

# Soil surface resistance to runoff

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Researching the resistance of different soil surfaces and post-harvest tillage types to flow

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*MSc. Thesis (minor)*

*Ton van der Linden*

*Wageningen University,*

*Soil Physics and Land Management Group*

*The Netherlands*

*Bioforsk, Norwegian Institute for Agricultural and Environmental Research*

*Soil and Environment Department*

*Norway*

*May 2015*

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*Supervision: ir. Jantiene Baartman & dr. Jerry Maroulis*



*Bioforsk –Soil and Environment–,*

*Norwegian Institute for Agricultural and Environmental Research*

*Norway*

*Supervision: dr. Jannes Stolte*



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## ABSTRACT

This thesis explored the influence of soil surface resistance (Manning's  $n$ ) to runoff and soil erosion by inserting new data into the LISEM erosion model for the Gryteland catchment near Ås, southeast Norway. Fieldwork was undertaken to measure Manning's  $n$ . Measurements were carried out for five land units based on soil type, land use, crop and tillage. LISEM was used to research the effect of soil surface resistance on runoff leaving the catchment by comparing the hydrographs of model runs using the original, literature-based Manning's  $n$  input data and the new, field-measured data. Three rainfall events, having different intensities and duration, were applied in the model runs. Results showed an increased runoff due to lower (onsite measured) Manning's  $n$  values during the rainfall events. During the runs, these larger runoff amounts levelled out until the level of computed runoff for original Manning's  $n$  values, indicating the disappearance of Manning's  $n$  effect. An assessment of tillage types on erosion reduction was carried out. Tilled soil, cultivated by means of a chisel plow, appeared to be the best solution regarding computed soil loss during low intensity rainfall events, while this scenario is the worst case during high intensity rainfall events. Constructing grass strips in waterways is the best soil conservation solution; a reduction in soil loss of about 50% was computed relative to that of tilled soil. Tillage or zero tillage at higher ends of the field does not make a difference in this case. Taking into account future changes such as climate change, introducing grass strips in the waterways is recommended.

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*Key words: Manning's  $n$ , soil surface resistance, erosion, Limburg soil erosion model, tillage, rainfall intensity, runoff, soil loss*

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Wageningen, May 2015

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# 1. INTRODUCTION

## 1.1 INTRODUCTION TO SOIL EROSION PROCESSES AND MODELLING

Agriculture and sustainable land use can be difficult to combine. Land degradation, the loss of soil functions, is a result of natural processes, but mostly it is human induced or accelerated by human impact (Imeson, 2011). Degradation of land has many causes, ranging from depletion of ground water resources to the use of pesticides for agricultural purposes.

Soil erosion is an environment changing process, which is a form of land degradation. This process occurs everywhere around the world. Besides arid and semi-arid regions, regions with milder climate conditions also face soil erosion problems. In these regions, the agricultural sector has undergone a process of intensification, resulting in higher production rates. Monocultures and intensive tillage are examples of this development.

Soil cultivation can lead to increased soil erosion (Morgan, 2005; Zachar, 1982). The lack of soil cover in autumn and winter and the removal of natural obstacles (i.e. forests and rocks) in fields result in less infiltration and water retention, which generates runoff. Runoff causes detachment and distribution of soil particles and finally the sedimentation of these particles. In general, the top soil loses fertility since it contains nutrients and organic matter that will be removed by erosion. In the long term this can negatively affect plant growth and so agricultural productivity will decline (Morgan, 2005).

The extent of the erosion problem indicates the urgency for sustainable land management in these intensively used agricultural fields (Zachar, 1982). The spatial and temporal variation of the environment should be investigated to get more understanding of the erosion rates (Morgan, 2005). Since the early nineties of the last century, several erosion models have been developed to be able to estimate these erosion rates (Smith et al., 2010). These models calculate and visualize environmental changes; changes in the past can be explained, and effects of future scenarios can be simulated. However, developing an accurate model is difficult, caused by the spatial variability and accuracy of input parameters (De Vente et al., 2013).

Calculation of flow velocity to simulate the flow of water over the land surface is a basic need in hydrological and soil erosion models. Overland flow can be calculated by two equations: the Darcy-Weisbach equation and Manning's equation. Both equations contain a factor representing soil resistance to water flow. Abrahams et al. (1990) studied Darcy-Weisbach resistance factor ( $f$ ) and found that it varies with flow rate, meaning that  $f$  is highly variable in space and time, as it depends on continuously changing flow conditions. This dependency is related to Reynolds number and Chezy  $C$  (Abrahams et al., 1990; Emmett, 1970). Hessel et al. (2003) found that Manning's  $n$  behaves in the same way as  $f$  (Darcy-Weisbach), and can be estimated from Reynolds number too. Manning's  $n$  was found to increase with slope angle, caused by a hardly increasing flow velocity with increasing slope, implying that in soil erosion models, the value of  $n$  should be a function of slope for surfaces that can erode by runoff.

Manning's  $n$  appeared to be an important parameter in erosion modelling, however, Manning's  $n$  values used for erosion modelling assignments are usually based on literature data; onsite measurements of these values are rare. Only few studies have been carried out where onsite measured Manning's  $n$  values are used. The question arises how the modelling results are

affected by Manning's  $n$  parameter values; it indicates the need for carrying out onsite measurements.

More knowledge on soil resistance to water flow can contribute to studies where soil conservation measures and tillage practices are assessed. There has been considerable debates for years about the soil cultivation effects on erosion after harvest as to whether it increases or decreases erosion rates. This study could contribute to a new approach in combating soil erosion in these intensively used agricultural fields in eastern Norway.

## 1.2 PROBLEM STATEMENT

In the case of erosion modelling, creating an accurate representation of the real situation is challenging (Jetten et al., 2003). If input data cannot be collected by field measurements, these are mainly based on values taken from the literature, or generated using e.g. pedotransfer functions.

The Limburg Soil Erosion Model (LISEM) has been used to calculate erosion rates for the Gryteland sub-catchment, part of the Skuterud catchment near Ås in southeast Norway (Kværno and Stolte, 2012). In this study, the initial Manning's  $n$  values were based on literature data. As a result, the correctness of these values and the influence on the model outcomes are unknown, while the sensitivity of Manning's  $n$  for calculating the erosion rates is high (De Roo et al., 1994).

## 1.3 OBJECTIVES

The main objective of this research was to obtain onsite-measured values for Manning's  $n$  for identified land units as input for the LISEM soil erosion model. The second objective was to compare the model outputs using these field-measured Manning's  $n$  values and literature-derived Manning's  $n$  values. Finally, an assessment of the effect of tillage practices on erosion was carried out using LISEM.

## 1.4 RESEARCH QUESTIONS

The main research questions were:

**How do computed LISEM outputs for the Gryteland sub-catchment change when using onsite measured Manning's  $n$  values in comparison with using Manning's  $n$  values derived from literature?**

**Which tillage practices are most effective in erosion reduction for the Gryteland sub-catchment?**

## 1.5 REPORT OUTLINE

This report will go through several steps resulting in answering the research questions. A separate section is spent on the study area, chapter 2. Chapter 3 contains the methodology, followed by chapter 4 providing the results of the field experiments, the modelling outcomes, and the assessment of different tillage types on erosion. Discussion and further research are presented in chapter 5. In chapter 6, the conclusions are provided, containing the main findings of the research.

## 2. STUDY AREA

This research was carried out in the Skuterud catchment in Akershus County, located in the southeast of Norway (Fig. 1). The catchment is part of the JOVA program, which is a land use and water-monitoring program in Norwegian agricultural catchments. This program was started in 1992 with the aim to investigate the effects of agricultural practices on water quality and soil condition (Bioforsk, 2014).

The catchment size is approximately 450 ha which mostly consists of arable land (60%), surrounded by forest (33%). A small part of the forest consists of peat land. The eastern part of the catchment is urban area (7%). The soils in the centre of the catchment consist of marine sediments; silt loam and clay loam containing gravel and stones, classified as Albeluvisols and Stagnosols. Surrounding the marine deposits, sandy silt and loamy sands are present, classified as Cambisols, Arenosols, Umbrisols, Podzols and Gleysols. In the higher parts of the catchment deposits consist of coarser materials. The catchment is split by marginal moraine ridges coming from the ice cap melting at the end of the last glacial period (Kværno and Stolte, 2012).

The mean annual temperature is 5.3°C and mean precipitation is 785 mm per year. The topography has a rolling character with altitudes ranging from 92 to 150m above sea level. Slopes range from 0° in the middle of the catchment to 30° at the edges of the catchment (Kværno and Stolte, 2012).

The main crops are cereals, which are sometimes rotated with cover crops in winter (in the case of spring-sown cereals). Grass strips of approximately 5m width are present adjacent to the stream.

In a sub-catchment, Gryteland (27 ha) (Figs. 2 and 3), drainage water and runoff water are monitored separately. For LISEM modelling, this partition of hydrological processes is a major advantage, which made the area suitable to carry out this research for Manning's n. In previous years measurements on several other input parameters of LISEM have been carried out in this area, such as aggregate stability and random roughness (Kværno and Stolte, 2012; Thomsen, 2013).



FIGURE 1: SOUTHERN NORWAY AND THE LOCATION OF THE SKUTERUD CATCHMENT (GOOGLE.MAPS, 2014).

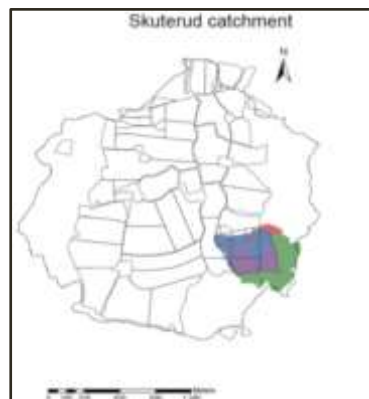


FIGURE 2: SKUTERUD CATCHMENT, IN COLOUR THE GRYTELAND SUB-CATCHMENT.



FIGURE 3: VIEW OF THE GRYTELAND SUB-CATCHMENT AFTER HARVEST 2014. THIS PICTURE SHOWS THE POST-HARVEST CONDITION OF AUTUMN 2014: TILLED FIELD AND THE UNTILLED WATERWAYS.

The emphasis of this research is on arable land. Tillage practices are determinants for runoff and erosion. Three post-harvest tillage practices were observed in the Gryteland catchment. The first type of soil tillage is cultivation by a chisel plow. Stubble was mixed with the soil, resulting in a loosened soil and a soil cover of approximately 20%-30% (Fig. 4).



FIGURE 4: TILLED SOIL BY CHISEL PLOW.

Zero tillage is a practice where arable field is untreated after harvest. The soil is not loosened and soil cover consists of wheat stubble, covering about 80%-90%. Tracks of machinery are still present, resulting in a compacted top soil (Fig. 5).



FIGURE 5: WHEAT STUBBLE ON UNTILLED SOIL.

Perennial grass has a full vegetation cover. This grass is used for erosion protection near the channel and as headland, but it is not used for cattle feed, resulting in a limited treatment of mowing at most two times a year (Fig. 6).



FIGURE 6: PERENNIAL GRASS.

### 3. METHODOLOGY

#### 3.1 LAND UNITS

Manning's  $n$  depends on surface cover, which spatially differs within the Gryteland sub-catchment. Land units were established based on a combination of soil type, land use, crop and tillage practice. According to these land units, measurement locations were determined. The number of soil types in the Gryteland sub-catchment is limited to sandy silt and clay loam while other soil types are excluded since their presence is negligible.

Land units have diverse properties, which affect the runoff rate, and probably Manning's  $n$ . The seasons also influence Manning's  $n$  values through changing vegetation type, density, and soil tillage. This research was based on post-harvest conditions of 2014.

Fig. 7 shows the selection of land units. This resulted in a selection of eight land units (green and grey coloured boxes in Fig. 7) where Manning's  $n$  was supposed to be measured. However, several constraints and simplifications, such as limited accessibility, the number of land units investigated was reduced to five land units, shown in the green coloured boxes.

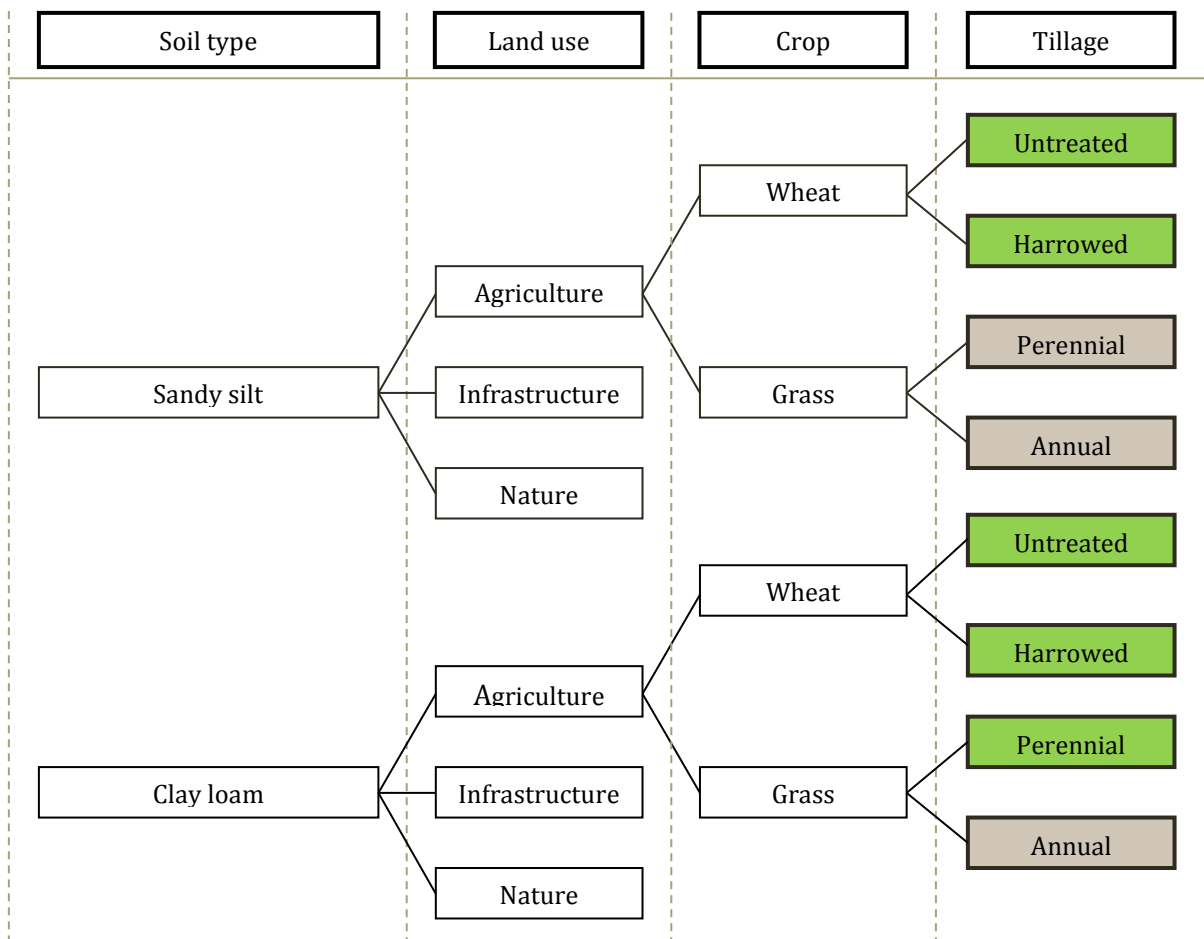


FIGURE 7: LAND UNIT DETERMINATION BASED ON SOIL TYPE, LAND USE, CROP AND TILLAGE. THE GREEN BOXES ARE THE LAND UNITS WHERE MEASUREMENTS WERE CARRIED OUT. THE GREY BOXES WERE SELECTED LAND UNITS BUT NO MEASUREMENTS ARE CARRIED OUT.

