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EVALUATION OF SOIL WATER MANAGEMENT PROPERTIES BASED ON LiDAR DATA AND SOIL ANALYSES, AT FARM LEVEL

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Abstract

Rapid weather fluctuations with an increasing demand for resource use impacts crop production sustainability leading to severe use of land and water resources. Laboratory analysis and technological improvements, such as remote sensing, generate new information and knowledge, to ease the visibility of effects by agricultural practices, bringing new opportunities to better use resources and improve farming sustainability and water management practices. Irrigation use and assessment are important to assure the sustainability; planning and modelling based on soil-plant economy relationship by the use of technological innovation, as Lidar imagery, enhancing the precision to large scale knowledge gained a plot-farm level.

Agronomics, agriculture engineers, management technologies aim to reduce non-productive water use in agriculture. Finding the correlation between soil water retention and physical parameters contributes to irrigation management plant, therefore, reducing water use, cutting costs for agri-food production and reducing environmental impact.

Soil sampling is performed in two depth and analysis of soil physical and water retention parameters with the correlation of LiDAR survey proving in-depth on-field information. Silt-loamy texture makes a good texture, water retention capacity. A decrease of silt content in the upper layer (6.4 %), an increase of sand and clay (7 % and 28 %) respectively. Conventional soil cultivation made an impact on the soil upper layer. Soil water retention did not show the major fluctuation of two layers regarding pF values. LiDAR results shown the area is not susceptible to erosion, 68 % is in the 1^{st} slope category and 28 % in the 2^{nd}. LiDAR, clear understanding and visualisation of site laboratory data for different.

The field is well drained, vegetation period and cultivation could require scheduled, separated irrigation on land based on DEM and runoff lines helping to improve irrigation planning and water use efficiency. Demonstration the benefits of using high accuracy remote sensing LiDAR data, preventing water logging, misuse, and improve irrigation management and shows good examples to use in large scale to ease comprehensive understating of data.

Key words: remote sensing, LiDAR, soil properties, Water retention, farm/in, irrigation

INTRODUCTION

Continuous warmer climate, rapid weather fluctuation and unpredicted change of rainfall and increasing demand for agro-food production due to population growth, along with the need for efficient use of natural resources, is becoming more challenging with imminence to act precisely. Determining which land and crops have the capabilities give the best production in the given conditions for the available resources, starting

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at plot farm level to up-scale, using up to date innovations, such as remote sensing technology, is highly important for the advancement of efficient planning and management practices.

Water scarcity will become a fundamental problem that will trigger changes in agricultural cultivation and management practices especially in arid and semi-arid conditions. Establishing changes in soil and water management and cultivation requires detailed information and planning about soil parameters, water resources, and cultivation plan. Lack of appropriate agricultural management strategies towards proper irrigation management, increase plant stress during drought periods, and non-sufficient use of ameliorative and drainage facilities can result in soil degradation. Waterlogging caused from intensified rainfall has an outcome on arable land in soil cultivation and crop production. Precipitation impacts the integrity of the soil aggregates as they begin to diminish and infiltration rate decreases.

Laboratory analysis with technology improvements, such as remote sensing, help to determine different issues occurring and ease solutions. Increase of temperature, change of rainfall patterns, intensified drought frequency and severity will lead to higher water demand (Nagy et al., 2018) and decrease of supply. Supplementary irrigation is likely to become more important in agriculture to support agriculture and maintain crop yields and its quality in multiple climate types. Irrigation performance assessment is critical and vital to ensure the sustainability of irrigated agriculture and this can be supported by different field measurements and prediction of factors like soil texture and structure (Rabot et al., 2018) and water retention capacity. Planning and modelling the irrigation based on soil-plant economy relationship, experienced at plot-farm level, by use of technological innovations, such as LiDAR (Light detection and ranging) imagery, enhances the quality of understanding of laboratory data and potentially to up-scale such technological innovations (Demelezi, 2019).

Water availability, climate change, and soil composition create many areas that have intrinsically saline nature and cause the salinization of soil. Strategies on soil salinity management can be considered. Considering applying irrigation in the field we should have detailed information about soil physical properties and water sources (Gálya et al., 2015).

