Enhancing common bean productivity and production in Sub-Saharan Africa

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Summary

When the TL II was initiated in 2007, breeding for drought tolerance in common bean had received only sporadic attention in East and Southern Africa. Under the TL I project, drought gained prominence and moved into the research agenda. Factors influencing the adoption of improved varieties of bean were found to be multiple and context-specific, but can be broadly categorized as technological attributes, household characteristics, and contextual factors. Across countries, adoption of bean varieties was higher in agro-ecological zones with moderate and high rainfall areas, but low in semi-arid areas. Improved varieties were preferred in regions with heavy and frequent rainfalls, probably, due to their disease resistance properties. This analysis was based on the adoption of varieties released between 2003 and 2008. The varieties released thereafter (2009-2013) though drought tolerant were not diffused to the communities then. Nurseries were distributed to the TL II participating countries, Malawi, Zimbabwe, Uganda, Kenya, and Tanzania. These nurseries consisted of materials segregating for drought tolerance and fixed lines by combining the drought tolerance with other traits, such as high mineral (iron and zinc) content, low soil fertility tolerance, pest resistance (bruchids and bean stem maggot; BSM), and disease resistance (common bacterial blight; CBB). Selections were made and materials were provided at different stages of the breeding pipeline. As many as 39 lines (2007-2014) were released for drought areas while others are in the last stages of the development pipeline. Most of the released lines had the yield advantage of nearly 10-40% over the commercial varieties in on-farm trials with additional traits of resistance to key pests and diseases and/or high grain Fe and Zn content. Effort was made to deliberately develop beans with drought tolerant germplasm with an added trait of high Fe and Zn content. The small-seeded Mesoamerican bush bean lines emerging from the breeding program in Colombia have 80% higher iron and drought resistance that was equal to or superior to the tolerant check. The improvement of mineral levels in climbing bean materials had been successful and had an added advantage of increased productivity per unit area.

High temperatures were shown to aggravate the stress imposed by drought, and combinations of stress tolerance would be necessary in the near future. While 20°C night temperature is normally considered to be a limitation for common bean, the breeding lines combining common bean with *P. coccineus* and *P. acutifolius* presented an excellent pollen formation and a good pod set at 22°C night temperatures. Some pod set is maintained at 25°C nights. Genetic diversity was fine-tuned and genetic analysis was applied to a number of national bean collections. In terms of genomic resources, the populations of recombinant inbred lines (RILs) were being developed for drought, yield, drought traits, and associated biotic constraints. High-quality maps were developed for several populations. Physiological studies, directed for understanding drought tolerance and yield processes *per se*, revealed the underlying mechanisms of drought resistance, and suggested how these could be applied within the breeding programs. While it was a challenge to find a consistent Quantitative Trait Loci (QTL) for yield under drought, focusing on the trait of Pod Harvest Index (PHI) was more promising, and some of the QTL candidates were being validated through additional phenotyping. Other factors limited the expression

of drought tolerance on farm. In particular, soil factors and poor soil fertility did not permit the adequate plant development for crops to sustain additional physiological stress imposed by drought. The establishment of SNP platform was the single most long-term result of the TL I project, since it would continue as the marker of choice for mainstream breeding programs with a modest budget in the foreseeable future. SNP markers for major disease resistance genes (BCMNV, CBB, bruchids, and ALS) were developed and markers of other classes (SCARS and SSRs) were converted to a SNP platform for ready to use purpose. Degree and technician training was undertaken with four PhD degrees and six MSc degrees granted. High priority was placed on the technicians given their role in the daily execution of field trials. Two seed delivery models were proved to be effective. One was small and low-cost seed packets within the easy reach of poor farmers (female) and the other was community exchange system of a kilo seed for a kilo harvested grain (barter system). Quality Declared Seed (QDS) was approved as a viable seed class for beans in Uganda, Tanzania, and Ethiopia which opened numerous opportunities for community-based seed systems.

Background

Phase II activities of the TL II project continued in five of the anchor countries, Kenya, Ethiopia, Tanzania, Malawi and Zimbabwe. Uganda was the newest entrant with activities initiated in August, 2012. In addition, efforts were extended to the Kagera and Kigoma regions of Tanzania and southern Tanzania. Activities were coordinated under the Pan-Africa Bean Research Alliance (PABRA) umbrella and results were presented in two steering committees Southern Africa Bean Research Network (SABRN) and East and Central Africa Bean Research Network (ECABREN) of PABRA. The main objective was to share results and products from TL II activities with other members of PABRA countries. TL II project activities were, hence, integrated into the PABRA framework to facilitate a wider dissemination and learning from the experiences. Among the anchor countries, country strategies were developed by laying out the seed road maps for each of the participating countries and defining the agroecologies for which the improved varieties were being developed and disseminated.

Description of TL II countries

Ethiopia: Ethiopia is the largest exporter of common bean in Africa, earning about $66 million in 2010. The export volume rose to about 77,000 tons in 2010, compared to 49,000 tons ($ 17 million) in 2006. Area under bean cultivation increased by 34.3% from 181,600 ha (2003) to 244,012 (2010), and 350,000 by 2012 ha. Production increased three-fold from 117,750 tons (2003) to 362,890 tons (2010), and the average yield more than the doubled from 0.615 tons/ha to 1.487 tons/ha. In terms of coverage, the common bean was widely grown across the country with highest concentrations in Oromia region, where more than 50% of the common bean grain products were produced for the export market. Central Rift Valley (CRV) that consists of parts of East Shewa, Arsi, West Arsi, and West and East Hararghe highlands belong to the Oromia region. The CRV areas were considered as the major “common bean belt” and were specialized in white pea beans, which was mainly produced for the export market. West and East Hararghe highlands produced beans that were intercropped with sorghum, maize, and chat. The Southern (SNNP) region included Sidama, Wolayta, and Gemu Gofa zones as the second production area though most of the production was for household consumption. Various administrative zones in the north and north-central, south-western, western, and north-western part of Ethiopia were also producing bean. Other regions, rather than CRV, mostly produced colored beans of various sizes that were used as food for local markets. They were also exported to the neighboring countries, like Kenya and Somalia, mostly through informal channels.

Kenya: Kenya is the seventh highest producer of dry beans in Africa. Dry bean contributed KES 13.18 billion to the national economy and are a source of dietary protein, especially for the rural and urban poor. They are the centerpiece for daily diet for many Kenyans. On an average, 401,880 tons of beans are consumed annually (Economic Review of Agriculture – 2009). In Kenya, beans are grown in a wide range of agro-ecological zones ranging from medium (800 m) to high altitude areas (2000 m above sea level; MASL) of Central, Rift Valley, Coast, Western, Nyanza, and Eastern provinces (Wortmann and Allen, 1994). They are mainly grown by smallholder farmers in high and medium rainfall areas. However in semi-arid lands, it is grown with additional rainwater harvesting. Beans are marginally grown in agro-ecological zone-5 due to the prevailing heat scenario. Bean research in Kenya is conducted by the Kenya Agricultural Research Institute (KARI), which works closely with CIAT in five of its centers Katumani, Thika (1500 MASL, Humic nitisols), Kabete (1800 MASL, Humic nitisols), Kakamega (1600 MASL, Dystric mollic nitisols), Embu, and Kitale. A substantial amount of the research on beans is also conducted by advanced universities, namely Kabete, Nairobi, Moi, and Egerton Universities.

Malawi: In 2012, common bean area was estimated at 243,700 ha and production at 127,464 tons. In the major bean growing areas, 74% to 90% of farmers grow beans as their main cash crop, and beans are second only to maize as a food crop (Scott and Maideni, 1998). About 35% of the production is marketed, contributing about 25% of total household income for over 68% of the households who sell their surplus (Kalyebara et al. 2005). Both production and demand for beans in Malawi are trending upwards, with an annual growth rate of 4% between 2002 and 2011 in production. Area under common bean increased tremendously in 2009 (51,844 ha) in response to the government mobilization of farmers to include legumes in their cropping system. This happened when some NGOs intervened with the provision of seeds as inputs to farmers and additional hectares under irrigation system. Projections for 2014-2020 suggest a continued growth in both national demand and production of beans. Common bean experiences high fluctuations in production associated with high variability in rainfall conditions, often resulting in excess demand. There is an indication of demand for improved high yielding common bean varieties to stabilize the yields. The bean improvement program in the Department of Agricultural Research Service (DARS) started developing bean varieties in 1996. This research is conducted in collaboration with CIAT, and through PABRA, and other NARS partners, such as the University of Malawi–Bunda College of Agriculture play key roles. So far, a total of 30 bean varieties have been released in Malawi, with 18 of them by DARS and 12 by the University of Malawi-Bunda College of Agriculture. The bean crop is grown across the country in three main agro-ecologies that are categorized according to altitude as high, medium, and low. Subhumid, > 1500 MASL, and >400 mm of unimodal rainfall and acidic soils covering the districts of Chitipa, Livingstonia, Viphya, and Dedza are categorized as high agroecology with an estimated area of 124,941 ha. Sub humid, 1000-1500 MASL, and >400 mm of unimodal rainfall covering the districts of Mzimba, Lilongwe, Dowa, Nmawera, and Shire are categorized as medium agroecology with an estimated area of 114, 198 ha. Low agroecology is categorized with <1000 MASL and unimodal rainfall covering 26,158 ha in the Lake basin and Phalombe. Beans are not well adapted to the lake shore areas and the Shire valley resulting in low cultivation.

