Tools and Equipment to Produce Drought Resistant Soils - Trends, concepts and challenges in a global perspective -*

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Abstract: Conservation tillage and even no tillage as a practice is not new. However, there appears to exist evidence that in some cases no-tillage is successfully incorporated into a new concept of truly sustainable agriculture, gaining popularity as "conservation agriculture" all over the world.

Conservation Agriculture is, besides no-tillage and direct planting, based on very old concepts such as green manures and crop rotations, but combining these principles in a new way. Green manure is used as cover crop to provide permanent soil cover even between crops. Conservation Agriculture tries to "least interfere" with natural processes. It is as such a practical solution to produce drought resistant soils. This naturally has implications on the required engineering contributions.

The paper shows how these differences become visible also in the engineering approaches towards no-tillage technologies and how they contribute to exponential adoption rates in some parts of the world, versus relatively low acceptance in other parts. Examples of different farming operations within Conservation Agriculture are shown and the implications for equipment design and mechanization needs are discussed. Those operations include the land preparation, planting, crop husbandry, residue management and harvest. Special consideration is given to machine traffic and compaction.

Keywords: Conservation Agriculture, Mechanization, no-tillage, direct planting, controlled traffic

INTRODUCTION TO CONSERVATION AGRICULTURE

Conservation Agriculture (CA) can be defined as a concept for resource-saving agricultural crop production that strives to achieve acceptable profits, 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, 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:

1. continuous minimum mechanical soil disturbance
2. permanent organic soil cover,
3. diversified crop rotations in case of annual crops or plant associations in case of perennial crops

Reducing the intensity of tillage for economic reasons (leading to minimum tillage) or for environmental reasons (leading to conservation tillage and finally to zero tillage practices) is not a new idea. One of the first references in modern agriculture to no-till farming is probably Edward Faulkner's "Ploughman's Folly" [1945]. Over the last few decades the practice of minimum and no-tillage had its ups and downs. In some situations it worked well, in others less well. Minimum tillage, conservation tillage and zero tillage were all applied as practices within conventional concepts of agriculture and therefore were not universally applicable. However, there appears to exist evidence that no-tillage can be successfully incorporated into a new concept of truly sustainable agriculture. In this case not tilling the soil mechanically becomes one underlying principle of a completely new understanding of agriculture. It is a practical solution to produce drought resistant soils. This concept

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shows in at least one world region over the last decade a consistent and exponential adoption curve. During the last few years it is, under the name of Conservation Agriculture (CA), gaining popularity all over the world [Derpsch 2001].

Besides no mechanical tillage intervention in the soil and direct planting, the other two principles of Conservation Agriculture are permanent organic soil cover and crop rotations. It could be argued that permanent organic soil cover has been known for a long time, similar to green manure and crop rotations as ancient examples of good agricultural practice. So, what is really new about it? Is Conservation Agriculture only old wine in new bottles? And, what role does engineering play in the development of that concept? Conservation Agriculture might well base on old, well known principles. But it combines these principles in a new way achieving synergies which had not been considered in the past and which only now are being understood and investigated. In the conventional understanding of green manure, the fertilizer effect with the addition of organic matter as positive side effect was the main objective. The main objective in Conservation Agriculture changes towards providing a favourable microclimate for soil life by protecting the soil surface from sun, rain and wind as well as providing feed for the soil micro and macro organisms. These organisms forming the soil life in CA are substituting biological tillage for mechanical tillage. The same applies for crop rotations. Besides the phytosanitary objectives, crop rotations serve to open different soil horizons with different rooting types. While conventional agriculture is "cultivating the land", using science and technology to dominate nature, conservation agriculture tries to "least interfere" with natural processes. Similar thoughts have been developed over the past 50 years also in the far east by Masanobu Fukuoka [1975]. While Fukuoka rejects even mechanization, this extreme is not justifiable in view of the requirements of modern agricultural production. But the approach naturally has implications for the required engineering interventions in agriculture and as such in the technical solutions offered.

The new understanding of engineering requirements does not apply only to the planting operation but covers the range of field operations in agricultural production. Actually one of the most important operations for seedbed- or land preparation under CA is harvest and residue management. This operation determines success or difficulties during the planting operation. Although technical details will be mentioned in some cases, the paper does not discuss these details in depth, but rather intends to open the eyes of those involved in no-till agriculture to some common features of the engineering components and their implications.

