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Review Article

Significance of Conservation Tillage in Dryland Farming Conditions

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Abstract

Most surface crop residues are buried in intensive tillage systems, which pulverize the soil and reduce surface roughness. Tilled systems may also hasten soil fertility loss and erosion, reducing the long-term sustainability of dryland agriculture. Conservation tillage systems can increase dryland agriculture sustainability by diminishing soil erosion, enhancing soil infiltration, decreasing soil moisture evaporation, and improving soil health and ecosystem services. This study examines the environmental and economic benefits of direct seeding and other forms of reduced tillage, as well as the sustainability difficulties caused by conventional tillage, such as soil erosion, soil fertility loss, organic matter depletion, and soil acidification.

Keywords: Conservation Tillage, Dryland Farming, Crop Residue, Soil Erosion.

Introduction

Tillage is defined as mechanical soil manipulation for crop production that affects soil properties such as soil water conservation, infiltration, soil temperature, and evapotranspiration processes (Busari et al., 2015). Due to irrigation water is scarce or farmers cannot afford the technology, agricultural production in arid and semi-arid regions is heavily reliant on rainfall. Rainwater conservation is critical in these areas for rainfed crop production to be successful (barron et. Al., 2003). The appropriate selection of tillage methods is important among the applications used to maintain soil moisture under dry farming conditions (mujdeci et al., 2010). On the other hand, the types of soil tillage used can have on both the positive and negative effects on soil properties. Conventional tillage system involving mouldboard ploughing have a negative impact on soil properties such as reduces soil organic matter (Troldborg et al., 2013), increases compaction, crusting, and erosion, and harms soil biota (Kladivko, 2001; Birkás et al., 2008; Hösl and Strauss, 2016). On an annual basis, conventional tillage disturbs and pulverises the soil, resulting in a finer and looser soil structure (rashidi, 2007). This practice has a rapid eroding effect. Therefore, more environmentally friendly soil management practices are required. Conservation tillage, which leaves the soil undamaged in order to retain most or all crop residues on the soil's surface, aids in soil quality preservation and reduces soil erosion (Lal, 2007; Sasal et al., 2010; Mwango et al., 2016). According to (Samarajeewa et al. 2006), conservation tillage systems may be more productive than conventional tillage (CT) systems due to improved soil quality and plant water use efficiency. De Vita et al. (2007) investigated the effects of conventional tillage and no-tillage on wheat yield. They discovered that zero-tillage resulted higher yields than conventional tillage.

The objective of this research is to demonstrate the benefits of using conservation tillage methods to increase crop yields in dryland farming. Although the emphasis is on dryland farming, the principles involved apply to irrigated crops as well. When water is available for irrigation, the requirement for conservation tillage to conserve water is frequently reduced or ignored. This article makes extensive use of the terms conservation tillage and dryland farming, which appear in the title. As a result, these terms must be defined and briefly discussed.

Tillage Systems

Tillage is a physical soil operation that aims to destroy weeds while also incorporating crop residues and amendments into the soil, increasing infiltration, and breaking hard layers to aid root penetration (Choudhary, et al., 2021). Tillage systems affect soil temperature, water content, bulk density, porosity penetration resistance, and aggregate distribution, among other physical properties. The tillage system is divided into two main groups: conventional tillage and conservation tillage.

Conventional tillage

Conventional tillage is a method in which 85% of crop residues are buried and less than 15% remain on the soil surface. Conventional tillage is a traditional farming method that involves completely inverting the soil with a tractor-pulled plough, followed by additional tillage to smooth the soil surface for crop cultivation. Conventional tillage system disturbs and pulverizes the soil, resulting in a finer and looser soil structure. Producers use conventional tillage (mechanical tillage) as well as the application of insecticides and mineral fertilizers. Nonetheless, crop yields continue to fall, resulting in lower incomes and food insecurity (Amadji et al., 2007). This demonstrates that conventional tillage has reached its limits. In fact, conventional tillage results in excessive soil fragmentation, collapse, and compaction. It also causes erosion, runoff, and land drying up, implying physical deterioration that is sometimes irreversible (Mrabet, 2001a; Abdellaoui et al., 2011; Dayou et al., 2017). Wheel traffic on the soil surface and the formation of a plow-pan in the subsurface layers cause soil compaction (Subbulakshmi et al., 2009). Conventional tillage on sloped areas can result in significant soil loss, especially if performed in both up- and down-slope directions (de Alba, 2003; Bertol et al., 2007; DeLaune and Sij, 2012).

