

The Laws of Diminishing Yields in the Tropics

R. Derpsch, Ing. Agr. MSc., Senior Advisor to MAG-GTZ Soil Conservation Project, Casilla de Correo 1859, Asunción, Paraguay

M. Florentín, Ing. Agr. MSc., DIA, Campo Experimental de Choré, Proyecto Conservación de Suelos MAG-GTZ, Casilla de Correo 1859, Asunción, Paraguay

K. Moriya, Ing. Agr. MSc., DEAG, Coordinador Contraparte, Proyecto Conservación de Suelos MAG-GTZ, Casilla de Correo 1859, Asunción, Paraguay

Introduction

The key problem of conventional agriculture in the tropics and subtropics is the steady decline in soil fertility, which is closely correlated with the duration of soil use. The reason for this can be found primarily in the occurrence of soil erosion, the loss of organic matter, leaching of nutrients into deeper soil layers, and soil physical degradation associated with conventional tillage practices that leaves the soil bare and unprotected in times of heavy rainfall and heat (Derpsch and Moriya 1998). The result of soil degradation is not only that farm land has to go out of the production process, but also that there is an increasing need for more inputs and investments to maintain high levels of productivity. In the United States for instance, 50 percent of fertilizer needs is applied only to compensate for the losses in soil fertility due to soil degradation, and in Zimbabwe, soil nutrient losses by erosion are three times higher than the total quantity of fertilizers applied (Stocking 1988, cited by Steiner 1996). The GLASOD project (Global Assessment of Soil Degradation), which is a United Nations program for the environment (UNEP) that aims to determine worldwide soil degradation, distinguishes four processes of degradation caused by man: degradation by water erosion, by wind erosion, chemical and physical soil degradation (Oldeman and others 1990). According to this study, the major cause of soil degradation is water erosion (56 percent), followed by wind erosion (28 percent). In other words, erosion is responsible for 84 percent of soil degradation worldwide (Oldeman and others 1993). The following major factors are mentioned as causing degradation by water erosion: deforestation (43 percent), overgrazing (29 percent), and bad soil management (24 percent). However, soil preparation, which is the major factor causing soil degradation, is not mentioned, and is probably confused with bad soil management and deforestation. According to Oldeman and others (1993), the most important forms of chemical soil degradation are the loss of nutrients and organic matter in South America, and

salinisation in Asia. Under the main causes of chemical soil degradation, bad soil management (56 percent) and deforestation (28 percent) are mentioned. Similar results are reported by FAO (1984). In this case also, the influence of soil preparation on soil degradation is not considered. It appears that most professionals avoid using the term "soil preparation" as a factor responsible for soil degradation and prefer to use terms like "bad soil management," where various factors, one of which is soil preparation, are involved.

There is evidence that conventional soil tillage, which leaves the surface of the soil bare and unprotected, is one of the major causes of erosion and soil degradation on agricultural land. Maximum sediment amounts as well as phosphorus and nitrogen content in the water of the Itaipú dam (shared by Paraguay and Brazil), were measured in times of soil preparation for winter and summer crops (Derpsch and others 1991).

The Laws of Diminishing Yields in the Tropics and Subtropics

In nature there are laws ruling the diminishing productivity of soils which have to be taken into account in agricultural and livestock production. Disregard of these laws promotes the degradation of soils and the loss of soil productivity. Respect for these laws is indispensable if we aim to obtain sustainable agricultural production.

1. Any agricultural or livestock production system that contributes to constantly reducing the organic matter content of the soil is not sustainable and results in poor soils and farmers.
2. Under tropical and subtropical conditions intensive and repeated tillage will generally mineralize (reduce) organic matter at rates higher than the potential for repositioning. This results in a decreasing organic matter content of the soil and diminishing crop yields over time.

