Conservation Agriculture in Developing Countries: The Role of Mechanization[1]

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1. Introduction

The per capita availability of agricultural land was 0.43 ha in 1960 and declined to 0.26 ha in 1999. Significant per capita declines are projected in the availability of another essential natural resource for agriculture - water. At the same time, the world must increase its food production by some 70% by 2050 to meet the needs of its growing population projected to reach 9.2 billion then [1].

There is no alternative but to increase agricultural productivity (i.e. crop yield per unite area) and the associated total and individual factor productivities (i.e. biological output per unit of total production input, and output per unit of individual factors of production such as energy, nutrients, water, labour, land and capital) to meet the global food, feed and biofuel demand and to alleviate hunger and poverty. Thus, feeding the world in 2050 and beyond will need further crop production intensification and optimisation. The type of farm power and farm equipment and machinery have a significant influence on intensification and optimisation outcomes, and on profit. However, until now, agricultural intensification generally has had a negative effect on the quality of many of the essential resources such as the soil, water, land, biodiversity and the ecosystem services which has caused yield and factor productivity growth rates to decline. Another challenge for agriculture is its environmental foot print and climate change. Agriculture is responsible for about 30% of the total greenhouse gas emissions of CO2, N2O and CH4 while being directly affected by the consequences of a changing climate [2].

The new paradigm of "sustainable production intensification" recognizes the need for a productive and remunerative agriculture which at the same time conserves and enhances the natural resource base and environment, and positively contributes to harnessing the environmental services. Sustainable crop production intensification must not only reduce the impact of climate change on crop production but also mitigate the factors that cause climate change by reducing emissions and by contributing to carbon sequestration in soils. Intensification should also enhance biodiversity in crop production systems above and below the ground to improve ecosystem services for better productivity and healthier environment. A set of soil-crop-nutrient-water-landscape system management practices known as Conservation Agriculture (CA) delivers on all of these goals. CA saves on energy and mineral nitrogen use in farming and thus reduces emissions; it enhances biological activity in soils, resulting in long term yield and factor productivity increases. Attention to soil health and good soil system management is critical and this message was highlighted in an international Technical Workshop held at FAO headquarters in July 2008 entitled: "Investing in Sustainable Crop Intensification: The Case for Improving Soil Health" [3]. Conservation Agriculture represents a practical concept to achieve improved soil health and better soil-crop-nutrient-water management leading to ecologically and economically sustainable agriculture. The Workshop recommended the mainstreaming of CA internationally and elaborated on the knowledge, policy, institutional and mechanisation support that must be organised to support the uptake and spread of CA.

[1] The views expressed in this paper are the personal opinion of the authors and do not necessarily quote the official policy of FAO

Conservation Agriculture in the context of sustainable agricultural mechanization is more than just a mechanical technique, such as no-till and direct seeding. It represents a fundamental change in the soil system management and in the cropping system design and management which in turn lead to consequential changes in the required field operations and the related mechanization solutions. When a tillage-based production system is to be transformed into a CA-based system, it involves a shift in the prevailing on-farm mix of mechanical technologies, some of which will remain but with only marginal use in future, and there will be the development of completely new set of mechanical technologies, changes in farm power requirements, and in land use suitability for sustainable intensification as elaborated in the following sections.

2. Conservation Agriculture in Developing Countries Globally

2.1. Definition of Conservation Agriculture

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 [4].

CA is characterized by three sets of practices which are linked to each other in a mutually reinforcing manner, namely:

- continuous no- or minimal mechanical soil disturbance (i.e., direct sowing or broadcasting of crop seeds, and direct placing of planting material in the soil; minimum soil disturbance from cultivation, harvest operation or farm traffic) (**Figure 1**);
- permanent organic matter soil cover, especially by crop residues and cover crops (**Fig. 1**);
- diversified crop rotations in the case of annual crops or plant associations in case of perennial crops, including legumes.

