Soil Structure and the Science of TerraStar

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The scientific basis behind the development of the TerraStar technology is founded upon three principles: 1) the fundamentals of soil and water management, 2) the norms of soil/tool interaction and 3) soil erosion processes.

Soil is the basis of farming and a myriad of other human activities. It constitutes the reservoir for water and nutrients, which are up taken by crops. The soil, as a porous media, also determines basic rainwater/runoff/erosion interactions. The goal of soil management is to protect soil and enhance its performance so farming can be profitable while preserving environmental quality in a sustainable manner.

By definition, soil is a natural body comprised of solids (minerals and organic matter), liquid and gases that occupy space on the land surface. Moreover, Soil is characterized by one or both of the following: horizons or layers, which are distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy and matter or the ability to support rooted plants in a natural environment (Soil Survey Staff, 2003).The spatial and temporal arrangement of the mineral, liquid and gaseous phases in the soil creates what we know as soil structure (Fig. 1). Soil structure determines several processes in the soil, such as water infiltration, runoff, erosion and soil aeration, as well as the extent and magnitude of soil properties such as strength, porosity and bulk density. Having a good and stable soil structure is a condition for soil and water management.

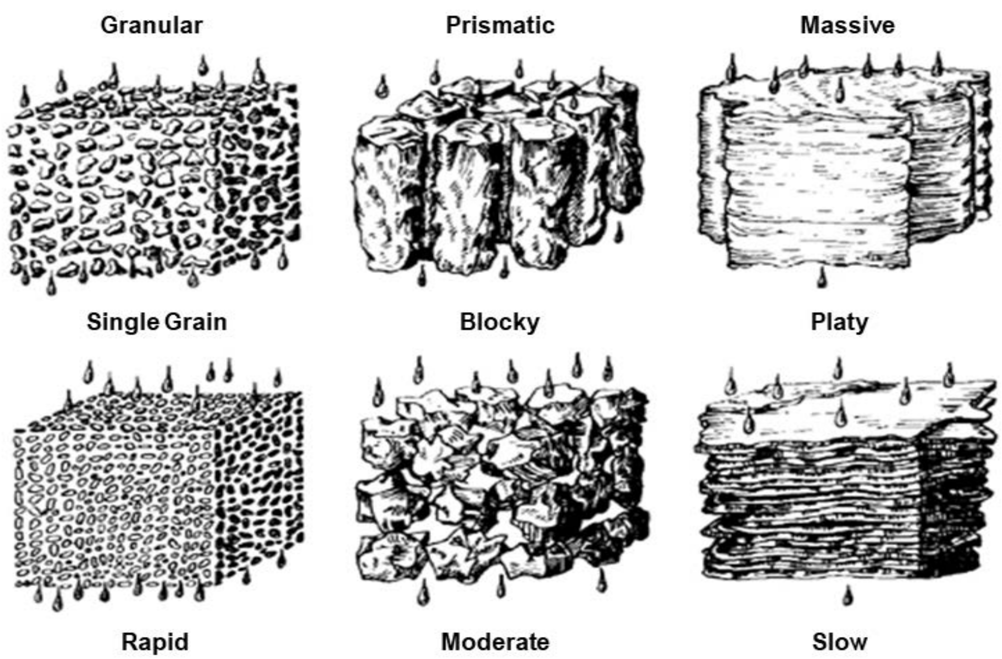


Figure 1. Soil structure and its effect on water movement in the soil

A traditional way of managing soils is by means of tillage. Tillage is valuable for loosening surface soil, preparing the seedbed and controlling weeds and pests. But tillage can also break up soil structure, speed the decomposition and loss of organic matter, increase the threat of erosion, destroy the habitat of helpful organisms and cause compaction. Compaction reduces the amount of air, water and space available to roots and soil organisms. Compaction is caused by traveling on wet soil or by heavy equipment. Reducing tillage minimizes the loss of organic matter and increases the residue protecting the soil surface.

The TerraStar technology falls into the category of a "Reservoir Tillage" system. This approach is founded upon the principle that tillage can provide increased levels of surface storage, which is one of the most effective means of controlling both runoff and soil erosion. Reservoir tillage creates basins or pits to hold water in place, allowing moisture to infiltrate the soil, thus preventing runoff.

