DEVELOPMENT OF THE CONSERVATION AGRICULTURE EQUIPMENT INDUSTRY IN SUB-SAHARAN AFRICA

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ABSTRACT. Smallholder farmers in many sub-Saharan African (SSA) countries are limited by farm power shortages. One way of reducing the constraint, and also the negative impacts of conventional tillage (with hoe and plow), is to practice conservation agriculture (CA) which uses no-till techniques to establish crops. CA can be practiced on small areas with rudimentary tools (a pointed stick to plant) and manual weed control methods. But to expand the area cropped, some mechanization is needed. The necessary equipment can include draught animal powered (DAP) rippers, sprayers, and no-till (NT) planters, and maybe knife rollers along with manual jab planters and herbicide applicators.

Development of CA equipment for smallholder farmers has been particularly impressive in Brazil where farmers, manufacturers, researchers, and the public sector have been instrumental in developing a flourishing CA machinery industry. Some of this equipment has been promoted in SSA and there is now a demand for locally manufactured equipment geared towards national and regional markets. There is now a budding industry in East Africa as result of exposure to Brazilian equipment and specialist technical training of East Africans in South America. Machinery being manufactured commercially includes DAP rippers and NT planters, manual jab planters, and sprayers. The industry continues to grow and mature and is now addressing the CA equipment needs for imported two-wheel tractors. In southern Africa there has been development of NT planters in Zimbabwe and this continues to prosper, with DAP NT planters currently being produced commercially in the private sector in collaboration with international researchers. Zambia is proceeding along the same track for farmers with access to DAP. For those with access only to manual labor, the chaka hoe for basin-based CA has been developed and manufactured commercially and has become a popular and viable solution. South Africa, despite its huge potential, seems to be a slow starter in the smallholder-oriented CA machinery market. Some progress has been made with planters and sprayers, but a great deal more can be achieved in the immediate future. This article contrasts the Brazilian and SSA situations and draws lessons and guidelines for the development of the CA equipment industry in SSA. The conclusions indicate that, although the industry in SSA is still in its infancy, there is good potential for support from international donors. Local adaptations are needed for local markets, materials, and skills and national governments can play a key role in supporting and promoting CA. Now is precisely the moment for decisive action.

Keywords. Smallholder farmers, Sub-Saharan Africa, CA implements and manufacture, Innovation systems, Sustainable mechanization.

Smallholder farm mechanization in sub-Saharan Africa (SSA) relies heavily on manual labor and the hand hoe is the main implement used for crop production on up to 80% of the arable land area. Draught animal power (DAP) represents a major advance in terms of available power and is especially important where human resources are being depleted by age, migration, and pandemics. However the use of DAP is restricted by the presence of the tsetse fly and by tick-borne diseases such as east-coast fever (FAO, 2006). Where DAP is possible it is often used to pull the moldboard plow, although chisel-tined rippers are increasingly used. Less than 10% of the land area in SSA is cultivated by tractor-powered systems, mainly on commercial farms; those systems will therefore not be considered in this article. Farmers perceive advantages with mechanized tillage operations (e.g., improved weed control; mobilization of nutrients from the organic matter; preparation of a smooth seed bed; elimination of compacted zones; incorporation of amendments; control of pests and diseases; control of water run-off and accumulation of water) (Hobbs et al., 2008). However the damaging effects of the use of hoes and plows soon become apparent. They reduce soil organic matter through oxidation, cause various forms of physical, chemical, and biological degradation (especially hard pans, soil crusting, and erosion) and produce lower yields, which result in increased poverty and hunger, reduced food security, and, eventually, abandonment of degraded farm land.

Conservation agriculture (CA) has been proposed to reverse this degradation in an effort to move towards sustainable cropping systems. CA is a crop production system based on minimum soil disturbance, surface crop
residue retention, and crop rotations and associations (FAO, 2002). The benefits and challenges of CA systems (including the critical problem of maintaining permanent organic soil cover in semi-arid regions and with crop-livestock competition) have been published widely (Wall, 2007; Kassam et al., 2009) however to date there is little information on the challenges of developing a viable CA machinery sector in SSA. Seed drills and planters developed for tilled soil present difficulties when planting through organic cover (in terms of seed placement and covering whilst penetrating the residues); another challenge is the precise and safe application of herbicides for the control of weeds and management of cover crops.

