WATER CONSERVATION TECHNICAL BRIEF

TB 9 - Use of a Conservation Tillage System as a Way to Reduce the Water Footprint of Crops

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WATER CONSERVATION

TECHNICAL BRIEFS

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Conservation tillage systems are gaining increased attention as a way to reduce the water footprint of crops by improving soil water infiltration, increasing soil moisture and reducing runoff and water contamination. At the same time, several studies conducted in the Americas have demonstrated that these systems can improve soil quality, reduce erosion and compaction, increase surface soil organic matter and carbon content, and moderate soil temperatures. This technical brief describes conservation tillage and analyses the differences between conventional and conservation tillage systems. The aim of this technical brief is to provide a general overview of conservation tillage practices, and how these practices can reduce the water footprint of crops in agriculture – if properly managed.

The structure of the technical brief is as follows: Section 1 introduces the concept of conservation agriculture and tillage. Section 2 provides a comparison between the agroecologic differences between conventional and conservation tillage practices. Section 3 contrasts the advantages and disadvantages of no-tillage practices at an economic, social and environmental level. Section 4 assesses no-tillage practices as a strategy to reduce the blue, green and grey water footprint of a crop. Section 5 set outs the state of implementation of no-tillage practices worldwide. Section 6 provides some recommendation to farmers on how to implement no/tillage at a farm level. Section 7 illustrates some case studies in Karakalpakstan and China. Section 8 presents some appendixes as a complementary lecture. Finally, Section 9 recommends some further reading.

Contents

Section 1: What is Conservation Tillage?[1]

Conservation Tillage (CT) refers to reduced-tillage cropping systems including no-tillage, strip tillage, mulch tillage and ridge tillage[a]. CT is technically defined as a crop system where at least 30% of the soil is covered with crop residue after planting[2]. These residues protect the soil from erosion, wind and water. The operating principle behind conservation tillage is to minimise the disturbance of the soil.[3]

A broader definition of CT is provided by Baker et al.[4] and states *"Conservation tillage is the collective umbrella term commonly given to no-tillage, direct drilling, minimum tillage and/or ridge tillage, to denote that the specific practice has a **conservation** goal of some nature. Usually, the retention of **30% surface cover** by residues characterizes the lower limit of classification for conservation tillage, but other conservation objectives for the practice include conservation of time, fuel, earthworms, soil water, soil structure and nutrients. Thus residue levels alone do not adequately describe all conservation tillage practices."*

In addition, FAO describes CT[5] as *"… a set of practices that leave crop residues on the surface which increases water infiltration and reduces erosion. It is a practice used in conventional agriculture to reduce the effects of tillage on soil erosion. However, it still depends on tillage as the structure forming element in the soil. Nevertheless, conservation tillage practices such as zero tillage practices can be transition steps towards Conservation Agriculture."*

Figure 1: In the no-till farming system, significant amounts of crop residue remain on the soil surface, protecting it from water erosion and improving soil quality. Source: www.ipm.iastate.edu/ipm/icm/node/451

[a] For definitions of strip tillage, mulch tillage and ridge tillage see Appendix A.

SECTION 2: AGROECOLOGICAL DIFFERENCES BETWEEN CONVENTIONAL TILLAGE AND NO-TILLAGE PRACTICES[6]

To understand the differences between conservation and conventional tillage practices at an economic, environmental and social level, it is essential to look at the agroecological functions of each of the systems, specifically the production of $C0_2$, aeration, water movement, runoff and infiltration.

In an open soil-plant system such as conventional tillage the following characteristics occur:

- This soil plant system is drought prone; accelerates soil surface erosion; requires high input level to maintain fertility; **causes sedimentation and water pollution downstream**.
- Net result is more intense Soil Organic Matter (SOM) oxidation, intense nitrate fluxes, the soil porosity collapses, **water infiltration capacity is reduced, runoff increases and fluxes of nutrients are washed away**.
- Tillage unlocks the potential from microbial activity by creating more reactive surface areas for gas exchange on soil aggregates that are exposed to higher ambient oxygen concentration (21%) and higher temperatures.
- Over time, ploughing creates a compaction zone which further prevents upward soil fauna movements and downward root development.
- Intense nitrate leaching and accompanying cations, e.g. Ca, Mg, out of the shallow root zone, **results in soil acidification and groundwater pollution**.

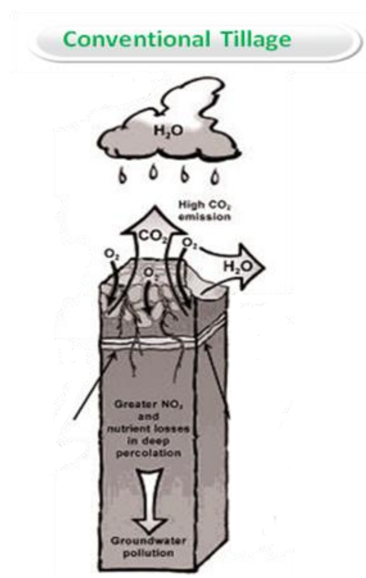

Figure 2: Conventional Tillage System. Arrows show an important release of CO_2, a high pressure of C02 and O2 in the soil atmosphere, intense water runoff and greater NO3 and nutrient losses in deep percolation and therefore groundwater pollution.