CONSERVATION AGRICULTURE PRACTICES

Some operations, like pest control or some components of harvest operations might remain the same between conventional and conservation agriculture. However, there are significant differences in most farming operations, namely in tillage, planting, weed and residue management and cropping systems as well as management of soil compaction. These differences are reflected partly in the different types of equipment to be used, but also in the approach to the design and use of equipment under each operation. As mentioned in the definition for CA, the aim is to minimize mechanical interventions in the soil and not to disturb or disrupt biological processes more than absolutely necessary.

Soil Tillage

Conservation Agriculture, and other conservation farming systems, excludes inversion tillage as general practice. There might be still the odd use of ploughs to shape surfaces or as a one-off intervention before starting the systems, but not as general practice. The same applies to all other forms of tillage. Under conventional agriculture, tillage is considered necessary to create a favourable physical soil structure to enable water infiltration and provide an environment for plants to grow. Optimum soil tilth and aggregate sizes were defined for specific crops, operations and purposes as criteria for the quality of tillage work. Equipment was designed to create different particle sizes in different horizons for the perfect seedbed. However, considering the ability of mechanical soil tillage to create soil structure, it can only reduce aggregate sizes and it can only arrange homogenous aggregates in horizontal layers. This does not really reflect the necessity for a variety of different pore sizes in a well structured soil, which should not be arranged horizontally, but randomly and vertically.

As a consequence in conventional tillage there is usually a distinct separation between the arable horizon and the subsoil. Soil macrofauna populations are reduced in the arable horizon due to intensive tillage, and hardly exist in the subsoil, which is usually a poorly structured dead mineral body with a higher bulk density than the topsoil. In the worst of cases there is often a compacted layer between the two horizons, resulting from the action of the tillage implements and from traffic. As a consequence of this, water infiltration under conventional tillage takes place mostly in the arable topsoil, while infiltration into the subsoil is reduced. Plant roots prefer the topsoil to grow in as this is rich in nutrients and water and often less dense than the subsoil. This can lead in dry years to water stress as the plant roots are not reaching deeper soil horizons before the topsoil dries out.

Contrary to this CA recognizes that tillage cannot create the ideal soil structure and is not increasing water infiltration, but might be necessary to repair damage. With this understanding any tillage under CA will always be understood as an exceptional intervention, trying to minimize the impact on the soil. Obviously before starting a no-till based CA operation, the field should be in the desired shape, which means levelled or with the desired surface structure, for example beds or ridges. Full tillage is usually necessary to create this surface. But in view of the transition to no-tillage agriculture every effort should be undertaken to avoid excessive destruction of the soil structure or any compaction problems as a result of the land preparation. Subsequently, with few exceptions, tillage will not be undertaken as standard operation under CA.

Ripping is one example of an operation that can become necessary even in CA, particularly during the early transition years on extremely degraded soils in absence of adequate organic matter levels and rooting structures. This is, for example, the case in some regions in Africa. Rippers are usually designed in a way to create maximum soil disturbance. Often they leave a considerable impact on the surface in the form of clods, calling for secondary tillage operations. Ripping under CA should always try to minimize the impact on the soil and leave few traces on the soil surface (Fig. 1). In practical terms ripping should be done at optimum moisture considering the entire profile of the intervention, to avoid excessive clod formation and smeared horizons. The maintenance of the ripper is also important, keeping cutting edges and points sharp. The design of the ripper should avoid lifting clods, which can be achieved, for example, by using rippers with the shanks bent sideward.

Fig. 1: Ripping with minimum soil disturbance with a Paraplow

Ripping is a costly and not completely risk free operation. Applied in the wrong conditions or without a long term concept for soil structure improvement it can even lead to more serious compaction problems than before the ripping. Therefore ripping will be considered under CA as a temporary feature or exceptional repair operation. In most cases mechanical ripping under CA can be more economically replaced by "biological ripping", growing crops with specific rooting characteristics. Those crops will be placed within the crop rotations along with cash crops that, mostly due to their harvest, could create soil damage and compaction.

