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EFFECTS OF SOIL AND WATER CONSERVATION MEASURES ON THE ENVIRONMENT: A REVIEW

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Abstract: The preservation and sustainable development of soil and water resources is one of the basic principles for the development of the environment. Soil degradation was a significant global issues during the 20th century and remains of high importance in the 21st century as it affect the environment, agronomic production, food security, and quality of life. This review provides an extensive review information on soil conservation strategies or methods and their applications. Based on this, the most promising soil conservation technologies are identified to improve the management and conservation of soil resources. This review also aims to provide general characteristics of soil and water loss, explore the relationship between soil and water conservation and sustainable development, and to provide relevant methods for soil and water conservation.

The result of this review shows that measures focused on soil and water conservation by ridging, constructing earth bunds and terraces, mulching, multiple cropping, fallowing, and tree planting. Mulching, crop management, and conservation tillage are appropriate technologies for conserving sandy soils of high erosivity and low water holding capacity. Leguminous cover crops and residue management reduce the impact of rain.

These measures also reported to enhance the levels of soil organic matter and nutrients, especially nitrogen, which is generally limited in tropical soils. Intercropping of compatible species is recorded as a promising cropping system, as cultures with different rooting patterns and growth cycles can promote nutrient recycling and suppress weeds.

Key words*: mulching, terracing, conservation tillage, soil, ridging, crop management*

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INTRODUCTION

Soil and water conservation is a comprehensive subject on the study of reasonable exploration and utilization of water resources. The preservation and sustainable development of soil and water resources is one of the basic principles for the development and sustainability of any environment. According to [1] there is a direct proportion between the water and nutrient absorbed by plants and soil capacity of the root system. A highly extended roots which is affected by soil structure can help plants to absorb nutrients needed.

The preservation and sustainable development of soil and water resources is one of the basic principles for the development any country. The United Nations predict that 1.8 billion people will experience absolute water scarcity in less than 5years, and worry that by 2025, two out of three persons will be living in water stressed region [2]. Already, every five persons worldwide cannot access their basic everyday water resources [2]. This is a fact recently witnessed in Cape Town, South Africa which is in dire need of water with serious rationing of the commodity. Water will be a renewable resource, but its capacity to renew itself depends on how it is managed. Restoration of degraded soil calls for the application of certain management and conservation measures and the undertaking of much needed precautions. Measures such as contour cultivation, tied ridging, terracing, strip cropping, dense vegetation and planting of cover crops, mulches, fast growing species and integrated cropping system, provision of alternative fuel sources, check structures, protected watersheds, proper land preparation and ploughing, application of fertilizer, amendments and organic manures and drainage systems are quite often mentioned as the techniques which help to protect and improve the soil [3].

Soil and land management practices such as tillage and cropping practices, directly affect the overall soil erosion problem and solution on a farm. When crop rotations or changing tillage practices cannot effectively control erosion on a field, a combination of measures might be considered necessary. For example, contour ploughing, strip cropping, or terracing may be considered. The most practiced measures involves: (1) Agronomic such as plant/soil cover, conservation farming , contour farming (2) Vegetative; such as planting barriers (vegetative strips), live fences, windbreaks (3) Structural; such as terraces, banks, bunds, cut off drains, barriers and lastly (4) Overall management; such as area closures, selective clearing.

Terraces

A terrace is an embankment or ridge of earth constructed across a slope to control runoff and minimize soil erosion [4]. A terrace reduces the length of the hill-side slope, thereby reducing sheet and rill erosion and prevent formation of gullies. Research have shown that soil loss by erosion is proportional to the length of slope to the 0.5 power [5; 6]. Doubling the length of slope increases erosion about 1.4 times. By shortening the length of slope, terraces contribute greatly to reducing soil loss. About 70 per cent of the soil disturbed by splash erosion moves downhill. Terraces produce a barrier to partially stop this downhill movement of soil. A great part of the splashed soil is deposited in the terrace channel (Fig 1).

Terracing, however, cannot be justified on crop land that can be protected by less expensive conservation measures. Agronomic measures such as contour tillage, crop rotation, and strip cropping are sufficient on many slopping areas.

These measures alone may furnish enough protection where rainfall intensities are low, the soil absorbs the rainfall rapidly or are erosion-resistant, and the slopes are gentle. Agronomic control measures may give a partial control, and they can be successfully reinforced with terracing [7]. Terraces should always be supplemented with the best possible cropping practices, since they fail to hold the soil adequately when used alone [8].

