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Effect of potato hilling on soil temperature, soil moisture distribution and sediment yield on a sloping terrain

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A B S T R A C T

Soil erosion rates are exacerbated in sloping arable lands of Central Kenya due mainly to the high soil disturbance caused by potato hilling. A field study was conducted in runoff plots to quantify the effect of potato hilling on soil loss, soil moisture distribution and soil temperature. Three hilling practices; hilling performed at before crop emergence (pre-hilling), one-pass hilling (at 15 days after potato emergence), the conventional two-pass hilling (at 15 and 30 days after potato emergence), and the control (non-hilling) constituted the treatments. Root length density, vegetal cover, soil surface roughness and soil water infiltration capacity were quantified at different stages of potato growth and related with the sediment yield. Soil temperature and soil moisture contents were monitored using Onset HOBO sensor probes throughout the potato growth cycle. Compared to the conventional two-pass hilling, pre-hilling increased the soil moisture content by 6% and lowered the soil temperature by up to 3.4 °C at crop emergence, thus optimized tuber germination and growth. This ensured earlier canopy closure and reduced the cumulative sediment yield by 12 t/ha. The increased surface roughness resulting from pre-hilled ridges puddled the surface water and increased the soil water infiltration rate by 7 to 9 mm/hr compared to the non-hilled plots. Planting potatoes in pre-hilled plots has a potential to optimize the soil temperature and soil moisture conditions and can reduce the high soil erosion rates in sloping arable lands.

1. Introduction

High temperatures and increased soil moisture stress in East Africa represent a serious limitation to the extension of potato production to warmer lowland areas where there is great consumer demand for the crop. Cultivation of potato is mainly done in the highlands which are characterized by sloping terrains and up-down slope operations which make soil erosion by water a major challenge causing soil loss at a rate greater than 24 t/ha/yr (Nyawade et al., 2016a). Potato is shallow rooted crop and is extremely sensitive to water stress (Fabeiro et al., 2001; Rens et al., 2018). High temperature late in the potato crop is detrimental to tuber yield, particularly when haulms are lodged and the soil is exposed to incoming radiation (Alva et al., 2012; Xiao-Ling et al., 2005). According to Xiaolin et al. (2016), potato yield is mainly regulated by the surface (10 cm) soil temperature and soil moisture content at 20 and 30 cm depths. A temperature range of 20–25 °C is optimal for haulm growth whereas the optimal range for tuberization and tuber growth is 15–20 °C (Xiaolin et al., 2016). Though potato root growth can occur at a temperature range of 10–35 °C, active root development occurs at soil temperature range of 15 °C –20 °C (Rykaczewska, 2015).

Soil tillage can play an important role in mitigating soil temperature and moisture limitations to crop growth and extend crop production to semi-humid lands (Paula and Teodor, 2012; Wang et al., 2015). In particular, potato hilling has been shown to moderate the soil temperature and soil moisture contents and could be a strategy to increase potato yields in lowlands if timely performed. The resultant ridges may lower the night soil temperatures faster than the flat beds if oriented in the east-west direction and this may create good conditions for potato growth (Oke, 1992). This is based on the fact that temperatures play critical influence on potato growth with a night temperature range of 12–18 °C considered optimal for potato growth (Kelly et al., 2017; Burke, 2012). The ridges raise soil temperature in colder soils allowing

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quicker germination and early crop growth (Mashhour, 2010). Xiaolong et al. (2017) highlighted the importance of ridging in improving soil drainage while retaining runoff from heavy rainfalls thus reducing the risk of crop flooding. However, the resultant ridges may quickly warm up the soil and aggravate the effect of temperature on potato growth (Ren et al., 2017). Chow et al. (2000) noted that frequent soil disturbance during ridging can cause soil loss which may exacerbate soil temperature conditions. Fluctuations in soil moisture status within the ridges will lead to uneven tuber bulking, tuber malformation and tuber growth cracks (Polgar et al., 2017).When used as the sole method of weed control, hilling performed at potato emergence or at an early growth stage achieves the greatest weed suppression effect and minimizes soil moisture competition (Burke, 2012; Vangessel and Renner, 1990). The remaking of the ridge at second hilling makes it possible for the fertilizer to be incorporated around the tubers (Muthoni, 2016). Hilling at this time ensures proper coverage of the developing tuber and prevents greening thus ensuring tubers are well shaped, more evenly sized and are at lower risk of damage (Bohl and Love, 2005; Xing et al., 2011). Carling et al. (1990) however observed that the vines of larger potato plants may sustain greater damage from hilling and increase the chances of damaging the roots and stolons.

In Kenya, potato is mainly grown in the lower and upper highland zones with a soil temperature range of 15–20 °C (Muthoni, 2016; CIP, 2008). Heat stress and low soil moisture often occurs during the early stage of the growing season, and has resulted in large yield losses (Karanja, 2008; Gitari et al., 2018b). The farmers mainly perform hoe tillage at the onset of rains to loosen the soil prior to potato planting (CIP, 2008). Potato seeds are then planted on flatbeds and hilled in the production cycle between emergence and canopy closure. First hilling is done at 15 days after crop emergence by heaping the soils around the potato vines, leaving only the top leaves exposed. This allows for a shallower second hilling done 2–3 weeks later with an additional 2–4 inches of soil brought around the vines. Second hilling is mainly meant to topdress the fertilizers and therefore takes a shorter interval from the first hilling (Muthoni, 2016). Some farmers however wait until vines are 30 cm or taller before the second hilling is performed to reduce the danger of covering plants with the soil (CIP, 2008). The repeated soil disturbance caused by the second hilling may disturb the already stabilized soil and again initiate soil loss (Xing et al., 2011).