Besides the general repair of soil damage, ripping or other tillage operations could be applied in very specific cases such as wet and cold climates and soils, for transplanting vegetables or for systems where pasture for livestock grazing is included in a crop rotation. In those cases tillage operations will be very time specific and limited in the form of strip tillage, either done in a separate operation or together with planting. Depending on the objective to be obtained, strip tillage can be done with fixed tools like chisels or with driven tools like narrow rotary knife harrows. Technologies for this are available for power levels from animal traction, through two wheel tractors up to heavy tractors.

Cropping systems involving surface irrigation and bed- or ridge structures might require regular reshaping of the beds. But this intervention usually is only restricted to the furrows, limited in depth and normally not intervening into the growing zones, but in the traffic areas of the system. Reshaping can be combined with the planting operation. The most suitable time for this operation within the cropping cycle also has to be determined with regard to the residue situation. In the long term permanent beds will become more stable and the necessity for reshaping will be less frequent than in the beginning.

Planting

Probably the most significant differences between CA and conventional agriculture can be found in the seeding and planting operations and their respective equipment. Conventional concepts for planting consider it necessary to create an optimal seedbed. The seedbed creates controlled conditions, under which the seeding equipment can place the seed with a maximum of precision. Particularly, correct depth placement is of high importance for field emergence and yield of a crop. Obviously the conditions for accurate seeding change dramatically when the seedbed surface is not clean but covered with crop residues. Conditions change completely when the soil as such is not loose and levelled to perfection.

The general idea of creating a seedbed, even in a limited way, is still reflected in many minimum-till- or direct-seeding seed drills. This is particularly the case with power take off driven direct seeding combinations, which in reality do a conventional seedbed preparation before seeding. The only difference is that all operations are done in one pass. In view of the intensive though shallow soil tillage and incorporation of the residues, this technique is not really considered no-till seeding under CA. But also many of the quite popular hoe type direct drills follow this principle. These practices would fall under the category of minimum tillage or conservation tillage farming. From a CA point of view they would still create unnecessary soil movements with the negative implications on weed growth, organic matter decomposition, fuel consumption and last not least increased draft power requirements (Fig. 2).

Under Conservation Agriculture the ideal situation would be to place the seed into undisturbed soil which maintains its natural capillary thus minimizing soil water loss at planting [Baker et al. 1996]. By minimizing soil movement and soil exposure to the light outside the mulch cover, the germination of weed seeds is also not stimulated more than necessary (Fig. 3). In terms of equipment to be used, the result could also be a "hoe" drill, but rather than being designed for maximum soil movement in the seedbed, it is designed for minimum soil movement resulting in a chisel or knife rather than a wide tine.

Fig. 2: Direct seeding with chisel furrow openers

Fig. 3: Direct seeding with double disk furrow openers

The type and design of seeder openers is another issue. Obviously there are different opener types for different soil conditions. But a farmer would normally choose the type which serves as a good compromise for most of the prevailing soil conditions on the farm. No-till seeders and planters are supposed to work in not tilled soils and as a worst case scenario these are considered to be "hard". For this reason no-till seeders often are heavy, resulting from high mass per seed row to guarantee penetration. This is particularly the case for double disk openers. Under CA there are two points to consider with respect to soil penetration. Provided the soil is kept under a permanent organic cover, it will accumulate organic matter particularly close to the surface. It is expected that with time the planting horizon will soften, requiring less vertical force to penetrate for seed placement. Therefore, depending on the soil type, the requirements for seeders and openers might actually change over the years under CA. After some years of consecutive application of CA, the top layers of the soil acquire a compost-like texture superimposed on the characteristics of the original soil texture and so facilitate planting.