### 3.2 MANNING'S N

Manning's n is the indicator of soil resistance to water flow in channels and surface flow (Tinkler, 1997). This factor depends on surface cover. It is part of the Gauckler-Manning equation that estimates the velocity of runoff (Jetten, 2002) (eq. 1).

$$V = \frac{K}{n} * R^{\left(\frac{2}{3}\right)} * S^{\left(\frac{1}{2}\right)} \quad \text{eq. 1}$$

where V is flow velocity (m/s), K is a conversion factor, depending on the units of R and S, S is slope (m/m), and R hydraulic radius (m). The hydraulic radius can be determined by dividing the cross-sectional area (A) by the wetted perimeter (Pw)  $R = A/Pw$  while N, Manning's n, is a dimensionless parameter. Manning's n was derived by measuring flow velocity and the other parameters of the Gauckler-Manning formula.

Field measurements were based on the set up (Fig. 8) developed by Hessel et al. (2003). To generate runoff, the top of the surface had to be pre-wetted until saturation. Two Mariotte bottles on the top of the plot drained water into a smaller bottle which directed the water into a gutter. This gutter divided water equally over the full width of the plot. Water flowed down over the surface and exited through a flume and into a bucket. The plot was delineated by two small walls to regulate the flow. Dye was added at the slide of the gutter to visualize the water flow and the time was noted when it entered the flume to calculate the flow velocity (distance/time). The length of the plots varied from 1.5m to 2.5 m.



FIGURE 8: THE MEASUREMENT SET UP SHOWING THE PLOT BOUNDED BY TWO SMALL WALLS, THE MARIOTTE BOTTLES, THE FLUME, AND BUCKET.

The measurement per land unit was repeated three times for approximately 10 minutes. For each run, the flow velocity was measured several times. By measuring discharge every 30

seconds, Manning's n could be determined every time flow velocity was measured. The discharge, flow velocity and flow width were measured to calculate the flow height in order to calculate the hydraulic radius. An average flow width was calculated by measuring the width in four sections, which were randomly selected. The hydraulic radius could be derived using eq. 2 (Hessel et al., 2003).

$$R = \frac{w \cdot h}{w + 2h} \quad \text{eq. 2}$$

where W is the flow width (m) and h is the flow height (m). This height was difficult to measure. Therefore another equation was used (eq. 3).

$$h = \frac{Q}{v \cdot w} \quad \text{eq. 3}$$

where Q is runoff discharge (m<sup>3</sup>/s) and V flow velocity of the runoff (m/s).

Slope (m/m) was measured using an inclinometer, which was transformed from degrees (°) to m/m.

As a result, for each land unit a total of 12-15 Manning's n values were generated. The average of these values served as the representative Manning's n value for that land unit. A comparative analysis of Manning's n values between land units, by means of a T-test of unequal variances, was carried out to search for possible significantly matching values.

### 3.3 LISEM

After the field experiments and data analysis, a comparison of the impact of the original and new Manning's n input values on modelled runoff was carried out using LISEM (Limburg Soil Erosion Model). By running the model with the original Manning's n input and the new input, differences in model outcomes could be determined. Runoff leaving the sub-catchment was depicted through hydrographs and thus, the effect of Manning's n could be assessed. The comparison was carried out for three rainfall events of differing intensities and duration.

#### 3.3.1 MODEL EXPLANATION

LISEM is a physically based model, which can simulate hydrological flow and soil erosion based on single rainfall events (De Roo et al., 1996). A grid consisting of cells of a certain size is the basis of the model representing the area. Version OpenLISEM 1.71 was used with a cell size of 10\*10 m.

The model uses input values for soil, plant and catchment parameters. Model input consists of all these parameters converted into GIS raster maps, using PCRaster (version 4.0.1). As a graphical user-interface for PCRaster, Nutshell 3.5 was used. Bioforsk provided additional field data and raster maps.

The hydrological and erosion processes underpinning LISEM are presented in Fig. 9. Overland flow is a result of an excess of water. When the surface storage, which is determined by the random roughness (RR), reaches its maximum, overland flow will occur. The runoff rate depends on the surplus of water, the Local Drain Direction (LDD), Manning's n and the slope. The runoff rate is of interest for the transport capacity of sediments. Calculations of each process are carried out for each grid cell per time step specified in the model input.

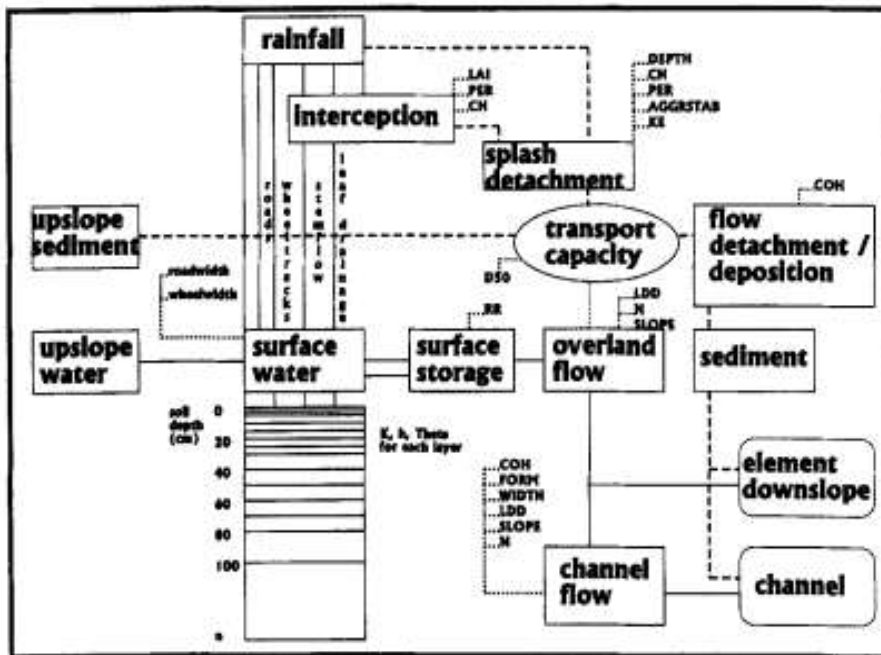


FIGURE 9: SCHEME OF PHYSICAL PROCESSES IN LISEM (DE ROO ET AL., 1996).

These parameters are processed within LISEM by means of maps. Besides, above-mentioned parameters, other parameters are included in the model. A selection of parameter maps are presented in appendix 1.

### 3.3.2 RAINFALL EVENTS

In this research three rainfall events with differing rainfall quantity, intensity and duration, were used. The differences in rainfall events can reflect the level of impact of Manning's n on the runoff discharge. The data of the rainfall events were taken from 19 August 2008, 13 August 2010, and 29 August 2011 (Fig. 7), and were provided by Bioforsk. The rainfall event of 13 August 2010 had the shortest duration of 500 minutes with three peaks reaching intensities of 40 mm/h. The rainfall of 19 August 2008 lasted for 1000 minutes containing several events, reaching intensities of 60 mm/h. The last event, 29 August 2011 had the lowest intensity with a maximum of 30 mm/h (Fig. 10).

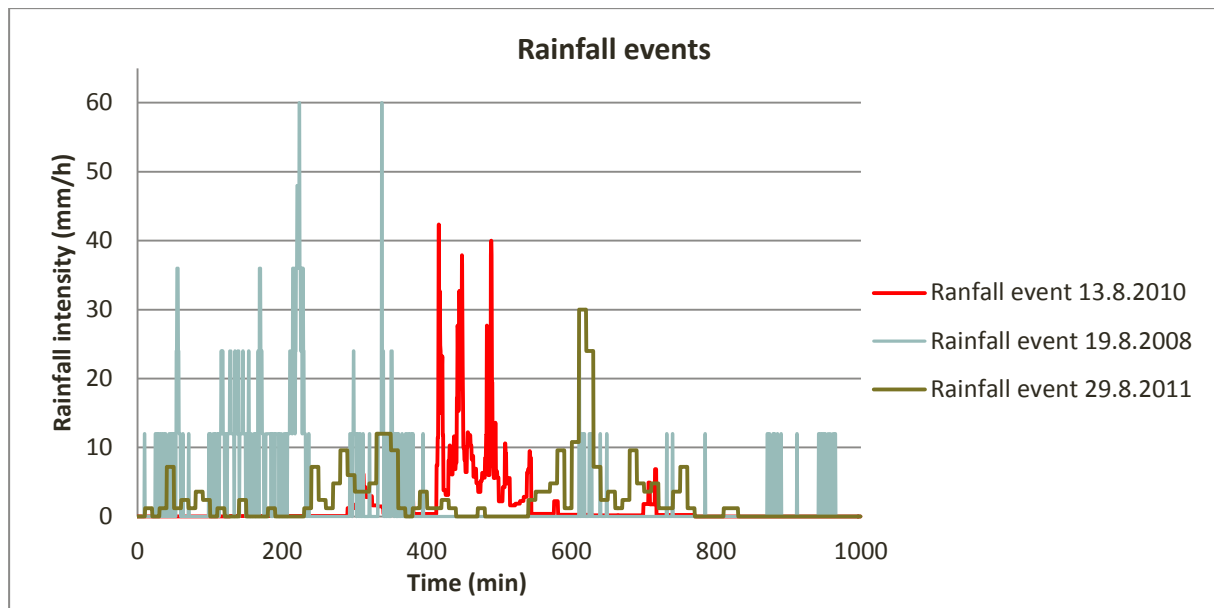


FIGURE 10: RAINFALL EVENTS USED FOR LISEM EXPRESSED AS RAINFALL INTENSITIES (MM/H).

### 3.3.3 CALIBRATION

The initial modelling outcomes needed to be calibrated, since the model result did not immediately match the measured runoff discharge. The calibration process was based on matching the modelled hydrographs; the visualization of the runoff discharge which leaves the outlet of the sub-catchment over time, to the measured hydrographs. Measured discharge data were provided for the rainfall events of 13 August 2010. Saturated hydraulic conductivity ( $K_{sat}$ ) was adjusted to meet the measured runoff discharge. In this study, the SWATRE infiltration module of the LISEM model was used (Belmans et al., 1983). The SWATRE infiltration model calculates infiltration rates using the Richard's equation.  $K_{sat}$  was adjusted for the clay loam soils in the area, while the sandy silt soil was not adjusted as the infiltration rate was much higher than clay loam, and thus runoff was not likely to appear (Kværno and Stolte, 2012).

### 3.4 TILLAGE ASSESSMENT

An assessment was carried out to analyse tillage impact on erosion. In this study, tillage practices are assumed to be represented by Manning's  $n$  and random roughness (RR). Random roughness is a parameter used to indicate the coarseness of the soil surface. Other parameters, depending on the tillage type, such as aggregate stability, were not adjusted since these data were not available for each tillage type. As a result, outcomes were only based on Manning's  $n$  and random roughness values. Random roughness (RR) was adjusted for tillage types as this parameter is related to Manning's  $n$  values, which influences the occurrence of overland flow. Values used were based on MSc Thesis work of Thomsen (2013) conducted in the same study area: tilled soil 1.63 cm, zero tillage 1.24 cm, forest 1.07 cm (Fig. 11). The values of the original map were 0.88 cm for arable land and 3.2 cm for forest (Fig. 12).

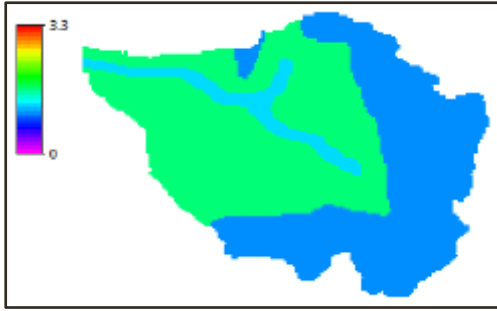


FIGURE 11: THE ADJUSTED RR-MAP (POST-HARVEST CONDITIONS 2014): TILLED SOIL 1.63 CM, ZERO TILLAGE 1.24 CM IN THE WATERWAYS AND FOREST 1.07 CM.

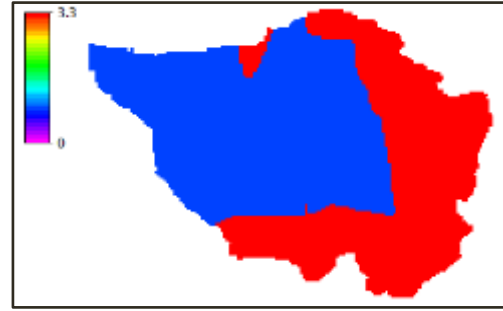


FIGURE 12: THE ORIGINAL RR-MAP: ARABLE LAND: 0.88 CM, FOREST: 3.2 CM.

Scenarios were compiled within a realistic range: maintaining wheat production and tillage types, which are most applicable for farmers in this area. The scenarios were:

- Tilled soil, untilled waterways (Fig. 13)
- Tilled soil
- Zero tillage
- Tilled soil, grass strips in the waterways
- Zero tillage, grass strips in the waterways

This assessment aimed at soil loss (kg/ha) and total runoff (m<sup>3</sup>) as calculated by LISEM. Results consisted of a comparison of the hydrographs for tillage types with an expected worst-case scenario: tilled soil. This comparison was carried out for both the intense event on 19 August 2008, and the less intense rainfall event on 13 August 2010.

The application of grass strips in the waterways was expected to be most effective in runoff and erosion reduction. The assessment is based on a comparison of hydrographs showing runoff discharge, soil loss (kg/ha) and total runoff leaving the catchment (m<sup>3</sup>).

Scenarios were assessed in the Gryteland sub-catchment based on two rainfall events; 19 August 2008 and 13 August 2010 to assess the influence of different rainfall intensities and durations.

Post-harvest conditions of 2014 have been assessed, shown in Fig. 13. The entire arable field has been tilled by a chisel plow, except the waterways. These circumstances are used as starting point for combining tillage types with grass strips.



FIGURE 13: POST-HARVEST CONDITIONS 2014: CHISEL PLOW TILLED SOIL COMBINED WITH ZERO TILLAGE IN THE WATERWAYS.

## 4. RESULTS

### 4.1 FIELD MEASUREMENT OUTCOMES

Measurement locations were both representative of the land unit and easily accessible.

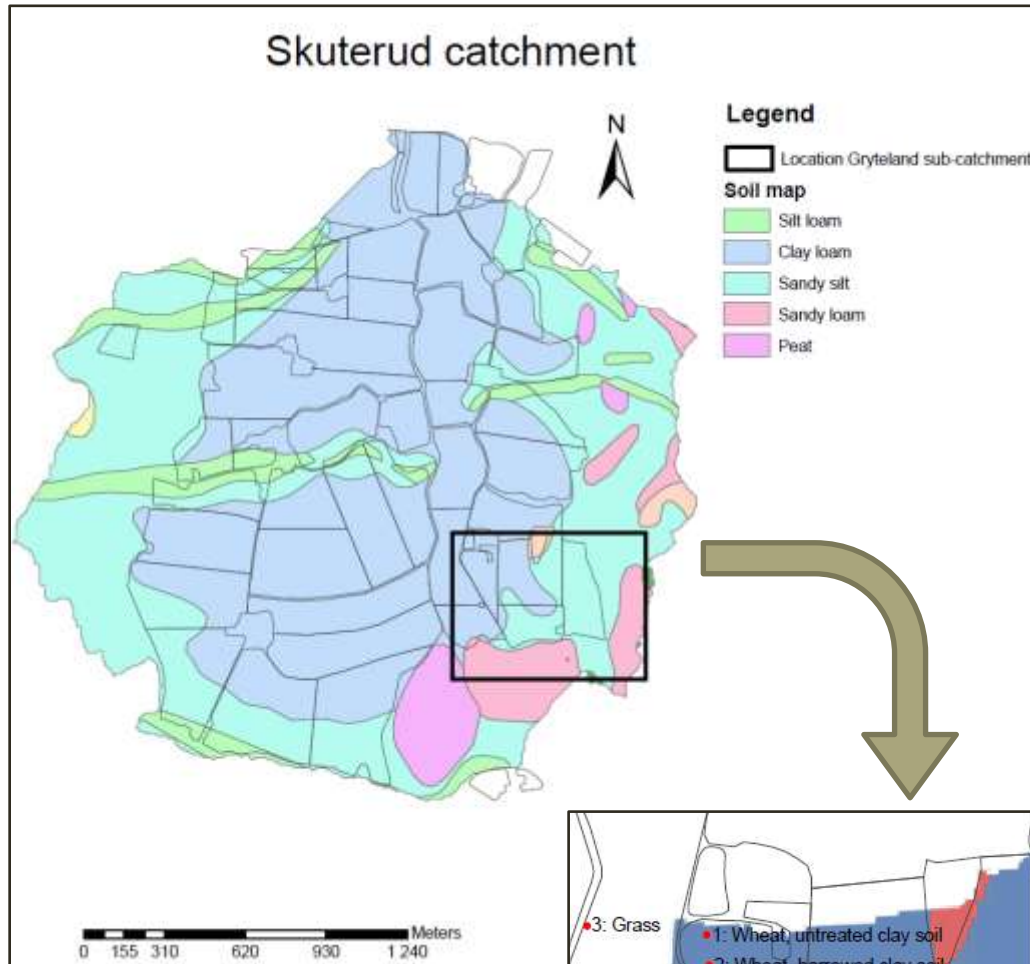


FIGURE 14: SOIL MAP OF THE SKUTERUD CATCHMENT, SHOWING THE AREA LOCATION OF THE GRYTELAND SUB-CATCHMENT.

