CHAPTER 1

LITERATURE REVIEW

1.1 Soil erosion mechanisms and processes

Soil erosion by water starts when raindrops strike the bare soil surfaces. It involves the detachment and transportation of soil particles (Tripathi and Singh, 1993; Unger, 1996; Barthes et al., 2001) followed by deposition (Barthes et al., 2001). Therefore, the fundamental erosion processes are detachment by raindrop impact and flow, displacement by raindrop impact, transport and deposition by flow (Foster, 1990). Detachment processes remove soil particles from the soil mass producing sediment while transport processes move sediment from its point of origin.

The main mechanisms of detachment are the disintegration of aggregates by slaking, cracking, dispersion and shearing by raindrop impact and runoff (Barthes *et al*., 2001). Slaking results from compression of air trapped inside rapidly wetted aggregates (Yoder, 1936 as quoted by Barthes *et al*., 2001); cracking results from differential swelling and shrinkage; dispersion results from the reduced cohesion between wetted colloidal particles (Le Bissonnaise, 1996). Shearing as well as transport by splash and runoff depend largely on kinetic energy of raindrops and runoff, but also on properties of the soil itself (Casenave and Valentin, 1989 cited by Barthes *et al*., 2001). As runoff increases according to the slope length, its shearing and transport capacities also increase, and erosion evolves from sheet erosion to more severe rill erosion (Roose, 1996).

1.2 Soil surface sealing and crusting

Surface sealing refers to the re-organization of the surface soil layer during a rainstorm and crusting is the hardening of the surface seal as the soil dries out (Morgan, 1995). Different mechanisms are involved in surface sealing. This include pore filling due to transport of fine particles into the pore spaces; particle deposition and reorientation and raindrop compaction with consolidation upon subsequent drying (West et al., 1992). Bajracharia and Lal (1999) also indicated that development of surface seal and crust involved several overlapping, parallel processes including: (a) mechanical disruption of soil aggregates by raindrop impact and slaking; (b) filling of inter-aggregate voids in surface layer of aggregates and clay illuviation; (c) raindrop compaction and rearrangement of particles in the seal layer; (d) smoothing and lowering of the surface 3-5 mm soil layer; and (e) drying and consolidation resulting in a cemented, rigid structural crust a few millimetres thick.

Soil crusting, a common phenomenon occurring in most cultivated soils in many regions of the world has major implications for agricultural production because of its effects on soil hydrological properties, erosion and crop establishment (Bajracharia and Lal, 1999). It results from the drying and hardening of surface seals, which form upon physical and chemical disruption and reorientation of soil aggregates and primary soil particles when exposed to rain or irrigation water (Bradford and Huang, 1992; Shainberg and Levy, 1996).

Rapid drop in infiltration rates of soils which was observed during rainstorms were mainly due to crust formation on the soil surface (Aarstad and Miller, 1981). Crusts are characterized by increased soil surface strength and density that leads to reduced porosity due to change in pore size distribution and infiltration capacity thereby leading to high runoff and erosion rates (Box and Bruce, 1996; Shainberg and Levy, 1996).

1.3 Effect of soil texture on sealing and erosion

Soil texture seems to be the most important soil variable influencing surface sealing (Mannering, 1967). Soil particle size distribution and the relative proportions of the various soil separates affect soil crusting. Lutz, (1952) as cited by Bradford and Huang, 1992, indicated that crusts can form on soils of any texture except coarse sand with an extremely low silt and clay contents. High clay contents generally favour aggregation and reduce crust formation although composition of the clay mineralogy and exchangeable cations will modify these generalizations (Van der Watt and Valentin, 1992). They indicated that medium textured (< 20% clay) soils are usually more susceptible to crusting. In a comparison of the sealing intensity of 8 binary mixtures, Poesen (1986) demonstrated that the soil texture most prone to sealing consists of approximately 90% sand and 10% silt and clay. In another report, Tackett and Pearson (1965) also indicated that crusts form more readily on sandy loam soils than clay loam but soils with high silt contents are even more susceptible. In an experiment involving the influence of silt and clay content on seal formation, on five soils (<20 mm aggregates), increasing silt content from 51 to 84 % while decreasing clay content from 45 to 8 % resulted in a 70 % increase in the surface strength and a 300% decrease in infiltration for a sand content <10% (Bradford and Huang 1992).