Fig 1.Illustration of bench terraces, [5]

Levelled bench terraces and earth banding on existing slopes are common earth structure used in soil and water conservation. Sometimes, and especially in the highlands, steps are constructed across hillsides and strips of crop residues are covered with soils dug from above. The resulting incorporation of organic matter increases soil fertility and enhances infiltration [9] through macro porosity as well as increased water retention in soils [10; 11]. The challenge however, is the high labour requirement in their construction and maintenance [12]. [13] observed highest maize yields in terraced compared to all other conservation measures in sloping land.

For instance in Kenya, there are three major principles on conservation agriculture practiced in Kenya; minimal soil disturbance, permanent soil cover and crop rotations [2]. Soils under conservation agriculture tend to considerably improve their soil organic matter content after applying the technology for several years. Soil organic matter can be considered as the most important soil fertility and quality factor influencing other soil properties such as macro porosity, infiltration, water holding capacity or soil structure. In conservation agriculture, only minimal or no soil tillage is applied and involves crop seeding without mechanical seedbed preparation and minimal or no soil disturbance since the harvest of the previous crop [12; 1].

Contour Farming

Contouring farming is the practice of conducting all field operations such as ploughing, planting, and cultivating land across the slope, rather than up and down the slope [14].

The small ridges and plant stems in the plant stems in the contoured rows hold water and thus prevent runoff and soil erosion [14]. The ridges are most effective in row crops, but the water holding ability of the ridges, supplemented by plant stems, makes contouring valuable for small grains. This practice is the simplest and easiest of all the mechanical soil conservation measures. When contouring is used alone on steeper slopes or under conditions of high rainfall intensity and soil erodibility, there is an increased hazard of gullying because of breaching of rows. Breaches cause cumulative damage as the volume of water increases with each succeeding row. The effectiveness of contouring is also reduced by changes in infiltration capacity of the soil due to surface sealing. Depressing storage is reduced after the tillage operations cease and settlement take place. Studies have shown that contour cultivation together with good grassed waterways reduced watershed runoff to 75 to 80 percent at the beginning of the season. This reduction dropped as low as 20 percent at the end of the year, with an annual average reduction in runoff, due to contouring, of 66 percent. For best results on steeper slopes contouring should supplement other conservation practices like strip cropping, terracing or bunding [15].

Strip Cropping

Strip cropping is the practice of growing alternate strips of close-growing and intertilled crops in the same field [9]. Strip cropping (Fig 2) of maize, oats and hay on the field. Crops have been grown in association with one another for centuries. In fact, crop mixture probably represents some of the first farming systems [16]. Complex crop mixture have been recognized as being important in the sub tropics and temperate zones, primarily in labor intensive cropping system.

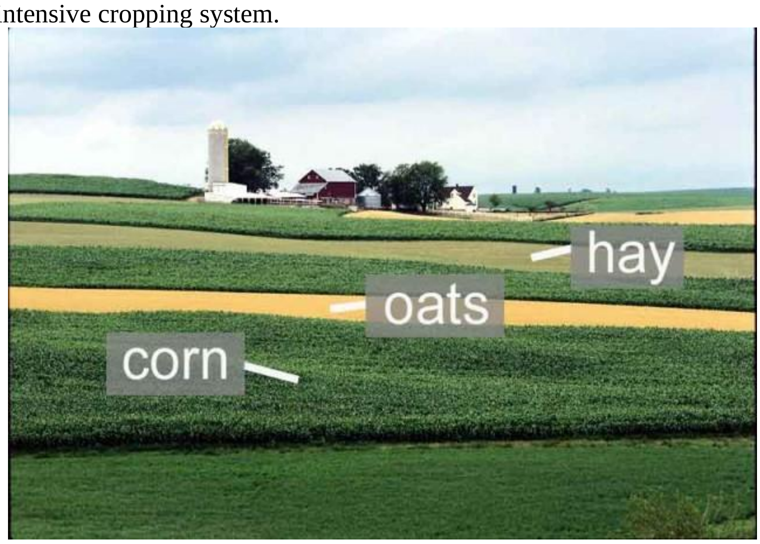

Fig 2. Strip cropping of corn, oats and hay on an agricultural field, [9].