These three practices have been quantified as follows:

- minimal Soil Disturbance: the disturbed area must be less than 15 cm wide or 25% of the cropped area (whichever is lower). No periodic tillage that disturbs a greater area than the aforementioned limits;
- soil cover should ideally be above 100%, measured immediately after the planting operation. Ground cover of less than 30% is not considered as a CA practice;
- crop rotation: Rotation should involve at least 3 different crops. However, monocropping is permissible as long as no other related problems occur.

CA is a no-tillage-based cropping system, which by synergistic interactions with other crop management techniques overcomes the known limitations of no-tillage when applied as an isolated technique. CA can and should be complemented by other good farming practices for further improvement in the overall performance and resilience of the cropping system. The CA concept and principles of soil-crop-nutrient-water-landscape system management is universally applicable, but it is not a one-size-fit-all ready-to-use blue print recipe for sustainable farming. The actual soil and crop management practices and cropping systems require site specific adaptations and eventually specially designed mechanical technologies and farm power.

2.2. Impact of Conservation Agriculture – cropping systems and environmental services

CA is not a theoretical paper model as it has become a reality on more than 105 million ha around the world with some farms practicing it for over 30 years. Over the past 20 years, the rate of transformation from tillage-based faring to CA has been some 5.3 million hectares per annum. Several countries have adoption levels of more than 50% of their arable land, which permits the observation of the longer-term and large scale effects of CA on the environment at a landscape scale, for example, at watershed or river basin level.

The yield levels of CA systems are comparable with conventional intensive tillage systems, which mean that CA does not lead to yield penalties. On the contrary, the improved soil health allows better root and plant development and crop health, and leads in the longer term to incremental improvement in yields and factor productivities until a new equilibrium is established. In few cases the change from tillage-based farming to CA can result in modest yield penalties during the first few years for instance due to changes in soil nutrient balance and locking up of nitrogen due to increase in soil microbial activity or in weed infestation. However, there is no inherent systemic reason for such temporary drop in yields. They are generally the result of management errors during the learning and adaptation phase of adoption, which requires changes in all aspects of crop and cropping system management, particularly in fertilizer, pest and weed management regimes. In situations, where the actual yield levels of tillage-based systems are low compared to the genetic and agroecological potential of the crops, the changeover to CA results in immediate yield increases, particularly in legume crops. This has been the case in most developing countries so far. With this kind of crop response CA fulfils the multiple requirements of sustainable intensification mentioned in the beginning, since it is a production system with a high output potential.

At the same time, CA complies with the generally accepted ideas of sustainability. In the long term the need for fertilizer, compared with tillage-based systems, is reduced due to lower nutrient losses through erosion and leaching and higher availability of soil nutrients to the crops. The soil biological life is stimulated in CA systems, resulting in increased biodiversity below the ground, some of which is responsible for biological nitrogen fixation and nutrient mobilization as well stimulating root and shoot growth, and in biological pest control. Equally the organic mulch cover and diversified crop rotations allow for increased biodiversity above ground including that of predators and parasitoids, resulting in improved pest control, better crop health and an estimated 20% reduction of pesticide use in the long term [5]. The same applies to weed management and herbicide use. During the changeover to CA the herbicide use might remain equal to tillage-based systems, but with a shift in the products used and in their timing of application. However, CA with the application of permanent ground cover, cover crops and diversified crop rotations, together with minimum soil disturbance results, after a transition period of about 2 to 4 years, in a significantly reduced weed pressure with the subsequent reduction in herbicide use [6].

Regarding the water resources the mulch cover and the increased soil organic matter levels in CA soils allow a better water retention in the soil in the entire root zone and in improved water use efficiency and crop water productivity, while the improved soil structure, particularly deep reaching continuous macrospores, increases the water infiltration and reduces surface runoff. The recharge of underground aquifers is increased, improving at the same time the water quality due to reduced contamination levels from agrochemicals and soil erosion [7]. This is of special relevance to improving the resilience of cropping systems under a climate change scenario. Crops within CA systems produce relatively more under drought or excess water conditions and have the potential to save 1,200 km^3/year of water by 2030. It further helps to sequester carbon in soil at a rate of about 0.5 t/ha/year [8]; thus the world is sequestering about 50 million tons of carbon per year on the 106 million hectares of arable and permanent crop land that is now under CA.

