Chapter 4
Soil Degradation, Land Use, and Sustainability

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4.1 Introduction

Soil resource is a critical part of all agricultural production systems, and maintenance of a high quality soil capable of supplying water, nutrients, and gases is necessary to sustain the production needed to meet the demands of an ever increasing world population on the same or smaller land mass. Lal (2009) described ten tenets for sustainable soil management that included:

- Causes of soil degradation and human suffering.
- Soil stewardship.
- Nutrient, carbon, and water balance.
- Marginality principle.
- Organic versus inorganic source of nutrients.
- Soil carbon and greenhouse effect.
- Soil as a sink for atmospheric CO_2.
- Productive soil combined with productive germplasm.
- Soil–plant interface—the engine of economic development.
- Traditional knowledge and modern innovations.

These factors provide a foundation for the assessment of the impact of soil degradation on our future ability to produce food, feed, fiber, and fuel from varied land resources. Both world population growth and the higher living standards expected by all peoples will drive the demand for food and require that we consider the present state of our soil resource and the role it plays in efficient agricultural production. We have lost sight of the fragile nature of the soil resource and how quickly it can become degraded and the effort it will take to restore our soils to their productivity capacity. Soils are the foundation of sustainable agriculture and in

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order to develop systems capable of meeting the world food needs and protecting environmental quality, there needs to be a renewed emphasis on enhancing the soil resource. These are challenges we need to address and develop strategies to implement solutions across a wide range of soils, climates, and cropping systems. Throughout this chapter, these concepts will be developed to help spur discussion and action on the need to understand soil degradation and how we can begin to increase our understanding of how to enhance our soil resource.

4.2 Soil Degradation

4.2.1 Processes

Degradation of the soil is a complex process and involves changes in the physical, chemical, and biological processes with the soil. If we look at degradation from landscape and soil profile perspectives, then degradation will have both depth and horizontal components. Changes in the soil will occur at the surface more than with depth because the forces causing degradation will manifest themselves at this part of the soil profile more than with depth. These changes will not be uniform across a landscape because different soils will respond differently to the forces causing degradation.

Physical degradation is linked with changes in the water and air exchanges in the soil. Primarily, this can be considered as a degradation of the soil structure that no longer allows the soil particles to maintain their ability to withstand either mechanical or hydrological forces. Thus, a breakdown in soil structure through reduction in aggregate strength or stability leads to increased slaking, crusting, and bulk density (compaction). This change in soil structure reduces soil porosity and diminishes gas exchange leading to less oxygen available in the soil profile. Erosive processes are increased when there is a diminished soil structure at the surface because under rainfall events, the stability of the soil surface decreases and as the water infiltration rate is no longer maintained then the soil will begin to move and if rainfall events continue long enough there will be erosion. Hamza and Anderson (2005) stated that potential methods for the alleviation of compaction involve increasing the organic matter content of the soil and incorporation of crops into the rotation which add a deep rooted crop to restore structure to the lower soil profile.

Chemical degradation incorporates changes in the chemical processes within the soil which will in turn affect plant growth. Soil acidification from a reduction in pH can be caused by leaching of bases through the soil profile or the continual addition of acid-producing fertilizers. Depletion of nutrients by removing plants or leaching without resupplying these nutrients is another form of chemical degradation. Conversely, soils can become toxic through the buildup of elements like Al, Fe, and Mn to levels where they become toxic to plants. Continual increases in soluble salts in the root zone to increase the electrical conductivity above 4 ds m^{-1} creates salinization of the soil while additions of Na ions through sodic salts can lead to alkalinization of the soil. Vanderpol and Traore (1993) found nutrient depletion in the soils of Mali to be substantial due to erosion and denitrification of N. The magnitude of the nutrient losses were equivalent to 40 % of the annual income from the farms in Mali.

Biological degradation is associated with the dynamics of the microbial systems within the soil profile. Microbial activity and soil biodiversity are linked with the soil organic carbon (SOC) pools in the soil and ultimately are associated with the depletion of SOC and the turnover rates of the SOC pool. Bastida et al. (2008) proposed the use of a biological index for soil quality, and when they compared different methods found metabolic quotient (ratio of respiration to microbial biomass) as an index to evaluate ecosystem disturbance or its maturity. They proposed that any method which incorporated some aspect of soil biological status or function would be a valuable indicator of soil quality or soil degradation. Soil biological systems are a critical component of soil function and implementation of indices which can quantify the changes in soil biology in response to soil changes.

