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Micro-topographical surface alteration caused by tillage and irrigation canal maintenance and its consequences on excess water development

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ABSTRACT

The most common forms of low relief plains created by agriculture are ridges and furrows that develop parallel to ploughing and irrigation or drainage canals. These micro-forms influence the surface run-off conditions of a field, as they act as overland flow paths or barriers depending on their orientation, resulting in the development of excess water. The consequences of excess water retention are soil degradation and crop loss, which for example, in 2011 threatened 11% of the agricultural lands of Hungary. The goals of the present research are to evaluate the spatial distribution and morphology of forms created by tillage and irrigation or drainage canal maintenance, and to study their effect from the point-of-view of blocked drainage and excess water build-up. The studied tillage ridges were formed during the last 20 years and their height reaches 0.19–0.26 m. The ridges block the overland flow and facilitate the development of excess water on 14.1% of the study area. Along 85.4% of the canal banks canal berms appear. Their average height is 0.38 m (max: 1.43 m) and width is 17 m (max: 54.8 m). Considering the height of the tillage ridges, they have less influence on overland flow than that of the canal berms, but, due to the low relief of the area, both play an important role in disconnecting overland flow routes. Thus (dis)connectivity could develop within an agricultural plot as the higher parts of the plot could be disconnected from the lower parts by ridges, and the canal berms disconnect the plot and the artificial drainage system. Regarding overland flow, ridges and berms disconnect the plots from their drainage canals (buffer function), and in the natural drainage routes they act as barriers. The dis-connectivity function of the studied forms increases over time and as a result of intensive tillage. Therefore, they will play a more and more important role in altering overland flow and developing excess water hazard.

1. Introduction

Agricultural activity can significantly alter the geomorphology of large territories, due to its thousands of years of history and various tillage methods (Gottschalk, 1945; Costa, 1975). Agricultural activity accelerates natural processes on agricultural lands, e.g., it can increase erosion caused by run-off, enhance aeolian activity, or alter the water and sediment discharge of rivers (Goudie, 2006). In Hungary, these problems are especially pronounced, as on the Great Hungarian Plain the proportion of arable lands (75%) is very high (Lóki, 2006; Kovács, 2011), and the history of farming and its geomorphological consequences date back to the Early Neolith (6–6.5 ka BC) period (Sümegi et al., 2003).

At a large scale, the most important geomorphological result of tillage is direct or indirect plantation (Erdősi, 1987; Szabó, 2006), but at small-scale different micro-forms may develop, depending on the method and direction of tillage. The most common forms are ridges and furrows that develop parallel to the ploughing direction (Beresford, 1948; Eyre, 1955; Evans, 1975; Szabó, 2006), ditches, ridges and berms on field boundaries (Lal, 1990; Li et al., 2009; Vieira and Dabney, 2011). Long-term tillage of agricultural plots might result in the development of saucer shaped depressions (Li et al., 2009). Ridge and furrow patterns were produced not just by medieval or modern tillage, but they appeared as early as Neolithic Times (Verrill and Tipping, 2010). Ridge and furrow patterns can be different, depending on the direction and method of tillage. For example, the Medieval English arable lands very often have S-shaped patterns (Eyre, 1955), while from Canada box pattern was described (Li et al., 2009), although the most common pattern is parallel with the axis of the plot (e.g., Coulthard et al., 2012; Couturier et al., 2013). As a result of tillage the ridges are 10–20 cm high (Lal, 1990; Birkás et al., 1998),

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though Rowley (1982) described some as high as 1.75 m. If the direction of tillage remains the same for decades, the height of the ridges may be doubled (up to 0.3–0.4 m), and their width might increase 15–20 m in 50 years (Li et al., 2009).

A ridge and furrow pattern provides favorable conditions for the cultivated plants, due to its water-retention and frost-protection effect (Mahrer and Avissar, 1985; Benjamin et al., 1990), and ridges perpendicular to the slope impede soil erosion (Zobeck and Onstad, 1987; Liu et al., 2014). However, tillage has also negative geomorphological consequences. Due to its large-scale planation effect, the landforms of the agricultural lands disappear; for example, several thousand of *ex-lege* protected tells and mounds vanished in Hungary (Tóth and Szabó, 2005). At a small scale, the ridges and furrows influence the surface run-off conditions, depending on the slope conditions of the plot. On steep slopes, the furrows act as overland flow paths, enhancing surface drainage (Buis and Veldkamp, 2008). Thus, furrows may support or block the run-off, depending on their orientation of their slope (Souchere et al., 1998; Patchett and Wilhelm, 1999; Takken et al., 2001; Li et al., 2009; Coulthard et al., 2012; Couturier et al., 2013). In the first case, furrows act as run-off routes, thus providing favorable locations for accelerated erosion and the development of rills (Giménez et al., 2007). However, on low gradient fields the ridges block the run-off efficiently, sometimes even blocking the natural waterways (Li et al., 2009). In the furrows the run-off water can be collected, and excess water patches develop (Benyhe, 2013). Despite these agronomic problems, overland flow directions influenced by tillage direction are usually not identified because the topographic information is mostly not accurate enough (Ludwig et al., 1995).

