Soyabeans and sustainable agriculture in southern Africa

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Maize is the dominant staple crop across most of southern Africa – it is so dominant in some areas that more than 80 per cent of the smallholder land area is planted with maize. Soyabean was identified as the crop with a potential to address the need for diversifying the cropping systems, which could assist in overcoming the pervading soil fertility constraints and could provide smallholder farmers with an opportunity to earn income while also addressing the nutritional security of households. An initiative was launched in the 1996/97 cropping season in Zimbabwe, to test soyabean as a potential smallholder crop. From an initial 55 farmers in the first year, soyabean production expanded rapidly to an estimated 10,000 farmers three years later. Since then, soyabean has diffused spontaneously to most smallholder farming areas in the higher rainfall zones of Zimbabwe. Thus, the initiative has assisted a large number of smallholders to grow soyabean, and exploded a long-held belief in Zimbabwe that soyabean is not a suitable crop for smallholders.

Keywords: nitrogen fixation; rhizobial inoculants; rotational benefits; soil fertility

Background

In the 1950s, soyabean became an important crop for large-scale farming in Zimbabwe. As in North America, farmers seized the opportunity to replace green manures in their rotation plans with soyabean – a valuable crop because of the dual products of vegetable oil and animal feed obtained from the grain. Soyabean rapidly displaced sunnhemp (*Crotalaria juncea* L.) from rotations on large-scale farms and became an important crop with national production up to 100,000 tonnes a year. Surprisingly, despite sporadic occurrence of soyabean on smallholder farms and promotion campaigns in the 1980s (Mabika and Mariga, 1996), it remained a minor crop in smallholder agriculture. By the 1990s it had become accepted that soyabean was not a suitable crop for smallholder farmers. This was due to both the limited extension support for smallholder soyabean production and the marginal soil and rainfall conditions in the majority of communal farming areas.

In 1995, an initiative led by the University of Zimbabwe brought together a wide range of representatives from research, extension and private sector agro-industrial organizations to discuss why soyabean was not widely grown by smallholders and to assess the possible constraints (Mpepereki *et al*., 1996a). The enthusiasm of the workshop participants led to the establishment of a Soyabean Promotion Task Force (SPTF), which went on to become the 'champion' of soyabean promotion in smallholder farming areas of Zimbabwe. The task force was comprised of members of the University of Zimbabwe (UZ), the Department of Research and Specialist Services (DR&SS), the extension service (AGRITEX), the Zimbabwe Farmers' Union, the Commercial Farmers' Union and the main company purchasing soyabean and processing it into vegetable oil and other products, Olivine Industries. Crop diversification away from maize monoculture using soyabean to improve soil fertility through biological nitrogen fixation was the main starting point from the

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scientists' perspective, but the multiple benefits of soyabeans such as cash income, household nutrition, livestock feed and increased maize yields in rotation were also important for farmers. Soyabean was also perceived to be more resistant to disease and pests than other candidate legumes for crop diversification such as the common bean (*Phaseolus vulgaris* L.) or cowpea (*Vigna unguiculata* [L.] Walp.), and given that substantial quantities of soyabean were imported, there appeared to be a ready market.

Soyabean is notoriously 'specific' in its requirement for rhizobial strains, meaning that only a few types of rhizobia are able to form nodules on soyabean roots and actively fix nitrogen. These varieties need to be inoculated with effective rhizobium strains in order to nodulate and fix nitrogen. Many other tropical legumes, notably cowpea, groundnut and common beans, are more permissive and form nodules and fix nitrogen with a wide range of rhizobia that are present in most soils. These are termed 'promiscuous' or 'naturally nodulating' legumes, and they make effective use of the inherent soil biodiversity of rhizobia indigenous to the soils (Giller, 2001). Some varieties of soyabean available in southern Africa are also 'promiscuous' and can nodulate well with indigenous rhizobia (Mpepereki *et al*., 2000).

