



## Runoff and erosion as affected by tillage system and polyacrylamide in two sandy loam soils differing in silt and clay contents in semi-arid regions

Nidal H. Abu-Hamdeh<sup>1\*</sup>, Saleh M. Ismail<sup>2</sup>, Samir G. Al-Solaimani<sup>3</sup> and Randa I. Hatamleh<sup>4</sup>

<sup>1</sup>King Abdulaziz University, Faculty of Engineering, Mechanical Engineering Department, Jeddah, Saudi Arabia

<sup>2</sup>King Abdulaziz University, Faculty of Meteorology, Environment and Arid Land Agriculture, Jeddah, Saudi Arabia

<sup>3</sup>King Abdulaziz University, Faculty of Meteorology, Environment and Arid Land Agriculture, Jeddah, Saudi Arabia

<sup>4</sup>Yarmouk University, Faculty of Engineering, Civil Engineering Department, Irbid-Jordan

### Abstract

This study aims to investigate the effect of three tillage practices and the effect of polyacrylamide application rate on surface runoff and erosion of sandy loam soils differing in silt and clay contents. Field experiments in split-split plot with four replications were carried out in two different locations; location A that consists of 25.2% silt plus clay and location B which consists of 38.5% silt plus clay. Three tillage practices were investigated; no-tillage (NT), mouldboard ploughing with rotor tiller (CT1), and chisel ploughing with disk harrow (CT2). Three polyacrylamide (PAM) rates were implemented in each tillage system; 0, 10 and 20 kg ha<sup>-1</sup>. The experiment was conducted during December 2015 to April 2017 and wheat was sown for the two seasons. Results showed that the CT1 and CT2 treatments reduced runoff by 15.3% and 50.0%, respectively in location A and by 6.4% and 13.8%, respectively, in location B compared to the NT treatment. Applying 10 and 20 kg ha<sup>-1</sup> of PAM decreased runoff by 9.5% and 22%, respectively in location A and by 4.5% and 12%, respectively in location B compared to the 0 kg ha<sup>-1</sup> PAM treatment. Applying 10 and 20 kg ha<sup>-1</sup> PAM reduced soil erosion by 19% and 28%, respectively, in location A and by 26% and 33%, respectively in location B compared to the 0 kg ha<sup>-1</sup> PAM application rate. Comparing the effect of tillage practices in location (A), the CT1 increased soil erosion by 16.5 % and 46.5% compared with the NT and CT2 treatments, respectively. Comparing the effect of tillage practices in location (B), the CT1 increased soil erosion by 38.6% and 75.6% compared to the NT and CT2, respectively.

**Keywords:** Chisel ploughing, mouldboard ploughing, no-tillage, surface runoff, erosion

### Introduction

The major tillage method to be used is the conventional tillage (CT) because it is effective for preparing the seedbed, incorporating manure and residue, compaction lessening and weed control. However, possible disadvantages of CT are soil tilth destruction, enhanced soil crusting, runoff and erosion, high costs of labour, energy and equipment (Das *et al.*, 2014; Kuotsu *et al.*, 2014).

Conservation of soil and water is the most significant in avoiding the degradation of land and production loss in the Mediterranean countries. The productivity of rain-fed farming may increase by implementation of non-conventional management, by improving the traditional soil and water conservation techniques and by better design of water harvesting systems (Rockström *et al.*, 2009; Baudron *et al.*, 2012; Palm *et al.*, 2013; Pittelkow *et al.*, 2014). Conservation tillage increases soil water storage by improving water infiltration, reducing surface runoff and decreasing evaporation (Moraes *et al.*, 2013). It conserves water within the root zone, minimizes soil erosion, and

improves agronomic productivity (Durr *et al.*, 2001). El Atta *et al.* (2013) investigated the efficiency of rainwater in water harvesting (quadrangular, terraces, semi-circular bunds) in the southwestern of Saudi Arabia. They found that these structures significantly increased infiltration rate, soil porosity and moisture content. Hence, runoff and soil erosion were significantly reduced.

Several research studies investigated the effect of tillage practices on infiltration of rain and their effects on erosion and runoff from soil. Based on laboratory studies, no-till management improved soil and water conservation in light textured soils, (Conant *et al.*, 2011; Kahlon *et al.*, 2013; Shekhawat *et al.*, 2016; Linhua *et al.* 2017). No-till has also been shown to provide substantial water conservation, energy and ecological benefits (Ngigi *et al.*, 2006; Morris *et al.*, 2010; VanWie *et al.*, 2013). On the other hand, many other studies showed no beneficial effect of NT on the hydraulic properties of the soils (Shukla *et al.* 2003). Based on field studies, results revealed that the beneficial effect of no-till and conservation tillage on some

\*Email: nabuhamdeh@kau.edu.sa

soil physical properties was not always demonstrated (Fuentes *et al.*, 2009; Gozubuyuk *et al.*, 2014; Salem *et al.*, 2015; da Costa and Crusciol, 2016).