Tanzania: Common bean is the leading leguminous crop accounting for 78% of land under legumes in Tanzania. It is estimated that over 75% of rural households in Tanzania depend on beans for daily subsistence (Xavery et al. 2006; Kalyebara and Buruchara 2008). The crop residues are used as livestock feed and source of organic matter to enhance the soil fertility. About 1.25 million hectares of bean are planted each year with the main production areas located in the Arusha region in the north, the great lakes region in the west and the Southern Highlands. Tanzania is the largest common bean producer in sub-Saharan Africa and the world's 7^{th} largest common bean producer. The area occupied by common bean is second to maize accounting for nearly 11% of the total cultivated land. Total production is approximately 933,000 tons of production each year while national demand is estimated at 724,017 tons making Tanzania the net exporter of common bean. Both production and national demand for common bean have been trending upwards. The area under bean production has been increasing at an average rate of 11% per annum over the last decade. On the other hand, yield growth rates have been modest in absolute terms, increasing from 0.48 ton/ha in 1970 to 0.77 ton in 2001-2007 (Katungi et al. 2010). Greater improvements in productivity are expected between 2014 and 2020. The Agricultural Research System in Tanzania is divided into seven agro-ecological zones, Eastern, Northern, Western, Lake, Southern, Southern Highlands, and Central Zones. Each of the zones has a specific mandate crop depending on its zone priorities. However, during the colonial period, the main emphasis was on cash crops. Research on the main food crops, including beans, gained importance after independence. The Bean Research Program of Tanzania was formally initiated in 1977 though the research work on beans began as early as 1965. Bean research in Tanzania has been conducted in close collaboration with the International Center for Tropical Agriculture (CIAT), which started as early as 1973 (Hillock et al. 2006).

Uganda: Common bean is the number one legume grown and consumed throughout Uganda. It is a major source of food and income for the rural smallholder farmers. The crop is the most important source of protein for over 30 million people in Uganda and provides up to 25% of the total calories and 45% of the total human dietary protein (Pachico 1993; Mauyo et al. 2007). For those in need of immediate food remedies, like in war-ravaged areas like northern Uganda, parts of DRC, and southern Sudan, common bean is the first crop of choice as the early maturing varieties take a short time (60-80 days) to grow. Beans are produced in all the major agro-ecological regions of Uganda; however, the types of bean grown do vary from one region to another depending on the preferences of the farmers and consumers of that region. To a large extent, all the regions of Uganda grow the red mottled bean varieties, which are highly marketable within and outside the country borders. Thus, they have been given emphasis in the breeding program. Common bean production in Uganda has been trending upwards with the area expansion as the main source of growth. Between 2001 and 2010, area under common bean increased by 28.7% resulting in an increase of 7.7% in bean supply as the yield got stagnated due to a range of biophysical constraints (soil fertility, drought, pests and diseases) (Kimani et al. 2006). Area under common bean is projected to continue its growth at a high rate in the next few years in response to the growing population and increasing bean trade from the country. The national bean program is one of the programs of the National Crops Resources Research Institute (NaCRRI) of the National Agricultural Research Organization (NARO) that has several research and trial testing sites distributed in the major agro-ecological regions of the country. Collaborative research with CIAT has been conducted in the country for more than 20 years now.

Zimbabwe: Common bean is a well-known protein source which is consumed directly by the major populace in Zimbabwe. As bean is rich in micronutrients (Zn and Fe), it suits malnourished children, pregnant women, and young children. Common bean is among the top five crops that provide a high income to the farmers and traders. Bean trade is not limited within the country but is expanded to South Africa, Malawi, Zambia, Mozambique and Tanzania. The level of genetic diversity is also high with *P. coccineus* cultivated by some farmers for domestic consumption and to trade amongst the farmers within short distances. Landraces are also common among farming communities and at times limit the productivity of these farming areas. Both public and private breeding programs contribute to bean research in Zimbabwe. Universities through student projects also contribute to the research work in Zimbabwe. The national breeding program under the auspices of the Crop Breeding Institute is housed at DR&SS in Harare. The private seed companies are located in Harare while their research sites are spread all over the bean growing areas. Seed houses, like Seed Co., PANNAR Seeds, Agriseeds, Sandbrite, and Progene Seeds are actively involved in either breeding or marketing of the bean products. Zaka Seeds, a community-based company, has also joined hands in popularizing the improved new varieties since 2011.

Key achievements

Adoption and impacts

Early adoption and interventions in the seed market

After phase I, emphasis for social sciences research was put on anchor countries, Ethiopia, Tanzania, and Uganda and studies were conducted in these countries. Kenya, which was the focal country in phase I was replaced by Uganda. In phase II, objective 1 research activities were carried out to evaluate the early adoption and associated interventions in the seed markets. In Southern Tanzania, the study covered 750 households selected across 75 villages to represent the region. Market value chains for common bean were also included in the analysis for southern Tanzania, in order to provide lessons on the market-related challenges and opportunities for enhancing its new variety uptake and improvements. In Ethiopia, the data were derived from a survey of 600 households selected from 16 districts (Woredas) across three agro-ecological zones that were important for bean production. In Uganda, analysis was based on a national representative sample of 1800 households surveyed in 2012 under the 'Diffusion of Improved Varieties in Sub-Saharan Africa (DIVA)' project funded by Bill & Melinda Gates Foundation and coordinated by SPIA. Survey tools, used in Southern Tanzania and Ethiopia, were designed and discussed with NARS in respective participating countries through two-day workshops attended by NARS scientists and enumerators in each country. In both countries, studies were implemented with additional resources leveraged through the PABRA.

The baseline study also indicated that the few varieties released in 1970s-1980s were dominating the bean area while new varieties released five years after the commencement of the project occupied between 1-10% of the bean area (Katungi et al. 2010). Low adoption was attributed to the poor accessibility of new variety seeds (Xavery et al. 2005; Chirwa et al., unpublished; Assefa et al. 2006).

Learning from phase II

In phase II, research under objective 1 contributed to the learning about the adoption of varieties that were developed under the project and those that were released five years before the project, but were still on the shelf, and the potential seed channels that supported adoption. More varieties have moved to the farming communities. Compared to the adoption in 2008, when two bean varieties released during 2003-2005 in Ethiopia were grown in the communities, at present seven varieties that were released in the same period, are being grown due to the enhanced capacity in seed delivery. Overall, out of 48 varieties, released between 2003 and 2012 in Ethiopia, 16 varieties were taken up by farmers to diffuse them in the farming communities. Varieties released during 2008-2011 accounted for 4.4% of the bean area in the study regions. Varieties that dominated the bean area in 2008 were being replaced by the new ones. For example, baseline studies conducted in 2008 indicated that Red Wolaita, released in 1970s-1980s, was a dominant variety in the southern region of Ethiopia occupying 69.5% of bean area while Nasir another cooking bean variety occupied less than 2% of the bean area during the same period (Katungi et al. 2010). Follow up adoption study, conducted in 2012, showed that Nasir is planted on 89% of the bean area in the southern region, dethroning Red Wolaita which accounted for 14.8% of the area (unpublished reports). In Southern Highlands of Tanzania, about 23.4% of the households adopted the bean varieties that were released between 2002 and 2010. Of these, 15% replaced their traditional varieties while 8.4% have adopted partially (new varieties alongside traditional varieties grown before the project). In terms of area, varieties released since 2002 were grown on 18.3% of the bean area as the varieties between 1970 and 2000 dominated 46.58% of the area.

Despite impressive achievements, there are still some barriers that slow down the diffusion of new varieties that deserve considerable attention in the next breeding and seed delivery strategies. Attributes of the physical environment are major determinants of decision on whether or not to grow such improved varieties. There is a higher diffusion of improved varieties in agro-ecological zones with moderate to high rainfall, but low in semi-arid areas. This is probably due to the disease resistance properties of the improved bean varieties released (2003-2008), which dominated the study. Varieties, with enhanced drought tolerance ability released between 2009 and 2012, should be prioritized in the dissemination efforts to reach farmers of the semi-arid zones.

Poor accessibility to seed of the improved varieties remains an important constraint for the adoption of improved legume varieties. Larger private sector companies continue to under-invest in the legume seed systems, which shows a sign of market failure and points towards the need for stronger public support for legume seed production at least in the early stage until demand is high enough to attract private sector seed companies. Majority of the farmers access the new seed varieties at the time of adoption from informal sources that are built around the social networks or grain markets, which, in turn depend on adoption levels achieved.