Using the inputs donated by local private sector fertilizer and seed companies, the SPTF established demonstration plots in 11 villages with five farmers in each village (a total of 55 farmers) in the 1996/97 season. Each farmer planted an area of 0.1ha of each of four soyabean varieties (two promiscuous and two specific). Every plot included four rows without rhizobium inoculant, which dramatically demonstrated the significant positive impact of rhizobium inoculation on the growth and yield of the specific soyabean varieties. The positive results persuaded the Rockefeller Foundation to avail a small grant to facilitate monitoring of the demonstration plots that emphasized inoculation and good agronomy. These large demonstration fields were established in central locations close to rural growth points so that they could be seen by many people passing by. The demonstration plots stimulated substantial interest from farmers so that more than 1,000 farmers demanded access to inputs the next year. In the second and subsequent seasons, all of the inputs of seed, inoculum and basal fertilizer were purchased by the farmers, mostly as combined 'starter packs'. Farmers paid the transport costs when their produce was collectively delivered and sold at the factory gate. The role of the project was to assist farmers with access to inputs on time, and to link farmers to the market. Farmers were keen to grow both the specifically nodulating varieties, because of their greater yield potential as a cash crop, and the 'promiscuous' varieties that they regarded as more robust as their production does not depend on the farmers being able to obtain inoculants. Farmers also recognized the greater potential of the promiscuous varieties for fodder and soil fertility improvement, as illustrated by the dramatic residual fertility effects that often doubled the yield of maize grown in rotation (Mpepereki *et al*., 2000).

Success was achieved by implementation of existing knowledge rather than by extensive research, although applied research continued to address the problems encountered. A strong emphasis was placed on enhancement of farmers' knowledge and learning about good varieties and agronomic practices (rhizobial inoculation, seeding rates, row spacing and the need for small amounts of basal lime and P fertilizer). The SPTF arranged for printing of leaflets written for development workers (extension and NGOs) both in English and in the local language (Shona) directly for farmers, with guidance on simple agronomy, on how to handle inoculants and on pest and disease management. As soyabean was a new crop for many farmers, extension staff gave training in local processing of soyabean for a variety of uses: for milling with maize meal to give a fortified porridge for children, baking soya bread, making soya milk and as a relish. The training was given through field days and field demonstrations.

Although the initial aim was to promote the promiscuously nodulating soyabean variety 'Magoye' (Mpepereki *et al*., 2000), the programme has largely relied on assisting farmers to access seed of specifically nodulating varieties, together with carefully educating smallholder farmers on the use of rhizobial inoculants. Specifically nodulating varieties were promoted together with rhizobial inoculation (with *Bradyrhizobium japonicum*) because there was not enough seed of Magoye to meet the rapid increase in farmers' demand. Excellent soyabean varieties are available in Zimbabwe from a long-standing and continuing breeding programme of the Crop Breeding Institute (CBI) of DR&SS and a private company, Seed Co. Limited. These varieties give excellent grain yields[1] of up to 5t ha^{-1}, have medium to large white seeds that give a good oil yield and are resistant to major diseases (bacterial pustule, frogeye, etc.). Soyabean rust (*Phakapsora pachyrhizi*) first appeared in the large-scale farms and later spread to the smallholder farms, necessitating the use of fungicides and thereby increasing production costs. Another key part of the input package was a small amount of lime and P:K:S fertilizer[2] to overcome the other nutrient constraints on the highly weathered sandy granitic soils that predominate in the smallholder farming areas of Zimbabwe.