But also the design and choice of openers for a seed drill or planter allows the design of low weight, low draft no till seeders and planters. Those can be pulled by one or two draft animals, a single axle tractor or a four wheel tractor starting from horsepower levels as low as 30 while at the same time handling mulch cover and penetrating into untilled soil. To solve this requirement was obviously the precondition to enable small farmers in South America to adopt CA. Most of the light weight animal draft 0-till planters use chisel type openers, either exclusively or in combination with disk openers. The chisel provides the down force facilitating penetration into the soil without the necessity of high equipment mass. The chisel can in this way also facilitate the work of the cutting disk applying additional down force. By design the chisel can still be shaped for minimum soil disturbance. Not only animal traction no till planters are benefiting from this experience. In general it can be noticed that it is also leading to lighter tractor 0-till seeders, allowing for smaller tractors. This becomes obvious by direct comparison of 0-till planters for example from the United States with planters providing similar features from Brazil. As consequence of this strict adherence to CA concepts in machinery design, the Brazilian farmer has the additional benefit of saving on tractor sizes and numbers. A comparable technology of combining a cutting disk for residue handling with the down forces of a chisel while minimizing soil disturbance is the cross-slot opener [Baker et al. 1996]. This furrow opener has been specifically designed around the necessity of the seed and the plant and provides the possibility to place the seed in undisturbed soil with a minimum of visible soil movement.

Compared to the standard hoe drill or sometimes even to a single disk drill, the double disk opener definitively has advantages in terms of soil movement. However, it has disadvantages particularly in very dry and in very wet soil conditions. Despite the problems associated with double disk openers they are probably the most popular no-till planter openers. As such they might be responsible for the perception that no-till planting is associated with higher risk, due to the intolerance of double disk openers to handle unfavourable soil conditions [Baker et al. 1996]. But they are also the reason for the high weight of no-till planters, due to the difficulties to penetrate into hard soils. Ways to improve the performance of double disk openers without giving up the advantages are to offset the two disks or to chose disks of different diameters [Baker et al. 1996]. A combination of both, offset double disks with different diameters are in fact very popular with no-till planter manufacturers in those parts of the world that actually show the highest adoption rates of CA such as the southern parts of South America. The resulting openers provide good penetration, low soil movement and good self cleaning action. Contrary to this manufacturers in the US where adoption of CA has slowed down or in Europe, where adoption is still marginal, offer mostly the standard double disk openers.

One of the most important parameters in seed placement for good emergence and yield is a uniform depth placement. In a conventional seedbed with a loose, uniformly aggregated fine soil surface the planter can shape the seedrow and thus create a uniform planting depth not only by controlling the release point but also, if necessary, by levelling the soil surface. Under no-till direct seeding conditions changes in the surface relief are not normally possible. It would anyway be undesirable as soil movement under no-till seeding should be kept to a minimum. The more advanced quality no-till seed drills and no-till planters therefore have independently suspended furrow openers for each row with independent depth control. This feature makes the machines usually more complicated, heavier and more expensive, but it achieves, even under strict no-till planting conditions, uniform seed depth placements. Under practical field conditions in Kazakhstan a seed depth with 90% of the seeds being placed with a tolerance of ± 1 cm could be obtained with furrow openers having independent suspension and depth control, while the rigid furrow openers resulted in a seed depth uniformity of only 67% of the seeds within the same tolerance [Matushkov 2003].

The availability of a suitable no-till planter is often considered to be the largest hurdle in the adoption of CA. Although procuring a no-till planter is not the first step to be undertaken in the adoption of CA, the technology used for planting can have a significant impact on early success or failure of the system. In many cases existing equipment can be adapted at a low cost to perform under no till without sacrificing the quality of the operations. Adaptations of conventional planters and seed-drills to no-till planters have been very popular in Brazil during the early years of the promotion of CA. But even today there are still companies specialized in upgrading old conventional seed drills and planters for no-till use. A similar approach was followed with projects promoting the introduction of CA in Mongolia and, more recently, in Kazakhstan. Often skilled farmers are also able to successfully convert their own planters [Schiffman 1999].

It is difficult enough, particularly for a smaller farmer, to buy a rather expensive new no-till planter, and it might be prohibitive to buy in addition to the no-till row crop planter a no-till seed drill. Over the last few years it could therefore be observed in those regions of the world with the highest CA adoption rates (especially in South America), that most of the established equipment manufacturer offer no-till planters and seed drills that can be converted from row crop planting to no till seeders for small grain crops.

Management of Weeds, Cover Crops and Crop Residues

Management of weed, cover crops and crop residues is another important feature of CA. The use of herbicides and desiccants for weed control and cover crop management is one option and requires the respective attention to spray equipment and operator proficiency, which is a separate topic. However, non chemical management of weed and cover crops is an important alternative for CA.