Improving rain water penetration and controlling runoff and erosion are expected to benefit from the application of Polyacrylamide (PAM) on the soil surface (Mamedov *et al.*, 2010; Lee *et al.*, 2015). Polyacrylamide (PAM) has been recognized to enhance aggregate stability and soil structure, increase infiltration rate and soil water retention, and an efficient mean to decrease runoff and soil erosion (Green and Stott, 2001; Peterson *et al.*, 2002; Graber *et al.*, 2006; Sojka *et al.* 2007; Lee *et al.* 2010). Yu *et al.* (2003) studied the influence of surface enhancement of silt loam and sandy clay during simulated rainstorms by granular PAM (10 and 20 kg ha<sup>-1</sup>) on soil erosion and surface runoff. Spreading dry PAM decreased erosion to 30% of the control and enlarged the final infiltration rate of the two soils by four times. Sojka *et al.* (2007) stated that PAM bonds fragment and produce bigger aggregates and thus avoid the formation of crust on the soil surface, hence decreasing erosion. It also modifies the soil chemical, biological, and physical properties, thus enhancing root and water penetration, aeration, and erosion resistance. The effectiveness of PAM is likely to be larger in soils with high clay content for the greater amount of charged bonding sites (Lee *et al.*, 2010). Enhancement outcomes of PAM last over extended time because of its 9.8% per year decomposition rate and it is the most unaffected by microbial dissolution among other normally utilized polymers (Lentz and Bjorneberg, 2003; Sojka *et al.*, 2007).

Our hypothetical concept in this study that sustainable rain-fed agriculture is better achieved under farming practices that are carefully designed in accordance with soil type. Therefore, the objectives of this research were to study the effect of no-tillage (NT) compared to the conventional tillage (CT) and to analyse the effect of PAM application rate on surface runoff and erosion of sandy loam soils differing in silt and clay contents.

## Materials and Methods

### Location, design and layout of the field experiment

This research study was conducted at the Agriculture Experimental Station of King Abdulaziz University (KAU) which is located at Hada Alsham, 110 km northeast of Jeddah city 21° 48' 3" N, 39° 43' 25" E), KSA. The period of the experiment was extended from December 1<sup>st</sup>, 2015 till end of April of 2017. Within this period the soil of both locations (500 m distance between the two locations) was cultivated for two consecutive seasons. The design used in this research study was a split-split plot design with four

replications. Two soil locations were taken as the main plot. The two locations have not been cultivated for many years and they were different in clay and silt contents. Location A consists of 74.8% sand, 15.5% silt, 9.7% clay while location B consists of 61.5% sand, 25.7% silt, 12.8% clay. Three tillage practices were taken as the sub main plots; CT1 stands for mouldboard ploughing with rotor tiller, NT stands for no-tillage, and CT2 stands for chisel ploughing followed by disk harrowing.

The second level of plots (sub-sub main plots), each with an area of 18 m<sup>2</sup>, were three granular rates of PAM application (0, 10 and 20 kg ha<sup>-1</sup>). In each experimental site a total area of 1560 m<sup>2</sup> was identified to apply all treatments that comply with the statistical design explained previously. The investigated area had a gentle slope of about 0.01%. No PAM was applied onto the surface of soil in the control PAM plots (0 kg ha<sup>-1</sup>) in all tillage systems. In the other treatments, PAM was added to the whole surface area of each plot and mixed manually with the upper layer of the soil. The only exception was in the NT treatment where PAM was thrown onto the topsoil. Application of PAM was done for one time before the starting of the experiment. After applying tillage systems and PAM rates, wheat seed was sown in all treatments at November 21, 2015 and 2016 in rows spaced apart at 20 cm by a seed drill that is 10 cm-wide at a seeding rate 130 kg ha<sup>-1</sup>. The recommended cultural practices for wheat crop were followed until the harvesting.