The major purchaser of soyabean in the country, Olivine Industries (a vegetable oil company), tested a wide range of samples of soyabean grain from smallholders and were so impressed with the quality that they agreed to change the grading of smallholder soyabean grain from 'D' grade to 'B' grade with an associated higher price. The smallholder grain was cleaner (less chaff and stalk) than grain produced on large-scale farms because it was hand-harvested and cleaned. Soyabean was publicized as a profitable smallholder crop by radio, television and in the popular press. Interest in soyabean production among smallholders was stimulated to the extent that villagers often travelled up to 300km to the University of Zimbabwe by bus to request extension support activities in their villages. The SPTF gave substantial assistance in marketing soyabean from communal farming areas to Harare during the first years when production was expanding rapidly. Technical staff employed by the Task Force through a small grant from the Rockefeller Foundation assisted groups of smallholders to consolidate their production at rural centres. Once a group had managed to collect together 30 tonnes of soyabean they contacted the Task Force coordination unit, who in turn phoned a haulage contractor to collect the soyabean load by truck and deliver it for sale to the oil-processing factory in Harare. From the payment for the load, the Task Force then deducted the cost of transport and arranged to repay the farmers in proportion to their contributed produce – quantities that ranged from as little as 7kg for one woman farmer to more than 3 tonnes for other wealthier farmers. Payment for the grain was then remitted to the farmers through local banks with the transport costs deducted. Although this approach helped to raise soyabean from a fledgling crop to widespread production, it could not be sustained in the long term because of the transaction costs for the bank of handling small sums of money for tens of thousands of farmers. Other marketing arrangements emerged with the SPTF providing market information, informing traders where substantial soyabean was available for purchase and informing farmers of current prices. Small to medium scale processing plants have been established at many rural service centres, allowing farmers easier access to local markets. Although it was hoped that traders would take up the role of buying smallholder production and delivering it to the central markets, the recent economic problems mean that accessing markets for their produce remains a major problem for smallholder farmers in Zimbabwe.

Rhizobial inoculants

A key to success was the existence of the inoculum production facility at the Soil Productivity Research Laboratory (SPRL), Marondera, Zimbabwe. This semi-commercial facility was established in 1964 and largely served the commercial farming sector until the expansion of smallholder soyabean production. The long history of inoculant production means that there is a solid body of expertise in inoculant production, including expert technical staff. More than 90 per cent of the inoculants produced are for soyabean and are made from pure cultures of *B. japonicum* (strains MAR 1491 and 1495, which are USDA 110 and 122, respectively). The carrier used is sterilized (heated to 120°C for 1h) bagasse impregnated with nutrients. Quality control is conducted on the mother culture and on all batches using plating for purity and counts, and plant infection tests for nodulation and nitrogen fixation. The inoculants have a shelf life of up to six months when refrigerated at 4°C. If the inoculants are kept cool, by storage in clay pots away from the sun in a shaded place in the house, they can be stored for up to four months before use by smallholders (Mabika and Mariga, 1996). During the early phase of activities of the SPTF, a grant from the International Atomic Energy Agency supported SPRL through the training of researchers, provision and maintenance of equipment for inoculant production, quality control, plant and soil sample analyses and a vehicle to improve mobility. Fridges were provided for the main inoculant distribution centres to improve the longevity of the product. Staff of Agricultural Technical and Extension Services (Agritex) were key partners in working with communities in the rural areas.

Production of inoculants increased until the collapse of commercial agriculture in 2001 to a peak of 136,000 sachets (Figure 1). Since 2000, a large amount of inoculant has been used in smallholder agriculture, with production gradually gaining ground in response to demand until 2006. In recent years, problems of intermittent electricity supply

