AGRICULTURAL APPLICATIONS OF LASERSCANNER DEMs: QUALITY REQUIREMENTS AND ANALYSIS METHODS

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ABSTRACT:

Laserscanning DEMs are a valuable data source for precision agriculture (PA). In PA, application rates can be adapted to the natural site heterogeneity by using GPS. Terrain properties control the movement of water in a landscape and, thus, influence the spatial pattern of soil attributes. The terrain is one of the most important natural factors causing heterogeneity on arable land. The functions of the terrain and the variability of soil properties can be represented by using high-quality DEMs. DEMs are the basis to derive a reproducible and stable spatial pattern for the generation of application maps e.g. soil tillage, seeding and fertilization. In this article, the suitability of two laserscanning DEMs (a 2 m grid size campaign and a 10 m grid obtained from a German mapping agency) and a RTK-GPS based DEM are evaluated. Common terrain analysis methods are presented. The article shows that terrain analysis for soil modelling requires "smooth" continuous surfaces with an height accuracy of ±10 cm and a spatial resolution of 2 – 10 m. These requirements can be met by both laserscanning and RTK-GPS. Problems can occur when the flight campaign is conducted during the vegetation period, i.e. a dense crop canopy is captured as "terrain" by the laser. RTK-GPS is restricted to the tram lines on the field, leading to an unfavourable sample point geometry. Finally, characteristic properties, quality requirements, applications and specific problems of DEMs for PA are discussed.

Kurzfassung:

Laserscanning-DGMs sind eine hochwertige Datengrundlage für Precision Agriculture. Bei dieser GPS -gestützten Form der Landbewirtschaftung werden Maßnahmen auf Standortunterschiede angepasst. Das Relief beeinflusst Richtung und Ausmaß der Bodenwasserbewegung und ist folglich eine Steuergröße bei der Ausbildung der Bodenheterogenität. DGMs bieten bei ausreichender Qualität eine Grundlage zum Verständnis der Variabilität der Standortbedingungen. Ein zeitlich stabiles, nachvollziehbares räumliches Muster kann für die Erstellung von Applikationskarten (z.B. Tiefe der Bodenbearbeitung, Aussage- und Düngemengen) abgeleitet werden. In diesem Beitrag wird die Eignung von Laserscanning-DGMs einer gezielten Messkampagne und eines 10 m-DGM der Landesvermessung im Vergleich zu RTK-GPS-DGMs dargestellt. Geeignete DGM-Analysemethoden werden vorgestellt. Es wird gezeigt, dass DGM-Analysen zur Abgrenzung von Bodenunterschieden „glatte", kontinuierliche Oberflächen mit einer Höhengenauigkeit von ±10 cm und einer räumlichen Auflösung von 2 - 10 m erfordern. Dies kann sowohl durch Laserscanning als auch RTK-GPS erreicht werden. Probleme bestehen bei Befliegungszeitpunkten mit Pflanzenbestand auf den Schlagflächen durch den hohen erfassten Detailreichtum. RTK-GPS ist dagegen bis in das späte Frühjahr einsetzbar, allerdings auf die Fahrspuren im Feld beschränkt, was zu einer ungünstigen Messpunktanordnung für die DGM-Interpolation führt. Charakteristische Eigenschaften und Qualitätsansprüche an DGMs sowie Anwendungsmöglichkeiten und spezielle Probleme im Precision Agriculture werden vorgestellt.

1 INTRODUCTION

1.1 Terrain Analysis and Precision Agriculture

Terrain characteristics control the proportion and direction of lateral movement of water in a landscape. The movement of water influences the spatial pattern of soil attributes such as soil moisture and particle size distribution and is one of the most important natural factors causing soil heterogeneity on arable land. The spatial pattern of yield is also partly influenced by terrain properties. The functions of the terrain can be represented using digital elevation models (DEM). The DEM gives a stable spatial pattern compared to other data sources needed for precision agriculture (PA), e.g. aerial photographs of crops, yield maps and soil chemical parameters. DEMs have been under investigation for agricultural applications for a number of years (e.g. Nugteren and Robert, 1999; Russel et al., 2000; Nolan et al., 2000; Yao and Clark, 2000; Bishop and McBratney, 2002, Schmidt and Persson, 2003) and will be more common with increasing availability and quality in the near future. Laserscanning campaigns will be the most important tool for potential precision agriculture applications of DEMs.