### Irrigation system and network

Sprinkler irrigation system was installed in each location to apply irrigation water as in natural rain fall. Under the current study, 2045-PJ Maxi-Bird TM rotator was used. The system's inlet pressure was 2.5 bars. The rotator's radius was adjusted to be 11.7 m with a 0.76 m<sup>3</sup>/h as maximum discharge and precipitation rate of 11 mm/h. After installation, the system distribution uniformity was measured and found to be about 90% in both locations. The daily crop water requirement was calculated based on metrological weather condition of the experimental area and crop growth stages using CROPWAT model. Sprinkler irrigation was applied three times during the growing season. Detailed analysis of soil physical and chemical properties and irrigation water in both experimental locations is presented in Table 1. The experimental site's metrological data throughout the period of the field work is presented in Table 2.

### Measuring runoff and soil erosion

When water supply either by irrigation or rainfall is higher than soil infiltration rate, part of the supplied water moves horizontal as runoff. The amount of runoff depends



**Table 1: Initial physical and chemical soil analyses before the starting of the experiment for experimental soil and irrigation water**

Variable	Experimental soil	
	Location (A)	Location (B)
Particle size analysis		
Clay %	9.7	12.8
Silt %	15.5	25.7
Sand %	74.8	61.5
Texture class	Sandy loam	Sandy loam
	Penetration resistance	
Layer 0-15	Moderate compacted	Slight compacted
Layer 15-30	compacted	compacted
Layer 30-45	compacted	compacted
Bulk density (g/cm <sup>3</sup> )	1.87	1.71
Air porosity (%)	29.4	35.4
infiltration rate (cm/hour)	16.0	7.0
Organic matter (%)	0.65%	1.10%

**Table 2: Metrological data of the experimental site during the period of the field work**

Year	Month	Minimum temperature °C	Maximum temperature °C	Relative humidity %	Wind speed km/day	Rainfall mm
2015	November	18.0	37.0	64.9	197	5.2
	December	12.5	31.7	68.4	284	4.7
2016	January	10.9	30.4	69.8	187	2.1
	February	11.0	36.0	58.7	226	7.0
	March	15.6	40.0	58.9	181	0.0
	April	15.7	39.7	55.3	208	34.5
	May	22.2	44.9	45.6	162	9.51
	June	22.8	45.5	35.2	183	0.0
	July	23.4	42.5	41.3	197	0.0
	August	23.4	43.3	55.5	178	0.7
	September	22.7	43.3	58.6	160	5.7
	October	20.6	41.0	59.5	134	2.0
	November	18.0	36.7	65.0	143	0.1
	December	14.5	32.8	71.6	138	1.6
2017	January	13.2	33.4	68.0	147	0.2
	February	15.6	33.0	55.5	240	0.3
	March	25.0	33.4	63.5	214	0.0

**Figure 1: Runoff and erosion unit installation and operation in the field**

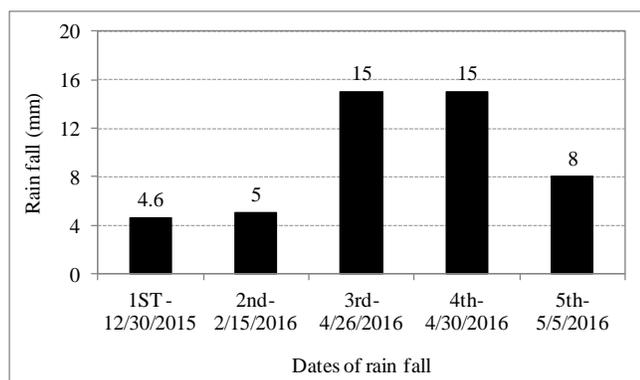
on the soil infiltration rate and on the amount of water supply. In this study, runoff and erosion collection devices were installed in both experimental fields at the beginning of December 2015 and kept in their locations until the end of April 2017. During that period, runoff was collected and

measured eight times. Five of these measurements were collected after natural rainfall while the remaining three measurements were collected when the fields were irrigated by sprinkler irrigation system that was used in the experiments as a supplementary irrigation method.

To reveal the effects of the various treatments on soil predisposition to erosion and runoff, each plot in the two experimental sites was enclosed by a galvanized plate of iron which was fixed at the end of the plot to interrupt the runoff and send it into a basin. The collecting plate was projecting 2 cm above the soil surface and implanted 15 cm into the soil surface. In order to prevent direct rainfall entry into the basins they were enclosed with lids. The basin conveyed the runoff into tanks each with 0.1 m<sup>3</sup> volume via a siphon pipe (Figure 1). After each storm, the volume of water was recorded then the tanks were emptied. Before emptying each tank, the content of the tank was blended completely and three sub samples (100 mL each sample) were taken to determine soil erosion by weighing the quantity of remaining sediment after oven drying these samples at 105 °C. These three sub samples represent three replicates of the measurements. Once the weight of soil particles in the 100 mL sample was obtained it was used to obtain the weight of soil in the runoff volume of each treatment that was collected after each storm, and then this was converted to kg of soil per hectare.