Besides agronomic practices such as crop rotations, inter- and relay cropping, the mechanical treatment of the cover is the option which this paper focus on. In most climates, with the exception of cold, wet ones, the major goal for the management of weeds and crop residues under CA is to minimize their interference with cropping, avoid further propagation in case of weeds, but extend their physical existence on the soil surface as long as possible. For this reason chopping of residues into small pieces is not necessarily required. This accounts also for straw being left behind a combine. Not chopping the straw reduces energy and thus fuel consumption but can also facilitate planting. Long straw is easier to cut and hair pinning with disk openers is reduced. This is the problem of straw being pushed by the disk furrow opener into the seed furrow, inhibiting the contact of the seed with the soil. Whether straw would be chopped or not in a cropping system under conservation agriculture depends very much on the crop rotations and following crop, the climatic conditions and the type of direct seeding equipment used. However, regardless of whether the straw is chopped or remains as long straw, it should always be spread as evenly as possible across the entire working width of the combine. This is a particular challenge with the steadily increasing header width and for working widths above 6 m, long-straw spreaders as combine attachments are difficult to find.

In this context specific mention should be made of the use of a grain stripper header for the harvest of grain crops. Although the versatility of this technology has not fulfilled the initial expectations, it is of particular advantage for no till systems. As it leaves the straw mostly standing and anchored in the soil the subsequent planting operation is very easy and residue problems are negligible. However, either in combination with the planting or as a separate operation, the standing straw will have to be rolled down. Only lying flat on the soil as a mulch cover will it fulfil best the functions of feeding and protecting the soil life and controlling weed growth. Considering the advantages within the entire cropping system, the energy saving and the easier planting, a stripper header could, within a CA system, become economically feasible when this would not be the case under conventional farming conditions.

This leads to another important tool for residue, covercrop and weed management, which is the knife roller (Fig. 4). In the south cone of South America it is probably the most important and characteristic tool for CA [Derpsch 2002]. It is adapted to all sizes of farms and levels of mechanization. Once the functional principle of the knife roller is understood and the plants which prevail on the farm are known, the knife roller can be replaced also by other low-cost equipment achieving the same effect. The idea of the knife roller is to break or crush plants, roll them flat on the soil surface, but not to cut them into pieces. In this way the plant dries out and eventually dies without resprouting. The residue cover pressed down to the soil has also a much better weed suppressing action than standing residues. Used at the right time in the right way this tool can, in combination with certain cover crops, replace the need for any chemical herbicide.

Fig. 4: Cover crop management with a knife roller

These examples show principles, but in practice a number of adaptations and compromises are possible. A farmer having a chopper mounted on the combine will proceed to use this under CA. It is important that the straw is evenly spread across the cutting width. Only when investing in new equipment, might ideal solutions be considered. Different practices might also result from climatic conditions. In northern Kazakhstan residues and weeds are left standing over winter to catch snow, while the weed suppressing action is less important during that time of the year.

Traditional mechanical weeding is possible even in CA but it requires special equipment and it is a second best option only. Obviously any cultivators used for mechanical weeding under CA will require some cutting disks to open a slot into the mulch cover. Usually the cultivator blades are then very wide to cut the weeds horizontally under the mulch cover close to the soil surface. Some soil disturbance occurs and with it increased mineralization of the mulch cover and obstruction of the continuous macro pore structure. But the impact is low as long as the mulch cover is maintained. However, in most cases mechanical weed control need not uproot and kill the weeds. It is often enough to suppress the weed growth until the crop is strong enough to outgrow the weed. In any case allowing the weeds to mature and set seeds must be avoided. This is a long term weed control strategy under CA, which can result in just mechanically chopping of the weed flower heads if possible.