There are a number of soil management practices that create conditions in which there is potential for increased soil degradation. One of the most critical decisions is the maintenance of crop residues on the soil surface and the effect on surface sealing and crusting because the direct impact of raindrops on the soil is to consolidate the surface layers leading to the formation of crusts. Surface soil properties are sensitive to the maintenance of stable soil aggregates which are created through the continual addition of organic material. For example, Ruan et al. (2001) found that it was necessary to maintain surface residue cover in order to prevent surface sealing. Tillage practices, e.g., no-till, which maintain crop residue on the surface and application of compost and manure as sources of organic materials reduce surface sealing and crusting (Cassel et al. 1995; Pagliai et al. 2004). Blanco-Canqui et al. (2006a) found that soils without residue cover developed crusts with a thickness of 3 cm and cracks with widths of 0.6 cm during periods in which there was no rainfall. Removal of crop residue affects the stability of aggregates, arrangement of soil particles glued together by organic materials, and depends upon the soil organic matter (SOM) concentration in the surface soils (Blanco-Canqui et al. 2006b; Rhoton et al. 2002). These changes in the soil structural stability are rapid and often degradation of the surface soils can occur within the first year when the soil has the residue removed (Blanco-Canqui and Lal 2009). Blanco-Canqui et al. (2009) conducted a regional scale study on various tillage systems across the US Great Plains and found aggregates under no-till systems were more stable under rain but didn't show any effect on dry aggregate stability (see Chaps. 5 and 10). Stable aggregates under rainfall event will lead to increased resistance to the soil erosion. Since erosion is one of the major causes of soil degradation, any change in a soil property increases the risk to intense rainfall events.

Implementation of any tillage practice compared to a virgin soil or sod may lead to a decrease in the physical quality attributes of the soil (Reynolds et al. 2007). They observed that converting bluegrass (*Panicum dichotomiflorum* Michx.) sod to a corn (*Zea mays* L.)-soybean (*Glycine max* (L.) Merr.) rotation with moldboard plow caused the surface soil physical characteristics, e.g., bulk density, macroporosity, air capacity, plant available water capacity, and saturated hydraulic conductivity, to decline within 3–4 years to levels similar to long-term corn-soybean with moldboard plow systems. Compared to virgin soil and sod systems, even the no-till system with the corn-soybean rotation showed declines in soil physical quality.

Tillage not only decreases the SOM content in the surface soil and causes a corresponding decrease in soil biological activity (Mahboubi and Lal 1998). Mahboubi and Lal (1998) found there was a seasonal response to tillage effects on aggregation and soil structure, which needs to be accounted for any assessment of the impacts on tillage on soil properties. Salinas-Garcia et al. (2001) observed that removal of crop residue from the soil surface decreased the soil microbial biomass C and N concentrations. After comparing three tillage systems in Nebraska, Doran et al. (1998) found a loss of soil carbon (C) from all three systems; however, the loss from no-till was less than conventional tillage. There was an increase in soil microbial activity near the soil surface in the no-till system. Similar observations were found by Karlen et al. (1994) in which removal of crop residue caused the soil aggregates to be less stable and decreased soil biological activity. The advantage of the no-till system was the maintenance of the protective soil cover and partially decomposed organic material near the soil surface that reduced the rate of soil degradation. Reeves (1997) stated that maintenance of SOM is critical for soil quality. Soil organic matter in the soil is a critical component in the soil. Loveland and Webb (2003) reviewed the literature from around the world and concluded that when organic C declines below 2 % there will be a decline in soil quality.

4.2.2 Extent

Soil degradation is extensive throughout the world. Lal (1993) stated that soil degradation is a major threat to agricultural sustainability and environmental quality and is particularly serious in the tropics and subtropics. For example, Nyssen et al. (2009) reported that nearly all of the tropical highlands (areas above 1,000 m asl covering 4.5 million km^2) are degraded due to medium to severe water erosion. Zhao et al. (2007) evaluated the change in the Horquin sands because of the conversion of farmland from the original pasture and found significant decreases in crop yield and poorer soil properties after conversion to cropland. Kidron et al. (2010) suggested that the increasing pressure for food alleviating the traditional practice of 10–15 years of cultivation followed by 10–15 years of fallow with a continuous cropping practice has increased the rate of soil degradation. They found that SOM content showed the strongest relationship to soil degradation and practices which accelerated the removal of SOM increased the rate of degradation.