Adoption studies also revealed that factors that influenced the learning about the existence of the improved varieties, their benefits, and the management practices were the significant determinants of the adoption of improved bean varieties. This was demonstrated by positive and significant relationship between adoption of new varieties with extension contact, education levels, membership in farmer associations, and context variable (ie, being in villages connected by better quality roads, better mobile phone coverage, and village population density) that reduced the cost of information acquisition. In Uganda, the poor bean-producing households were found to be less likely to adopt the new bean varieties, indicating potentially important poverty reductions that could occur if the poor producers can gain better access to the new bean technologies.

The competitiveness of new bean varieties on the market is important for their adoption at farm-level in most parts of the project area. Bean varieties, with highly demanded traits in the market, were favored by some producers over the new ones, which were not popular in the market even when the new varieties performed well in terms of the yields. New varieties being developed to replace the old ones (released in 1980-1990s), that are declining in productivity due to climate change should be able to outperform the existing ones in terms of market preferences. Social research was also necessary to generate new knowledge on the consumption patterns and market outlook in order to meet the targets of the breeding program.

Productivity of improved varieties

The preliminary estimates of productivity in Ethiopia and southern Tanzania also indicated about the positive and significant yields from the newly improved varieties. Improved common beans varieties, released in 2002-2010, gave an average yield of 437 kg ha^{-1} (higher than the landraces) in southern Tanzania and over 200 kg ha^{-1} in Ethiopia, where the varieties used as local checks were the improved varieties released in 1974-1990. However, the yield gained from the improved bean varieties are conditioned to crop management. Farmers using good management practices obtained higher yields compared to the non-practitioners. This means improving the agronomy and using inputs to manage the soil fertility in legume production could help in contributing significantly to the yield growth, thus, closing the yield gap. The challenge is that crop management practices, responsive to the climate variability, soils, and local socio-economic conditions, tend to be site-specific and require well-planned and targeted dissemination strategies.

Crop improvement

Genetics and Physiology of drought tolerance

Project work at CIAT headquarters, Colombia involved both breeding in support of the program in Africa, and physiology work as a complement to the breeding program. At the outset of the TL II project, substantial progress was made to improve the drought resistance of the small seeded Mesoamerican beans. This was carried out in part under a BMZ-Germany funded project in which Nicaragua, Rwanda, and Malawi participated. In 2009 and 2010, small red-seeded varieties with drought resistance capability were formally released from that effort in Rwanda and Nicaragua. The research works in TL II project were designed on the previous experiences, and it sought to extend its reach to the medium-to-large seeded beans of the Andean gene pool. Mechanisms being investigated, involve both root to access soil moisture, particularly from the deeper soil layers, and remobilization of photosynthate to grain (partitioning of biomass).

Studies on mechanisms of drought resistance: In phase I, a set of 36 elite lines were evaluated in the drought season of June to September in CIAT, Colombia. The variability in annual rainfall created different patterns of drought stress, which was experienced in the three-year period ie, light intermittent drought (2008), terminal drought (2009), and low rainfall extending to most of the vegetative period (2010). The crop response was different to each drought pattern and the ranking of genotypes changed under different drought patterns. Light intermittent drought in 2008 resulted in an acceptable yield from the drought-selected lines, although there were wide differences in relation to the commercial check. Under terminal drought (2009), early materials ranked relatively better, as expected. These included SER 125 (released in Nicaragua), SER 16 (released in Rwanda), and G40001 (*Phaseolus acutifolius*). SER 78 was the highest yielding variety in 2009 and was mediocre in other years. In 2010, occasional light rainfall during the vegetative phase of the crop resulted in more modest shoot development and the change in the ranking of some lines. The genotypes SXB 412 and SXB 405, developed for Brazil, ranked relatively better with adaptation to poor soil, whereas the early materials were mid-to-low in ranking. Such patterns of drought stress, due to low rainfall during the vegetative growth of the crop, might have stimulated the earlier root growth in some genotypes while the early materials could not benefit from this condition. On the other hand, genotypes SXB 412 in 2008 and SXB 405 in 2009 were mediocre under intermittent and terminal drought conditions. A few entries, particularly the black-seeded lines, were excellent under all drought patterns when provided with adequate soil moisture through irrigation. SEN 56 stood out among all these genotypes. In spite of being relatively early to mature, it was the best line in 2010 while other early materials slipped in ranking. NCB 226 genotype was especially noteworthy since it was also one of the best lines under combined stress of low phosphorus (P) and drought (Figure 3). Both lines had excellent remobilization of photosynthates to grain. This trait, shared with SER 118, was found to be good in 2010 and had performed well under low soil fertility conditions. These observations bode well for the potential of the developing varieties of the common bean with multiple stress resistance. However, these results also indicated about the complexity of the interactions of stress on the crops. Plant responses to different types of stress may well be independent traits, and if this is the case it appears that they can be recombined in lines, such as NCB 226. Correlations between yield and plant attributes under irrigated and rainfed conditions of the 36 lines varied from year to year probably reflecting the varied rainfall patterns of each year (Table 26). For example, days to flowering varied from -0.28 to -0.59 and leaf area index varied from -0.09 to 0.44 in rainfed trials. However, pod harvest index (PHI) or the percentage of pod biomass represented by seed weight was consistently positive, and this trait should be considered as a selection criterion for breeding.

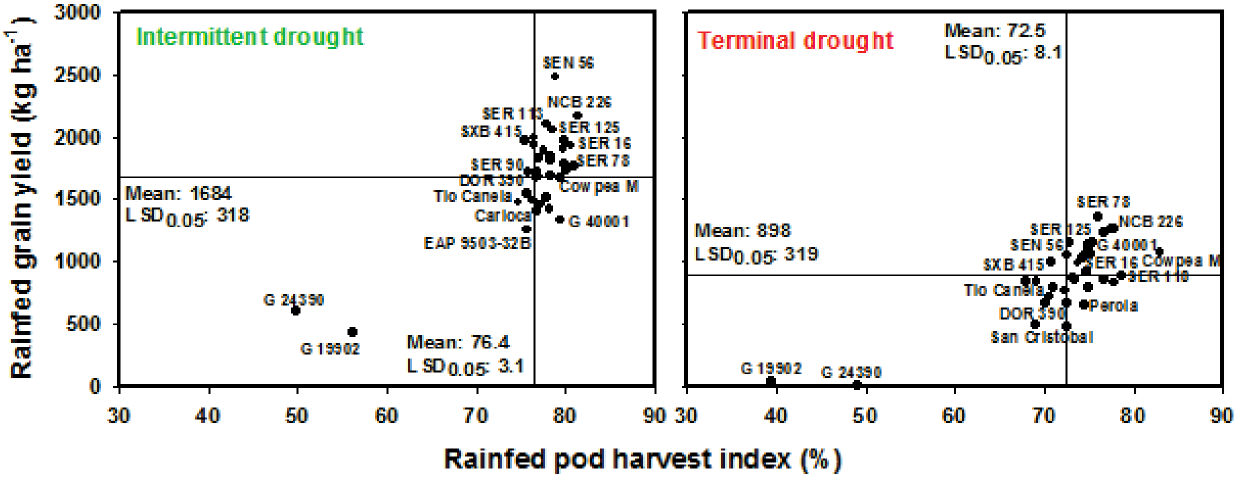

Figure 3. The relationship between pod harvest index and seed yields in lines planted under drought stress conditions.

Table 26. Correlation (r) between grain yield and plant traits.

Plant traits	Irrigated	Intermittent	Irrigated	Terminal
Leaf area index (m^2/m^2)	0.60***	0.34***	-0.25**	0.44***
Canopy temperature depression (°C)	0.29***	0.23***	0.12	0.24**
Canopy biomass (kg ha^{-1})	0.52***	0.21**	-0.01	0.59***
Pod partitioning index (%)	0.11	0.38***	0.21*	0.56***
Harvest index (%)	0.19**	0.46***	0.28**	0.61***
Pod harvest index (%)	0.64***	0.56***	0.64***	0.61***
Stem biomass reduction (%)	-0.22***	0.07	0.17	-0.03
Days to flowering	-0.12	-0.34***	-0.38***	-0.59***
Days to maturity	-0.13*	-0.20**	-0.46***	-0.60***
100 seed weight (g)	0.59***	0.60***	0.62***	0.52***
Seed CID (‰)			-0.14	0.45***

* significant at 0.05 probability level
** significant at 0.01 probability level
*** significant at 0.001 probability level

Rao et al. (2013)

In phase II, genetic diversity was fine-tuned and genetic analysis was applied to a number of national beans collections. In terms of genomic resources, populations of recombinant inbred lines (RILs) were developed for drought, yield, drought traits, and associated biotic constraints. High-quality maps have been developed for many of these populations, which will be available for the public to evaluate for traits for which the parents are contrasting to identify QTL. In addition, physiological studies directed at the understanding of drought tolerance and yield processes *per se* revealed the underlying mechanisms of drought resistance capability, and suggested how these could be applied within the breeding programs. Some of these mechanisms include remobilization of photosynthates from stems to pods and to seed enhancing the movement of photosynthate from pod walls to grain. Tolerant lines also displayed a pattern of traits that is consistent with transpiration efficiency. While it was a challenge to find a consistent QTL for yield under drought stress, the focus on the trait of Pod Harvest Index (PHI) was more promising, and some candidate QTL are being validated through additional phenotyping (Table 26). Research work supported by TL II confirmed the selection for PHI under drought conditions would have a beneficial effect on yield potential, ie, shoot biomass (g plant^{-1}) r =0.31, pod partitioning index (PPI) (%) r = 0.87, and PHI (%) r =0.58.