This is a more intensive soil conservation practice than contouring, but is not as intensive as terracing or bunding. It is quite often used in conjunction with terracing or bunding. Strip cropping is not a single practice; it is a combination of several good farming practices, particularly crop rotations, contour farming and cover cropping. It may also include conservation tillage operations and stubble mulching. When strip cropping is combined with contour tillage or terracing, it effectively divides the length of the slope, checks the velocity of runoff, filters out soil from the runoff water and facilitates absorption of rain. The growing of perennial grass in the rotation provides protection for a part of the field at times when the intertilled strips are bare.

Strip-cropping to control soil erosion against runoff, derives its effectiveness mainly from the following two reasons: (a) reducing the runoff flow through close growing sod strips, (b) increasing the infiltration rate under cover conditions. The reduction in runoff velocity between the row strips is because of making obstruction in the flow path [17; 14]. The obstructions created by row crops are also responsible to dissipate the kinetic energy of flowing water, as a result the flow velocity at the downstream section get reduced sufficiently, which causes deposition of soil particles over the soil surface.

The crops grown in strips not only reduce the flow velocity of water over the surface, but also encourage the water intake rate of the soil, which might be due to the following reasons: (1) the crops provide an obstruction in flow path of surface water, that is water gets additional time to stand between the rows. By this virtue, a large amount of water infiltrated into the soil, as result the depth of water causing runoff generation is reduced significantly, and thereby the soil loss also get reduced accordingly; (2) the root system of the crops makes the soil more porous causing more amount of water is absorbed by the soil, and thus reduces the runoff and soil loss; (3) the water also gets additional intake path along the roots of the plant, which creates a similar effect on runoff and soil loss.

When strips are laid with varying degree of divergence from the contour, then effectiveness of strip-cropping is influenced by the soil types, degree and length of land slopes, previous erosion. The effect of soil type is imposed by all those soil properties, which are responsible to increase water intake capacity. From field investigations it has been found that 2 to 3 times greater soil loss is from the soil having moderately heavy to heavy sub-soil than the soils with light textured sub-soil for the same slope conditions [18]. The degree and length of land slope have pronounced effect on soil loss. The reason may be justified as: the erosive power of flowing surface water is increased due to increase in slope inclination, as a result the certain range, the erosion also increases, accordingly, but at greater length there start sediment deposition due to reduction in runoff volume and its velocity. The combine effect of slope and its length is more significantly on soil loss. In addition to control the soil erosion/soil loss, the strip cropping is also very effective to maintain the soil fertility; and creating effects on several good farming practices including crop rotation, contour cultivation, proper tillage, stubble mulching, cover cropping, mainly.

Erosion reduction by strip cropping on hillsides

Another dimension of strip cropping is the use of annual small grains or perennial hay crops in alternating strips with corn or soybeans.

In addition, crop rotations, residue management and conservation practices all contributes to the maintenance of productive top soil on erosive hillsides. Water-induced soil erosion is retarded by introducing small grain or meadow/legume crops as part of alternative farming systems [16].

Crop Rotation

Crop rotation is defined as the practice of growing a sequence of plant species on the same soil [19]. Crop rotation is characterized by a cycle period, while crop sequence is limited to the order of appearance of crops on the same piece of land during a fixed period [20]. Crop rotation (Fig 3) is along used concept in models to represent the temporal dimensions of cropping plan decisions. The succession of crops in a given area has effects on production and consequently on cropping plan decisions, the traditional approach developed by agronomists was to derive cropping plans from the crop proportions in crop rotation. Some authors have argued that the reproducibility of a cropping system over time is only ensured when crop choices are derived from crop rotation. Cropping plan decisions consequently require one to look back and forth in time [20].

Fig 3. Crop rotation a way to boost yield and increase profit, [21]

Crop rotation can be more effective for controlling the soil erosion when accompanied with strip-cropping system. It can be used on the same piece of land by growing tilled crops, small grain crops, hay crops or grasses either under strip-cropping system or in a separate field system.

In the areas, where perennial grasses and legumes are not feasible to grow, then the row crops of small grain and annual legume crops can be grown in the strips. It is a general rule that, no two cultivated strips should have the same planting or harvesting dates.
The sequence of crops should be in such a manner, that there could be formed a dense-fibrous root system to hold the soil and retard the erosion, until the roots are broken under tillage operations. All these activities under crop rotation add the organic matter in the soil, thereby the physical condition of the soil gets improved, and ultimately the soil absorbs more water and also increases the capability to resist the erosion [19; 22].