Hansen and Trimmer (1997) reported that reservoirs or basins catch and hold water in place until it can infiltrate into the soil, and are created with specialized commercially available tillage machines. Before TerraStar, two basic methods were commonly used to construct reservoirs. Method one is pitting the soil, punching holes or depressions 6 to 10 inches in diameter, 6 to 8 inches depth and spaced about 2 feet on center. Method two builds up small earthen dams or dikes with a tillage tool that scrapes and carries loose soil down the furrow. The diking tool trips at preset intervals, creating small dams in the furrows to retain rainwater. Small basins created by these dikes hold the precipitation until it can infiltrate the soil (Fig. 2). This technology is commonly referred to as Furrow Diking.

Figure 2. Furrow diking for crop production

Furrow diking has long been used in Texas, where the Texas Water Resources Institute (1985) reported that during one 24-hour period at Bushland, TX, diked furrows held six inches of rain without runoff. Furrow diking is also economical – the equipment needed to form dikes can pay for itself in just one season with increased yields from only 75 acres of cotton. In comparing fields with and without furrow diking, researchers at

Vernon, TX have found that diking can increase cotton yields by 25% and sorghum yields by as much as 30%. Research at Vernon has shown that just one inch of moisture stored in a field increases cotton lint yield by 30 pounds, while scientists near Amarillo, TX have learned that one inch of water stored in the soil may increase grain sorghum yields by 350 pounds per acre and wheat yields by 2.5 bushels per acre. It is estimated that more than 3 million acres are now furrow diked at some time during the year, much of which are located on flat areas. However, little information has been reported for sloping areas.

Aarstad and Miller (1973) found that creating small basins in the soil reduced runoff from 40 percent to 1 percent and increased sugar beet and potato yields under center-pivot sprinklers. Over the decades since, there have been numerous attempts to develop machines for the construction of small basins (reservoir tillage).

Most of the limitations of furrow diking are related to the following facts:

1. The small earthen dams make traffic difficult over the field
2. Furrow diking does not improve soil structure and rainwater can remain on the soil surface for several days before infiltrating into the soil. Potential evaporation from the free surface of water is maximized, which results in loss of harvested water.
3. Furrow diking is not an “in situ” rainwater harvesting technique and it takes time for the water to get from collection area to the crop area and root system area. This situation is more difficult on sandy soil.
4. Furrow diking does not perform well on sloping areas, unless it is combined with contour farming.

Still today, general acceptance of reservoir tillage systems by growers has not taken place due to the limitations of each of the various systems. **What is required is an integrated system that can efficiently combine the management of soil surface and structure to increase water infiltration and moisture content in the soil, thereby sustainable increasing crop yields at an acceptable cost**. TerraStar was developed to address this critical need.

The **TerraStar technology imprints the soil to efficiently create small basins on the surface of tilled soils**. The small depressions increase soil roughness in an orderly fashion which we call Geometrically Ordered Roughness (GOR).

The GOR created by TerraStar disks is different from the Random Roughness produced by other tillage implements, such as plows and disks. TerraStar disks make a repetitive depression-ridge pattern or “weir system” that allows for the release of excess water down slope without causing soil erosion. Plows, disks and other such tillage implements create random roughness with interconnected rills, making it easier for the water to flow down the slope to create and intricate network of rills once the soil surface is saturated, prompting high rates of soil erosion and loss of water (Fig. 3).

Figure 3. Random Roughness (left) vs. TerraStar-Created GOR (right)

Surface roughness is critical in evaluating tillage and erosion processes. Kuipers (1957) first introduced parameters that have been used in the past to describe surface roughness. Kuipers defined a roughness index $R_K = 100 \log(\sigma)$, in which σ is the standard deviation of the various elevation readings of the surface. Following this, Allmaras et al. (1966) refined Kuipers roughness index by measuring the standard error of measured elevation points referenced to some plane. Several studies involving roughness characterization on surfaces used these parameters (Moore and Larson, 1979; Onstad, 1984). A major critique with using the roughness index was that this roughness parameter did not describe the spatial dependence of the roughness elements. The roughness index characterized the variation of heights, or vertical roughness, but did not describe the spatial distribution of roughness on the surface. For example, two surfaces may have the same roughness index but one surface may have the roughness on average spaced farther apart on the surface. A more complete characterization would describe not only vertical scales of roughness but also the horizontal scales. This idea is taken into consideration by the concept of GOR characterized by fractal analysis (Huang, 1998)

In any situation, soil surface roughness, especially GOR, will promote rainfall detention and a greater water infiltration while reducing runoff and soil erosion (Fig. 4).