The aim of PA is to improve a sustainable use of soil resources by considering site-specific differences of the soil quality in the management process. Thus, the use of fertilizer, pesticides etc. can be optimized due to a site-specific variation of the application rates. By saving e.g. fertilizer on some parts on the field, farmers can save money and reduce nitrate leaching. Positive environmental effects are expected as well as cost effects. Digital terrain analysis can support the generation of application maps for soil tillage (depth of tillage), seeding, irrigation, fertilizing and pesticide spreading. For this purpose, topographic attributes such as slope, aspect, drainage area (flow accumulation) or the Topographic Wetness Index (TWI) have to be derived from the DEM. The use of terrain analysis for PA and quality aspects have been studied in the joint research project "pre agro" (1999 - 2002) and will be presented in this article. In total, 53 DEMs, mainly based on RTK-GPS campaigns, were captured and evaluated (Schmidt, 2001). For two farms in different German regions with 6 plots each, laserscanning DEMs were obtained. This article concentrates on the results of 6 plots and refers to experiences with the remaining study plots. The spatial background set by agricultural technology in Germany are typical plot sizes of 5 –

200 hectares (with generally larger plots in the East) and site-specifically manageable units of approx. 400 m². This results from usual tram line distances of 18 – 24 m on the field multiplied by up to 10 m waylength to adjust the application machinery (e.g. sprayer).

2 METHODS AND MATERIAL

2.1 Study sites

The main test site Kassow (Figure 1) is located in North-East Germany, 30 km south of the Baltic Sea (latitute 53°52' N, longitude 12°04' E). The landscape is a slightly undulating ground moraine area, dominated by glacial till. The main soil texture is loamy sand; sand and loam are also present. On this farm, 4 agricultural plots with a total area of 350 ha have been studied (Schmidt, 2003). Figure 1 shows the largest plot (141 ha) that includes a complete catchment area. Most of the plots show clearly visible erosion forms and several small depressions without outlets. The Kassow plots range from 1 – 48 m over sea level with slope angles from flat to 18°. The mean annual precipitation is rather low with 530 mm.

A second laserscanning grid was obtained and analysed for two plots with 35 ha on a smaller farm near Beckum in the West of Germany (latitude 51°45' N, longitude 8°00' E) at the altitude range of 88 –106 m above sea level. Mean slope (1°) and standard deviation of slope (0.3°) are significantly lower compared to the four Kassow plots (mean sope 1.9° – 4.5° and standard deviation 1.2° – 2.9°). In contrast to Kassow, the soils are typically loamy to clayey. The mean annual precipitation is about 750 mm.

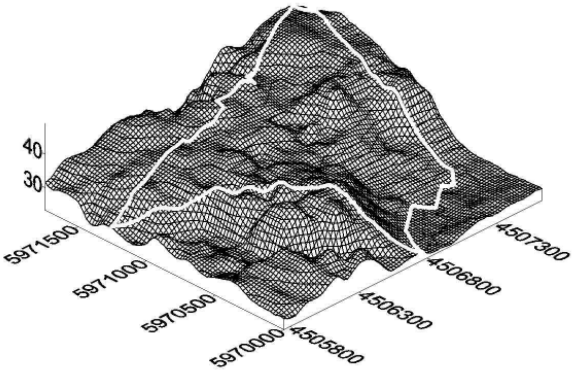

Figure 1. Wireframe model of Kassow, plot 104. The x, y, z axes are displayed in m (vertical exaggeration factor: 20).

2.2 Methods for data capture

Two different DEMs were captured. The first DEM was calculated from 32,800 sample points of a RTK-GPS campaign with a Leica SR 399 receiver and a base station on the edge of the field. The rover was mounted on a tractor. Sample geometry was restricted to tram lines (18 m difference). Data were recorded every second (i.e. 3 - 5 m). The laserscanning campaign was conducted and pre-processed in March 2000 by TOPSCAN (ALTM 1020). Sample points used for the DEM generation were distributed roughly equal with a mean density of 1.9 m and provided as a 2 m grid. Data from both campaigns were further processed in the German national grid (Bessel ellipsoid and Gauss-Krüger co-ordinates).

2.3 Data processing

The RTK-GPS data were interpolated with GoldenSoftware SURFER 7.0 using the Kriging method (e.g. Wackernagel, 1998). The method of interpolation has a significant influence on the quality of the DEM. Several methods provided by common software have been tested in previous studies. Best fit of the variogram model was reached for the study sites with a power model (Schmidt, 2003).

Both DEMs laserscanning and RTK-GPS were further analysed with ArcView GIS 3.2. For the laserscanning grid, various parameters of neighbourhood statistics (mean filter) have been studied to smooth the grid prior to the application of flow algorithms.

2.4 Derivation of Terrain Attributes

The analysis of a DEM is based on the derivation of terrain attributes from the elevation data. Primary and secondary terrain attributes can be determined.