Conservation tillage

Conservation tillage is an application that covers at least 30% of the soil surface with crop residues to reduce water and wind erosion as well as soil moisture loss.

Conservation tillage is more suitable because it is a method that prevents water loss from the soil in regions where the annual precipitation is 200–500 mm. Soil properties and climatic conditions should be carefully evaluated before choosing a tillage system. Ploughs and other tools that work the soil by overturning are not used in the conservation tillage system. In areas where soil compaction is a problem, chisels and other tools are used to process the soil by tearing it at a certain depth. crop residues are left on the field surface in this system. Conservation tillage and direct sowing have positive effects on erosion control. In general, the field surface should be covered with at least 30% plant residue in the protective tillage system (Köller, 2003). The presence of even a small amount of vegetation on the surface prevents erosion to a large extent, according to the research. The amount of plant residual required is determined by factors such as soil type, slope condition, and crop rotation (Aykas et al., 2010). Compaction and crusting are major production constraints in intensive agriculture, regardless of ecological region. Some soils in Africa's arid/semi-arid regions are naturally compacted, limiting root growth. To improve crop growth, mechanical loosening as part of conservation tillage may be required. As a result, reducing tillage encourages carbon sequestration in the soil. Many crops can now be grown with minimal tillage thanks to advances in weed control methods and farm machinery over the last few decades (Smith et al., 2008).

Crop residue management on the soil surface is required for conservation tillage. Crop residues, a renewable resource, play a critical role in conservation tillage. Crop residues that are managed properly protect soil resources, improve soil quality, restore degraded ecosystems, improve nutrient cycling, increase water conservation and availability, reduce runoff and off-site nutrient leaching (SARE, 2020). The extent of tillage effect on the ability of the soil to adsorb and retain water depends on the level of soil disturbance studies from different regions of the world have shown that conservation tillage systems are important for crop production because of increasing soil water content (Acar et al., 2017).

Conservation tillage (CT) has divided into five systems including no-tillage, strip tillage, minimum tillage, mulch tillage and ridge tillage (ECAF, 1999).

No tillage

No-tillage is generally defined as planting crops into soil that has not been tilled since the previous crop's harvest. No-till also reduces fuel and labour requirements when compared to other tillage systems. Weed control is primarily accomplished through one or two well-timed surface applications of preemergence or postemergence herbicides. Because the soil is not tilled, this technique conserves moisture in the soil profile and the new crop is planted directly into the previous crop's stubble (ACT, 2013). According to lal (1997a), no-till systems have better soil physical properties than other tillage systems. It has been reported that well-drained soils with light to medium texture and low humus content respond favorably to conservation tillage, particularly no-tillage.

Reduced (Minimum) tillage

A reduced-tillage system is a soil conservation system that aims to reduce the amount of soil manipulation required for successful crop production. It is a tillage method that does not turn the soil over and eliminates intensive tillage. The following are the benefits of minimum tillage over conventional tillage: the cost and time for field preparation are lowered by reducing the number of field operations. Soil compaction is relatively low. The soil structure is preserved. Water loss due to runoff and erosion is minimal. The plough layer's water storage capacity is increased. This system reduces the risk of environmental pollution by reducing losses of nutrients and decreased direct and indirect greenhouse gas (Chetan et al., 2016).

Ridge tillage

Ridge-till is a low-impact planting method in which crops are planted and grown on ridges formed during the previous growing season and with shallow, in-season cultivation equipment. Tillage is typically shallow, disturbing only the ridge tops. Planting is done on ridges in a seedbed prepared with sweeps, disc openers, coulters, or row cleaners. Ridge tillage is primarily used to grow agronomic row crops such as corn, soybeans, cotton, and so on. Ridge systems work well on flat or gently sloping fields, especially those with poorly drained soils. A ridge system is a good choice for frequently wet soils.