On the contrary, no-tillage practices represent a closed soil plant system, characterised by the following:

- The soil plant system mimics a natural soil ecosystem. It is more drought resistant, it ensures highly efficient use of existing nutrients (or added if required); **it reduces contamination risks.**
- Due to the intense biological activity, **the soil pore atmosphere is richer in CO_2** and has a lower PO_2/PCO_2 ratio.[b] Soil temperature is also lower. Both conditions lead to reduced oxidation rates and accumulation of SOM.
- Permanent soil cover protects from the soil from the rain drops' energy, increases water infiltration, and hence drastically **reduces water runoff** and soil erosion risks. When rain drops hit the soil they destroy soil aggregates so that tiny soil particles clog the pores impeding water to infiltrate the soil.
- Increased population of earthworms, insects and greater root development contribute to better soil aeration, and SOM distribution in the soil profile through biological macropores.
- **Efficient water and nutrient cycling** as a result of root development and stable biological porosity.
- **Clean water drained**

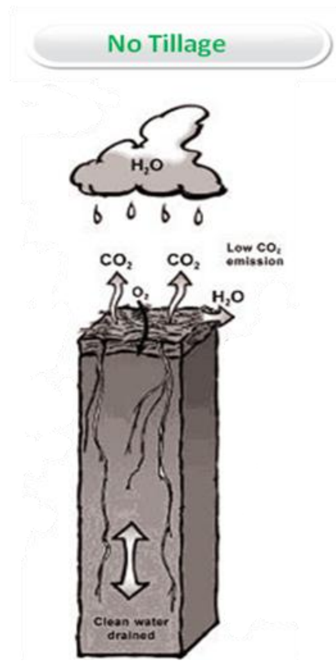

Figure 3: No-tillage System. This figure shows an efficient water balance, a limited release of C02 to the atmosphere and clean water drained downward.

[b] Ratio of partial pressure of CO_2 and O_2 in the soil atmosphere.

TB 9 – Use of Conservation Tillage System

The following table depicts the differences between both systems. It looks at soil cover, soil temperature, biological activity, root system, porosity, weed and organic residues, compaction, runoff and soil nutrient movement.

Table 1: Agroecological differences between conventional and no-tillage system.

Conventional Tillage	No tillage
Greater NO3 and nutrient losses in deep percolation ➔Groundwater Pollution	Clean water drained
Periodically bare soil	Permanent soil cover (organic residues)
High temperature fluctuations	More stable temperatures throughout the day and the year
PO/CO2 high (Ration of partial pressure of CO2 and 02 in the soil atmosphere)	PO/CO2 low
Unstable mechanical porosity	Stable/high biological activity and adequate soil porosity
Root system, weed seed and organic residues mostly in the tilled layer	Deep and diverse root system
Contributes to soil organic matter SOM degradation	Intense downward and upward movement to soil fauna
Intense water runoff and soil erosion. Loss of SOM (oxidation by microorganisms)	Very low risk of soil erosion (no splash effect to rain drops, better infiltration, limits runoff)
Upward movement of soil fauna limited by soil compactation	SOM accumulation on the top layer and distribution in deeper layers through soil fauna movements
Intense nutrient leaching under the root zone, deep water pollution	Efficient nutrient and water cycling

Source: World Bank
http://info.worldbank.org/etools/docs/voddocs/339/665/NotillFarmingforSustainableDevelopment.pdf

SECTION 3: ADVANTAGES AND DISADVANTAGES OF NO-TILLAGE PRACTICES[7]

No-tillage systems have a number of advantages and disadvantages. Is important to note that '**no-tillage'** needs to be adapted to site-specific conditions[c,8], therefore it is important to ensure a comprehensive management that ensures the selection of the most appropriate system for particular soil and climatic conditions on the farm in question and the selection and operation of appropriate equipment.

a. Advantages[d]: Conservation tillage has several environmental, social and economic advantages[9].

Economic

- Energy and labour[e] across the total production process can be reduced
- Reduced use of fertilisers and lower production costs
- Crop productivity increased[10,f]

Social

- According to Derpsc[h], better profitability and higher crop yields mean that the farming family could have a greater chance of succeeding and remaining on the land[11]

Environmental

- Crop yields are equal to or better than under conventional tillage
- Maintenance or increase in the SOM content (enhancement of soil quality)
- Soil improvement (chemical, physical and biological characteristics). Studies of no-tillage have shown that it leads to significant changes in the physical and biotic characteristics of the soil environment. Most studies have shown that the

[c] This advantages and disadvantages have been taken from experience in the Americas, where no-tillage practices are common.

[d] As noted before, these advantages have been taken mainly from experiences in USA, Brazil and Argentina. In USA, Brazil and Argentina No-tillage is practiced on more than 75 Million ha.

[e] Labour can be reduced unless the weed management require extra labour when not using herbicides. See Giller K. E., Witter E., Corbeels M. and Tittonell P., 2009, Conservation agriculture and smallholder farming in Africa: The heretics' view, Field Crops Research, 114 (1), pp. 23-34.

[f] This is based on case studies in US, Brazil, Argentina.

soil becomes more dense, primarily because the number of larger pore spaces in the soil is reduced and the number of smaller spaces is increased. This reduces aeration somewhat, but tends to increase the water holding capacity of the soil. No tilled soils tend to be cooler than others, partly because a surface layer of plant residues is present Carbon is sequestered in the soil enhancing its quality, reducing the threat of global warming[g]

- Planting times are more flexible. Planting can take place immediately after rain and there is no wait for tillage operations. In double cropping situations (cowpeas after maize, for instance), harvesting, slashing, spraying, and planting can take place within a few days
- Water runoff is reduced, which is beneficial in two ways: more water is available for the crop and soil erosion is reduced
- Reduced wind and water erosion. Reduced erosion can lead to off-site benefits such as a reduced rate of siltation of water courses and increased recharge of aquifers ,
- Increased water infiltration into the soil and increased soil moisture

b. Disadvantages: On the other hand, the disadvantages of minimum and no-tillage systems are:

Economic

- Short term yield effects have been found to be variable (positive, neutral or negative yield responses which can discourage the adoption of CT[h]). The variability in short-term crop responses to CT is principally the result of the interacting effects of crop requirements, soil characteristics and climate.