Primary terrain attributes are first order derivatives such as slope and aspect and second order derivatives such as plan and profile curvature. Algorithms to determine primary terrain attributes are usually based on central finite-difference-models of a 3*3 matrix moving on the DEM, starting with the inner grid cell and analysing the relation to the neighbouring cells. Based on these, catchment area, flow path lengths, etc. can be calculated. The most important step for modeling agricultural landscapes is the determination of the drainage direction and connectivity of the elements in order to calculate flow path lengths and upslope contributing area.

Secondary or compound attributes such as the topographic wetness index TWI are combinations of primary attributes or include simplified equations that represent the underlying physics of natural processes (Wilson and Gallant, 2000). These attributes are important to assess potential soil moisture and potential erosion. The TWI $\ln(A_s/\tan\beta)$ is calculated from specific catchment area of a point (A_s) and the local slope gradient $\tan\beta$. The concept was first presented by Beven and Kirkby (1979) and further developed in the 1990s (Wilson and Gallant, 2000). The TWI is based on the assumption that topography controls the movement of water in sloped terrain and thus the spatial pattern of soil moisture. High values of the TWI are found in converging, flat terrain. Low values are typical for steep, diverging areas. The concept is only valid for areas with a significant amount of lateral water movement and uniform vertical flow (i.e. homogeneous distribution of soil conditions). Barling et al. (1994) demonstrated that the hydraulic conductivity declines with depth. Thus, even in gently sloped areas, the piezometric head can be assumed to be parallel to the terrain surface.

The spatial pattern of TWI values is influenced by the method to derive both specific catchment area A_s and, to lesser extent, $\tan\beta$. Three approaches to calculate the flow accumulation have been compared by Schmidt and Persson (2003). In this study, terrain attributes such as the TWI and the similar stream power index (SPI) $\ln(A_s * \tan\beta)$ were derived with ArcView scripts based on the D8 algorithm.

A further terrain attribute that was implemented for this study was Moore and Wilson's (1992) empirical equation to calculate the Length-Slope factor that gives a value for the water erosion potential relative to a slope of 22.13 m length and a slope angle of 5° and is intended to be used as factor LS in the revised universal soil loss equation (RUSLE):

$$LS = (m+1)\,(A_s/22.13)^m\,(\sin\beta\,/0{,}0896)^n \tag{1}$$

with $m = 0{,}4$ and $n = 1{,}3$ for a slope length <100 m and a slope angle <14°.

A different approach is to determine so-called landform elements. Here, both plan and profile curvature are grouped into the classes convex/converging, concave/diverging and straight/ parallel respectively. The three classes of the two attributes can be combined into nine form element classes. In addition, flat areas are determined as slope < 1°. The resulting classes are convex-diverging, convex-parallel, convex-converging, straight-diverging, straight-parallel, straight-converging, concave-diverging, concave-parallel and concave-converging. Converging and concave forms are potential sites of higher soil moisture due to the accumulation of water. Results look similar to TWI maps since both are mainly based on the curvature; the form elements directly and the TWI as a result of flow directions controlled by plan curvature.

2.5 Methods for quality assessment

Data capture

The 2 m laserscanning DEM was compared to RTK-GPS sample points. The GPS height accuracy was shown to be in the range of ±1 – 5 cm standard deviation (Schmidt, 2003). The equivalent laserscanning elevation value was queried from the DEM and the root mean square error (RMSE) was calculated. Both capturing methods are assumed to have a similar elevation measurement accuracy (±0.1 - 0.15 m). Since both methods are independent of each other, the evaluation of the deviations allows an assessment of the overall quality of the elevation measurement.

DEM quality: Surface properties

In addition to the calculation of RMSE of interpolated RTK surfaces (see Schmidt, 2001, for comparison of interpolation methods), the DEM surface was inspected visually in order to detect incorrect forms/artifacts that affect the calculated flow pattern. Typical errors are due to poor interpolation (RTK-GPS) or data processing of the laserscanner data (e.g. at borders of tiles).

Applications: Predicted soil moisture pattern

Maps of the TWI were calculated from the RTK and the laserscanning DEM. Both TWI maps were compared to gravimetric and TDR-based point measurements of soil moisture on plot 111 (Kassow). For both TWI maps, Pearson's correlation coefficient of TWI value and soil moisture measurements at 20 monitoring points along a catena was calculated for 6 time steps and 3 soil depths. Furthermore, the pattern of the highest and lowest TWI values was compared to the greyscale of soil-bearing aerial photographs.