In the subhumid and semiarid Argentinean Pampas, Buschiazzo et al. (1998) observed that intensive cultivation for over 50 years had resulted in soil degradation leading to moderate to severe erosion across the region. A similar conclusion was developed by dos Santos et al. (1993) for southern Brazil in which they attributed the severe soil degradation to the widespread use of wheat (*Triticum aestivum* L.)-soybean or barley (*Hordeum vulgare* L.)-soybean double cropping systems coupled with intensive tillage. Krzic et al. (2000) observed that in the maritime climate of the Fraser Valley in British Columbia with over 1,200 mm of annual rainfall that conventional tillage over a number of years has contributed to poor infiltration, low organic matter content, and poor soil structure.

In southern Brazil and eastern Paraguay, Riezebos and Loerts (1998) observed that mechanical tillage resulted in a loss of SOM leading to soil degradation across this region. The conversion of semi-deciduous forests to cultivated lands has the potential for soil degradation, and proper management will be required to avoid degradation. Degradation of the soil resource occurs in many different forms and in Nepal, Thapu and Paudel (2002) observed watersheds are severely degraded from erosion. They found erosion has impacted nearly half of the land area in the upland crop terraces. This degradation was coupled with depletion of soil nutrients which in turn is continuing to affect productivity in this area. This is similar to the observation in Ethiopia by Taddese (2001) where severe land degradation caused by the rapid population increase, severe soil erosion, low amounts of vegetative cover, deforestation, and a lack of balance between crop and livestock production will continue to threaten the ability to produce an adequate food supply for the population.

Wang et al. (1985) observed that differences in soil structure and saturated hydraulic conductivity were related to cropping systems and degradation of soil structure in the profile led to corn yield reductions as large as 50 %. This decrease in yields could be related to the shallow root growth and limitations in water availability to the growing plant. Impacts of poor soil structure on plant growth and yield can be quite large, and continued degradation of the soil resource will have a major impact on the ability of the plant to produce grain, fiber, or forage.

Eickhout et al. (2006) stated that over the next 20 years, in order to meet food demand, there may have to be an additional clearing of forest land for production to offset the declining soil quality in the current land resource base. They advocated that we need to consider nitrogen (N) dynamics in current and future food production systems and increase our emphasis on N use efficiency and focus on improvements in agronomic management to offset the impacts of soil degradation (see Sripada et al., Chap. 8, Reetz, Chap. 15).

4.2.3 Impacts

The impacts of soil degradation on food security are profound and examples from developing countries (see Chaps. 11, 12 and 13), e.g., Hadgu et al. (2009) are available. In their study from Ethiopia, spatial variation in agro-biodiversity and soil degradation assessed in 2000 and 2005 at 151 farms in relation to farming operation, productivity, wealth, social, developmental, and topographic characteristics revealed a significant decrease in agro-biodiversity between 2000 and 2005, associated with inorganic fertilizer use (see Reetz, Chap. 15), number of credit sources, and proximity to towns and major roads. Higher ratings of agro-biodiversity were observed at farms with higher soil fertility (available P and total N) and higher productivity (crop yield). Soil erosion was related to lower crop diversity and steeper slopes. The more intense the cultivation practices the lower the ratings on agro-biodiversity and conversely the less intense cultivation was linked with greater agro-biodiversity. Another study in Vietnam has found that as much as half of the total land area is already degraded by soil erosion and nutrient depletion (Clemens et al. 2010). Degradation is related to deforestation and is affecting producers in the mountainous areas in northwestern Vietnam. The main physical processes were erosion and sedimentation on lower parts of the landscape. Farmers have underestimated the impact of soil degradation productivity but were aware of the impacts of soil quality on production (Clemens et al. 2010). High fertility soils were located on less eroded upper parts of hills and where there was recent conversion to agricultural production. In their observations, they found that soils, once degraded by cultivation practices, did not recover even after more than 50 years of fallow. Unsustainable land use leads to soils on middle and lower slopes being affected by severe soil erosion, whereas foot slope soils suffer from accumulation of eroded infertile subsoil material. A unique feature of this study was the evaluation across the landscape and the connectivity among slope positions because use of unsustainable land use practices at upslope landscape positions had a severe impact on downslope areas. Soil management practices which reduce erosion will have a positive impact on soil quality and production at all slope positions.

Ahaneku (2010) observed the linkage among poverty, intensification, and extensification of marginal lands as major threats to the sustainability of soil and water resources in Nigeria (see Oikeh et al., Chap. 13). This study recommended "home grown: soil and water conservation practices and water quality management techniques are vital to ameliorate the problems of soil degradation, erosion, and water quality." Ahaneku (2010) suggested that education and training producers about soil management practices to enhance the soil resource provided the most viable option to avert food crisis in Nigeria.