Social

- Not tilling the soil may results in increased weed pressure. The increased amount of labour required for weeding with CT may outweigh the labour-saving gained by not ploughing, unless herbicides are used to control weeds. In Africa, no-

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[g] Recent studies show how no-tillage system can contribute to lessen the emission of CO_2 into the atmosphere when compared to conventional agriculture systems.

[h] As an example, in northern China yields under no-tillage systems are equivalent to those under conventional tillage system in years with an average rainfall pattern, higher in dry years, and usually lower during wet years.

tillage has resulted in increased labour requirements when herbicides are not used [12]

- In some countries, no-tillage might result in a gender shift of the labour burden to women[13]
- Competing uses of crop covers (priority given to feeding of livestock with crop residues)[14]

Environmental

- Herbicides must be used often and with accuracy. Application of herbicides is critical in cases where the farmer does not plough or till to control weeds and grasses. Before planting, any vegetation present must be killed with a broad – spectrum herbicide, the effects of which are non persistent; after planting, more specific and more persistent herbicides are usually required to control specific weeds particular to the crop situation.[15] See Appendix B for a comparison of herbicide applications between different tillage systems.

  Specialised planting equipment is needed (See Figure 5 for examples)

SECTION 4: NO-TILLAGE AS A WAY OF REDUCING WATER FOOTPRINT

The concept of water footprint is defined as the total volume of freshwater used, directly or indirectly, to produce a product or process including the total amount of water required in agriculture for growing crops. Hoekstra and Hung, distinguished three types of water depending on the source: green, blue and grey.[16] Blue water is the freshwater withdrawn from water bodies such as rivers, lakes or aquifer, and used for irrigation; green water is the water used from rain usually stored in the soil that evaporated from crop fields, while grey water is the theoretical amount of water needed to dilute polluted water to legal standards.[i]

As it has being mentioned previously in this report, the application of no-tillage practices can have positive consequences on the water use in crop production. However, the effects of conservation tillage on water quality may vary based on many factors. Some of these factors include climate, soils, topography, geology, existing cultural and management activities, as well as modifications made to the practice standards that govern how the practices are to be applied in local settings.[17] Management practices should only be chosen after a thorough evaluation of their

[i] Usually acceptable standards are considerer standards set by regulatory bodies as European Environmental Agency (EEA) or US Environmental Protection Agency (EPA).

potential impacts and side-effects. The following figure depicts some general effect of the application of these practices on green, blue and grey water use.[j]

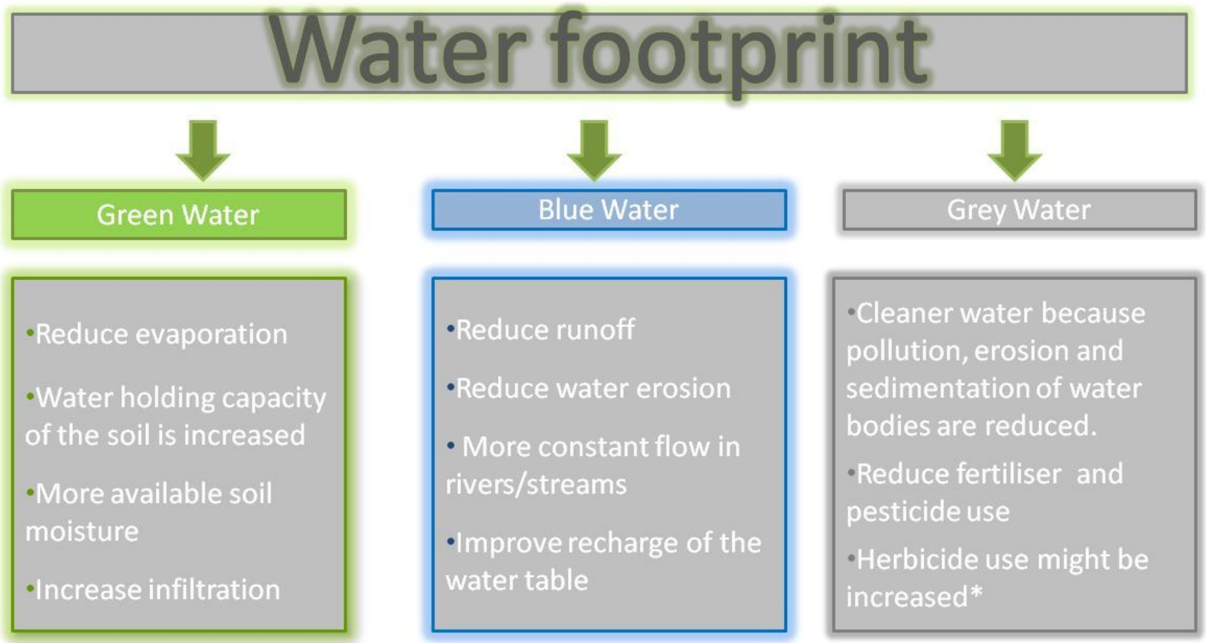

Figure 4: No-tillage effects on water footprint of a crop. *Note that herbicide use might be increased depending on the way used to deal with weeds. Integrated weed management can offer an excellent way of improving weed control without increasing grey water.

A. Green water

No-tillage systems are very effective in reducing evaporation from soil, to increase the water holding capacity and soil moisture and increase water infiltration.[k,18]

- The use of soil covers reduces water evaporation and therefore water is available for crop production.[19] For example, a study completed by the University of Nebraska showed 15.4 cm less evaporation on soil with residue compared to bare soil, and 7.62 cm of less evaporation even when the crop has canopied.[20]

- No tillage systems increase soil water infiltration substantially compared to the infiltration of the moldboard-ploughed soil.

[j] They are based on literature review.
[k] This applies for rain-fed and irrigated cropping conditions.

- The covered surface of no-tillage fields acts as a protective skin for the soil. This soil skin reduces the impact of raindrops and buffers the soil from temperature extremes as well as reducing water evaporation.[21]

B. Blue water

No-tillage systems are very effective to reduce runoff, water erosion, improved recharge rate of the water table and allow more constant flow in the river stream.