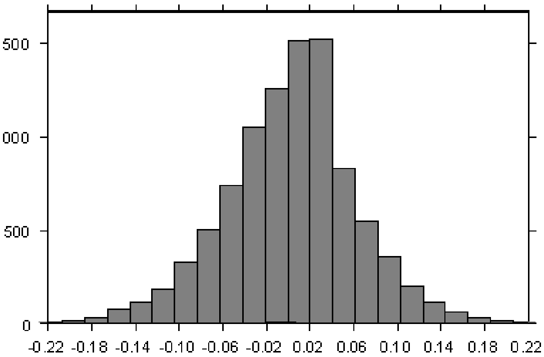

Figure 2. Deviations of laserscanning DEM and RTK-DEM at Kassow test site (9576 sample points)

3 RESULTS

3.1 Data capture

The accuracy of the RTK data was assessed by comparing it to the laserscanning model at the study site Kassow. After removing a 0.12 m offset between the 3,878 RTK sample points and the laserscanning DEM, a RMSE of 0.09 m remained. The offset obviously resulted from the calibration at different reference points. The maximum deviation was 1.18 m, possibly caused by vegetation. The same investigation on a neighbouring field for 20,815 sample points showed a RMSE of 0.06 m and a maximum deviation of 0.97 m. Thus, the measurement quality for 68% of the points is twice as good as the accuracy of both capturing methods given by the manufacturers. According to error statistics, it can be assumed that 95% of the measured points are in a range of ± 0.12 m.

The direction of the deviations was studied along several transect of the undulating terrain (approx. 1000 m length, Kassow, plot 104). Positive deviations of the laserscanning data compared to the RTK measurements were found on crests and toeslopes whereas straight slopes usually showed RMSE < 0.03 m. The shape of the terrain forms were represented similarly. Thus, the deviations had no effect on the calculated flow pattern.

3.2 DEM quality: Surface properties and flow patterns

Interpolation (RTK-GPS)

The quality of the interpolated RTK-GPS DEM which was used as reference surface in this study, was examined by Schmidt (2001). Under the conditions of the tram line geometry, Kriging proofed to be the superior interpolation method of the standard software to generate surfaces such as SURFER 7. Cross-validations of the kriged DEM delivered a RMSE of 0.17 m for an interpolation search radius of 18 m, 0.13 m for 9 m and 0.12 m for 6 m tram line distance. The maximum deviation was 1.38 m. Simple interpolation methods such as Inverse Distance Weighting (IDW) showed a RMSE worse than 0.2-0.3 m and maximum deviations of up to 4 m for the Kassow plots.

Laserscanning DEM surface

For the given scale, the interpolation of the laserscanning data did not cause any serious problems since the original data had already the required sample point density. Problems, however, occurred due to the crop surface on the plots. At the time of the measurment campaign (mid-March), the height of the crops was 10 - 15 cm. Because of the dense canopy, obviously a mixture of soil and winter wheat surface was recorded. Just a few points were recorded below winter wheat surface, i.e. on the tram lines (parallel lines in 18 m distance). Thus, the canopy was processed as surface with channel-like parallel structures (Fig. 3). This effect is not visible in the classified DEM due to the class size. However, both hillshade model and derivations such as slope or TWI show these artifacts.

Figure 3 shows that the elimination of the alder trees along the small ponds (glacial depressions) worked well whereas the 10 – 15 cm deep tram lines in the crop stock are clearly visible. There is no such effect on the neighbouring pastures, that are not managed with tram lines. The observed effect even stayed after testing various filtering options with the software SCOP and a resampling to 5 m grid size. The observed tram lines dramatically affect the derivation of attributes (see following sub-chapter).

In contrast, the 10 m laserscanning DEM of the study site Beckum (obtained from the mapping agency) did not show any tram line effects and was well suited for flow modeling and the detection of erosion paths and deposition areas.

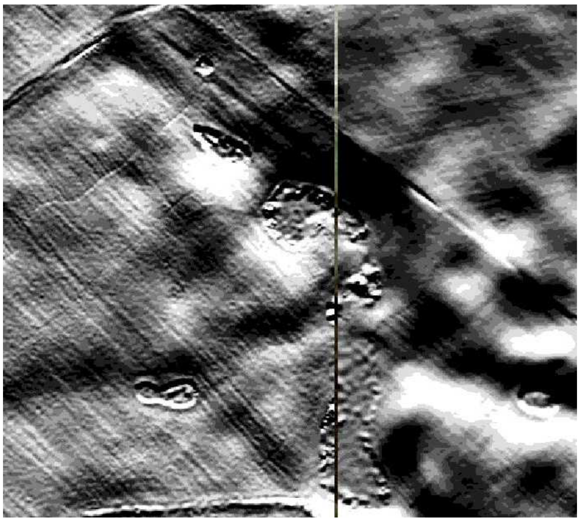

Figure 3. Hillshade-Modell (azimuth = 40°; light from North) of laserscanning DEM (Kassow, plots 107 and 104, along tiles). Details like tram lines (parallel stripes), roads and depressions are visible as well as the border of the tiles.

