Field trial to investigate the role of cover crops in reducing runoff and soil erosion in maize

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Summary

This research investigated the role of different cover crops (CC) towards reducing runoff and soil erosion from maize. An eight-month field trial was undertaken whereby runoff was collected from bounded erosion plots. Treatments comprised (n=5): i) *Lolium multiflorum*, ii) *Lolium multiflorum and Vicia villosa*, iii) *Lolium multiflorum and Trifolium alexandrinum*, iv) control (no CC). The experiment was divided into three blocks according to in-field topography. Mean runoff was 1.8 times greater, and soil loss double, in control plots as compared to those with CC. This difference was not significant due to the high variability within each treatment caused by changes in plot micro-topography, which was evident from a different runoff flow direction between blocks. We concluded that the effect of CC on runoff and soil erosion on shallow slopes is not definitive, and further investigation is needed. Future assessments of soil erosion should take into account the variability of field micro-topography.

Key words: Maize, soil erosion, cover crops, micro-topography

Introduction

Surface water runoff and accelerated soil erosion often occur in maize cultivations in the UK, even on shallow slopes (Morgan, 2005). This poses a serious risk to water quality and riverine habitats, and often leads to degradation of soil health (Boardman, 2013). This erosion is mainly caused by the standard post-harvest management of leaving stubble over autumn and winter, which provides inadequate soil cover during the heavy rains associated with that period (Jokela *et al*., 2009). Additionally, compaction caused by the late harvesting of maize often in wet soil conditions, facilitates runoff and thus erosion (Boardman & Poesen, 2006; Posthumus *et al*., 2011). The cultivation of forage maize in the UK has increased from 29,000 ha in 2014 to 51,000 ha in 2016 (National Statistics, 2016), mainly for its use in anaerobic digestion (AD) for biogas production. Defra sees AD plants as pivotal to achieve the target 26% reduction of CO_2 UK emissions compared to 1990 levels by 2020 (Climate Change Act, 2008), thus encouraging future expansion of maize cultivation. However, if soil conservation measures are not implemented, the negative impacts of maize cultivation could outweigh future environmental benefits of biogas production. Cover crops, such as grasses, legumes, and cereals, are used as soil conservation practice for erosion protection and for soil nutrient management. Cover-cropping is used world-wide in maize cultivation, especially in the US (Brennan & Boyd, 2012; Dabney *et al*., 2001; Snapp *et al*., 2005), and it is also an emerging practice in the EU (Gabriel *et al*., 2012; Gabriel & Quemada, 2011; Thorup-Kristensen *et al*., 2003). The use of CC with maize in the UK could not only decrease the offsite environmental costs of maize, but it could also be advantageous for UK farmers to enter agri-environmental schemes. For example Defra (2015) Good Agricultural and Environmental Conditions (GAEC) states: GAEC-4 -