Cultivation requires detailed planning and information about soil parameters such as physical, chemical and microbiological soil parameters. Soil productivity should be maintained and improved over time, but this causes water resources depletion and misallocation of water resources based on the crop needs and weather conditions. Therefore, scheduling irrigation according to the average soil moisture content of the entire profile may be beneficial for plants and farmers. Soil analysis recovers enough information about soil characteristics and linking them with LiDAR data of the arable land results in better management of the water and soil sustainability and sustainable production

The effects of climate change will create instability of crop production especially on the crops that are depended on irrigation or have high water demand. Identification and improvement of water management on arable field focusing on the soil water capacity and soil physical properties in relation to remote sensing technology, such as LiDAR is highly important. Soil conditions and soil water potential availability are crucial to be analysed and visualised, via remote sensing technology, to ease interpretation of practical use in large scale, since they support, makes room for the maximum supplement for plant needs considering the fact the moisture in the soil is an important crucial factor in nutrient cycling in the soil matrix. Good soil texture and structure of soil and water retention of the soil is important to have a good crop production to the farm. Therefore, the use of LiDAR may contribute to enhance the precision to a large scale by knowledge gained at plot-farm level.

MATERIAL AND METHOD

The researched arable land is located in Nyírbátor, in this research are analysed the water management properties of the arable land (85.5 ha). Nyírbátor is located in Szabolcs-Szatmár-Bereg county in the eastern region of Hungary. Bátortrade Ltd. is located in Southeast of Nyírség, the location of the sampling is 47°48'51.5"N 22°09'21.7"E, 147 metre above the sea level and with an area of 553 km^2. Figure 1 shows the location of the sampling area indicated on purple, and sampling points on the field.

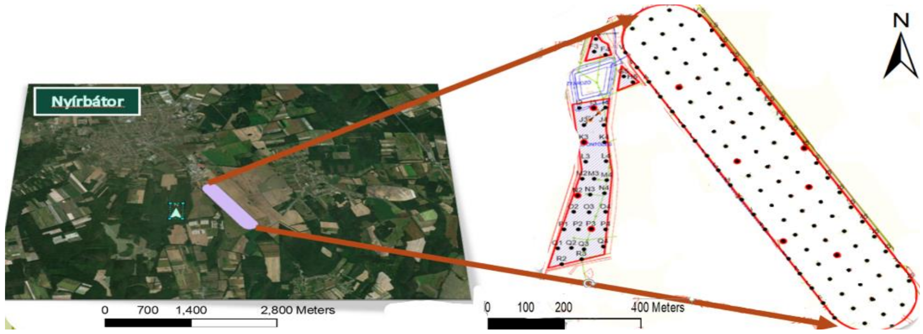

Fig. 1. Sampling area

Nyírbátor is situated on the edge of a moderately warm and moderately cool climate belt. The average annual temperature is 9.5 - 9.7 °C, which increases during the growing season and reaches a value of around 16.6 °C. On the hottest summer days, the maximum temperatures are around 34 °C, the average temperature of the coldest winter days are between -17.0 ° C and -18.0 ° C. The annual rainfall is 570-600 mm, in the summer it is about 350-360 mm. The most common wind direction is north-east and south-east, with an average speed of 2.5 m / s.

In terms of terrain, the broad area is at altitudes between 117.5 and 183.4 meters above sea level. Approximately 50 % of the surface is corrugated plain and 40 % is of medium elevation. In the northern part of the region; high percentage of the soil is sandy and lamellic-arenosol brown forest soil. Considering the percentage distribution, the largest type is sandy soil around 37 %. The second one is the brown forest soils with 26 % (Soil Survey, 2014). The remaining 21 % is made up of marshy soils (4 %) and meadow soils (17 %). The area is mainly characterized by forest area (50 %) and arable land (35 %).

It is a dry area, however typical of the area to develop inland water, occurring as a result of the periodic rainy years. There is no stagnant water, constant water in the area. The depth of the groundwater is about 4 to 8 m (Gálya et al., 2018).

Soil sampling was performed in two depths, 30 and 60 cm. Since the upper layer of the soil is under cultivation and deeper depth can be considered as not influenced or actively under cultivation but affected by agricultural techniques. On the analysed arable land, we modelled at 102 points, representing more than 1 sample per hectare (1.19 samples/ha), from a total of 510 samples. Strategy chosen for analysis was proposed by Christakos and Olea, 1992.