Table 1 shows the influence of grid size on the terrain statistics. As expected, mean slope, standard deviation and maximum slope decline with grid size and mean filtering. Information about small terrain shapes that can influence the flow pattern get lost. Accordingly, the mean value of the TWI is rising since slope is one of its factors. However, the standard deviation of the TWI has no clear correlation to the change of grid size. The calculated flow pattern gets more generalized and reduced to a few main flow paths.

Table 1. Effects of grid size, resampling and mean filter on slope and TWI statistics.

Kassow Plot 111	slope ∅ [°]	slope s	Slope Max [°]	TWI s
2 m (laser)	1,98	1,13	13,8	0,74
5 m (laser) resampled	1,87	1,04	9,9	0,70
2 m (laser) mean filter	1,78	1,00	11,4	0,75
5 m (RTK-GPS)	1,80	1,00	9,3	0,71
10 m (mapping agency)	1,38	0,80	6,1	0,73
25 m (mapping agency)	1,22	0,71	4,9	0,69
50 m (mapping agency)	0,98	0,90	4,4	1,16

Patterns of terrain attributes

The quality of the DEM in terms soil modeling can be assessed by visual inspection of the derived form elements and flow patterns or by comparison with field data such as soil moisture measruements, maps of electrical conductivity (ECa) of the soil (Lück et al., 2001) or aerial photographs.

The form elements that were derived from the laserscanning DEMs showed, in contrast to the RTK-GPS-DEMs, a dominance of small landforms, usually of a size smaller than 3 pixels. Borders of the field are visible as single convex land forms, even after two runs of the mean filter. Stripes due to recorded crops are convex-divergent all 18 m representing the management geometry of the field. The scale captured by this examination is too detailed for the modeling of lateral soil water movements. In addition to surface run-off, sub-surface flow contributes to the distribution of water in the landscape. Thus, the surface-roughness recorded by the laserscanning DEM is too detailed to derive clear flow patterns. The result are often noisy images with low connectivity of the flow paths/converging foem elements. Figure 4 shows the form elements derived from the laserscanning DEM for a 5 m deep erosion land form on plot 106 (Kassow). The effects of the tram lines dominate the pattern of the form elements.

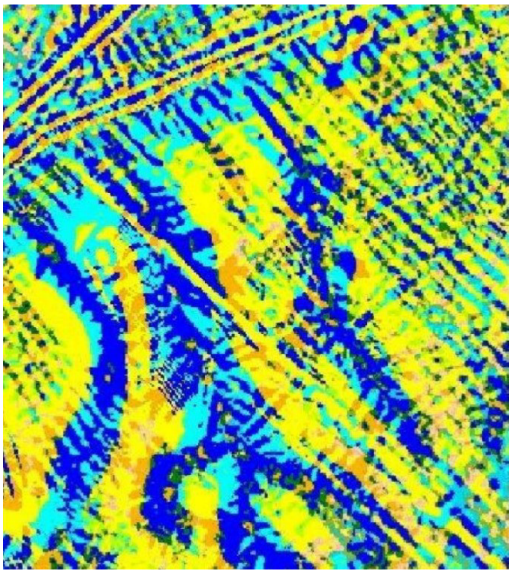

Figure 4. Form elements derived from a 2 m grid, mean filtered. Plot 106, Kassow. Edge length of image: 500 m. The blue/dark North-exposed forms are three up to 5 m deep channels on the plot. Yellow/light stripes show tram lines (18 m distance, parallel in North-West direction) and a road/railway line in the North-West.

The TWI was compared to patterns of soil moisture measurements, aerial photographs and ECa-maps.

The goodness of correlation with 20 soil moisture samples changed with time. Whereas in early spring, best correlations were reached close to the surface, in early summer the correlation increased with depth. Below 0.9 m, however, correlations became less since soil moisture usually is more uniform due to longer infiltration time. The best correlations were found in spring 2-3 days after precipitation events and at a depth of 0.6-0.9 m (Tab. 2; more: Schmidt, 2003; Bobert et al., 2001).

Table 2. Correlation of TWI and soil mositure content (r^2) at Kassow for three sampling campaigns and 0-0.3 m soil depth (January and March) and 60-90 cm (June) respectively.