Mulch tillage

Mulch tillage is defined as a tillage system that leaves a significant amount of crop residue on the soil surface to reduce erosion. In primary tillage, it is usually achieved by substituting chisel ploughs, sweep cultivators, or disc harrows for the moldboard plough or disc plough. This change in implements is appealing because residues are not buried deeply in the soil, promoting aerobic decomposition. Herbicides and/or cultivation are used to control weeds. The soil is prepared or tilled in such a way that plant residues or other materials cover the surface to the highest possible extent. Mulching on the soil surface to protect soil and water losses is a widely used and accepted alternative technology in many developing countries (bhatt and khera, 2006; ramakrishna et al., 2006). Nonetheless, it will be more effective when local species are used (marques et al., 2007). Mulching has three major effects in terms of soil erosion protection: intercepting rainfall by absorbing the energy of raindrops and thus reducing surface sealing and runoff, retarding erosion by decreasing surface flow velocity, and physical restraint of soil movement (Donjadee & Tingsanchali, 2016).

Strip tillage

Strip-till is a seedbed preparation technique that involves tilling confined strips of soil prior to planting. Strip-till has received much interest due to evidence that it combines many of the best features of both no-till and conventional tillage systems. Strip-tilling has the potential to be more environmentally friendly and efficient than traditional tillage methods. By leaving the inter-row area untilled, crop residues are retained on the soil surface, increasing erosion resistance and organic matter inputs. Strip tillage can also reduce field passes and input costs when compared to traditional tillage.

Environmental benefits of conservation tillage

When compared to conventional tillage, conservation tillage increases the organic matter level in the soil, reduces field traffic, and reduces water and wind erosion because more plant residues remain on the surface. Erosion-induced soil degradation can reduce agricultural land productivity (Montgomery 2007). Erosion can reduce soil water retention capacity and other important soil properties, making eroded soil agriculture more vulnerable to climate-related risks. Water and wind erosion have an impact on 40% of the world's agricultural lands. Researches have revealed that 150 tons/ha of soil is lost annually due to erosion caused by wrong and unconscious tillage. The most natural way to prevent these losses is to till the soil without overturning it, to reduce the number of operations, and to cover as much of the soil surface as possible with vegetation. In an uninverted soil, plant residues accumulate over time forms a layer of mulch on it. While this layer shields the soil from the physical effects of rain and wind, it also maintains the consistency of moisture and temperature on the surface and provides a habitat for soil creatures and microorganisms. Microorganisms come into contact with the mulch, mix it with the soil, and decompose it, converting it to humus (Yalçın et al., 2003). It also acts as a buffer in the soil for organic matter, water, and nutrients. The larger creatures in the soil fauna preserve the natural structure of the soil and increase soil infiltration during heavy rains by digging tunnels into the depths. Organic matter in the soil is not only a nutrient; it is also a critical regulator that keeps the soil's natural structure for a long time.

Conservation tillage alters the surface soil water balance, which accounts for a large portion of the potential risk reduction from climate change and variability. When compared to conventional tillage areas, conservation tillage agricultural areas will exhibit the following changes in water balance: less erosion and runoff, more water infiltration, more plant-available water, less soil water evaporation, and less diurnal temperature fluctuations. Conservation tillage can slow the runoff of excess rainfall and increase infiltration by maintaining residue cover at the soil surface. Residue cover can also help to reduce daily soil temperature fluctuations, evaporation, and crusting. Increased plant-available water from improved soil organic carbon near the surface improves the efficiency of rainfall and/or irrigation events conserves water (Smith et al., 2008).

Economic advantages of conservation tillage

Traditional tillage requires higher inputs in terms of machinery investment, maintenance-repair, and labor compared to conservation tillage, especially zero tillage. Tillage is one of the most power-required processes in agricultural production. Furthermore, today's high energy costs force farmers to seek out alternative economic tillage methods. It is widely acknowledged that the use of energy-saving methods can make significant contributions to the economy (Bayhan et al., 2006). As a result, conservation tillage is becoming more appealing to farmers because it clearly reduces production costs when compared to conventional tillage (Vita et al., 2007). According to studies, protective tillage and direct sowing increase energy efficiency by 25-100% and reduce energy demand by 15-50 % (Yalçın et al., 2003). In the direct sowing method, only one pass through the field is required for sowing. This number is at least two or more in the traditional method. Fewer passes result in less machine wear and lower costs for maintenance. When compared to traditional tillage, direct sowing saves an average of 31.5 liters of fuel per hectare per year. When compared to the traditional method, the direct sowing methods for annual crops save an average of 40-60 euros per hectare in southern European conditions and improve crop productivity and profitability.

