Spatial and temporal stability of corn grain yields in the Upper Rhine Valley

Johanna Link, Simone Graeff and Wilhelm Claupein

University of Hohenheim, Institute of Crop Production and Grassland Research (450), Fruwirthstr. 23, 70599 Stuttgart,
Germany, www.uni-hohenheim.de, Email evajlink@uni-hohenheim.de

Abstract

Year to year consistency of crop yields within a field is needed for site-specific management decisions such as yield goals for fertilizer recommendations. A six year study was conducted on three fields in the Upper Rhine valley, close to Weisweil, northwest of Freiburg (Germany) from 1998 to 2003. The objective of the study was to determine if corn grain yield patterns were stable over space and time and if this information could be used to identify management zones for site-specific farming. Geo-referenced yield data were collected over the six years by using a dGPS-system on a combine harvester. Constant data collecting points were set up within each field at a distance of 40 m to analyze soil characteristics like soil type, soil electrical conductivity, phosphorous, potassium, magnesium, pH and organic matter content. The results of the study show, that grain yields were influenced by climate and varied temporally over years. Within the tested fields spatially consistent high and low yielding zones could be delineated over the investigated years. Spatial consistency of yield patterns could partly be explained by the investigated soil parameters. However, the datasets indicated that yield maps may be useful for determining site-specific management zones, if yield patterns are stable over years. Yield patterns will have to be further evaluated by means of crop modeling in order to detect the possible yield limiting parameters.

Media summary

Spatial and temporal variability of corn yields and their interrelation to soil and plant parameters were investigated over 6 years. Results suggest a potential for separate management zones in a field.

Key Words

Precision farming, yield pattern, yield stability, crop modeling, management zones.

Introduction

Spatial and temporal grain yield variability has been accepted by agricultural producers for a long time. Understanding and managing yield variability within corn fields has become a great challenge in current crop production research. Yield monitoring has given producers a direct method for measuring spatial variability of crop yield (Pierce and Nowak, 1999). Yield maps have shown high-yielding areas and have revolutionized the way producers might improve their management decisions. Yield maps are confounded by many potential causes of yield variability (Pierce et al., 1997) as well as potential error sources from combine yield sensors (Lamb et al., 1997). Yield variability may be caused by many factors, including spatial variability of soil type, landscape position, crop history, soil physical and chemical properties, and nutrient availability (Wibawa et al., 1993). Interactions among biotic and abiotic factors may also lead to spatial variability of crop growth (Mulla and Schepers, 1997; Sadler et al., 2000). Wibawa et al. (1993) detected yield differences that were a function of soil map units and landscape position. Other researchers have reported in-field variability caused by chemical and physical variability inherent to soils, which can influence localized nutrient availability (Penney et al., 1996). When geo-referenced information about various field parameters is available, several layers of data can be analyzed to explain yield variability and may provide a useful basis for applying site-specific management strategies.

The evolution of new technologies, including variable rate applicators and geographic positioning equipment have spawned a revolution in how farmers are managing their fields. No longer do fertilizer and pesticides need to be applied uniformly across a field, but now may be varied to match the soil potential as the soil type varies across the field. These technologies offer the possibility to identify and treat specific areas within a field differently from others. To successfully evaluate and implement site-specific farming technologies more information on spatial and temporal stability of yield patterns and on factors affecting grain yields is required. Thus, the objectives of this study were (i) to evaluate the temporal and spatial variability of corn grain yields and selected soil and plant parameters on three test sites in the Upper Rhine Valley, and (ii) to determine whether this information could be used to identify management zones for site-specific farming.

Methods

Experimental design

The study was conducted as an on-farm study from 1998 through the 2003 growing season on three fields (I1, I2, I3) in the Upper Rhine Valley (48? 19' N, 7? 67' E) next to Weisweil, northwest of Freiburg, Germany. The normal annual precipitation in this area averages at about 700 mm and the average temperature is about 10? C. The sum of yearly solar radiation in the Rhine valley averages at about 11740 KJ m^{-}?.

