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Effects of conservation tillage on soil moisture content, organic matter management, soil erosion and runoff control

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ABSTRACT

The purpose of conservation tillage is to reduce the intensity of tillage operations and increase the amount of crop residue on soil surface. One of the characteristics of soil in arid and semi-arid areas is the lack of organic matter. Crop residue management is one of the soil fertility and improvement methods that is achieved by conservation tillage. Compared to residue burning, maintaining crop residue on or near the soil surface under no-tillage and minimum tillage methods will improve the organic carbon, Soil structure and activity of micro-organisms. Soil organic matter in a temperate and humid area increased by 16% and in a temperate and dry area increased by 10% than conventional tillage systems.

Introduction

In the past, excessive use of tillage implements that threatening soil conservation was common and it had destructive long-term and short-term effects on soil. Conservation tillage is one of the main approaches in modern and mechanized agriculture; in developed countries conventional tillage systems are widely replaced by conservation tillage systems and this in addition to improving the qualitative and physical properties of soil can result in increasing water maintaining and infiltration and also saving water especially in areas with limited water resources. Foregoing can't be reached unless further studies and researches are done especially in arid and semi-arid areas.

As tillage systems are able to control or reduce erosion and damages from water runoff, they are one of the most important activities in touch with maintaining the physical, chemical and biological properties of soil. Conservation tillage refers to those tillage operations which cause the least damage to water and soil resources. Tillage is directly related to wind and water erosion, maintaining soil quality and also maintaining soil organic matter and its quality (Lopez et al., 1997) thus the type of tillage system and determining the amount of residue on soil surface are of the most important factors in successful farming both of these two factors have a significant impact on the quality and yield of crop plants (Marbet, 2000).

Therefore existence of residue on the soil surface causes soil water infiltration, reduces evaporation from the soil surface and also helps to maintain or keep the snow on the farmland for water storage particularly in the dry land areas (Hillel, 1982; Romaneckas et al., 2009). In this regard, studies have shown that existence of crop residue on the soil surface and extensive surface roots in the soil up to 60% compared to no-covered and without residue farmlands, are factors of increasing soil bulk density (Swan et al., 1994). In the center and north of the Great American Plateau, the main reason for the decrease in soil moisture storage gained from rainfall, is lack of crop residue in dryland farming and because of this reason, use of stubble mulch is recommended in these areas (Unger et al., 1980).

In general, conservation tillage refers to any tillage and planting system in which more than 30% of the soil surface is covered with residue after planting for the purpose of reducing water erosion and at least 2000 Pounds per Acre (2250 kg/ha) of residue exist on the surface during the time of wind erosion (Fawcett et al., 2003). Benefits of conservation tillage, especially in no-tillage systems with surface residue covering, have been reported in cases such as stabilization of moisture content and soil temperature (Benegas, 1998(, Improving aggregates stability and increasing soil organic matter (Hajabbasi et al., 2000; Chauhan et al., 2002), increasing of water infiltration into the soil (Tullberg, 2010; Singh et al., 2011) and reduction of soil erosion (Dabney et al., 2004). Tillage management can affect root penetration in plants by affecting the size of the pores (soil voids) and soil electrical conductivity, because of disturbing the capillary tubes in conventional method the amount of water stored in the no-tillage method is higher than conventional method whereas these tubes remain unspoiled In no-till method (Azooz et al., 1996).

Conservation tillage and soil moisture content

The use of conservation tillage and crop rotation systems for storage of moisture in the soil is one of the main factors affecting the yield of dryland crops in semi-arid and semi-humid areas. By doing so, the next crop won't face a severe water shortage and the yield would be appropriate. Larson et al (1983) have noted that the moisture stored in the surface layers of the soil profile, which is obtained from crop residue and no-tillage methods, is very important in plant initial period of growth and establishment. At the same time, it seems that maintaining the moisture in the time of plant growth is more important than fallow conditions. Infiltration and water movement in soil is influenced by soil voids and soil bulk density; two factors which are inversely proportional to each other (Angers et al., 1997). Stott and Diacks (2004) reported by reducing tillage Intensity, soil infiltration rate was increased, but the adhesion as a measure of soil compaction was reduced. On the other hand, one way to