CA MECHANIZATION OPTIONS FOR SMALLHOLDER FARMERS

The following are the main CA equipment options in use on smallholder farms in SSA. Sub-soiling and deep ripping with chisel-point tines have shown significant yield benefits on soils with hardpans (fig. 1).

For planting, the mulch can be penetrated or cut with vertical discs or jab planter beaks – or even a pointed stick. Chisel point tines are suitable in low-residue cover situations. The aim of CA is minimum soil disturbance both for planting and weed control. For weed management all options should be explored including shallow scraping, hand pulling, knife rolling (fig. 2), effective utilization of soil cover and cover crops, and the use of herbicides. Chemical weed control under CA systems has often been an important step towards farmer adoption of CA due to the significant reduction in labor requirement when compared with manual mechanical control.

However, if herbicides are introduced there should be a medium term aim to reduce them to the minimum as soon as the agronomic control measures are showing impact. Innovations are needed when farmers opt for chemical weed control as the conventional option is the knapsack sprayer, which is notorious for contaminating the operator. Knapsack sprayers can be mounted on a wheeled chassis, fitted with a multi-nozzle boom, and hand-pulled so removing the operator from the risk of contamination (fig. 3). Larger capacity boom sprayers are manufactured for animal traction. The investment costs for such equipment are, unfortunately, beyond the financial resources of many SSA smallholder farmers; and it is here that the potential of CA mechanization service providers becomes apparent. One interesting development from Zambia is the Zamwipe applicator which operates on the wick principle with glyphosate as the application herbicide (fig. 4). Farmers have, however, expressed some difficulties with this implement as the flow rate is not easy to control and if the application head touches the soil the herbicide is deactivated.

DEVELOPMENT OF THE CA MACHINERY MANUFACTURING INDUSTRY

BRAZIL

Brazil has witnessed a revolution in CA equipment development and manufacture in the past 50 years (Casão et al., 2012). It is estimated that in the 1960s, 10 tonnes of soil was being lost for every tonne of grain produced. Pioneer farmers tried new approaches to reduce soil tillage, while programs of physical soil conservation (mainly terraces and contour bunds) went ahead. After the initial efforts had been made, research institutes and commercial companies joined the effort to investigate cover crops, crop rotations, weed control methods, and no-till planters. No-till farmers’ associations were formed and flourished. The machinery industry developed and still produces hundreds of models of planters and sprayers for CA for all sizes of farm and for all soil types. The success of the revolution in Brazil (which has now spread to many other countries) can offer important lessons for SSA.
The CA equipment manufacturing industry in East Africa is in its infancy. Principally as a result of initiatives of FAO, CA has been introduced in Tanzania, Kenya, and Uganda, and this has resulted in the current demand for the necessary equipment. However, prior to the efforts of FAO, there had been little interest in CA, especially at the level of the smallholder producer and consequently the domestic manufacturing output of CA equipment in the early years of the 21st Century was close to zero.

Early work in Uganda was centered on the Agricultural Engineering and Appropriate Technology Research Institute (AEATRI) of the National Agricultural Research Organization (NARO) (figs. 5 and 6). There was small batch manufacture of animal-drawn knife rollers and hand-pulled field sprayers, but their web site (www.naro.go.ug/technologies/aeatri.htm) has no mention of these as currently available technologies. Additionally, as experience has proven, public sector R&D institutions, like AEATRI, are unlikely to provide sustainable manufacturing capacity; the private sector needs to be motivated, incentivized, and involved.

The situation in Kenya and Tanzania has been markedly improved as a result of the activities of the FAO implemented CA-SARD project. The Conservation Agriculture for sustainable Agricultural and Rural Development project (CA-SARD) was a project funded by the German government and executed by FAO from 2004 to 2011. Although there are only a few companies actively manufacturing CA equipment, all the signs indicate that there is solid growth in the sector. Part of the activities of the CA-SARD project have been directed towards strengthening the local manufacturing capacity and to do this they embarked on a program of exposure to the Brazilian manufacturing environment. In 2008 the project organized a study tour of Brazilian CA equipment manufacturers for selected East African manufacturers (http://www.act-africa.org/publication/LAB/proceedings.html). This tour culminated in a 3-day workshop where the situations in each of the countries were explored and explained and individual manufacturers pursued discussions on possible joint action and joint venture activities. Although the door was left open for future collaboration, the workshop concluded that at the time the technological gap between the Brazilian and East African manufacturers was too great and that it would be premature to enter into formal joint venture arrangements. However, some Brazilian companies did agree to export specialist parts to aid the nascent industry in East Africa. These parts included such items as seed expellers for no-till planters and other, mainly plastic, parts which have a low-unit cost only if they are produced in large quantities.