1.4 Effect of slope gradient on runoff and soil loss

Apart from slope length that was not included in the treatments of this study, slope gradient is one of the important factors affecting soil erosion by water. At low slopes, due to the low overland flow velocities, detachment or removal of soil particles from the soil surface in to the water layer is due to rainfall detachment alone (Stern, 1990). Furthermore, at low slope gradients, particles are splashed in to the air in random directions unlike the case with steeply sloping surfaces where preferential down-slope splash occurs (Watson and Laflen, 1985). However, as slope gradient increases, the ability of overland flow alone to entrain and transport sediments rises rapidly until the entrainment by the surface flow becomes the dominant mechanism contributing to the sediment transport (Stern, 1990). Runoff velocity and the effective depth of interaction between surface soil and runoff increases with increase in slope steepness (Sharpley, 1985). In the early version of the USLE, soil erosion was predicted as a power function of slope gradient (Fox and Bryan, 1999). Some researchers, for instance (Zingg, 1940; McCool *et al*., 1987) indicated that soil erosion increases exponentially with increase in slope gradient. This relationship is indicated in equation 1.1 after Zingg (1940).

$$\mathbf{E = aS^b} \qquad (1.1)$$

Where, E is soil erosion, S is slope gradient (%) and a and b are empirical constants. The value of b usually ranges from 1.35- 2.0. The other relationship between erosion and slope gradient for inter-rill erosion is given by (McCool et al., 1987)

$$\mathbf{E = a\ sin^{b}\ Q + C} \qquad (1.2)$$

Q is the slope angle in degrees
a, b, C are empirical constants.

However, even if the effect of slope gradient on erosion is well recognized, several studies indicated that the power relationship between slope gradient and soil loss over predicts interrill erosion rate by as much as two or more times (Torri, 1996; Fox and Bryan, 1999), and the relationship is better described as linear or less than linear.

1.5 Effect of rainfall intensity on runoff and soil loss

Soil loss is closely related to rainfall partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to runoff (Morgan, 1995). This applies particularly to erosion by overland flow and rills for which intensity is generally considered to be the most important rainfall characteristics.

If rainfall intensity is less than the infiltration capacity of the soil, no surface runoff occurs and the infiltration rate equals the rainfall intensity (Horton, 1945) as cited by Morgan (1995). If the rainfall intensity exceeds the infiltration capacity, the infiltration rate equals the infiltration capacity and the excess rainfall forms surface runoff.

The effect of rainfall intensity on infiltration rate and runoff is modified by other soil characteristics like water content and soil texture. According to Morgan (1995), when the soil is unsaturated, the soil matric potential is negative and water is held in the capillaries due to the matrics suction. Hence, under unsaturated conditions, sands, which normally have low levels of capillary storage, may produce runoff very quickly although their infiltration capacity is not exceeded by the rainfall intensity. Since rainfall intensity partly controls hydraulic conductivity, increasing the rainfall intensity may cause conductivity to rise so that, although runoff may have formed rapidly at relatively low rainfall intensity, higher rainfall intensities do not always produce greater runoff (Morgan, 1995). This mechanism explains the reason why infiltration rates sometimes increase with rainfall intensities (Nassif and Wilson, 1975). This increase in infiltration capacity with increased intensity was also reported by Bowyer- Bower (1993) who found that, for a given soil, infiltration rate was higher with higher rainfall intensities because of their abilities to disrupt surface seals and crusts which otherwise keep the infiltration rate low.

