Topography impact on nutrition content in soil and yield

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ABSTRACT

The main aim of this study was to determine the dependence of yield and selected soil properties on topography of the experimental field by using topographical data (elevation, slope and flow accumulation). The topography and yield data were obtained from a yield monitor for combine harvester, and soil properties data were taken from sampling points of our experimental field. Initially, the topographical parameters of elevation and slope were estimated and then the Digital Elevation Model (DEM) grid was created. On the basis of field slope the flow direction model and the flow accumulation model were created. The flow accumulation model, elevation and slope were then compared with the yield and content of nitrogen and organic carbon in soil in the years 2004, 2005 and 2006 in relation to the sum of precipitation and temperatures in crop growing seasons of these years. The correlation analysis of all previously mentioned elements was calculated and statistical evaluation proved a significant dependence of yield and soil nutrition content on flow accumulation. For the wettest evaluated year the correlation coefficient 0.25 was calculated, for the driest year it was 0.62.

Keywords: precision agriculture; topography; GIS; flow accumulation; yield; nutrition content; management zones

One of the aims of site-specific agriculture is to optimize the use of spatial and temporal management strategies. Such optimization can improve the crop yield and quality and at the same time reduce the risks for nutrient and pesticide leakage. In the past decade, several projects focused on quantifying and characterizing variation in factors such as crop yield, soil properties and precipitation and their interrelationships (Persson 2005).

Topography is one of the most obvious causes of variation found in field crops both for its direct effect on micro-climate and for related soil factors such as soil temperature, which influences germination, tiller production and crop growth. For the majority of practical farming purposes it is unchangeable and thus it can only be used to explain variation (Godwin and Miller 2003).

Pilesjö et al. (2005) featured that different topographical parameters can be used to delineate agricultural management zones. That indicates that the different parameters should be used individually in order to create different zones and thus explain spatial variability of different soil parameters. In their study, area, elevation and drainage area were the most suitable parameters to delineate zones; they explained organic matter, clay content, content of phosphorus, potassium, magnesium, pH and yield.

Soil characteristics play an important role in crop growth and yield. In more complex terrains, soil forming factors and erosion do not act uniformly but vary with position. Intuitively, we do not expect soil properties to be independent of one another; it is presumed that what eroded at

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higher landscape positions must move downhill and alter what is described at lower lying positions (Marques da Silva and Alexandre 2005).

Soil properties also vary with topographic settings. One reason is the orientation of hill slopes on which soils develop; this affects the microclimate, such as north vs. south-facing slopes, and hence the soils (Iqbal et al 2004).

Marques da Silva and Alexandre (2005) also said, that the effect of soil and topographic attributes on yield variability may be perceived when data of these attributes are compared to the yield data. The geographic information system (GIS) can generate and overlay various data layers in order to relate them over space and time. Crop yield is an outcome of many complex soil and climate factors, and their effect on yield might be better interpreted using the GIS map overlay.

Topographical data in combination with soil information are useful for explaining yield variability on an agricultural field scale. Topographical information can be especially helpful in site-specific management for delineating areas where crop yields are more sensitive to extreme weather conditions (Kravchenko and Bullock 2000).

On the basis of these previously published findings, the main aim of this study was to evaluate the relationships between spatial variability of yield, soil nutrition content and topography characteristics in our experimental field. Achieved results should enable to find influences of topography on yield and explain how much the yield and soil properties were influenced by elevation, slope and flow accumulation and why.

MATERIAL AND METHODS

Experimental yield and soil data

The experimental data of this study were collected from our experimental field in Prague-Ruzyne (50°05'N, 14°18'E). Total area of the field is 14 ha. The field soil is Orthic Luvisol, average precipitation is 526 mm per year, and average temperature 7.9°C. The major part of our experimental field is south-oriented with the altitude from 338.5 to 357.5 m above sea level. The slope of the field is approximately 3°.

Precision farming has been employed in this experimental field since the year 2002. 70 locations measured with GPS were created on a regular grid of 40 × 40 m. These locations are sampling points for soil and plant samples. The soil samples were analyzed for the content of nitrogen and organic carbon.