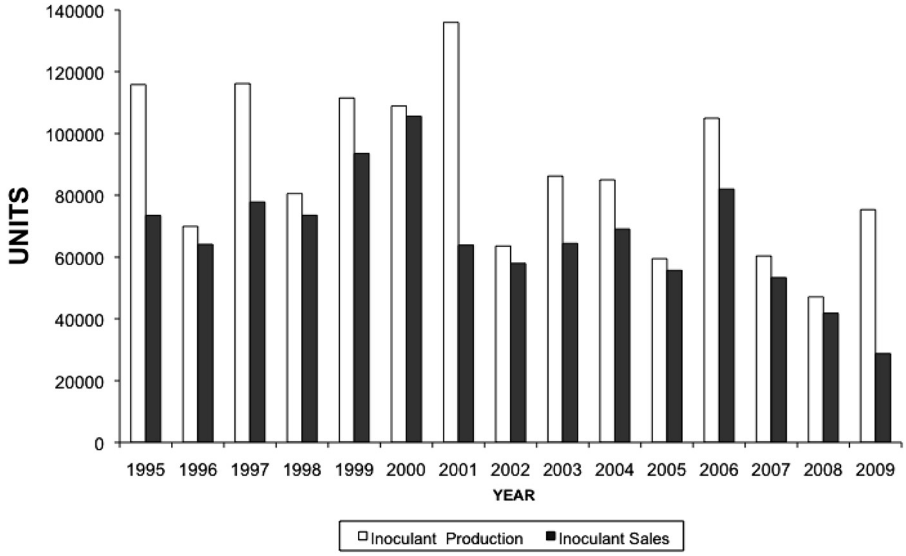

Figure 1 | Production of soyabean inoculants (indicated in number of 100g sachets) at SPRL, Marondera, Zimbabwe since 1995

have hampered production, but the committed staff have worked at night when power was available (often from 22:00h until 4:00h the following morning!) to ensure production.

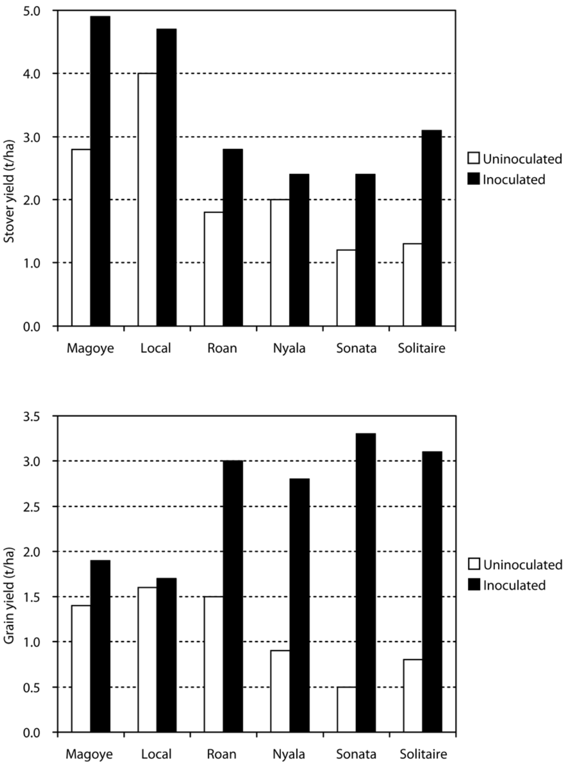

Figure 2 | Response to inoculation in a smallholder farmers' field in Zango, Hurungwe District, Zimbabwe (drawn from the data in Kasasa, 1999). See the text for further explanation