1.6 Soil erosion impacts

1.6.1 Soil physical properties

Progressive soil erosion increases the magnitude of soil related constraints for crop production. The constraints can be physical, chemical or biological. Among the important soil physical constraints for crop production exasperated by erosion include: reduced rooting depth, loss of soil water storage capacity (Schertz et al., 1984; Kilewe, 1988; Ebeid et al., 1995; Sertsu, 2000), crusting and soil compaction and hardening of plinthite (Lal, 1988). Erosion also results in loss of clay and colloids due to preferential removal of fine particles from the soil surface (Fullen and Brandsma, 1995). The loss of clay influences soil tilth and consistency. Exposed subsoil is often of massive structure and harder consistency than the aggregated surface soil (Lal, 1988).

Development of rills and gullies may change the micro-relief that may make mechanized farming operations difficult. Another physical effect of erosion concerns the management and timing of farm operations. Achieving a desired seedbed with friable tilth necessitates a delay in ploughing until the soil is adequately watered (Lal, 1988).

1.6.2 Soil chemical properties

Erosion reduces the fertility status of soils (Morgan, 1986; Williams et al. (1990). Soil chemical constraints and nutritional disorders related to erosion include: low CEC, deficiency of major plant nutrients (N, P, K,) and trace elements (Lal, 1988; Fullen and

Brandsma, 1995). Massey et al., (1953) reported an average loss of 192 kg of organic matter, 10.6 kg of N and 1.8 kg of exchangeable K per ha on a Winsconsin soils with 11% slope. Sharpley and Smith (1990) reported that the mean annual loss of total P in runoff from P fertilized watersheds is equivalent to an average of 15 %, 12 %, and 32 % of the annual fertilizer P applied to wheat, mixed crop and grass, and peanut - sorghum rotation practices respectively. Various workers (Massey *et al*., 1953; Lal, 1975) have also reported extensive loss of N in eroded sediments. Based on the nutrient contents and ranges of soil losses in the highlands of Ethiopia, Sertsu (2000) estimated the annual nutrient losses due to erosion to be in the range of 36 to 429 kg ha^{-1} of N, 0.412 to 5 kg ha^{-1} of the available P and 1.4 to 17 kg ha^{-1} of the exchangeable K.

1.6.3 Productivity

Quantifying the effects of soil erosion on crop yields is a complex task because it involves the assessment of a series of interactions among soil properties, crop characteristics, and the prevailing climate. The effects are also cumulative and often not observed until long after accelerated erosion begins (Lal, 1988). Furthermore, the magnitudes of erosion’s effect on crop yields depend upon soil profile characteristics and management systems. Crop yield, an integrated response to many parameters is difficult to relate under field conditions to any individual factor. It is, therefore, difficult to establish a one-to-one, cause and effect relationship between rates of soil erosion and erosion induced soil degradation on the one hand and crop yield on the other (Lal, 1988).

Despite all these, it is well known that soil erosion can reduce crop yields through loss of nutrients, structural degradation and reduction of soil depth and water holding capacity (Timilin *et al*., 1986; Lal, 1988). In Ethiopia, the average crop yield from a piece of land (1.2 t ha^{-1} for cereals, 0.6 t ha^{-1} for pulses and 0.5 t ha^{-1} for oil crops) is very low according to international standards mainly due to soil fertility decline that is associated with removal of topsoil by erosion (Sertsu, 2000). The loss of economy due to reduced agricultural production resulting from the effect of soil erosion has been estimated on average to amount to 600 million Birr (Ethiopian currency per year; 8.56 Birr ≈ 1US$ in 2003). In addition to reduced grain yield, erosion also increases crop production costs (Lal, 1988; Sertsu, 2000). Improved technology may however, mask the effect of lost fertility and water storage capacity making the effects difficult to quantify (Schertz *et al*., 1984, Lal, 1988).

Generally, fertility and soil structure can be restored through management practices that include addition of plant nutrients and crop rotation. However restoration of water holding capacities and soil depth is not economically feasible. In rain-fed agronomic systems, yield reduction due to changes in these characteristics can be permanent (Frye et al., 1982)

Loss of production in eroded soil further degrades its productivity, which in turn accelerates soil erosion. The cumulative effect observed over a long period of time may lead to irreversible loss of productivity in shallow soils with hardened plinthite or in soils that respond only to expensive management and to additional inputs (Lal, 1988).