3. High rainfall and wind intensities prevailing in the tropics and subtropics are generally associated, under intensive and repeated tillage, with soil loss rates (due to wind or water erosion) that are higher than natural soil regeneration. This results in loss of nutrients and organic matter and in diminishing yields over time.
4. Under tropical and subtropical conditions, intensive and repeated tillage will generally damage the soil structure and lead to excessively high soil temperatures. This will have negative effects on root growth, soil flora, and fauna (soil biological processes) and on soil moisture resulting in diminishing yields over time.
5. Any agricultural or livestock production system in which important losses of nutrients occur through extraction without reposition (for example, soil exploitation) through volatilization (for example, regular burning), and/or through leaching (for example, fallow periods without crops), is not sustainable and results in poor soils and farmers.

Additionally soil carbon is lost very fast to the atmosphere (as carbon dioxide) after the soil is intensively tilled. This results in unacceptable CO₂ emissions into the atmosphere, and instead of carbon being deposited in the soil, improving its fertility, tillage contributes to the greenhouse effect and to the global warming of the planet. (Kern and Johnson 1993 a and b, Reikosky 2000).

In summary, the unavoidable negative effects of intensive and repeated soil tillage in the tropics and subtropics on organic matter content, soil erosion, soil structure, soil temperature, soil moisture, water infiltration, soil flora and fauna (soil biological processes) and loss of nutrients, result in chemical, physical and biological soil degradation. This results in diminishing yields over time and in productivity losses of the soil and leads to poor soils and farmers.

As a consequence of the laws of diminishing productivity of tropical soils, sustainability of agricultural or livestock production cannot be achieved as long as repeated and intensive soil tillage is performed in the tropics and subtropics. Nor can sustainability be achieved as long as the soil is exploited without reposition of nutrient losses through leaching and/or extractions that occur with harvests, and as long as frequent burning of fields is performed.

Analysis of the Laws of Diminishing Yields

1. Any agricultural or livestock production system that contributes to constantly reducing the organic matter content of the soil is not sustainable and results in poor soils and farmers.

Soil organic carbon is the soil attribute most consistently reported in long-term studies and is a keystone soil quality indicator, being inextricably linked to other physical, chemical, and biological soil quality indicators (Reeves 1997). Soil organic matter may be one of the most important soil quality characteristics in relation to tillage because of its influence on other soil physical, chemical and biological properties (Cannel and Hawes 1994).

Due to the fact that the cation exchange capacity of most tropical soils is very low (Sánchez 1976), organic matter is much more important for storing nutrients in the tropics than in temperate regions. Therefore the efficiency of mineral fertilizers is greatly reduced if organic matter is not added at the same time. On the other hand, it is necessary to consider that organic matter is mineralized about five times more rapidly in the tropics than in temperate regions. Consequently, the organic matter content of the soil is of overriding importance in relation to soil fertility in the tropics and subtropics.

Therefore we can state that any agricultural production system that does not add sufficient organic matter and/or gradually reduces the organic matter content of the soil below an adequate level is not site-appropriate, will result in soil degradation, and is not sustainable.

2. Under tropical and subtropical conditions intensive and repeated tillage will generally mineralize (reduce) organic matter at rates higher than the potential for repositioning. This results in a decreasing organic matter content of the soil and diminishing crop yields over time.

Soil tillage results in rapid mineralization of organic matter stored in the soil, liberating nitrogen that will be available for plants. This can lead to an increase in yield for a few years. However, when soil tillage is performed under favorable conditions for mineralization of organic matter (heat, humidity, good aeration) leaving the soil under fallow (bare), valuable nitrate reserves are lost by lixiviation (washing into deeper soil layers), without crops being able to utilize them.

Once organic matter has been consumed, more nitrogen cannot be liberated and crop yields remain low. The result is a depleted soil, where the indispensable organic matter is missing.

The long-term influence (100 years) of soil preparation on the organic matter content in the Argentinean Pampas is described by Yamada (1999). Over this period a reduction in the organic matter content of the soil from 6.0 to 2.5 percent could be observed.