Agronomic and adaptive research

Substantial background research was conducted in parallel to the promotion campaigns to gain a better understanding of the benefits and constraints of growing soyabean on smallholder farms. Agronomic research was conducted to measure the responses in growth and yield of soyabean to rhizobial inoculation. Some responses to inoculation in farmers' fields were spectacular (Figure 2). In this experiment, yields of the specific soyabean varieties increased from 0.5–1.5t ha^{-1} to 2.8–3.3t ha^{-1}. Magoye and Local are two promiscuously nodulating varieties that have not been subjected to intensive breeding for higher yield. In this experiment both stover and grain yields of the promiscuous varieties were improved by inoculation. The specifically nodulating varieties, Roan, Nyala, Sonata and Solitaire, all produced much less stover, but with inoculation they yielded more than a tonne of extra grain compared with Magoye and Local, demonstrating the advantage of the breeding programmes of increased yield and disease resistance. The amounts of nitrogen fixed from the atmosphere by soyabean ranged from 60–130kg N ha^{-1} on smallholder farmers' fields to 160–260kg N ha^{-1} on the fertile soils of the University of Zimbabwe farm (Kasasa, 1999). Strong rotational benefits were observed by breaking the continuous cultivation of maize. In experiments under farm conditions, maize grown after maize commonly yielded only 0.5t ha^{-1}, whereas yields of maize after soyabean were more than 1.5t ha^{-1} (Kasasa *et al.*, 1999). Growing soyabean was sufficient to replace the basal N fertilizer, but in order to achieve yields of 3–4t ha^{-1} of maize, extra N fertilizer as top-dressing is required.

Soyabean does not grow well on the very coarse sandy granitic soils found in many smallholder farming areas in Zimbabwe. Pronounced gradients of soil fertility are found from relatively fertile infields close to the homesteads compared with 'outfields' that may only be 50m further away, but do not receive much in the way of inputs of manure or fertilizer (Zingore *et al*., 2007). Highly variable responses of the promiscuous variety Magoye were found across these gradients with yields of around 1.2t ha^{-1} only found on the better infield soils (Zingore *et al*., 2008). On the degraded outfields, yields were only around 0.3t ha^{-1} even when P fertilizer was added, indicating that rehabilitation of the soils using manure is needed before soyabean can yield well.

Research on rhizobia in Zimbabwe

Microbiological studies revealed that a wide range of soils in Zimbabwe contained rhizobia that were compatible with 'specific' varieties of soyabean, even where there was no history of inoculation (Mpepereki *et al*., 1996b; Musiyiwa *et al*., 2005a). A variety of serological and physiological methods showed that these indigenous isolates were highly diverse (Davis and Mpepereki, 1995; Mpepereki *et al*., 1996b; Musiyiwa *et al*., 2005a). All of the strains isolated and authenticated on soyabean were shown to be slow growers (Musiyiwa *et al*., 2005a).

Adding more than the recommended dose of the inoculant from SPRL improved the response in crop growth and nitrogen fixation on sandy soils (Chirinda *et al*., 2003). Screening and comparison of a wide variety of rhizobial isolates led to the isolation of a number of strains that performed better than the standard inoculant strains currently used (Musiyiwa *et al*., 2005b; Zengeni and Giller, 2007). This indicates that there is considerable scope to improve the quality of the rhizobial inoculants through further research on inoculant formulations and strain identification.

A question often raised by farmers is whether re-inoculation is necessary every year. Zengeni *et al*. (2003, 2006) assessed the persistence of the soyabean rhizobial inoculant strain MAR 1491 (USDA 110) in 52 soils from Guruve, Hurungwe and Goromonzi districts of Zimbabwe, which had been inoculated up to six years previously. Most probable number estimates of rhizobia in the soils showed that population sizes decreased with increasing time since the last inoculation. Rhizobial populations of up to 10^2cells g^{-1} soil were found in soils inoculated three years earlier from Guruve, while persistence in Hurungwe and Goromonzi soils was significant for soils inoculated two years earlier. The greater rhizobial persistence in Guruve soils was attributed to their higher clay (>20 per cent) and organic C (>1 per cent) compared with the sandier, less fertile soils from Hurungwe and Goromonzi. This suggests that soyabean can be grown for at least three years without the need for repeat inoculation on soils richer in clay such as those in Guruve. Application of cattle manure led to increased indigenous rhizobial numbers and greater persistence of rhizobia in the sandy soils from Goromonzi (Zengeni *et al*., 2006).