Ostergard et al (2009) suggested that food security will require a radical shift in crop production practices to address the problems of soil degradation, loss of biodiversity, polluted and restricted water supplies, future fossil fuel limitations, and increasingly variable climatic conditions. They identified practices such as "(i) building soil fertility by recycling of nutrients and sustainable use of other natural and physical resources, (ii) enhancing biological diversity by breeding of crops resilient to climate change, and (iii) reconnecting all stakeholders in crop production" as necessary practices to achieve food security.

Degradation of soil structure leads to an increased risk of run-off and soil erosion and to avoid reductions in food production caused by the degraded soil resource, it will be necessary to use more sustainable management practices (Blair et al. 2006). Small-grain rotations with legumes were evaluated for their effects on total C, labile C, non-labile C, total N, aggregation (mean weight diameter (MWD)), and infiltration on a Black Earth (Pellic Vertisol) and a Red Clay (Chromic Vertisol) soil near Tamworth, in New South Wales, Australia compared with an adjacent uncropped pasture for each soil type. Cropping reduced all C fractions, total N, aggregation, and infiltration on both soils. Interestingly degradation increased when a long fallow was part of the rotation. Use of the long fallow decreased labile C by 70 % in the Red Clay soil and by 78 % in the Black Earth compared with the adjacent pasture while aggregation decreased by 61 % in the Red Clay and 91 % in the Black Earth. Adding legumes to the cereal rotation caused smaller decreases in C fractions, total N, aggregation, and infiltration compared to pasture. Adding alfalfa (*Medicago sativa* L.) to the rotation caused labile C to be 41 % higher, aggregation to increase by 45 %, and infiltration to increase by 87 % compared to the long fallow on the Red Clay soil and increase by 65, 126, and 43 % on the Black Earth soil, respectively (Blair et al. 2006). Soil sustainability may be increased by introduction of forage legumes into the rotations by altering the rate of C decrease fractions, total N, aggregation, and infiltration (Blair et al. 2006). Martinez-Mena et al. (2008) evaluated the impact of water erosion and cultivation in the semiarid region of south-eastern Spain and found the conversion of forest land to cultivated land increased erosion risk and reduced the C stock on the upper 5 cm by 50 %. An interesting observation from this study was the loss of the labile C fraction was due to mostly cultivation rather than erosion. This would suggest that cultivation of soil should be minimized to avoid degradation of the soil resource.

Changes in biological activity in soils are rapid when there is a change in the tillage practice or crop rotation. Aslam et al. (1999) observed rapid changes in soil microbial systems when permanent pasture was converted to crop rotation using corn and winter oat (*Avena sativa* L.) under both plow tillage and no-till systems. Within 2 years under the plow tillage system, there was a 45 % decline in soil microbial biomass C, a 53 % decline in microbial biomass N, and a 51 % decline in microbial biomass phosphorus (P) in the upper 5 cm of the soil profile. The changes in microbial dynamics with no-till compared to permanent pasture were insignificant suggesting that adoption of no-till can reduce the biological degradation when soils are placed under cropping systems (Aslam et al. 1999). These results are similar to those observed in West Africa by Babalola and Opara-Nadi (1993) from their study showing that mechanical tillage of the structurally unstable Alfisols and Utisols caused more adverse than beneficial effects. Increased tillage caused both a decrease in SOM and increased the release of nutrients, and they found that use of no-till with crop residue mulch maintained soil properties with favorable characteristics to resist soil degradation. In Iran, Barzegar et al. (2003) found for chickpea (*Cicer arientinum* L.) grown under three different tillage systems on a silty clay loam soil (Typic Xerorthens) after 20 years of continuous wheat, crop yields, and soil physical properties were most improved under the single point chisel plow system. This tillage system also exhibited the greatest soil water storage, which produced the highest total biomass and grain yield. In an evaluation of the changes in soil properties affected by tillage systems in the Argentinean Pampas, Buschiazzo et al. (1998) observed that reductions in tillage intensity increased SOM content of the soil more in subhumid than in semiarid regions. These differences in SOM content and aggregate stability were limited to the upper 5 cm of the soil profile. A study of tillage practices by Lal (1997) in Nigeria on corn showed that yield was related to SOC, exchangeable Ca^{2+}, and cation exchange capacity (CEC). Continuous cropping degraded soil chemical quality, and the rate of decline was faster with intensive tillage than with no-tillage practices. Any practice that can increase productivity and protect the soil surface from erosion will have a positive benefit on soil properties. Melero et al. (2009) compared conservation tillage and conventional tillage in Spain under rainfed crop rotations and found conservation tillage increased both soil microbial biomass C and enzymatic activity (dehydrogenase (DHA), o-diphenol oxidase (DphOx), and β-glucosidase (β-glu)). These enzymes are associated with microbial activity in the soil and indicative of the size of the microbial population. They suggested that active C was the most sensitive indicator to detect differences in soil management impacts. Tejada et al. (2009) added different rates of composted plant residues as a method of restoring soil and found that all composted material had a positive effect on soil physical properties. In addition, there was a positive impact on the soil chemical and biological properties in the soil, and they attributed this effect due to the more favorable C:N ratio in composted material compared to fresh plant material. Zhang et al. (2010) compared nine soil hydrolases which are related to nutrient availability including (β-galactosidase, α-galactosidase, β-glucosidase, α-glucosidase, urease, protease, phosphomonoesterase, phosphodiesterase, arylsulphatase) and five different enzyme kinetics after 10 years of different cropping systems. In their study they compared different cropping systems to the traditional wheat production system and included wheat–cabbage (*Brassica oleracea* var. capitata L.) sequential cropping, wheat–corn intercrop, wheat–sunflower (*Helianthus annuus* L.) rotation, and wheat–soybean rotation. There were differences among the cropping systems on the enzyme activities with the wheat–corn intercropping system showing the highest activities.