In our experimental field the yield has been measured since 2003. A combine harvester equipped with the yield monitor was used for the harvest of cultivated crops. Measured yield data were proc-

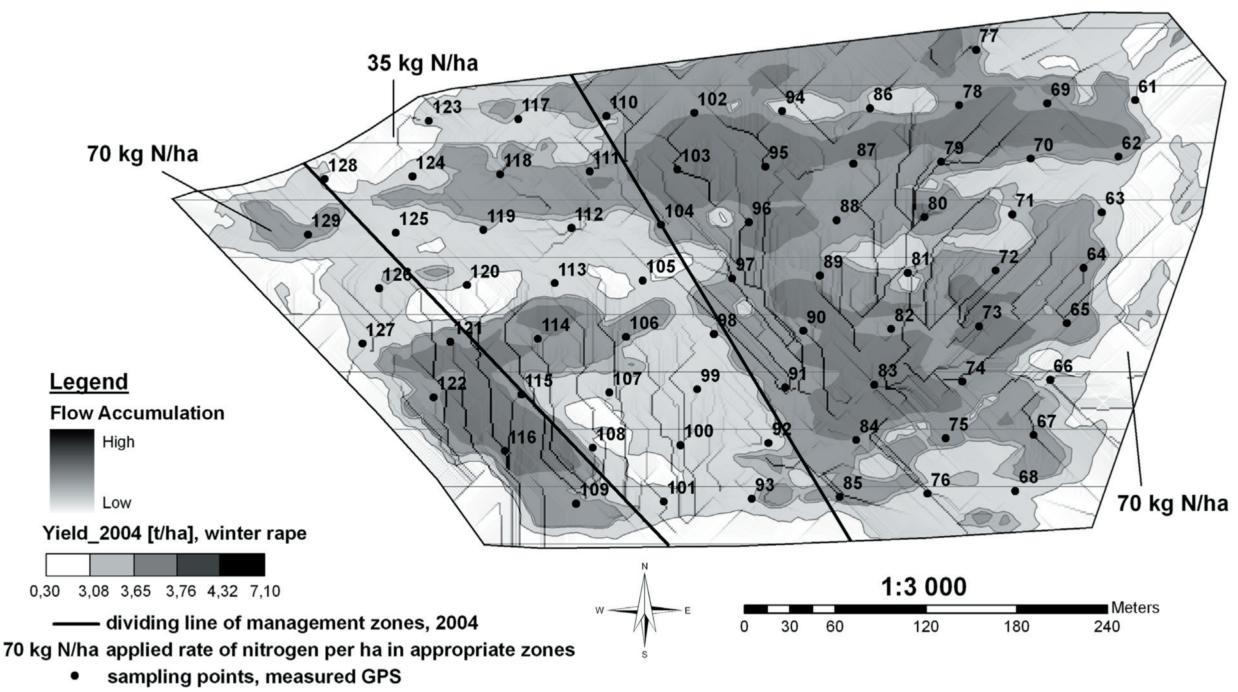

Figure 1. Yield of winter rape in the year 2004 with the flow accumulation layer and the management zones with applied rate of nitrogen per hectare