Agricultural mechanization is regarded as the most important factor contributing to total energy inputs in the agricultural system. Tillage accounts for half of all field operations performed each year. As a result, reducing tillage has the potential to reduce energy inputs and production costs (Osunbitan and colleagues, 2005; Ozturk et al., 2006). Therefore, the reduction in expenditures encourages producers to adopt conservation agriculture. Erosion, one of the most serious threats to soil, significantly reduces crop yield. For example, the yield of some plants in heavily eroded areas may be 9–34% lower than in other regions (Yalçın et al., 2003). The following benefits of protective agriculture should also be considered: Fuel, time, machine wear, and labour savings, regularity in production, conservation of nutrients in the soil, ease of crop cultivation in arid climate zones, maintaining the quality of farm and groundwater.

Conservation tillage in dryland farming

Dryland farming is not the same as rain-fed agriculture. Rain-fed agriculture is crop production that takes place during the rainy season. On the other hand, dryland farming refers to crop production during a dry season by utilizing the residual moisture in the soil from the rainy season, which is typically found in areas with 20 inches or more of annual rainfall. Dryland agriculture is primarily reliant on rainfall and the main limiting factor in crop production is soil water. Therefore, dryland farming uses a conservation tillage system, surface protection, and drought-resistant varieties to conserve soil moisture during long dry periods. Farmers must effectively manage crop residues and tillage to control soil erosion and store and use the limited precipitation received for crop production. Conservation tillage techniques, which are soil-surface crop residue management systems that use little or no tillage, are essential for conserving moisture for crop production (Kar et al., 2021). Dryland tillage practices should aim to: conserve as much water as possible in the root zone during noncrop periods and create a seedbed that enables the crop to demonstrate at the optimal time to use the restricted water supply efficiently. Conservation tillage has been proposed as an effective method of conserving soil water in dryland agriculture. Conservation tillage has recently been recognized as an important soil management measure in the study of dryland agriculture, with the potential to conserve soil water and improve crop productivity (Liu et al., 2013; Jabro et al., 2016; Lampurlanes et al., 2016).

Conclusion

In sustainable agriculture, the introduction of conservation tillage is of greater importance than traditional tillage, which targets the overturning of the soil and increases field traffic. Conservation tillage is any tillage method that reduces the amount and/or rate of runoff and increases water infiltration into the soil. Conservation tillage provides good soil leveling in dry agricultural areas with annual precipitation less than 500 mm prevents soil moisture evaporation and prevents capillary deterioration. Which tillage system will be chosen for a particular soil and product should be decided by considering the topography, climate and weather conditions, and soil structure in the region where the application will be made. If conservation tillage is to be applied in a region, first of all, subject experts should be consulted, a good crop rotation suitable for that region should be prepared, and work should be started.

References

Abdellaoui, Z., Teskrat, H., Belhadj, A., & Zaghouane, O. (2011). Étude comparative de l’effet du travail conventionnel, semis direct et travail minimum sur le comportement d’une culture de blé dur dans la zone subhumide. *Options Méditerranéennes: Série A. Séminaires Méditerranéens*, *96*, 71-87

Acar, M., Çelik, İ., & Günal, H. (2017). Effects of long-term tıllage systems on soıl water content and wheat yıeld under medıterranean condıtıons. *Journal Of New Theory*, 17, 98-108.

ACT, (2013). No-Till or Zero-Tillage Systems - Conservation Tillage. http://www.act-africa.org/news.php?com=68&com2=6&item=156#.Y5HUtnZBzIU.

Amadji, G. L., Koné, B., Amouzouvi, K., & Aholoukpe, H. N. S. (2007). Amelioration de la production du niebe sur les terres de barre degradees du Benin. *Journal de la Recherche Scientifique de l'Université de Lomé*, 9(2).

Aykas, E., Yalçın, H., & Çakır, E. (2010). Koruyucu toprak işlemede yöntemler, örtü bitkisi ve ekim nöbetinin önemi. *Tarım Makinaları Bilimi Dergisi*, *6*(4), 247-252.