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However, the event did produce an invitation from one Brazilian (Fitarelli, http://www.fitarelli.com.br/) and one Paraguayan (Agropastoril) company to give intensive training to high-ranking technical staff from East African factories. As a result, and following a period of detailed negotiation, six trainees spent a month studying the design, fabrication and field operation of a range of CA equipment in three factories (http://www.guaranyind.com.br/) sprayer factory in Itu, Brazil was included after FAO received an invitation from the company. See figures 7, 8, and 9).

The results of this training have been immediately positive in the case of two factories in Tanzania. The trainee from the Nandra factory in Moshi (http://www.nandra-engineering.co.tz/) has been promoted to the position of technical supervisor for the whole of the manufacturing section of the company (figs. 10 and 11). Not only does he continue to produce manual and draft animal powered equipment but has now embarked on the development of a ripper to be attached to the two-wheeled
tractors (2WTs) being imported in large numbers into Tanzania.

The trainee from Intermech Engineering in Morogoro (http://www.intermech.biz/) has also enjoyed similar promotion and is now the supervisor of development and testing of agricultural machines, including CA machines.

The Government of Tanzania is committed to modernizing smallholder farming (albeit with a fairly low investment in the sector in terms of percentage of GDP) and has embarked on the importation of 10 000 2WTs and these are being offered to farmer groups at subsidized prices. Intermech has identified a major market niche for no-till planters for 2WTs as none of the imported machines come with any suitable equipment. After a lengthy and diverse development program the company has now produced a pre-production prototype (Chisawillo, 2011; see fig. 12).

Other beneficiaries have not, to date, been so productive but there are encouraging signs both in Kenya and Tanzania that the manufacture and supply of animal drawn rippers and manually operated jab planters is on the increase.

One company that did not find it possible to participate in the 2010 training mission to Brazil and Paraguay was Ndume of Gilgil in Kenya (http://www.ndumekenya.com/). However, although their main product line is aimed at larger scale commercial farmers, they have developed a no-till planter and sprayer to be attached to a 2WT (the Bwana Ndogo planter/sprayer). The power unit is a Chinese made 2WT already imported by Ndume. The sprayer is an optional extra and the planter is a two-row machine with chisel tine openers which are sufficient in low surface residue conditions (fig. 13).
The no-till planter designed by Jeff Esdaile in Australia (http://www.crawfordfund.org/assets/files/publications/Notill.pdf), developed with funding from the Australian Centre for International Agricultural Research (ACIAR), and manufactured by Spring Ridge Engineering has also been trialled in Kenya and Tanzania (fig. 14). In fact one unit was constructed in Morogoro by Intermech Engineering. This machine, fitted to the rear of a 2WT, can plant up to four rows with zero tillage. It has been tested in South Asia and is available on the market in Bangladesh. However, it has not, so far, been greeted with overwhelming enthusiasm in East Africa where it is currently under test at the Tanzanian Centre for Agricultural Mechanization and Rural Technology (CAMARTEC).

### Southern Africa

Machinery design and manufacturing of CA equipment in southern Africa goes back to the mid-1980s mainly aimed at the commercial farming sector, when fuel shortages in the region increased the need for planting systems with a lower energy requirement. Zimbabwe was at the forefront of designing new direct seeding machines, which were tested with a commercial farmer association, the Agriculture Research Trust, on their farm near Harare. As a result of these first initiatives, a star-wheel planter (called the Supernova) was developed by Rio Tinto, which later became Hastt Zimbabwe (http://www.agmachine.com/ammd5608.htm).

