Degradation of Natural Resources and Measures for Mitigation

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ABSTRACT

Nearly all of the soils under agricultural use show signs of degradation. This is obviously more severe in the tropics and has more dramatic impact than in moderate climate zones. However, the processes and consequences are in principle the same. Most visible signs for these degradation processes are increasing wind and water erosion and, as a result, disturbed water balances. Erosion, falling ground water tables, drying rivers or floods are only symptoms caused in many cases by soil degradation. Particularly important in this respect is the decrease in soil organic matter, and as a consequence, a decrease in soil life and the loss of soil structure. Intensification of agriculture has led, particularly with progressing mechanization, to an intensification of soil tillage. In combination with a decreasing input of organic matter, this has resulted in a reduction in soil organic matter.

As a response to dramatic wind erosion problems in the USA in the 1930s, conservation tillage was developed. But only the dramatic water erosion in the hilly parts of southern Brazil led to the development of a completely new kind of agriculture. This agriculture avoids permanently any kind of mechanical soil movement using the already known techniques of zero tillage and direct seeding. Through synergy effects created in the system combining zero tillage with other well-known techniques such as mulching and diversified crop rotations, a sustainable cropping system is established.

Conservation agriculture (CA) is actually expanding exponentially in many regions of the world.

Experiences with the long-term and large-scale adoption of CA have shown other positive side effects which suggest that this is a globally valid concept for sustainable agriculture.

1. INTRODUCTION

The degradation of natural resources is discussed in view of global trends concerning the achievement of the millennium development goals. At present, more than 800 million people suffer from chronic malnutrition – a number which hasn't changed over the past years (FAO 2006). Degradation is, in this context, understood as the reduction of the productive

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potential of a resource, i.e., either a decrease in qualitative terms or a quantitative decrease in the availability of the resource.

This paper will focus particularly on soil and water resources; biodiversity, land and climate will be covered as important factors for agricultural production.

Agricultural production was and is the base for human development. With the growing world population, the production of food and renewable resources also has to increase. This was made possible by technological progress.

At present, the actual agricultural production can cover the demand for food. The fact that still 800 million people suffer from malnutrition is more a question of access to and distribution of food than of production. However, despite a decline in the growth rate of world population, this growth rate is still higher than the actual increase in food production. Until 2030, food production has to double to satisfy the increasing food demand of a growing world population in qualitative and quantitative terms (FAO 2002). In addition to this demand for food, there is an increasing demand for the production of renewable resources, including bio-energy, based on the same natural resources as food production.

Agricultural production in the near future has to increase significantly. In the past, production increases were mainly achieved by yield increases and only to a lesser extent by expanding the production area. Also in future, the potential for an expansion of agricultural land is globally limited, particularly since further deforestation of tropical rain forests or the use of other natural reserves should be avoided. The available agricultural land per capita will further decline globally. About 80 per cent of the production increase in countries with developing economies will therefore result from intensification of food production (FAO 2002). However, there are no available technologies which would allow dramatic yield increases in the short term. In many world regions with already intensive agricultural production, it rather seems as if the ceiling of the actual yield potential is already reached. Fortunately this is not the case in regions with the most severe production deficits, like Africa. In those regions, production can be multiplied with rather simple technologies (FAO 2002). Against this background the millennium development goals have been formulated (UN 2005). While in regions with temperate climate the degradation of natural resources is just being noticed, it can, at global level, be threatening the existence of many lives.

Globally, agriculture has to become more intensive and more productive. At the same time the trend to degrade the natural resource base, which so far has been considered an inevitable collateral damage of agricultural production, has to be reversed. In times of globalization, this is a challenge which concerns all – developed and developing countries.

2. DEGRADATION OF NATURAL RESOURCES

2.1 Soil

Nearly all agricultural soils of the world show signs of degradation. Most visible indicators are increasing wind and water erosion and as a result disturbed water balances. Erosion, falling ground water tables, drying rivers or floods, however, are only symptoms of soil degradation. Particularly important in this respect are the decrease in soil organic matter and subsequently a decrease in soil life and the loss of soil structure. Intensification of agriculture has led, particularly with progressing mechanization, to an intensification of soil tillage. This in combination with a decreasing input of organic matter led to a reduction in soil organic matter in some cases of dramatic dimension.