Figure 4. Rainwater detention on a soil surface with GOR

There is an inverse relationship between infiltration and runoff. Therefore, by increasing rainwater infiltration with GOR, runoff will be reduced. And by reducing runoff, GOR increases the amount of water entering into and sequestered by the soil, which in turn reduces soil erosion (Fig. 5).

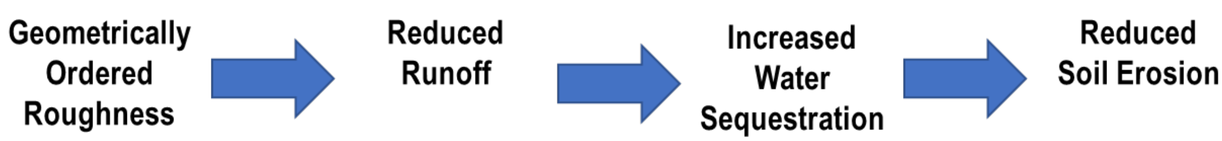


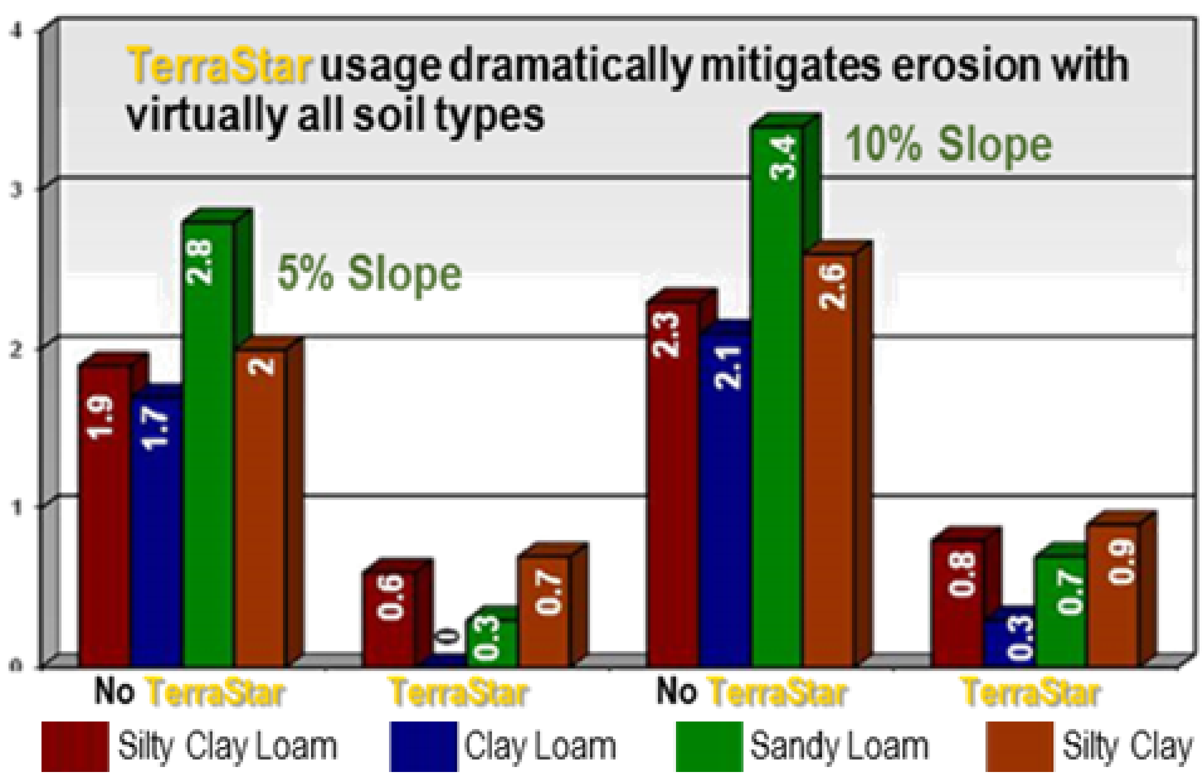
Figure 5. Benefits of TerraStar-Created GOR

Greater infiltration also means higher soil moisture contents. Increased soil water content is one of the main benefits of the TerraStar technology by means of Water Harvesting. Water Harvesting is a general term used to describe the collection and concentration of runoff for various uses, including agricultural. Originally, most water harvesting techniques consisted of a catchment area and a receiving area for the capture of runoff. The areas are generally small in size and harvesting occurs near where the rain falls. Pacey and Cullis (1986) classify rainwater-harvesting techniques in three broad categories: macro-catchment, micro-catchment and rooftop-runoff collection. Macro-catchment rainwater harvesting includes the collection of water from large areas substantially distant from the cropped areas. Micro-catchment rainwater harvesting is a system where the collection and the cropped area are distinct but adjacent to each other.