Changes in the soil properties can be detected quickly. Munoz et al. (2007) observed improvements in the physical, chemical, and biological parameters in direct seeding and direct seeding with cover crops after 2 years in a corn production system compared to conventional tillage systems. They observed that soil water content (see Alam et al., Chap. 5) increased by over 30 %; organic C, organic N, and aggregate stability increased after the second year of these conservation systems, and microorganism populations were twice as large in the direct seeding with a cover crop compared to conventional tillage. These improvements in soil properties translated to an improvement in corn production. In Mexico, Roldan et al. (2003) found the intensive cultivation associated with corn production had led to degradation in the soil throughout the Patzcuaro watershed and established an experiment in 1995 with legumes added as cover crops in 1998. By 2000, the effect of no-tillage and the increased crop residue cover and legumes had increased soil enzymes, SOC, biodegradable C fractions, water soluble carbohydrates, microbial biomass C, and wet aggregate stability. They found the rates of change in these parameters were directly related to the mass of residue inputs to the soil. This is different than the rate of change So et al. (2009) observed for a loam soil in New South Wales, Australia, in which they did not see any affect of tillage in the first few years, but after 14 years the no-till treatments had increased soil porosity and structural stability. In this study, the no-till system on soybean had higher infiltration, increased plant available water, water use efficiency, crop yields, and improved SOC content in the no-till of 3.37 % compared to 1.67 % in the conventional tillage (So et al. 2009).

The effects of improved soil physical properties are not isolated to grain crops; Carter and Sanderson (2001) evaluated the effect of tillage systems as part of a rotation experiment with potato (*Solanum tuberosum* L.) in rotation with barley in a 2-year cycle or barley-red clover (*Trifolium pretense* L.)-potato system. They found neither the conventional or conservation tillage systems were sustainable with a 2-year rotation; however, under the 3-year rotation, the conservation tillage system showed a significant improvement in organic C and soil structural stability but no increase in plant productivity. Carter and Sanderson (2001) concluded conservation tillage in a 3-year rotation was able to maintain crop productivity, protect the soil from erosion, and improve soil quality. Components of cropping systems coupled with conservation tillage that would have a positive impact on the soil are the inclusion of deep-rooted legumes, e.g., red clover into the rotation. In another rotation experiment in Uruguay, Ernst and Siri-Prieto (2009) observed that soil degradation induced by intensive tillage was severe and evaluated potential systems to reverse this degradation by implementing rotation systems which included pastures mixed with crops and subjected to either conventional tillage or no-tillage practices. They evaluated the changes in a number of soil properties over the course of a 12-year experiment in pasture systems composed of birdsfoot trefoil (*Lotus corniculatus* L.), white clover (*Trifolium repens* L.), and tall fescue (*Festuca arundinacea* L.) in combination with a number of different crops grown in rotations of winter and summer crops. In their experiment winter crops were wheat, barley, and oat (*Avena sativa* L.), and summer crops of corn, sunflower (*Helianthus annus* L.), sorghum (*Sorghum bicolor* L. Moench.), and soybean, all grown under conventional tillage or no-tillage systems. After 12 years, no-till (NT) had 7 % higher SOC compared to conventional tillage (CT) and 8 % higher total SOC in the 0–18 cm depth. There was no significant difference between the tillage systems for the dry matter input; therefore, the accretion of the SOC has to be related to a reduced loss rate under the no-till systems (Ernst and Siri-Prieto 2009). There was a decline in the total soil N in all of the treatments; however, introduction of rotations reduced the deletion rate. Water stable aggregates increased under the no-tillage systems, and there was less water runoff for these systems. For degraded soils, introduction of long-term rotations with pastures may be a viable method of restoring degraded soils (Ernst and Siri-Prieto 2009). Gomez et al. (2001) found there was less soil degradation using no-till on a corn–wheat–soybean rotation in Argentina on a Chernozemic clay loam soil (Vertic Argiudoll) and if continuous cropping systems were to be used, then crops with high C inputs would be necessary to avoid soil degradation in terms of soil structure. The effects of converting alfalfa to row crops doesn't always show a negative impact on soil properties and Karunatilake and van Es (2002) found there was minimal impact on soil structural properties; however, this soil was a well-structured soil at the onset of the conversion.