Here it is necessary to remember that in warmer climates organic matter reduction is processed much more

quickly, and reductions below 1 percent, sometimes as low as 0.2 percent can be reached in only one or two decades of intensive soil preparation.

Recent research by USDA Agricultural Research Service (ARS) shows that soil carbon is lost very fast – as carbon dioxide – within minutes after the soil is intensively tilled (plowed). After 19 days, total losses of carbon from plowed wheat fields were up to five times higher than for unplowed fields. In fact, the loss of carbon from the soil equaled the amount that had been added by the crop residue left on the field the previous season (Reikosky 2000). For the first time, scientists now know with certainty how tillage reduces the organic matter in the soil. It is the loss of carbon (as carbon dioxide – CO₂) from the soil during tillage that lowers levels of organic matter (CTIC, 1996)

3. High rainfall and wind intensities prevailing in the tropics and subtropics are generally associated, under intensive and repeated tillage, with soil loss rates (due to wind or water erosion) that are higher than natural soil regeneration. This results in loss of nutrients and organic matter and in diminishing yields over time.

Occurrence of erosion can be considered the most important factor causing soil degradation. Under the concept of sustainability, the first negative factor in relation to productivity and profitability, and the major aggressor of the environment is soil erosion. Consequently, sustainability can only be achieved if soil erosion is stopped completely.

When agriculture is practiced on slopes in undulating topography, and rains of a certain intensity occur, soil preparation, especially with disc implements, results in bare soil, and this results in water erosion, or - in regions of heavy winds - in wind erosion.

It is estimated that soil losses in cropland in Latin America reach 10 to 60 t/ha/year (Steiner 1996, Derpsch and others 1991). Average soil losses in the State of Paraná, Brazil, where good soil conservation is practiced, are as high as 16 t/ha/year. In Paraguay, on 4000 m² plots with 6 percent and 8 percent slope on high clay content Oxisols, average soil losses of 21.4 t/ha were measured in conventional soil preparation, while only 633 kg/ha of soil loss were measured in no-tillage (Venialgo 1996). For the same experiment after extreme precipitation of 186 mm on June 9 and 18, 1995, soil losses of 46.5 t/ha were measured under conventional tillage, as compared to soil losses of only 99 kg/ha under no-tillage (both plots on 8 percent slopes). This resulted in 470 times higher soil losses when soil was prepared. (Venialgo 1996)

The high losses from agricultural soils have to be compared with consideration given to the annual rates of soil regeneration that are estimated to be not more than 250 to 500 kg/ha/year. Some scientists accept that

natural soil regeneration may reach 1000 kg/ha/year. When soil losses are higher than natural soil regeneration rates, sustainable agriculture is not possible.

Recent studies show that soil erosion is a selective process, with the most fertile soil particles taken away. Eroded soil sediments usually contain several times more nutrients than the soils they originated from (Stocking 1988).

Research has shown that soil cover is the most important factor that influences water infiltration into the soil, thus reducing runoff and erosion (Mannering and Meyer 1963). Under conventional tillage, lower infiltration rates have been measured by comparison with no-tillage (Roth 1985), and this results in a drastic increase of erosion when the soil is tilled.

4. Under tropical and subtropical conditions, intensive and repeated tillage will generally damage the soil structure and lead to excessively high soil temperatures. This will have negative effects on root growth, soil flora, and fauna (soil biological processes) and on soil moisture resulting in diminishing yields over time.

In conventional tillage, lower soil moisture content and higher soil temperatures as well as lower aggregate stability have been measured (Kemper and Derpsch 1981, Sidiras and Pavan 1986, Derpsch and others 1991).