Also, in socio-economic terms CA systems perform better than tillage-based farming. The production cost and the risk is significantly reduced, which increases farm profits and food security. Labour requirements are reduced by about 50%, and particularly the heavy work of soil tillage and deep cultivation is eliminated [9]. This allows mechanized farmers to save on labour, fuel and machinery costs. For many farmers in South America the adoption of CA has not been a choice but a question of survival. Farmers with draught animals can complete their farm operations without having to hire tractors for tillage work. Small farmers using manual labour and hand tools can farm more easily, even if their physical strength is limited or reduced due to disease, malnutrition or age, which is the case in many developing countries. The time saving allows such farmers also to dedicate more time to other, more profitable occupations than growing a crop, such as raising livestock, adding value with post harvest processing or seeking off farm employment. In the long term the livelihoods of farmers and rural population are significantly improved [10], resulting in a reduction and even reversal of the rural-urban migration.

2.2. History, development and relevance of CA in developing countries

Tillage, particularly in fragile ecosystems, was questioned for the first time in the 1930s, when the dustbowls devastated wide areas of the mid-west United States. Concepts for reducing tillage and keeping soil covered came up and the term conservation tillage was introduced to reflect such practices aimed at soil protection. Seeding machinery developments allowed then, in the 1940s, to seed directly without any soil tillage. At the same time theoretical concepts resembling today’s CA concept were developed by Edward Faulkner who published a book called Ploughman’s Folly [11] and Masanobu Fukuoka who published a book called One Straw Revolution [12]. But it was not until the 1960s for no-tillage to enter into farming practice in the USA. In the early 1970s no-tillage reached Brazil, where farmers together with scientists transformed the technology into the system which today is called CA. Yet it took another 20 years before CA reached significant adoption levels. During this time farm equipment and agronomic practices in no-tillage systems were improved and developed to optimize the performance of crops, machinery and field operations. From the early 1990s CA started growing exponentially, leading to a revolution in the agriculture of southern Brazil, Argentina and Paraguay. During the 1990s this development increasingly attracted attention from other parts of the world, including development and international research organizations such as FAO, CIRAD and CGIAR. Study tours to Brazil for farmers and policy makers, regional workshops, development and research projects were organized in different parts of the world leading to increased levels of awareness and adoption in a number of African countries such as Zambia, Tanzania and Kenya as well as in Asia, particularly in Kazakhstan and China. The improvement of conservation and no-tillage practices within an integrated farming concept such as of CA led also to increased adoption including in developed countries after the end of the millennium, particularly in Canada, Australia and Finland.

CA crop production systems are experiencing increased interest in most countries around the world. There are only few countries where CA is not practiced by at least some farmers and where there are no local research results about CA available. The total area under CA in 2009 is estimated to be 106 million hectares [13]. CA is now practiced by farmers from the artic circle (e.g. Finland) over the tropics (e.g. Kenya, Uganda), to about 50º latitude South (e.g. Malvinas/Falkland Islands); from sea level in several countries of the world to 3,000 m altitude (e.g. Bolivia, Colombia), from extremely dry conditions with 250 mm a year (e.g. Morocco, Western Australia), to heavy rainy areas with 2,000 mm a year (e.g. Brazil) or 3,000 mm a year (e.g. Chile). No-tillage is practiced on all farm sizes from less than half a hectare (e.g. China, Zambia) to thousands of hectares (e.g. Argentina, Brazil, Kazakhstan). It is practiced on soils that vary from 90% sand (e.g. Australia) to 80% clay (e.g. Brazil’s Oxisols and Alfisols). Soils with high clay content in Brazil are extremely sticky but this has not been a hindrance to no-till adoption when appropriate equipment is available. Soils which are readily prone to crusting under tillage farming do not present this problem under CA because the mulch cover avoids the formation of crusts. CA has even allowed expansion of agriculture to marginal soils in terms of rainfall or fertility (e.g. Australia, Argentina). All crops can be grown adequately in CA and to the authors' knowledge there has not yet been a crop that would not grow and produce under this system, including root crops [14].