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increase water storage in the soil is to increase water infiltration. By creating postal and long on the surface of the soil, Conservation tillage can reduce water runoff speed and increase soil infiltration. In this context, Malecka et al (2012) in their research project found that tillage systems significantly affected the physical properties of the soil. There was a significant difference in the soil moisture content with reduced tillage (RT) or no tillage (NT) in comparison to conventional tillage (CT) at both depth (0-5 and 10-20 cm) measurements. The soils tilled under RT and NT were shown higher recorded moisture content values, especially in the top layers. Volumetric water content values in 0-5 cm soil layer increased by 3.1% under RT and 5.4% under NT compared to CT ($P \leq 0.01$). Water content values in the 10-20 cm soil layer was increased by only 1.6% under RT and 2.5% under NT relative to CT ($P \leq 0.05$). In the 10-20 cm soil layer, the difference in soil water content between RT and NT was not significant. The soil tillage systems significantly modified soil bulk density in the upper soil layer ($P \leq 0.01$). At the 0-5 cm depth, RT caused an increase in the soil bulk density value in the surface soil layer of 0.15 Mg m^{-3}, and NT caused an increase of 0.30 Mg m^{-3} compared to CT which reported by Hoyle (2013), Osunbita et al (2005),Thomas et al (2007), McVay et al (2006) and Blecharczyk et al. (2007 This would be related to the existing stubble residue on top of non-tilled soils that provides organic matter and food for soil fauna, particularly for earthworms, which loosen soil surface through burrowing activities (Hoyle, 2013; Osunbita et al., 2005; Katsvairo et al., 2002; Blanco-Canqui et al., 2005).

In Kentucky, an experiment which was done in the case of evapotranspiration rates in conventional tillage and no-tillage methods, used in the production of oilseeds (maize), has shown that in no-tillage method the monthly moisture evaporation of the soil is low and the average annual evaporation is reduced up to 15 cm (Sprogue et al., 1986). Jin et al (2011) also in an 11 years long-term experiment reported that stored soil moisture at a depth of 30 cm for winter wheat, in no-tillage method, is 60 millimeters and in conventional method is 55.8 millimeters thus in total the amount of stored moisture in no-tillage method has improved for 19.3%. According to Fawcett's report (1978), the amount of stored moisture in the soil is not affected by primary tillage method; in treatments which there was straw on the ground surface and the weeds were controlled by using herbicides, the amount of stored water was increased and this storage was still in progress during fallow periods. In tropical and semitropical regions, it seems to be really important to create favorable conditions for soil moisture conservation and preventing runoff by using appropriate tillage implements in autumn; because the much of the rain fall occurs in autumn and winter. Increase in wheat crop yield, like any other agricultural products, in addition to other factors depends on land preparation, establishing proper seedbed, keeping soil fertility and preventing soil compaction (Khodabandeh, 1991).

Safari et al (2013) in a research projects, split-split complete randomized block design applied with three replications. Crop residue treatments included 0 residue, 45 percent and 90 percent of soil covered by stubble in the main plots and tillage treatments included two passes combined tillage, moldboard plow followed by double disc and without till seeding in sub plot and sowing treatments included flat and raised bed planting were located in sub-sub plots. Soil moisture content, bulk density and soil moisture content at depth 0-10 and 10-20 cm were recorded. Without-tillage with an average 18.7% moisture content was shown the highest moisture content at seedling emergence. The 90 percent residue increased soil moisture content compared to no residue treatment.

Conservation tillage not only reduces water loss through runoff, it also reduces evaporation losses so that more soil moisture is preserved for crop production. In one study, cumulative water losses for the first five hours after tillage were 0.113 in. (0.29 cm) with conventional tillage vs. 0.052 in. (0.13 cm) for no-till (Reicosky et al., 1994). In Kentucky, annual evaporation was reduced by 5.9 inches (15.0 cm) with no-till (Siemans, 1998). In areas where rainfall is limited, such as the Great Plains of the United States, grain production is made possible by fallowing land. No crop is planted for a year or part of a year so that soil moisture can be stored for use by the next planted crop. Weeds must be controlled during the fallow period to prevent them from drawing moisture out of the soil. Traditionally, weeds in fallow land were controlled by repeated tillage operations. However, tillage increases evaporation losses, causes wind and water erosion and disturbs wildlife habitat. Chemical fallow or eco fallow systems, which use herbicides to control weeds, have been developed for crops planted no-till following the fallow period (Wicks, 1976, 1986). In Kansas, Norwood found that water use efficiency was increased by 28 percent in no-till corn grown in a wheat-corn-fallow rotation, compared with conventional tillage (Norwood et al., 1999).