The research area of the three fields covered ~ 5.5 ha and the major soil type was a silty loam with 1,7 % organic matter. No differences in elevation existed within the experimental area. Over the six years the fields were planted continuously with corn from April – October, with exception of field I1 in 1999, where wheat was planted. Cultural practices used for corn production were applied uniformly to the 5.5 ha site. The fields were ploughed in spring and harrowed shortly before planting. Corn was planted with a four row planter between mid April and early May with 85.000 up to 105.000 kernel ha^{-1}. The corn cultivars varied over years and fields. At sowing and around the 4^{th} leaf stage corn was fertilized with KAS (26?% N) and urea (46?% N) respectively. The necessary amount of nitrogen fertilizer was determined at the 4^{th} leaf stage of corn by taking soil samples and analyzing N_{min} in the soil. The nitrogen rates varied over fields and years between 80-190 kg N ha^{-1} depending on soil nitrogen content. Herbicides and pesticides were broadcast if necessary.

Yield and soil data

During the six years geo-referenced yield data were collected by using a digital (?) global positioning system (dGPS) on a combine harvester. In addition to grain yields, several soil parameters were investigated in the years 2000 and 2003 to find possible yield limiting factors. Therefore, constant data collecting points were set up within each field at a distance of 40 m, resulting in seven data collecting points per hectare. To gain information about the variability of soil characteristics, ten soil samples of the upper soil layer (0 – 30 cm) were taken at each data collecting point at the beginning of the growing seasons. The soil samples were analyzed for soil type, phosphorous, potassium, magnesium, pH and organic matter content. Soil electrical conductivity was measured with a Veris 3100 to a depth of roughly 90 cm. The Veris 3100 uses electromagnetic induction as a non-invasive method to determine soil EC. Different soil depths can be measured by varying the orientation (horizontal vs. vertical) and instrument height above the soil surface. By integrating the unit with a GPS and data logger, field scale maps can be created. Shortly before harvest several yield parameters like number of plants per m?, cobs per m?, kernels m?, thousand-kernel weight, moisture content of the kernel, and nutrient uptake during the growing season were determined at each data collecting point by hand harvesting an area of 1 m?.

Data analysis

Yield data were analyzed for spatial and temporal stability by building a grid of 273.3 m? around each data collecting point. Geo-referenced yield data corresponding to these grids were correlated with all determined plant and soil parameters belonging to the specific collection point. Pearson correlation coefficients (r) were calculated between grain yields over years. Multiple regression models were used to assess the additive effects of soil properties on yield. All statistical analysis were performed using the general procedures of Sigma Stat 2.0 (Jandel Scientific, San Rafael, CA).

Results

Corn grain yields were collected from 1998 through the 2003 growing season in three fields. Table 1 shows the annual average grain yield within each field. Corn grain yields ranged from 5.67 T ha^{-1} in 1998 to 11.20 T ha^{-1} in 2000. Statistical analysis indicated significant differences in the yield potential over the three fields between the six years. The average corn grain yield over one field in each year was significantly different from the yield in the other five years indicating that grain yields were greatly affected by yearly variations in climate, particularly by year-to year changes in seasonal water supply.

Table 1. Average corn grain yield (T ha^{-1}) of the fields I1, I2 and I3 over six years of investigation (I1 in 1999 is yield of wheat). Letters behind average yield indicate significant differences between the three fields at the 0.001 probability level.

	1998	1999	2000	2001	2002	2003	Average
I1	5.67 a	8.24 b	11.20 b	7.84 b	9.09 b	7.55 a	8.27
I2	5.93 a	7.58 a	11.03 b	9.03 c	8.09 a	7.64 a	8.22
I3	8.32 b	8.56 c	9.25 a	6.56 a	9.14 b	8.22 b	8.34
Average	6.64	8.13	10.49	7.81	8.77	7.80	

Figure 1 shows the obtained yield pattern for the three fields in the years 2000 and 2003. Aggregating yields in grids of 16 * 16 m made it possible to delineate spatial consistent high yielding and low yielding zones in each of the three fields over all tested years. In the year 2000 corn yield varied considerably and ranged between 3.36 and 14.86 T ha^{-1}. In the year 2003 total corn yield was generally lower and the variation of yield from 2.64 T ha^{-1} to 10.56 T ha^{-1} was considerably less.