Pests and diseases

Soyabean has relatively few pests compared to other grain legumes. It is subject to attack by leaf eaters such as semi-loopers and leaf rollers. The crop can tolerate up to 30 per cent defoliation without significant yield loss, above which economic yield loss occurs and insecticides are needed. When the SPTF first introduced soyabean into the smallholder sector in 1996, the only disease of consequence was frog-eye leaf spot. The problem was solved through the use of new disease-tolerant varieties that did not need spraying of fungicides. In 1997/98 soyabean rust appeared, which required the application of expensive fungicides. The SPTF persuaded chemical companies such as Syngenta to package fungicides in 500ml bottles, thereby improving access for smallholder farmers. New rust-tolerant soyabean varieties are now available from Seed Co., (J. Tichagwa, personal communication, 2010) that do not require fungicides.

Understanding marketing problems

Before the SPTF embarked on promotion, an economic study was conducted to assess models for involvement of farmers' organizations, and to confirm the market demand for soyabean (Rusike *et al*., 2000). Once the production constraints were addressed, the farmers faced marketing problems due to the scattered production of soyabeans and the small volumes of the crop (Figure 3). This, together with poor information flows and lack of trader capital, created hurdles for

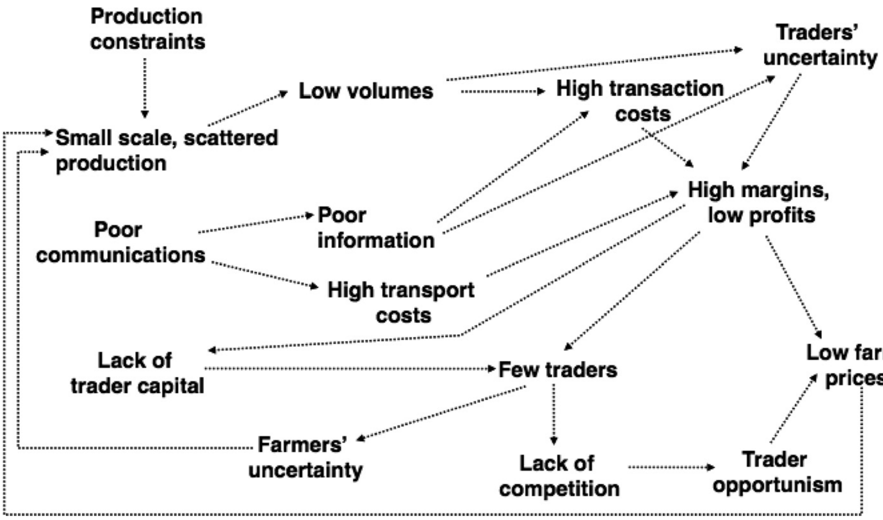

Figure 3 | Once the production constraints were addressed, the farmers faced marketing problems due to the scattered production of soyabeans (from Rusike *et al*., 2000). See the text for further explanation

traders that needed to be overcome – typical for expansion of a fledging crop. Support for marketing in the early years was key to increasing the amounts of soyabean produced in rural areas to volumes that were interesting for traders. Consolidation of produce into 30 tonne loads was necessary to bring down transport costs. Initially payments were remitted as cheques to individual producers, but the transaction costs were too large so that the banks cancelled this arrangement after one season. Further support was provided in cash payments remitted back to farmers, but this involved drivers carrying large quantities of cash around that was deemed to be too risky to continue. It was hoped that once the crop had become established, external support for marketing could be scaled down as private traders would take over the role of marketing, and early signs indicated that this role of support worked as a 'stepping stone' to functional markets. Unfortunately, the collapse of the economy in Zimbabwe has impeded this trade.