Grid	12/01/2001 (0 - 0.3 m)	17/03/2000 (0 - 0.3 m)	22/06/2000 (0.6-0.9 m)
Laser (2 m)	0.64	0.43	0.46
Laser, mean filter (2 m)	0.38	0.20	0.44
RTK-GPS (5 m)	0.36	0.11	0.15

The reasons for the partly rather low correlation coefficients of measurements and TWI values can be best understood when considering the soil map. High TWI generally corresponds to high soil moisture (usually in depressions and converging areas) and low TWI corresponds to small peaks and ridges, where run-off exceeds incoming water. The worst correlation was recorded at the points which are the only sandy soils along the studied transect (Schmidt and Persson, 2003). Soil sampling showed that sandy material was deposited in channels (local depressions = high TWI) by erosion processes. In June, the sandy soils drain much better than the loamy sand and sandy loam, thus counteracting the TWI that identifies for these two points a minor flow channel. Such coincidences were observed for Kassow and Beckum by combining TWI maps and ECa-maps that mostly reflect the particle size distribution of the soil (fractions of sand, silt and clay) due to the higher electrical conductivity of clay particles. Figure 5 shows the pattern of site differences on plot 104, Kassow, according to aerial photograph (24 Feburary 2002; with emerging crops and bare soil), ECa map and TWI map (based on mean-filtered and resampled laserscanning DEM), combined with the 1 m contours. In the center of the image, a converging land form ("flow channel") that extends towards South-East is visible. The ECa map shows low values that indicate sandy, eroded soils along this land form. The TWI map indicates high soil mositure potential due to converging terrain (high flow accumulation). The effect of flowing water in terms of erosion has been confirmed by the ECa map, although this might only happen a few hours a year after a high precipitation intensity. The comparison of emerging plants and TWI map mainly demonstrates that potential dry spots (slope crests/shoulders) coincide with reduced crop growth in early spring.

As a result, it can be stated that visual similarities between independed data layers confirm the significance of terrain analysis. Processes controlled by terrain and displayed by terrain attributes such as the TWI are visible as well on maps of soil properties and aerial photographs with low vegetation height. However, the similarities do not produce high correlation coefficients on complete coverages. At least extreme site characteristics such as wet depressions, flow channels and dry shoulders can be detected with satisfying certainty and be confirmed by soil moisture measurements on those plots and periods when topography controls the lateral movement of water.

3.3 Applications

Soil moisture patterns

Potential soil moisture patterns derived by terrain analysis can be used for adapting application amounts to local site-differences. It has been applied by various partners in the preagro project for site-specific seeding, fertilizing and the depth of tillage (Schmidt, 2003). For this purpose, polygons of extremely dry and extremely wet spots as indicated by the TWI were used to vary the application amounts. When planning the seeding amount, both types of extreme polygons are assumed to provide poor quality for the emerging plants (Roth and Kühn, 2002). Hence, the tillage algorithms assign deep tillage to enrich structure and air volume on these spots, whereas on the "normal" plot areas, low tillage saves energy and time (Sommer and Voßhenrich, 2002). Concerning fertilzer amounts, Wenkel et al. (2001) propose reduced application both on spots with low TWI (due to poor growth and nitrogen uptake) and on spots with high TWI (due to lateral in-flow with subsurface flow as calculated from the DEM).