Fig. 14 shows the location of the Gryteland catchment within the Skuterud catchment, while plot locations are represented in Fig 15. Fig. 15 shows a combination of land use and soil type. The blue area is arable land on clay loam soil; purple is arable land on sandy silt soil; green is forest; and red represents a rocky surface.

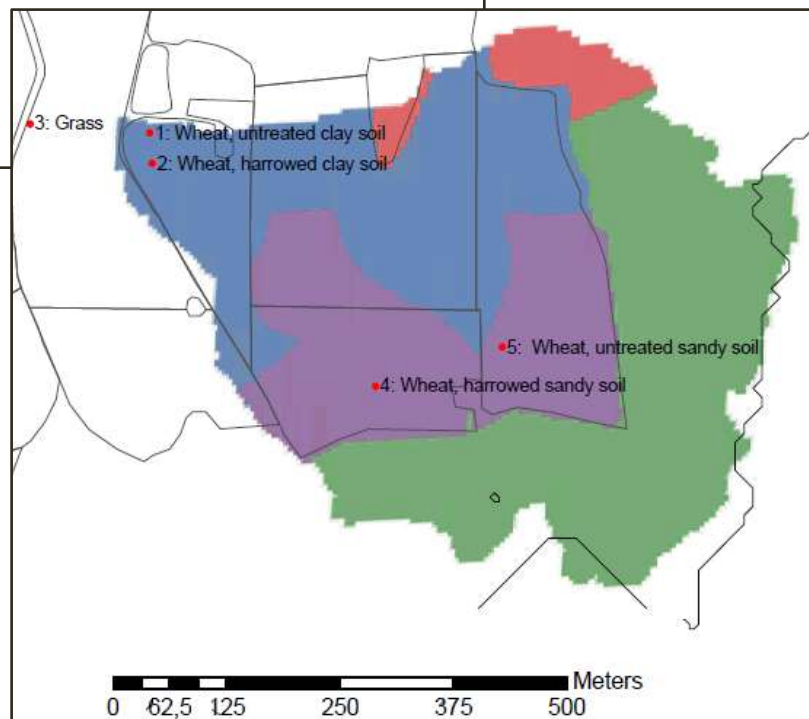


FIGURE 15: PLOT LOCATIONS WITHIN GRYTELAND SUB-CATCHMENT PRESENTED ON A LAND USE MAP IN PCRASTER.

Table 1 contains the Manning's n values, representing the average values of measured Manning's n values. Field data and calculations for Manning's n are listed in appendix 2.

TABLE 1: AVERAGE MANNING'S N VALUES AND STANDARD DEVIATION PER LAND UNIT.

Land unit	Average Manning's n (-/-)	Standard deviation
Wheat stubble on clay loam, zero tillage (plot 1)	0,17	0,049
Wheat stubble on clay loam, tilled soil (plot 2)	0,20	0,034
Grass (plot 3)	0,42	0,033
Wheat stubble on sandy silt, tilled soil (plot 4)	0,06	0,007
Wheat stubble on sandy silt, zero tillage (plot 5)	0,18	0,032

There were a few surprising values that emerged from the analysis. A Manning's n value for wheat stubble on tilled sandy silt soil of 0.06 represents a quite low value and can be explained by the influence of soil tillage direction, which was parallel to the prevailing slope direction. Water converged into two small channels (drill lines) shaped by the machine used for harrowing the soil and due to the slope, water flowed down easily through these two small channels resulting in a high runoff discharge and thus a low soil resistance. In contrast, the high Manning's n value of 0.42 for grass can be explained by the high crop density, which increases surface resistance (Table 2).

A boxplot of Manning's n values for each plot is shown in Fig. 16 highlighting the deviation of measurements and the comparative differences. Calculations for the boxplots are given in appendix 3. Plots 1, 2 and 5 do not differ significantly, according to T-test analyses (Appendix 4). However, plots 3 and 4 do differ significantly from the other plots.

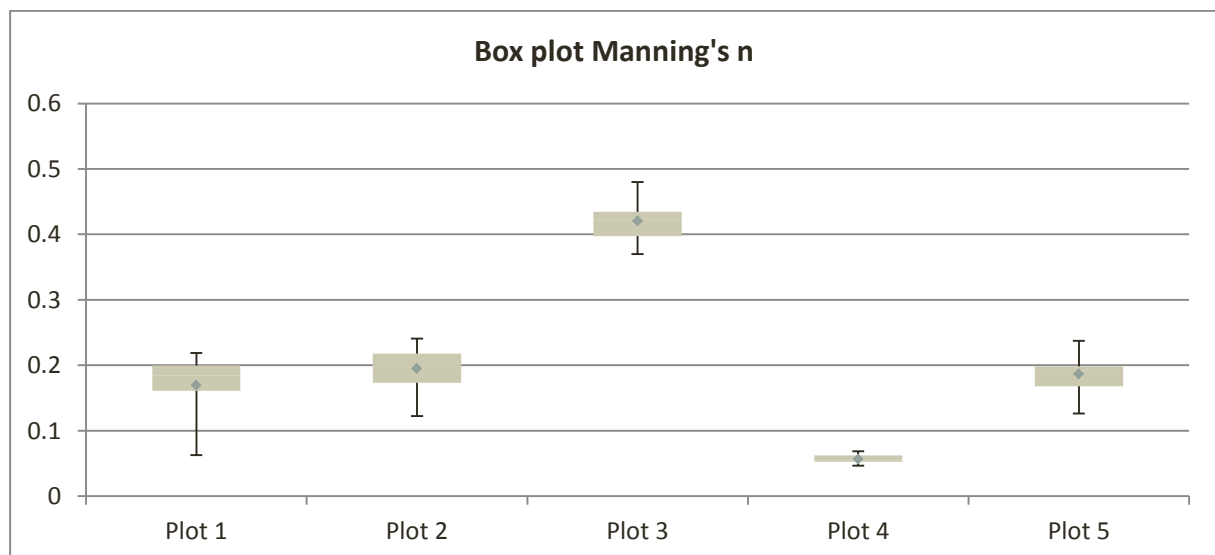


FIGURE 16: BOXPLOT OF MANNING'S N VALUES OF FIVE PLOTS SHOWING THE DEVIATIONS AND THE MUTUAL DIFFERENCES.

## 4.2 MANNING'S N EFFECT IN LISEM MODELLING

### 4.2.1 MAPPING MANNING'S N VALUES

The original input values for Manning's  $n$  were 0.25 for arable land and 1.2 for forest (Fig. 17), which was then adjusted to the new values (Fig. 18). This led to a diversification of the map, according to Manning's  $n$  values in the post-harvest conditions of 2014; a tilled soil excluding the waterways in the field.

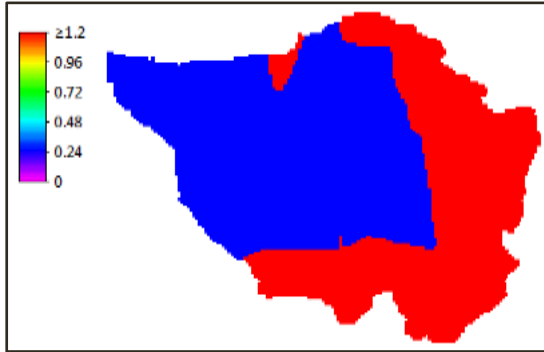


FIGURE 17: ORIGINAL MANNING'S N-MAP: ARABLE LAND 0.25, FOREST 1.2.

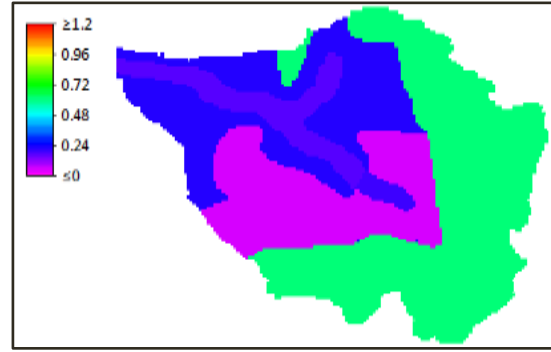


FIGURE 18: ADJUSTED MANNING'S N MAP BASED ON FIELD MEASUREMENTS.

### 4.2.2 MODEL CALIBRATION

Fig. 19 shows the hydrographs of the calibrated model runs for the rainfall event of 13 August 2010; the results of the runs with the original Manning's  $n$  map, the new Manning's  $n$  map and the measured runoff discharge in the catchment outlet. Multiplication of  $K_{sat}$  by 5.5 within the SWATRE infiltration model for clay loam soil resulted in the best fit of the hydrograph of the adjusted Manning's  $n$ -map (Fig. 19). Sandy silt soil was not adjusted as the infiltration rate was assumed to be much higher than clay loam, and thus runoff was not likely to appear (Kværno and Stolte, 2012).

Results of the model run containing the adjusted Manning's  $n$  values show increased peak discharge at 210 and 250 to 270 minutes. The peak at 300 minutes shows minor differences and a steeper decrease of discharge peaks was calculated.

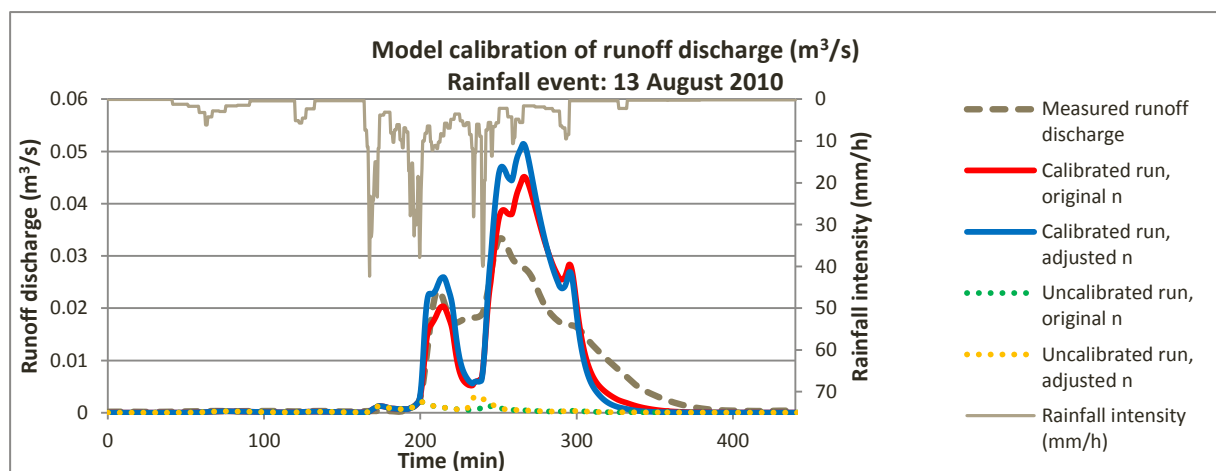


FIGURE 19: HYDROGRAPH OF THE MEASURED RUNOFF DISCHARGE, UNCALIBRATED AND CALIBRATED MODEL RUNS INCLUDING THE ORIGINAL MANNING'S N-MAP AND THE ADJUSTED MANNING'S N-MAP. THE CALIBRATED RUNS HAVE EQUAL MULTIPLICATIONS OF  $K_{SAT}$  (5.5).

#### 4.2.3 MANNING'S N EFFECT ON OTHER RAINFALL EVENTS

The effect of Manning's n was assessed for two other rainfall events with varying intensities. These events occurred on 29 August 2011 (Fig. 20) and 19 August 2008 (Fig. 21).

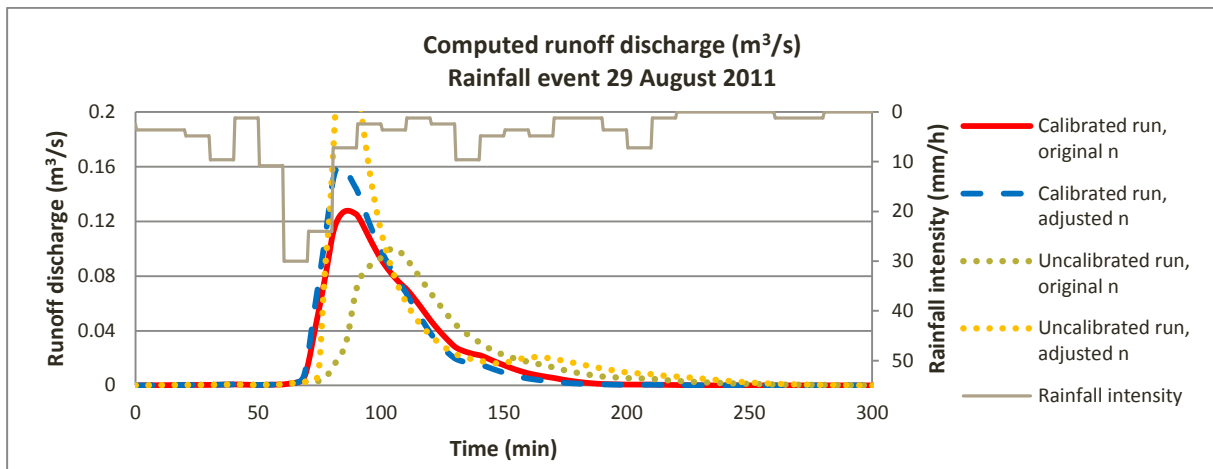


FIGURE 20: MODELLING RESULTS FOR RAINFALL EVENT OF 29 AUGUST 2011 SHOWING A HIGHER RUNOFF INTENSITY PEAK FOR THE RUN WITH ADJUSTED MANNING'S N VALUES.

The results indicate an increased discharge peak ( $0.16\text{m}^3/\text{s}$  versus  $0.13\text{m}^3/\text{s}$ ) and a steeper decline of discharge for the run containing new Manning's n values, indicating the reduced soil resistance on runoff caused by lower Manning's n values for higher rainfall intensities (Figs. 20 and 21).

Rainfall on 19 August 2008 is the most intense event reported in this study. Fig. 21 as in Fig. 20, shows an increased peak discharge at 230 minutes in its hydrograph ( $0.45\text{m}^3/\text{s}$  versus  $0.5\text{m}^3/\text{s}$ ). Again, the adjusted Manning's n resulted in a reduced soil resistance on runoff during high intensity rainfall events.