A study of different systems in almond (*Prunus dulcis* (Mill.)) orchards in southeastern Spain compared management systems in which intensive tillage of the soil below the trees was replaced by grass cover crops, native vegetation, cover crops, and reduced tillage (Ramos et al. 2011). All of the treatments had a positive impact on aggregate stability, SOC, total N, enzyme activity, available potassium, and phosphatase activity compared to the intensive tillage systems. In these orchard systems, the introduction of grass cover systems produced improvements in the physical, chemical, and biological properties of the soil (Ramos et al. 2011).

Water use efficiency by crops is dependent upon the available water resource in the soil under rainfed conditions and is one of the metrics often used as a measure of productivity and soil degradation (Bai et al. 2008; Wessels et al. 2007). Wessels et al. (2007) found that degraded soils have reduced precipitation use efficiency for rangeland soils. De Vita et al. (2007) compared conventional vs. no-tillage systems in durum wheat (*Triticum durum* Desf.) grown in southern Italy. No-till systems had the advantage over conventional tillage (see Chap. 5) on wheat yields because of the reduction in soil water evaporation coupled with the enhanced soil water availability induced by better water holding capacity (Hulugalle and Entwistle 1997). This degree of response is not surprising because there is a linear relationship between SOM content and water holding capacity as described by Hudson (1994). Unger et al. (1991) stated that conservation practices which maintain crop residue on the soil surface have a positive impact on water conservation, and in semiarid regions this would translate into greater water availability for the crop.

Crop production responses to changes in management vary with the climate and soil. Arshad and Gill (1997) evaluated a canola (*Brassica campestris* L.)-wheat–barley rotation with a green manure crop (field pea, *Pisum sativum* L.) under tillage systems and found that as rainfall increased there was a corresponding increase in grain yield and total dry matter. Reductions in tillage reduced the soil disturbance, increased residue cover, retained soil water, and decreased erosion from these clay soils (Mollic Solonetz). Yield increases with improved residue, or reduced tillage intensity does not always translate to enhanced crop yields even though there is substantial improvement in the soil structure and organic matter content.

4.3 Sustainability of Crop Production

Sustainable practices for the future must consider the impact of soil degradation and the potential cost of restoring soil productivity. Currently agricultural production varies because of the variation in rainfall supply to the crop and the ability of the soil to supply adequate water at critical periods of plant development. Sustainable crop production is dependent upon water storage and availability which are coincidentally the factors most affected by soil degradation. There is ample evidence from field observations that yield variation in fields is affected by water availability more than any other factor (Hatfield and Prueger 2001). Improving water availability in soils throughout the world would provide a strong foundation for enhancing the sustainability of crop production.

The attributes associated with soil degradation whether physical, chemical, or biological can have a positive or negative impact on plant growth. Positive impact allows the full expression of the genetic potential of the crop and the associated environmental conditions while practices that foster soil degradation will be the limiting factor on plant growth and yield. Our inability to overcome the limitations imposed by the soil places a barrier on our ability to adequately supply food, feed, and fiber for future generations. Our challenge is to develop effective strategies to improve the soil and link this information into crop production systems that support sustainable food production.

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