1.6.4 Off-site effects of soil erosion

Among the most important offsite effects of erosion include: siltation of reservoirs, crop failure at the low-lying areas due to flooding, pollution of water bodies due to the various chemicals brought by the runoff from the different areas. Several studies reported the significance of the off -site effects of erosion on land degradation (e.g. Wall and van Den, 1987; Lo, 1990; Robertson and Colletti, 1994; Petkovic et al., 1999; Suresh et al., 2000)

Surface rainwater washes away materials that originate from fertilizers and various biocides (fungicides, insecticides, herbicides and pesticides, etc.) which are applied in ever increasing doses with the result that they reappear in greater quantities in the hydrosphere polluting and contaminating the water environment (Zachar, 1982; Intarapapong et al., 2002; Verstraeten, and Poesen, 2002; Withers, and Lord, 2002). It is estimated that in some regions, upon 40% of this matter is carried into the rivers. This is also true for industrial fumes that increasingly pollute the soil surface from where they are carried by the flow in to watercourses. Owing to chemical pollution of water mainly by organic matter from farm fields, a rapid eutrophication takes place in waterways (Zachar, 1982; Zakova et al., 1993; Lijklema, 1995).

Problems associated with sediment accumulation in the low-lying areas are recognized in Ethiopia. For instance, the reduction in hydroelectric power production at the Koka reservoir in the year 2002 was ascribed to siltation (Nyssen et al., 2003). It is estimated that 18 x 10^6 tonnes of sediments enter into the reservoir from a catchment of approximately 4050km^2 (Shahin, 1993 as quoted by Nyssen, 2003). The Atbara, Blue Nile and White Nile sub-basins are considered to be the main sources of sediment deposition in the Aswan High Dam (Fahmy, 1998, Nyssen, 2003). Lake Alemaya, which is closer to Alemaya University, is also drying due to siltation problem.

1.7 Soil erosion models

Models are simplifications of realities (Morgan, 1995). Modeling soil erosion is the process of mathematically describing soil particle detachment, transport and deposition on land surfaces (Nearing et al., 1994). Erosion models can be used as predictive tools for assessing soil loss, conservation planning, soil erosion inventories and project planning. Moreover they can be used as tools for understanding erosion processes and their impacts (Nearing et al., 1994).

A wide range of models that differ in terms of their data requirement for model calibration and use, complexity and processes considered are available for use in simulating sediment and pollutant transport (Merritt et al., 2003). These models are basically categorized into three types namely empirical or statistical, conceptual and physically based (Morgan, 1995, Nearing et al., 1994, Merritt et al., 2003). The distinction between these models is somewhat subjective as there is no sharp difference among them.

1.7.1 Empirical models

Empirical model are based primarily on observations and are usually statistical in nature. They are based on inductive logic, and generally are applicable only to those conditions for which the parameters have been calibrated (Nearing et al., 1994, Merritt et al., 2003). The primary focuses of the empirical models have been in predicting average soil loss although some extensions to sediment yield have been developed (Williams, 1975 as quoted by Nearing et al., 1994). Empirical models are generally based on the assumption of stationarities that is, it is assumed that the underlying conditions remain unchanged for the duration of the study period. They are not event responsive and ignore the process of rainfall- runoff in the catchments being modeled. They make no inferences as to the processes involved at work. However, as they can be implemented in situations with limited data and parameter inputs, empirical models are frequently used in preference to the more complex models and are particularly useful as first step in identifying sources of sediment and nutrient generations (Merritt et al., 2003). Among the commonly used empirical erosion models include: the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978), RUSLE (Renard et al., 1994) and the Soil Loss Estimation Model for Southern Africa (SLEMSA) (Elwell, 1978)