Attempts to increase crop water productivity of potato while reducing soil loss through legume cover crop intercropping has been proposed in Central Kenya highlands (Gitari et al., 2018b; Nyawade, 2015). Though this strategy has got the potential to confer shade and cool the surface temperatures, the cover crops may compete for soil moisture, light and nutrients (Jajang and Suradinata, 2015; Gustave et al., 2008; Gitari et al., 2017). Mulches which have been shown to reduce soil temperature during later part of tuber bulking however face competitive uses and their reflective and insulatory features important for soil cooling degenerate as the season progresses (Petr et al., 2012).

Carrying out hilling at planting (pre-hilling) when the soil is friable may moderate the soil moisture content and soil temperature and eliminate the potential for potato root pruning (Xing et al., 2011; Carling et al.,1990). The pre-hilled ridges have the potential to moderate the soil temperature at 10 cm soil depth thus resulting in earlier seed emergence compared to planting on flat beds (Xiaolin et al., 2016). The earlier formation of hills may however change the soil micro-relief and create local steep slopes that may increase soil erosion, especially if rain occurs immediately after planting (Nyawade, 2015). The furrows and ridges created by hilling cause systematic change in soil surface configuration thus causing oriented roughness (Takken, 2000).

According to the previous authors, surface roughness affects seedling germination, infiltration rates, depressional storage, runoff, solar radiation reflectance, sediment yield, and sediment deposition (Govers et al., 2000; R¨omkens et al., 2001; Gomez and Nearing, 2005; Nyawade et al., 2016b). The furrows temporarily store the surface runoff and delay the time to runoff generation. As cumulative rainfall and rainfall kinetic energy increase, surface roughness degradation occurs (Zobeck et al., 2001). The rate of this degradation however depends on its initial roughness values and generally increases with increasing micro-relief height (Vidal et al., 2007). Soil surface roughness effects are mainly evident during the early stages of erosion process, a period characterized by raindrop splash, seal development and runoff generation (Helming et al., 1998; Vidal et al., 2007; Nyawade et al., 2016b).This study was therefore conducted to assess the effect of pre-hilling, one-pass hilling and the conventional two-pass hilling on distributions of soil moisture and soil temperature, and to quantify their effect on sediment yield in Central Kenya highland. We hypothesized that no significant differences exist in sediment yield, soil temperature and soil moisture contents under different hilling practices. This study is expected to enhance understanding of potato hilling effects on the dynamics of soil loss, soil water contents and soil temperature variations. Quantification of soil roughness due to potato hilling is important as it affects surface storage, infiltration and ultimately sediment detachment.

2. Methods

2.1. Site description

This study was carried out in Kabete, Kenya during the short and long rainy seasons of 2017. Kabete lies along latitude 1° 15′ S and longitude 36° 44′ E at an altitude of 1834 m above sea level (Fig. 1). Kabete has a rolling landscape and is representative of the Central Kenya highlands. This area is classified as upper midland zone and is highly suitable for potato production (CIP, 2008; Muchena and Gachene, 1989). The area receives mean annual rainfall of 1006 mm, mean annual maximum temperature of 24 °C, mean annual minimum temperature of 18 °C and mean evapotranspiration of 1152 mm (Jaetzold et al., 2006). The soils are dark red friable clay, with clear and smooth boundaries and are classified according to the FAO soil classification system as humic nitosol (Jaetzold et al., 2006; IUSS Working Group WRB, 2015). Soil erosion occurs mainly on the cultivated steep slopes, especially on areas where potato is grown without effective soil conservation measures (Nyawade et al., 2016a). The soil at the start of this study had a bulk density of 1.04 g cm^{-3}, pH of 5.5 (soil to water ratio of 1:2.5), organic carbon content of 2.9%, available total nitrogen content of 0.29%, and available phosphorus content of 18.8 ppm. Exchangeable Na, K, Mg and Ca contents were 1.2, 1.8, 2.5 and 9.0 cmolc kg^{-1}, respectively.

2.2. Experimental design and crop husbandry

This study was conducted in runoff plots laid out in a randomized complete block design on a 12% slope. Three hilling practices each replicated four times were used in this study: hilling performed at before crop emergence (pre-hilling), one-pass hilling (at 15 days after crop emergence) and conventional two-pass hilling (at 15 and 30 days after potato emergence). These treatments were compared with a control plot in which planting was done on flat beds without hilling (non-hilling). Pre-hilling was done at planting using hand hoes which were used to pile up the soil to a height of 20 cm and 15 cm top width with hills oriented across the slope. Well sprouted tubers were planted at a uniform depth of 10 cm on the pre-hilled ridges and spaced at 30 cm within the rows and 75 cm between the rows. Weeding was done by carefully hand plucking the emerging weeds at 15 days after potato emergence.

Conventional hilling was carried out according to the hilling standards used by smallholder potato producers on scheduled dates with hills oriented up-and-down the slope (CIP, 2008; Gitari et al., 2018b). Well sprouted tubers were first planted at a depth of 10 cm and spaced at 30 cm within the rows and 75 cm between the rows. At 15 days after emergence, first hilling was done by piling up the soil to a height of approximately 20 cm and 15 cm top width. The second hilling was