Similar problems can be caused by canals with dual purpose (irrigation and drainage). As a result of canal digging and maintenance, the excavated soil is usually piled along the canal, forming a berm. Such berms were described in China, where the high berms (up to 5 m) provided higher irrigation canal volume (Wallace et al., 1994), and in Arizona where few decimeter-high berms were excavated along a prehistoric irrigation system (Purdue et al., 2010).

Excess inland water retention is a typical management problem of low relief plains (Darboux et al., 2002; Pásztor et al., 2006). Retention in these lowlands is caused by a precipitation surplus, combined with blocked drainage or impeded infiltration, and low soil water storage capacity and infiltration rates. These conditions arise when the soil is frozen, or if a plough-pan develops as the result of soil compaction caused by heavy machines (Birkás et al., 2009). The consequences of excess water retention are soil degradation and crop loss (Puskás et al., 2012); therefore, it is one of the greatest environmental hazards in Hungary. For example, in 2011 excess water covered 11% (3350 km^2) of the agricultural lands of the Great Hungarian Plain for months (van Leeuwen, 2012). Our field surveys and the aerial photos show (Fig. 1) that excess water bodies appear not just on the low-lying plots, but also on their higher surfaces and along the drainage canals. But the impacts of ridge and furrow patterns and canal berms have not yet been evaluated, mainly due to a lack of precise elevation data.

This data gap could be filled by the new terrestrial and airborne laser scanning technique, which enables researchers to study the terrain in detail, even for large areas. However, the terrestrial aser scanning technique has mostly been applied on small plots (2–100 m^2), and on hilly areas when the researchers studied the effect of tillage on run-off modification and erosion. Based on detailed terrain models, the morphology of the plots was investigated (Li et al., 2009; McCoy et al., 2011). The transportation of soil particles (e.g., Mwendera and Feyen, 1992; Darboux and Huang, 2005; Haubrock et al., 2009), and drainage pattern development

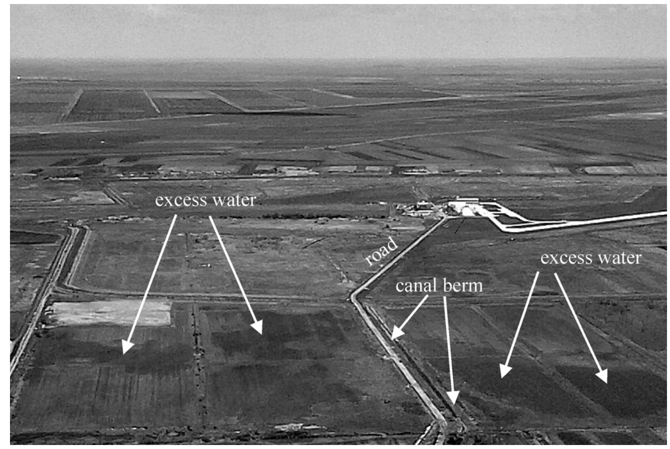

Fig. 1. Excess water appears on disconnected agricultural plots.

and surface depression storage in ridge and furrow systems were also studied (Martin and Valeo, 2008; Vázquez et al., 2010; Barneveld et al., 2013). On a larger scale, the micro-morphological features caused by tillage and their effects have rarely been investigated, especially in relation to flat plain surfaces.

The goals of the present research are to evaluate the spatial distribution and morphology of forms created by tillage and irrigation canal maintenance, and to study the effect of these forms from the point-of-view of blocked drainage and excess water build-up. The aims are: (1) to determine the morphometric parameters of the ridges and canal berms, (2) to determine the location of areas without drainage, in order (3) to evaluate the spatial distribution of disconnected plots and the potential areas of excess water pooling.

2. Materials and methods

2.1. Study area

The research was carried out on the Lower Tisza Region (Hungary), which was a marshland throughout the Holocene and became suitable for agriculture just after 19th century flood protection works. The surface is covered by 10–20 m thick Holocene fluvial deposits, with a finer grain size towards the surface (Gábris, 2007), providing favorable conditions for inland excess water development.

The northern half of the area is characterized by huge Tisza River paleo-channels that were almost completely filled up by organic material and overbank deposits. On the southern part, crevasse channels and filled-in ox-bows of the Maros River could be identified. Along the paleo-channels, natural levees and point-bars formed, which blocked or impeded run-off and created natural local depressions. Before the river regulations, the whole area was a floodplain (Kiss and Hernesz, 2011). Thus, the channel fragments and crevasse channels played important roles in drainage, as the floodwaters flowed in and out from the Tisza and Maros Rivers, depending on the stage of the flood. After the regulations and the establishment of a drainage canal network, the role of these natural forms became limited, and they just control the local overland flow.

The whole area has high or medium excess water risk (Pálfai et al., 2004), which can be explained by low relief, micro-forms and low infiltration capacity of the soils (Keveiné Bárány, 1988). The almost zero hydrologic conductivity and the resulting very small infiltration capacity ($K \leq 10^{-6}$–10^{-7} m/s; Benyhe, 2013) is explained by the high clay content of the present fluviosols, meadow soils, and the development of a plough-pan layer formed