1.7.2 Conceptual models

Conceptual models are based on spatially lumped forms of water and sediment continuity equations (Lane et al., 1988 in Nearing et al., 1994). They usually tend to include a general description of catchment processes, without including the specific details of process interactions which would require detail catchment information (Merritt et al., 2003). These models can therefore provide an indication of the qualitative and quantitative effects of land use changes, without requiring large amounts of spatially and temporally distributed data. Conceptual models play an intermediatory role between empirical and physically based models (Beck, 1987). Te main feature that distinguishes the conceptual models from the empirical models is that the conceptual model, whilst they tend to be aggregated, they still reflect the hypothesis about the processes governing the system behaviors (Merritt et al., 2003). The Agricultural Non-point Source Model (AGNPS) (Young et al., 1989), Agricultural Catchment Research Unit (ACRU) (Schulze, 1995), Hydrologic Simulation Program, Fortran (HSPF) (Walton and Hunter, 1996), and Simulator for Water Resources in Rural Basins (SWRRB) (Arnold et al., 1990) are among the conceptual models (Merritt et al., 2003) used in erosion and /or water quality studies.

1.7.3 Physically based models

Physically based models are based on solving fundamental physical equations describing stream flow and sediment and associated nutrient generations in a catchment (Merritt et al., 2003). They are developed to predict the spatial distribution of runoff and sediment over the land surface during the individual storms in addition to total runoff and soil loss (Morgan, 1995). Physically based models are also termed process-based models (Morgan, 1995) as they still rely on empirical equations to describe erosion processes. Most physically based models use a particular differential equation known as the continuity equation, which is a statement of the conservation of matter as it moves through space over time. The common physically based models used in water quality and erosion studies include: The Areal Non-Point Source Watershed environment Response Simulation (ANSWERS) (Beasley et al., 1980), Chemical Runoff and Erosion from Agricultural Management systems (CREAMS) (Knisel 1980), Griffith University Erosion System Template (GUEST) (Misra and Rose, 1996), European Soil Erosion Model (EUROSEM) (Morgan, 1998), Productivity, Erosion and Runoff, Functions to Evaluate Conservation Techniques (PERFECT) (Littleboy et al., 1992), and Water Erosion Prediction Project (WEPP) (Laflen et al., 1991).

1.7.4 Selection of models for use in the present study

A good model should satisfy the requirements of reliability, universal applicability, ease of use with a minimum data, comprehensiveness in terms of the factors and erosion processes included and the ability to take account of changes in land use and conservation practice (Morgan, 1995). It is generally considered that no single model is ‘the best’ for all applications. The most appropriate model for a particular study will depend on the intended use and characteristics of the catchments being considered. Merritt et al. (2003) described other factors that affect the choice of a model for application that include: data requirement including the spatial and temporal variation of model inputs and outputs; the accuracy and validity of the model including its underlying assumptions, the components of the model reflecting its capabilities; the objectives of the model use(s) including the ease of use of the model, the scales at which the model outputs are required and hardware requirements.

Models might also be acceptable if they meet their objectives and design requirements (Morgan, 1995).

The main criteria that were considered for selection of the soil loss models used in most studies include: less input requirement, computational simplicity, wide applicability and relative validity in the study areas. The conceptual and physically based models require high input data which are not usually available and are more sophisticated than the empirical models (Merritt et al.,. 2003). There is a lack of simplified and distributed physically based models that can be applied under conditions where limited data is available. Model applications under such situations have mainly tended to be of an empirical nature. To this effect, the empirical models, particularly the USLE and SLEMSA were considered for use in this study due mainly to their simplicity and less input requirement while reasonably meeting the objectives of the study. Although RUSLE is the latest, most advanced, computer based version of USLE, its use for this study was limited by the insufficient data availability for the study sites.

The Universal Soil Loss Equation (USLE) was included in the study due to its adaptation and applications in some parts of Ethiopia (Hurni, 1985; Griffiths and Richards 1989; Nyssen, 1997; Eweg et al., 1998; Reusing et al., 2000) and the fact that it is a widely applied model in the world (Nearing et al., 1994; Morgan, 1995; Merritt et al., 2003). Moreover, it is relatively simple and requires relatively few data (Wischmeier and Smith, 1978; Morgan, 1995; Merritt et al., 2003). Therefore, it can be used to provide first hand information for different planning purposes in data-poor situations like this one.