In the small-scale farming sector, development of the machinery industry was much slower. Important advances were achieved in Zimbabwe and Zambia and to a certain extent in South Africa where various donor-funded initiatives kick-started CA machinery development. In Zimbabwe, a GTZ/BMZ [Deutsche Gesellschaft für technische Zusammenarbeit and Entwicklung (GTZ); Federal Ministry of Economic Cooperation and Development 7(BMZ)] funded conservation tillage (Contill) project was active between 1988 and 1998 (Hagmann, 1998) and led to the formation of the African Conservation Tillage Network (ACT). The Contill project developed various designs of ripper tines that could be attached to existing plow beams pulled by a pair of oxen. Rio Tinto (later Hastt) was active in developing these ripper tines and also started to develop a ripper-planter called the “Haka planter.” The latter was however unsuitable for planting into mulch. In many cases this first generation of equipment was developed on the drawing board with university- or government research station-based researchers. There was very little farmer interaction and feedback, limited equipment modification, and adaptive research, insufficient testing of equipment and a low level of training of extension officers on the guiding principles CA. Consequently the first CA equipment prototypes never achieved widespread adoption in rural farming communities.

In Zambia, a major donor push started in 1996 when the World Bank and later Norwegian-, Swedish-, and EU-funded initiatives led to the formation of a conservation farming unit (CFU) within the National Farmers Union. At the same time, several research stations where converted into a trust, the Golden Valley Agriculture Research Trust (GART, www.gartzambia.org). Both GART and CFU were active in promoting two CA systems (Haggblade and Tembo, 2003). One was based on digging planting basins, which led to the development of a heavy digging hoe (the Chaka hoe). The other was based on rip-line seeding, which led to the development and testing of new CA equipment at the Magoye and Palabana research stations. The resulting equipment was the Magoye chisel-tine opener and the Palabana subsoiler. The Magoye furrow, or planting slot, opener is a ripper tine attached to a conventional moldboard plow beam, which operates at shallow depth (up to 15 cm) and can be used for seeding into un-tilled soils. The Palabana subsoiler operates at 20- to 25-cm depth and can mechanically remove plow or hoe pans, if the subsoiling is done at the right (i.e. friable) soil moisture content (fig. 15). Both equipment types are typically pulled by a pair of oxen. The initiatives in Zambia and developments of CA equipment were donor driven, and the resulting equipment was tested and developed with little farmer involvement. An association of rural blacksmiths...
(Smallholder Agriculture Implement Suppliers and Workshop Association of Zambia SASWAZ) however started to multiply both ripper and subsoiler, which led to some multiplication and diffusion of the attachments. The ripper is made by local manufacturers and several thousands are in use in Zambia and in neighboring countries [they are made, for example, by Nandra Engineering in Tanzania, and Hastt, Zimplow (http://www.zimplow.co.zw/) and Grownet in Zimbabwe].

In 2004 a new paradigm of research and extension, embracing the ideas and concepts of innovation networks, was introduced to the region and small-scale CA machinery was increasingly developed in collaboration with farmers. Several initiatives at this time started to import CA machinery, namely animal traction direct planters and manual jab-planters from the Brazilian Fitarelli company (fig. 16). In Zimbabwe, machinery manufacturers were initially very skeptical about the equipment and due to the economic meltdown in the country did not invest in developing new CA equipment. Nevertheless three companies (Hastt, AG-Venture, and Zimplow) and the Institute of Agricultural Engineering (IAE) tried to make local versions of the machines between 2007 and 2009. The first production attempts were very disappointing as machines were over-engineered, often too heavy, unsuitable for no-till planting and of low quality both in design and manufacturing. Some of the prototypes were rigorously tested by farmers and their feedback was initially very negative.

In 2009, a new initiative started with Grownet Investments to make a planter based on the Fitarelli animal traction direct planter and manual jab-planter. Grownet a private company originally focusing on food processing machines, worked very closely with the International Maize and Wheat Improvement Centre (CIMMYT, www.cimmyt.org) to manufacture and improve these machines (fig. 17). The first Grownet prototype was tested in 26 farming communities and the company managed to sell 130 planters to various organizations in the first year. At this stage farmers still preferred the Brazilian machine over that of Grownet due to some dysfunctional parts of the latter machine. The operational problems highlighted by farmers and implementing partners included crushing of seed by the seed plate, seed not dropping during planting, and gears made of self-lubricating plastic failing to cope with the work load. The inclusion of researchers, farmers, and open-minded machinery manufacturers led to the development of a second direct planter prototype with an inclined seed plate (fig. 18) which now enables farmers to plant multiple crops, including groundnuts – something not possible even with the imported Brazilian planters.