The physical parameters of each sample were measured (> 2 mm, 200 µm - 2 mm, 50 - 200 µm, < 50 µm) to determine soil texture and soil water retention parameters as: maximum water capacity, minimum water capacity, moisture capacity, wilting point, available water, gravitational water and capillarity gravitational water content, in addition the GPS coordinates data were taken per sample.

Data processing

Based on the measured data, we created a GIS database (X and Y coordinates, and Z variables) according to UTM system (zone N34), and then prepared the maps using an appropriate interpolation method. We used kriging method to generate the maps, which is one of the most effective and often used methods for most spatial analysis in scientific articles, known as an interpolating technique (Virdee and Kottegoda, 1984), the spatial resolution of the map was set automatically to 0.5 m.

Processing numerous data's, we used Surfer and ArcGIS environment. In the first step of processing, we created grid files in the Surfer software environment by creating a grid file, with the Kriging gridding method.

Arable land was surveyed between harvesting the former crop and sowing the next one. The combination of the resulted appropriate factors provided a good opportunity to understand the topography of the area and evaluate differences in micro-relief and ignoring the vegetation. The aerial LiDAR survey was done by the Institute of Water and Environmental Management and Eurosense Ltd. On the arable land of 85.55 hectares with its immediate vicinity. Using IGI LiteMapper laser system, the resolution of LiDAR data points is 14.58 point/square kilometres thus it can be used to build high-resolution models.

The laser point cloud processed by photogrammetry was pre-processed with Global Mapper software. I also carried out a preliminary elevation profile analysis in the software for the arable site.

On the basis of the LiDAR image, I have made the digital elevation model and map of slope categories based on high-resolution LiDAR data. During processing I have made different optimisation methods for pixel aggregation. Then, I have sorted the roads, canals, and reservoirs. During the next phase, I have investigated the run-off and accumulation relations on the basis of slope conditions.

For the statistical analysis have used IBM SPSS Statistics 24 software used the descriptive analysis tool from the analysis tool, and the generated the statistical analysis for required parameters.

RESULTS AND DISCUSSION

Results of all parameters measured and estimated in the study described and discussed are presented such as soil physical analysis, soil moisture content analysis and comparison and correlation of results with the LiDAR digital elevation model.

Soil composition for the soil particles larger than 200 micrometres classified as sand and gravel in the upper layer of the soil is around 37 % while for the distribution in the deeper layer is 34.46 %. There is an increase of sand particles in the upper layer compared to the bottom to 7.37 % of sand.

Silt content for 30 cm depth had 57.3 % of silt and 61.27 % in 60 cm depth. Based on their spatial distribution there is decreased percentage of its content in the soil for the upper layer for about 6.4 % (Table 1). The underground level of 4 to 8 m provides an advantage for capillarity rise (Kirkham, 2007) to cache upper layers during the summer.

Silt is the determinant factor for our soil with high spatial distribution differences between two layers (Fig. 2). In two depths we can see a difference between their content in the soil. In the upper layer the mean is lower as well as the minimum concentration of silt particles is lower whereas in the 60 cm depth where we have done analysis the mean and minimum concentration is higher.

Table 1

Statistical distribution for soil physical parameters analysis (in percentage)

Descriptive Statistics of soil particles								
	Min		Max		Mean			
	30 cm	60 cm	30 cm	60 cm	30 cm	Std. Error	60 cm	Std. Error
> 2 mm	0.1	0.01	29.0	31.40	3.64	0.58	2.73	0.475
200 µm - 2mm	15.8	15.6	46.6	49.60	33.31	0.72	31.73	0.6605
50 µm - 2 mm	26.0	39.2	76.8	77.80	57.3	0.97	61.27	0.832
< 50 µm	0.4	0.2	12.6	10.60	5.5	0.24	4.278	0.239