To investigate the effects of conservation tillage on soil water conservation, crop yield, and water-use efficiency the field experiment was conducted using reduced tillage (RT), no tillage with mulching (NT), subsoil tillage with mulching (ST) and conventional tillage (CT) and table (1) shows the obtained results about soil water storage of four tillage systems. In comparison to CT, NT, and ST improved fallow rainfall storage efficiency during the 6-year study period, especially during dry growing seasons and fallow periods. The soil water available at wheat planting was significantly affected by the tillage treatment; NT and ST soil water was significantly higher than that of CT (Su et al., 2007).

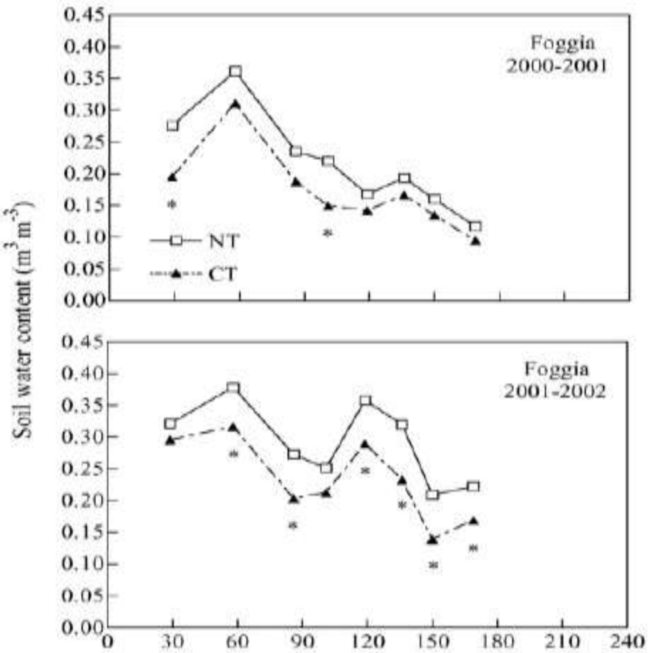

Figure 1. Soil water content under conventional tillage (CT) and no tillage (NT) during 2000–2001 and 2001–2002 growing seasons at Foggia, Italy

*Significant difference at $P < 0.05$ level probability between tillage treatments

Table 1. Soil water storage (mm) at wheat planting time of four tillage systems from 2000 to 2005 at depths of 0–200 cm[1]

Year	RT	NT	ST	CT
2000	406c	485a	477a	426b
2001	398c	488a	478ab	455b
2002	364c	427a	409b	370c
2003	475c	426a	507b	493b
2004	472c	515a	492b	489b
2005	401d	499a	485b	437c
average	419b	490a	474ab	448b

Values with the same letter within a column are not significantly difference at p = 0.05

At Foggia, soil water content was significantly greater under NT than CT, at the beginning of the wheat cycle, during each of the two growing seasons (Fig. 1). Higher soil water content under NT than CT indicated reduced water evaporation during the preceding period. This condition guaranteed an earlier and more uniform emergence in NT than in CT, where whole plot emergence was delayed. In2000–2001, soil water content was always greater under NT than under CT, but differences declined towards the end of the crop cycle (Lipiec et al., 2006).

Conservation tillage and soil organic matter

Soil disturbance and cultivation can accelerate the decomposition of organic matter, increasing its rate of mineralization. Cultivation and soil disturbance exposes previously protected organic matter to soil biota increasing its decomposition. Minimum tillage has the greatest potential to maintain, or perhaps increase levels of organic matter in cropping soils over the long-term, especially in surface soils. The increasing use of soil management practices such as moldboard ploughing is likely to have a profound effect on the amount and distribution of soil organic matter and needs further study.