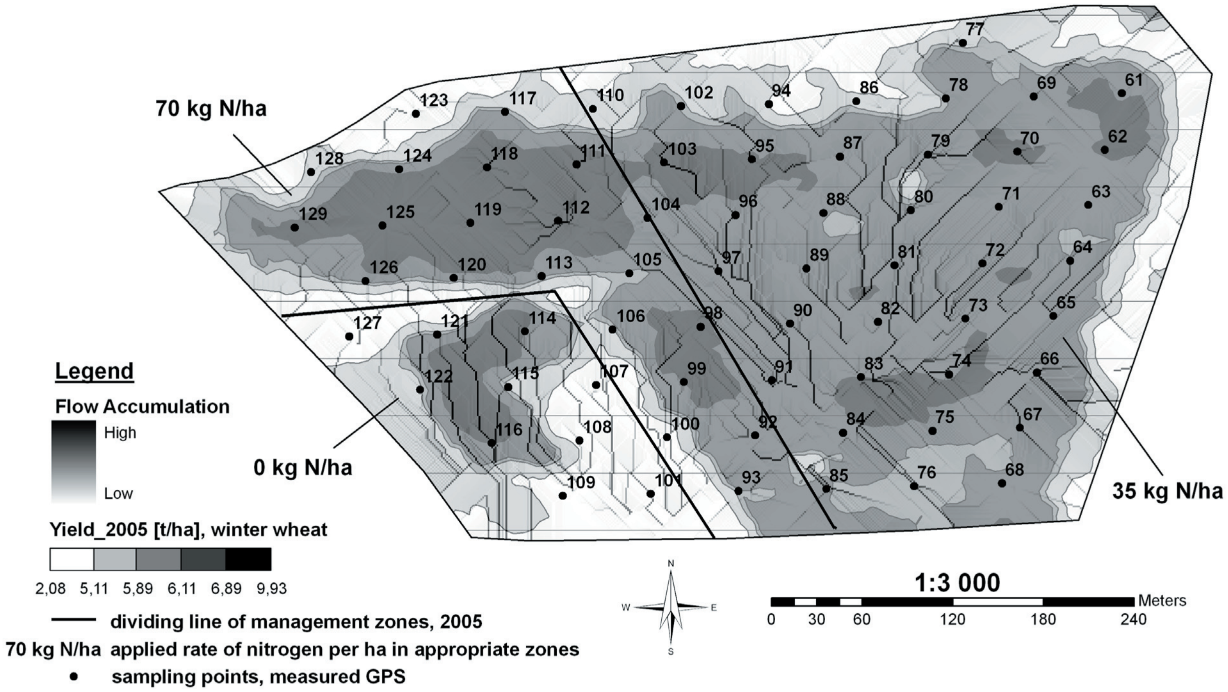

Figure 2. Yield of winter wheat in the year 2005 with the flow accumulation layer and the management zones with applied rate of nitrogen per hectare

essed in a combine harvester onboard computer and together with the position data were saved into PCMCIA memory card. The data obtained were processed by statistical methods with the ArcGIS 9.1 SW.

Since 2001 crop rotation was as follows: 2001 – sugar beet, 2002 – spring barley, 2003 – winter wheat, 2004 – winter rape, 2005 – winter wheat and 2006 – oat.

Until 2002 the experimental field was tilled uniformly without variable application. Since 2003, however, site-specific application of nitrogen was used with the aim to balance the yield variability on observed field to be as uniform as possible. For that purpose, the field was divided into four regular site-specific zones in 2003. Two zones were with variable rate application and two zones were with uniform rate application. In 2004 the field was divided into three zones based on the content of NO_3 in soil measured the year before. Into the zones with poor supply of nitrogen in soil, 70 kg of nitrogen per hectare was added, while only 35 kg of nitrogen per hectare was supplied into soils with higher content of nitrogen. Similarly, the field was divided into three zones in 2005; these site-specific zones were based on the yield map from 2004. In the zones following rates of nitrogen were applied: 0 kg N/ha, 35 kg N/ha and 70 kg N/ha. In the year 2006 the field had the same site-specific zones as in the previous year. The applied rates of nitrogen were: 76 kg N/ha, 38 kg N/ha and 57 kg N/ha. The rates were set on the basis of the 2005 yield map results. The rates of nitrogen should unify the yield of oat in the whole field (Figures 1–3).

Total monthly precipitation and temperature data from this area were provided by Agro Meteorology Station in location of the Crop Research Institute, Prague-Ruzyne. Precipitations in phenological phases, the sum (per growing season) and the average of precipitations from the years 2004 to 2006 are shown in Figure 4. For the purpose of this study the sum of precipitations and the sum of temperatures were used. Other information in the graph is shown to closer describe the temperature and precipitation trends in the observed years.

Topographical data

The topographical data were collected from the PCMCIA memory card from the combine harvester. Longitude, latitude and altitude were saved during the harvest together with the yield. For the control, the altitude was measured with the hand GPS signal receiver (device GPS Map 60CS) on every sampling point after the harvest.

Initially, the digital elevation model (DEM) from the point shapefile of elevation data was created. Input point shapefile had a lot of errors in terrain