However, it soon became evident that other factors limited the expression of drought tolerance on farm. In particular, soil factors and especially poor soil fertility did not permit adequate plant development for the crop to sustain the additional physiological stress imposed by drought (Figure 4). A paper presented at the 4th InterDrought meeting in September 2013 at Perth, Australia highlighted this problem. The text of that paper was accepted for publication in 2014 in Crop and Pasture Science.

Applying physiological principles to breeding beans of the Andean gene pool

Historically, progress in improving the Andean beans tends to be slower than Mesoamerican beans. On one hand, Andean grains are larger with very specific criteria of size, shape, and color making the recovering of the commercial grain more difficult in segregating populations. This makes introgression of novel genes more laborious. On the other hand, most Andean-type varieties are of determinate growth habit, which limits the yield potential to some extent. In spite of the limitation, our first efforts in improving Andean beans for drought resistance were quite positive. Selected lines expressed excellent grain filling under stress, suggesting an enhanced remobilization to grain. Although they expressed an advantage of high yield over checks in optimal conditions of soil fertility, these lines were excessively early and resulted in poor yields under more realistic conditions of low to moderate fertility. Thus, Andean beans presented the same pattern as Mesoamerican bean types. We immediately adjusted the breeding program by including parents with a longer growth cycle and adaptation to poor soil, especially the cultivar CAL 143 from southern Africa. The results with selections under drought stress were excellent. Among the parental materials in the crosses represented in Table 27, CAL 143, KAT B1, and PAN 127 were the commercial varieties in Africa, and the last column represents their respective yields. Yields of the progenies are far superior to the yields of the parents.

Establishment of a SNP platform

This is the single most long term result of TL I project, and SNP will be probably used as the marker of choice for mainstream breeding programs of modest budget in the foreseeable future. With the support of TL I, communication was established with United States Department of Agriculture (USDA) to access the sequences of SNP identified these and under GCP they were converted to the KASPar system. SNP markers for major disease resistance genes (for BCMNV, CBB, bruchids, and ALS) were developed and markers of other classes (SCARS and SSRs) were converted to a SNP platform for ready-to-use purpose. To date, a number of students and NARS projects are utilizing this platform for key traits (CBB, root rot, bruchids, etc). Under TL I project markers for key resistance genes, for bean common mosaic virus

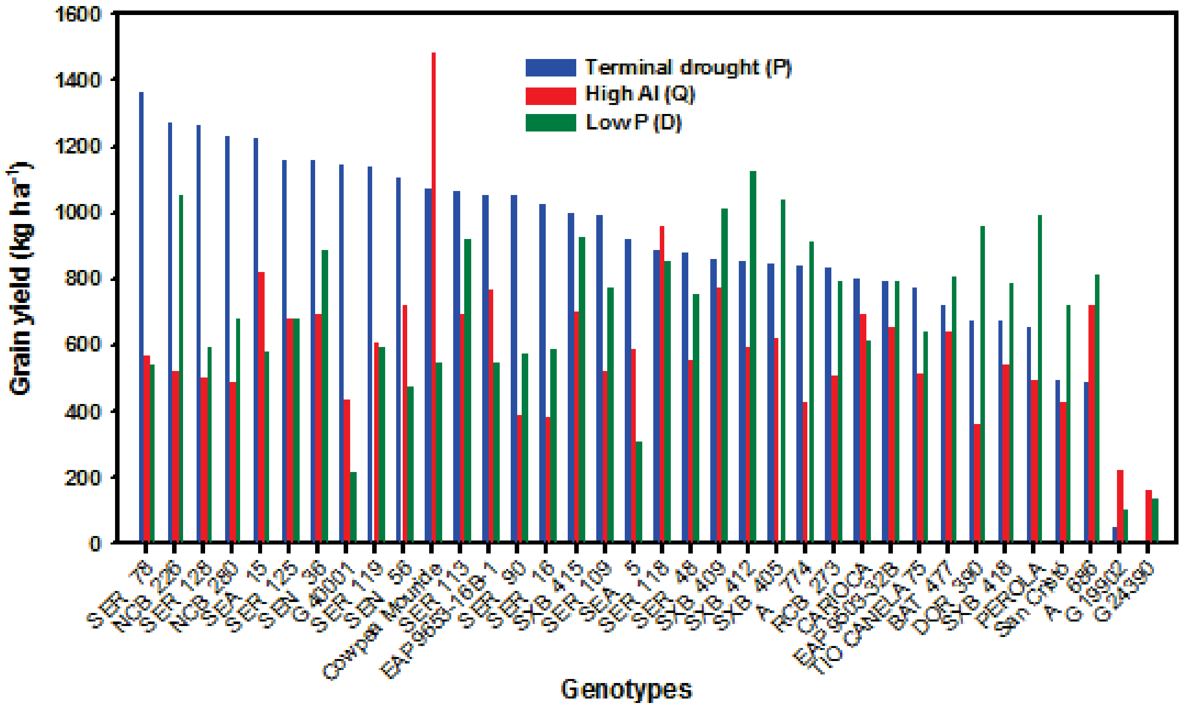

Figure 4. Grain yield of common bean under different abiotic stress conditions in the field.

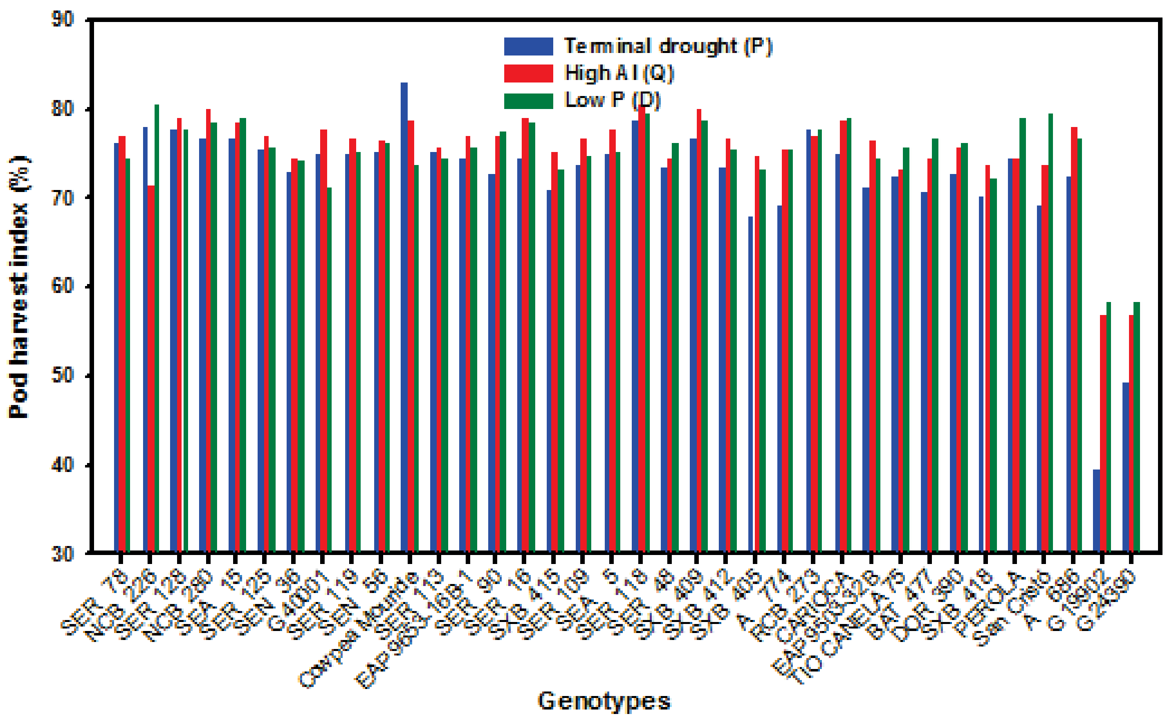

Figure 5. Pod harvest index under different abiotic stress conditions in the field.

Table 27. Yield (kg ha^{-1}) of elite lines of the Andean gene pool, evaluated under terminal drought in 2009.

Line	Yield (kg ha^{-1})	Commercial check (kg ha^{-1})
(CAL 143 x SAB 616) X SAB 629	1857	363
(CAL 143 x SAB 616) X SAB 629	1880	363
(CAL 143 x SAB 616) X SAB 629	1930	568
(KAT B1 x SAB 618) X (SAB 620 x SAB 631)	1962	1222
(KAT B1 x SAB 618) X (SAB 620 x SAB 631)	1882	1561
(SAB 630 x PAN 127) X SAB 676	1976	18

(BCMV), CBB, and bruchids were developed. Therefore, parental materials selected from these trait-based nurseries would permit the subsequent application of markers to their progenies.