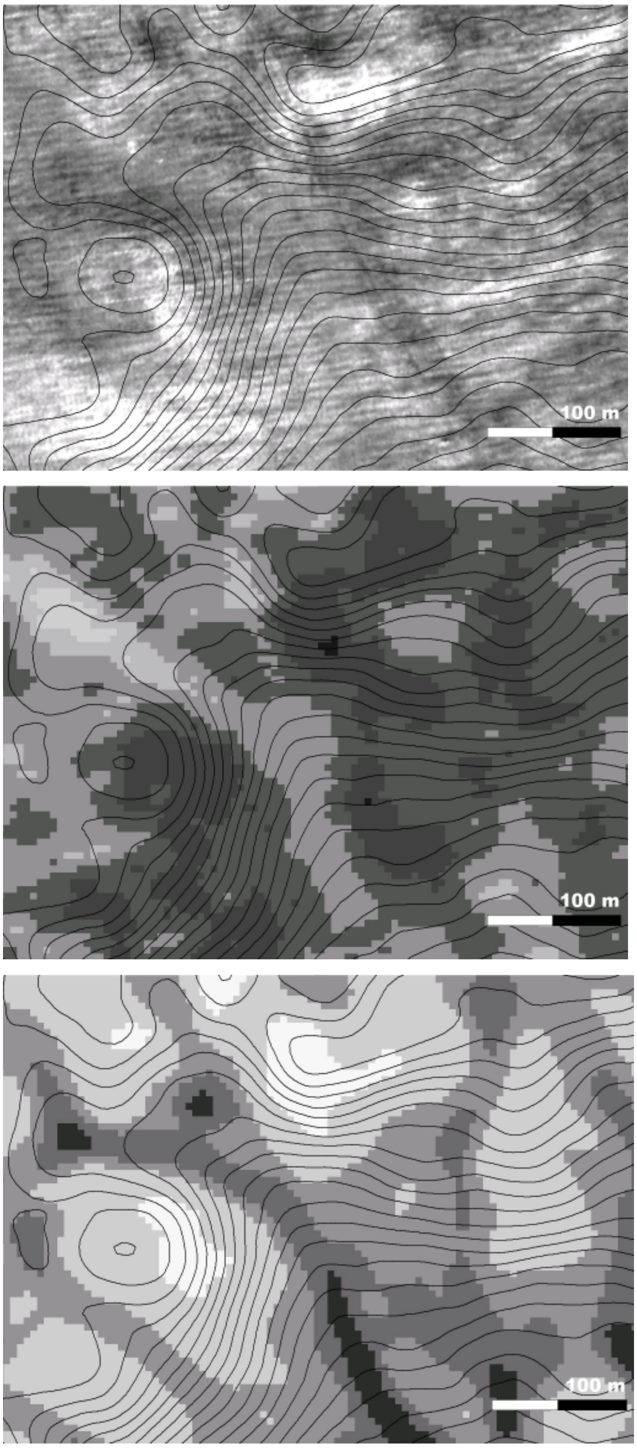

Figure 5. Pattern of site-differences for the neighbourhood of a converging land form and two local peaks on plot 104 (Kassow). From top to bottom: a) aerial photograph (G. Grenz-dörffer, Insitute for Geodesy and Geoinformatics, Rostock, 24.2 2002) with emerging plants (dark grayscale) and bare soil (light grayscale), b) map of electrical conductivity (ECa) of the soil (E. Lück, Potsdam University); dark grayscale = high conductivity (i.e. smaller soil particle size and organic content) c) TWI based on the laserscanning DEM. On each image, the 1 m contours are displayed.

Erosion

The spatial pattern of soil erosion is a useful information to plan measures to reduce soil loss on agricultural fields. In hummocky terrain, erosion is mostly based on water flow after strong precepitation events. The process-based Stream Power Index (SPI) predicts similar flow lines like the TWI. However, the grid values increase with slope, representing the flow acceleration that water experiences downhill (Fig. 6 (a)). The simulated flow lines could be clearly observed on the test site after rainfall, thus showing where to establish measures to mitigate the flow acceleration and the erosive force. However, there is no information about the deposition of transported soil particles. Deposition occurs where the velocity of the surface water is reduced by terrain. A useful hint can be derived by calculating the slope of the SPI: Areas on which the stream power changes are thus detected. They correspond to deposition along toeslopes. The effect of the laserscanning DEM (in contrast to the coarser but smoother RTK-GPS DEM) can be seen by the high amount of small parallel flow lines along the main aspect of the slope, contributing to the main flow channels. The unfiltered laserscanning DEM did not show a clear flow pattern at all, since the recorded tram lines dominated the flow direction. For water erosion during the vegetation period, this corresponds to reality, the orientation of the tram lines, however, can change and do not dominate the flow pattern on bare soil.

A different approach is to use the empirically derived “Length-Slope-Factor” (Fig. 6 (b)).

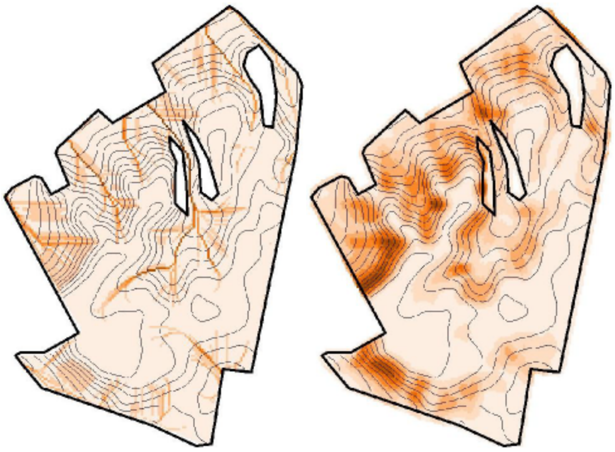

Figure 6. (a) Pattern of Stream-Power-Index SPI (left) and (b) Length-Slope-Factor (right) for plot 109, Kassow. The erosion potential is rising with darker colour. The slope is mainly exposed to North-West. East-West extension of image: 700 m. 2 m Contours are given (7 - 31 m over sea level).

The LS-Factor indicates spots on the field that have both a steep slope and relatively large amounts of incoming water. Whereas the classical LS-Factor used for the soil loss equation was based on the length of a slope (assuming higher amount of incoming water), Moore’s LS-Factor that was used in this study considers the 3-dimensional effects of the flow accumulation. The pattern shown in Fig 6 (b) has been confirmed on aerial photographs taken in early spring, similar to the results shown in Fig. 5.