Farmers initially expressed concerns about the price for direct planters but linking those farmers with a micro-finance organization in the innovation network helped to overcome the farmers’ cash flow problems. At present, farmers can access loans through the micro-credit facility, then buy a direct planter and herbicides on credit, and pay back the loan after one year.

In a somewhat parallel development, in 2010 GART developed a draft animal powered no-till planter and fertilizer distributor to replace the ripper and imported no-till planters (figs. 19 and 20). The first batch of these planters has been manufactured by a Lusaka-based company (Saro Agro-Industrial Ltd.) who also make rippers and sprayers.

It is often the case that smallholder farmers find it difficult to justify the investment in CA equipment. Given this concern a reasonable alternative that is gaining popularity in many countries in SSA is the development of custom hire services. One Zambian initiative is noteworthy. AFGRI is the Zambian John Deere dealer with its headquarters in Lusaka; it is also a registered bank and can extend and manage credit lines to its customers. A current plan (applying to four farmers as a pilot) is to supply a tractor complete with a two-tined ripper and a trailer as a service provider’s kit to sell CA ripping services to smallholder farmers (fig. 21). This will mean that service provision entrepreneurs can supply a quality service at a reasonable cost to smallholder farmers whilst making a living by doing so.

Figure 16. Fitarelli draft animal drawn no-till planter under inspection in Zimbabwe (photo courtesy of M. Listman).

Figure 17. Grownet (Zimbabwe) draft animal-drawn no-till planter (photo courtesy of C. Thierfelder).

Figure 18. Grownet inclined plate planter (photo courtesy of C. Thierfelder).
The CFU is planning a collaborative effort with AFGRI by supporting 250 such machinery packages over a five-year period. The loans (extended by AFGRI) are for three years with CFU guaranteeing the payback.

**South Africa**

The development of a manufacturing industry targeting smallholder CA farmers is still in its infancy in South Africa. Early efforts at providing CA mechanization options for this group concentrated on importing Brazilian CA equipment (Casão Junior, 2004; Fowler, 2005). These included Fitarelli manual jab planters, 1- and 2-row DAP planters and 2-row tractor-mounted machines. Jahnel (Brazil) hand-pulled sprayers and knife rollers were also included in a consignment of implements imported under an FAO technical cooperation project (TCP/SAF/2902) in 2004. There were serious doubts about some of the technical aspects of these machines that were revealed during testing by the Agricultural Research Council’s Institute of Agricultural Engineering – ARC-IAE (and discussed by Ruy Casão Junior in his 2004 report).

In 2003 there was work done at the Fort Hare University, Alice, to adapt the Zimplow Mealie Brand (www.zimplow.co.zw/mealie-brand) planter to no-till by fitting a residue cutting disc in front of the chisel-tined opener for seed and fertilizer, fig. 22 (Sims, 2003).

Since that time there has been some development in the private sector as reported by Hendrick Smith and Peter Hittersay (personal communications, 2011):

Afritrac (www.afritrac.co.za) in Gauteng province makes and sells kits to convert moldboard plows to Magoye-design DAP rippers. The company also manufacturers what they call a DAP minimum till planter with a chisel tine seed slot opener. And they produce a kit to convert planters of the now defunct SAFIM company to no-till (South African Farm Implement Manufacturers, SAFIM also owned Zimplow produced several thousand DAP implements annually. Due to political and technical changes in South Africa, the factory was closed in about 1989). The Piket company (www.piket.co.za) makes a range of tractor-mounted planters, including for no-till and they have developed a DAP planter somewhat similar to the Brazilian Knapik machine (www.knapik.com.br). The Dragon Engineering Company (www.dragonengineering.co.za) is manufacturing a manually-pulled sprayer of IAE design. The 1.5-m boom sprayer has a constant application rate independent of ground speed (figs. 23 and 24).

In conclusion it can be said that although there would seem to be immense potential for supplying equipment to the smallholder farming market in South Africa (and, indeed in other SSA countries), it seems that to date, there has not been much response from the manufacturing sector. Perhaps they are waiting to see how CA adoption rates progress before investing. In the meantime, Brazilian equipment continues to be imported (e.g. by Intrac Trading and Rovic & Leers).