- When rain drops hit the soil they destroy soil aggregates so that tiny soil particles clog the pores impeding water to infiltrate the soil, and hence it may reduce water runoff.

- The increase in green water reduces the need of blue water to satisfy the water crop requirement. According to Peiretti[22], under irrigated conditions no-tillage significantly contributes to reducing the amount of water needed for crop production. That means farmers can save on irrigation and, just as importantly, this reduces water logging of the crop.[23] Water savings of 15-50% have been calculated under no-tillage systems.[24] Moreover, in China, water use efficiency has increased (with up to 35%) following the implementation of reduced tillage practices.[25]

- By reducing evaporation of soil moisture reserves and by improving soil water infiltration, irrigation needs can be reduced under CT.[26]

- To ensure a reduction of blue water, competition for water from weeds needs to be restricted.

C. Grey water

Water quality may be improved in no-tillage if fertiliser and pesticide use is minimised, clean water is drained and pollution, sedimentation and erosion are reduced.

- Permanent soil increases water infiltration, hence water runoff[l] and soil erosion risks may be reduced. The reduction of water runoff and the consequent

[l] Trails in Europe has demonstrates that CT can reduce runoff by 40-69%, with consequent decreases in herbicide, nitrate and soluble phosphate content of surface waters (70%, 85% and 65% respectively) Available at: www.sowap.org

reduction –or avoidance- of soil erosion implies a better water quality of surface water as fewer nutrients are carried by the runoff.

- In Brazil the application of the no-tillage system has resulted in clean water drained in watersheds even in times of heavy rainfall and a reduction of sediments in watersheds.[27]

- According to Rolf Derpsch, no-tillage systems can have benefits for the environment by reducing the sedimentation of rivers, reservoirs, lakes and micro catchments and enhanced water quality[28] and therefore reduced grey water

- If not conducted properly, the no-tillage system might result in an increased use of herbicides or to control weed management. No-tillage farmers will need to adopt more diverse pest and weed management strategies, including biological, physical and chemical measures to lessen the use of herbicides.[29,m]

- Experience from cultivation of no-tillage maize in Europe has demonstrated that CT reduces herbicide (e.g. IPU) losses in runoff due to reductions in runoff volumes, better absorption to organic matter on the surface and in topsoil, and accelerates degradation due to higher microbial activity. Only in the case of highly persistent and low-sorptive chemicals (e.g. egclopyralid), could potential result on groundwater contamination increase under conservation tillage.[30]

- In some studies, no tillage systems have been shown to reduce nitrate leaching over conventional tillage, as well as proper crop rotation, especially those including a nitrogen-fixing crop. However, other studies have shown that conservation tillage increases the infiltration rate of soils.[31]

[m] See Technical Brief on Integrated Pest Management for more detail.

SECTION 5: FARMER ADOPTION OF NO-TILLAGE PRACTICES

Farmer adoption on no-tillage practices is over 106 million ha. About 47% of all no-tillage farming is practiced in the USA and Canada, 39.6% in South America (Mainly Brazil and Argentina)[n], 9.4% in Australia and 3.9% in the rest of the world, including_Europe, Africa and Asia.[32] In Sub-Saharan Africa, no-tillage practices have limited adoption with only small groups of adopters in South Africa, Ghana[o] and Zambia. However, the results have not being very promising in this region because of the increased labour demand for weed management and the lack of access to external inputs such as machinery.[33]

Figure 5: On the left, maize planted directly into a flowering turnip crop in Switzerland. On the right, the green manure plants are then sprayed off with a non-selective herbicide to provide a favourable microclimate for the maize seedlings and also to protect against pesticide run-off and nitrate leaching. Source: www.sowap.org

Europe adoption on no-tillage practices has been low in comparison to America.[34] Evidence suggests that environmental benefits, both on and off the farm, can be delivered across the range of European cropping systems. Over time, soil structure and health improve and biodiversity is encouraged. Soil erosion and diffuse water pollution are reduced. In the long run, costs of labour, energy and, often, agrochemical and fertilizer inputs decrease, even if yields are sometimes lower.[35] Early adopters, and ultimately advocates, of CT are most likely to be found in younger or more entrepreneurial farmers, more willing and able to change their approach and systems.[p]

Nonetheless, there is a very big potential to bring CT practices to Europe, Africa and Asia[36], although limiting **climatic and socio-economic factors have to be taken into account**. Eastern European countries seem to have the biggest potential for a fast growth of this technology.[37]

[n] South America has the highest adoption rates and has more permanent no-till and permanent soil cover.

[p] Perceptions exist and need to be overcome. In the more arid parts of Europe, farmers need to be convinced that a cover crop can be managed to prevent competition for water.

SECTION 6: SECTION GUIDELINE FOR IMPLEMENTATION

Usually the full benefits of CT take time and, during the initial transition years the advantages might not been seen thus discouraging farmers from adopting CT systems.[38] Weeds are often a major initial problem that requires integrated weed management over time to get them under control. Soil physical and biological health also takes time to develop. According to experts, around three to seven years may be needed for all the benefits to be realised.[39]

To ensure an adequate implementation of these practices, it is pivotal to conduct a critical assessment of the ecological and socio-economic conditions under which CT is best suited for smallholder farming.

To adopt no-tillage practices successfully, Derpsch[40] recommends that farmers consider the following before starting with the no-tillage system.[q]

- Improve the knowledge about all aspects of the system but especially in weed control
- Analyse the soil and if necessary incorporate lime and correct nutrient deficiencies
- Avoid soils with bad drainage
- Level the soil surface if this is rough for any reason
- Eliminate soil compaction using chisel ploughs[41] or subsoilers
- Produce the highest amount possible of mulch cover
- Buy a no-tillage machine. See figure 6 for some example of wheat no till machines.
- Start on only 10% of the farm to gain experience
- Use crop rotations and green manure cover crop to reap the full benefits of the system
- Be prepared to continuously learn and be up to date with new developments

[q] These recommendations have been successfully applied in America.