Barron, J., Rockström, J., Gichuki, F., & Hatibu, N. (2003). Dry spell analysis and maize yields for two semi-arid locations in east Africa. *Agricultural and forest meteorology*, 117(1-2), 23-37.

Bayhan, Y., Kayisoglu, B., Gonulol, E., Yalcin, H., & Sungur, N. (2006). Possibilities of direct drilling and reduced tillage in second crop silage corn. *Soil and tillage research*, *88*(1-2), 1-7.

Bertol, I., Engel, F. L., Mafra, A. L., Bertol, O. J., & Ritter, S. R. (2007). Phosphorus, potassium and organic carbon concentrations in runoff water and sediments under different soil tillage systems during soybean growth. *Soil and Tillage Research*, *94*(1), 142-150.

Birkás, M., Jolánkai, M., Kisić, I., & Stipešević, B. (2008). Soil tillage needs a radical change for sustainability. *Agriculturae Conspectus Scientificus*, *73*(3), 131-136.

Busari, M. A., Kukal, S. S., Kaur, A., Bhatt, R., & Dulazi, A. A. (2015). Conservation tillage impacts on soil, crop and the environment. *International Soil and Water Conservation Research,* 3(2), 119-129.

Chetan, C., Rusu, T., Chetan, F., & Simon, A. (2016). Influence of soil tillage systems and weed control treatments on root nodules, production and qualitative indicators of Soybean. *Procedia Technology*, 22, 457-464.

Choudhary, S., Pramanick, B., Maitra, S., & Kumar, B. (2021). Tillage Practices for Enhancing Crop Productivity under Dryland Conditions. *Just Agriculture*, *1*(5), 206-212.

Dayou E. D., Zokpodo K. L. B., Glèlè K. A. L. R., & Ganglo C. J. (2017). Impacts of the conventional tillage tools and reduced tillage on the soil fertility preservation: critical review. *Journal of Applied Biosciences 117: 11684-11695*

De Alba, E., Weiler, S., & Tjandra, N. (2003). Solution structure of human saposin C: pH-dependent interaction with phospholipid vesicles. *Biochemistry*, *42*(50), 14729-14740.

De Vita, P., Di Paolo, E., Fecondo, G., Di Fonzo, N., & Pisante, M. (2007). No-tillage and conventional tillage effects on durum wheat yield, grain quality and soil moisture content in southern Italy. *Soil and tillage research*, *92*(1-2), 69-78.

DeLaune, P. B., & Sij, J. W. (2012). Impact of tillage on runoff in long term no-till wheat systems. *Soil and Tillage Research*, *124*, 32-35.

Donjadee, S., & Tingsanchali, T. (2016). Soil and water conservation on steep slopes by mulching using rice straw and vetiver grass clippings. *Agriculture and Natural Resources*, *50*(1), 75-79.

Hösl, R., & Strauss, P. (2016). Conservation tillage practices in the alpine forelands of Austria—Are they effective?. *Catena*, *137*, 44-51.

Jabro, J. D., Iversen, W. M., Stevens, W. B., Evans, R. G., Mikha, M. M., & Allen, B. L. (2016). Physical and hydraulic properties of a sandy loam soil under zero, shallow and deep tillage practices. *Soil and Tillage Research*, *159*, 67-72.

Kar, S., Pramanick, B., Brahmachari, K., Saha, G., Mahapatra, B.S., Saha, A. & Kumar, A. (2021). Exploring the best tillage option in rice based diversified cropping systems in alluvial soil of eastern India. Soil and Tillage Research 205: 104761.

Khursheed, S., Simmons, C., Wani, S. A., Ali, T., Raina, S. K., & Najar, G. R. (2019). Conservation tillage: impacts on soil physical conditions–an overview. *Advances in Plants & Agriculture Research* (2), 342-346.

Kladivko, E.J., (2001). Tillage systems and soil ecology. *Soil Tillage Research,* 61, 61-76.

Kuzucu, M., & Dökmen, F. (2015). The effects of tillage on soil water content in dry areas. *Agriculture and Agricultural Science Procedia*, *4*, 126-132.