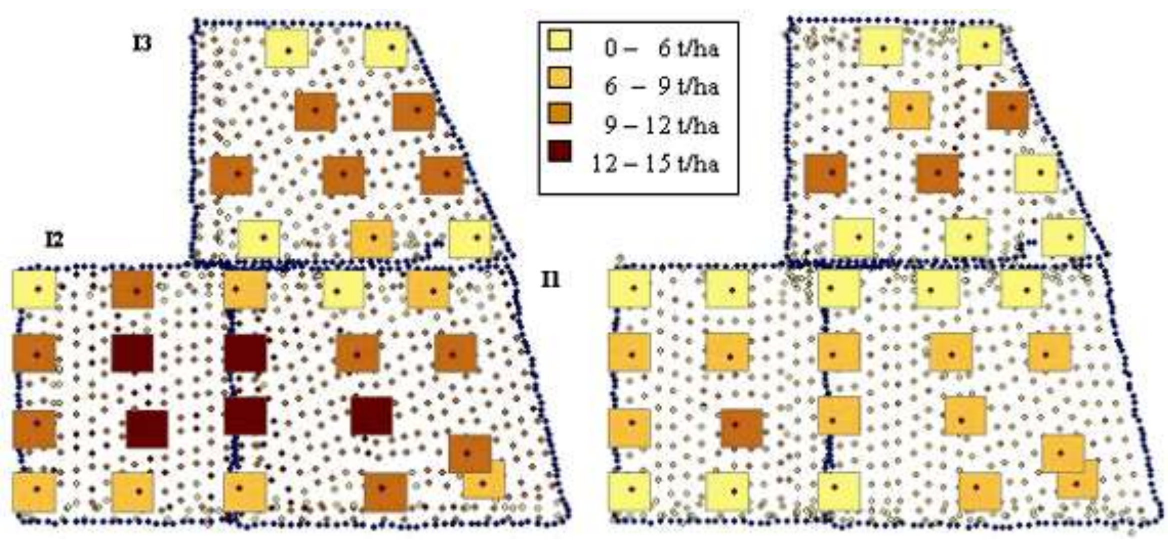

Figure 1. Grids within the fields showing the distribution of high yielding and low yielding zones in 2000 and 2003.

Table 1 presents the results of the Pearson correlation for each field between the yields of each investigated year. In field I1 and field I2 the strongest correlation was found between the yield pattern in year 1999 and 2003 (r = 0.90, r= 0.87). The strongest correlation between yield pattern of field I3 was ascertained between year 2001 and year 2002 with r = 0.88. These results indicate that the yield levels within the three fields were spatially consistent.

Table 2. Pearson correlation coefficients of corn grain yield over different years for field I3, I2, and I1.

I3		1999	2000	2001	2002	2003
1998	r	0.182	0.795	0.719	0.842	0.625
	P	0.614	0.006	0.019	0.002	0.053
1999	r		0.629	0.730	0.377	0.501
	P		0.051	0.017	0.283	0.141
2000	r			0.854	0.781	0.738
	P			0.002	0.008	0.015
2001	r				0.882	0.694
	P				0.004	0.026
2002	r					0.629
	P					0.052

I2		1999	2000	2001	2002	2003
1998	r	0.596	0.409	0.479	0.666	0.567
	P	0.119	0.314	0.230	0.071	0.143
1999	r		0.722	0.596	0.674	0.874
	P		0.025	0.119	0.067	0.005

2000	r			0.316	0.315	0.747
	P			0.445	0.447	0.033
2001	r				0.292	0.779
	P				0.482	0.023
2002	r					0.543
	P					0.164

I1		1999	2000	2001	2002	2003
1998	r	0.710	0.683	0.108	0.836	0.626
	P	0.010	0.014	0.739	0.001	0.030
1999	r		0.722	0.352	0.520	0.901
	P		0.008	0.261	0.083	0.000
2000	r			0.033	0.452	0.808
	P			0.920	0.140	0.002
2001	r				-0.215	0.367
	P				0.503	0.247
2002	r					0.346
	P					0.271