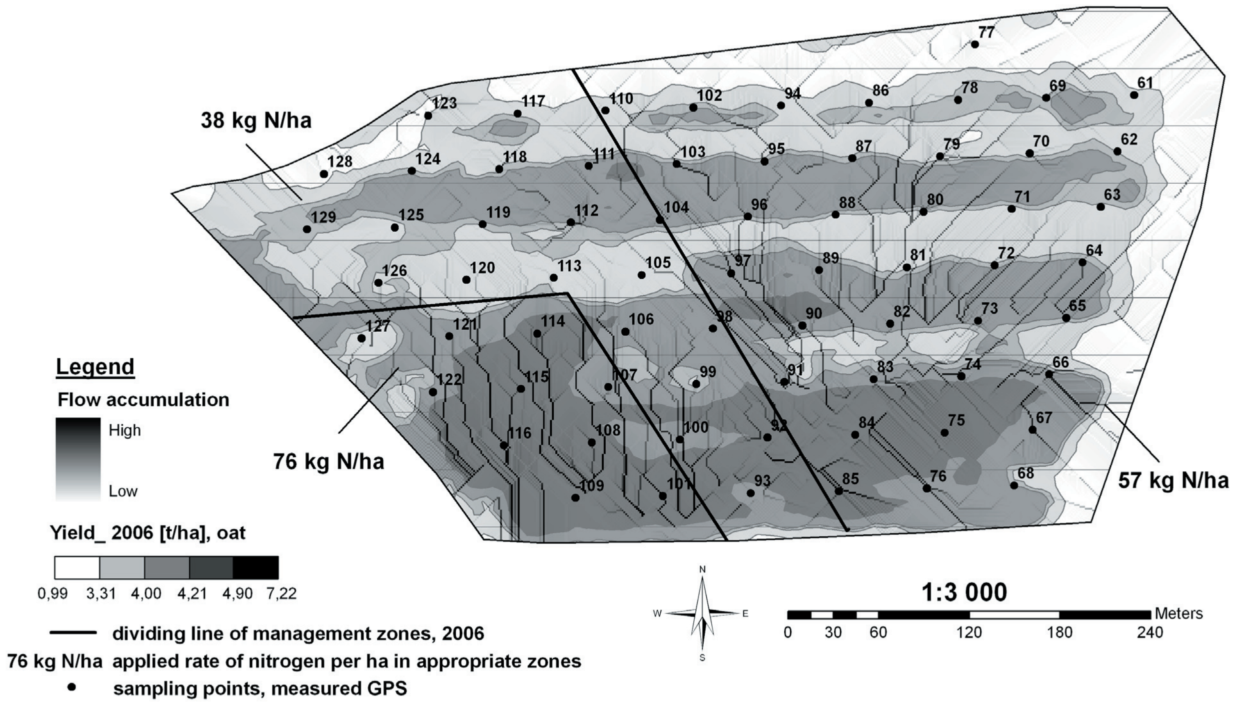

Figure 3. Yield of oat in the year 2006 with the flow accumulation layer and the management zones with applied rate of nitrogen per hectare

relief, which was caused by logging errors in altitude determination during the work of combine harvester. Hence, it was necessary to exclude wrong highs and lows from our data. The point shapefile layer was interpolated via interpolation method "spline" for that reason, and smooth continuous data were then obtained. Based on these altitude data the model of slope was created. This slope model was then used for creation of the direction of flow and then for the flow accumulation model. All these procedures were made in SW ArcGIS 9.1.

The direction of flow is determined by finding the direction of the steepest descent from each cell. This is calculated as a change in z-value divided by distance multiplied by 100 (result is in %). The distance is calculated between cell centers. Therefore, if the cell size is 1, the distance between two orthogonal cells is 1, and the distance between two diagonal cells is 1.414. This method of deriving flow direction from a digital elevation model (DEM) was presented in Jenson and Domingue (1988).

The result of flow accumulation is a raster of accumulated flow to each cell, as determined by accumulating the weight for all cells that flow into each down slope cell. Cells of undefined flow direction will only receive flow; they will not contribute to any downstream flow. The accumulated flow is based on the number of cells flowing into each cell in the output raster. The current processing cell is not considered in this accumulation. Output cells with a high flow accumulation are areas of concentrated flow and may be used to identify stream channels. Output cells with a flow accumulation of zero are local topographic highs and may be used to identify ridges. If the inflow direction raster was not created, there is a chance that the defined flow could loop; if the flow direction does loop, flow accumulation will go into an infinite loop and never finish (ESRI 2005).

Flow accumulation was defined as the total number of cells contributing to water inflow into a given cell. Prior to calculating the flow accumulation, main flow directions were determined based on slope differences. The main flow direction corresponded to the direction of the steepest descent in slope. Based on the main direction map, the flow accumulation was calculated by summing all the cells that flowed into the given cell (Jenson and Domingue 1988). The absolute value of the flow accumulation depended on the total number of cells in the map; hence, it was a function of both the size of the field and map resolution. The flow accumulation was not applicable for comparing fields of different size. However, within a field, flow accumulation was useful for explaining yield/topography and soil/topography relationships (Kravchenko and Bullock 2000).