### Statistical analysis

The obtained data were statistically analysed through analysis of variance procedures to determine the significance of the treatments and the interactions. LSD test was used to compare the means after applying the statistical analysis assumptions according to El-Nakhlawy (2010) using SAS (2006).



**Figure 2: Amounts and dates of rainfall on the experimental area during the period from December 1, 2015 till April 30, 2017**

## Results and Discussion

### Surface runoff

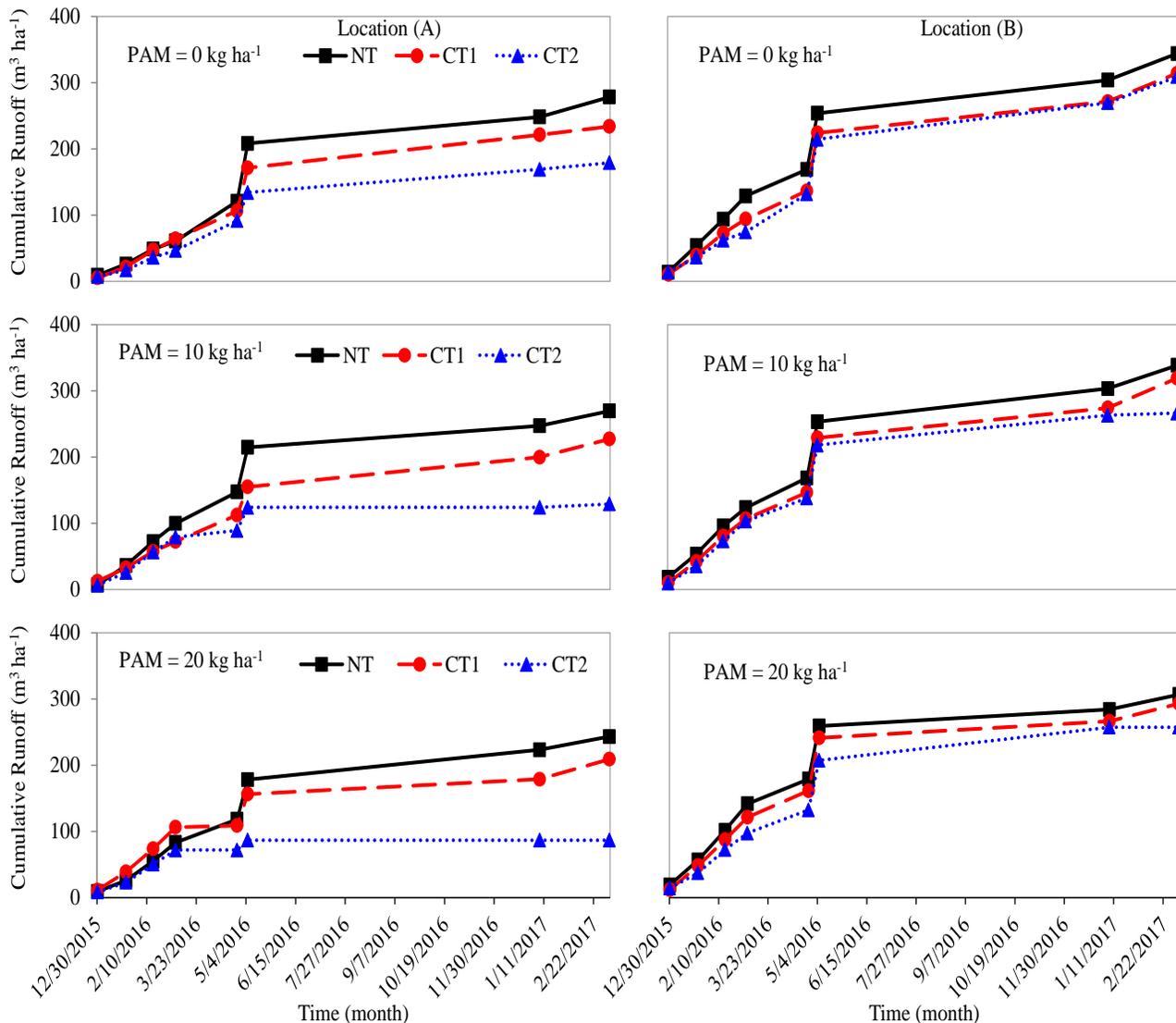
When water supply either by irrigation or rainfall is higher than soil infiltration rate, part of the supplied water moves on surface horizontally along the slope as runoff. The amount of the natural rainfall occurred in each of the

five times of the measurements is shown in Figure 2. The highest rainfall occurred in April 26 and 30 of 2016 and the second highest rainfall occurred in May 5, 2016. At the time of May measurement wheat crop was harvested and the soil was bare. The next highest rainfall occurred in February 15, 2016 where the soil was still covered by wheat crop. The least rainfall occurred in December 30, 2015.