Analysing the success

The initial impetus for this initiative came from a group of researchers and extension workers with a strong drive to see the application of their knowledge to improve the livelihoods of smallholder farmers. From a relatively small-scale demonstration exercise, the interest generated in the smallholder farming communities led to rapid expansion of the crop. The approach focused on using best practice and ensuring that all components were available – seed, inoculants, basal fertilizer and lime – coupled with strong extension in management practice and local processing. The SPTF, which brought together researchers and government extension workers with farmer organizations, input suppliers and purchasing companies, was instrumental in promoting the crop. Local processing provided a domestic use for soyabean that has clear nutritional benefits for the households, and direct consumption stimulated substantial interest. But the local market for soyabean was readily satisfied, and further expansion of the crop was dependent on assisting farmers in marketing their produce. Key elements for success included the strong commitment of the SPTF to demonstrate the tangible multiple benefits of soyabean to farmers (cash income, food and nutrition for humans and livestock and residual soil fertility) and the timely engagement of relevant stakeholders at each stage of the value chain. In many ways the approach used is similar to the much-lauded 'innovation systems' approach that has gained widespread support in the research and development community in Africa in recent years. The underlying reason that soyabean took hold in smallholder farming relied on the development of both a strong technology and a strong institutional setting (Figure 4). With the high yields of soyabean due to good varieties, inoculum and agronomy, the crop was economically attractive for farmers. Only when there was sufficient volume of production was the crop economically valuable for traders.

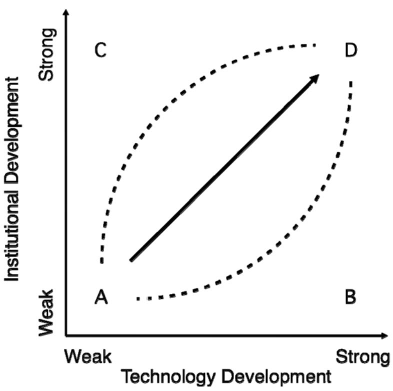

Figure 4 | The need for both strong technology development and strong institutions (taken in a broad sense to include extension, input and output markets). From a starting point, point A, if attention is given only to technology development, a strong fledgling technology is likely to fail due to the lack of functioning institutions (point B). If only attention is given to developing the institutional environment, a technology vacuum prevents overall development (point C). Only when a strong technology is embedded in a strong institutional environment (point D) will it take hold and expand. From Giller (2001), adapted from Dorward *et al*. (1998)

The NGO community became major partners in the promotion of soyabeans among smallholders. In Matabeleland, ORAO and OXFAM were distributing soyabean as part of their drought relief and engaged the SPTF as technical partners to train farmers and women in processing soyabeans for home consumption. In wetter areas of Mashonaland, AFRICARE and World Vision sought to diversify the cropping systems of target smallholder communities with the SPTF providing training and advisory services for soyabean production. The Lutheran World Federation also worked with the SPTF to introduce soyabean in Midlands and Masvingo provinces. These partnerships with NGO and private sector actors allowed the SPTF to reach out to all of the eight rural provinces of Zimbabwe. Many other NGOs have recognized the benefits of soyabean and have continued the promotion of the crop, but further investment is needed to promote local agro-dealers to facilitate access to inputs of seed, inoculum and fertilizer and to act as intermediaries in purchasing the crop and selling to the large market for processing.

Early adopters had a clear advantage in selling seed locally and profited the most from the introduction of soyabean. Gains were proportional to the area planted with soyabean, so that better-resourced farmers who had the land and labour (including animal traction) undoubtedly benefited more than poorer farmers. The small amounts of grain ($<$10kg) marketed by some individual farmers indicated that poorer farmers were also participating actively. In terms of domestic consumption and nutritional benefits to the households, it is likely that introduction of soyabean had more immediate direct benefits for the poorer farmers.