For example, the organic matter content of black chernosem soils in the Siberian steppe declined to half the original value since the beginning of cultivation. Depending on climate and soil, the loss of organic carbon in cultivated soils is 53-493 g/m² (Rusalimova et al. 2006). Organic matter levels of below 2 per cent are common on cultivated agricultural soils. The result, besides a bad soil structure, is also reduced fertilizer efficiency (Pell et al. 2004). The mineralization of soil organic matter in the tropics is more dramatic than in temperate climates. In the intensively cultivated plains of northern India, soils have an organic matter content of less than 0.1 per cent (PDCSR 2005). Increasing fertilizer rates do not lead to any yield increase under these conditions (Aulakh 2005). The global assessment of soil degradation demonstrates signs of soil degradation on all agriculturally used soils worldwide. The degradation is more advanced in tropical regions and leads to more dramatic consequences than in temperate climates (FAO 2000). However, the processes and results are the same everywhere. Agriculture, based on intensive soil tillage, leads to a reduction of the productive potential of soils, which becomes visible as structural degradation and leads finally to desertification (Shaxon & Barber 2003). This biological and physical degradation goes along with a chemical degradation. Increased leaching of nutrients leads to a depletion of nutrients in degraded soils. This causes a negative feedback in the way that nutrient poor soils have a reduced capacity to build up soil organic matter, even if organic material is supplied. For a recovery of such degraded soils, a balanced supply of mineral nutrients and organic matter is required (Probert 2007).

2.2. Water

Water is one of the most important resources for agricultural production. Agriculture accounts actually for about 70 per cent of the total consumption of available blue water (FAO 2002). With the actual trends in water consumption the demand for blue water will exceed the available resources in 2025 (Ragab and Prudhomme, 2002). An important reason for the expected water shortage is not only the increasing demand but the careless use and waste of this precious resource. Wide landscapes are sealed by construction. Open soils are increasingly compacted and do not allow the precipitation water to infiltrate completely and replenish the groundwater reserves. Excess water instead is led away through drainage channels without making proper use of it. Agriculture is increasingly part of the problem since most agricultural soils are, as a result of intensive cultivation, compacted and degraded and left with only a limited infiltration capacity. Forest areas are converted into agricultural land. The result of these developments is an increase in flood disasters (DBU 2002).

In the Indian state of Punjab, the ground water level is falling at a rate of 0.7 m per year due to the high water consumption for irrigation (Aulakh 2005). At the same time the monsoon rains cause serious flooding every year, resulting in large amounts of fresh water being lost unused without recharging the groundwater. Climate change with increasing temperatures and less reliable rainfall will further aggravate the water problems in agriculture in many regions of the world. Problems can be expected even with the total yearly precipitation remaining the same, if the trend for less but more intensive rainfall events continues and the infiltration capacity of the soils is exceeded for each event. This seems to be the case more often in recent years (Met Office 2005).

2.3.Land

Besides soil as qualitative resource, the available land area is also an important factor for agricultural production. Land is also a limited resource and in some areas the available land for agriculture is already overexploited. In addition, there is a constant loss of agricultural land for non agricultural use, such as urbanization and road construction. This loss is estimated in countries with developing economies, excluding China, at about 1.3 million ha per year (Alexandratos, 1995). To this loss has to be added the land lost due to severe degradation and salinization.

Globally there are about 1.2 billion ha considered severely degraded, of which 300 million are not anymore suitable for agricultural use (FAO 2002). Half of the land reserves still available for agricultural use are forest or are under protection as natural reserve. The largest land reserves are available in Latin America and Africa, while in Asia about 90 per cent of the available land is under agricultural use. In the Middle East, the land used for agriculture exceeds already the suitable land (FAO 2002).

2.4. Biodiversity

Agricultural production goes along usually with a decline in biodiversity. Diverse plant societies are replaced by single crops. Traditional varieties are replaced by a reduced number of high yielding breeds as a result of intensification. The use of modern production inputs leads further to a decline in micro flora and fauna. This is not only a matter of imaginary values but has also repercussions in production. Natural balances are disturbed and beneficial organisms are not anymore available to control pest populations, which leads to an increase in the use of agrochemicals ending in a vicious circle. The availability of nutrients and hence the efficiency of fertilizer use is affected by a decline of soil micro flora and fauna, leading to an increased use of fertilizer (Sprent 2007). An increased and rich biodiversity therefore can be of economic value in agricultural production (Bullock et al. 2001).