TB 9 – Use of Conservation Tillage System

The difficulty of weed control without tillage is one of the most important limits on the use of conservation tillage practices for crop production. The general practice in reduced tillage systems is to substitute herbicides, mowing, or burning for cultivation to kill the existing vegetation before the vegetable crop is planted, but few options exist for weeds that germinate after the crop is planted.[42] Since the herbicide cannot be incorporated into the soil except in strip tillage[r] systems, the herbicide must be applied over the mulch or stubble[s] and moved into the soil by rainfall or irrigation.[43]

Figure 6: Various equipment for planting wheat no-till. (a) inverted-t coulter; (b) indian no-tillage drill using inverted t; (c) disk type planter; (d) star-wheel punch planter (e) "happy planter", which picks up straw and blows it behind the seeder; (f) disk plan Source: http://www.ecaf.org/index.php?option=com_content&task=view&id=93&itemid=64

[r] For definition see Appendix A.
[s] Stumps of grain and other stalks left in the ground when the crop is cut.

SECTION 7: CASE STUDIES

Pilot project for no-tillage practices in Karakalpakstan and Tashkent[44]

This project was conducted by FAO in Karakalpakstan[t] and Tashkent from 2005 to 2007 as a way to introduce on a pilot scale an integrated package of more sustainable agricultural practices, including CT practices[u]. Both projects focused on the introduction of the new technologies, including training for farmers and specialists and on-farm demonstration of technology components to adopt no-tillage practices.

Figure 7: Winter crop in no-till

Figure 8: An Indian no till bed planter. Source: http://www.fao.org/ag/ca/doc/CA_UZB_WP2.pdf

The basic principle of bed planting consists of sowing crops on ridges or beds (instead of on a level field). The advantages of bed planting practices constitute about 50% in seed savings; **40 to 50% water savings**; higher yields than those in conventional systems; reduced lodging; easier mechanical weeding of wheat by tractor; opportunities for a last irrigation at grain filling; **avoiding temporary water logging problems**; allowing surface basal and top dressed fertilizer placement, lower nitrogen

[t] Uzbekistan, north of Turkmenistan and Afghanistan.

[u] CA practices included maintenance of soil cover, direct planting/seeding with minimal soil disturbance and appropriate crop rotations.

applications; rainwater conservation.

The bed planting practices were conducted by planting three rows of winter wheat on 1.2 mt beds. The winter wheat variety, Dostlik, was sown at a rate of 140 kg/ha.

The results showed that bed planting practices:

- **saved an average of 30% water**
- improved yield
- increased fertilizer efficiency
- reduced herbicide use
- saved seeds
- reduce production costs by 25-35% when permanent beds are used
- that retention of crop residues improves the chemical, physical and biological soil qualities, essential for long-term sustainable
- It became clear that the extensive tillage with its associated high costs and long turn-around time could be dramatically reduced by the use of permanent beds.

The machinery to work for CT was constructed locally and made available for the national market.

Developments in conservation tillage in rainfed regions of North China[45]

The increasing population in China has resulted in an increased demand for food, thus putting pressure on the land. It has forced farmers to increase land use intensity. The intensification of crop production has contributed to a range of negative environmental effects such as soil degradation and poverty. Most provinces of northern China face serious poverty problems related to poor land use management (See figure 9). Demonstration and extension of conservation tillage practices is actively has been promoted by the Chinese

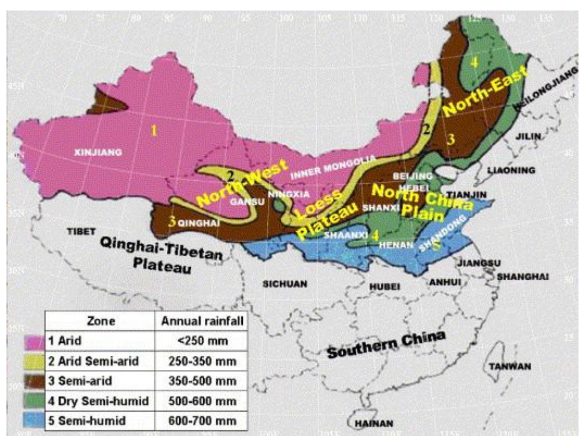

Figure 9: Map of the climatic and agricultural zones in North China

government since 2002, following the recognition of the increased rate of degradation of the environment due to erosion and water shortages in northern China.

The use of reduced tillage practices has shown promising results in some regions of China. Research conducted in China concludes that conservation tillage systems increase soil water storage, reduces wind erosion, increases crop yields, and water use efficiencies, saves energy, and reduces labour inputs as compared to conventional tillage.

The following table shows the results of the research conducted by Wang X.B. et al.[46] in 8 different locations. As is shown in the table, the soil water storage capacity and water use efficiency improve under the conservation tillage system.

Location & crop	Soil water storage (increased from 3 up to 50%),	Water Use Efficiency (increased 2–36%)
Tunliu, Shanxi, winter wheat	49% with DP	
Linfen, Shanxi, winter wheat	40–49% with SS; 15% with NT	Up 2–27% with NT/SS
Linfen, Shanxi, winter wheat		Up 19% with NT/SS
Luoyang, Henan, winter wheat	3–16% with NT; 2–12% with SS	
Tunliu, Shanxi, spring maize		Up 1–20% with DP + RI; up 15–18% with RM
Shouyang, Shanxi, spring maize	3–15% with DP + RI; 6–13% with NT/SS	Up 29–36% with DP + RI; up 10–32% with NT/SS
Shouyang, Shanxi, spring maize		Up 23% with RI (11 year average)
Daxing, Beijing, summer maize		Up 46% with RM; up 19% with SS
Note: NT: no-till; DP: deep ploughing; SS: subsoiling; RI: residue incorporated; RM: straw mulching.		