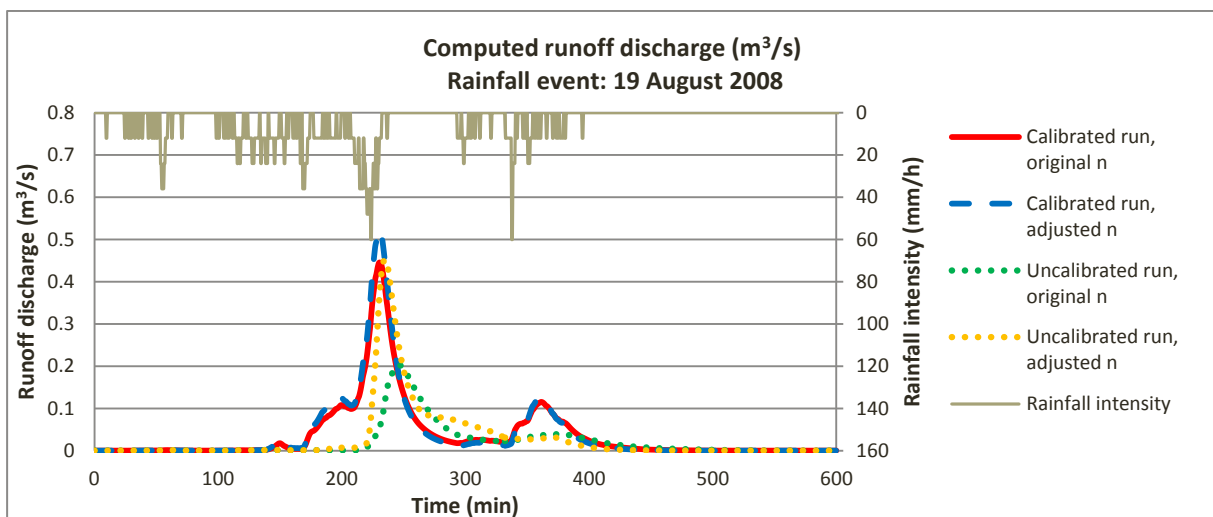


FIGURE 21: MODELLING RESULTS OF RAINFALL EVENT OF 19 AUGUST 2008 SHOWING MINOR DIFFERENCES OF THE RUNS.

The measurements resulted in lower Manning's n values, resulting in higher discharge peaks and steeper declines in discharge for all rainfall events.

## 4.3 TILLAGE ASSESSMENT

### 4.3.1 SCENARIO 1: TILLED SOIL

This scenario includes the cultivation of the entire arable land, which is the tillage type expected to have the highest erosion rates since the top layer of the soil is loosened resulting in easier detachment and transport of soil particles. However, Manning's  $n$  for tilled soil has the lowest value while random roughness does have the highest value for this tillage type, which implies that runoff is obstructed in its path resulting in a decrease in runoff. Due to the soil cultivation, a higher capacity to retain water in small depressions is created and the enlarged surface area to absorb water into the soil. This scenario was compared with hydrographs of the 2014 post-harvest conditions showing no differences in Fig. 22, indicating that differences in random roughness and Manning's  $n$  do not result in changing hydrographs during the rainfall event of 2008. Fig. 23 shows a reduced runoff peak at 200 minutes and 250 minutes representing the obstructing effect of a higher random roughness. This effect disappeared during the runoff peaks at 260 minutes and 290 minutes where runoff rates become similar, water retention caused by a higher random roughness has apparently ended.

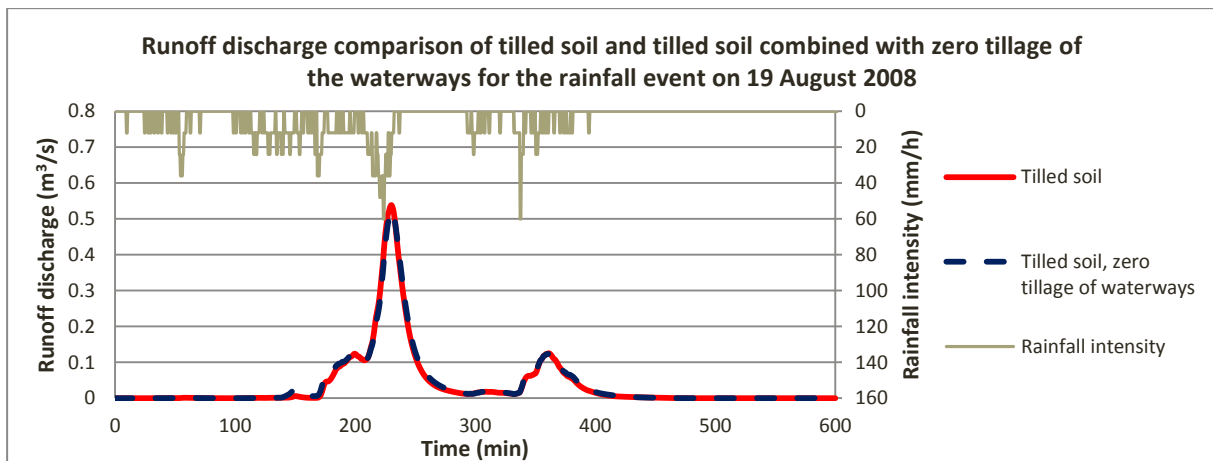


FIGURE 22: HYDROGRAPH COMPARISON OF TILLED SOIL VERSUS TILLED SOIL COMBINED WITH ZERO TILLAGE OF THE WATERWAYS FOR THE RAINFALL EVENT OF 19 AUGUST 2008.

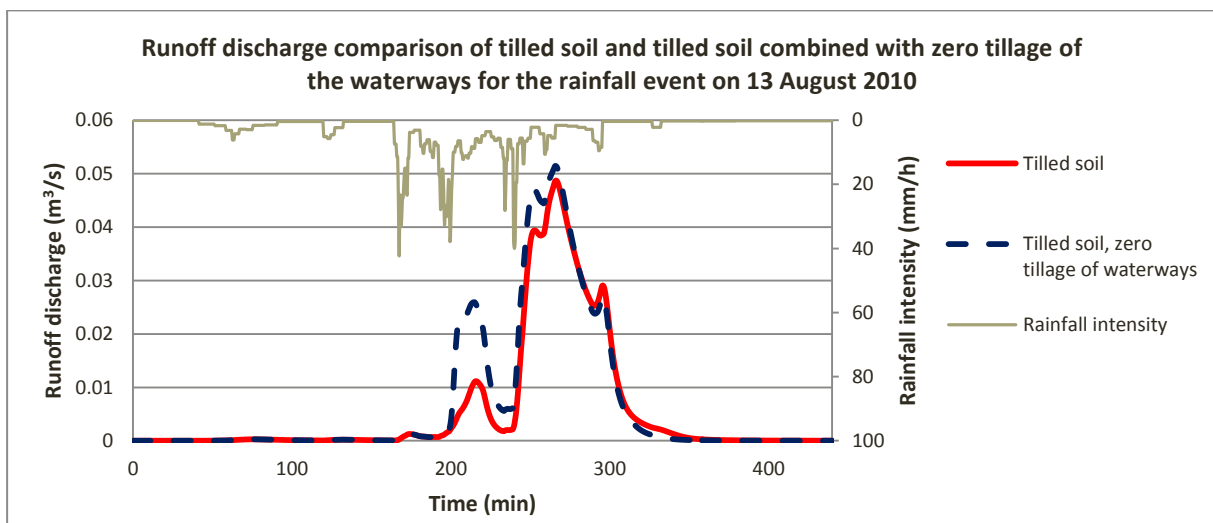


FIGURE 23: HYDROGRAPH COMPARISON OF THE TILLED SOIL VERSUS TILLED SOIL COMBINED WITH ZERO TILLAGE OF THE WATERWAYS FOR THE RAINFALL EVENT OF 13 AUGUST 2010.

Table 2 shows the results of the two model runs in more detail; tilled soil and tilled soil combined with zero tillage of the waterways. At low rainfall intensity, the difference in soil loss is 0.4 kg/ha to the advantage of tilled soil, relatively this is a difference of 6.3%. For the higher intensity rainfall event soil loss decreases by 26.9 kg/ha which is 7.5% compared to soil loss for tilled soil. The total runoff showed differences in favour of tilled soil; 4.0% for the event of 19 August 2008 and 16.8% for the low intensity rainfall event of 13 August 2010, confirming the hydrographs.

TABLE 2: COMPARISON OF SOIL LOSS AND TOTAL RUNOFF FOR THE TILLED SOIL AND TILLED SOIL COMBINED WITH ZERO TILLAGE OF THE WATERWAYS.

	Soil loss (kg/ha)		Total runoff (m3)	
	19 Aug 2008	13 Aug 2010	19 Aug 2008	13 Aug 2010
Tilled soil	331.3	6.3	1356.5	149.1
Tilled soil, zero tillage of the waterways	358.2	6.7	1412.8	179.1

#### 4.3.2 SCENARIO 2: ZERO TILLAGE

Zero tillage reduces detachment of soil particles; however, its lower random roughness results in higher runoff quantities. This scenario was put together with the scenario of tilled soil. Results at higher rainfall intensity show a minor difference in the peak of the runoff discharge, Fig. 24. Tilled soil reaches a runoff peak at 230 minutes of 0.54m<sup>3</sup>/s, while in the case of zero tillage, the peak reaches a runoff of 0.56m<sup>3</sup>/s. The shape of the peaks are similar.

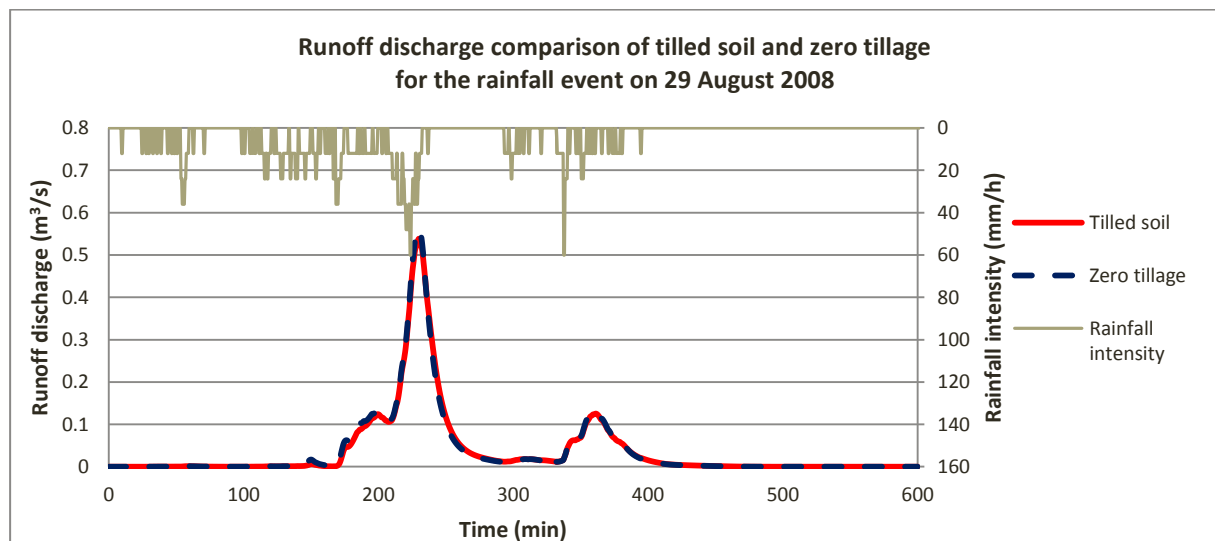


FIGURE 24: HYDROGRAPH COMPARISON OF TILLED SOIL VERSUS ZERO TILLAGE FOR THE RAINFALL EVENT ON 29 AUGUST 2008.

Fig. 25 displays a higher runoff in the first peak at 230 minutes for zero tillage of 0.022m<sup>3</sup>/s compared with 0.011m<sup>3</sup>/s for tilled soil. This effect appears in the following peaks at 260 minutes and 270 minutes. In the last peak at 290 minutes the runoff discharge is similar for both circumstances. Thus, differences in runoff discharge of the tillage types are visible in the beginning of the low intensity rainfall event, in the end, this difference in runoff discharge disappears, meaning that the runoff reducing effect of tilled soil has diminished.

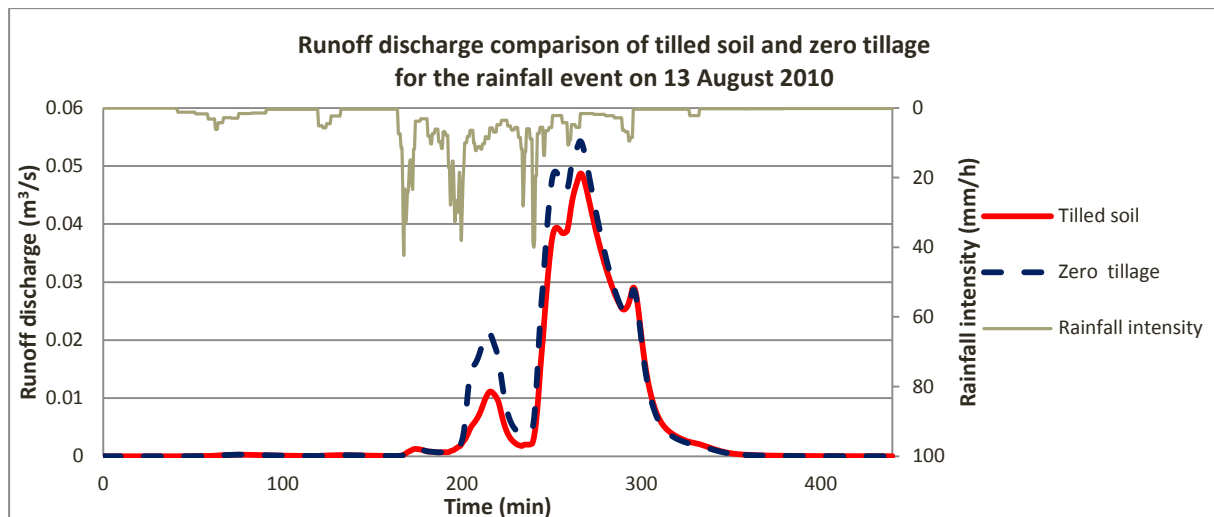


FIGURE 25: HYDROGRAPH COMPARISON OF TILLED SOIL AND ZERO TILLAGE FOR THE RAINFALL EVENT ON 13 AUGUST 2010.

Table 3 shows the modelling results of tilled soil and zero tillage. The rainfall event of 29 August 2008, revealed a difference in soil loss of 419.1 to 331.3 kg/ha (21.0%) in favour of tilled soil. For the low intensity rainfall event of 13 August 2010, soil loss of tilled soil was 8.7% less than zero tilled soil. This trend also applies to total runoff; an increase of 19.4% for the low intensity rainfall event and an increase of 2.2% for the high intensity rainfall event for zero tillage. These outcomes show the distorted view caused by a hydrograph since a corresponding shape (Fig. 24) does not result in similar soil losses.

TABLE 3: COMPARISON OF SOIL LOSS AND TOTAL RUNOFF FOR TILLED SOIL VERSUS ZERO TILLAGE.

	Soil loss (kg/ha)		Total runoff (m <sup>3</sup> )	
	29 Aug 2008	13 Aug 2010	29 Aug 2008	13 Aug 2010
Tilled soil	331.3	6.3	1356.5	149.1
Zero tillage	419.1	6.9	1386.8	178.0

#### 4.3.3 SCENARIO 3: TILLED SOIL WITH GRASS STRIPS IN WATERWAYS

Implementation of grass strips on arable land is a soil conservation measure. By applying grass strips at locations where runoff converges, this measure has been a highly successful erosion reduction solution (Hessel and Tenge, 2008). According to Hessel and Tenge (2008), a soil loss reduction of 21% has been reached due to the presence of grass strips on terraces. In this scenario, grass strips in waterways on a tilled field were investigated. High vegetation density obstructs runoff, resulting in slowing down flow velocity and a greater infiltration time, resulting in a reduction of soil loss and runoff discharge.