Cropping Systems

An important feature of CA is the crop rotation and with it the entire cropping system. This again has implications for the equipment to be used as the idea is not to till the soil for any crop in the rotation. This is easy if the crop rotation includes only rainfed annual grain crops. It becomes more demanding when crops are included that require different surface relief, like vegetables grown on beds or root crops or if surface irrigation practices are used. In these cases often completely new approaches to growing a crop and to designing equipment according to the agronomic needs are required. In many parts of the world field crops such as wheat or even paddy rice are grown in rotation with row crops grown on ridges or vegetable crops grown on beds. In most of these systems, particularly if water management demands this, it is recommended to adopt the ridges or beds as the permanent surface structure, rather than requiring all crops to be grown on level fields. In this case the cereal crops such as wheat or paddy rice are grown on the same beds or ridges. All the equipment has to be adapted to the row width of the beds or ridges, seed drills and planters have to accommodate the surface relief. However, this is perfectly possible and it is done, including even crops like irrigated rice on beds used to grow melons between the rice crops. The position of the crops on the beds or ridges depends on the moisture and climatic conditions. In humid conditions cereals could be grown on top of the ridges, in dry or extremely cold climates they could be planted in the furrows. These techniques are not yet very popular and the equipment used for these specific cropping systems is often adapted by the farmers for the specific purpose. However, especially in Asia there seems to be a great potential for these types of cropping systems and fortunately the local equipment manufacturing industry is usually able to respond to the demand for specialized equipment.

This specialized equipment often includes some form of reshaper for the beds or ridges, which can be operated either separately or, more commonly, together with the seeder (Fig. 5). For the seeder units it is important that the actual planting depth is controlled and maintained. This requires free floating furrow opener units with a depth control close to the release point. In case of fixed units, the shape and surface of the beds either need to be very uniform or, otherwise the furrow opener and seed release point should be at a point of the equipment where a uniform depth from the finally reshaped bed surface is maintained. This is usually at the rear end of the bedformer.

Fig. 5: Bed planter for single axle tractor

Avoiding Soil Compaction

Soil compaction is another point of discussion for no-tillage systems. Soils that are not tilled tend to support more weight, resulting in better trafficability. However, this also has limits. In a no-till farming system the repair of soil damage such as compaction is extremely expensive – because it is not foreseen – and maximum care should be taken to avoid compaction problems in the first place. This is best done by controlling the traffic, choosing suitable tyres or tracks but also, depending on soil type and climate, limiting the maximum mass of machinery. It might prove more economical to use two smaller units rather than one big unit if in this way compaction can be kept at a tolerable level.

However, the best option seems to restrict any traffic to limited areas of the field and not to allow any traffic at all on the cropping areas. Field results show that a 15% loss of surface can be compensated in such a system by the yield increase in the never compacted areas [Kerr 2001]. However, ideally the traffic areas are kept at a minimum between 10 or 15% of the surface. Controlled traffic systems are not yet very common in most parts of the world. But in combination with no-till farming systems such as CA they make even more sense [Gaffney and Wilson 2003]. In addition to this they are very easy to introduce in cropping systems using permanent rows or beds and even in flat field crops they do not create a major hurdle in times of commercially available GPS technologies. It is important that all traffic at all times is restricted to the same tracks. Broadcast crops would usually require the use of differential GPS tracking systems which allow the permanent tracks to be found with an accuracy in the cm-range even when they are not visible in the field. For row crops with permanent beds a continuous controlled traffic system can also be implemented without the need for GPS tracking, as the rows remain visible and the tracks can be marked if necessary.

The strict application of controlled traffic for all operations provides a chance for the introduction of CA in mechanized farming and in crops, in which some field operations have to be carried out under wet soil conditions which invariably would lead to compaction. Examples could be pest control operations in cotton under tropical climatic conditions or harvest operations in crops like sugar cane or sugar beet. From the machine side this approach would require basic design changes, as the high equipment masses, for example of self propelled harvesters, could not be supported anymore across the working width with flotation or with multiple tyres, but they would have to be supported along the track with a footprint as narrow and as long as possible (Fig. 6). Since the rubbertrack technology is fairly advanced this should be technically possible but it is not yet realized to a sufficient extent in commercially available machinery (Fig. 7). However, recently some manufacturers have appeared on the market, for example with self propelled sprayers, adding a third axle and using narrow high tyres rather than flotation tyres to support the machinery weight.

Fig. 6: Six row cotton picker prepared for controlled traffic farming on a 3 m track

Fig. 7: Combine harvester on rubber track

Harvest Operations

Some considerations for harvest operations have been discussed already in the sections on residue management or on compaction. Those considerations would lead to changes in the design of harvest equipment or its operation.