2.5. Climate and climate change

Climate is not really a resource and hence cannot degrade. However, agriculture is more than most other production areas heavily depend on climate. Any change of established climate patterns will therefore have a direct impact on agriculture. Since agricultural production practices have adapted to existing climate regimes over extended time periods, any change will create problems. This can be compared to a degradation process. As the latest IPCC report has clearly stated, not only is the climate changing, but the causes of the changes are not of natural origin but manmade (IPCC 2007). Agriculture is part of the process since about 40 per cent of land surface are under cultivation and human use (FAO 2006). The above mentioned degradation processes and deforestation have released major amounts of carbon into the atmosphere. Climate change is on one side characterized by a change in average temperature. This can have positive or negative repercussions. On the other side, the precipitation is affected, with varying regional trends. There will be winners and losers of climate change, but any change will require adaptation by changing production practices and will hence result in investment costs. More serious, however, is the trend to higher climate variability and less reliable weather conditions. This kind of change affects agriculture dramatically. Rainfall events are less reliable and less frequent but often with higher intensity. Also the temperature variations are more extreme (Met Office 2005). Any agricultural production system will suffer from these less reliable weather conditions.

3. RESOURCE CONSERVING PRACTICES

The development of conservation tillage began in the USA in 1935 with the establishment of the Soil Conservation Service, as a result of the dust bowl which devastated in the 1930s large areas of the United States. The principal objective was to retain a minimum cover by crop residues of 30 per cent on the soil surface to protect the soil from erosion (Uri 1999). In the 1940s the discussion about zero tillage started (Faulkner 1945) resulting finally in an introduction of zero tillage in the agricultural practice. In the early 1970 zero tillage was introduced in Brazil, mainly as an answer to severe water erosion problems (Derpsch 2001).

During the history of agriculture, a large number of resource conserving practices has been developed and recorded. This has even led to the creation of the World Overview of Conservation Approaches and Technologies (WOCAT) as an institution. WOCAT has collected an impressive amount of conservation technologies, mostly focusing on soil and water conservation (WOCAT 2007). Many of these traditional techniques tried to resolve a specific problem by physical means. Erosion, for example, is considered a problem. Traditional erosion control was tried with the 30 per cent soil cover to protect the soil surface physically from the impact of wind or water erosion by reducing the speed of the erosive medium. Also terraces and contour lines attempt to reduce the speed of surface run off water limiting the erosive effect. Terraces, on the other side, have the disadvantage of being cost and labour intensive in their creation and they are often obstacles for agricultural mechanization (WOCAT 2007). Unresolved is the further loss of water, which has to be removed as surface water from the terraces. This leads often to gully erosion downhill. To make use of this water, further investment in collection and storage structures is required (WOCAT 2007).

The already mentioned reduced or particularly the zero tillage practice is also considered as resource conserving technology. It leads to a reduction in the use of fuel and time inputs in production and further to an effective erosion control (Baker et al. 2007). Even more important is the reduced mineralization of soil organic matter under zero tillage which facilitates the capturing and storage of carbon dioxide from the atmosphere in the soil (Reicoscky 2001). In the long term, this leads to improved soil structure and increased water infiltration capacity of soils (DBU 2002). In addition to this, zero tillage leads to a reduction in unproductive evaporation of soil water resulting in water savings of 15-20 per cent compared with conventional soil tillage (PDCSR 2005). On the downside, zero tillage can, as isolated technology, lead to problems with weed control and soil compaction.

Another resource conserving technology, independent of zero tillage, is direct seeding, particularly where it replaces the transplanting of small plants as, for example, in rice. Many rice growing areas are changing from traditional puddling and transplanting to direct seeding technologies. This saves labour, time, fuel, and water (PDCSR 2005). But also, direct seeding as an isolated technology leads to new problems with weed management and surface crusting (RWC-CIMMYT 2003).