The list of problems detected with the imported CA equipment ranged from the lack of English manuals for assembly and operation to inadequate seed plates and sprayer pressure control, amongst a range of others (Fowler, 2005). Given this, and also that the ARC–IAE is mandated to test and authorize farm equipment before they can be purchased by the government and associated agencies in South Africa, it would seem even more appropriate to develop the local manufacturing industry in South Africa for CA implements aimed at the local market.

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**Figures 19**. The GART, Zambia inclined plate planter for animal traction (photo courtesy of B.G. Sims).

**Figures 20**. The GART, Zambia inclined plate planter for animal traction (photo courtesy of B.G. Sims).

**Figures 21**. AFGRI (Zambia) package for entrepreneurs to offer CA ripping services to smallholder farmers (photo courtesy of B.G. Sims).

**Figure 22**. Zimplow Mealie Brand planter modified for no-till planting (photo courtesy of B.G. Sims).
POINTS OF CONTRAST BETWEEN BRAZIL AND SSA

Given the outstanding success of the Brazilian experience, and the similar interests in SSA, it seems highly likely that SSA can benefit from the lessons learnt in Brazil. To that end the following is a list of the main points of contrast between the SSA situation and that pertaining in Brazil.

- **Development and financing of CA equipment.** From the 1980s the Brazilian government has been concerned to develop and disseminate CA equipment for smallholder farmers. This public sector support has been crucial to the success of CA for this farming sector. Appropriate machinery has been developed by consortia of public sector expertise and the farming community. Finance for machinery acquisition has been made available to smallholder farmers at very advantageous rates and this has stimulated the manufacturing industry to become self-sufficient.

- **Materials supply.** There may be import duty on steel but not on imported agricultural machinery (e.g., in Kenya), which will disadvantage local manufacturers as it might be difficult for them to compete on price with their local products being made with materials subject to tax whilst imported agricultural equipment is tax free. Scrap steel may be appropriate for small-scale blacksmiths, but not larger scale manufacturers.

- **A lack of appreciation of the importance of critical part design and materials considerations:** e.g. jab planter beaks (fig. 25); tine dimensions, attack angles, and materials (use of high carbon spring steel or easier to work alternatives such as Bennox steel); vertical loading on residue cutting discs; seed metering, placement, and covering; seed plates for different crops, fertilizer placement, depth control.

- **Creation of demand.** Manufacturers are reluctant to manufacture before having firm orders; at the same time farmers complain that the technology is not in the marketplace. This highlights the importance of development projects which, as happened in Brazil, can create the demand and maintain the interests of manufacturers until effective farmer demand can take over. Other actions have been seen to be important and these include the creation of dealer networks and their role in promotion through demonstrations and field days. The public sector’s role in providing subsidies and credit in the initial stages is also important. A specific targeted subsidy system (e.g., with vouchers) that supports the use of CA equipment would help.

- **Need for training to improve the skills base.** Skills need to be improved at both the user and manufacturer levels in order for equipment to be effectively designed and properly operated and maintained. Important areas are calibration, field operation, maintenance, and business skills (especially for manufacturers and hire service providers).

- **Interactions between stakeholders.** As in the Brazilian case, the different stakeholders in the CA equipment supply chain will include the following groups which should act synergistically with mutually reinforcing policies and actions:
  - **Policy makers**
  - **R&D institutions (universities, public institutions and private manufacturers)**
  - **Extension and training services**
  - **Finance institutions**
  - **Manufacturers, importers and retailers for equipment and spare parts**
  - **Machinery hire service providers**
  - **Machinery repair services**
  - **Farmers**

The way that the stakeholders may interact is illustrated in figure 26.
Innovative ideas. Rather in contrast to Brazil, the ideas for CA have not, to date in SSA, emanated from local farmers. CA equipment manufacturers have access to new ideas which have been farmer-proven in other regions of the world. This has usually been possible through the actions of international, donor-funded programs and projects. However this should lead in time to an improved situation where local public sector R&D can play a major role in producing locally adapted technologies. When CA equipment is manufactured and in the market, a national dealer network will supply technical back up (and training) for end users (farmers and contractors) and at the same time will be kept fully up-to-date and trained by the manufacturers themselves.