The main barriers to the adoption of CA practices continue to be: knowledge on how to do it (know how), mindset (tradition, prejudice), inadequate policies, for example, commodity based subsidies (EU, US) and direct farm payments (EU), unavailability of appropriate equipment and machines (many countries of the world), and of suitable herbicides to facilitate weed and vegetation management (especially in developing countries) [15].

3. Implications of Conservation Agriculture for agricultural mechanization

3.1 Changes in mechanization and field operations

The most significant change from tillage-based farming to CA is in the land preparation and seeding practices. The use of tillage as a standard periodic operation is completely eliminated in a fully functioning CA system and remains only for very specific tasks, such as creating the conditions for changing over to CA by breaking up compacted soil or levelling the soil surface. Braking compacted soil may also become necessary within CA system under mechanized farming, particularly in humid climates. In such cases implements with minimum soil disturbance, such as the Paraplow, are preferred (Figure 2). However, the main goal under CA is to avoid soil compaction in the first place for which technical solutions are available. In surface irrigated systems the maintenance of the irrigation furrows between permanent raised beds is a regular operation requiring tillage equipment and in cold moist climates strip tillage before or together with the planting operation can be applied. In the absence of specialized equipment for direct seeding farmers using animal traction can apply a ripping tine to open seed furrows for subsequent hand seeding. Small farmers can open with a hand hoe planting holes which remain as permanent planting microbasins in the field, allowing new plant roots to follow the root channels of the previous crop. Overall, the significance of tillage implements in a functioning CA system is reduced drastically.

Another area of significant change is the seeding and planting operation. Equipment for seeding and planting must be able to deposit the seed with a similar accuracy of conventional seed drills into an untilled soil which ideally is covered with a heavy mulch of crop residues. For this reason the equipment must have specially designed furrow openers which can penetrate the mulch without collecting it or pushing it into the soil and deliver the seed into the soil at the desired depth. In order to do this, no-till direct seeding equipment is usually strong enough to resist the higher soil forces, and heavier than a conventional seed drill, particularly when disk type furrow openers are used. As no-tillage systems such as CA mature and are optimized over a period of time, the trend goes clearly towards minimum disturbance no-till furrow openers, such as double disk, cross slot or star-wheel type tools, which also facilitate weed control management [16].

Equipment for weed management remain partly unchanged under CA system. While cultivators and hoe type equipment loose importance in CA systems, slashers, cutters or crimper-rollers are used for mechanical surface weed management. Chemical herbicide applicators play a significant role, whereas wick type and low volume applicators (CDA) are of particular importance for small farmers operating manually. Sprayers remain the main tool for herbicide application. In many developing countries, particularly among small farmers, herbicide use is so far unknown and herbicide application is eventually a completely new operation for such farmers when adopting CA. However, contrary to tillage-based systems, weed management in CA does not necessarily aim at complete elimination or removal of weeds. Important point here is that weeds are not allowed to multiply or interfere with the crop growth. Some cover crops that are nowadays used in CA were previously considered as weeds.