Research shows enough evidence that lower biological activity occurs when the soil is intensively tilled by comparison with a field that is not tilled. Microorganisms will die because of famine under a bare soil system because they will not find organic substances at the surface to supply them with food. In addition, the less favorable soil moisture and temperature conditions under conventional tillage have a negative effect on microorganisms of the soil. For these reasons fewer earthworms, arthropods, (acarina, collembola, insects), fewer microorganisms (rhizobia, bacteria, actinomycetes), and also fewer fungi and micorrhyza are found under conventional tillage conditions than under no-tillage conditions (Kemper and Derpsch 1981, Kronen 1984, Voss and Sidiras 1985).

5. Any agricultural or livestock production system in which important losses of nutrients occur through extraction without reposition (for example, soil exploitation) through volatilization (for example, regular burning), and/or through leaching (for example, fallow periods without crops), is not sustainable and results in poor soils and farmers.

When high amounts of nutrients are exported from fields with harvested crops (or animals), without reposition, depletion of nutrients will occur in the medium or long term. Regular burning is another reason for nutrient depletion from fields, because nutrients are lost through volatilization. Major nutrient losses also

occur from tilled fields which are left fallow without a crop in the short, medium, or long term. As no roots are present that could prevent the downward movement of nutrients, these are lost through leaching into deeper soil layers, where they are out of reach of annual crops.

What Do We Conclude From the Laws of Diminishing Yields?

First of all we conclude that plowing and soil tillage are in opposition to sustainable land use in the tropics and subtropics.

Secondly, we conclude that we have to change the traditional farming practice of tilling the soil. We need a new production system that does not show the negative consequences of tilling the soil.

Thirdly, we can conclude that conservation tillage and especially no-tillage appear to be the production systems that can replace the traditional practice in small, medium, and large-scale agriculture. Why?

There is enough scientific evidence from warmer and increasingly also from temperate areas showing: a) that tillage is not necessary to produce a crop, b) that no-tillage has positive effects on chemical, physical and biological soil properties in comparison with conventional soil preparation, improving soil fertility over time, c) that no-tillage and conservation tillage save time, labor and fuel, and show higher economic returns than conventional tillage, and d) that no-tillage is a very efficient tool for controlling erosion and therefore it is environmentally and socially desirable.

It is now generally accepted that conservation tillage systems offer numerous benefits that intensive tillage systems cannot match. These advantages have been summarized as follows (ISTRO, 1997):

1. Reduced labor requirements
2. Time savings
3. Reduced machinery wear
4. Fuel savings
5. Improved long-term productivity
6. Improved surface water quality
7. Reduced soil erosion
8. Greater soil moisture retention
9. Improved water infiltration
10. Decreased soil compaction
11. Improved soil tilth
12. More wildlife
13. Reduced release of carbon gases
14. Reduced air pollution

Adoption of No-tillage

The superiority of no-tillage over conventional tillage practices is mirrored in high rates of adoption of this new technology. No-tillage is now being practiced on more than 16 million ha in Argentina, on 21.8 million ha in Brazil, on 23.7 million ha in the USA and on approximately 90 million ha worldwide. In the MERCOSUR countries (Argentina, Brazil, Paraguay, and Uruguay) the technology has seen a 59-fold increase between 1987 and the year 2004 (from 670,000 ha to 39.65 million ha) (Derpsch and Benites 2004). This shows that farmers are satisfied with the technology, that they feel the numerous benefits of the system, and that profitability is higher than with the conventional tillage systems.

On the other hand, 86 percent of no-tillage is practiced in the Americas (North and South) and 10 percent in Australia, but only 3.6 percent is practiced on the three other continents Europe, Asia, and Africa. There is a huge potential for bringing this soil-conserving, productivity-enhancing production system to those areas where it is still not practiced.

With oil prices forcing tillage cost ever higher, and the proven benefits of no-tillage in reducing costs, erosion, greenhouse gas emissions, etc, it is becoming a worldwide imperative that this technology be practiced by small, medium, and large-scale farmers all over the world. If socioeconomic or agro-ecological reasons make the use of no-tillage difficult, other forms of conservation tillage such as minimum tillage will be the second-best choice.

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