In a long-term study of 10 years conservation tillage, 12 tones additional organic matter was made in the soil compared to conventional tillage. And also during 20 years applying conservation tillage, the organic matter of soil showed an increase of 16% in temperate and dry area and 10% in temperate and dry area, compared to conventional tillage. This increase of organic matter content during no-tillage system, in addition to increasing moisture absorption and maintenance, results in improving the crop production and thus increasing field covering of conservation tillage and reducing soil erosion; here the reason is that by higher organic matter in the soil there would be more nutrients for crop to consume(Wright et al., 2007).

Soil organic matter and in particular the humus fraction can hold several times its own weight in water. It seems logical, then, that increasing the organic matter content of soil would have a positive impact on the water holding capacity of a soil However, while there is indeed an established link between soil organic matter and water holding capacity, its importance declines with soil depth and increasing clay content (Hoyle et al., 2013). About 60percent of the organic matter in the top 30 cm of soil occurs in the surface layer (0-10 cm), so the influence of soil organic matter on soil water is most evident in the topsoil There is little influence of organic matter on plant available water late in the season when soil moisture is usually below 30 cm. Clay also functions to absorb soil water, decreasing the relative influence of soil organic matter on water holding capacity as the clay content of a soil increases.

Plant residues that cover the soil surface prevent the soil from sealing and crusting. This can result in better water infiltration and decreased water losses associated with run-off. Evaporation is also decreased and up to 8 mm of soil water can be saved where more than 80 percent of the soil surface is covered with residues compared with bare soil. If this water was available to plants it could return the equivalent of about 120 kg grain per hectare in wheat (Duiker et al., 2002).

Crop type, rotation and management influence soil organic carbon content. In general, soils under pasture have a higher soil organic content than those under cropping (Blair et al., 2006), while minimum tillage and stubble retention can either maintain or increase soil organic carbon in cropped soils (Chan et al., 2005). Applying inorganic fertilizers to low fertility soils can sometimes promote microbial activity and soil organic matter decomposition where nutrients are limiting, but also support greater plant productivity. Loss of topsoil from erosion results in a direct loss of soil organic matter. Soil organic matter can also be affected indirectly by erosion when exposed sub-surface soil layers are subject to higher temperatures leading to an increase in organic matter mineralization (Liddicoat et al., 2012).

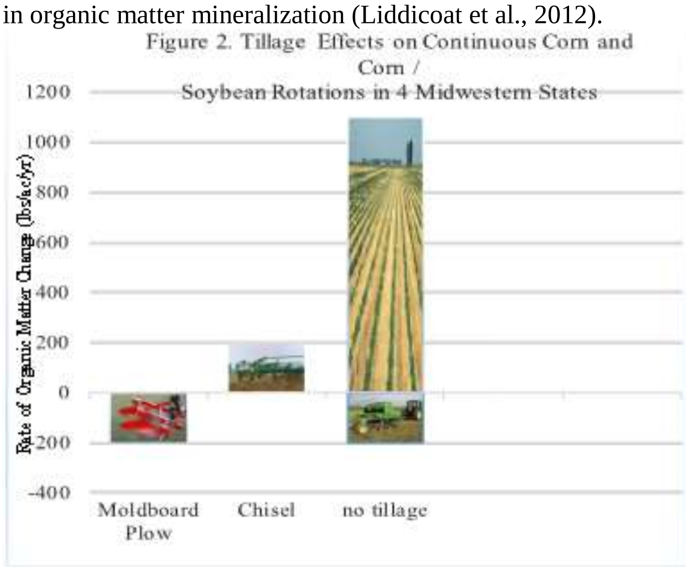

Figure 2. Tillage Effects on Continuous Corn and Corn / Soybean Rotations in 4 Midwestern States