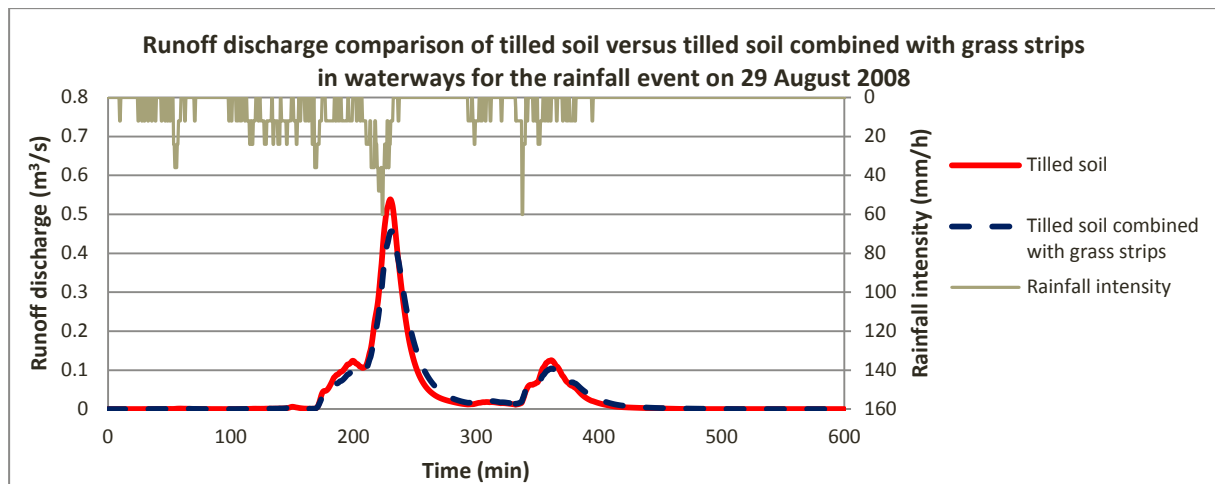


FIGURE 26: HYDROGRAPH COMPARISON OF TILLED SOIL VERSUS TILLED SOIL COMBINED WITH GRASS STRIPS IN THE WATERWAYS FOR THE RAINFALL EVENT ON 29 AUGUST 2008.

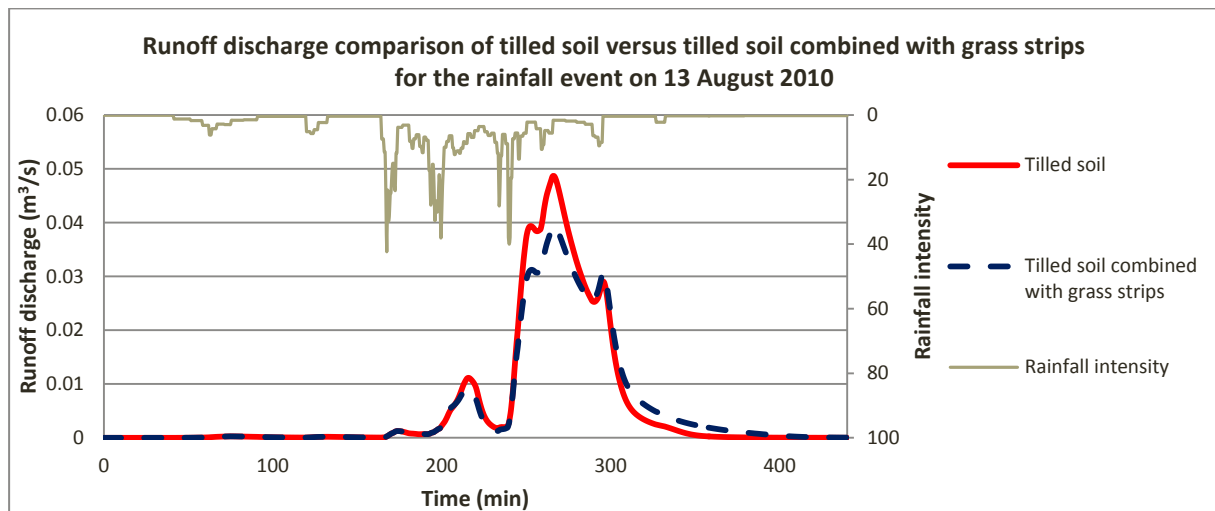


FIGURE 27: HYDROGRAPH COMPARISON OF TILLED SOIL VERSUS TILLED SOIL COMBINED WITH GRASS STRIPS IN THE WATERWAYS FOR THE RAINFALL EVENT ON 13 AUGUST 2010.

For both the 2008 and 2010 rainfall events, lower peaks in runoff discharge were evident (Figs. 26 and 27) for tilled soil combined with grass strips. During the high intensity rainfall event, Fig. 26, peak discharge is lower at 230 minutes. The peak reaches a discharge  $0.47\text{m}^3/\text{s}$  while this is  $0.54\text{m}^3/\text{s}$  for an entirely tilled soil. During the rainfall event of 13 August 2010 (Fig. 27), the scenario of tilled soil combined with grass strips has a lower discharge peak continuously, except the last peak at 290 minutes, which reaches the same runoff discharge as the scenario of a tilled soil. Both hydrographs show a more smooth decrease of the runoff discharge which will lead to a lower peak flow for the entire catchment.

TABLE 4: RESULTS OF MODEL RUNS SHOWING PREDICTED SOIL LOSS (KG/HA) AND TOTAL RUNOFF ( $\text{M}^3$ ) FOR TILLED SOIL AND TILLED SOIL COMBINED WITH GRASS STRIPS IN WATERWAYS

	Soil loss (kg/ha)		Total runoff ( $\text{m}^3$ )	
	29 Aug 2008	13 Aug 2010	29 Aug 2008	13 Aug 2010
Tilled soil	331.3	6.3	1356.5	149.1
Tilled soil with grass strips	159.7	7.11	1334.3	143.0

The results in table 4 do not fully correspond with the hydrographs. For the low intensity rainfall event, soil loss for tilled soil with grass strips is larger than for tilled soil: 7.1 kg/ha versus 6.3 kg/ha for tilled soil, meaning that more soil loss is calculated for tilled soil combined with grass strips. However, soil loss under the high intensity rainfall event of 29 August 2008 was reduced from 331.3 kg/ha to 159.7 kg/ha in the advantage of tilled soil combined with grass strips. Runoff reduction is low for both events to the advantage of tilled soil with grass strips 1.7% and 4.3%, meaning that runoff reduction by grass strips is limited.

#### 4.3.4 SCENARIO 4: UNTILLED SOIL WITH GRASS STRIPS IN WATERWAYS

This scenario assesses soil loss and runoff discharge in the situation of untilled soil with grass strips in the waterways. This scenario is expected to be most protective against soil loss, since the soil cover density is highest and the top soil is not loosened, resulting in less detachment and transportation of soil particles.

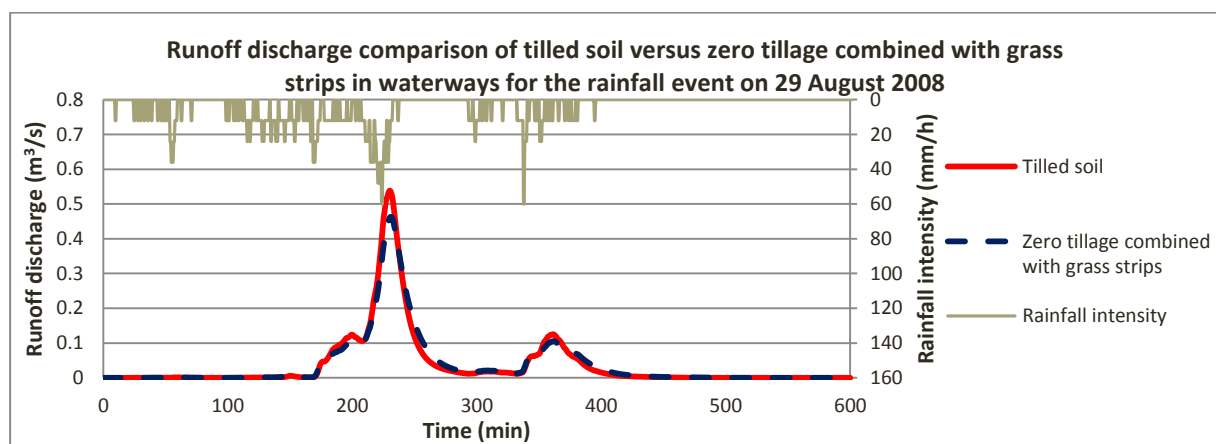


FIGURE 28: HYDROGRAPH COMPARISON OF TILLED SOIL VERSUS ZERO TILLAGE COMBINED WITH GRASS STRIPS IN THE WATERWAYS FOR THE RAINFALL EVENT OF 29 AUGUST 2008.

The hydrographs of Fig. 28 show a variance in the peak at 230 minutes between both scenarios. A reduction of 0.1m³/s in this peak, relatively 20%-25%, being beneficial for zero tillage combined with grass strips. A more smooth decrease of runoff discharge for zero tillage with grass strips is calculated as well. Small differences were calculated during the peak at 200 minutes and 360 minutes.

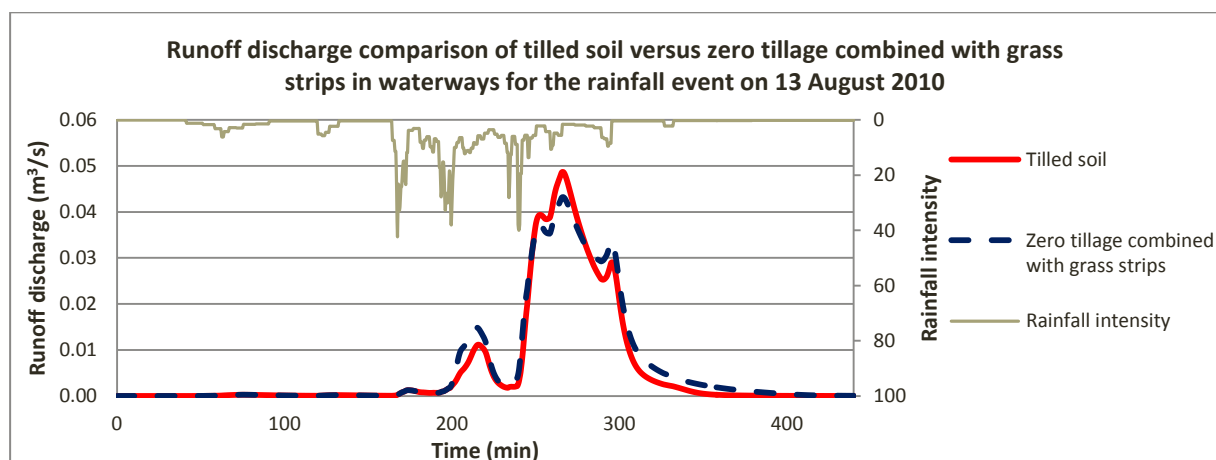


FIGURE 29: HYDROGRAPH COMPARISON OF TILLED SOIL VERSUS ZERO TILLAGE COMBINED WITH GRASS STRIPS IN THE WATERWAYS FOR THE RAINFALL EVENT OF 13 AUGUST 2010.

During the first peak of the low intensity rainfall event of 13 August 2010 (Fig. 29), runoff discharge is higher for zero tillage with grass strips compared to tilled soil. This is in contrast to the first peak in Fig. 27 where tilled soil combined with grass strips has been assessed, having a lower discharge peak compared to tilled soil. The conclusion is that in this scenario, zero tillage combined with grass strips, runoff is less obstructed due to a lower random roughness and lower Manning's n values which makes this scenario more susceptible for runoff.

The second and third peak, the greatest peak at 270 minutes, shows a difference in runoff discharge of about  $0.007\text{m}^3/\text{s}$  which is a difference of  $\sim 15\%$ . This development can be explained by the diminished effect of Manning's n and random roughness for tilled soil, while Manning's n still has influence for the scenario zero tillage combined with grass strips. The last peak reaches a runoff discharge of  $0.033\text{m}^3/\text{s}$  for zero tillage combined with grass strips and  $0.029\text{m}^3/\text{s}$  for tilled soil, implying that Manning's n and random roughness affect runoff on tilled soil again. However, a more smooth decrease of the last peak is present for zero tillage combined with grass strips showing the obstructing effect of grass. Overall, the lower peak at 270 minutes and the smooth decrease of runoff discharge would be benefiting for the soil loss reduction in this scenario.

Table 5 shows a difference of  $17.1\text{ m}^3$  (11.3%) in total runoff during the rainfall event of 13 August 2010 and similar runoff quantities for the event of 19 August 2008. However, for soil loss, the scenario of zero tillage with grass strips is benefiting by 47.9% during the high intensity rainfall event of 19 August 2008. In the case of the low intensity rainfall event, soil loss is less for tilled soil, 20.6%. This result demonstrates the relatively larger erosion reducing effect with increasing rainfall intensities and quantities by introducing grass strips.

TABLE 5: RESULTS OF MODEL RUNS SHOWING THE SOIL LOSS (KG/HA) AND TOTAL RUNOFF ( $\text{M}^3$ ) FOR TILLED SOIL VERSUS ZERO TILLAGE COMBINED WITH GRASS STRIPS IN WATERWAYS.

	Soil loss (kg/ha)		Total runoff (m3)	
	19 Aug 2008	13 Aug 2010	19 Aug 2008	13 Aug 2010
Tilled soil	331.3	6.3	1356.5	149.1
Zero tillage with grass strips	172.6	7.6	1355.1	166.0

## 5. DISCUSSION

### 5.1 MANNING'S N EFFECT IN LISEM MODELLING

This part of the study was built on answering the first research question: *How do computed LISEM outputs for the Gryteland sub-catchment change when using onsite measured Manning's n values in comparison with using Manning's n values derived from literature?*

Regarding onsite measurements, plot 1, 2 and 5 (0.17, 0.20 and 0.18) did have small differences in values compared to the original Manning's n value (0.25) which indicates that runoff discharge may not differ greatly to model runs containing original Manning's n values. A deviating value was found for tilled sandy silt soil (0.06) which can be explained by a cultivation direction parallel to slope direction leading to more runoff. Model runs have been done for three rainfall events, differing in intensity and duration.

When comparing the measured Manning's n values with Manning's n values from literature, Fig. 30 (Cive 445, 2015), measured values are generally within the range of literature values. Tilled soil, resulting in 0.06 and 0.20, appears to be a wide range, which is plausible, depending on residue cover. In this case, 0.06 seems to be more probable than 0.20, which was unexpected. Wheat stubble on untilled soil is not represented within the table, but measured values of 0.17 and 0.18 match range grass or short prairie grass of 0.15 and is an acceptable value. Measured Manning's n for grass (0.42), which could be described as dense grass, does have the largest deviation. Fig. 30 represents a value of 0.24, which is a much lower value. However, it matches with the Manning's n value of Bermuda grass (0.43). A clear explanation cannot be given; the description of grass differs could be a probable cause.

Surface Description	Manning $n$
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.05
Cultivated ground (residue cover less than or equal to 20%)	0.06
(residue cover greater than 20%)	0.17
Grass	
Range, short prairie	0.15
Dense	0.24
Bermuda	0.43
Range	0.13
Woods	
Light underbrush	0.40
Dense underbrush	0.80

*Note:* Dense grass includes weeping lovegrass, bluegrass, buffalo grass, blue gamma grass, native grass mixture, alfalfa, and the like.

FIGURE 30: LIST OF MANNING'S N VALUES FROM THE LITERATURE.

Hessel et al. (2003) studied the role of slope on Manning's n and relationship between Manning's n and Reynolds number, measuring Manning's n in the same way as was done in this research. Though the study of Hessel et al. (2003) did have another purpose, field results can be

compared. Manning's  $n$  appeared to become larger, when slope increased, as shown in Fig. 31. This finding will also apply to this research, however, this slope-angle-dependency is not taken into account, Manning's  $n$  is considered constant, independent of slope. Further, in the study of Hessel et al. (2003), measured values are also generally lower than measured values in this study. However, land units do not fully correspond, cropland and fallow land (land uses which can be compared), had average values of 0.104 and 0.076, indicating the lower values.