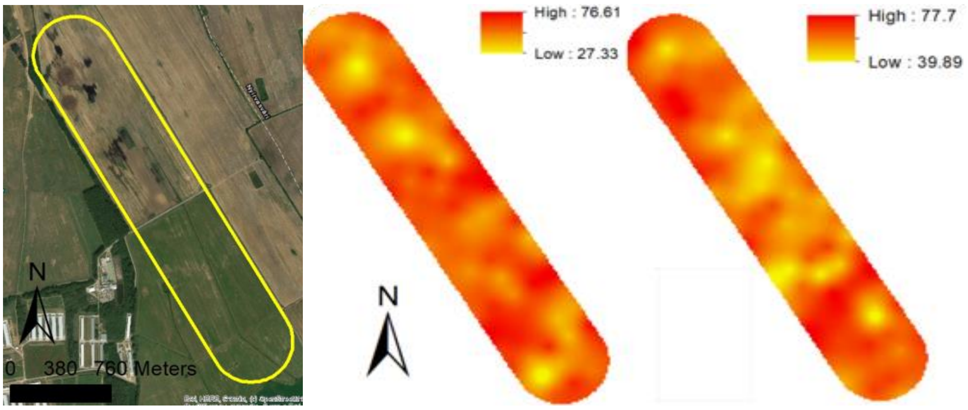

Fig. 2. Spatial Distribution of silt particles at 30 cm (left) 60 cm (right), with a site picture

The clay content of the soil particles smaller than 50 micrometres, for 30 cm (Table 1) depth their content is 5.5 % of clay for 30 cm depth and 4.27 % for 60 cm.

Soil texture calculation for 30 cm depth

37 % (sand) + 57.3 % (silt) + 5.5 % (clay) = 100 %

Soil texture calculation for 60 cm depth

34.46 % (sand) + 61.27 % (silt) + 4.27 % (clay) = 100 % Eq. (1)

Soil texture based on the data we determined that the soil parameters tell that on this soil we have the soil type Silty-Loamy texture. Characterised by a small percentage of clay and sand dominated by silt particles. Having a (Soil Survey, 2014) perfect combination for growth of most plants, fertile, fairly well drained and hold more moisture than sandy soil but are easily compacted. Loamy are comprised of a mixture of clay, sand, and silt that avoid the extremes of clay or sandy soils and are fertile, well-drained and easily cultivated. They can be clay-loam or sandy-loam depending on their predominant composition and cultivation characteristics. If it is sandy soil its water holding capacity will be much lower than at clay (Soil Taxonomy, 2006).

Water in nature arrives in soil surface as precipitation, in form of rainfall, hail or snow. Soils contain pore, and that the size of these pores is determined by the particle size distribution of soil where here we have done its determination of the soil texture (Eq. 1).

The in-situ measurement of field water parameter provides the spatial distribution of water quality (Priju et al., 2014) which affect groundwater quality. Soils can hold different water holding capacity, the higher the percentage of silt and clay sized particles, the higher the water holding capacity affected as well by organic matter. Smaller particles, less than 50 µm (clay and silt) have a much larger surface area than the larger sand particles.

The total water content of the soil for 30 cm depth (Table 2) the minimum measured was 30.92 % while the maximum 48.34 % and the mean value was 38.42 % with a standard deviation of 3.21 %. Arable land soil is cultivated and under conventional tillage (Busari et al., 2015).

Table 2

Statistical distribution for soil physical parameter in 60 cm depth

Descriptive Statistics for soil samples at 60 cm depth								
	Min		Max		Mean			
	30 cm	60 cm	30 cm	60 cm	30 cm	Std. error	60 cm	Std. Error
Total water content	30.92	29.42	48.34	45.0	38.42	0.344	38.17	0.31
Minimum water capacity	11.09	9.19	40.96	40.62	27.03	0.7	26.17	0.78
Field capacity	4.61	1.75	36.58	37.73	19.05	0.86	18.95	0.88
Wilting point	1.43	2.16	25.21	23.5	10.90	0.46	10.83	0.41
Available water content	4.01	1.95	25.85	25.94	11.14	0.44	10.78	0.48
Gravitational water	0.11	0.8	20.42	20.77	8.94	0.45	9.606	0.47

Figure 3 the spatial distribution of total water content differs in two depths. Important to mention that in the middle-south part of the plot is the area where is both depths are the minimum of water content. Deep ploughing (FAO Soils Bulletin 54) which is mostly applied in the farm has the ability to reach the depth of 35 cm on average and since the parental material and the soil horizons are the same from the depth of 10 to 120 cm on average, the soil contents can be the same for the same horizon based on Rasmussen, 1999. Continuous cultivation of the soil causing severe compaction in the 30 cm depth because of conventional farming and decreasing of organic matter and soil moisture conditions.