The harvest operation in CA is part of the land preparation for seeding the next crop. The management of crop residues during the harvest has direct influence on ease, problems and quality of the subsequent planting operation. Standing residues, anchored in the soil, or at least a tall standing stubble can facilitate seeding particularly in high or difficult residue situations, such as in the case of high yielding rice. In semi-arid continental climates with winter precipitation and extremely low winter temperatures, a standing residue or high stubble facilitates the trapping of snow and hence water retention [17]. Another important aspect is the treatment of the residues. In tillage-based systems the fast decomposition of residues is desired to facilitate incorporation and mineralization in the soil. Hence residues are mostly chopped. Under CA the integrity of the residues as soil cover is important. In most developing countries, particularly in Africa, the agroecological and socioeconomic farm conditions often limit the amount of residues which can be retained as soil cover; and in case of the warm humid tropics, the organic matter decomposition rates are so rapid that any further acceleration of the decomposition through tillage should be avoided. Hence, the retention and even the spreading of un-chopped residues are preferred. Depending on the type of residues and furrow openers, this also facilitates the subsequent seeding compared to chopped residues. Farmers practicing CA often use simple residue spreaders, rather than choppers, which has the additional benefit of a lower energy requirement. One of the most important tools specific to CA, and which is used for residue, cover crop and weed management especially in sub-humid or humid climates, is the knife roller or crop crimper or vegetation crusher. It is also used in organic no-till farming, which essentially is CA without the use of synthetic agro-chemicals (**Figure 3**).

Residue retention in CA is an issue in many developing countries since residues are often used as animal feed, also by nomadic herds. The integration of crop and livestock production is therefore an important issue. Forage production as part of the crop rotation with forage, cover or relay crops will have to be inserted in the cropping system, and the grazing or withdrawal of residues for forage purposes will have to be controlled to strike a compromise between feeding the soil and feeding the livestock. Obviously also in such areas there will be options for equipment and technological solutions, starting from forage cutting and collecting equipment to controlled grazing equipment, such as solar powered electric fences.

Another significant change that is taking place is in the farm power requirements. Without the heavy tillage operation, the required peak farm power on a farm is roughly halved. Small farmers using animal traction or single axle tractors, which in tillage-based systems would hire four wheel tractors for ploughing or consider their actual mechanization level as transition to a tractor, under CA system can continue farming without changing or hiring additional farm power. In mechanized systems the overall power requirement for tractors decreases by about 50% with an additional shift towards lower horsepower by about 40%. For a farmer switching completely to CA system, there would be significantly lower amount of capital tied up in farm machinery [18].

3.2 Opportunities for new technology developments

While some common farm equipment, such as tillage equipment, looses importance when changing from tillage-based farming to CA system, other new equipment, such as the knife roller and residue spreaders are introduced, offering new opportunities for technology development. The consequent application of CA will also lead to modifications in the design of some existing equipment. Root

crop harvesters will have to reduce the impact on soil structure, as for example puller type opposed to digger type peanut harvesters, or they will have to operate in a completely different environment, such as in case of the mulch potato which so far is commercially grown only in areas using hand harvest.
Another aspect which will gain increasing importance under permanent no-till CA system is the avoidance of soil compaction, particularly in mechanized farming and in humid climates. Existing mechanical technologies to reduce the danger of compaction, such as low pressure tyres and rubber tracks, tyre pressure adjustment systems and wheel track monitoring to warn the driver, will become economically more feasibility for the CA farmer since the mechanical removal of soil compaction or surface tracks will not be a standard operation as is in the tillage-based farming. A safer approach to completely avoiding soil compaction in the crop zone is the controlled traffic farming which is increasingly gaining popularity in Australian CA farms, but also in mechanized no-till farms in Africa and Central Asia, using satellite based guidance and eventually auto-steer options. In permanent bed systems, for example in South Asia, controlled traffic can be applied without any guidance systems since all crops in the rotations are planted on the same beds. The consequent application of controlled traffic concepts would eventually lead to completely different generations of farm machinery, from tractor through seeders to sprayers and spreaders to harvesters and transport equipment (**Figure 4**). General design features would be track spacing as wide as possible, eventually standardized, while the tracks as such would be as narrow as possible. Machinery weight, rather than being spread evenly across the surface, as is the case with actual wide and multiple tyres, will be concentrated in the track and spread along the track with multiple axles or rubber tracks. Working width for each of the farm equipment would have to be standardized according to the track spacing as multiples of the same.