Schmidt and Persson (2003) found out that the flow of ArcView flow accumulation request

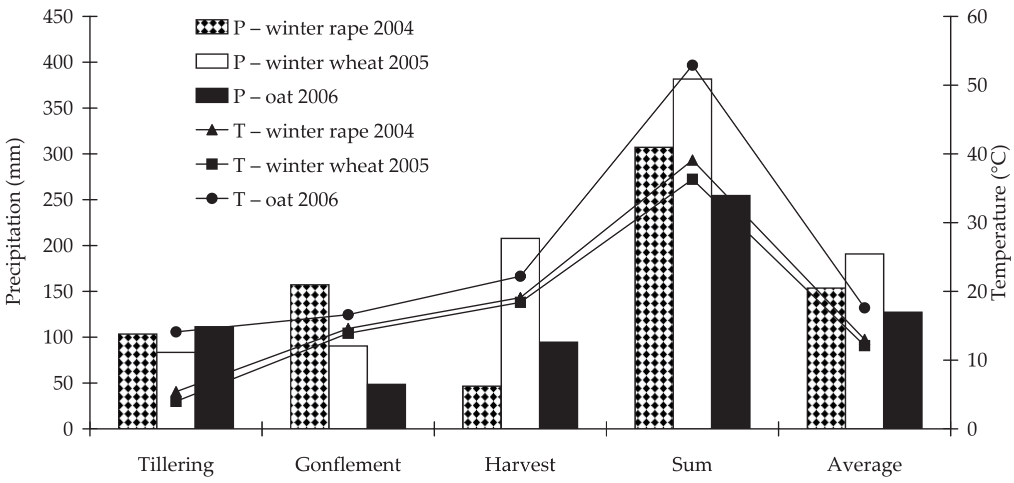

Figure 4. Precipitation (P) and temperature (T) in phenological phases, the sum (per growing season) and the average of precipitation and temperature from 2004 to 2006

("D8" algorithm; Jenson and Domingue 1988) can only be routed to one neighbouring cell, that is, to the neighbour with the steepest downward slope. One of its disadvantages is that it produces parallel flow lines on plane slopes. This results in large differences between neighbouring points that should have a similar catchment area. The difference is caused by the small width of the calculated flow lines. The D8 cannot model flow divergence on convex slopes. The D8 algorithm is implemented in most common GIS packages.

In our experiment the "D8" algorithm model in ArcGIS 9.1 package was used. In spite of knowing about the disadvantages mentioned before, this procedure was applied because it is a part of widely used GIS software under Czech Republic conditions. Nevertheless efforts were made to reduce these disadvantages as much as possible.

The flow accumulation was recounted on abovementioned sampling points and then the flow accumulation model was created with the help of kriging method in order to reach the area distribution (it means not lines distribution of flow accumulation values). Flow accumulation model in that shape was then possible to compare with yield, soil and other models mentioned.

RESULTS AND DISCUSSION

On the basis of the findings previously described in the Material and Methods section, the Flow Accumulation Model (FAM) of the experimental field was created at first. The model was then compared with the yield of the years 2004, 2005 and 2006; comparison of the yield of individual years with FAM is shown in Figures 1–3, respectively. The Figures 1–3 also show management zones with applied rates of nitrogen in respective years.

Next evaluation step was to calculate a correlation matrix of dependence of the recorded values; its results are shown in Table 1.

Figure 4 indicates that the year 2005 was the wettest and the coldest from all observed years; however, it is possible to see in Table 1 that the yield was not dependent on flow accumulation too much; the correlation coefficient (r) was 0.25.

On the contrary, the year 2006 showed the reverse trend. This year was the driest and warmest (Figure 4) but Table 1 shows that the correlation coefficient (r) between the yield and flow accumulation was 0.62. Moreover, Table 1 shows that the yield was dependent on elevation ($r = -0.39$) and slope ($r = -0.61$). Nevertheless, the flow accumulation was derived from elevation and slope as it was just described before.

The year 2004 was in the middle of the observed years as for the precipitation and temperature (Figure 4). The correlation coefficient (r) between the yield and flow accumulation was calculated as 0.36.

It is possible to derive from the visual evaluation of the Figures 1–3 that the highest yield values correspond with the highest flow accumulation values for every observed year. Nevertheless, temperature and precipitation had probably another influence on the yield distribution.

