. Fig. 4 reveals the correlation between relative yield and sugar content of the beet roots.

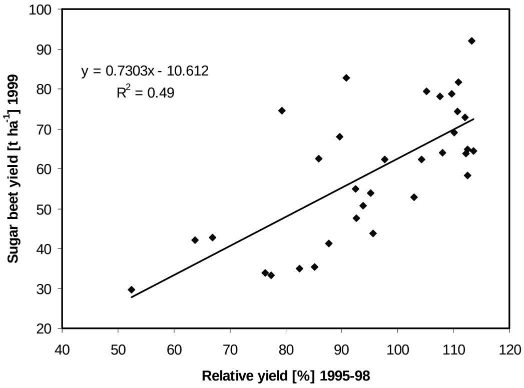

Fig. 3: Relationship between sugar beet yield (1999) and relative yield of combinable crops (1995-98) at 'Grosser Fuchsberg' in Mariensee

A coefficient of determination of 57% demonstrates that even a higher percentage of the variation of the sugar content could be explained by the variations of the relative yield of combinable crops than it was the case for sugar beet yield.

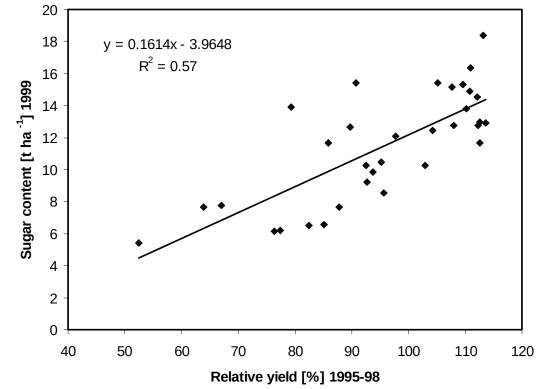

Fig. 4: Relationship between sugar content (1999) and relative yield of combinable crops (1995-1998) at 'Grosser Fuchsberg' in Mariensee

Further investigations focused on the main factors causing yield variability In a first step standard soil analysis was carried out for the 33 topsoil samples (Tab. 2).

Tab. 2: Descriptive statistics for soil characteristics of top-soil samples (0-10 cm) of 33 sample points collected in October 1999 and results from ANOVA statistics for relative yield classes

Soil parameter	Descriptive statistics				ANOVA	
	Min.	Max.	Mean	CV %	P value	Sign.
pH	5.7	6.2	6.0	2.3	0.675	ns
C (%)	1.3	2.1	1.6	13.0	0.016	*
P (mg kg^{-1})	67.0	133.2	106.0	14.9	0.726	ns
K (mg kg^{-1})	93.2	299.8	151.1	28.6	0.819	ns
Mg (mg kg^{-1})	43.6	71.3	55.4	10.0	0.319	ns

Note: probability levels: <0.05 (*); <0.01 (**); <0.001 (***); not significant (ns)

Tab. 2 represents an overview about the descriptive statistics of the analysed parameters. The ANOVA procedure was applied in order to attribute variation in soil characteristics to individual yield classes. Significant differences were proved only for differences in the soil organic carbon content for individual yield classes.

The results reveal that all analysed soil parameters were above critical threshold values for producing maximum yield and therefore not yield limiting. After a first classification of samples based on sensory analysis of soil texture (Haneklaus & Schnug, 1999), laboratory soil texture analysis was performed at the final 16 MPC's. This is an efficient way to gather crucial information about the variation of this parameter and its significance for yield, which would otherwise be denied due to high costs. Next to the texture analysis for the MPCs, standard soil analysis was conducted to allow comparisons between the results of directed sampling points and MPCs. As can be seen in Tab. 2 and 3, MPCs reflect the variation of soil properties adequately. Soil texture analysis revealed a high variation in all horizons (Tab. 3). For example, in the topsoil layer sand contents varied between 46-87%, silt 10-48% and clay 3-6%.

The ANOVA procedure for the results from soil texture analysis showed strong and significant differences for this parameter between yield classes in relation to the sand, silt and clay content in all soil horizons (Tab. 4). As soil texture is directly linked to the soil water regime, and thus the water holding capacity of soils, it can be concluded that the access to plant available water was the main yield limiting factor on this field.

This finding can be transferred to all other crops under consideration of evapotranspiration rates during growth. The combined yield map can therefore be used to create a spatially variable yield expectation map resulting for instance into variable rate nitrogen fertiliser applications depending on the variable demand of the crop due to restricted plant growth caused by limited water availability. Further analysis of precipitation data during the vegetation periods of 1998 and 1999 (Fig. 5) confirmed the assumption that access to plant available water in relation to soil texture differences was the major yield limiting factor and explains the wide range of sugar beet yield of 29.8-92.0 t ha^{-1} in 1999. Fig. 5 also reveals that the annual rainfall from November 1998 to October 1999 (sugar beet harvest) with 591mm was more than 100 mm lower then the long term average precipitation in the region (699 mm).

The lack of rainfall particularly during May and June 1999 hampered, especially on the lighter, sandier areas of the field with correspondingly lower water holding capacities, the development of the crop.