Fast track evaluation of drought and heat tolerant *Phaseolus* species

At the outset of the TL II project, a nursery was compiled of more than 1700 entries, with contributions from PABRA (ECABREN in eastern Africa and SABRN in southern Africa), as well as from CIAT headquarters in Colombia. Some materials were selected under drought stress from CIAT-Colombia while some others were derived from regional nurseries like the Bean Improvement for Low soil Fertility in Africa (BILFA) nursery composed of selections made under various low fertility regimes. Others were elite lines from general breeding nurseries. Given limitations of seeds in their early stages, the first nursery was planted in KARI, Katumani, Kenya in two repetitions and short rows. The nursery developed vegetatively well in spite of suffering a moderate level of terminal drought stress with late rainfall conditions. It was, however, a useful nursery for the first evaluation of drought response of lines, many of which were not exposed to moisture stress previously. From this nursery, a sub-set of 500 entries were identified for subsequent distribution to other research sites in the ECABREN region. The nursery in Katumani served a training purpose as well. It was the first nursery planted under the TL-II project, and was the most significant effort in drought resistance till date. The nursery was also the first significant opportunity to expose regional scientists to physiological sampling techniques for the evaluation of drought resistance traits. Moreover, it was also the first opportunity to test the physiological parameters that were identified in CIAT-Colombia as potential indicators of drought resistance. A description of the training exercise *per se* is presented in the section on capacity building. With regards to the results of the physiological analysis, both PHI (seed biomass/pod biomass x 100) and PPI (pod biomass at harvest/ total shoot biomass at mid-pod fill x 100) proved to be closely associated with the seed yield, validating the results from Colombia. A similar nursery of 1700 entries was planted in Kandiyani Research Station of DARS, Malawi under the SABRN network, but it suffered a severe attack by bean stem maggot (BSM; *Ophiomyia* sp.). Attack of BSM was a natural result of late planting that was practiced to simulate terminal drought stress, and thus delayed the progress in SABRN. Fortunately, materials selected under a parallel project on drought were advanced and these were employed in PVS trials.

In phase II, nurseries were distributed to the TL II participating countries Malawi, Zimbabwe, Uganda, Kenya and Tanzania. These nurseries consisted of materials segregating for drought tolerance and fixed lines combining drought tolerance with other traits, such as high mineral (Fe and Zn) content, low soil fertility tolerance, pest resistance (bruchids and bean stem maggot; BSM), and disease resistance (CBB). Selections were made for materials at different stages of the breeding pipeline. These nurseries for specific traits served to evaluate the breeding lines for their potential use as parents in additional crosses, and for the application of molecular markers to recover resistance with greater confidence. Currently, the application of marker assisted selection to populations developed in national programs is pending. Below is a brief report on the status of selections in different categories.

Improved drought tolerant germplasm with multiple traits

Evaluation of improved drought tolerant materials was conducted in Uganda, Zimbabwe, Kenya, and Malawi. In Kenya, three nurseries Andean drought tolerant populations (60 entries), 70 advanced lines with *bc*3 gene for BCMNV resistance, and 68 advanced lines from an interspecific cross between *P. vulgaris P. acutifolius* and drought tolerant Andean nursery (427 DAB lines), received from CIAT-Colombia, were evaluated for drought tolerance at two sites – Katumani and Kambi ya Mawe – under rain-fed conditions. High significant differences under both moisture stress treatments were observed in all three nurseries. The average yield of Katumani (2,463 kg ha^{-1}) and Kambi ya Mawe (1,123 kg ha^{-1}) were obtained among the lines with *bc*3 gene, most of which were of the small red market class (the third most-preferred seed types in Kenya). At Katumani, yield ranged between 1772 kg ha^{-1} (BCB 741) and 3,087 kg ha^{-1} (SCN 10). Only four lines had yields less than 2,000 kg ha^{-1} that included BCB 741 (1,772 kg ha^{-1}), GLPx 92 (1,818 kg ha^{-1}), SCR 7 (1,845 kg ha^{-1}), and SCR 2 (1,991 kg ha^{-1}) at Katumani. GLPx92 is a standard local cultivar considered to be drought tolerant, but with poor grain color. The obtained lines yielded far better than GLPx92 and with better color bodies would have a better future impact. The yields at Kambi ya Mawe ranged between 823 kg ha^{-1} (SCR 12) and 1,689 kg ha^{-1} (SCR 20). The average yield of 1,616 kg ha^{-1} across the two test sites was recorded among the inter-specific lines. The crop yield ranged between 709 kg ha^{-1} (INB 840) and 1,612 kg ha^{-1} (INB 812) with an average of 1,064 kg ha^{-1} at Kambi ya Mawe and 1,601 kg ha^{-1} (INB 822) to 2,631 kg ha^{-1} (INB 806) with an average yield of 2,168 kg ha^{-1} at Katumani. Among the 427 DAB lines, most adapted 191 lines were selected and evaluated further for adaptability during the April- July 2013 growing season at both KARI Katumani and Thika. Thirty-six out of the 191 lines were further evaluated at the farmers' fields at Nyeri, Kirinyaga, and Machakos.

In Ethiopia, selection results within the fast track nursery were less successful in the Melkassa program as not a single line convincingly out-yielded the local check, Nasir. This variety proved to be drought-tolerant likely due to its history of selection. It was originally selected in Honduras, a drought-prone region, which could have made it experience the drought pressure during its development. Moreover, accession of a Mexican race - Durango is present among its parental lines, which has been a source of drought tolerance. On the other hand, recombinant inbred lines introduced as part of a PhD thesis proved to be quite successful for the identification of high-yielding navy beans for Ethiopia's export market, both in managed drought trials that amply out-yielded the check (data not shown) and in regional trials although in 2010, rainfall was plentiful, and the yield data did not reflect any drought in

Table 28. Mean yield performance of 12 drought tolerant varieties in seven environments.

Environment	Mean yield (kg ha^{-1})	Min. yield (kg ha^{-1})	Max. yield (kg ha^{-1})	Standard deviation	Variance	%CV
Abi ZARDI	2389.6	1067	3583	657.8	432636	27.53
Ngetta ZARDI	928.4	115	1500	485	235202	52.24
Mbarara ZARDI	631.2	83	1225	363.7	132248	57.62
Nakasongola	582.3	106	1377	308.5	95178	52.98
Mobuku	227	0	592	203.4	41390	89.62
Nabuin	143.9	20	381	110	12107	76.44
NaSARRI	72.3	13	208	66.4	4404	91.77

ZARDI= Zonal Agricultural Research and Development Institute that particular year. Selections 23 with 11% and 80 with 12% yields were especially stable, which was more than the elite check Awash-Melka across environments, and 29% and 19% more in the lowest yielding environment, Pawe (Awash-Melka was distributed as an elite variety under objective 8). Data on disease were taken at all four test sites, but only data from Jimma are shown as, here, the disease pressure was especially intense. Several lines were superior to Awash-Melka in disease resistance, especially line 23 that was superior to others in reaction to four different diseases. In evaluations with traders, all lines were quite acceptable. However, line 80 was rated highest in canning quality in the tests carried out at Italy.

In Uganda, a nursery comprising of 34 elite lines, received from CIAT HQ (Table 29), was evaluated for drought tolerance during the off-season at NaCRRI-Namulonge under both rain-fed and irrigated conditions. The trials were set and subjected to the normal seasonal conditions of different localities. The north of Uganda is characterized by frequent droughts and high temperatures, thus, is considered as one of the few bean growing areas of Africa. Black beans are more preferred in this region. The black seeded introductions in this trial represented the first introductions of black seeded lines for drought tolerance. Results showed significant difference ($p<0.01$) between lines of the SCN bean lines series and the *bc*3 gene yielding slightly higher than the other series. The yields ranged from 875 to 2,447 kg ha^{-1} for the irrigated trials and from 638 to 2,030 kg ha^{-1} for the non-irrigated trials. Bean lines DOR 364, SCN 1, SCN 11, SCN 17, SCN 4, SCN 74, SCN 8, SCR 26, SEN 1, SEN 56, SEN 74, SEN 70, SEN 80. SEN 90, SEN 95 and SEN 98 were less affected by the drought as their yield losses due to drought were less than 20% of that achieved under irrigated conditions. The best performing lines were SCN 1, SEN 1, SCN 8, SEN 70, SEN 95 and SEN 98 with a yield loss of 15% and below. Significant differences ($p<0.05$) were also noted in the days to 50% flowering, where lines KAT X56, KAT B1, KAT B9, SCN 1, SCN 17 and SCR 118 flowered

Table 29. Number of drought tolerant lines evaluated and selected among the TL II countries.

Country	No. lines evaluated	No. of lines selected
Kenya	665	36
Uganda	34	16
Zimbabwe	377	168
S. Tanzania	92	4
Malawi	20	-

Table 30. Nurseries evaluated in the TL II countries.