Lal, R. (1997). Residue management, conservation tillage and soil restoration for mitigating greenhouse effect by CO2-enrichment. *Soil and tillage research*, *43*(1-2), 81-107.

Lal, R. (2007). Carbon management in agricultural soils. *Mitigation and adaptation strategies for global change*, *12*(2), 303-322.

Lampurlanés, J., Plaza-Bonilla, D., Álvaro-Fuentes, J., & Cantero-Martínez, C. (2016). Long-term analysis of soil water conservation and crop yield under different tillage systems in Mediterranean rainfed conditions. *Field Crops Research*, *189*, 59-67.

Leys, A., G. Govers, K. Gillijns, E. Berckmoes, & I. Takken. (2010). "Scale Effects on Runoff and Erosion Losses from Arable Land under Conservation and Conventional Tillage: The Role of Residue Cover." *Journal of Hydrology* ,390(3-4):143-54.

Montgomery, D. (2007). "Soil Erosion and Agricultural Sustainability." *Proceedings of the National Academy of Sciences of the United States of America*, 104 (33):13268–72.

Mrabet, R., Saber, N., El-Brahli, A., Lahlou, S., & Bessam, F. (2001). Total, particulate organic matter and structural stability of a Calcixeroll soil under different wheat rotations and tillage systems in a semiarid area of Morocco. *Soil and Tillage Research*, *57*(4), 225-235.

Mujdeci, M., Kara, B., & Işıldar, A. A. (2010). The effects of different soil tillage methods on soil water dynamic. *Scientific Research and Essays*, *5*(21), 3345-3350.

Mwango, S. B., Msanya, B. M., Mtakwa, P. W., Kimaro, D. N., Deckers, J., & Poesen, J. (2016). Effectiveness of mulching under miraba in controlling soil erosion, fertility restoration and crop yield in the Usambara Mountains, Tanzania. *Land Degradation & Development*, *27*(4), 1266-1275.

Ramakrishna, A., Tam, H. M., Wani, S. P., & Long, T. D. (2006). Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut in northern Vietnam. *Field crops research*, *95*(2-3), 115-125.

Rashidi, A. M., Akbarnejad, M. M., Khodadadi, A. A., Mortazavi, Y., & Ahmadpourd, A. (2007). Single-wall carbon nanotubes synthesized using organic additives to Co–Mo catalysts supported on nanoporous MgO. *Nanotechnology*, *18*(31), 315605.

Reeder, R.C. (2002). Maximizing performance in conservation tillage systems–an overview. ASAE Annual International Meeting/CIGR XVth World Congress (Paper No. 021134). Chicago, IL. July 28–31, 2002.

Samarajeewa, K. B. D. P., Horiuchi, T., & Oba, S. (2006). Finger millet (Eleucine corocana L. Gaertn.) as a cover crop on weed control, growth and yield of soybean under different tillage systems. *Soil and tillage research*, *90*(1-2), 93-99.

Sasal, M. C., Castiglioni, M. G., & Wilson, M. G. (2010). Effect of crop sequences on soil properties and runoff on natural-rainfall erosion plots under no tillage. *Soil and Tillage Research*, *108*(1-2), 24-29.

Smith P, Martino D, Cai Z, Gwary D, Janzen HH, Kumar P, Mccarl B, Ogle S, O'mara F, Rice C, Scholes RJ, Sirotenko O, Howden M, Mcallister T, Pan G, Romanenkov V, Schneider U, Towprayoon S, Wattenbach M & Smith J. U. (2008): Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society B*, 363:789-813.

Subbulakshmi, S., Saravanan, N. & Subbian, P. (2009). Conventional Tillage vs Conservation Tillage. *Agricultural Reviews, 30 (1) : 56 – 63.*

Troldborg, M., Aalders, I., Towers, W., Hallett, P. D., McKenzie, B. M., Bengough, A. G., ... & Hough, R. L. (2013). Application of Bayesian Belief Networks to quantify and map areas at risk to soil threats: Using soil compaction as an example. *Soil and Tillage Research*, 132, 56-68.

Yalçın, H., Aykas, E., & Evrenosoğlu, M. (2003). Koruyucu tarım ve koruyucu toprak işleme. *Ege Üniversitesi Ziraat Fakültesi Dergisi*, *40*(2).