For some crops of which the harvested part is underground there is additional care to be taken. This is not so much the case for crops like sugar beet, cassava or some peanut harvesting technologies, where the crop is either pulled or lifted out of the soil. The soil in this case might be disturbed to a certain degree but the original aggregates are not necessarily destroyed. An additional advantage of growing these crops under no till conditions is that the shape of the crop is more regular, for example cassava or sugar beet, and that the soil attached to the crop is reduced due to the better aggregation of the soil.

More of a problem are crops, such as potatoes, which are harvested using sieve chains. These harvesting operations would destroy at least the permanent macro pore structure of the soil. But even under conventional growing practices the soil protection for potatoes can be improved by using mulching practices. This could be done by deliberately seeding a green manure cover crop into the maturing potato crop leaving that cover crop as mulch on the soil surface after harvest. However, at least at small scale farming, potatoes are also grown without any soil movement above the soil surface but under a thick light absorbing mulch layer of straw or plastic. Recognizing the importance of not disturbing the soil structure more than absolutely necessary it seems to be possible to adapt most of the cropping practices even if major changes are required. For the agricultural machinery industry this might open the path to completely new developments.

IMPLICATIONS FOR AGRICULTURAL MACHINERY INDUSTRY

The result of such a farming concept, if applied consequently, is less time and labour required for farming, which means more time is available for more pleasant or more profitable occupation than farming. This is particularly important in areas where labour is scarce or loosing its work potential, such as the HIV/AIDS stricken regions of Africa and Asia. For a mechanized farmer fuel savings range up to 60%, the machinery investment in tractors is reduced by half and the tractor size goes down by 20 to 40% [Doets et al. 2000]. Recent experience of introducing CA in large farming operations in northern Kazakhstan show a reduction in tractor numbers of 50% and in tractor horsepower by 30% as compared to conventional farming [Bistayev 2002]. Tractor life is extended up to threefold, which is positive for the farmer, but not necessarily welcomed by the tractor industry. This is one reason why a consequent application of CA in regions with a strong tractor and agricultural machinery industry and lobby is not showing the same growth rates as, for example, in Latin America.

Specific equipment choices, such as combinations of narrow chisel openers with disk coulters, offset double disk openers with different disk sizes, combined no-till seed-drills-cum-planters and relatively light weight, low power no-till planters and seed drills are very common features in the southern parts of South America. At the same time there is a very strong equipment manufacturing sector specialized in equipment for this type of agriculture making the region probably technology leader for CA [Derpsch 2002]. These manufacturers in some cases even provide agronomic advice and extension when they enter into new export markets and sponsor the formation and organization of farmers groups practising CA. At the same time we have for more than a decade consistent exponential adoption rates of CA in South America.

Other world regions characterized by powerful full-line machinery manufacturers with significant manufacturing shares in tractor and tillage equipment segments show a different dynamic. Industry in these regions is not opposing, but also not pushing for the adoption of CA. As they put it, they are responding to the demand of farmers. At the same time conservation tillage models are promoted which address only the tillage practice, not being universally applicable. Typically these cropping systems still include tillage operations, hence the savings in the machinery investment for the farmer are not as dramatic as in the case of full CA adoption [Gogerty 1995]. In these world regions, such as in North America or Europe the adoption of CA is either stagnating or marginal [Derpsch 2001].

CONCLUSIONS

CA as a holistic concept of agriculture requires different engineering approaches to solving mechanization tasks compared to conventional agriculture. The consequent application of conservation agriculture principles in the entire cropping system would lead to changing requirements for equipment and machines for most of the operations within a cropping cycle. While the traditionally known and most visible changes take place in the tillage and planting operations, also the crop husbandry, the residue management, harvest and the traffic passes on the field have to be reconsidered. New requirements for new equipment open a potential for the machinery industry for continuous development of new technologies. Regions where this is recognized and implemented through the equipment manufacturing industry are at the same time, characterized by consistent and exponential growth rates in the adoption of CA. On the other hand, regions with a well established and strong conventional machinery manufacturing sector are slower in the adoption of CA as the conservative attitude of the farming sector is complemented by a conservative behaviour of the machinery manufacturing sector.

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