Cover crops for soil fertility and erosion control

Cover crops are fundamental sustainable tools used to manage soil quality [23; 24], water, weeds, pests, diseases and diversity in an ecosystem. Keeping the soil covered is a fundamental principle of conservation agriculture. Crop residues are left on the soil surface to protect soil surface after harvesting or during kill-down when the cover crops are slashed and left in the field at flowering [10;11]. Effects of cover crops are positive when managed to improve infiltration and reduce evaporation [11]. Cover crops have an influence on physical soil properties such as water relationships, aggregation, infiltration capacity, bulk density, soil temperature and hydraulic conductivity. Cover crops influence soil water content through reduced surface evaporation due to mulch effect and increased infiltration and retention of precipitation [2; 10; 11].
Judicious use of cover crops residues, either incorporated in the soil or placed on soil surface can help maintaining adequate infiltration rates [25; 26; 27; 28], preventing soil surface crusting [29; 30; 31; 32; 33], improving soil aggregation [34; 35; 36; 37; 38; 39], and aeration in the soil [40]. [41] found that final infiltration into the soil were increased from 2.3 to 5.3 cm/hr when 2.2 Mg/ha of wheat straw was mulched on the surface (Fig. 4). [42] reported that runoff from tropical Nigerian soil was five times greater where crop residues where ploughed under other than for no-tillage system with crop residues remaining on the soil surface. [43], modeling crop residue mulching effects on water use and production of maize under semi-arid and humid tropical conditions, observed that even small amounts of surface residue are effective at reducing water loss and increasing yield. Some cover crops have been shown to suppress weeds, reduce nematode loads, improve soil fertility, reduce water leaching and control erosion. Mulch's impact in reducing the splash effect of the rain, decreasing the velocity of runoff, and hence reducing the amount of soil loss has been demonstrated in many field experiments conducted on several Nigerian research stations [25; 44; 45; 46; 47; 48].

Fig. 4. Application of mulch in agriculture, [25].

Conservation Tillage

Conservation tillage describes the method of seedbed preparation that includes the presence of residue mulch and an increase in surface roughness as key criteria [49; 50; 44]. The practice therefor ranges from reduced or no-till to more intensive tillage depending on several factors, such as climate, soil properties, crop characteristics, and socioeconomic factors [51].

Tillage is a fundamental practice in agricultural management. It can be defined as a method of working the soil either physically, chemically, mechanically or biologically to create suitable conditions for seedling germination, establishment and growth [52]. Conservation tillage embraces not only primary cultivation practices based on ploughing or soil inversion, but also secondary operations directed at land preparation and sowing or planting. Conservation tillage typically involves inversion tillage which disturbs the soil to a depth of 20-30cm, redistributes soil layers and expose subsurface horizons to oxidation [50; 53; 52].

Minimum Tillage

Minimum tillage describes a practice where soil preparation is reduced to the minimum necessary for crop production and where 15% to 25% of residues remain on the soil surface [54; 55]. The sustainable development of agriculture has stated that there is no universally applicable system for soil tillage because of the local differences, especially climate and soil type and also the technical level of endowment. Reduces establishment costs, saves time, and reduces soil erosion, nutrient leaching and fuel use. Improves soil structure and builds organic matter.

Although not all fields will be suitable for minimum tillage. It depends on the level of compaction and surface residue. Less resistance to root growth, improved structure, less soil compaction by the reduced movement of heavy tillage vehicles and less soil erosion compared to conventional tillage [51].

Zero Tillage

Zero tillage (Fig. 5) is characterized by the elimination of all mechanical seed bed preparation except for the opening of a narrow strip or hole in the ground for seed placement.

The surface of the soil is covered by crop residue mulch or killed sod [56].

Fig 5. Zero tillage Agriculture

Research on quantifying the effects of different tillage operations on runoff and erosion were conducted by [51]. He recorded that soil loss was 42 times higher from the ploughed watershed than from the no till watershed. Other erosion measurement on soil loss were made by [57]. The result clearly show the suitability of conservation tillage as an effective soil erosion control measures through the protective effect of residue mulch.

CONCLUSIONS

Investigations focusing on the influence of different tillage methodologies performed manually or mechanically on soil properties and crop yield are numerous. According to these studies, no till and mulch farming are sustainable management technologies for humid and sub-humid tropics, whereas rough ploughing, ridging, and mulching are appropriate techniques for the semi-arid regions. Different tillage operations are necessary in locations with unfavorable climatic conditions or problematic soils. However, high labour intensity, time consuming, regular inspections, high consumption of scarce farmland, and large amount of construction materials required are factors that hinder farmers from installing or maintaining terraces.