Table 1 shows that the distribution of N_t and C_{org} in the experimental field was influenced by flow accumulation and slope. It might be caused by the flush of N_t and C_{org} from local topographic heights through stream channels into flow accumulation

Table 1. Correlation coefficients (r) among yield, soil properties and topographical land features in the years 2004, 2005 and 2006

	Year	Elevation 04 05 06	Slope 04 05 06	FA 04 05 06	Yield 04 05 06	N_t 04 05 06	C_{org} 04 05 06
Elevation	2004	1					
	2005	1					
	2006	1					
Slope	2004	0.63	1				
	2005	0.63	1				
	2006	0.64	1				
FA	2004	–0.56	–0.87	1			
	2005	–0.55	–0.88	1			
	2006	–0.57	–0.89	1			
Yield	2004	0.07	–0.16	0.36	1		
	2005	–0.02	–0.11	0.25	1		
	2006	–0.39	–0.61	0.62	1		
N_t	2004	0.07	–0.22	0.14	–0.09	1	
	2005	–0.07	–0.38	0.39	0.07	1	
	2006	–0.3	–0.58	0.43	0.48	1	
C_{org}	2004	–0.45	–0.71	0.63	0.07	0.62	1
	2005	–0.41	–0.53	0.43	0.08	0.78	1
	2006	–0.41	–0.69	0.65	0.56	0.79	1

FA – flow accumulation

areas and consequently by better availability of these elements for plants because of water reserve in that areas. The correlation coefficients (r) between flow accumulation and N_t were 0.14, 0.39 and 0.43 in 2004, 2005 and 2006, respectively. A similar tendency showed the C_{org} dependence on flow accumulation. The correlation coefficient (r) between C_{org} and flow accumulation in 2004 was 0.64, in 2005 r = 0.43 and in 2006 r = 0.65. In both cases (N_t and C_{org}) the highest correlation coefficient was calculated for the driest year (2006). This supports the idea of the flush of the observed soil elements. The correlation coefficients among flow accumulation and N_t or C_{org} from the years 2004 to 2006 had a similar tendency as the correlation coefficients among flow accumulation and yield, which can result from the same influence of weather in combination with flow accumulation and slope in these years as in the case of dependence of flow accumulation and yield.

In order to closer evaluate the influence of different factors, statistical methods were applied. Multifactorial analysis of variance from Statistica Cz software was used. The influence of two factors, namely flow accumulation and site-specific application of nitrogen, on crop yield was studied. Tuckey HSD test was used for a detailed evaluation of tested factors. All values were calculated for α = 0.05 probability level.

The results obtained for the year 2004, which was in the middle of the observed years with respect to the precipitation and temperature, were as follows: the yield on our experimental field was influenced partly by nitrogen fertilization (medium and high levels of fertilization had statistically important positive influence on yield) and partly by flow accumulation (medium and high levels of flow accumulation had statistically important positive influence on crop yield).

In the year 2005, which was the wettest and the coldest, a statistically important positive influence of nitrogen fertilization was proved for medium and high level of fertilization but no influence of flow accumulation on crop yield was determined.

In the year 2006, the driest and the warmest year, a statistically important positive influence of nitrogen fertilization was proved only when high level of fertilizers was applied. Compared to 2005, a statistically important positive influence of flow accumulation on crop yield was proved for all three levels of flow accumulation observed: low, medium and high.

These statistical evaluations suggest that the results for three different observed years are in accordance with the results previously discussed. Statistical evaluation of the observed data underlines the obtained results; it means that the influence of field topographic parameters on crop yield can be crucial, especially in dry years.

Relations between weather conditions, topography and yield reported in literature are rather contradictory. Halvorson and Doll (1991) observed lower influence of topography on yield in dry years than in wet ones. They related it to lower amounts of water available for topographical redistribution during dry years. In such years water content could be expected more homogenously distributed through the field. However, Simmons et al. (1989) reported the greatest influence of topography on yield in dry years.

In our experiment it was found that the relation between yield and topography (elevation, slope and flow accumulation) was more important in dry years.

As it was possible to derive from visual and statistical comparisons of flow accumulation and yield maps in the observed years, the yield can be dependent on flow accumulation and water redistribution in the field in dry years more than in wet years. It was also possible to conclude from described experiments that the flow accumulation layer could be used for delineation of management zones. Nevertheless, the dependence of the yield on the flow accumulation can vary from year to year and it is dependent on weather conditions in the given year.

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