In-situ water harvesting, also known as water conservation, consists of creating storage available in areas where the water will be utilized. Some water conservation methods such as mulching, deep tillage, contour farming and ridging are often referred to as in-situ rainwater harvesting techniques (Habitu and Mahoo, 1999). The purpose of these methods is to ensure that rainwater is held long enough on the cropped area to allow more water infiltration into the soil.

The **TerraStar technology not only complies with the definition of "in-situ" rainwater harvesting, it may be the only technology that truly fits the concept**. The TerraStar technology includes a soil tillage tool. Tillage increases soil water retention and storage capacity by increasing soil porosity. In addition, runoff is reduced through TerraStar induced GOR at the soil surface, which in turns increases the time available for water to infiltrate into the soil.

Modification of soil structure through tillage and creation of a GOR is achieved by the soil/tool interaction of the TerraStar technology. Soil structure and surface roughness are modified by applying an external force when the TerraStar disks roll over the tilled soil surface. The simple wheel or disk concept applies pressure on the loose, tilled soil to firm the soil and create the mini reservoirs or imprints. This action does not compact the soil, but rather consolidates it given the cohesive forces holding the soil together in the shape imprinted by the wheel. The more friable the tilled soil consistency, the better to achieve soil consolidation and firming without compaction. The external force exerted upon the soil by the TerraStar disks leads to soil consolidation which promotes air and water movement and significantly reduced to promote runoff immediately.



It is very important to make a distinction between Soil Compaction and Soil Consolidation. There are several definitions of Soil Compaction, but in general the term is used to describe a composite, generic, negative impact on plant growth and soil health as a result of a reduction of large pore space which restricts air and water movement into and through the soil. Soil compaction is primarily caused by working or driving on wet fields and can develop at or below the soil surface.

An early sign of compaction is crusting in the upper one inch of soil and can be seen as plants germinate and emerge. The plant must push up through the compacted surface soil or grow laterally until it finds a crack. If the seedling does not reach sunlight it will die. Also, if food reserves in the seed are used up before the plant establishes a good root system the seedling may not emerge or it may emerge and then die (Fig. 6).

Figure 6. Soybeans struggle to emerge through crusted soil

The last major plant symptom of soil compaction is reduced yield. Compaction can reduce yields up to 60% depending upon the depth of compaction and its severity.