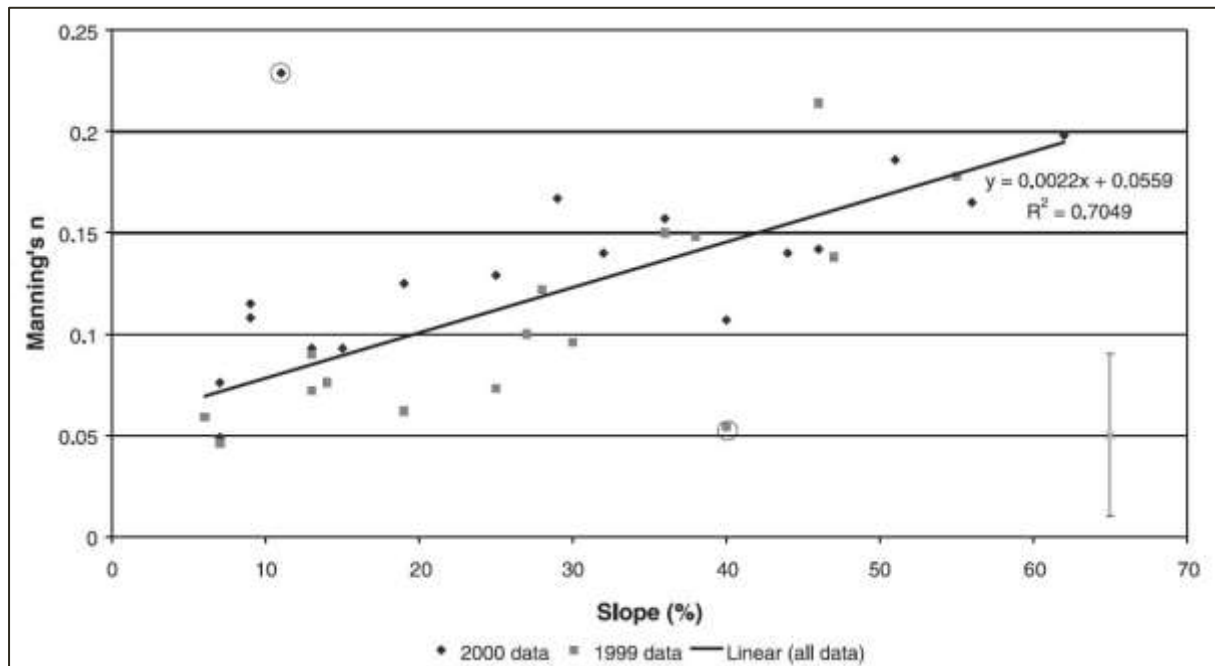


FIGURE 31: RELATIONSHIP MANNING'S  $n$  AND SLOPE ANGLE (HESSEL ET AL., 2003).

Overall results of the hydrographs show that the new Manning's  $n$  values give higher runoff quantities in the first runoff peaks, while this effect diminished in the last parts of the runoff flow. Further, steeper declines in discharge peaks were computed for runoff based on the new Manning's  $n$  input. The derivations in the first peaks can be explained by the lower Manning's  $n$  values, resulting in higher runoff discharge. Minor differences in the last parts of the runoff flows is apparently the result of a diminishing effect of Manning's  $n$  due to the duration and increasing total runoff quantity. No runoff originates on the sandy silt soil due to high infiltration rates and unsaturated soil as in the study of Kværno and Stolte (2012). This means that the low  $n$ -value, 0.06 for tilled sandy silt soil, did not have a runoff-increasing effect since a high infiltration rate for this soil did not generate runoff during this event.

This study complies with the sensitive character of Manning's  $n$  on runoff rates; large differences in runoff quantities, while differences in Manning's  $n$  values were small (De Roo et al., 1994). This became clear during the calibration of the model, since differences in runoff discharge were observed, while differences in Manning's  $n$  on clay loam soil were not significantly different from the original value.

As mentioned before, a threshold consists in soil resistance to runoff during the rainfall events; the effect of soil resistance disappears when duration increases; differences in hydrographs, caused by different Manning's  $n$  values, become smaller and even similar when a rainfall event persists. This is caused by prior runoff, which changes soil surface by creating stream ways for water to run off more easily.

A clear threshold value cannot be given according to the model results of these three rainfall events; this threshold depends on a single event differing in intensity and duration. Post-harvest field conditions of 2014 in the Gryteland sub-catchment proved to generate more runoff for all rainfall events. As a result, the application of zero tillage in the waterways is not beneficial regarding runoff.

Scale effects do affect results in LISEM modelling. In the study of Hessel (2005) it turned out that grids cell size and time step length do have an impact on results in the LISEM model. An increase in cell size and an increase in time step length resulted in a decrease in predicted discharge and soil loss. Further, the measurements are based on point runoff, multiplying this runoff with the length of the slope or area of the catchment does not apply in practice (Van de Giesen et al, 2005; Williams and Bonell, 1988; Joel et al., 2002). Point runoff quantities are relatively greater than runoff from a slope or catchment. Besides, spatial variability is another cause of scale effects. Running the model for the entire Skuterud catchment of 8450 ha would result in absolute and relative differences in runoff for the same rainfall events compared to the outcomes for the Gryteland sub-catchment. As expected, runoff amounts leaving the Skuterud catchment will be relatively lower, since runoff on longer slopes or entire fields has more opportunity and time to infiltrate than runoff on short slopes (Van de Giesen et al, 2005). This effect on runoff can be linked to Manning's  $n$ ; a longer distance for runoff to cover will increase soil surface resistance, causing a reduction of runoff. The point measurements of Manning's  $n$  with plot lengths of 1.5m to 3m are doubtful, longer plots are recommended for more representative Manning's  $n$  values. Another effect of upscaling from plot level to catchment level would be the appearance of more smooth increases and decreases of runoff discharge in combination with relatively lower runoff discharge intensity peaks, since duration of runoff flow will enlarge, runoff has to cover longer distances before reaching the catchment outlet.

## 5.2 TILLAGE EFFECTS ON SOIL LOSS AND TOTAL RUNOFF

According to the field measurements, an assessment of tillage types was carried out to answer the next research question: *Which tillage practices are most effective in erosion reduction for the Gryteland sub-catchment?*

Assumed was that a tillage type was represented by changing two LISEM parameters; Manning's  $n$  and random roughness. Conventional tillage and soil conservation tillage were applied and compared based on computed total runoff and soil loss. Tillage also affects other LISEM parameters which subsequently affect simulated runoff and soil loss, meaning that results from this study are limited. Table 6 shows relative differences in soil loss and total runoff in relation to conventional tilled soil (chisel plow) as referring field conditions, based on two rainfall events on 13 August 2010 and 19 August 2008. Soil loss values are simulated by LISEM, this simulation was not calibrated, meaning that results can be compared, but absolute values are doubtful. Tilled soil is beneficial regarding soil loss during the rainfall event on 19 August 2010. On the other hand, this advantage disappeared during the higher intensity event on 13 August 2008, where scenarios tilled soil with grass strips and zero tillage with grass strips showed significant reduction (48%) of simulated soil loss relative to the reference scenario with only tilled soil.

TABLE 6: SOIL LOSS AND TOTAL DISCHARGE OF TILLAGE SCENARIOS COMPARED TO TILLED SOIL IN PERCENTAGES.

	Soil loss benefits (%)		Total discharge benefits (%)	
	29 Aug 08	13 Aug 10	29 Aug 08	13 Aug 10
Tilled soil combined with zero tillage in waterways	-8.1	-6.3	-4.2	-20.1
Zero tillage	-26.5	-9.5	-2.2	-19.4
Tilled soil combined with grass strips	48.2	-12.9	1.6	4.1
Zero tillage combined with grass strips	47.9	-20.6	0.1	-11.3

X > 10%	(reduction relative to tilled soil)
0% < X < 10%	(reduction relative to tilled soil)
0% > X > -10%	(increase relative to tilled soil)
X < -10%	(increase relative to tilled soil)

A shift in best tillage practices occurred depending on rainfall intensities and duration. This means that a threshold consists where grass strips get a soil loss reducing effect. Tilled soil is advantageous during low intensity events, but disadvantageous during high intensity rainfall events. The effect on soil losses cannot be directly related to the total runoff.

This result was not expected. The erosion-reducing effect of tilled soil during a low intensity rainfall event was unexpected and still questionable. This effect is explainable by a higher soil roughness, leading to more water retention and so less runoff and erosion. However, a loosened soil will erode more easily, meaning that other parameters have an important influence on detachment and transportation. Aggregate stability and cohesion are the most important missing parameters in this study. Adjusting these parameters to more realistic values would probably result in different soil loss and runoff quantities.

The computed disadvantageous effect of grass strips on soil losses during a low intensity event is not plausible. More soil resistance will reduce runoff quantities and so soil losses are less likely to occur during low intensity rainfall events. Probably, a low random roughness does have more influence than Manning's n during the model runs. In reality, grass strips will even have a runoff and soil loss reducing effect even during low intensity events.

### 5.3 RECOMMENDATIONS

The results of the tillage assessment do not give a clear answer on the question which tillage type will mitigate erosion. Adapting to the predicted climate change is necessary to pursue agriculture in a sustainable way; the introduction of grass strips appears to be a good opportunity to reduce soil loss regarding the occurrence of more intense rainfall events in future. Soil conservation measures appeared to be disadvantageous during low intensity rainfall events, which do occur more often. A consideration has to be made by the farmers: adaptation to unpredictable, uncommon, high intensity rainfall events in future or keep focus on soil losses caused by common, low intensity, rainfall events. Since the introduction of grass strips in waterways is highly advantageous in absolute and relative soil loss numbers during high intensity rainfall events, applying these measures is recommended. Differences in soil loss

during low intensity rainfall events are small, having minor effect on soil loss and so less advantageous.

#### 5.4 RESEARCH LIMITATIONS AND FUTURE RESEARCH

There were a number of limitations that emerged during the conduct of this investigation, resulting in new opportunities for future research.

- Limited measuring plots and number of measurements

The number of measuring plots was limited. For each land unit, only one plot has been prepared to carry out the measurements. An assessment of the outcomes of the first measurement round is recommended.

- Erosion dynamics within the catchment

Erosion dynamics within the catchment have not been studied, which would give an indication of erosion processes occurring within the catchment (Jetten et al., 2003). This could be of greater importance than modelling soil losses in the outlet of the catchment as done in this study, since erosion at the outlet is only a small part of the total soil erosion within the field. Future ongoing research is investigating catchment erosion, observing spatial erosion patterns. According to Jetten et al. (2003) this would overcome some limitations in erosion modelling.

- Change of other parameters during tillage change

The method of simulating tillage types by changing Manning's  $n$  and random roughness is questionable, more parameters than Manning's  $n$  and random roughness will change according to tillage type. Other LISEM parameters, which will be affected by changing tillage, are aggregate stability, cohesion of bare soil and roots, compaction fraction, crust fraction, fraction of soil cover by canopy, leaf area index and vegetation height. In this study, values of these parameters were not adjusted to tillage type, resulting in a limited representation of real conditions. Important erosion affecting parameters are cohesion and aggregate stability. For example, erodibility increases due to harrowed field conditions resulting in lower aggregate stability and cohesion (Kværno and Øygarden, 2006). This higher susceptibility to erosion is not taken into account in the calculations as all parameters were maintained constant. As a result, soil loss quantities in the model runs would have been higher in the case of chisel plow tilled soil.

- Modelling results only serve as approximation of real runoff and soil loss quantities

Computed numbers of runoff and soil loss only serve as an approximation of reality. There are too many limitations within field measurements and LISEM (in combination with scaling problems) to be able to calculate exact erosion and runoff values.

- Seasonal variation of Manning's  $n$

A possibility to continue with this research is to carry out this research for every season. This research is based on post-harvest conditions, meaning that it does not provide an overall insight of a whole year. It is certain that the melting season also has an effect on erosion, which makes this research more interesting to carry out. Other circumstances, a frozen surface could have another effect on runoff.

## 6. CONCLUSION

This research had three objectives: (i) to obtain onsite-measured Manning's  $n$  values, a parameter indicating the soil surface resistance to overland flow, for identified land units as input for the LISEM soil erosion model; (ii) to compare both the LISEM model outputs of the (estimated) literature-derived Manning's  $n$  values and the onsite-measured values; and (iii) to assess impacts of different tillage types on soil losses and runoff using the LISEM model and the newly measured Manning's  $n$  values.

Measured Manning's  $n$  values of five different land units ranged from 0.06 to 0.42. The highest Manning's  $n$  value was measured on grass cover and was significantly different from the other values caused by a dense soil cover. The lowest value (0.06) was also significantly different from the other values, but was affected by tillage direction along the slope resulting in fast runoff and so a low resistance to flow. Measured values are in agreement with literature values.

The modelling exercise showed that the computed discharge peaks were higher for the model run with new Manning's  $n$  values and the decrease of the discharge peaks was steeper compared to model runs using the original, literature-based values. Besides, Manning's  $n$  appears to be dependent on the function of rainfall intensity and duration, since its effect on runoff discharge disappeared during the rainfall events. This is due to prior runoff, which changes soil surface by creating stream ways for water to run off easily.

During the tillage assessment, tilled soil appeared to be the best solution during the low intensity rainfall event since this tillage type caused lowest soil loss. This result is questionable since other parameters (cohesion and aggregate stability) were not adjusted to real values within the model. During a higher intensity rainfall event in combination with a longer duration, the scenario of tilled soil had the highest soil losses. This time 'tilled soil combined with grass strips in the waterways' and 'zero tillage and grass strips in the waterways' showed great benefits: a reduction of ~50% of soil loss was obtained relative to tilled soil and would even be more when other parameters are adjusted too real conditions. According to this study, grass strips appear to be advantageous regarding soil erosion prevention during high intensity rainfall events and thus grass strips are a sustainable and practical solution for soil loss reduction for future climate change.

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## APPENDICES

Appendix 1	Selection of LISEM input maps
Appendix 2	Field measurement results
Appendix 3	Box plot analysis
Appendix 4	T-test analysis

## Appendix 1      Selection of LISEM input maps

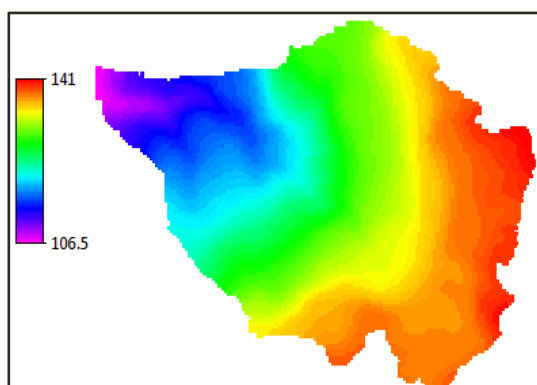


FIGURE 32: DIGITAL ELEVATION MODEL (METERS ABOVE SEA LEVEL).

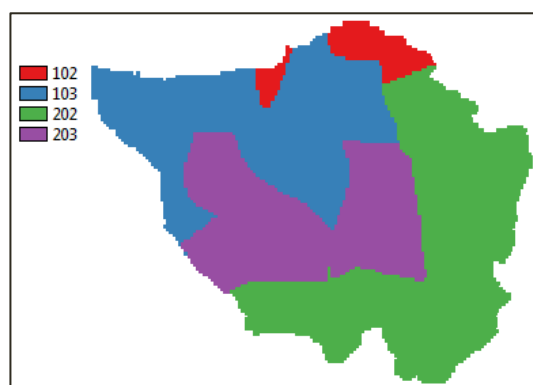


FIGURE 33: SOIL PROFILES, 102: FOREST ON CLAY, 103: CROPLAND ON CLAY, 202: FOREST ON SAND, 203: CROPLAND ON SAND.

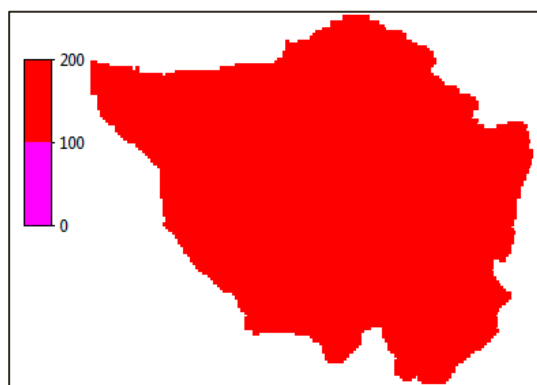


FIGURE 34: AGGREGATE STABILITY (-/-): 200.

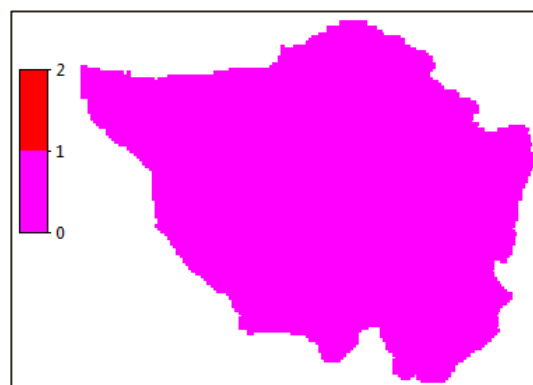


FIGURE 35: STONE FRACTION (-/-): 0.