Similarly, SLEMSA was considered in this study as it was widely applied in the African continent (Igwe et al., 1999) especially the Southern Africa (Elwell and Stocking, 1982; Elwell, 1984; Granger, 1984; Abel and Stocking, 1987; Stocking, 1987; Annersten, 1988; Chakela and Stocking, 1988; Albaladejo and Stocking, 1989; Hartmann et al., 1989; Chakela et al., 1989; Elwell, 1994; Mulengera et al., 1996; Smith et al., 1997; Morgan et al., 1998; Svorin. 2003). The details of the descriptions of the input factors considered, their assumptions, procedures and sensitivity analysis of the USLE and SLEMSA models are presented in chapter 3**.**

1.8 Role of crop residue mulching on soil properties and erosion control

Mulching involves covering the soil surface with agricultural by-products (Kohnke and Bertrand, 1959) for instance, straw stubble, wood chips, plastic films (Unger and Jones, 1981) manure and natural sources like rock fragments (Box, 1981). According to Erenstein (2003), mulching (organic) can be defined as a technology whereby at least 30% of the soil surface is covered by organic material. Covering the soil with crop residue mulch increases infiltration capacity and decreases runoff and erosion losses in practically all cases (Kohnke and Bertrand, 1959). Agassi (1996) also indicated that mulching is a very efficient means to dissipate raindrop impact and control the ensuing soil surface sealing, runoff, and erosion. It can also reduce evaporation of rainwater and overhead irrigation water. Therefore it can be a vital factor in improving water use efficiency (Erenstein, 2003).

Mulching affects the physical, chemical and biological conditions of the soil; the overall conditions being good for soil and water conservation (Kohnke and Bertrand, 1959; Erenstein, 2003). The soil conservation effect of crop residue mulching is summarized in Fig 1.1 and the details of some major effects are discussed subsequently.