Literature on investigation into drainage systems is scarce. The implementation probably needs special knowledge of the water regime of the area and the construction of waterways. Structural barriers made of stones or vegetation installed along contour lines are another mechanical erosion control measures. As they operate as filters, they may not reduce the runoff amount but retard its velocity and hence encourage sedimentation, increase infiltration, and facilitate the formation of natural terraces [51]. References on the use of stone lines installed as barriers on the field were not found in this review. In general, mechanical measures are effective soil conservation technologies as they reduce soil loss. But as the installation and maintenance is usually labor intensive, these structures are not likely to be adopted by farmers. According to various literatures reviewed, soil conservation measures should be site specific depending on the local factors such as topography, soil texture, water regime, and farming system. Conservation tillage, mulching, crop management are some of the appropriate technologies for conserving sandy soils of high erosivity and low water holding capacity. These measures also enhance the levels of soil organic matter and nutrients such as nitrogen, which is generally in short supply in tropical soils. From literature reviewed, alley cropping is regarded as an effective erosion control measure but is not practiced on farms in Nigeria as this technology is very labor intensive and the benefits on soil fertility did not yield the expected returns on investment. Research on minimum tillage has shown its beneficial effect on chemical, physical, and biological soil properties. However, the application of minimum tillage is problematic on soils with poor drainage, compacted layers, surface crust that still require periodic soil preparation to enhance infiltration. Minimum tillage and no-till are effective erosion control measures on coarse and medium texture soil with good drainage, whereas ridge tillage is advantageous in areas with low or variable rainfall, shallow soils and where root and tuber crops are cultivated.

Conservation tillage operations that use the effect of surface covers or increase roughness to reduce erosion risks ought to be chosen according to factors such as rainfall, crop, and depth, texture, and drainage conditions of the soil.

Permanent mechanical methods for conserving the soil are rare, as implementation and maintenance are labor, time and cost intensive and success is visible only after long periods. Water resources development will go a long way to mitigate some of the extreme climate condition that can adversely affect the soil negatively.

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EFEKTI MERA ZAŠTITE ZEMLJIŠTA I VODE NA ŽIVOTNU SREDINU: PREGLED

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Apstrakt: Očuvanje i održivi razvoj zemljišta i vodnih resursa jedan je od osnovnih principa razvoja životne sredine. Degradacija zemljišta je bila značajno globalno pitanje tokom 20. veka i ostaje od velikog značaja u 21. veku jer utiče na životnu sredinu, poljoprivrednu proizvodnju, sigurnost hrane i kvalitet života.

Ovaj pregled pruža opsežne informacije o strategijama ili metodama očuvanja zemljišta i njihovoj primeni.

Na osnovu ovoga, identifikovane su najperspektivnije tehnologije očuvanja (zaštite) zemljišta za poboljšanje upravljanjem i očuvanjem resursa zemljišta. Ovaj pregled takođe ima za cilj da pruži opšte karakteristike gubitka površina zemljišta i vode, istraži vezu između očuvanja zemljišta i vode i održivog razvoja i tako pruži relevantne metode za očuvanje zemljišta i vode.

Rezultat ovog pregleda pokazuje da su mere bile usmerene na očuvanje zemljišta i vode kroz eliminaciju nagiba, izgradnju terasa i traka, malčiranje, združene useve, zatravljivanje površina i sadnju pojasa sa drvećem.

Malčiranje, upravljanje usevom i konzervacijska obrada zemljišta su odgovarajuće tehnologije za očuvanje peskovitih zemljišta pretežno sa visokim stepenom mogućnosti pojave erozije i malog kapaciteta zadržavanja vode. Pokrovni usevi sa mahunarkama i upravljanje biljnim ostacima smanjuju uticaj padavina u pojedinim predelima.

Ove prikazane agrotehničke mere takođe pokazuju povećavanje sadržaja organske materije i hranljivih materija u zemljištu, posebno azota, koji je generalno u malim procentima prisutan u tropskim zemljištima. Zajedničko gajenje kompatibilnih vrsta je zabeleženo kao obećavajući sistem useva, jer biljne kulture sa različitim načinima ukorenjivanja i ciklusima rasta mogu promovisati recikliranje hranljivih materija i efikasno suzbiti pojavu korova.

Ključne reči: *Malčiranje, terase, konzervacijska obrada, zemljište, banak, upravljanje usevom*

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