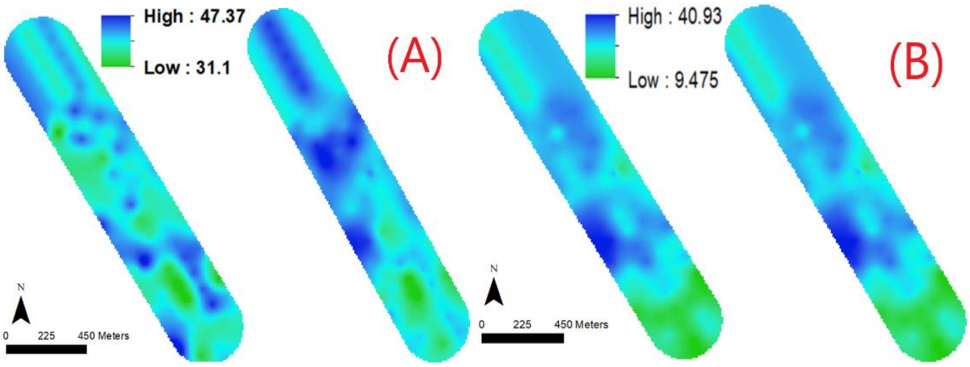

Fig. 3. Spatial distribution of water content: a) Total water capacity; b) Minimum water capacity

The minimum water capacity is the amount of water hold in soil after few days of free drainage for the depth of 30 cm a mean of 27.03 % with a standard deviation of 6.08 %. In the 60 cm a mean value of 26.17 with a standard deviation of 7.35 %. Spatial distribution of soil analysis for minimum water holding capacity shows that we have three main areas with heterogenous distribution of water holding capacity, both layers have similar minimum water holding capacity.

Field capacity (Denmead and Shaw, 1962) names the amount of water which can be held in soil after free drainage of excess water. On 30 cm depth the mean values are 19.05 % with a standard deviation of 8.09 %. In the 60 cm depth the mean value of 18.95 % with a standard deviation of 8.25 % (Fig. 4).

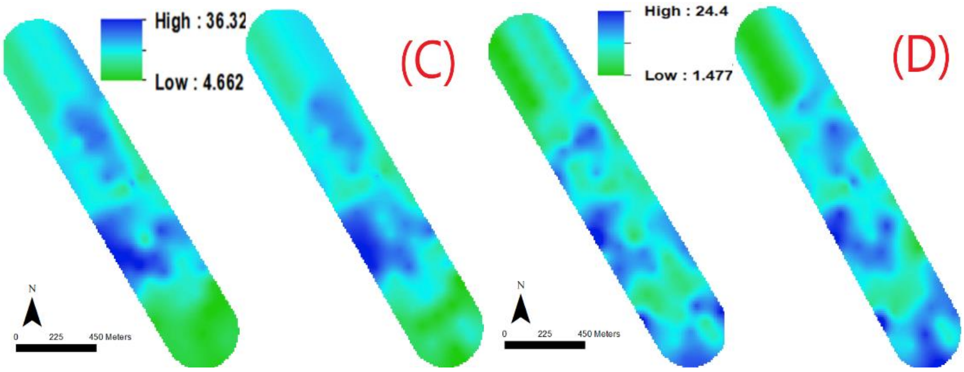

Fig. 4. Spatial distribution of water content: c) Field capacity; d) Wilting point

The wilting point of the soil is considered where the plants' wilt as a lack of moisture in the soil (Kirkham, 2007) for the upper layer of the mean value is 10.9 % with a standard deviation of 4.41 %. Lower values for a 60 cm depth layer are observed with a mean value of 10.83 % and a standard deviation of 3.89 %. Evaporation from the soil surface, transpiration by plants and deep percolation combined reduce soil moisture status between water applications. Soil water content reaching wilting, plants become stressed and wilt.