A new promising complementary technology in this context also could be the Bio-Agtive Emissions Technology, which is currently under development and investigation to fully understand it's functioning and potential benefits and consequences. By directing tractor exhaust emissions into the soil, for example through the seeder furrow openers, not only the tractor emissions into the atmosphere can be further reduced, but the heat and elements contained in the emissions can obviously act as stimulator for soil life and directly as plant nutrient, resulting in a potential for reducing mineral fertilizer use, particularly nitrogen, which is another major source of GHG emissions from agriculture [19].

3.3 CA mechanical technologies with special relevance to developing countries

Agriculture in developing countries comprises all possible mechanization levels, from the small farmer using exclusively manual power to the large scale mechanized farmer applying precision farming with satellite guidance. Suitable CA mechanical technologies exist for all these technology levels, commercially available and functional. However, the actual availability of the technologies and hence the accessibility and affordability for the farmer depends very much on the existing adoption level of CA. In particular, small scale CA hand and animal traction tools and equipment so far are easily accessible for the farmers only in southern Brazil and Paraguay, while single axle tractors with CA attachments can be found only in Bangladesh and Brazil on the market. The actual challenge is to improve the accessibility and commercial availability of such tools and equipment in Africa and Asia for the small holder farmer, as well as in parts of Latin America, where in some countries small workshops and manufacturers are starting to produce manual and animal traction no-till planters.

At manual technology level, besides using a planting stick or the hoe, the most common planting tool is the jab planter (**Figure 5**) which is available in different designs especially for no-till planting, mainly for row crops. While, the small grains farmers in sub-humid areas would broadcast into the mulch, the manual seeding of small seeds in semi-arid climates under CA still has no suitable mechanization solution. The rolling type jab planter has been of marginal use only. For weed management the most popular options at the manual level are light hoes and slashers as well as lever operated knapsack-sprayers, wick type applicators (example ZAMWIPE) (**Figure 6**) and, in high value crops, low volume applicators with rotary nozzles. Also, manually pulled small boom-sprayers on a cart or spray boom attachments for knapsack-sprayers are available. Occasionally handheld motorized bush-cutters are used for weed and cover crop management, particularly in permanent or plantation crops.

Simple row crop precision planters exist for animal traction, often with fertilizer application, using ripper tines or double disks as furrow openers. The designs range from simple light weight long-beam type ripper-planters (**Figure 7**) to self suspended one or two row animal drawn planters, eventually even with a ride-on option (**Figure 8**). A problem, similar to the manual technology level, is the seeding of small grained cereal crops. In sub-humid climates this is done by broadcasting into the mulch and then shaking the seed through the mulch with an animal drawn roller or disk harrow, while for semi-arid conditions with less mulch cover there are no satisfactory solutions available as yet. Simple 3-5-row animal traction no-till seeder exists in India, but without any residue handling capacity, while two other models built in Chile and Bolivia in small quantities are prohibitively expensive. Heavier and more sophisticated no-till small seed drills pulled by multiple horses can be found in Amish or Mennonite communities deploying CA system. For residue and weed management knife rollers and boom sprayers are available for animal traction.

For single axle tractors one or two row precision planter attachments are available, similar to the ones used on four wheel tractor no-till planters (Brazil) (**Figure 9**). In addition to those, there are low cost no-till planters available, however with a limited residue handling capacity (e.g. in Bangladesh). For direct seeding of small grains into no-till soil and into residues, strip-till-cum-seeders could be used based on modified power tillers leaving only the knives under the seed rows in place. This kind of equipment is available especially in Bangladesh and China. With support of international research centres (CIMMYT), as well as Australian and North American research support, multi-purpose single axle tractor no-till seed drills and planters have been developed in South Asia (Bangladesh) (**Figure 10**), and from there they have reached countries in East Africa (Kenya, Uganda) where some initial steps for local manufacturing have been undertaken (**Figure 11**)[20]. For permanent bed systems there are also bed planters available for single axle tractors (Bangladesh).