maintenance of a minimum soil cover, GAEC-5 - implementation of erosion control measures, and GAEC-6 - maintenance of soil organic matter. The selection of CC species needs to be fit to the management goals (e.g. soil erosion protection), soil type and the climatic conditions. Species choice is important as additional benefits other than erosion control can be achieved. For example, legumes, such as vetches (*Vicia sativa, Vicia villosa*) and clovers (*Trifolium repens, Trifolium pratense and Trifolium alexandrinum*) are used to restore soil fertility by fixing nitrogen (N) (Brennan & Boyd, 2012). Grasses, such as Italian ryegrass (*Lolium multiflorum*) and cereal rye (*Secale cereale*) are often selected for erosion control as they rapidly establish, protecting the soil from the direct impact of raindrops, have a fibrous root system that contributes to decreased soil erodibility, and have a high stem density which reduce runoff velocity (Liedgens et al., 2004; Burney & Edwards, 2005). Other crops that contribute to erosion control are tap-rooted crops (e.g. Forage radish, *Raphanus sativus* and Rapeseed, *Brassica napus*), which increase water infiltration and decrease soil compaction (Chen & Weil, 2011; Pratt *et al*., 2014), thereby reducing runoff. Oats (*Avena sativa*), barley *(Hordeum vulgare)* and winter rape *(Brassica rapa*), are few examples of CC also known as catch crops. They are used to decrease the leaching of nutrients such as phosphorous (P) and N over-winter (Meisinger *et al*., 1991; Salmerón *et al*., 2010 Gabriel *et al*., 2012; Restovich *et al*., 2012). Although the use of CC in the UK is still largely experimental, this practice is starting to gain prominence. Cover crops are promoted among maize growers by Catchment Sensitive Farming advisors and independent agronomists. More knowledge is required to demonstrate the potential of CC for reducing soil erosion while improving physical, chemical and biological aspects of soil quality in maize systems, on CC sowing and termination techniques and on CC resistance to herbicides. This research aimed to quantify the role of Italian ryegrass and mixtures of Italian ryegrass with legumes as compared with un-amended controls with regards to reducing surface runoff and soil loss in maize cultivation. It was hypothesised that the presence of CC would reduce runoff and soil loss as compared to control plots without CC, and that Italian ryegrass would decrease runoff and soil loss more than mixtures of legume-grass because it would provide a faster soil cover due to its rapid growth. Field dominant slope and the runoff flow direction were also assessed to determine whether any underlying micro-topographical variation was affecting experimental variables.

Materials and Methods

The experiment ran from July 2015 to March 2016 within a field of commercially grown maize (Herefordshire, UK: OS grid references: 344505 E, 257646 N) (Figure 1). Annual average rainfall was 793.8 mm yr^{-1} (Met Office, 2016), soil was a sandy loam and the slopes ranged from 3° to 4°. The experiment, arranged in a randomised design, comprised four treatments replicated five times. Experimental treatments included: i) Italian ryegrass (*Lolium multiflorum*), ii) Italian ryegrass and hairy vetch (*Vicia villosa*), iii) Italian ryegrass and berseem clover (*Trifolium alexandrinum*), and iv) control (post-harvest wintered maize stubbles). The experiment was divided in three blocks according to site topography. These blocks are referred to as A (from plot 1 to plot 8), B (from plot 9 to plot 14) and C (from plot 15 to plot 20) (Figure 1). The intention was to assess whether topographical variability at field-level was influencing experimental findings. Forage maize (Sergio & Kentaurus varieties) was drilled with a 75 cm row space in May 2015. Cover crop options were broadcast by hand at the end of June in strips inside the erosion plots (12 m × 1.5 m), which were oriented parallel to the maize rows and to the direction of the dominant slope. Seeding rates were double the standard seeding rates for the single species to insure crop establishment: i) Italian ryegrass 56 kg ha^{-1}, ii) Italian ryegrass and hairy vetch 56 kg ha^{-1} and 62 kg ha^{-1}, and iii) Italian ryegrass and Berseem clover 56 kg ha^{-1} and 59 kg ha^{-1}. The dominant slope across the plot areas was not significantly different between treatments or between blocks.