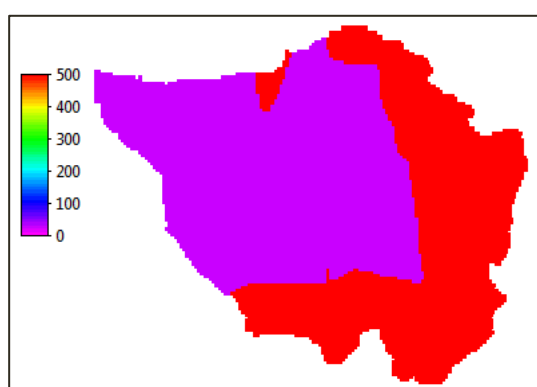


FIGURE 36: COHESION (KPA), ARABLE LAND: 0.25, FOREST: 500.

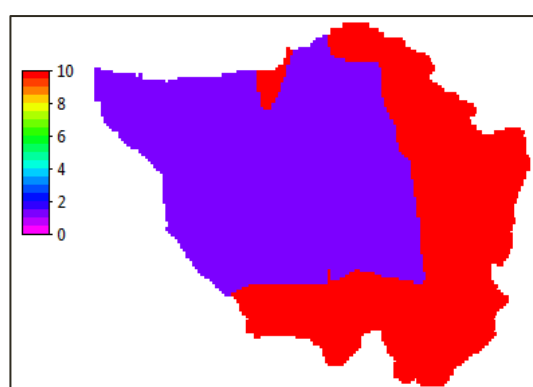


FIGURE 37: COHESION BY ROOTS (KPA), ARABLE LAND: 1, FOREST: 10.

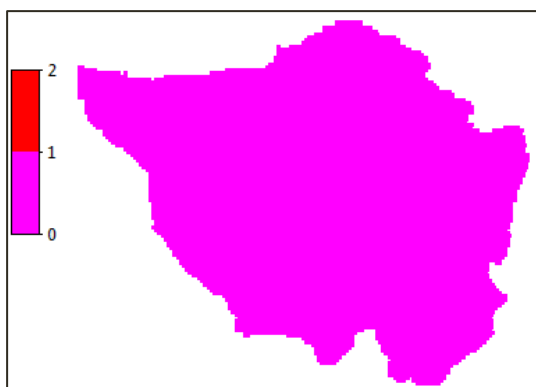


FIGURE 38: CRUST FRACTION (-/-): 0.

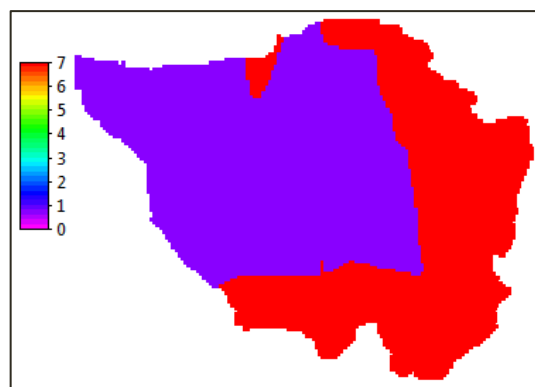


FIGURE 39: VEGETATION HEIGHT (M), ARABLE LAND: 0.7, FOREST: 7.

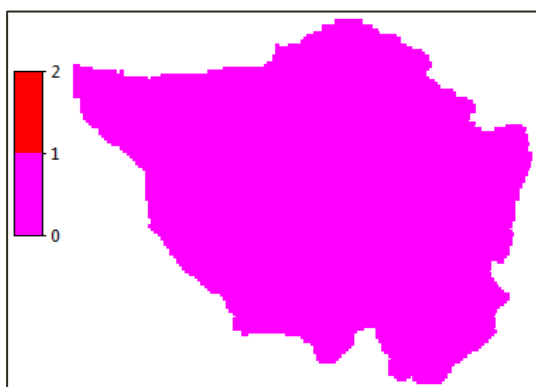


FIGURE 40: COMPACTION FRACTION (-/-): 0.

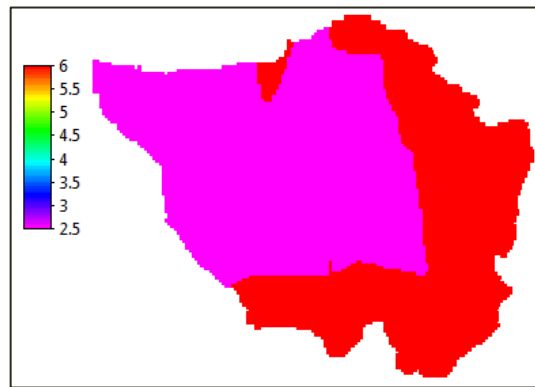


FIGURE 41: LEAF AREA INDEX (-/-), ARABLE LAND: 2.5, FOREST: 6.

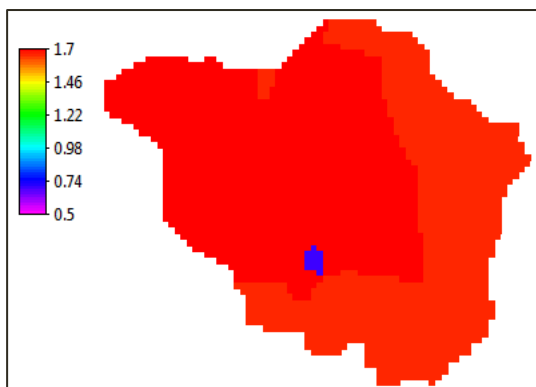


FIGURE 42: SATURATED HYDRAULIC CONDUCTIVITY (MM/H), ARABLE LAND: 1.69, FOREST: 1.66, GARDEN: 0.69.

## Appendix 2      Field measurement results

Plot 1	Zero tillage, loam clay
Length (m)	1.6
Width (m)	45.5
Distance dye inlet-end	1.6
Slope (%)	7
Slope (°)	4
Slope (rad)	0.07
Slope (m/m)	0.07



FIGURE 43:  
REPRESENTATION OF ZERO  
TILLAGE ON CLAY LOAM  
SOIL.

### Measurement 1

[illegible]

Measurement 2

Minute	Time (begin-end) (s)	Velocity (m/s)	Slope (m/m)	Discharge (l/min)	Discharge (m³/s)	Average flow width (m)	Water height (m)	Hydraulic radius R	Manning's n
1 (0 s)			0.07	0.7	0.00001	0.30			
2 (60 s)	54	0.030	0.07	2.1	0.00004	0.30	0.004	0.0038	0.219
3 (120 s)			0.07	1.4	0.00002	0.30			
4 (180 s)	52	0.031	0.07	1.4	0.00002	0.30	0.003	0.0025	0.158
5 (240 s)			0.07	1.4	0.00002	0.30			
6 (300 s)	60	0.027	0.07	1.4	0.00002	0.30	0.003	0.0029	0.200
7 (360 s)	50	0.032	0.07	1.4	0.00002	0.30	0.002	0.0024	0.148
8 (420 s)	52	0.031	0.07	1.6	0.00003	0.30	0.003	0.0028	0.172
9 (480 s)			0.07	1.4	0.00002	0.30			
10 (540 s)			0.07	1.2	0.00002	0.30			
									0.179

Measurement 3

Minute	Time (begin-end) (s)	Velocity (m/s)	Slope (m/m)	Discharge (l/min)	Discharge (m³/s)	Average flow width (m)	Water height (m)	Hydraulic radius R	Manning's n
1 (0 s)			0.07	2	0.00003	0.34			
2 (60 s)	55	0.029	0.07	2.1	0.00004	0.34	0.004	0.0035	0.209
3 (120 s)			0.07	2.2	0.00004	0.34			
4 (180 s)	52	0.031	0.07	2	0.00003	0.34	0.003	0.0031	0.185
5 (240 s)			0.07	2	0.00003	0.34			
6 (300 s)	55	0.029	0.07	1.9	0.00003	0.34	0.003	0.0032	0.196
7 (360 s)			0.07	2	0.00003	0.34			
8 (420 s)			0.07	2	0.00003	0.34			
9 (480 s)			0.07	2.1	0.00004	0.34			
10 (540 s)	58	0.028	0.07	1.8	0.00003	0.34	0.003	0.0032	0.207
									0.199

Average Manning's n	0.171
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<b>Plot 2</b>	<b>Tilled loamy clay</b>
Length (m)	1.82
Width (m)	0.425
Distance dye inlet-end	1.82
Slope (%)	5
Slope (°)	2.9
Slope (rad)	0.05
Slope (m/m)	0.05



FIGURE 44:  
REPRESENTATION OF  
TILLED CLAY LOAM SOIL.

### Measurements

#### Measurement 1

Minute	Time (begin-end) (s)	Velocity (m/s)	Slope (m/m)	Discharge (l/min)	Discharge (m <sup>3</sup> /s)	Average flow width (m)	Water height (m)	Hydraulic radius R	Manning's n
1 (0 s)			0.05	2.5	0.00004	0.245			
2 (60 s)	55	0.033	0.05	2.5	0.00004	0.245	0.0051	0.0049	0.197
3 (120 s)			0.05	3.1	0.00005	0.245			
4 (180 s)	50	0.036	0.05	2.2	0.00004	0.245	0.0041	0.0040	0.155
5 (240 s)			0.05	2.9	0.00005	0.245			
6 (300 s)	55	0.033	0.05	2.6	0.00004	0.245	0.0053	0.0051	0.202
7 (360 s)			0.05	2.6	0.00004	0.245			
8 (420 s)	55	0.033	0.05	2.9	0.00005	0.245	0.0060	0.0057	0.217
9 (480 s)			0.05	0	0.00000	0.245			
10 (540 s)			0.05	0	0.00000	0.245			
									0.193

Measurement 2

Minute	Time (begin-end) (s)	Velocity (m/s)	Slope (m/m)	Discharge (l/min)	Discharge (m <sup>3</sup> /s)	Average flow width (m)	Water height (m)	Hydraulic radius R	Manning's n
1 (0 s)			0.05	2	0.00003	0.25			
2 (60 s)	48	0.038	0.05	2.8	0.00005	0.25	0.005	0.0048	0.170
3 (120 s)	52	0.035	0.05	3.4	0.00006	0.25	0.007	0.0063	0.219
4 (180 s)			0.05	2.3	0.00004	0.25			
5 (240 s)	48	0.038	0.05	2.7	0.00005	0.25	0.005	0.0047	0.166
6 (300 s)			0.05	2.8	0.00005	0.25			
7 (360 s)			0.05	2.8	0.00005	0.25			
8 (420 s)	55	0.033	0.05	1.2	0.00002	0.25	0.002	0.0024	0.123
9 (480 s)			0.05	0	0.00000	0.25			
10 (540 s)			0.05	0	0.00000	0.25			
									0.169

Measurement 3

Minute	Time (begin-end) (s)	Velocity (m/s)	Slope (m/m)	Discharge (l/min)	Discharge (m <sup>3</sup> /s)	Average flow width (m)	Water height (m)	Hydraulic radius R	Manning's n
1 (0 s)			0.05	2	0.00003	0.25			
2 (60 s)			0.05	3.8	0.00006	0.25			
3 (120 s)			0.05	2.5	0.00004	0.25			
4 (180 s)	50	0.036	0.05	2.7	0.00005	0.25	0.005	0.0048	0.177
5 (240 s)			0.05	2.5	0.00004	0.25			
6 (300 s)	60	0.030	0.05	2.5	0.00004	0.25	0.006	0.0054	0.227
7 (360 s)			0.05	2.7	0.00005	0.25			
8 (420 s)	55	0.033	0.05	2.5	0.00004	0.25	0.005	0.0049	0.197
9 (480 s)			0.05	0	0.00000	0.25			
10 (540 s)			0.05	0	0.00000	0.25			
									0.200

Measurement 4

Minute	Time (begin-end) (s)	Velocity (m/s)	Slope (m/m)	Discharge (l/min)	Discharge (m³/s)	Average flow width (m)	Water height (m)	Hydraulic radius R	Manning's n
1 (0 s)	0		0.05	2.5	0.00004	0.14			
2 (60 s)	40	0.04550	0.05	2.9	0.00005	0.14	0.008	0.00695	0.180
3 (120 s)	0		0.05	3.2	0.00005	0.14			
4 (180 s)	45	0.04044	0.05	2.9	0.00005	0.14	0.009	0.00772	0.217
5 (240 s)	0		0.05	2.8	0.00005	0.14			
6 (300 s)	48	0.03792	0.05	2.9	0.00005	0.14	0.009	0.00817	0.241
7 (360 s)	50	0.03640	0.05	2.6	0.00004	0.14	0.009	0.00769	0.241
8 (420 s)	0		0.05	1.2	0.00002	0.14			
9 (480 s)	0		0.05	0	0	0.14			
10 (540 s)	0		0.05	0	0	0.14			
									0.220
Average Manning's n									0.196

<b>Plot 3</b>	<b>Grass</b>
Length (m)	2.02
Width (m)	0.38
Distance dye inlet-end	2.02
Slope (%)	6
Slope (°)	3.4
Slope (rad)	0.06
Slope (m/m)	0.06



FIGURE 45:  
REPRESENTATION OF  
GRASSED SURFACE.

*Measurement 1*

Minute	Time (begin-end) (s)	Velocity (m/s)	Slope (m/m)	Discharge (l/min)	Discharge (m³/s)	Average flow width (m)	Water height (m)	Hydraulic radius R	Manning's n
1 (0 s)			0.06	1.5	0.00003	0.25			
2 (60 s)	90	0.022	0.06	2.8	0.00005	0.25	0.008	0.0078	0.427
3 (120 s)			0.06	2.8	0.00005	0.25			
4 (180 s)	90	0.022	0.06	2.3	0.00004	0.25	0.007	0.0065	0.377
5 (240 s)			0.06	2.4	0.00004	0.25			
6 (300 s)	95	0.021	0.06	2.3	0.00004	0.25	0.007	0.0068	0.412
7 (360 s)			0.06	2.7	0.00005	0.25			
8 (420 s)	90	0.022	0.06	2.5	0.00004	0.25	0.007	0.0070	0.398
9 (480 s)			0.06	1.2	0.00002	0.25			
10 (540 s)			0.06	0	0.00000	0.25			
									0.404

Measurement 2

Minute	Time (begin-end) (s)	Velocity (m/s)	Slope (m/m)	Discharge (l/min)	Discharge (m³/s)	Average flow width (m)	Water height (m)	Hydraulic radius R	Manning's n
1 (0 s)			0.06	1	0.00002	0.25			
2 (60 s)	102	0.020	0.06	1.8	0.00003	0.25	0.006	0.0058	0.396
3 (120 s)			0.06	1.7	0.00003	0.25			
4 (180 s)	100	0.020	0.06	1.7	0.00003	0.25	0.006	0.0054	0.370
5 (240 s)			0.06	1.8	0.00003	0.25			
6 (300 s)			0.06	2.9	0.00005	0.25			
7 (360 s)			0.06	1.5	0.00003	0.25			
8 (420 s)			0.06	2.3	0.00004	0.25			
9 (480 s)	120	0.017	0.06	1.6	0.00003	0.25	0.006	0.0060	0.480
10 (540 s)	105	0.019	0.06	2.2	0.00004	0.25	0.008	0.0072	0.472
									0.429

Measurement 3

Minute	Time (begin-end) (s)	Velocity (m/s)	Slope (m/m)	Discharge (l/min)	Discharge (m³/s)	Average flow width (m)	Water height (m)	Hydraulic radius R	Manning's n
1 (0 s)			0.06	1.5	0.00003	0.25			
2 (60 s)	95	0.021	0.06	2.5	0.00004	0.25	0.008	0.0074	0.434
3 (120 s)			0.06	2.2	0.00004	0.25			
4 (180 s)	95	0.021	0.06	2.4	0.00004	0.25	0.008	0.0071	0.423
5 (240 s)			0.06	2.4	0.00004	0.25			
6 (300 s)			0.06	2.2	0.00004	0.25			
7 (360 s)	100	0.020	0.06	2.1	0.00004	0.25	0.007	0.0066	0.423
8 (420 s)			0.06	2.5	0.00004	0.25			
9 (480 s)			0.06	2.3	0.00004	0.25			
10 (540 s)	100	0.020	0.06	2.2	0.00004	0.25	0.007	0.0069	0.436
									0.429

Average Manning's n	0.421
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<b>Plot 4</b>	<b>Tilled silty sand</b>
Length (m)	2.4
Width (m)	48.75
Distance dye inlet-end	2.4
Slope (%)	7
Slope (°)	4
Slope (rad)	0.07
Slope (m/m)	0.07



FIGURE 46:  
REPRESENTATION OF  
TILLED SANDY SILT SOIL.