Innovation networks. Traditional linear pathways of technology extension (where knowledge is generated on research stations, passed on to extension officers, which themselves pass it on to farmers hoping for adoption) are not appropriate approaches for complex systems such as CA. CA does not involve just a simple change in one production practice, but rather is a complex technology involving simultaneous change in many practices also including machinery. Multi-agent innovation networks have been proposed for complex change (Rycroft and Kash, 1994), and in Latin America these have proved to be an efficient way for the development and adoption complex agricultural change – the uptake of CA and no-tillage agriculture. Unlike the linear research and extension pathway, innovation networks make use of complex interactions between stakeholders, because the different players differ in their activities and abilities. In other words, researchers, extension agents, and farmers work together in partnership to adjust the CA system to local circumstances also involve other players as necessary, such as machinery manufacturers and other private sector stakeholders. New learning routines such as participatory research methods, multidisciplinary approaches, acceptance of information generated without experimental design, creation of a common language, and open dissemination of information have proved to facilitate such networks and lead to new, accepted and adapted machinery (Thierfelder and Wall, 2011).

Policy environment. The policy environment which can lead to a well-functioning supply chain should include reduced taxation on steel and necessary spare parts, extending credit and subsidies to farmers for machinery purchase, collaborative research between research institutions, manufacturers, input suppliers, and international donors.

GUIDELINES FOR SUCCESS IN THE DEVELOPMENT OF THE INDUSTRY IN SSA
Having seen the technological, organizational, and policy gaps between Brazil and SSA, the following are guidelines for the development of the industry in SSA which are conclusions from an analysis of the situations in the two regions:

The need for manufacturers to carry out market studies to find out who does what and how. This can be guided by the creation of innovation networks to overcome the demand vs. supply conundrum through promotion of dialogue
between manufacturers, researchers, farmers, farmers’ groups, farming organizations input, and credit suppliers and other stakeholders described above. Study tours for manufacturers can be a source of inspiration for new ideas (e.g., the FAO tour to Brazil in 2008 – www.act-africa.org/publication/LAB/index.html).

- **The importance of thorough testing of equipment before commercial batch production.** To reduce the possibility of distributing sub-optimal equipment, it is important to subject prototypes to a rigorous testing regime including farmer evaluation in real on-farm conditions. First prototypes very rarely perform as well as hoped and so modifications should be expected to be incorporated into production machines. Manufacturers need to be willing and prepared to incorporate user feedback into the next generation design. Putting unproven equipment on the market creates a bad impression and can result in rejection of future machines emanating from the same source.

- **The provision of technical training for operators, dealers, and extension staff.** Manufacturers and hire service providers will, in addition, often require training in business skills and business diversification.

- **Support for hire service providers.** Today there are increasing efforts to support hire services for tractor or animal traction owners. However, often the highest demand is for plowing and land preparation services. In order for service providers to make their living they may be obliged to offer these traditional services in order to sustain their business. Hence, the introduction of CA equipment may have to proceed in steps and there will probably be gradual shift as awareness of the CA concept and equipment will develop over time.

- **Active promotion of products.** Manufacturers need to make their products known amongst the farming community through events such as on-farm demonstrations, field days, and participation in agricultural shows. Participation in meetings of functional innovation networks is another excellent forum for further promotion and adaptation of equipment.

- **The formation of CA practitioners mutual support groups.** Would-be CA practitioners derive great help from the support of their peers. CA groups in Brazil and other South American countries continue to support their members and help to solve technical, financial, and social problems.

**CONCLUSIONS**

- Generally the CA equipment industry in SSA is in its infancy and needs careful nurturing by many stakeholders for it to achieve the required level of maturity. There is a major opportunity for international donors to support the implementation of the guidelines for success indicated.

- Although it is easier to import, there is a need for local adaptation to materials, conditions, economic circumstances, and skills levels. This requires that the relevant manufacturing infrastructure is built and assisted. In the meantime imports should continue to be supported.

- National governments aspiring to support the scaling out of CA and the growth of their indigenous manufacturing industries should pay special attention to the creation of an environment in which these goals can be achieved. Pro-smallholder and pro-CA policies are essential, as is a well-trained and focused extension service.

- In the long term, cheaper equipment tailored to local circumstances will be required by local smallholder users. Now is precisely the moment to intervene with appropriate technical support. An example is the recent training and study tour by a group of East African manufacturing technical staff to CA equipment manufacturers in Brazil and Paraguay (Sims, 2010).

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