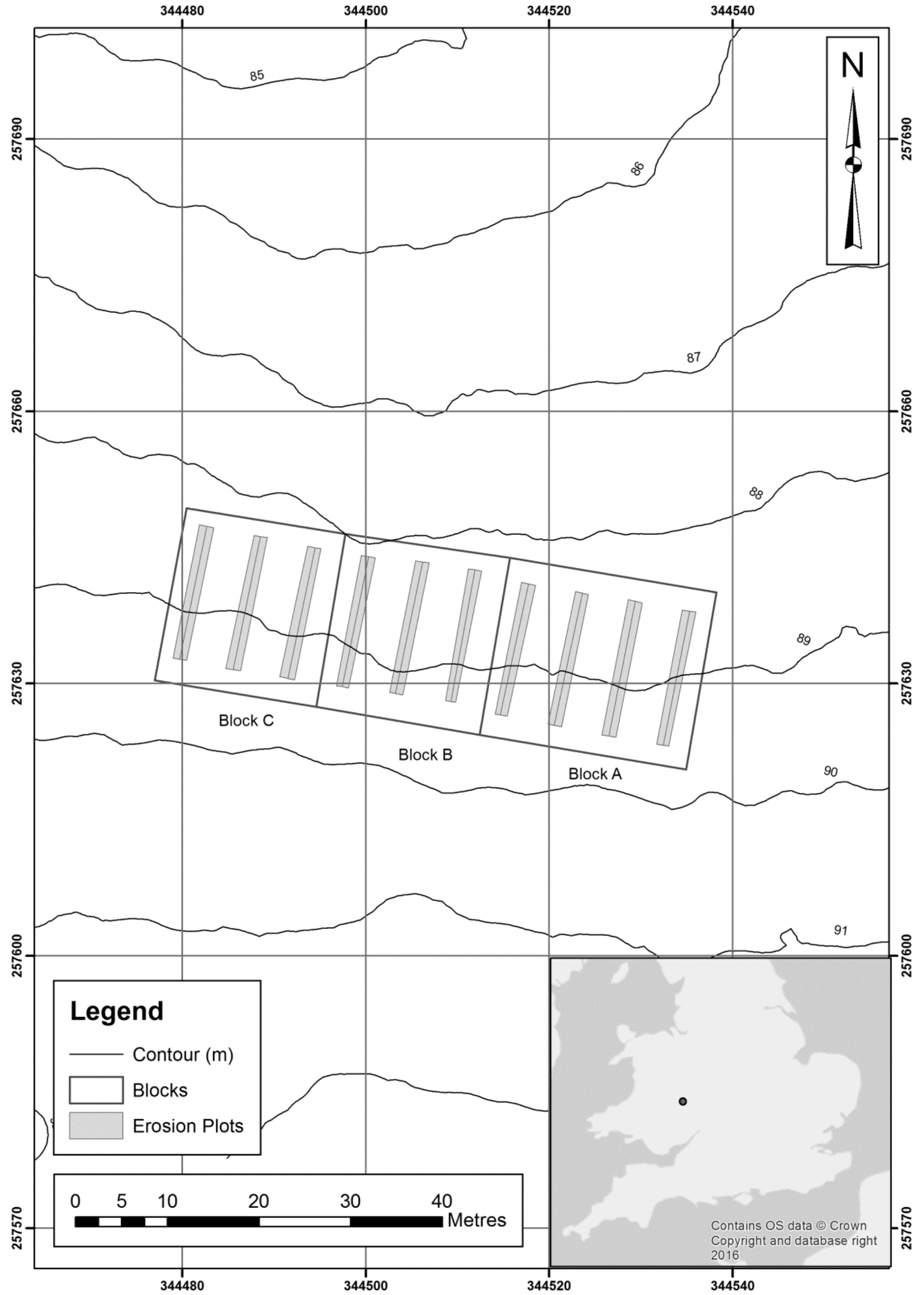

Fig. 1: Map of the field trial showing the three zones identified to assess the effects of topography.

Runoff and sediment sampling

Plots were hydrologically isolated from field runoff by soffit boards dug into the soil (to a depth of *Ca*. 0.2 m) on three sides. Runoff and sediments were collected by a stainless steel Gerlach trough placed at the bottom of the plots connected with a 68 mm diameter pipe to a water tank (220 l capacity). Tanks were sampled five times during the eight-month experimental period (Table 1). At each sampling event, water level was recorded and after agitation, runoff and sediment samples were collected using three 500 ml sub-sample bottles, kept at 10 cm distance from the bottom of the tank. Where runoff level in the tank was very low, runoff was collected with a scoop. Following sampling, the tanks were emptied in preparation for the next sampling period. Subsamples (250 ml) of the runoff collected for each tank were oven-dried (105°C for 12 h) to measure the total sediment load (Clesceri *et al*., 1999). The amount of sediment present in the runoff was use to estimate soil loss per hectare.