Two broad categories of tillage systems are recognized: conservation tillage, which includes all tillage systems that leave more than 30% crop residue cover after planting; and conventional tillage, which leaves less than 30% crop residue cover after planting. A 30% residue cover limit has been set because significant soil erosion reduction is achieved only when more than this amount is present. In a Minnesota study, five times more carbon was lost shortly after moldboard plowing than without tillage. The carbon lost in 19 days after plowing was more than what was present in the roots and straw of the preceding wheat crop. In a review of 20 long-term studies with moldboard plowing, the average loss of organic matter was 256 lbs/acre/yr. These studies were conducted with continuous corn or wheat and rotations of corn with soybeans and oats in Illinois, Oregon, and Missouri However, in 10 long-term no-till studies conducted in Ohio, Alabama, Georgia, Kentucky, Illinois, Minnesota and Nebraska, organic matter increased an average 953 lbs/acre/yr. These studies were with continuous corn or soybeans, and corn-soybean rotations. A summary of results with continuous corn or corn-soybean rotations from 4 Midwestern states (Fig. 2) shows that approximately 400 lbs/acre/yr were lost with moldboard plowing, 200 lbs/acre/yr were gained with chisel plowing, and more than1000 lbs/acre/yr were gained with continuous no-till.

Besides increasing total soil organic matter content, no-till results in a different distribution of organic matter. Most organic matter is concentrated at the surface of the soil in no-till where it is mixed in the plow layer with tillage. The residue protects the soil from erosion, surface sealing and crusting. The increased surface organic matter content helps improve soil tilth and aggregate stability. In a conventional tillage situation, the reverse happens and a lack of residue cover exposes the soil to the elements. The result is sealing, crusting, and erosion. No-till has also been found to affect the stability of organic matter pools. The residence time of organic matter in no-till can increase by 10-15 years over conventional tillage (Duiker et al., 2002).

African farmers consider increasing of soil organic matter content and breaking surface soil hardpan, which prevents rain infiltration, as a method for increasing stored moisture during drought times; and for achieving this purpose they use conservation tillage methods in order to maintain residue on soil surface (Stroosnijder, 2009).

Calculating how much water can be stored in soil

While soil organic matter can hold between 2-5 times its weight in water, the impact of increasing soil organic matter on water holding capacity depends on the mineral composition of the soil, the depth to which organic matter has increased and the contribution of organic inputs to the various soil organic fractions. As a general rule, each one percentage increase in soil organic matter increases water holding capacity in agricultural soils by an average of 2-4 percent (0.8–8.0 percentage range; Hudson 1994). This is the equivalent of less than two percent on average for a one percent increase in soil organic carbon. For a soil that held 200 mm of soil water this would be equal to an additional 4 mm of water.

A one percent increase in soil organic carbon (SOC) in the top 10 cm of a sandy soil, with a bulk density (BD) of 1.4 g/cm3 and no gravel or stone content and Calculated according to equation 1.

Figure 3. Soil erosion, the number one cause of soil degradation

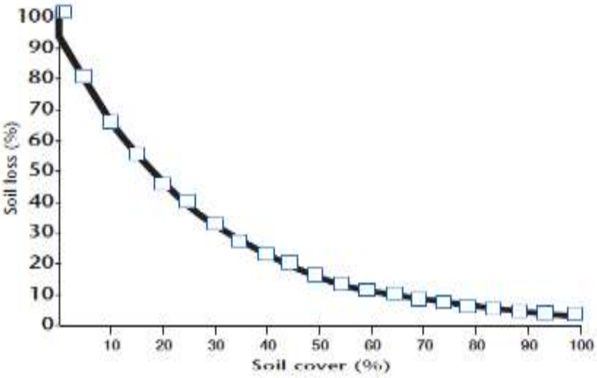

Figure 4. Residue cover – relative soil loss relationship. With 30% residue cover, soil loss is reduced 70%.

(1) Calculation (assuming one part soil organic carbon retains four parts water)

[SOC (%) x BD (kg soil/ha to 10 cm depth)] x retention factor= [0.01 x (1.4 x 100)] x 4= 1.4 kg/m^{2}x 4= 5.6 liters/m^2 (or the equivalent of 5.6 mm).

While unlikely, if this change was observed to 30 cm then = [0.01 x (1.4 x 300)] x 4 = 16.8 mm However, as most of the soil organic matter will be in the top 10 cm of the soil, reports of increases in water holding capacity beyond 10 cm are likely to be an over-estimation (Frances, 2003).

Conservation tillage and Soil erosion

One of the problems of agriculture in arid and semi-arid of reduced rainfall in drought conditions and consequently reduction of soil surface covered by plant, possibility of erosion and particularly wind erosion will greatly increase. Residue management which is gained through conservation tillage can be very effective in reducing erosion (Changnon et al., 1989). Figure 3 shows the erosion of land without crop cover and Figure 4 shows the relationship between crop cover on the soil surface with soil loss.