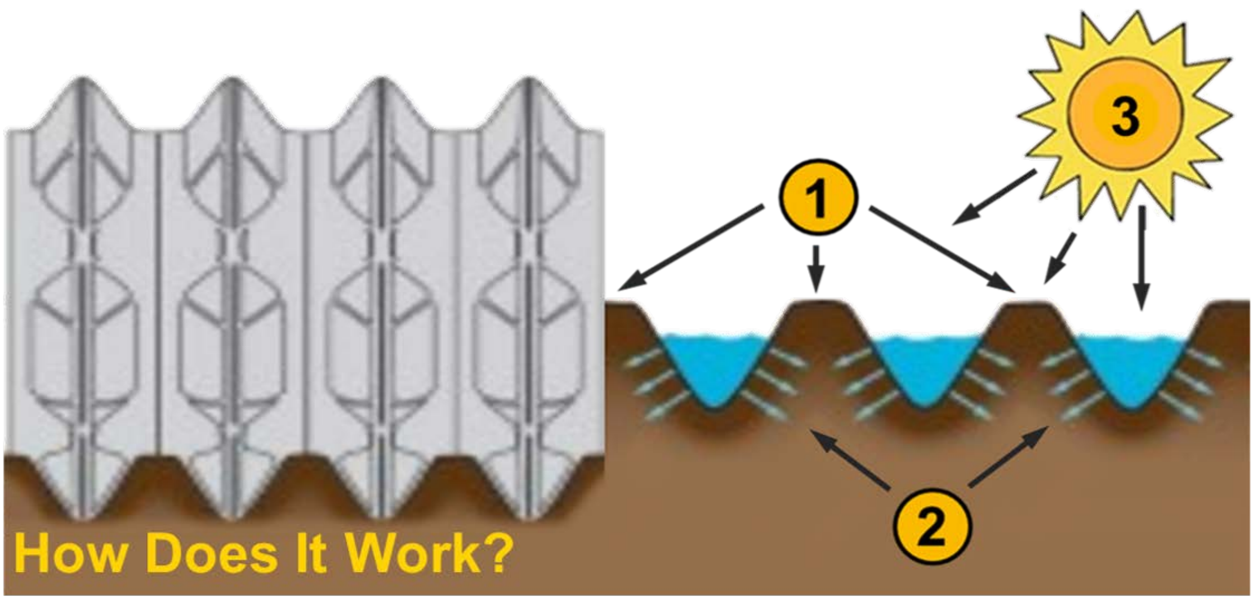
Two variables used to measure soil compaction are soil bulk density and soil strength. Penetrometers are used to evaluate soil strength. There is no specific numerical soil strength value that identifies compaction. But it is important to mention that a good indicator of soil compaction in the soil is the presence of compacted layer, such as plow pans, which restrict air and water movement and root growth. The values of soil strength in those compacted layers are indicative of soil compaction. Several research results indicate that soil strength for a compacted layer is above 250 psi (pounds per square inch).

Compaction problems arise only when the degree is such that plant growth and yield are materially reduced. Even though compaction is a negative term, the process of compaction itself is dynamic and has different degrees. Slight and moderate compaction (Soil Consolidation) will not typically affect yield. In this case, we practically consider that there is no compaction, since the movement of soil and water and plant growth and yield has not been affected negatively. However, soil management practices should be changed to minimize the development of further compaction.

Recently-tilled soils **must be consolidated without inhibiting air and water movement** to achieve optimal results. Unlike compaction, consolidation of the soil is necessary to achieve a sustainable medium for enhanced plant growth. When soil is consolidated via TerraStar, the result is a modification of soil structure which increases internal bonding and soil strength as more soil particle to soil particle contacts are made. This in turn improves soil resistance to erosion and enhances the thermal properties of the soil. Consolidation also increases soil to seed contact and thus promotes germination.

The TerraStar technology uses consolidation principles to imprint the soil and create a Geometrically Ordered Roughness (GOR) on the soil surface. According to research results in Vertisols (heavy clay soils), the TerraStar never consolidates the soil to a value larger than 250 psi. Larger pressure forces will compact the soil, and will not allow the creation of GOR.

Results from research at the University of Queretaro have demonstrated, in five consecutive years, that **consolidation by TerraStar disks to create GOR have increased water intake and moisture content, reduced runoff and erosion, increased plant germination and growth and finally, it has increased yield**.



1. **Soil:** top soil is tightly consolidated via imprinting - mitigate soil erosion and enhance soil-seed and soil-root contact
2. **Water:** imprints (reservoirs) hold water with loosely consolidated sides - reduce runoff and increase water sequestration in the soil
3. **Sun:** surface area of soil increased - enhance sun exposure and increase access of oxygen, carbon and hydrogen to root zone

All of these positive results are attributable to the process of **optimal soil consolidation using TerraStar**.

Conclusion

After five years of research and evaluation under laboratory and field conditions, it can be concluded that the TerraStar Technology offers an effective and economical alternative for crop production while conserving soil and water by means of creating a Geometrically Ordered Roughness on the soil surface (a and consolidating (not compacting) the soil effectively to reduce soil crusting and sealing and a longer lasting system of soil impressions.

The benefits of implementing the TerraStar Technology include:

1. Reduction of runoff and soil erosion, both due to the overland and concentrated flow
2. Increase of rainwater infiltration and soil moisture content
3. Soil consolidation to reduce soil surface sealing and crusting
4. Better soil/seed contact for better germination and emergence
5. Reduction in production costs, making farming a more profitable activity
6. Healthier crops by overcoming the limitations of droughts and making more efficient the use of soil nutrients
7. Higher yields

The full implementation of the TerraStar Technology will benefit not only the individual farmer but also the economy of societies around the world while preserving two of our most valuable resources for future generations: soil and water.

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