Table 1: Runoff collection periods.

Runoff collection period	Sampling event
28 July 2015 – 15 October 2015	1
27 November 2015 2015 – 21 December 2015	2
21 December 2015 –13 January 2016	3
13 January 2016 – 16 February 2016	4
16 February 2016 – 15 March 2016	5

Flow direction analysis

Elevation point measurements were taken every 7-10 m across the field before the implementation of the field trial with a Trimble GeoXH, which is equipped with real time kinematic corrections and a horizontal and vertical precision of <3 cm. After the establishment of the erosion plots, erosion plot corners and their elevation were also recorded as described before. Analysis of the topographic properties of the field was carried out using ArcGIS software (ESRI), version 10.2. A surface elevation raster with a resolution of 3.0 m was extrapolated from the survey points using an Inverse Distance Weighted interpolation technique. A resolution of 3.0 m was deemed suitable for the surface raster based on the original point measurement resolution and to maintain micro-topographic features of interest within the field. The flow direction tool within ArcGIS was applied to create a raster representing the direction of the runoff flow. The tool outputs one of eight cardinal directions (N, NE, E, SE, S, SW, W, and NW) for each cell in the raster, denoting the direction of surface flow from that grid cell to one of its immediate neighbours. The flow direction raster was converted to a polygon feature, which was overlain and intersected by the demarcated plot boundaries. Subsequently, the area (%) of each flow direction class (N, NE, E, SE, S, SW, W, and NW) within the plots was calculated. Total area extent of each flow direction class was compared between treatments and between the blocks.

Statistical analysis

Statistical analysis was performed using the software STATISTICA 12 (Dell Inc. 2015). One-way ANOVA follow by post-hoc Fisher LSD analysis was performed on the runoff and soil loss data to find homogenous groups. The level of significance was set at 0.05. Pearson product - moment correlation coefficient (r) was used to determine linear correlations between runoff and soil loss. Since the two tests assume normality and homogeneity data was normalised using Box-Cox transformation (Mancini *et al*., 2017).

Results

Experimental manipulations did not affect runoff flow direction but there was a significant difference ($P<0.05$) in flow direction between blocks. The area of the flow direction class NW in block C was significantly smaller than in block A. The area of the flow direction class N in block C was significantly smaller than in block A and B. The area of the flow direction class NE in block C was significantly greater than in block A and B (Mancini *et al*., 2017). These results confirmed the presence of a depression in the area occupied by block B, which was previously noticed by in-field observations. There were no significant differences in runoff and soil loss between the treatments during any collection period (Mancini *et al*., 2017). In addition, there were no significant treatment effects for either total cumulative runoff or soil loss throughout the duration of the experiment (Table 2). Significant differences were found between the treatment blocks for total cumulative runoff and soil loss (Table 3). Cumulative runoff collected in block C (34 m^3 ha^{-1} ± 28) was significantly lower compared to the runoff collected in block B (187 m^3 ha^{-1} ± 32).

Cumulative soil loss in block C (48 kg ha^{-1} ± 44) was significantly lower than cumulative soil loss in B (233 kg ha^{-1} ± 67). Runoff and soil loss for each sampling period, their cumulative values and the runoff flow direction classes were compared using Pearson product - moment correlation coefficient (r). Runoff and soil loss for each sampling period were linearly correlated r >0.9 (P<0.05: Table 4).

Table 2: Cumulative runoff and soil loss (mean ± standard error) comparing experimental treatments.