For better visualization of the influences of tillage methods and rate of PAM application on surface runoff, results of cumulative runoff measured during the whole period of this study are presented in Figure 3. When averaged across all treatments, runoff in the second location (B) was significantly greater than its value in the first location (A) by about 48%. The results are logical and expected because the soil texture in the first location (A) was lighter than that of the second location (B). The sand content was 74.8% in location A while it was 61.5% in location B. In light textured soil, infiltration rate and saturated hydraulic conductivity increased by increasing sand content due to the presence of large pores. As a result, more water infiltrated and less water runoff in location A when compared with location B.

Obviously, tillage system significantly affected runoff in both locations. The highest runoff was measured in the NT treatment followed by the CT1 treatment while the least runoff was recorded in the CT2 treatment. The results could be attributed to the reduction in infiltration rate of the NT treatment compared to the CT1 and CT2 treatments. Decreasing infiltration rate increased the horizontal movement of water which resulted in higher runoff in the NT treatment compared to the other two treatments. Soil macropores have been investigated widely; the results are not consistent (Bhattacharyya *et al.*, 2006; Daraghmeh *et al.*, 2009). In some cases, even lower than that under tillage treatment, as in deeply tilled soils, intensive tilled soil pores are formed primarily by the tillage tool. Similarly, Zhang *et al.* (2016) concluded that No-tillage although increased water conducting macropores but did not increase hydraulic conductivity. However, our results are contradictory with soil macroporosity under no-tillage is usually higher (Bodhinayake and Si, 2004; Coquet *et al.*, 2005; Moret and Arrúe, 2007) under tilled soil. As indicated in Figure 3 and 4, soil runoff was higher in the CT1 treatment than in the CT2 treatment. Soil ploughing might destruct soil aggregates and pore system distribution in soil which is responsible for the filtration of water in soil (Smith *et al.*, 2007). Because the destruction results from mouldboard ploughing was higher than that resulted from chisel ploughing, water infiltration was decreased and runoff was increased in the CT1 treatment than in CT2 treatment. Numerically, the CT1 and CT2 reduced runoff by about





**Figure 3: Cumulative runoff m<sup>3</sup> ha<sup>-1</sup> from the experimental soil as affected by locations, tillage systems and PAM rates for wheat crop along the growth period of the two seasons of 2015/16 and 2016/17. Location A: (clay and silt = 25.2%), Location B: (clay and silt = 38.5%), NT: no tillage, CT1: mouldboard ploughing with rotor tiller, CT2: chisel ploughing with disk harrow, PAM: polyacrylamide polymer**

15.3% and 50.0%, respectively, in location A compared with that of the NT treatment. In location B, the CT1 and CT2 treatments reduced runoff by about 6.4% and 13.8%, respectively, compared to the runoff of the NT treatment.

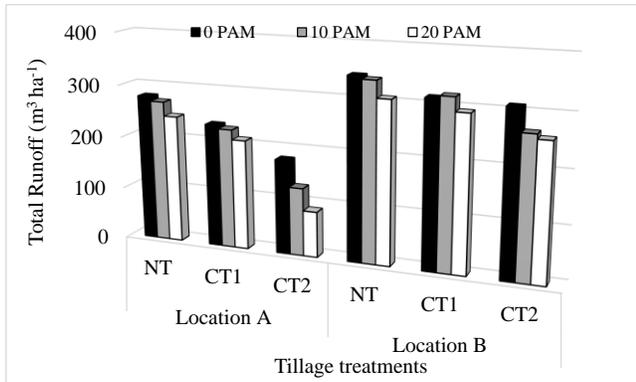
As for the effect of PAM application rate on runoff, increasing PAM application rate gradually and significantly decreased runoff in all tillage treatments in both locations as shown in Figure 4 which presents the total runoff results as influenced by tillage method, locations, and PAM application rates during the whole growth period of the two seasons. The results might be due to the improvement in soil

infiltration rate because adding PAM was found to be effective in decreasing erosion and increasing infiltration (Yu *et al.*, 2003).