During the sampling campaigns on ‘Grosser Fuchsberg’ relief changes in the field were mapped, too. Sensory analysis of soil texture showed distinct differences for this parameter with a higher sand content on elevated areas. Fig. 6 reflects variations of geomorphology in relation to yield distribution patterns in the field.

Tab. 3: Soil sampling results (0-90 cm) of August 2000 at MPCs

Soil parameter		Depth [cm]	Unit	Minimum	Maximum	Mean	CV %
Texture	Sand (63-2000µm)	0-30	%	46.1	87.0	59.1	16.0
	Silt (2-63µm)	0-30	%	10.1	47.8	35.9	24.7
	Clay (< 2µm)	0-30	%	2.9	6.1	5.0	14.2
	Sand (63-2000µm)	30-60	%	41.8	96.4	64.4	23.6
	Silt (2-63µm)	30-60	%	1.8	52.8	31.8	45.0
	Clay (< 2µm)	30-60	%	1.6	5.5	3.9	27.8
	Sand (63-2000µm)	60-90	%	42.0	98.4	74.4	23.1
	Silt (2-63µm)	60-90	%	1.0	53.0	22.6	71.4
	Clay (< 2µm)	60-90	%	0.6	5.2	3.0	47.4
Soil chemistry	pH	0-30		5.9	6.4	6.2	2.0
	C	0-30	%	0.6	2.1	1.5	20.1
	P	0-30	mg kg^{-1}	67.2	129.7	105.7	15.0
	K	0-30	mg kg^{-1}	110.8	277.4	180.9	22.4
	Mg	0-30	mg kg^{-1}	36.8	81.4	63.1	25.7

Tab. 4: Results from ANOVA procedure for soil texture analysis at MPCs and yield classes

Texture	ANOVA	
	P value	Significance
Sand 0-30 cm	0.0098	**
Silt 0-30 cm	0.0123	*
Clay 0-30 cm	0.0039	**
Sand 30-60 cm	0.0002	***
Silt 30-60 cm	0.0003	***
Clay 30-60 cm	0.0066	**
Sand 60-90 cm	0.0003	***
Silt 60-90 cm	0.0004	***
Clay 60-90 cm	0.0033	**

Note: probability levels: <0.05 (*); <0.01 (**); <0.001 (***); not significant (ns)

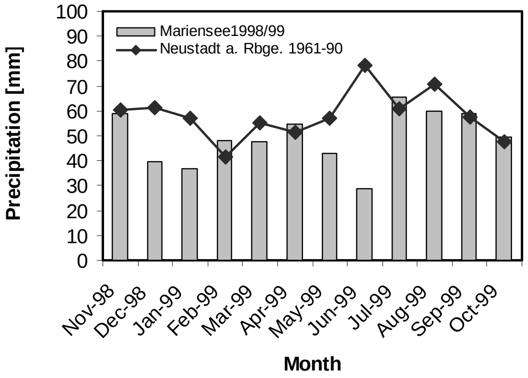

Fig. 5: Precipitation in Mariensee (Nov. 1998 – Oct. 1999) in comparison to the long-term data (1961-1990) for Neustadt a. Rgbe. (9.4667° E; 52.5000° N)

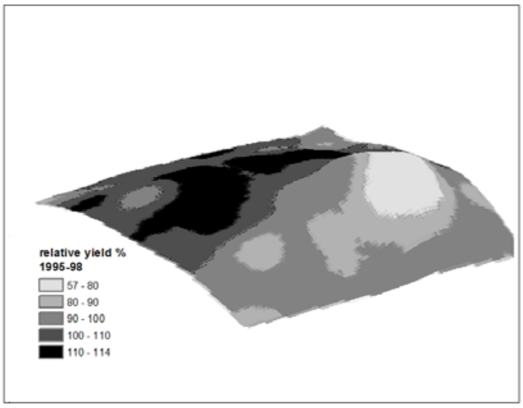

Fig. 6: Relative yield (1995-98) of combinable crops in relation to elevation changes at 'Grosser Fuchsberg' in Mariensee

Changes in geomorphology together with the spatial variation of soil texture are the main driving factors for water flow, soil moisture and nutrient availability in the field and thus highly relevant factors for crop yield. Haneklaus et al. (1996) demonstrates how knowledge about geomorphology can be integrated in the decision making process for variable N fertilisation algorithms. Digital elevation models (DEM) can be ordered from ordinary survey offices or derived from ordinary survey maps as well as kinematic GPS systems with the ability to gather DEMs on the go whilst running other field operations. Knowledge of the spatial variation of geomorphology as one of the major factors for crop productivity is essential for decision making processes in Precision Agriculture (Reuter et al., 2005).

Conclusions

In a case study yield maps of combinable crops showed a high potential as an aid for variable management decisions, for combinable as well as non combinable crops. Yield limiting factors need, however, to be verified before general conclusions for variable management strategies can be made as water availability may restrict growth of all crops in relation to soil and climatic conditions. Though sugar beet has a high demand for essential plant nutrients such as K, this parameter was not yield limiting in the presented investigation. Provided that yield limiting factor(s) could be determined, variable management applications can be designed accordingly. The used sampling strategies 'directed sampling' followed by the 'MPC' approach demonstrated successfully their fully satisfactory suitability to identify main yield limiting factors and thus proved to be an efficient tool to address causal factors of soil and plant variability.

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