Available water of the upper layer has mean values of 11.14 % with a standard deviation of 4.12 %, in the deeper layer, we also noticed lower values of available water content the mean values are 10.78 % with a standard deviation of 4.55 %. The surface water generated from rainfall or irrigation moves horizontally or in surface based on the slope of the land, groundwater moves laterally and slowly towards the sea to complete the hydrological cycle, but part of it will seep into springs, streams, rivers, and lakes on the way.

Gravitational water (Kirkham, 2007) is the free water moving through soil porosity by the force of gravity for 30 cm depth mean values of 8.94 % with a standard deviation of 4.22 % in the deeper layer of the soil a mean of 9.6 % with a standard deviation of 4.42 % and spatial distribution seen in figure 5. The greater difference between the gravitational water mean values. A slower rate of movement of gravitational water on the soil causing flooding in case of higher amounts of water found in the upper surface as in case of heavy rainfall or excessive irrigation.

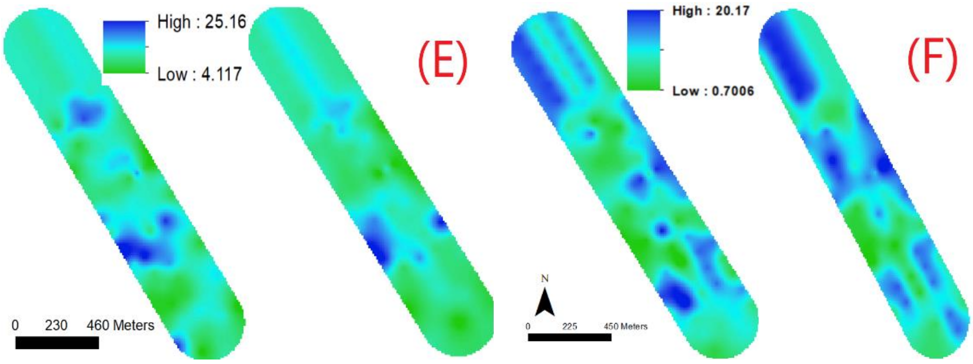

Fig. 5. Spatial distribution of water content: e) Available water content; f) Gravitational water

The capillary rise is the available water transported upwards by a capillary rise from the water table and surface tension properties (cohesion and adhesion forces) to the root zone depends on the soil type, the depth of the water table and the wetness of the root zone. Capillarity water can normally be assumed to be zero when the water table is more than about 1 m below the bottom of the root zone.

Remotely sensed data such as LiDAR brings a high advantage on data gathering and visualisation of site information. Analysing (Johannsen and Carter, 2004) adding GIS maps and digital terrain and field operation information is valuable in plot-farm level, aiming with LIDAR data to potentially experience use of it on large scale, in much detailed analysis. Assist and ease decision making much faster in the agricultural sector particularly in productivity and environment management.

Digital elevation model (Fig. 6, below) of arable land based on processed LiDAR data. Showing elevation difference of 10 meters, in the northern part of the area is higher (151-156 m), while the southern part of it is lower (149-146 m) indicated in brown colour. The slope map of the area with a spatial resolution of 0.5 m, higher the resolution the much better the accuracy of the slope delineation.

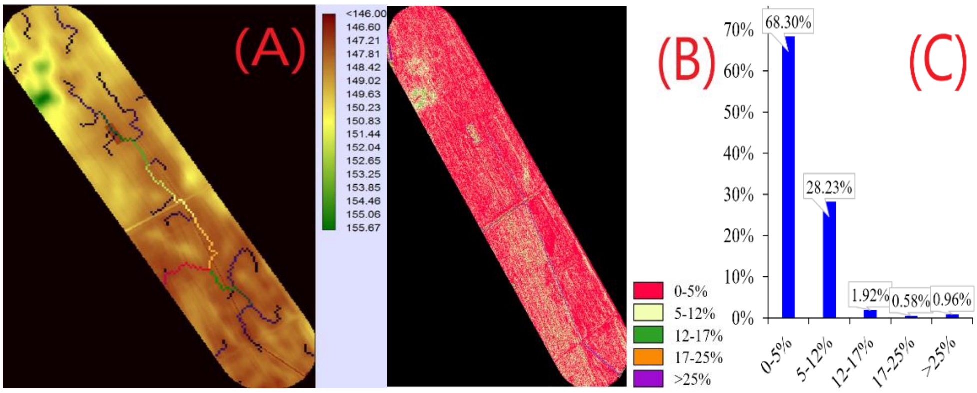

Fig. 6. a) Digital elevation model with run-off lines; b) Slope categories; c) Histogram of slope categories