In order to possibly explain the spatial yield variation multiple regression analysis were performed between determined soil parameters and corn grain yield. The regression analysis resulted in r? = 0.74 for field I1, r? = 0.56 for I2 and r? = 0.75 for I3, which implied a strong influence of tested soil properties on corn yields and spatial yield variability. The use of single soil characteristics for regression analysis indicated that with the exception of silt content in field I2 (r? = 0.33) the tested soil characteristics like organic matter content, pH, phosphorous, potassium, magnesium and nitrogen content did not explain spatial yield variability within these three fields. The results suggest that either interactions among the soil properties influence yield or that there might be other factors beyond those measured affecting yield.

Studies of Sudduth et al. (1996) and Kravchenko and Bullock (2000) have shown that linear analysis alone often failed to produce good functional models explaining yield variability. More complex models have to be applied to the problem of relating crop yield to site and soil characteristics. Thus, the DSSAT 4.0 crop growth model will be employed to the obtained datasets to finally determine the cause of spatial grain yield variability within each field. By using the spatial tool of the DSSAT model a relationship between yield data and yield limiting parameters within the fields will be estimated. Based on the results of the crop model, management zones with regard to high and low yielding zones may be clearly delineated and the parameters capturing yield variability may be determined.

Conclusion

Spatial and temporal variability of corn yield in the Upper Rhine Valley was assessed in a six year field study. High and low yielding zones could be delineated in the different fields over the six years. The results of the study indicated, that yield pattern were spatially consistent over the six years and were influenced by multiple soil characteristics. These results suggest that yield maps and site-specific information may help to demarcate management zones in a field. Knowledge of spatially consistent yield pattern may provide a valuable source of information that needs to be fully exploited in the future.

Acknowledgement

We thank the ITADA-Projekt 1.1.1 ‚Nutzbarmachung von Verfahren der Pr?zisionslandwirtschaft am Oberrhein – Analyse und Interpretation der Variabilit?t von Ackerfl?chen in der Rheinebene', bearbeitet von Dr. Ivika R?hling (IfuL) und Didier Lasserre (ICTF) mit Kofinanzierung durch EU-Gemeinschaftsinitiative INTERREG II Oberrhein Mitte-S?d for providing the datasets.

References

Kravchenko, AN, and Bullock, DG (2000). Correlation of corn and soybean grain yield with topography and soil properties. Agronomy Journal 92, 75-83.

Lamb, JA, Dowdy, RH, Anderson, JL and Rehm, GW (1997). Spatial and temporal stability of corn grain yields. Journal of Production Agriculture 10(3), 410-414.

Mulla, DJ and Schepers, JS (1997). Key Processes and Properties for Site-Specific Soil and Crop Management. In 'The State of site-specific management for agriculture' (Ed. FJ Pierece, EJ Sadler) ASA-CSSA-SSA Madison, WI, USA, pp. 1-18.

Penney, DC, Nolan, SC, McKenzie, RC, Goddard, TW and Kryzanowski L (1996). Yield and nutrient mapping for site-specific fertilizer management. Communications of Soil Science and Plant Analysis 27,1265–1279.

Pierce, FJ and Nowak, P (1999). Aspects of precision agriculture. Advances in agronomy. 67, 1-85.

Sadler, EJ, Bauer, PJ and Busscher, WJ (2000). Side-specific analysis of a droughted corn crop: I. Growth and grain yield. Agronomy Journal 92, 395-402.

Sudduth, KA, Drummond, ST, Birrel, SJ and Kitchen, NR (1996). Analysis of spatial factors influencing crop yield. Proceedings of the 3rd International Precision agriculture conference, Minneapolis, ASA, CSSA, and SSA Madison, WI, p. 129-140.

Wibawa, WD, Duduzile, L, Swenson, LJ, Hopkins, DG and Dahnke, WC (1993). Variable fertilizer application based on yield goal, soil fertility, and soil map unit. Journal of Production Agriculture 6(2), 255-261.