The use of green manure cover crops and crop residues as surface mulch does not only protect the soil against erosion. In case of legume cover crops, they can also lead to significant nitrogen supply of up to 200 kg.ha-1 depending on the growth conditions. This can lead to a 50-75 per cent reduction in the nitrogen fertilizer needs (RWC-CIMMYT 2003). Mulching with crop residues also reduces the evaporation of soil water resulting in water savings of 30 per cent (Bot & Benites 2005). Mulch covers on the other side require special equipment for seeding, without which they can become a serious problem for crop establishment. Also, incorporation of heavy crop residues into the soil can tie up soil nitrogen which then is not available to the crop. In wet soils, incorporation of organic matter can lead to undesired anaerobic fermentation zones.

Another interesting technique for soil conservation is controlled traffic farming using permanent tram lines. For this system, all the machines on a farm need a standardized track width which allows using always the same tram lines. These areas will never be cultivated again. The soil between the tram lines results in a better structure and free of any compaction, while the heavily compacted tramlines provide better trafficability and traction (RWC-CIMMYT, 2003). As a result, the cost for tillage is reduced and the yield increase in the cropping area exceeds the loss of land due to the tramlines. This obviously depends on the width of the track and the tramline (Kerr, 2001). However, the increased machinery cost for the special wide track machines is often prohibitive for conventional tillage-based farms to adopt this technique.

While many of the so far mentioned techniques are beneficial for both soil and water resources, there are also a large number of techniques focusing particularly on water consumption, especially under irrigated farming conditions. Significant water savings can be achieved with technical irrigation practices, especially with drip irrigation. This technology has been simplified and there are low cost applications available which are within the economic reach of small farmers in developing countries (WOCAT 2007). However, the surface irrigation is still the most widespread irrigation technique worldwide, in many cases with very low efficiency (FAO 2002a). But surface irrigation can be improved by special preparation of the fields resulting in significant water savings. The micro-levelling of the soil surface with laser technology can result in water savings of up to 50 per cent compared to traditional farmers' practice. In traditional rice growing, water savings of up to 70 per cent was reported. In the meantime, laser levelling carried out by contractors in India even for small farmers are accessible and economically feasible (Jat et al., 2006). In conventional tillage-based agriculture, the laser levelling has to be repeated every 3-5 years.

A further water savings technology which is actually promoted in the Indo Gangetic plains of Pakistan, India and Bangladesh is the bed planting with irrigation furrows between raised beds instead of basin irrigation, flooding the entire field. This practice has been successfully introduced in rice and wheat crops. Water savings of 26 per cent in wheat and 46 per cent in rice has been reported with yield increases of about 6 per cent (RWC-CIMMYT 2003).

4. SYNERGY EFFECTS OF DIFFERENT TECHNIQUES

The so far mentioned examples of resource conserving technologies all have advantages and disadvantages and are as isolated technologies not universally applicable. However, combining these technologies can create synergy effects which eliminate the disadvantages while retaining or even enhancing the advantages. With the introduction of zero tillage in the early 1970s in Brazil, a new concept of agriculture was developed, named “direct seeding into straw” (plantio direto na palha), which is now growing worldwide under the name of conservation agriculture (CA), using exactly these synergy effects. The concept had already been described by visionary people dating back to the early 1940s (Faulkner 1945, Fukuoka 1975). But only in Brazil it was extensively introduced into the agricultural practice accompanied by scientific investigation (Derpsch 2001).

The Food and Agriculture Organization of the United Nations (FAO) defines CA as follows:

CA is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. CA is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with, or disrupt, the biological processes. CA is characterized by three principles which are linked to each other, namely:

Continuous minimum mechanical soil disturbance;

Permanent organic soil cover; and

Diversified crop rotations in the case of annual crops or plant associations in case of perennial crops (FAO 2007).

CA is actually practiced worldwide on 95 million ha with exponential growth rates (Derpsch 2005). CA has the longest tradition and highest adoption rates in the southern cone of Latin America. In Paraguay, the area under conservation agriculture exceeds 50 per cent of the total agricultural land (Lange 2005). Also in Brazil, about 50 per cent of the agricultural land is under CA. CA is further common in the USA and Canada. But also Australia, Central Asia, China, India and southern Africa have increasing areas under CA. Practical experiences with CA farming exist from areas close to the polar circle down to the tropics and for nearly all crops, including vegetables, roots and tubers. Despite the reduced tillage, CA must not be mistaken as low intensity agriculture. The same and often even higher yields can be obtained as in highly intensive conventional agriculture.