One of the problems of agriculture in arid and semi-arid areas is lack of soil organic matter. Lack of proper management of machinery (Inappropriate use of machinery and equipment and heavy field traffic), burning crop residue, heavy rain, lack of crop rotation, excessive use of chemical fertilizers and other factors have caused that soils in these areas to be exposed to wind and water erosion and every year a large amount of soil in such areas gets out of the farm, by rainfall and excessive irrigation, and flows into the rivers. One of the implements which exacerbate the erosion every year is moldboard plow which is outdated in many parts of the world. Studies indicate that every year 5 to 7 million hectares of agricultural lands in the world are losing their fertility (Steiner et al., 1998). Thus the use of appropriate technologies such as conservation tillage systems, as one of the applied methods in sustainable agriculture, can slow down the land degradation and increase agricultural sustainability (Swanton et al., 1991).

Organic matter is one of the important factors in the maintenance of soil against erosion. Organic matter by increasing aggregate stability, particularly in the area of soil surface, prevents dispersion of soil particles during the flow of wind and water. Analysis of observations of tillage on soil quality in Illinois revealed that soil organic carbon is the most sensitive and also best indicator of soil quality assessment; on the other hand, the main factor of increasing the oxidation and accelerated loss of soil organic carbon is [conventional] tillage (Manlay et al., 2007). Soil erosion by wind and water are the main causes of waste of soil and loss of its quality. In general, because of reduced rainfall in drought conditions and consequently reduction of soil surface covered by plant, possibility of erosion and particularly wind erosion will greatly increase. Residue management which is gained through conservation tillage can be very effective in reducing erosion (Changnon et al., 1989). Figure 3 shows the erosion of land without crop cover and Figure 4 shows the relationship between crop cover on the soil surface with soil loss.

Many long-term no-till farmers have noted improvements in water infiltration or absorption in their fields. There are times during the same storm when no runoff occurs in no-till fields while adjacent tilled fields produce large amounts of water and sediment runoff. Similar observations have been made by researchers. At the North Appalachian Experimental Watershed, runoff from the no-till watershed was only a fraction of that of the moldboard plowed watershed (Table 2). Here we see the power of residue cover illustrated again. By breaking the impact of falling raindrops, soil sealing and crusting is reduced dramatically. Improved surface tilth also stimulates infiltration. The channels created by soil organisms such as worms, soil insects and the decomposed plant roots that are found in the continuous no-till system increase water infiltration. The residues on the soil surface act as small barriers, slowing runoff and giving water a greater opportunity to infiltrate (Duiker et al., 2002).

In Australia, annual soil losses from erosion are negligible under a good pasture, but can be up to eight tonnes per hectare under planted crop. Erosion risk is strongly influenced by the amount of ground cover and the highest risk scenarios are most often associated with bare fallow, under which typical soil losses in a single year can reach between 60-80 tonnes per hectare.

Table 2. A 4-year comparison of runoff and erosion on a no-till and moldboard plowed watershed at the North Appalachian Experimental Watershed

Year	Rainfall (inches)	Runoff (inches)		Erosion Lbs / A	
		No-Till	Moldboard	No-Till	Moldboard
1979	44	0.14	5.52	8	436
1980	46	0.19	12.47	15	8455
1981	42	0.00	5.60	1	7645
1982	35	0.00	4.46	0	2461
average		0.09	7.01	6	4748