The sharp increase in runoff values at the 5<sup>th</sup> and 6<sup>th</sup> measurements as shown in Figure 3 might be due to the large amount of the rainfall immediately before the measurements were taken as clearly indicated by the amounts of rainfall on the experimental area (presented in Figure 2). Increasing water supply for longer time decreases infiltration rate. Firstly, water enters, or infiltrates quickly but after certain time the infiltration decreases to a constant



rate while rainfall continues which resulted in an increase in runoff (Benham *et al.*, 2003). In short, Application of PAM decreased runoff in both locations. The reductions in locations A were about 9.5% and 22% in the 10 and 20 kg ha<sup>-1</sup> PAM application rate treatments compared with the 0 kg ha<sup>-1</sup> PAM application rate treatment. However, the reductions in location B were 4.5% and 12% in the 10 and 20 kg ha<sup>-1</sup> PAM treatments compared with the 0 kg ha<sup>-1</sup> treatment.



**Figure 4: Total runoff in m<sup>3</sup> ha<sup>-1</sup> from the experimental soil as affected by locations, tillage systems and PAM rates for wheat crop during the whole growth period of the two seasons. Location A: (clay and silt = 25.2%), Location B: (clay and silt = 38.5%), NT: no tillage, CT1: mouldboard ploughing with rotor tiller, CT2: chisel ploughing with disk harrow, PAM: polyacrylamide polymer (LSD 0.05 = 32)**

### Soil erosion

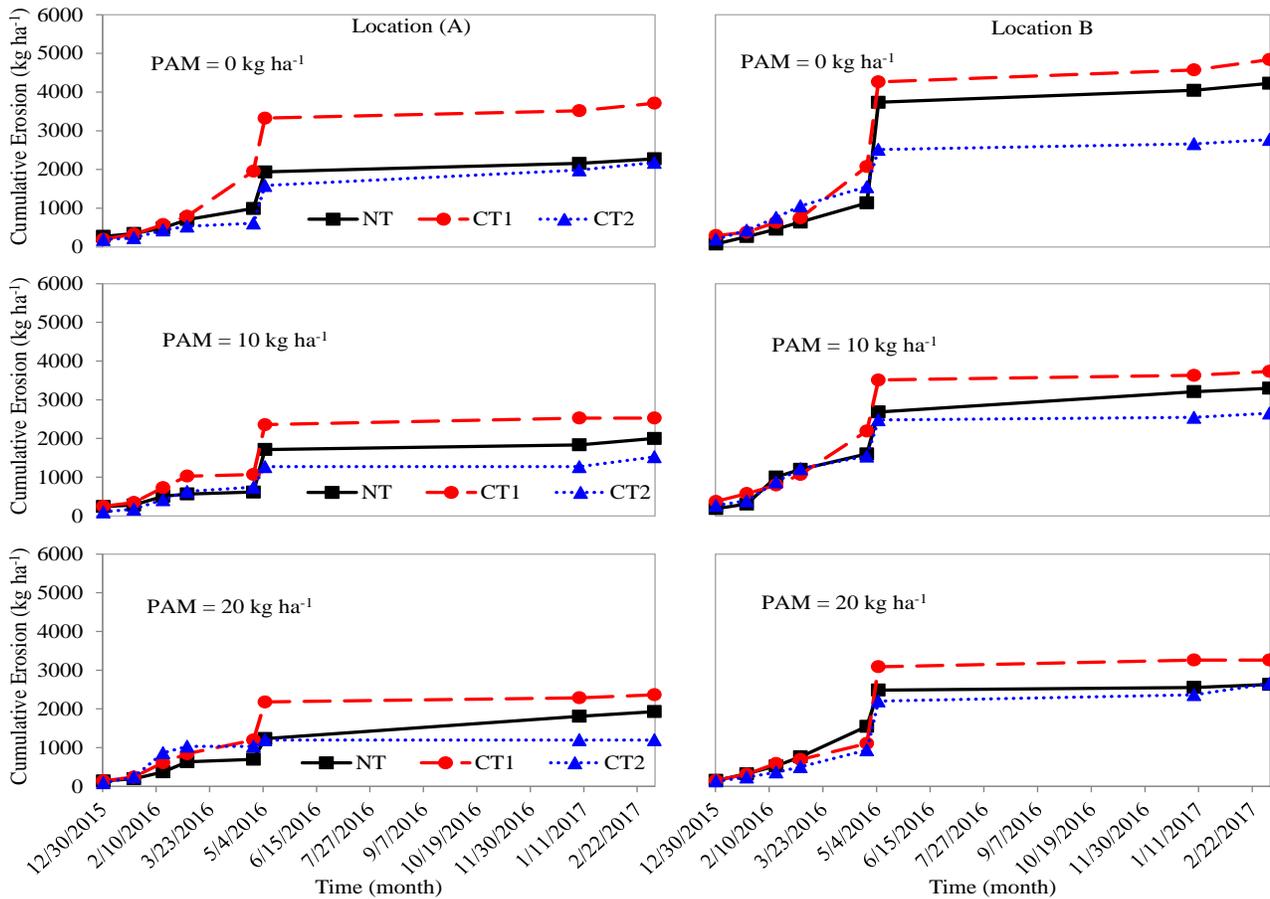
Soil erosion was measured in same plots used to measure runoff as explained in methodology section. The results of the cumulative erosion during the period of the field experiment (beginning of December 2015 till the end of April 2017) as affected by tillage system and PAM application rates are presented in Figure 5. Results clearly show that soil erosion in location A was significantly higher by about 52.5% than that in location B. This could be related to the higher percentage of fine particles in location B compared to location A. The presence of fine particles might encourage soil granulation and stabilized soil aggregates in the second location (B) more than it did in the first location (A). Increasing the number and size of aggregates might decrease settling time of particles suspended in runoff water, consequently decrease soil erosion (McLaughlin and Bartholomew, 2007).