Small to medium enterprises (SMEs) were established using soyabean as the raw material. In Musana Communal Lands near Bindura, farmers put up a factory building and commissioned soya oil presses, grinders and roasters and blenders for making soya-based feeds. In Mount Darwin, farmers set up a soy-milk processing plant that supplied both ‘fresh’ and ‘sour’ milk to local schools and community. In a discussion with women from Kazangarare, in Hurungwe district in 1999, a total of 17 supermarket grocery items were identified that could be substituted with soyabean-based products. These ranged from milk, butter, coffee, cooking oil, cakes, bread and various relishes. Training of women in home processing and consumption of soyabean had the greatest stimulatory effect on adoption. Indeed, many HIV/AIDS infected people in the promotion areas underwent remarkable improvements in their health conditions when they were put on soya-based diets. The popularization of soyabean as a health food has gone some way to ease the plight of the poor who cannot afford the expensive supplements prescribed for AIDS patients.

Environmental benefits

The rotational benefits often lead to a doubling of maize yields in soils where maize has been grown for many years. These benefits are due to breaking the continuous cultivation of maize and the addition of nitrogen to the soil from the residues of soyabean that gives a small but significant improvement in soil fertility. The first certified agricultural methodology for reducing carbon dioxide (CO_2) emissions under the United Nations Clean Development Mechanism issued in 2008 was rotation with soyabean. The reductions in C emissions are largely due to substitution of nitrogen fertilizer in soyabean–maize rotations, which is highly relevant in North America. It is unlikely that smallholder farmers in Africa can be easily registered under such a scheme, as they currently use little N fertilizer.

Current status and future prospects

Soyabean has become established as a smallholder crop in Zimbabwe. Whereas in the 1990s soyabean was grown on small plots in just a few rural areas, it is now widespread throughout the higher rainfall areas of Zimbabwe. Detailed surveys that quantify soyabean production in the smallholder sector and its contribution to rural livelihoods are lacking. Given that at least 10,000 farmers were growing soyabean in 2001, a conservative estimate would be tens of thousands, and the true number could be well over 100,000 farmers. A significant statistic is the fact that smallholders contributed only 415 tonnes to the formal soyabean market in 1995, just one year prior to the promotion, but this leaped to 10,900 tonnes by 2001 (Ministry of Lands and Agriculture, 2001). Estimated mean yields per hectare also increased from 495 to 1,014kg ha^{-1} over the same period. This success owes much to the commitment of the SPTF to championing the production of soyabean in the smallholder farming sector.

Given the collapse of the commercial farming sector in Zimbabwe and the massive demand for soyabean for the national food and animal feed market (current processing capacity in Harare is estimated to be around 400,000t $year^{-1}$) there is an insatiable demand for the crop. Yet the total national production in the past season was estimated at only 20–30,000 tonnes due to collapse of the commercial farming sector and the problems smallholders face in marketing. Soyabean is a particularly valuable crop because of the multiple products – for food, vegetable oil and animal feed – obtained from the grain. Much of the pressed soy cake is used in the rapidly expanding chicken and pig industries. As Zimbabwe is a landlocked country, the costs of importation make local production economically competitive. A further potential market opportunity for Zimbabwe and other countries of southern Africa (excepting South Africa) is that all soyabean varieties used are from classical breeding programmes and can thus be marketed as free of genetic modification. All these factors indicate that there is a great potential for expansion of soyabean production in the smallholder sector.

A new initiative entitled ‘Putting Nitrogen Fixation to Work for Smallholder Farmers in Africa’ (www.N2Africa.org) aims to replicate this success in eight countries of sub-Saharan Africa. This project aims to assist smallholder farmers to access the best available technologies for production of the major grain legumes – not only soyabean – so that the benefits from symbiotic nitrogen fixation can help to build profitable and sustainable futures for smallholder farmers.

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Notes

1. Grain yields of up to 6t ha^{-1} have been recorded in replicated plots in Zimbabwe by Seed Co., with one exceptional yield in a long growing season of around 7t ha^{-1} (J. Tichagwa, personal communication 2010).
2. Just 0.5t ha^{-1} of Dolomitic lime was recommended to supply calcium and magnesium and a small amount of basal fertilizer (about 10kg P ha^{-1}, 12kg K ha^{-1} and 12kg S ha^{-1}).

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