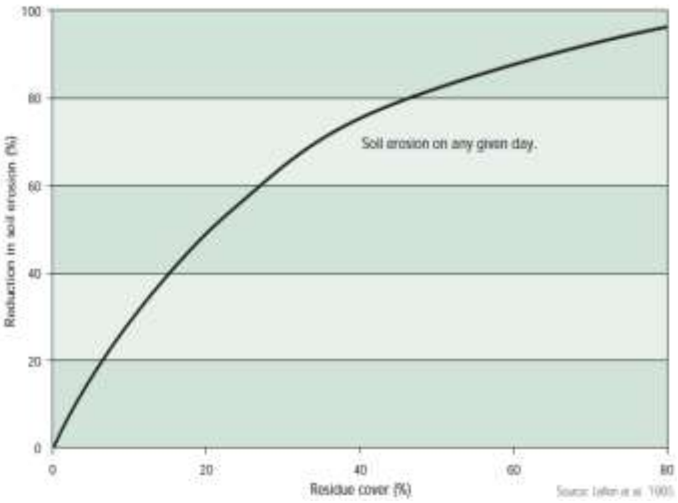

Figure 5. Effect of Residue Cover on Soil Erosion

While less common, wind and water erosion resulting from single, high-intensity storms can erode up to 300 tonnes per hectare see Plate 6.2). Since a 1 mm depth of soil weighs between 10-15 tonnes per hectare (assuming a bulk density of 1.0 to 1.5g/cm3), erosion events in cropped soils represent a significant loss of topsoil along with its associated carbon and nutrient-rich fractions (Hoyle et al. 2013). Soil physical attributes associated with high organic matter content such as more stable soil aggregates, greater porosity, improved water infiltration and improved workability at high moisture content (plastic limit) all contribute to a lower risk of soil loss from erosion.

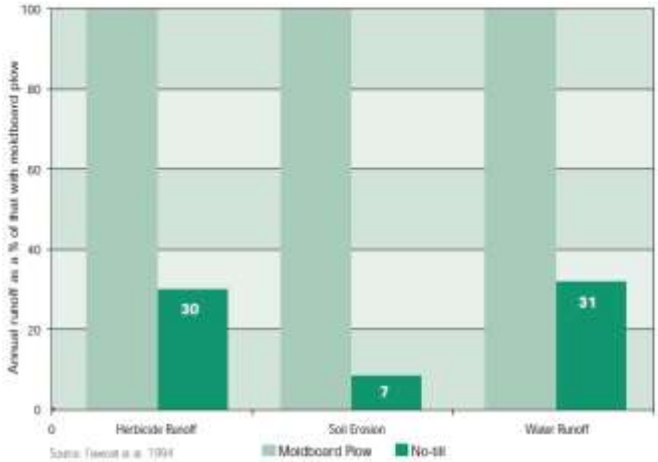

Figure 6. Runoff and Erosion in No-till Watersheds Compared to Conventional Tillage Watersheds

Conservation tillage is one of the most practical and economical ways to reduce soil erosion. Reducing or eliminating tillage operations leaves more crop residue on the soil surface, protecting the soil from the erosive impacts of wind and rain. Reductions in erosion are proportional to the amount of soil covered by crop residue (Fig.5; Laflen et al., 1985).

Also, runoff of pesticides, both soil-attached and dissolved, usually is reduced in conservation tillage. No-till sometimes has resulted in complete elimination of pesticide runoff(Foy et al., 1989; Glenn et al., 1987; Hall et al., 1991).A summary of published natural rainfall studies comparing no-till with moldboard plowing showed that, on the average(over 32 treatment-site-years of data), no-till resulted in 70 percent less herbicide runoff, 93 percent less erosion and 69 percent less water runoff than moldboard plowing(Fig.6; Fawcett et al., 1994).

Other conservation tillage systems also have reduced herbicide runoff. In a Kentucky natural rainfall study, both no-till and chisel plowing (mulch-tillage) reduced runoff of atrazine, simazine and cyanazine by more than 90 percent, compared with moldboard plowing (Sander et al., 1989).Ridge-till has reduced herbicide runoff by an average 42 percent in natural rainfall studies (Fawcett et al., 2003).

Conclusion

The use of conservation tillage systems is one of the most important management approaches to preserve and improve the physical, chemical and biological properties of the soil and keep more moisture in the soil. One way to reduce evaporation, before the complete overshadow of the main plant, is to cover soil with the previous crop residue. Maintaining crop residue on or near the surface of the soil using reduced or no-tillage operations reduces evaporation from the soil surface which resulted of temperature decrease, preventing of vapor diffusion and wind speed decrease on the soil surface.

Organic matter by increasing aggregate stability prevents dispersion of soil particles during wind and water flow. Therefore the inseparable part of conservation tillage, i.e. crop residue, reduces wind and water erosion in such a way that by the means of 30% and 80% of land by residue cover, the erosion can be reduced up to 70% and 90% respectively.

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