While the principles of CA are not new, the simultaneous application is creating the above mentioned synergy effects. Zero tillage reduces the mineralization of soil organic matter. In addition to this, the soil habitat remains undisturbed and soil life can develop in quantity and quality better than on tilled soils. Vertical continuous macro pores as created by earthworms or roots are not destroyed and remain as drainage channels for rainwater into the subsoil. By not disturbing the soil, the weed seed bank in the soil does not receive the stimulation for germination. This can be perfected even during the seeding process by furrow openers with minimum soil movement allowing the “invisible seeding”. The permanent soil cover protects the soil surface from wind, rain, sun and from drying out.

In addition, the mulch suppresses the germination and growth of weeds, provides habitat for beneficial fauna and feed for the soil life and hence the substrate for the creation of soil organic matter. Allelopathic or other repellent effects of specific cover crops can be used for weed and pest management. The treatment of the mulch cover therefore is part of the weed management under CA. For this purpose, a knife roller is used to roll down and break cover crops and weeds without cutting them completely (picture 1). Black oats *(Avena strigosa)*, treated during the milky grain stage with a knife roller dies without the need of herbicides or desiccants. The mulch cover created by the knife-rolled black oats crop is so dense and has allelopathic effect that it inhibits any weed growth. Provided that during the seed process no soil is exposed to sunlight, a crop can be grown in this cover without the need of any further weed control (Friedrich 2005) (pictures 2 and 3).

Crop rotation is of particular importance with regard to zero tillage and permanent soil cover. Different crop species with different root systems explore different soil horizons and hence increase the efficiency of the use of soil nutrients. In addition, a diversified crop rotation is beneficial for avoiding pest and weed problems. When designing the crop rotation, it is important that the entire growth period is used by growing some crop, if only for cover.

Also the other previously mentioned resource conserving technologies can be integrated into CA with beneficial complementarities. Direct seeding of rice facilitates the integration of the rice crop into a CA system with permanent zero tillage. The mulching reduces the problems of surface crusting and weeds. Controlled traffic farming is an important element of CA in mechanized farming (picture 4), especially in humid climates where traffic in the field during crop protection or harvest operations cannot always respect the optimal soil conditions. In CA, it is particularly important to avoid compactions and wheel-tracks created by heavy machines, since those would oblige subsequent tillage operations which would destroy the structure built up in years of zero tillage. Surface irrigation requires some special care with the mulch management under CA. On the other hand, the effect of laser levelling remains longer under CA since the soil surface is not disturbed after the levelling. Even bed planting systems can be adapted for CA using permanent beds. This reduces the costs for the bed establishment and leads automatically to a controlled traffic system without the need of satellite guiding technology.

5. EFFECT OF CA ON NATURAL RESOURCES AND CLIMATE

The above described synergy effects have positive impact on productivity, efficiency of input use as well as on environmental effects and economic profitability of the production system. Soil erosion is reduced to a level below the regeneration of soil. In some cases, the soil is literally growing. Under humid temperate conditions the soil growth rate can amount up to 1 mm per year for 30 to 50 years, until the soil organic matter level reaches a new balance (Crovetto 1999). Depending on the supply of organic matter and climate conditions the increase of soil organic matter can reach 0.1-0.2 per cent per year. Soil structure is improved, soil volume available to root growth is increased, providing access to more soil nutrients and improving the fertilizer efficiency (Bot & Benites 2005). Continuous macro pores in the soil increase the water infiltration and hence the absorption capacity of soils during heavy rainstorms. This can be instrumental for the reduction of flood risks (DBU 2002).

The increased water infiltration contributes also to a recharge of the aquifer which is of particular importance for regions with falling ground water tables (PDCSR 2005). In view of the regular floods during the monsoon season in India and Bangladesh, during which large volumes of fresh water are lost without making use of them, and at the same time falling ground water tables in these regions, it would make sense to increase the infiltration capacity of the actually sealed rice soils by changing the cultivation practice. A better water infiltration does not only improve the availability of groundwater in a watershed, but also the water quality. Since the excess water is channelled in macro pores, it does not leach the soil. In addition the effectively reduced soil erosion provides for less fertilizer and pesticides being washed into surface waters. Watersheds with a wide application of CA report better water quality and reduced costs for the treatment of drinking water (Bassi 2000, Saturnino & Landers 2002).