Field slope map were created 5 categories (0-5 %; 5-12 %; 12-17 %; 17-25 %; > 25 %). Having 68.30 % of area in 1st category (0-5 %) distribution as flat land and 28.23 % of the arable land belongs to the second category of the slope. Slope categories 12-17 %, 17-25 %, and more than 25 % represent a smaller percentage of the area in total 3.49 % of the total arable land (Fig. 6c).

Water can easily come to a stop on these areas and create waterlogged areas, the infiltration of air and water is decreased because of soil tillage (Rasmussen, 1999). Areas where are paths on the field for machinery movement and transport or channels for excess water. Soil heterogeneity (Chen et al., 2017) affects the distribution of soil moisture through variation in texture, organic matter content, porosity, structure, and macro-porosity, all of which affect the fluid transmission and retention properties (Mohanty and Skaggs, 2001). Research of Gilding, 1983 shows that during summer or drought periods the moisture content or the available water is decreased more in the upper portion of the soil.

With DEM we can create the runoff map of the arable land (Bales et al., 2007) (Fig. 6a) from the elevation data differences in connection with soil water retention under the climatic information of the region there might be areas of waterlogged areas. Runoff lines created by DEM can help drain the field. Although the south area is more prone to waterlogging, drain channels should be considered.

GIS and remote sensing techniques are vital means, providing better alternatives compared to conventional techniques in monitoring and assessment of drainage (Singh, 2018) as well they could be used for irrigation planning, irrigation performance, water management practices, monitoring of irrigation at different scales and water resource utilization (Bastiaanssen et al., 1999). Prone to excess water based on tables 1 and 2 and figure 3 the south part of the field shows lower values of the field distribution in each parameter. Evaluation of irrigation programs for the field to separate the area for better water management and soil cultivation and LiDAR possibilities of area delineation factors contributing to soil water management.

CONCLUSIONS

Variation of soil analysis in two depth 30 and 60 cm could be seen more easily when they were displayed used ArcMap for their spatial distribution these variations were observed as well by Mohanty and Skaggs, 2001. The arable land texture is classified as silt-loamy, a comparison of two depths of soil texture showed that clay and sand content has been increased in the upper layer (28 % and 7.37%) while silt content dropped (6.4 %) compared to the deeper soil layer.

Smoothed spatial distribution in the upper layer and scattered in a 60 cm layer, changes which have come from soil cultivation, conventional soil tillage practice, and weather condition. Cultivation practices made an impact up to 30 cm of the soil depth. On the 60 cm layer had more variances, divergent and higher standard error results compared to 30 cm layer with less variation regarding soil texture classification.

Excluding the total water content seen an increase of maximum values reached and the available water content of the soil is lower in the deeper layer. Other soil water retention parameters of the soil did not show major fluctuation of two layers related to pF values of the soil.

LiDAR data shows us the whole field and understand the DEM, DSM. It resulted that the area is not susceptible to erosion since 68 % is in the first category of the slope and 28 in the second category of the slope. Elevation models and surface model which were created to a raster display permits to optimise cultivation, irrigation practices, water flow and logging in the field.

The field can be well drained, applying irrigation should be scheduled/separated for different areas of the same field. DEM and runoff line would improve irrigation planning and water use efficiency. Increased water use, intensified droughts, and weather fluctuation will require improved agricultural practices toward appropriate crop production and sustainable development.

The use of remotely sensed data such as LiDAR brought a high advantage on data gathering and visualisation of site information. Hence, mapping and digitalisation of terrain information are valuable, comprehensive and easily understandable in plot-farm level.

As such, LiDAR experience benefits at plot-farm scale and it brings advantages to up-scale its larger agricultural zones.

Results demonstrate the spatial visualization of data the benefits and advantages of using high accuracy remote sensing LiDAR data to prevent possible field waterlogging, finding of soil hydrological characteristics and the correlation with results soil parameters analysis for a better water and irrigation management planning.

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