Nursery	Trait	Codes	Recipient countries
Small reds	Drought and high minerals	SMR	Zimbabwe
Small reds	Drought	SER	Zimbabwe
Small reds	Drought and bc3	SCR	Uganda, Kenya
Small reds	Low soil fertility and drought	BFS	Kenya, Uganda, Zimbabwe
Blacks	Drought and high minerals	SMN	Zimbabwe
Blacks	*bc3*	NCB, BRB	Kenya, S. Tanzania
Blacks	Drought	SEN, SCN	Uganda, Kenya
Mixed colors	Bruchids	MAZ	Zimbabwe, Kenya, Uganda, Malawi
Mixed colors	Drought and high minerals	SMC, SMB	Zimbabwe
Mixed colors	*bc3*	BCB	Kenya
Mixed colors	BSM	BH, CIM	Zimbabwe, Uganda, Malawi
Mixed colors	CBB	CIM	Zimbabwe, S. Tanzania
Andean	Drought	DAB	Kenya, Zimbabwe
Andean	Drought	DAB	S. Tanzania, Zimbabwe

2-7 days earlier than the rest of the bean lines. Most lines were shown to be resistant to rust and BCMV, and moderately resistant to acetolactate synthase (ALS) and CBB. Twelve selected lines were further evaluated in six drought-prone areas of Uganda under on-station conditions (ABIZARDI, Mbarara ZARDI, NASARRI, NgetaZARDI, Mobuku, Nabuin and Nakasagola). They included DOR 364, SCN 1, SCN 11, SCN 8, SCR 26, SCR 35, SEN 46, SEN 56, SEN 70, SEN 80, SEN 95 and SEN 98 along with four Uganda market class varieties, K132, NABE 4, NABE 15 and NABE 16 as checks. AbiZADRI was the best environment for the genotypes with an average yield of 2389.6 kg ha^{-1} while NaSARRI with an average yield of 72.3 kg ha^{-1} was the worst performing environment (Table 28). The reason behind the good yield performance was the abundant rainfall in AbiZARDI (data not shown) than other environments during the growing season leading to higher yield potentials. It can also be noted, due to the intense drought experienced in these environments like Mobuku, total yield losses were obtained for some bean genotypes. Results showed that only AbiZARDi and NgettaZARDI environments had net positive effects on the genotypes, the rest of the environments contributed negatively to the performance of the genotypes. Yields of genotypes, SEN 70, SEN 80, SEN 56, SEN 46 and SCN 8 were not significantly ($p \geq 0.001$) different in the different environments whereas the yield of genotypes SEN 98, SCN 11, SEN 95, SCN 1, NABE 15 and SCR 35 significantly differed among the six environments.

In Zimbabwe, a total of 1007 lines were first evaluated for adaptation and photo-sensitive response under the irrigation scheme at Harare Research Station in August 2008. Some lines were adapted and those that excelled were planted again in two sets. One was planted under water stress and the other with irrigation at Gwebi Variety Testing Centre in February 2009. However, the crop in the irrigated field was partly grazed by antelopes during the trifoliate stage. Drought in the water stress treatment was not as severe as expected, since unexpected rains were received during the early podding stage. However, 200 lines were selected under drought conditions. During the 2009-10 summer season in Zimbabwe, the selected 200 lines were sent to farmers for participatory variety selection to expose genotypes to the natural drought conditions and farmer environment, improve efficiency of researcher's selections, meet standards of variety release, and increase chances of variety adoption once released. Many parts of the country received below-average rains and persistent dry spells were recorded that gave rise to two types of drought depending on the region/district. One type affected the beans at flowering stage (mid-season drought) and the other due to the late planting favored the terminal drought. There was also an extreme scenario where the rains did not even support the seed germination in the drought-prone areas, like Gutu and Mushagashe in Masvingo province. Of the 200 lines, farmers from different areas managed to select 30 lines. Farmers' selection criteria were mainly based on varieties resistant to drought since 2009-10 was a drought year. We managed to receive a few grams/line from the farmers since the majority of farmers retained some quantity of the seed. The varieties, which were selected by farmers under farmers' fields category, were reconstituted into one nursery and were bulked up at Harare Research Station to enable on-station trials under drought conditions of Lowveld during winter of 2011-12. The physiological parameters for drought tolerance will be precisely measured. The multilocation variety evaluation would have been followed then with a possible release of at least one drought tolerant variety in 2012/13 season. In phase II, 36 drought lines received from CIAT-Malawi were evaluated at Gwebi Variety Testing Center for tolerance to drought and fungal diseases. Fifteen lines were selected on the basis of high yield potential under terminal drought stress and tolerance to CBB and ALS. Another drought tolerant nursery (drought Andean bush; DAB with 130 entries) was evaluated at Harare Research Station, Gwebi Variety Testing Center, and Save Valley Experiment Station. Sixty-four lines were selected. The selected lines combined good stomatal control with high grain yield, which will be advanced into the Preliminary Yield Trials (PYT). Five other nurseries (drought physiology lines, drought Andean red & white nursery, BSM nursery, advanced backcross drought nursery, and Andean drought red mottled nursery were evaluated at Gwebi Variety Testing Center and Kadoma Research Station for their resistance/tolerance to different environmental constraints. Fifty lines were selected from 99 drought physiology lines, 20 lines were selected from 35 drought Andean red & white nurseries, eight were selected from 28 BSM nursery lines, and 11 lines were selected from 49 advanced backcross drought nursery. The selected lines were advanced into PYT. Nine BRB lines (*bc*3 gene) constituting the BCMV resistance nursery were evaluated in Zimbabwe, out of which four lines (BRB 267: 2,426 kg ha^{-1}, BRB 268: 2263 kg ha^{-1}, BRB 264: 1,510 kg ha^{-1}, and BRB214: 1,460 kg ha^{-1}) combined high grain yielding ability with high disease resistance (Angular Leafspot, Bean Common Mosaic Virus, Rust & Anthracnose). In addition, 36 genotypes (CBB nursery) were established at Harare Research Station for seed increase and identification of disease resistant sources. Six lines ie, BRB 265/VAX 3-5 (1,150 kg ha^{-1}), SEQ 1003/VAX 3-12 (1120 kg ha^{-1}), SEQ 1003/VAX 3-13 (1320 kg ha^{-1}), SEQ 1003/VAX 3-17 (1,440 kg ha^{-1}), SEQ 11/RMX 19-1 (1,460 kg ha^{-1}), SEQ 11/RMX 19-3 (1,410 kg ha^{-1}) were the best adapted ones with average yields ranging from 1,100 kg ha^{-1} to above 1,400 kg ha^{-1}. These lines also exhibited an exceptional performance with regard to their disease resistance (ALS, Rust and BCMV).

In South Tanzania, 36 drought bean lines were evaluated in a replicated trial at Ismani Research Station for adaptation and agronomic performance during the rainy season. Six genotypes, CAL 143, ALB 4, SER 80, SEN 39, SER 85, and NCB 280 were selected for drought tolerance testing. In addition, 56 bean lines were evaluated for tolerance to drought at ARI-Uyole and Ismani Research Station. Results are still under analysis.

A number of nurseries were evaluated for resistance or tolerance to multiple stresses in S. Tanzania. Eight lines from SARBYT (20 entries), 6 lines from Khaki nursery (29), 11 genotypes from Khaki lattice (36 entries), 11 genotypes from Sugar bean nursery lines (22), six from NUA (22 lines) were selected. Drought lines AS 16358 - 020, SAB 691 and MR 14125-3 gave higher yields under drought and low P (30 kg P/ha) environments at Ismani site and also showed resistance to anthracnose, bacterial blight, and rust. F4 Climber lines (56), Drought lines (36), BILFA lines nursery (18), Climbing bean nursery (Fe & Zn) (136), F3 Climbers pops (114), SARBYT Climbers (20), SABREN Climbers (49) were also evaluated.

In Malawi, evaluation of the fast track nursery in southern Africa was delayed due to attack of bean stem maggot or bean fly (*Ophiomyia* spp.), which was exacerbated by late planting of nurseries to increase the probability of drought stress. Lines are still being processed, but in the off-season nursery in Kasinthula 51 lines produced 30% more grain that the average of four checks, although almost none of them could beat the best check by this margin. We have noted that lines selected under the Malawian program have performed well in other environments, and the local soil materials might already have a degree of tolerance. While the fast track entries were recovered and cycled through the evaluation scheme, lines selected previously under a parallel project were advanced and were at the point of release. Across four sites including two on-farm sites in the north of Malawi (CHS and BOK), small red seeded lines out-yielded the local check CAL 143 by as much as 50%. Although not the most preferred type in Malawi, small red beans do appear in local mixtures. The national program is considering the release of SER 83 and SER 45. In Malawi, an experiment that evaluated 20 bean genotypes for multiple stress tolerance at Chitedze was conducted and ten lines were selected. Seeds were increased in these ten lines during the preparation for multi-location evaluation in the 2013/2014 season. In Ethiopia, 501 lines of different market classes were evaluated in different bean growing regions, out of which, 294 promising advanced lines were identified for further evaluation under advanced multi-location yield trials.