	Cumulative Runoff (m^3 ha^{-1}) ± SE	**Cumulative soil loss (kg ha^{-1}) ± SE**
Control	149 ± 61[a]	210 ± 98[a]
L. multiflorum	99 ± 39[a]	90 ± 38[a]
L. multiflorum & *T. alexandrinum*	103 ± 58[a]	183 ± 108[a]
L. multiflorum & *V. villosa*	46 ± 24[a]	39 ± 22[a]
CC treatments	83 ± 24[a]	104 ± 39[a]

CC cover crops, letters represent statistical groupings

Table 3: Cumulative runoff and soil loss (mean ± standard error) comparing blocks.

	Cumulative Runoff (m^3 ha^{-1}) ± SE	**Cumulative soil loss (kg ha^{-1}) ± SE**
Block A	82 ± 38[a, b]	116 ± 68[a, b]
Block B	187 ± 32[a]	233 ± 67[a]
Block C	34 ± 26[b]	48 ± 44[b]

Letters represent statistical groupings

Table 4: Pearson product - moment correlation comparing soil loss and runoff. Soil loss 1 = soil loss during sampling period 1.

y	**x**	**Equation**	**r**
Cumulative soil loss	Cumulative Runoff	y = 0.97 x - 47	0.98
Soil loss 1	Runoff 1	y = 0.43 x - 0.03	0.94
Soil loss 2	Runoff 2	y = 0.9 x - 0.2	0.96
Soil loss 3	Runoff 3	y = 1 x - 0.31	0.96
Soil loss 4	Runoff 4	y = 1.04 x - 0.04	0.98
Soil loss 5	Runoff 5	y = 0.98 x - 0.03	0.96

Discussion

Contrary to the hypotheses, although mean runoff and soil loss were 1.8 and 2.0 times greater in the control plots as compared to the CC treatments, none of the CC treatments statistically affected either runoff production or soil loss. The lack of significant differences between treatments was likely due to high variability (SE) within the treatments caused by field spatial heterogeneity. Differences in field micro-topography led to a differentiation of the runoff flow direction, which became the main factor that contributed to the variation between the plots. Runoff and soil loss collected in block C were significantly lower than in block B. This was in large part due to the micro-topography of the field, which probably facilitated the convergence of sub-surface soil moisture in the depression that was block B, decreasing soil infiltration in that area and therefore increasing surface runoff and soil erosion. Additionally, the presence of subsidiary slopes inside the plots in block A and C led to an underestimation of the runoff and soil loss collected in those blocks, adding to the variation within the treatments. Contributing factors to the lack of differences between Italian ryegrass and the mixtures of Italian ryegrass with legumes were probably the dominance of the grass in the grass-legumes plots, which was observed in the spring, and the double total seed rate of the grass-legumes plots compared to the grass-alone plots. In light of these results, competition between species needs to be taken into account in the future when choosing CC mixtures and further investigation on CC sowing rates is needed. Field-based measurements of erosion and runoff have always been challenging due to: i) the extreme complexity and the scale-dependency of the erosion process, ii) the natural variability of the soil environment and iii) inevitable disturbance caused by the design of the erosion plots and by field operation e.g. harvest (Boix-Fayos *et al*., 2006; Gómez *et al*., 2005). Consequently, many papers have recorded high variability in runoff and soil loss within the same treatment, despite a statistically appropriate number of replicates (up to 40 in Gómez *et al*., 2001), refer to Rüttimann *et al*. (1995) and Hjemfelt & Burwell, (1984) for other examples. This paper did not aim to review the advantages and disadvantages of using a certain type and size of erosion plots (refer to Boix-Fayos *et al*. (2006) and Kinnell, (2016)) or to argue if they are adequate to measure runoff and soil erosion (refer to Wainwright *et al*. (2000) and Boix-Fayos *et al*. (2006)). However, future measurements of in-field soil erosion should undertake detailed assessments of within plot micro-topography as support for explaining experimental results. Many studies, have reported that CC caused a significant decrease of soil loss and runoff, see Dabney *et al*. (2010) and Delgado *et al*. (2007); nevertheless CC effects in this project were obscured by the micro-topography of the field, further investigation is therefore needed to understand the potential of CC use in the UK in maize systems.

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