Source: Data obtained from paper Developments in conservation tillage in rainfed regions of North China. *Soil and Tillage Research.*

Notwithstanding the achievements and the promotional activities of the government, conventional tillage practices are still common, and considerable efforts will have to be made to accomplish widespread application of conservation tillage.

SECTION 8: APPENDIXES

Appendix A: Tillage Type Definitions[47]

Strip-till: The soil is left undisturbed from harvest to planting except for strips up to 1/3 of the row width (strips may involve only residue disturbance or may include soil disturbance). Planting or drilling is accomplished using disc openers, coulter(s), row cleaners, in-row chisels or roto-tillers. Weed control is accomplished primarily with crop protection products.

Ridge-till: The soil is left undisturbed from harvest to planting except for strips up to 1/3 of the row width. Planting is completed on the ridge and usually involves the removal of the top of the ridge. Planting is completed with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is accomplished with crop protection products (frequently banded) and/or cultivation. Ridges are rebuilt during row cultivation.

Mulch-till: Full-width tillage involving one or more tillage trips which disturbs all of the soil surface and is done prior to and/or during planting. Tillage tools such as chisels, field cultivators, disks, sweeps or blades are used. Weed control is accomplished with crop protection products and/or cultivation. It leaves more than 30% soil covered with residues after seeding.

Reduced-till systems are somewhat similar to mulch till in that they involve full-width tillage,use the same implements and may use one to three tillage trips. Reduced-till, however, leaves 15-30% residue on the soil surface after planting. Weed control is accomplished with crop protection products and/or row cultivation.

Conventional-till or intensive-till involve full-width tillage and may involve one, three or perhaps up to 15 tillage passes. There is less than 15% residue on the soil surface after planting. Moldboard ploughing and/or multiple tillage trips are involved.

Appendix B: Conventional Tillage

Conventional tillage includes practices such as crop residue burning or deep soil inversion by tilling to control weeds and to prepare the seedbed. These techniques considerably increase soil deformation by compaction, erosion and river contamination with sediments, fertilisers and pesticides. In addition, conventional agriculture techniques increase the emission of CO_2 into the atmosphere, contributing to global warming and reduce the sustainability of agriculture by lowering soil organic matter and fertility, along with further negative environmental effects (e.g. a decrease in biodiversity).

Tillage practices have been applied for many years to incorporate crop residues, weeds, or amendments added to the soil, such as inorganic or organic fertilizers, to prepare the soil for a seedbed,[v] to aerate the soil organic matter, which in turn helps release and make available to plants nutrients tied up in this important soil component. Finally it has been used to control several soil and residue borne diseases and pests, since residue burial and soil disturbance have been shown to help alleviate such problems.

Although there are many different tillage sequences, the basic pattern for conventional practices is: (See figure below for more detail)

- An initial deep ploughing that loosens and turns the soil, burying old crop residues and other materials
- A secondary tiling for the preparation of a fine seedbed
- One or more pre-emergence or post emergence cultivations or herbicide treatments to eliminate weds
- In addition, weather conditions sometimes prevent tiling from being accomplished at the correct time, and various heavy, shallow, stony or peaty soils cannot be cultivated successfully by these methods.[48]

Figure 10 contrasts three farming systems (No-tillage, Conservational Tillage and Conventional Tillage) for a corn-soy bean rotation in the US corn belt.

[v] Soil that is prepared to receive the seed of the planted crop. For most seeding systems, manual or tractor powered, some soil loosening and residue management is needed to allow the seed to be placed at a proper depth for germination in the soil.