Drought and low soil fertility

In Kenya, 16 genotypes from Kabete, KARI-Kakamega, and KARI Katumani along with three commercial checks were planted to evaluate the effect of P on the grain yield at Muguga and Kabete university farm. There were varied responses to the applied P at medium P (30, 60) and high P (90) rates by all the genotypes. All the varieties showed a response to medium and high P rates, except for KK 20, VNB 81010, and KK 15 that did not show any response to the increase in P rates. KK 20 and VNB 81010

Table 31. Yield, under drought induced by low rainfall in the vegetative phase and post flowering water deficit, of SER 16 and its ALB progenies derived from a cross with runner bean (*Phaseolus coccineus*) evaluated during the drought season in 2010.

Line	Yield (kg ha^{-1})	Line	Yield (kg ha^{-1})
ALB 60	2155	ALB 147	1618
ALB 180	1908	ALB 77	1565
ALB 213	1830	SER 16	1558
ALB 209	1826	ALB 110	1312
ALB 214	1734	Tio Canela	1283
ALB 91	1713	LSD (0.05)	436
ALB 6	1631		

yielded more than all the other varieties under low P conditions (0 kg P/ha). The recently improved genotypes (KK15, NCB 226 and SEA 15) yielded relatively more than the older varieties. Drought susceptible varieties had a remarkable response to the P fertilizer applications. Lines NCB 226, SER 118, and SEA 14 selected for drought tolerance yielded relatively well under low P levels compared to older genotype, KAT B1, which was selected locally. In Malawi, experiments were conducted to identity low P and N tolerant bean germplasm at two sites of Bvumbwe and Chitedze. The results are still pending. In Zimbabwe, 23 BFS genotypes (low soil fertility and drought tolerance) received from CIAT-Colombia were evaluated for adaptation to low soil fertility and drought tolerance. NUA45 and Gloria were the control genotypes in this trial. A total of 14 genotypes (BFS 10, BFS 14, BFS 23, BFS 27, BFS 29, BFS 30, BFS 32, BFS 33, BFS 39, BFS 55, BFS 62, BFS 67, BFS 75 and SXB 412) were selected based on high yielding ability with earliness, good stomatal conductance, and resistance to common bacterial blight and angular leafspot. Four genotypes (BFS 32, BFS 55, BFS 67 and SXB 42) outperformed the two check varieties (NUA 45 and Gloria) in terms of high grain yield.

Screening for resistance to bean stem maggots

Screening for bean stem maggot resistance was done in Kenya, Uganda, and Zimbabwe though extensive studies, which were conducted under TL I in Ethiopia. In Kenya, KARI-Thika obtained eight bean lines with resistance to BSM from KARI Katumani. Ikisinoni, Mlama 127, Ikinimba, CCC 888, Mkombozi, Macho, CIM 9314-36, and Ex 290 lines were tested under the breeding protocol for their evaluation of BSM resistance that was validated at different sites as a standard protocol, which is yet to be adopted. In Kenya, the emergence of the adults from pupae, kept at room temperature ranged from 30-80% and from 30-60% in an incubator at 28 °C while the time of emergence ranged from 3-14 days.

In Uganda, pupae from NABE 4 were obtained from the field and reared in cylindrical jars (30 pupae/ cylinder). Adult emergence was at an average rate of 53.42%. Thereafter, the adult flies were introduced into the cage at five DAE, and this was repeated every ten days. Thirty-two genotypes were assessed based on weekly plant mortality until flowering, ovipunctures (2WAE), number of pupae per plant (4WAE), stem damage on a scale of 1-9 (4WAE), and rated on a scale of 1-9 where 1 represents immune and 9 represents extremely susceptible. From this protocol, 14 lines were found to be resistant and 13 moderately resistant. One experiment evaluating 100 genotypes for BSM tolerance was implemented at Chitedze, but the data was being analyzed to identify superior genotypes. In Zimbabwe, 29 genotypes constituting the Bean Stem Maggot (BSM) nursery were included with the selections from CIM-x SUG- cross and CIM- x RM- cross, which were later evaluated at two sites. High infestations of BSM were observed at both the sites. A total of 8 genotypes (CIM-RM-03-42-20, CIM-RM-03-42-09, CIM-

RM-03-42-10, CIM-SUG-03-09-15, CIM-SUG-03-09-07, CIM-SUG-03-09-06, CIM-SUG-03-09-05, CIM-SUG-03-09-02) were tolerant to BSM across the tested sites. These genotypes also had average yields of above 1,500 kg ha^{-1}. This BSM nursery is currently being evaluated in southern Tanzania. In Ethiopia, the research work on BSM was conducted under TL I project.

Screening for resistance to bean bruchids

In Zimbabwe, 100 MAZ lines were evaluated both in the field for yield performance and in laboratory for bruchid resistance. The field trial consisted of the entire 100 genotypes while laboratory screening was done for 28 genotypes inclusive of three check varieties (NUA 45, Gloria and PAN 148). Laboratory experiments assessed tolerance to the Mexican bean weevil. Eleven lines, MAZ 190 (1,000 kg ha^{-1}), MAZ 2 (1,315 kg ha^{-1}), MAZ 173 (1,481 kg ha^{-1}) MAZ 42 (1,037 kg ha^{-1}, MAZ 211 (1,352 kg ha^{-1}), MAZ 116 (1,222 kg ha^{-1}), MAZ 207 (1,630 kg ha^{-1}), MAZ 145 (1,630 kg ha^{-1}), MAZ 204 (1,667 kg ha^{-1}), PAN 148 (930 kg ha^{-1}) and GLORIA (1,200 kg ha^{-1}) showed exceptional performances with regard to the bruchid resistance and potential yield. The varieties Gloria and PAN 148 were identified as improved varieties with high resistance to bruchid attack, however, it would require more confirmation. Results also showed that the shiny, small seeded MAZ lines and sugar types were more resistant to bruchid attack as compared to the large red MAZ lines. Evaluation of another sub-set of MAZ lines (25) is still in progress.

In Kenya, one hundred bruchid resistant lines (MAZ 4-217) received from CIA- Colombia were planted in the field at KARI Katumani to test for their adaptability during the short rainy season within November 2012-February 2013. Most of the lines consisted of the grain types preferred in the market. The grain yield during this season ranged from 22 g to 215 g per 1.5 m row. MAZ 3, 31, 150, 185, 207, 110, 112, 109, 205 and 150 were among the entries with highest seed yield. This trial was repeated during the long rainy season within April-July 2013, where the 100 MAZ lines were evaluated for adaptability at KARI Katumani. The 100 entries were then tested for resistance to bruchids under artificial infestation to identify the entries that could be used to cross with the susceptible commercial varieties. The same set of 100 MAZ lines was distributed to Uganda (AGRA, MSc study), Ethiopia (ACCI, PhD study), and Tanzania for evaluation. In Uganda, 28 accessions were screened for resistance to *O. spencerella* with an artificial infestation and ten resistant lines selected. These ten genotypes were screened to confirm the levels of resistance to bruchids for utilization in crosses, and the results are still pending.

Climbing beans responding to increasing bean production and productivity

Climbing beans have been shown to out-yield bush beans by doubling and tripling the yields (Niringiye et al. 2005; CIAT 2012), and utilizing the vertical space, and therefore, are becoming a very attractive enterprise among small-scale farmers for whom land is a major constraint. Moreover, the horizontal expansion of their agricultural land is also difficult. Climbing beans are a relatively new technology in Kenya and Ethiopia but have been found to exist in Uganda, Tanzania, Malawi and Zimbabwe even though they have been limited to specific agro-ecologies most specifically in the highland areas. With recent development of the Mid-Altitude Climbing (MAC) beans, the technology can be promoted in less traditional environments. Effort in phase II was to promote the climbing beans to new areas that were conducive for growth and the less traditional environments within the participating countries. In Central Kenya, for example, climbing beans is a relatively new technology with a different growth habit and crop management from the bush beans. Major constraints to their production included lack of information on the technology and availability of stakes, since the climbing beans have to be staked to produce optimally.

One of the areas identified to be potential for climbing beans is the Kagera and Kigoma region of Tanzania. Ten climbing bean varieties, Gasirida, Kenya Mavuno (MAC 64), Kenya Tamu (MAC 34), MAC 9, MAC 44, MAC 49, Mamesa, RWV 1129, RWV 5348 and Umubano, were introduced to this effect by CIAT and evaluated for adaptability and acceptability in Kagera region during the long rainy season of March-May 2013. A mother trial was designed in a split plot with and without P as the main plot and the variety as the sub plot, which was established on-station. The line RWV 5348 had a high overall mean yield of 1.26 t/ha, followed by varieties Kenya Tamu (1.13 t/ha), MAC-49 (1.11 t/ha), and Umubano (1.08 t/ha). RWV 5348 and Umubano also had high mean yield both in plots with and without P. Gasirida variety had the lowest overall mean yield of 0.319 t/ha, in with 0.39 t/ha in the plot with P and 0.25 t/ha in the plot without P. The overall mean yield for other varieties were 0.93 t/ha for MAC 44, 0.87 t/ha for MAC 9, 0.75 t/ha for Mamesa, 0.72 t/ha for Kenya mavuno, and 0.61 t/ha for RWV 1129. Gasirida and Mamesa were severely infected by viral disease both on-station and at Irango village. RWV 1129 was infected by angular leafspot and leaf rust diseases at low score levels.