Tillage system shows significant very clear effect on soil erosion. The highest eroded sediment was recorded in

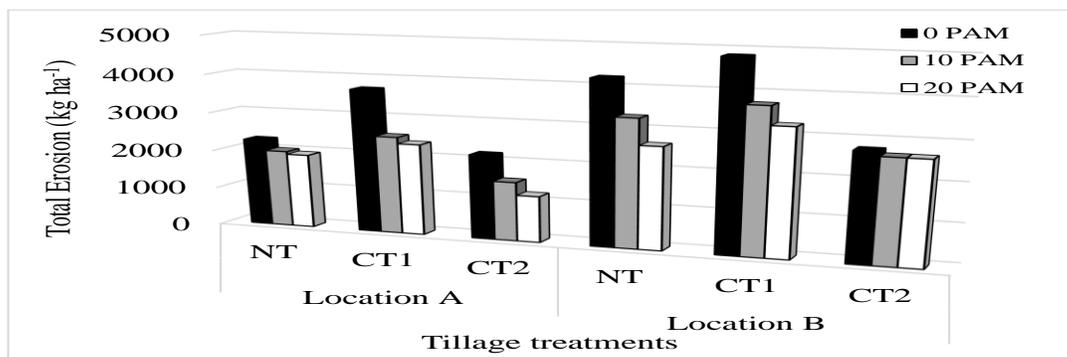
the CT1 followed by the NT and CT2, respectively, in both locations. Ploughing loosen the soil particles in the surface soil layer especially in the CT1 treatment. Without using cohesive material to join the soil particle after ploughing, the chance for sediment transport with irrigation water or raindrops increased. Tillage disrupts soil aggregates causing break down and reduce the aggregate size (Alvaro-Fuentes *et al.*, 2008). Soil erosion in the NT treatment was lower than in the CT1 treatment. The results could be explained by the stability of the structure in the NT which reduced sedimentation compared to the CT1 treatment. On the other hand, soil erosion in the NT treatment was higher than in the CT2 treatment. This is because of the greater runoff in the NT compared to the CT2 treatment. As runoff increases, its ability to load soil sediment increases and results in higher erosion. The least soil erosion was recorded in the CT2 treatment which could be explained by knowing that the lowest runoff values were measured in the CT2 treatment among other tillage treatments. Mohamadi and Kaviani (2015) stated that decreasing runoff might be met by low soil erosion since the water is the main source to erode and transport loosen soil. To summarize, the CT1 increased soil erosion by 16.5% and 46.5% compared with NT and CT2, respectively. The CT2 reduced soil erosion by 20.5% compared with the NT treatment. In location B, the CT1 increased soil erosion by about 38.6% and 75.6% compared with the NT and CT2, respectively. The CT2 reduced soil erosion by about 21% compared with NT treatment.