For four wheel tractors the full range of no-till seeders and planters, for small tractors of 30 hp (**Figure 12**) up to the large tractors of 400 hp, is available (**Figure 13**). Among the equipment operating with double disk furrow openers, the versions with offset disks of different diameters (**Figure 14**), which is particularly popular in Brazil, is very suited for smaller tractors, since it can cut into most residues and soil conditions with equipment weights of less than 100 kg/row, while other double disk seeders often require weights of 150 to 250 kg/row. However, for many developing countries, particularly in Asia, the double disk planters are prohibitively expensive due to the cost for the high quality steel for the disks and the additional weight. Yet, chisel type no-till seeders and planters, as actually favoured in India and China as a low cost equipment for small size tractors, have serious limitations with the residue handling, particularly when seeding small grain cereals like wheat into heavy maize or rice straw residues. The approaches taken so far to solve this problem are the use of PTO power for strip tilling with narrow rotary harrows to facilitate the penetration through the residues with a light weight seeder (China), or by picking up the residues in front of the furrow opener with a strip-chopper and blowing them on top of the planted row behind the equipment. This type of seeder has been developed in China (**Figure 15**) as well as in the Indo-Gangetic Plains in India and Pakistan where it has became popularly known as the “happy seeder” (**Figure 16**). It is commercially available in both countries from several manufacturing companies.

For the harvest operation under CA the shift from a two step harvest, with stationary threshing at the field side or on the farm yard, towards a one stage harvest with combine harvesting or at least mobile pick-up threshing is preferred as this facilitates the retention, return and spreading of as much crop residues as possible.

For larger tractors as well as for all the other farm operations the same type of equipment as in developed countries is used and mostly as in tillage-based cropping (application and harvest equipment).

3.4 Policy and institutional support implications for developing countries

Due to the benefits of CA in combining a high output intensive production with sustainability and improved environmental services, policy makers are increasingly becoming interested in harnessing the potential of CA systems. Yet, for the successful introduction and up scaling of CA in a country, the availability and accessibility of equipment and machinery for CA is often one of the biggest impediments. Suitable policies would need to facilitate capital access for farmers and eventually even directly subsidize the cost of the equipment and machinery to reduce the investment risk for early adopters. This “subsidy” could be justified as payment for environmental services, considering the reduced impact on the environment from CA compared to tillage-based farming. But even with adequate capital, farmers in most countries would not be able to source suitable equipment. To address this problem the market needs to be stimulated, import taxes for equipment and raw material need to be adjusted to facilitate the import and eventually national manufacturing of CA equipment. As long as no national producer of equipment is servicing the farmers, existing suppliers from other countries need to be proactively brought into the country, including facilitating the building up of dealership and service networks.

Mechanization policies, especially in those countries which start from a low mechanization level, as is the case for most African countries, need to be coherent with CA policies. This would mean that the standard equipment for a tractor would not be the plough or the disk harrow but a no-till seeder. Also the reduced farm power requirements under CA need to be considered when planning a national mechanization strategy. Considering also the other savings, for example in tillage equipment, the overall investment requirements for complete replacement or new mechanization programmes can be reduced by 50% compared to tillage-based systems [18]. This is of relevance for example in the countries of the former Soviet Union which after independence were left with mostly obsolete machinery in need of complete replacement. In Africa, where new agricultural mechanization programmes are under way in many countries, the improved economics of CA mechanization could increase the feasibility and viability of such programmes. By reducing the overall demand for farm power, the change to CA is not necessarily a threat to the agricultural machinery industry because it could facilitate the opening up of new markets which so far have been completely left out of farm mechanization. In this regard, there is a need for local manufactures and equipment suppliers to provide support in supplying seeders and other equipment that would normally not be available in rural outlets.