The increased organic matter levels under CA also provide for better water retention capacity of the soil. For each percent of soil organic matter 150 m3ha-1 of water can be stored in the soil. Loss of soil water is further reduced and in general water savings of 30 per cent under CA are reported compared to conventional cropping systems under similar climatic conditions (Bot & Benites 2005).

The visible increase of soil life and of fauna above the soil surface under CA can be taken as an indicator for an increased biodiversity of this cropping system. As a result, the ecosystem is more stable and less susceptible to pest attacks. This is also noticeable in a long term decline in pesticide use under CA (Saturnino & Landers 2002, Baker et al. 2007). Also higher fertilizer efficiency results last but not least from the increased soil life and is equally reflected in a long-term decline of fertilizer needs (Saturnino & Landers 2002, Derpsch 2005).

Climate change is becoming increasingly important for agriculture. Extended drought periods and heavy rainstorms are becoming common features of the weather not only in the tropics (Met Office 2005). CA can help to adapt to these changing and less stable climatic conditions. The increased water infiltration allows soils to absorb most of the rain water even during extreme rainfall events, reducing the risk of erosion and flooding (Saturnino &

Landers 2002). Increased organic matter levels and a better rooting environment in the soil improve water holding capacity of the soils and the ability of plants to survive during drought periods. Yield variations between dry and wet years are less pronounced under CA than under conventional farming practice (Shaxon & Barber 2003, Bot & Benites 2005).

In addition, agriculture can also help mitigate climate change by reducing the emissions of green house gases into the atmosphere. Since 40 per cent of the world's land surface is under agricultural use, the contribution of agriculture to climate change mitigation could be significant. CA can reduce the emissions of fossil fuels compared to conventional agriculture by up to 60 per cent (Doets et al. 2000). In addition to this, the use of fertilizer and agrochemicals can be reduced in the long term by 20 per cent. Even the capital investments into heavy machinery such as tractors can be reduced by 50 per cent (Baker et al. 2007; Bistayev 2002). This would reduce the emissions resulting from the production of these inputs. However, the largest contribution to mitigate climate change with CA can be obtained from carbon sequestration and the storage of atmospheric carbon in the soil. The levels of carbon to be captured in the soil vary depending on climate and production system. On average under humid temperate conditions, 0.1-0.5 t.ha-1.y-1 of organic carbon can be captured. Under semi arid or tropical conditions, these levels decrease to about 0.05-0.2 t.ha-1.y-1 (Baker et al. 2007). This process continues for 25-50 years before a new balance is reached (Reicoscky 2001). Even the emissions of other green house gases such as methane and nitrous oxides can be positively influenced by a change of the cropping practices to CA. These gases occur in smaller volumes but have a much stronger effect as green house gases than carbon dioxide. Methane is for example released from rice fields under anaerobic conditions. CA would change the rice soils into a more aerobic environment without permanent flooding, which would reduce the methane emissions (Belder 2005; Gao 2006). Similar effects can be achieved for nitrous oxides as a result of changes in the nitrogen fertilizer and the soil water management. Suitable selection of fertilizers and placement in the soil can reduce the emissions also under conditions of zero tillage (Izaurralde et al. 2004; Gao 2006).

6. CONCLUSIONS

The actual degradation of natural resources is also a consequence of agricultural land use and as a result urges for changing the actual practices. The combination of several resource conserving technologies results in synergy effects leading to a sustainable, resource-enhancing agriculture which allows at the same time high productivity and profitability. This kind of agriculture is expanding under the term conservation agriculture. Besides being resource enhancing, productive and profitable, CA also helps in facing the challenges of climate change in agriculture and can contribute to mitigate against climate change. Technologies for CA exist globally but locally, the availability of suitable equipment and adapted knowledge may still be lacking being an obstacle for a more rapid adoption.

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Picture 1: Knife roller used for rolling down a cover crop (photo by Friedrich).

Picture 2: Direct seeding with minimal soil movement into heavy
mulch cover (photo by Friedrich).

Picture 3: Cross slot®-furrow opener allowing direct seeding under no-till conditions into heavy mulch with minimum soil movement (photo by Friedrich).

Picture 4: Six-row cotton picker adapted for controlled traffic farming at 3 m track width; additional support wheels in the front have been constructed by the farmer to support the header weight without double tyres (Jamie Grant/Australia) (photo by Friedrich).