Applying PAM revealed significant great influence on soil erosion. The highest eroded soil was found in the 0 kg ha<sup>-1</sup> PAM treatment. Applying 10 kg ha<sup>-1</sup> of PAM resulted in sharp decrease in soil erosion in both locations but the reduction was pronounced in the first location (A) more than it is in the second location (B) especially in the NT and CT1 treatments. Increasing PAM application rate to 20 kg ha<sup>-1</sup> increased the reduction of soil erosion but the reduction in soil erosion as PAM rate increased from 10 to 20 kg ha<sup>-1</sup> was less than the reduction resulted from increasing PAM rate from 0 to 10 kg ha<sup>-1</sup>. Figure 6 shows the total eroded soil over the whole period of the experiments. It shows that the highest eroded soil was in 0 kg ha<sup>-1</sup> PAM application rate followed by the 10 and least with 20 kg ha<sup>-1</sup> application rate, respectively. PAM is considered as a cohesive material so its presence in the soil encourages granulation and soil aggregation (Sojka *et al.*, 2006; Mamedov *et al.*, 2010). Increasing structure stability and aggregate in soils might lead to stabilize the surface of the soil versus shear-inducing detachment, decreasing soil susceptibility to seal formation, runoff generation and soil erosion. Application of little quantity of mild to high molecular weight of PAM has efficiently seal formation in soils from semiarid and arid zones and controlled aggregate breakdown (Bjorneberg and





**Figure 5:** Cumulative soil erosion in kg ha<sup>-1</sup> from the experimental area as affected by locations, tillage systems and PAM rates for wheat crop along the growth period of the two growing season of 2015/16 and 2016/17. Location A: clay and silt = 25.2%, Location B: clay and silt = 38.5%, NT: no tillage, CT1: mouldboard ploughing with rotor tiller, CT2: chisel ploughing with disk harrow, PAM: polyacrylamide polymer



**Figure 6:** Total soil erosion in kg ha<sup>-1</sup> from the experimental soil as affected by locations, tillage systems and PAM rates for wheat crop during the whole growth period of the two seasons. Location A: (clay and silt = 25.2%), Location B: (clay and silt = 38.5%), NT: no tillage, CT1: mouldboard ploughing with rotor tiller, CT2: chisel ploughing with disk harrow, PAM: polyacrylamide polymer (LSD 0.05 = 118)

Aase, 2000). Yu *et al.* (2003) reported similar results. They stated that spreading dry PAM decreased erosion by 30%

compared to control in sandy loam and sandy soils. Moreover, constitution of soil aggregates as a result of PAM



application might increase the size and thus decrease settling time of particles suspended in runoff water (Green *et al.*, 2004; Petersen *et al.*, 2007; McLaughlin and Bartholomew, 2007). To recap, increasing PAM rates decreased soil erosion in both locations. Applying 10 and 20 kg ha<sup>-1</sup> PAM reduced soil erosion by 19% and 28% compared to the 0 kg ha<sup>-1</sup> PAM application rate in location A while the reductions were 26% and 33% for the same treatments in location B.

Large amounts of eroded soil were produced at the 5<sup>th</sup> and 6<sup>th</sup> measurements expressed as sharp increase in soil erosion as shown in Figure 5. Stable structure help soil particles to stay undisturbed and their ability to erode depend on the shear stress associated with running water. This means increasing the amount and velocity of running water would increase the ability of soil particles to erode. The large amount of rainfall occurred immediately before the 5<sup>th</sup> and 6<sup>th</sup> measurements could be the reason behind the sharp increase in soil erosion at the 5<sup>th</sup> and 6<sup>th</sup> measurements as indicated in Figure 5. Mohamadi and Kavian (2015) stated that increasing rainfall intensity yielded the highest runoff, sediment concentration and soil loss.

## Conclusions

The main purpose of this study was to investigate the effect of three tillage practices and the effect of polyacrylamide application rate on surface runoff and erosion of sandy loam soils differ in silt and clay contents. The runoff results show that the CT1 and CT2 reduced runoff in both locations compared with that of the NT treatment. The CT2 had higher reduction in runoff compared to the CT1. PAM worked as a cohesive material to join the soil particle after ploughing such that the addition of PAM in both locations decreased runoff. The erosion results show that the highest eroded soil was in the CT1 treatment followed by the NT treatment and least in the CT2 treatment, respectively. The addition of PAM to the soil surface always reduced soil erosion in both locations. Higher application rates of PAM always resulted in less soil erosion. It can be concluded from the results obtained that the best PAM amounts to apply is 20 kg ha<sup>-1</sup>. The findings support the hypothetical concept that sustainable rain-fed agriculture is better achieved under farming practices that are carefully designed in accordance with soil type.

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