TB 9 - Use of Conservation Tillage System

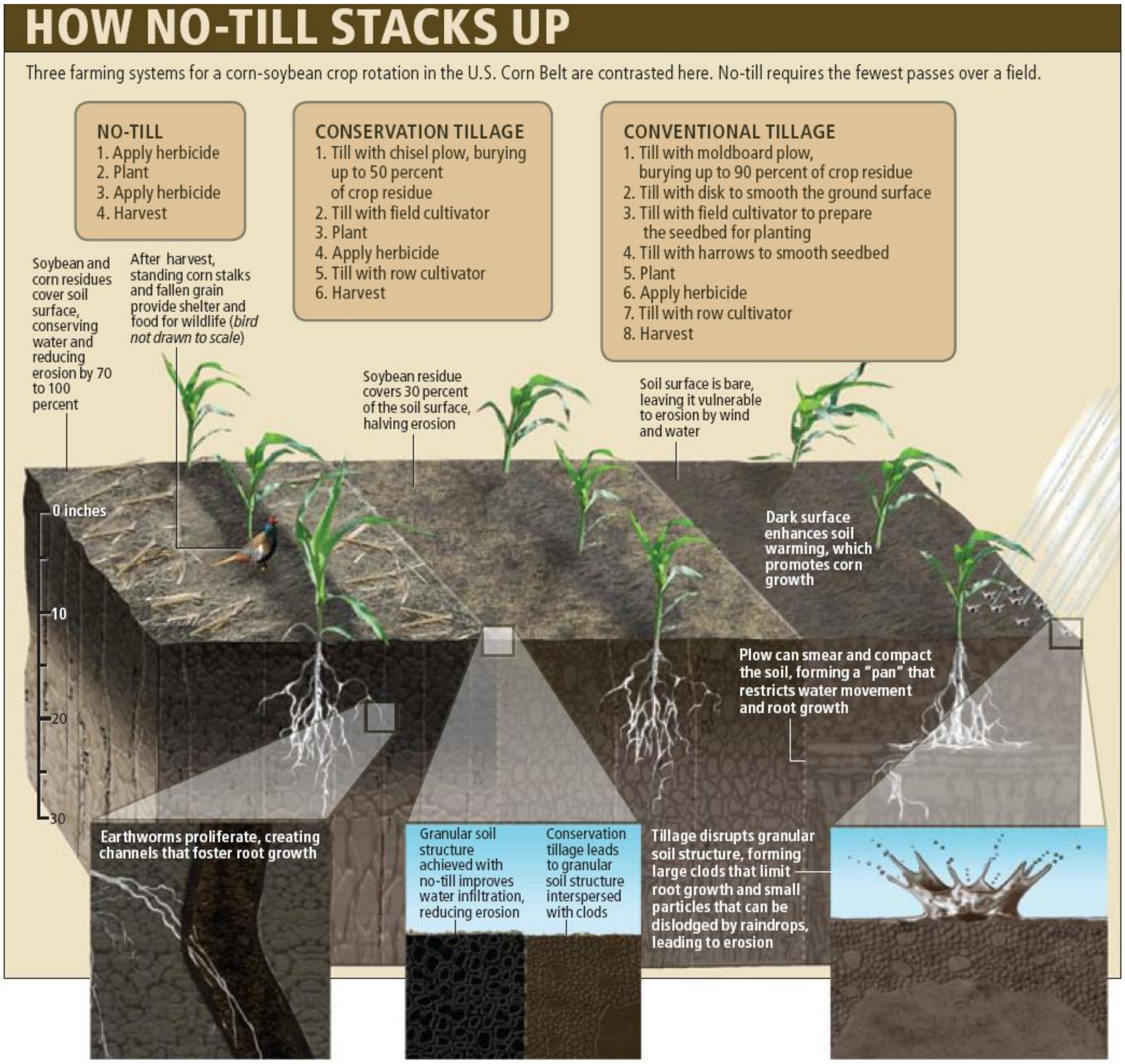

Figure 10: Contrast of No-tillage, Conservational Tillage and Conventional Tillage for a corn-soy bean rotation in the US Corn Belt. Source "No-till: The quiet revolution." Scientific American. Available at: http://www.mudcitypress.com/PDF/notil.pdf

The main limitations and problems with conventional tillage are the erosion and compaction of soil. Some of the tillage effects on both the environment and farmers are:

- Tillage costs money in the form of fuel for tractors, wear and tear on equipment, and labour costs. If animals are used as the power source, the costs of feeding and caring for the animals over a full year are also high
- Greenhouse gas emissions from the burning of diesel fuel add to global warming
- Soil organic matter is oxidized when it is exposed to the air by tillage with resulting declines, unless organic matter is returned to the soil as residues, compost, or other means
- Tillage disrupts the pores left by roots and microbial activity

TB 9 – Use of Conservation Tillage System

- The bare surface exposed after tillage is prone to the breakdown of soil aggregates as the energy from raindrops is dissipated. This results in the clogging of soil pores, reduced infiltration of water and runoff, which leads to soil erosion. When the surface dries, it crusts and forms a barrier to plant emergence
- The bare surface after tillage is prone to wind erosion
- Tillage reduces the rate of water entry into the soil by removal of ground cover and destruction of aggregates, resulting in compaction and crushing.

Section 9: References and further reading

No-Tillage, Sustainable Agriculture in the New Millennium

A no-tillage agriculture website by the famous no-tillage agronomist, Rolf Derpsch. It reviews the benefits of no-till, including a paradigmatic comparison between tillage and no-tillage agriculture, as well as topics relating to sustainability; organic matter; soil quality; etc.

Rolf Derpsch - GTZ

http://www.rolf-derpsch.com/

Opportunities for Conservation Tillage in Vegetable Production

http://www.ag.auburn.edu/auxiliary/nsdl/scasc/Proceedings/1999/Phatak_a.pdf

Sustainable Soil Management

http://attra.ncat.org/attra-pub/PDF/soilmgmt.pdf

Nutrient Quantity or Nutrient Access? A New Understanding of How to Maintain Soil Fertility in the Tropics

http://ppathw3.cals.cornell.edu/mba_project/moist/RolandB.html

Problems and Challenges of No-tillage Farming for the Rice-Wheat Systems of the Indo-Gangetic Plains in South Asia

http://www.css.cornell.edu/faculty/hobbs/Papers/5491-3_Lal_CH06_102303_R1_Chap.pdf

Case Study: Conservation agriculture in northern Kazakhstan and Mongolia

http://www.fao.org/ag/ca/doc/J8349e.pdf

No-Till Farming for Sustainable Rural Development.

World Bank

http://info.worldbank.org/etools/docs/voddocs/339/665/NotillFarmingforSustainableDevelopment.pdf

TB 9 - Use of Conservation Tillage System

Conservation agriculture in Europe: An approach to sustainable crop production by protecting soil and water?

http://www.sowap.org/comms/media/pdf/conservationagriculture.pdf
A guide providing information about drivers and constraining factors, and CT in arable crops, maize, olives and perennial crops, grassland and field vegetables.

No-till: The quiet revolution."

http://www.mudcitypress.com/PDF/notil.pdf
Scientific American

A No-Tillage Tomato Production System

http://www.sarep.ucdavis.edu/newsltr/v7n1/sa-11.htm

European Conservation Agriculture

This Presentation contains national statistics about No-tillage practices
http://www.ecaf.org/docs/ecaf/no%20tillage%20worldwide.pdf

Websites

FAO Conservation Agriculture Website

http://www.fao.org/ag/ca/

Case study in Argentina

http://www.inta.gov.ar/suelos/info/documentos/informes/la_siembra_directa.htm
Available in Spanish

Conservation tillage methods

http://www.cals.ncsu.edu/sustainable/peet/tillage/cons_til.html
Dr. Mary Peet, North Carolina State University
Sustainable Practices for Vegetable Production in the South