*Measurement 1*

Minute	Time (begin-end) (s)	Velocity (m/s)	Slope (m/m)	Discharge (l/min)	Discharge (m <sup>3</sup> /s)	Average flow width (m)	Water height (m)	Hydraulic radius R	Manning's n
1 (0 s)			0.07	1	0.00002	0.28			
2 (60 s)	35	0.069	0.07	2.6	0.00004	0.28	0.002	0.0022	0.065
3 (120 s)			0.07	2.8	0.00005	0.28			
4 (180 s)	36	0.067	0.07	2.6	0.00004	0.28	0.002	0.0023	0.068
5 (240 s)			0.07	2.7	0.00005	0.28			
6 (300 s)	33	0.073	0.07	2.3	0.00004	0.28	0.002	0.0018	0.055
7 (360 s)			0.07	3.2	0.00005	0.28			
8 (420 s)	30	0.080	0.07	2.3	0.00004	0.28	0.002	0.0017	0.047
9 (480 s)			0.07	1.5	0.00003	0.28			
10 (540 s)			0.07	0	0.00000	0.28			
									0.059

Measurement 2

Minute	Time (begin-end) (s)	Velocity (m/s)	Slope (m/m)	Discharge (l/min)	Discharge (m <sup>3</sup> /s)	Average flow width (m)	Water height (m)	Hydraulic radius R	Manning's n
1 (0 s)			0.07	1	0.00002	0.22			
2 (60 s)			0.07	3	0.00005	0.22			
3 (120 s)	30	0.080	0.07	3	0.00005	0.22	0.003	0.0028	0.066
4 (180 s)			0.07	3.2	0.00005	0.22			
5 (240 s)	28	0.086	0.07	2.7	0.00005	0.22	0.002	0.0024	0.055
6 (300 s)			0.07	3.3	0.00006	0.22			
7 (360 s)	28	0.086	0.07	2.6	0.00004	0.22	0.002	0.0023	0.053
8 (420 s)			0.07	3	0.00005	0.22			
9 (480 s)	30	0.080	0.07	3	0.00005	0.22	0.003	0.0028	0.066
10 (540 s)			0.07	0	0.00000	0.22			
									0.060

Measurement 3

Minute	Time (begin-end) (s)	Velocity (m/s)	Slope (m/m)	Discharge (l/min)	Discharge (m <sup>3</sup> /s)	Average flow width (m)	Water height (m)	Hydraulic radius R	Manning's n
1 (0 s)			0.07	3.1	0.00005	0.25			
2 (60 s)	26	0.092	0.07	3.6	0.00006	0.25	0.003	0.0025	0.053
3 (120 s)			0.07	3.4	0.00006	0.25			
4 (180 s)	27	0.089	0.07	3.3	0.00006	0.25	0.002	0.0024	0.054
5 (240 s)			0.07	3.6	0.00006	0.25			
6 (300 s)	28	0.086	0.07	3.4	0.00006	0.25	0.003	0.0026	0.058
7 (360 s)			0.07	3.4	0.00006	0.25			
8 (420 s)	26	0.092	0.07	3.4	0.00006	0.25	0.002	0.0024	0.051
9 (480 s)			0.07	0	0.00000	0.25			
10 (540 s)			0.07	0	0.00000	0.25			
									0.054

Measurement 4

Minute	Time (begin-end) (s)	Velocity (m/s)	Slope (m/m)	Discharge (l/min)	Discharge (m <sup>3</sup> /s)	Average flow width (m)	Water height (m)	Hydraulic radius R	Manning's n
1 (0 s)			0.07	2	0.00003	0.25			
2 (60 s)	28	0.086	0.07	3.5	0.00006	0.25	0.003	0.0027	0.059
3 (120 s)			0.07	3.9	0.00007	0.25			
4 (180 s)	26	0.092	0.07	3.3	0.00006	0.25	0.002	0.0023	0.050
5 (240 s)			0.07	4	0.00007	0.25			
6 (300 s)	26	0.092	0.07	3	0.00005	0.25	0.002	0.0021	0.047
7 (360 s)			0.07	0	0.00000	0.25			
8 (420 s)			0.07	3	0.00005	0.25			
9 (480 s)			0.07	0	0.00000	0.25			
10 (540 s)			0.07	0	0.00000	0.25			
									0.052
Average Manning's n									0.056

<b>Plot 5</b>	<b>zero tillage, silty sand</b>
Length (m)	1.75
Width (m)	0.4625
Distance dye inlet-end	1.75
Slope (%)	7
Slope (°)	4
Slope (rad)	0.07
Slope (m/m)	0.07



FIGURE 47:  
REPRESENTATION OF ZERO  
TILLAGE ON SANDY SILT  
SOIL.

*Measurement 1*

Minute	Time (begin-end) (s)	Velocity (m/s)	Slope (m/m)	Discharge (l/min)	Discharge (m <sup>3</sup> /s)	Average flow width (m)	Water height (m)	Hydraulic radius R	Manning's n
1 (0 s)			0.07	1.8	0.00003	0.32			
2 (60 s)	55	0.032	0.07	2	0.00003	0.32	0.003	0.0032	0.182
3 (120 s)	60	0.029	0.07	2	0.00003	0.32	0.004	0.0035	0.210
4 (180 s)			0.07	2	0.00003	0.32			
5 (240 s)	55	0.032	0.07	2.1	0.00004	0.32	0.003	0.0034	0.188
6 (300 s)			0.07	2	0.00003	0.32			
7 (360 s)	55	0.032	0.07	2.2	0.00004	0.32	0.004	0.0035	0.193
8 (420 s)			0.07	2.1	0.00004	0.32			
9 (480 s)			0.07	1.8	0.00003	0.32			
10 (540 s)			0.07	0	0.00000	0.32			
									0.193

Measurement 2

Minute	Time (begin-end) (s)	Velocity (m/s)	Slope (m/m)	Discharge (l/min)	Discharge (m³/s)	Average flow width (m)	Water height (m)	Hydraulic radius R	Manning's n
1 (0 s)			0.07	1.8	0.00003	0.26			
2 (60 s)	48	0.036	0.07	1.7	0.00003	0.26	0.003	0.0029	0.147
3 (120 s)			0.07	1.9	0.00003	0.26			
4 (180 s)	55	0.032	0.07	1.9	0.00003	0.26	0.004	0.0037	0.198
5 (240 s)			0.07	1.9	0.00003	0.26			
6 (300 s)	50	0.035	0.07	1.6	0.00003	0.26	0.003	0.0028	0.152
7 (360 s)			0.07	1.9	0.00003	0.26			
8 (420 s)	54	0.032	0.07	1	0.00002	0.26	0.002	0.0019	0.127
9 (480 s)			0.07	0	0.00000	0.26			
10 (540 s)			0.07	0	0.00000	0.26			
									0.156

Measurement 3

Minute	Time (begin-end) (s)	Velocity (m/s)	Slope (m/m)	Discharge (l/min)	Discharge (m³/s)	Average flow width (m)	Water height (m)	Hydraulic radius R	Manning's n
1 (0 s)			0.07	1.5	0.00003	0.31			
2 (60 s)	60	0.029	0.07	2.3	0.00004	0.31	0.004	0.0042	0.236
3 (120 s)			0.07	2.2	0.00004	0.31			
4 (180 s)	52	0.034	0.07	2.4	0.00004	0.31	0.004	0.0038	0.191
5 (240 s)			0.07	2.5	0.00004	0.31			
6 (300 s)	48	0.036	0.07	2.4	0.00004	0.31	0.004	0.0035	0.168
7 (360 s)			0.07	2.6	0.00004	0.31			
8 (420 s)	53	0.033	0.07	2.4	0.00004	0.31	0.004	0.0039	0.197
9 (480 s)			0.07	1.6	0.00003	0.31			
10 (540 s)	55	0.032	0.07	2.9	0.00005	0.31	0.005	0.0048	0.237
									0.206

Average Manning's n	0.185
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## Appendix 3      Box plot analysis

Data					
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5
	0,063	0,197	0,427	0,065	0,182
	0,063	0,155	0,377	0,068	0,210
	0,171	0,202	0,412	0,055	0,188
	0,183	0,217	0,398	0,047	0,193
	0,200	0,170	0,396	0,066	0,147
	0,219	0,219	0,370	0,055	0,198
	0,158	0,166	0,480	0,053	0,152
	0,200	0,123	0,472	0,066	0,127
	0,148	0,177	0,434	0,053	0,236
	0,172	0,227	0,423	0,054	0,191
	0,209	0,197	0,423	0,058	0,168
	0,185	0,180	0,436	0,051	0,197
	0,196	0,217		0,059	0,237
	0,207	0,241		0,050	
		0,241		0,047	

Calculations					
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5
Count	14	15	12	15	13
Mean	0,169	0,195	0,421	0,057	0,187
Stdev	0,04942	0,033507	0,033305	0,006926	0,032403
Max value	0,219	0,241	0,480	0,068	0,237
3rd Quartile	0,199849	0,217979	0,434699	0,062282	0,198274
Median	0,184	0,197	0,423	0,055	0,191
1st Quartile	0,160941	0,173294	0,397403	0,052423	0,167655
Min value	0,063	0,123	0,370	0,047	0,127

Preparation					
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5
Bottom	0,160941	0,173294	0,397403	0,052423	0,167655
2 Q box	0,023	0,024	0,026	0,002	0,024
3 Q box	0,016	0,021	0,011	0,008	0,007
Whisker -	0,098	0,051	0,027	0,006	0,041
Whisker +	0,019	0,023	0,045	0,006	0,039

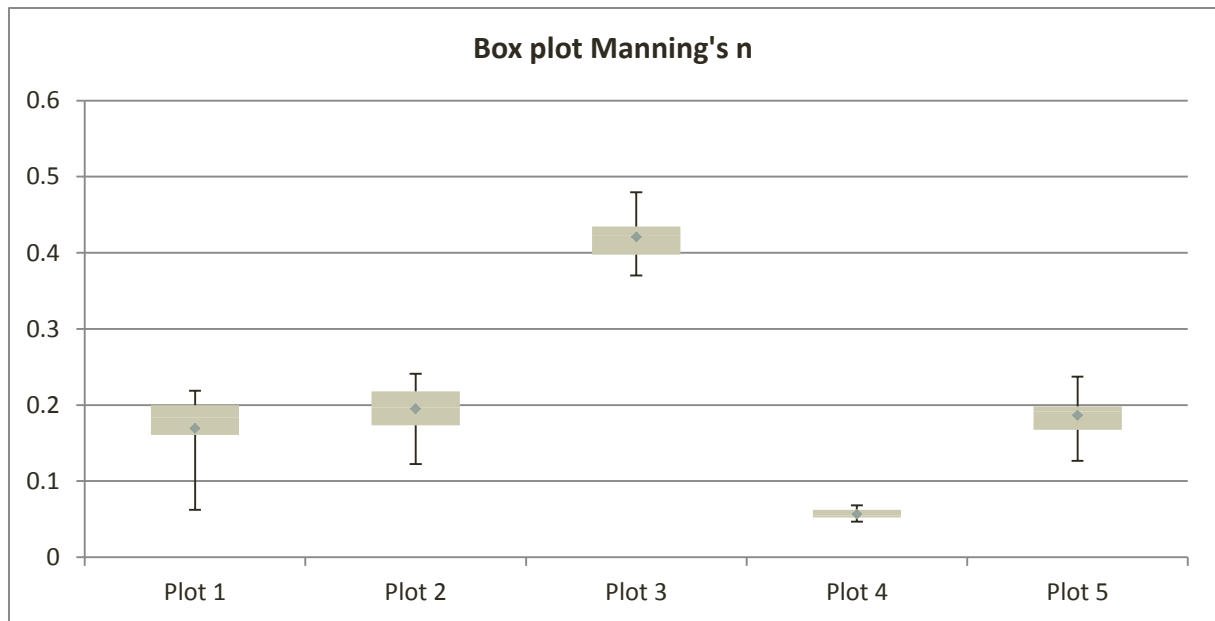


FIGURE 48: BOXPLOT OF MANNING'S N VALUES SHOWING THE DEVIATIONS FOR EACH LAND UNIT

## Appendix 4      T-test analysis

t-Test: Two-Sample Assuming Unequal Variances	1 loamy clay, zero tillage	2 loamy clay, tilled soil
	<i>Variable 1</i>	<i>Variable 2</i>
Mean	0.169386909	0.195191914
Variance	0.00244229	0.001122713
Observations	14	15
Hypothesized Mean Difference	0	
df	23	
t Stat	-1.634352103	
P(T<=t) one-tail	0.057899879	
t Critical one-tail	1.713871528	
P(T<=t) two-tail	0.115799759	
t Critical two-tail	2.06865761	
	t-stat<-T Critical	False
	t-stat> T Critical	False
Null-hypothesis rejected, no convincing differences: plots do not differ significantly		

t-Test: Two-Sample Assuming Unequal Variances	4 Sandy silt, tilled soil	5 Sandy silt, zero tillage
	<i>Variable 1</i>	<i>Variable 2</i>
Mean	0.05655464	0.186566009
Variance	4.79699E-05	0.001049975
Observations	15	13
Hypothesized Mean Difference	0	
df	13	
t Stat	-14.18833667	
P(T<=t) one-tail	1.36836E-09	
t Critical one-tail	1.770933396	
P(T<=t) two-tail	2.73672E-09	
t Critical two-tail	2.160368656	
	t-stat<-T Critical	True
	t-stat> T Critical	False
Null-hypothesis approved, convincing differences: plots do differ significantly		

t-Test: Two-Sample Assuming Unequal Variances	<b>2</b> loamy clay, tilled soil	<b>4</b> Sandy silt, tilled soil
	<i>Variable 1</i>	<i>Variable 2</i>
Mean	0.195191914	0.05655464
Variance	0.001122713	4.79699E-05
Observations	15	15
Hypothesized Mean Difference	0	
df	15	
t Stat	15.6930039	
P(T<=t) one-tail	5.12194E-11	
t Critical one-tail	1.753050356	
P(T<=t) two-tail	1.02439E-10	
t Critical two-tail	2.131449546	
	t-stat<-T Critical	False
	t-stat> T Critical	True
Null-hypothesis approved, convincing differences: plots do differ significantly		

t-Test: Two-Sample Assuming Unequal Variances	<b>1</b> loamy clay, zero tillage	<b>5</b> Sandy silt, zero tillage
	<i>Variable 1</i>	<i>Variable 2</i>
Mean	0.169386909	0.186566009
Variance	0.00244229	0.001049975
Observations	14	13
Hypothesized Mean Difference	0	
df	23	
t Stat	-1.075340504	
P(T<=t) one-tail	0.146686977	
t Critical one-tail	1.713871528	
P(T<=t) two-tail	0.293373953	
t Critical two-tail	2.06865761	
	t-stat<-T Critical	False
	t-stat> T Critical	False
Null-hypothesis rejected, no convincing differences: plots do not differ significantly		

t-Test: Two-Sample Assuming Unequal Variances	<b>2</b> loamy clay, tilled soil	<b>3</b> Grass
	<i>Variable 1</i>	<i>Variable 2</i>
Mean	0.195191914	0.4207355
Variance	0.001122713	0.001109244
Observations	15	12
Hypothesized Mean Difference	0	
df	24	
t Stat	-17.43823785	
P(T<=t) one-tail	1.95908E-15	
t Critical one-tail	1.71088208	
P(T<=t) two-tail	3.91817E-15	
t Critical two-tail	2.063898562	
	t-stat< T Critical	True
	t-stat> T Critical	False
Null-hypothesis approved, convincing differences: plots do differ significantly		