A simple map query can help to plan the optimal direction of the tram lines: Assuming a significant amount of erosion for tram lines in the main slope direction for a slope angle >3°, for the Kassow plots, the current tram line direction has been compared to a direction orthogonal to it. The area affect by this 3° slope criteria would increase from 2.3% to 4.9% of the plot.

Further agricultural applications

Further possible applications could be based on the terrain-climate interactions. Cold air in winter can damage crops that are not protected by a snow cover. The most damaging winds in central Europe usually are continental winds from North-East and East. Areas affected most severely are located on slope crests with East-Northeast aspect and can be identified by a simple map query based on slope, aspect and profile curvature.

Another damage potential to the growth of crops is accumulating cold air in depressions in clear, cold spring nights. The flow of cold air can be modeled similarly to the flow of water, e.g. with the TWI. Depressions can be identified using fill algorithms.

In terms of nature conservation on agricultural plots, terrain analysis can help to identify small spots of low productivity that could be managed less intense since no significant economic loss is to be expected. Such spots are usually on slope crests and suited for endangered weed species. The way of subsidising (e.g. more specifically for environmental measures) will decide on the success of such nature conservation efforts and PA in general.

4 DISCUSSION

For applications in precision agriculture, DEMs are required for a field size varying from 5 - 200 hectares. The level of detail is similar to a topographic map scale 1:5,000. However, high demands on the surface quality were identified. Beside an elevation accuracy of approx. ±10 cm, a relatively smooth grid of a raster size 2 - 10 m is needed. This means that the surface must show low curvatures, according to the real shape of the field and, thus, exclude micro-topography and vegetation.

Airborne laserscanning and RTK-GPS both capture elevation data at a similar elevation accuracy on agricultural lands. The resolution both horizontally and vertically is sufficient for the representation of terrain features. Local peaks, ridges and depressions are well represented in the DEM. However, care has to be taken, when the laserscanning DEM shows features of the crops, i.e. the tram lines as lines of lower elevation instead of the generally smooth land surface. Due to the centimeter resolution of the elevation data, this influences the flow paths calculated from the DEM. For the modeling of erosion processes caused by overland flow, this might be an advantage; for the modeling of subsurface flow it will unfavourably alter the drainage areas. This can be seen by the noise in the laserscanning-based TWI grids. In such cases, the DEM should be smoothed before the modeling. The use of mean filter alters the data which are, in consequence, not comparable in terms of absolute values. However, it is an acceptable change of the data because the modeling mainly aims at lateral subsurface flow.

The most striking advantage of laserscanning DEMs is the high density of the sample points. Hence, the effects of interpolation methods are reduced to a minimum. Derivatives such as aspect and drainage area or a simple hillshade model are sensitive to anomalies and are a good indicator for the overall DEM quality.

As necessary meta information, the following data were identified: date of capture (to assess the height of crops and other vegetation), the capturing method (i.e. laserscanning or GPS), data processing (mean filtering, resampling, co-ordinate transformation parameters, etc.) and an image of a hillshade model to assess the surface quality. Taking into account the high complexity of the surface properties and their influence on the results that in turn cannot be compared in terms of absolute values, the method should focus more on the general pattern in combination with local “expert knowledge” of the farmer.

Possible applications of terrain analysis based on laserscanning DEMs were demonstrated. Currently, agricultural technology and field management software such as the modules developed during the preagro project require polygon geometries for reduction or surcharges of the application amounts. Terrain can be considered facultatively. The main deficiency of the methods presented here is the low knowledge about terrain-soil-plant interactions. Effects on the crop can be different each year according to weather (e.g. lengths of dry periods or wet seasons) and there are opposite approaches if to react with high or low amounts on specific conditions. Thus, the maps presented here should be used to enhance the knowledge of the farmer iteratively to explain the yield of each season in combination with other PA data.

5 CONCLUSIONS

Laserscanning DEMs have proved to describe several processes of surface and subsurface flow on agricultural fields. A particularly useful terrain attribute is the topographic wetness index TWI. When interpreting TWI maps, the real influence of terrain features on the lateral movement of water has to be considered. Elevation range and mean slope gradient calculated from the DEM can be an indicator. When topography is controlling a significant amount of the soil water movement, terrain analysis provides valuable data for precision agriculture applications. Depending on the level of detail of the DEM, a mean filter applied to the TWI map can help to identify clear structures of subsurface flow patterns and thus areas that are worth to manage site-specifically. The functions of the terrain and the variability of soil properties can only be represented with high-quality DEMs with “smooth” continuous surfaces with an height accuracy of ±10 cm and a spatial resolution of 2 – 10 m. These requirements can be met by both laserscanning and RTK-GPS. Problems can occur when the flight campaign is conducted during the vegetation period, i.e. a dense crop canopy is captured as “terrain” by the laser.

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