Ultimately, it must be recognised that a behavioural change in all stakeholders must be encouraged and facilitated to help the changeover to CA system. This includes the role and competences of the key national extension, research and education institutions, the government departments, development agencies and donors that support them, as well as the private sector including farmers and farm managers who have an important and often unique role to play in innovation processes and in input supply markets including for equipment and machinery.

CA is knowledge intensive with many new aspects and those who must promote it or practice it require training and practical experience. In the case of farmers, an opportunity to test, learn and adapt is necessary. For extension staff and NGO staff, training is necessary in alternative mechanization technologies. Similarly, in universities and national and international research institutions, there is a need to include training and research on CA-related agronomy and cropping system management at the field, farm and landscape level, as well on the equipment options for different sources of farm power.

4. Conclusions

Considering the current world challenges posed by increasing demand for food, feed, fibre and biofuel from crop production, ecological and economic sustainability has to be considered in any intensification and productivity enhancement strategy. Hence, innovations for sustainable agricultural mechanization can only be meaningful and effective within the context of sustainable crop production systems, and never in isolation. Conservation Agriculture includes the basic elements of such a sustainable production system, increasing productivity and production while reducing the need for external inputs and the environmental footprint of farming. CA improves the delivery by agriculture of ecosystem services such as water resources, biodiversity and the mitigation of climate change while strengthening the ecological foundation of cropping systems to also adapt to changing climates. Conservation Agriculture requires adequate and very specific mechanization inputs which could be described as “innovations for sustainable agricultural mechanization”, notwithstanding the fact some of the currently used and promoted technologies will be reduced due to their negative impact on the environment and society.

Yet, to become fully sustainable, the socioeconomic component of the production system as well as the mechanization structure has to be considered. Improved profitability of farming and farmers’ livelihoods form an economic base that also allows the mechanization sector to develop and prosper in a sustainable way. In many developing countries, especially in Africa, supportive and guiding policies are required to attract and encourage the agricultural machinery sector to open up and develop markets for agricultural mechanization in general and for CA equipment in particular and to establish the required commercial and service infrastructures. Without this change in the machinery sector, future agriculture development needs of developing countries for food security, poverty alleviation, economic growth and environmental services cannot be achieved.

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Figure 1 - No-till direct seeding into heavy residue mulch, Nicaragua (foto Friedrich)

Figure 2 - Paraplow for subsoiling with minimum soil movement, Nicaragua (foto Friedrich)

Figure 3 - Knife roller or crop crimper, Brazil (foto Friedrich)

Figure 4 - Cotton picker adapted for Controlled Traffic Farming with 3 m track and single tyres; additional front support wheels to distribute the header weight along the track, Australia (foto Friedrich)

Figure 5 - Hand jab planter for no-till planting, Zambia (foto Kienzle)

Figure 6 - ZAMWIPE wick-type herbicide applicator, Zambia (foto Friedrich)

Figure 7 - Simple long beam animal traction no-till planter, Tanzania (foto Kienzle)

Figure 8 - Animal traction no-till planters, Cuba (foto Friedrich)

Figure 9 - Single axle tractor with two row no-till planter, DPR Korea (foto Kim Kyong Il)

Figure 10 - Multicrop no-till seeder for single axle tractor, Bangladesh (foto Hossain)

Figure 11 -Multicrop no-till seeder for single axle tractor, Kenya (foto Sims)

Figure 12 - 28 hp Cholima tractor with 7-row no-till seeder, DPR Korea (foto Friedrich)

Figure 13 - Large scale no-till seeding equipment, Kazakhstan (foto Friedrich)

Figure 14 - Double disk furrow opener with offset disks of different diameter from Brazil, Uzbekistan (foto Friedrich)

Figure 15 - No-till seeder with residue chopper, chisel type fertilizer and double disk seed furrow opener, China (foto Friedrich)

Figure 16 - No-till seeder with residue chopper and chisel furrow openers, Indian “Happy Seeder”, Egypt (foto Friedrich)