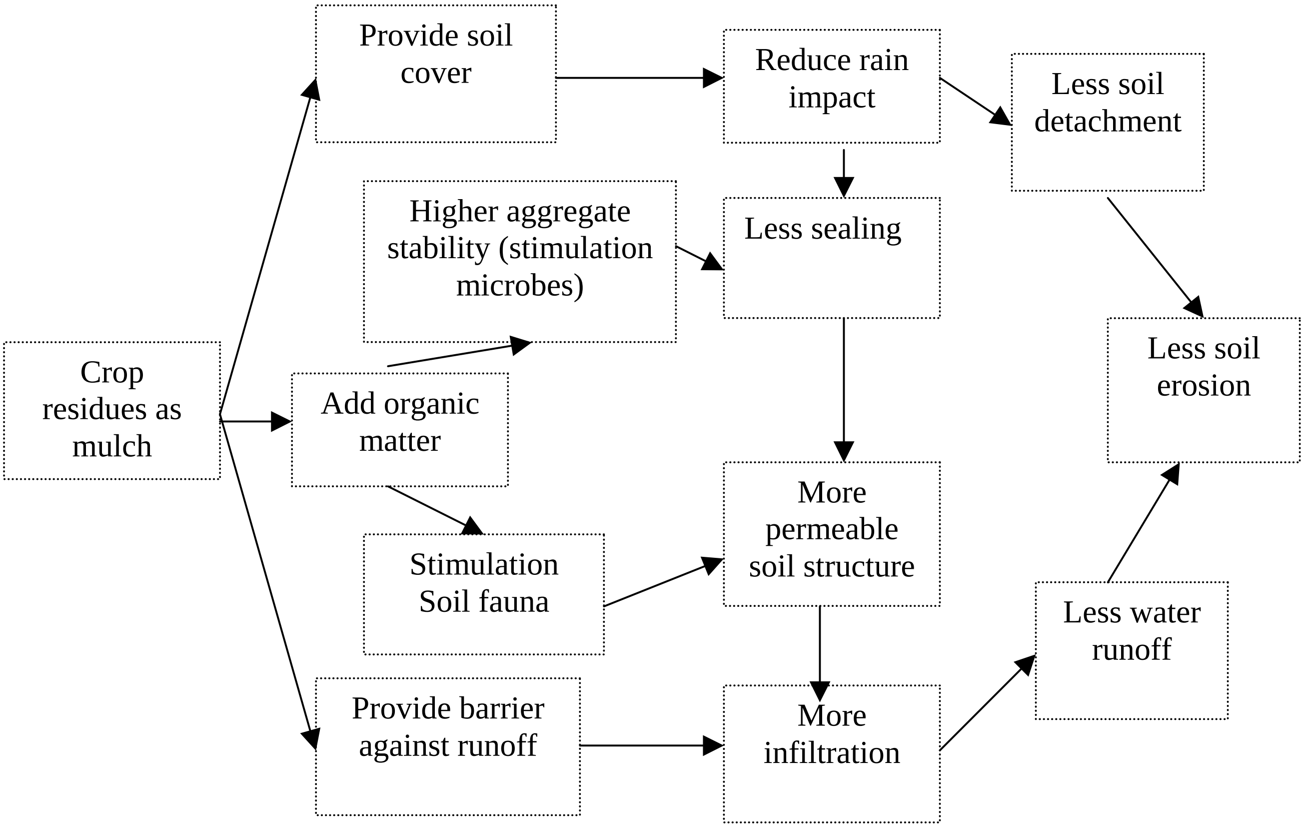

Fig. 1.1. The soil conservation effect of crop residue mulching (Erenstein, 2002)

1.8.1 Soil physical properties

Mulching affects the physical properties of soils in different ways. These include: reduction in direct impact of raindrops (Kohnke and Bertrand, 1959; Suwadjo and Abujamin, 1983), decreasing the amount and distance of splash, reducing fluctuation in soil moisture and soil temperature (Kohnke and Bertrand, 1959), reducing temperature during hot seasons (Lal, 1979; Bonsu, 1983; Suwadjo and Abujamin, 1983), increase temperatures during low temperature seasons, reduce the rate and frequency of soil freezing and depth of frost penetration, increase aggregation of soil surface resulting in improved soil structure (Suwadjo and Abujamin, 1983), and increase resistance of the soil to detachment by wind erosion.

Reports also indicate that, as compared to bare soils, mulched soils have greater porosity (Suwadjo and Abujamin, 1983); increased water holding capacity (Unger and Wiese, 1979; Unger and Jones, 1981; Edwards et al., 2000), higher infiltration rate (Bonsu, 1983), increased amount of percolation, less runoff and water erosion (Suwadjo and Abujamin, 1983), less evaporation (Unger and Jones, 1981), decreased wind velocity and erosion.

Moreover, Black and Siddoway (1979) indicated that mulching reduced soil crusting and erosion. It is also reported that mulching increases water use efficiency (Bonsu, 1983; Unger and Jones, 1981; Erenstein, 2003) and reduce soil loss (Edward et al., 2000).

1.8.2 Soil chemical and biological properties

In addition to its effect on physical properties of soils, various researchers indicated that mulching also plays a vital role in releasing plant nutrients like N, P (Buerkert et al., 2000) and K in available form (Bonsu, 1983). Mulched soils were found to encounter less loss of plant nutrients in runoff and sediments (Bonsu, 1983; Shock et al., 1997). It is also indicated that mulching a soil with crop residues result in a possible fixation of the available N and P in organic form shortly after application of straw thereby reducing its susceptibility to runoff loss (Kohnke and Bertrand, 1959). These authors also reported increased biological activities near the soil surface because of increased energy supply and more uniform moisture and temperature conditions in mulched soils. Soils with organic mulches are also reported to have stable organic matter content due to temperature regulation (Suwadjo and Abujamin, 1983). Mulching also implies C-sequestration through temporary immobilization of CO_2 (a green house gas contributing to global warming) thereby potentially converting annual cropping from a net source to a net sink of CO_2 (Kern and Johnson, 1993; Lal and Bruce, 1999; Follett, 2001; Erenstein, 2003)