Conservation Technology Information Centre

http://www.ctic.purdue.edu/

Case studies on no-tillage practices

http://www.inta.gov.ar/suelos/info/documentos/informes/la_siembra_directa.htm
Available in Spanish

Aapresid

No-tillage organisation in Argentina
www.aapresid.org.ar

Resources on Cover Crops

Managing Cover Crops Profitably

http://www.sare.org/
Sustainable Agriculture Research and Education

Overview of Cover Crops and Green Manures

ATTRA
http://attra.ncat.org/attra-pub/covercrop.html

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[1] No-Till Vegetable Production: Non-Chemical Methods of Cover Crop Suppression and Weed Control Available at: www.attra.org/downloads/notill_veg.doc
[2] http://www.ctic.purdue.edu/media/pdf/TillageDefinitions.pdf
[3] No-Till Vegetable Production: Non-Chemical Methods of Cover Crop Suppression and Weed Control Available at: www.attra.org/downloads/notill_veg.doc
[4] Baker, C.J., K.E. Saxton, and W.R. Titchie. 2002. No-tillage seeding: Science and Practice. 2nd Edition. Oxford. In Conservation Agriculture: What Is It and Why Is It Important for Future Sustainable Food Production? By Peter R. Hobbs. Available at: www.ecaf.org
[5] http://www.fao.org/ag/ca/
[6] This section was extracted from: World Bank, 2002. No-Till Farming for Sustainable Rural Development. Available at: http://info.worldbank.org/etools/docs/voddocs/339/665/NotillFarmingforSustainableDevelopment.pdf
[7] Mechanized minimum and no-till crop production for research farms Available at http://www.fao.org/sd/erp/toolkit/BOOKS/irg11.pdf
[8] Rolf Derpsch, Personal Communication.
[9] Taken from http://www.rolf-derpsch.com/notill.htm and Mechanized minimum and no-till crop production for research farms Available at http://www.fao.org/sd/erp/toolkit/BOOKS/irg11.pdf
[10] Ibid.
[11] Ibid.
[12] Giller K. E., Witter E., Corbeels M. and Tittonell P., 2009, Conservation agriculture and smallholder farming in Africa: The heretics' view, Field Crops Research, 114 (1), pp. 23-34.
[13] Ibid.

[14] Ibid.

[15] Cox, George W., 1979, Agricultural ecology: an analysis of world food production systems; W. H. Freeman. Tillage systems, pg 336.

[16] Hoekstra, A.Y. and Hung, P.Q. (2002) Virtual water trade: A quantification of virtual water flows between nations in relation to international crop trade. Delf, The Netherlands, UNESCO-IHE. Report number: Value of water research report Series No 11.

[17] http://epa.gov/nps/agmm/chap3.pdf

[18]http://www.fao.org/fileadmin/templates/agphome/images/iclsd/documents/wk1_c2_Peiretti.pdf

[1919] http://www.aapresid.org.ar/institucional_sd_suelo.asp

[20] No-Till Notes:"No Till and Water" By Mark Watson Panhandle No-Till Educator Available at http://www.npnrd.org/notill.htm mwatsonntec@charter.net

[21] http://attra.ncat.org/attra-pub/soilmgmt.html#tillage

[22] Roberto Pieretti is a agronomist Engineer from Argentina See: http://www.iisd.org/pdf/2004/natres_water_quality_final_report_es.pdf

[23] http://www.css.cornell.edu/faculty/hobbs/Papers/5491-3_Lal_CH06_102303_R1_Chap.pdf

[24] http://www.ecaf.org/index.php?option=com_content&task=view&id=93&Itemid=64

[25] Developments in conservation tillage in rainfed regions of North China. *Soil and Tillage Research*, *Volume 93, Issue 2, April 2007,Pages 239-250* X.B. Wang, D.X. Cai, W.B. Hoogmoed, O. Oenema, U.D. Perdok

[26] http://www.sowap.org/comms/media/pdf/conservationagriculture.pdf

[27] http://www.rolf-derpsch.com/notill.htm

[28] Ibid.

[29] http://research.wsu.edu/resources/files/no-till.pdf

[30] http://www.sowap.org/comms/media/pdf/conservationagriculture.pdf

[31] http://epa.gov/nps/agmm/chap3.pdf

[32] http://www.ecaf.org/docs/ecaf/no%20tillage%20worldwide.pdf

[33] Giller K. E., Witter E., Corbeels M. and Tittonell P., 2009, Conservation agriculture and smallholder farming in Africa: The heretics' view, Field Crops Research, 114 (1), pp. 23-34.

[34] http://www.sowap.org/comms/media/pdf/conservationagriculture.pdf

[35] Idid.

[36] http://www.rolf-derpsch.com/notill.htm

[37] Ibid.

[38] http://www.ecaf.org/index.php?option=com_content&task=view&id=93&Itemid=64

[39] Ibid.

[40] http://www.rolf-derpsch.com/notill.htm

[41] For a picture and information about chisel plough see: http://www.marketfarm.com/cfms/chisel_plow.cfm

[42] http://www.cals.ncsu.edu/sustainable/peet/tillage/cons_til.html

[43] Ibid.

[44] This case study can be found in more detail in http://www.fao.org/ag/ca/doc/CA_UZB_WP2.pdf

[45] Developments in conservation tillage in rainfed regions of North China. *Soil and Tillage Research*, *Volume 93, Issue 2, April 2007,Pages 239-250* X.B. Wang, D.X. Cai, W.B. Hoogmoed, O. Oenema, U.D. Perdok

[46] Developments in conservation tillage in rainfed regions of North China. *Soil and Tillage Research*, *Volume 93, Issue 2, April 2007,Pages 239-250* X.B. Wang, D.X. Cai, W.B. Hoogmoed, O. Oenema, U.D. Perdok

[47] Information taken from http://www.conservationinformation.org/resourcedisplay/322/ and http://www.ctic.purdue.edu/media/pdf/TillageDefinitions.pdf

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