1.8.3 Soil erosion control

Proper use of crop residues is one of the most effective tools to solve soil erosion problems (Larson et al., 1978; Erenstein, 2002). The reduction of runoff and erosion by surface mulches of plant residues (Schomberg and Steiner, 1999) under natural vegetation has been recognized for many years (Aarstad and Miller, 1981). According to Erenstein (2002), soil erosion tends to decline asymptotically to zero as cover increases. A complete cover of the soil surface fully protects the soil from raindrop impact (Sharma, 1996) and can conceivably eliminate soil erosion (Erenstein, 2003). In a study of corn residue management to reduce erosion in irrigation furrows, Aarstad and Miller (1978) suggested that corn residue in irrigation furrows can eliminate erosion and runoff water turbidity and increase infiltration. In another study involving the effect of different mulching rates on furrow irrigation, Aarstad and Miller (1981) observed that erosion rates, as indicated by the amount of sediments in the runoff water were decreased greatly by all residue treatments. Turbidity of runoff was markedly decreased by all residue treatment compared with that of clean furrows. They indicated that the highest residue rate (2.2 Mg ha^{-1} of residue placed uniformly along the furrows) reduced runoff water turbidities to less than those of the inflow water. Wischmeier (1973) also estimated that each 2.2 Mg ha^{-1} crop residue reduces soil loss from water erosion by 65%. In general, he reported that 3-4 Mg ha^{-1} of crop residue is needed to minimize soil erosion and reduce it to the tolerable level.

Soil surface covers dissipate raindrop impact energy, reduce the area of erodible surface causing flow energy to be dissipated on non-erodbile cover in contact with the surface, increase infiltration by reducing surface sealing and reduce the velocity of runoff flow (Box and Bruice, 1996; Sharma, 1996).

According to (Aarstad and Miller, 1981), infiltration rate increased as the amount of residue in the furrow increased. The increase in infiltration rates due to the residue results largely from reduced water velocity and increased wetted perimeter in the furrows.

In a continuous rotations of no-tillage annual winter crops (Barley, winter wheat and crimson clover) and summer crops like soybean or sorghum, Mills et al., (1988) observed that runoff and soil loss were greatly reduced where crop residues were left on the soil surface. Similar results were observed for conservation tillage of cotton in Alabama (Yoo and Touchton, 1988). Foster et al. (1985) emphasized on the physical roles of crop residues on soil surface involving dissipation of raindrop energy, retardation of runoff and consequent impedance to soil particle detachment, suspension and transport

Moreover, many other workers attribute the reduction in soil erosion due to no-tillage to increased amounts of crop residues on the soil surface which protect the surface from raindrop impact and reduce the transport capacity of surface flow (Foster et al., 1985; Meyer, 1985)

The efficiency of residue cover is affected by physical variables like rainfall, soil and topography that influence the water erosion process. Relatively low levels of residue from 1 to 3 Mg ha $^{-1}$ (20-60% cover) can greatly reduce soil losses (Rodriguez, 1997). Crop residue requirements for erosion control also depend on the type of residue, type of erosion (wind vs. water), and the condition of the residues (flat vs. standing). According to Unger (1988) requirements of crop residue are generally high for soils of loamy texture with residue flat on the soil surface.

In his studies on effect of grain straw and furrow irrigation stream size on soil erosion and infiltration, Brown (1985) observed that straw reduced erosion as water entered the furrows from gated pipes. The straw treated furrow is wider and shallower increasing the wetting perimeter than the non-straw treated furrows. Straw reduced net sediment yield by 52% and 71% during the irrigation season at low and high flow rates respectively. Runoff and soil losses were 42 and 29% higher in high flow rates respectively than in low flow rates.

In a study that evaluated the effects of combining cottage cheese whey and straw on infiltration and erosion on irrigated furrows, Brown et al. (1998) indicated that these treatments significantly reduced soil loss and increased infiltration thereby conserving soil, water and plant nutrients compared to untreated furrows at the ARS South Farm of the USDA (2.4Kms south west of Kimberly on coarse, silty, mixed, mesic, Durixerollic Calciorthid). They also indicated that straw alone significantly reduced season-long sediment outputs by 84%. The straw became partially covered and held in place by sediments creating mini-dams that slowed the water which increase the wetted perimeter causing higher infiltration.