Development and deployment of parental materials for various stresses

Development of new multiple stress resistance populations: Segregating populations were developed for selection in CIAT-Colombia, in CIAT research sites in Africa and in NARS programs. Based on the evaluations made in Colombia, elite parental lines were selected for another cycle of crossing with emphasis on beans from the Andean gene pool. Effort was made to deliberately develop bean germplasm that was drought tolerant with an added trait of high Fe and Zn content. Small seeded Mesoamerican bush bean lines, emerging from the breeding program in Colombia, presented as much as 80% higher iron and drought resistance equal or superior to the tolerant check variety. The improvement of mineral content in the climbing bean materials has been successful with an added advantage of increased productivity per unit area. High temperatures aggravate the stress imposed by drought, and combinations of stress tolerance would be necessary in the near future. While 20 °C night temperature is normally considered to be a limitation for common bean, the breeding lines combining common bean with *P. acutifolius* presented an excellent pollen formation and good pod set at 22 °C night temperatures. Some pod sets were maintained at 25 °C nights. Approximately, 60 populations were evaluated per year in CIAT-Colombia. Other populations were sent to the partners in four out of five participating countries while in Zimbabwe, the program focused only on giving follow up to the existing populations (Table 31-43). Additional crosses were made in the Ethiopian program (Table 31-43) and the parental materials were delivered to KARI-Kenya to initiate a crossing program over there.

Interspecific crosses with tepary bean

Phaseolus acutifolius or tepary bean is a desert species with multiple drought-resistance traits. It can be crossed with common bean only by using the embryo rescue, yet with great difficulty. However, several years of effort has resulted in the accumulation of a sizable number of interspecific progenies. The most drought resistant varieties were identified and intercrossed, and the selections from the second cycle were evaluated under terminal drought conditions of 2009. A very unusual breeding line- INB 841 was identified with the high level of resistance to wilting and rapid pod development, but root evaluations suggested that its root system is not superior. Thus, we suspect that it may possess possible mechanisms of stomatal regulation and/or osmotic adjustment to resist wilting. Its trait of rapid pod elongation may also be associated with hormonal regulation of pod growth and development. Lines, developed from this species, are being evaluated both by CIAT and other national partners, which show a lot of promise.

Inter-specific crosses with runner bean

As part of a BMZ project, combinations of drought resistance and aluminum (Al) tolerance were sought. Accessions of runner bean, or *Phaseolus coccineus*, proved to be highly resistant to Al, hence were crossed to drought resistant line SER 16. This cross was designed to combine the vigor and biomass of the runner bean with the remobilization capacity of the line. The resulting population was subjected to an intensive study of root attributes revealing large differences in the rooting patterns and morphology that are relevant for improvement of common bean for drought resistance. Runner bean has a coarse and rugged root system with thick basal roots that can penetrate acidic soil under drying conditions much better than common bean. Some lines from the runner bean source also display less wilting. Some progenies of runner bean also tend to produce large biomass and excellent yield potential reflecting in part their vigorous root system. We used these lines as parents for improved yields in combination with sources of enhanced photosynthate remobilization. This is still another source of traits that are being investigated as potentially relevant for drought resistance. Data presented in Table 31 represent yields under drought conditions induced by limited water supply during the vegetative phase, followed by soil drying through much of the reproductive phase. All ALB lines are derived from the cross of runner bean with SER16. The advantage of some ALB lines over the SER 16 parent is due to the introgression of genes and traits from the runner bean. Yield, under drought induced by low rainfall in the vegetative phase and post-flowering water deficit, of SER 16 and its ALB progenies derived from a cross with runner bean (*Phaseolus coccineus*) was evaluated during the drought season of 2010.

Population development by national partners

In phase II, Zimbabwe developed 85 single cross combinations involving 43 parents to develop new breeding lines combining bruchid and CBB resistance with BCMV resistance for good performance under drought pressure. The sources of resistance were selected from the MAZ line trials, DAB trials, BRB lines, and CBB trials. The aim of the hybridizations was to improve the yield of common beans by developing bean cultivars' tolerance to bruchids, CBB, BCMV, and drought. Fifty-three F1 populations were advanced to F2 under greenhouse conditions during December 2012. A total of 53 F2 populations were established at Save Valley Experiment Station in winter. These lines, resulted from bi-parental crosses, were initiated in 2012 with an aim of improving their tolerance to low N, low P, acid pH, and BCMV in commercially cultivated large-seeded beans. No selections were made due to the low heritability of the quantitative traits in common bean resulting in the delayed selection to F4/F5 stage. From the F5.6 nursery consisting of 47 progenies, a total of 15 families were selected based on their tolerance to CBB, ALS, and Rust.

In Uganda, NACRRI embarked on introgression of bruchid and bean stem maggot (BSM) resistant genes into the farmers' preferred varieties. Six exotic bruchid resistant genotypes sourced from Malawi, MALUWA/KK25/443, KK25/MALUWA/112-mw, KK25/MALUWA/19-mw, KK25/NAGAGA/184-mw, KK25/NAGAGA/184-mw, MALUWA/KK25/9-mw and one local (Tapara) were crossed with four susceptible local varieties (ie, NABE 4, NABE 15, NABE 17 and NABE 23). In addition, 16 different crosses were made to introgress with the BSM resistant genes into susceptible Ugandan market class varieties (NABE 4, NABE 15, NABE 16 and NABE 17) with known BSM resistant genotypes from CIAT. A field screening trial was set up to identify other bean genotypes that are resistant to BSM. Till the end of the project in Uganda, crosses were made with three local bean lines (K132, NABE 4, and NABE 15) and five drought elite lines (SCR 48, SCR 6, SCR 9 SEN 98 and SEN99) that resulted in 183 segregating populations that are still undergoing screening.

In Kenya, KARI-Thika conducted crosses targeted at introgressing observed BSM tolerance from eight lines into the popular bean varieties grown in central Kenya (ie, GLP 2, GLP 585, GLP 1127, GLP 24 and KAT B1). Successful crosses included Ikisinoni x GLP 24, GLP 24 x CCC888, GLP 585 x Mkombozi, GLP 24 x Ikinimba, GLP 2 X CCC 888, GLP 2 x macho, EX 290 x GLP 1127, CIM 9314 x GLP 2, GLP 1127 x Mrama 127, Mrama 127 x GLP 2, and Mrama 127 x GLP 2. The F1 seeds were planted in the screen house in May 2013 in Ethiopia. Crosses targeted the drought tolerance and seed market class. In Ethiopia, seven new single crosses were also made and successful pods were harvested in this pattern with genetic variability of several sources.

An ideotype for Mesoamerican beans

Beans are often planted in marginal soils. The Mesoamerican beans, in particular, often occupied the more difficult niches, even within a farm. Soil fertility is a critical issue for the improvement of bean yields, and poor fertility conditions often override the benefits of drought resistance. Beans are sensitive to poor fertility conditions compared to other legumes, due to their short growth cycle of less than 80 days. Our experience over the past many years has shown that rusticity and yield in poor soil fertility are greatly affected by the phenology. In one such experience, the trial of drought resistant lines were planted for evaluation in response to the low soil P availability that unexpectedly suffered severe mid-season drought. The better yielding lines tended to be late flowering while the grain filling period was not noticeably different (Table 32). We believed that the ability to withstand low fertility permits an overall plant vigor and root development, which contributes to drought resistance. A short season crop does not have sufficient time to explore the soil profile, whereas farmers prefer early varieties of bean. This presents a contradiction between the demand for a new ideotype that is rustic, yet not late-maturing. We suggested that such an ideotype would have an extended vegetative period to permit better root development, better plant nutrition, and greater biomass production followed by a reproductive phase characterized by aggressive remobilization and rapid dry down at maturity. Experience gained in characterization of remobilization in TL II project makes us hopeful that this is possible. In particular, one red-seeded line-SER 118 is consistently superior in PHI (a measure of remobilization) and tends to present the pattern of mid-late flowering and acceptable maturity. It often yields among the best lines.

Table 32. The four highest yielding entries and the four lowest yielding entries out of 36 drought resistant lines and checks subjected to combined stress of low available soil P and midseason drought. Darien, Colombia, 2009.

Line	Yield (kg ha^{-1})	Days to flowering	Days to grain filling
SXB 412	1257	41	38
NCB 226	1206	33	41
SXB 409	1187	40	42
SXB 405	1175	39	40
SEA 15	625	34	43
SEN 56	563	32	43
SEA 5	379	34	39
G 4001-P. acutifolius	190	37	39
LSD (0.05)	266	2.5	

Selections from segregating populations

Sixty-six segregating Andean drought populations were generated from two-, three-, four- and five-way crosses between Katumani drought tolerant varieties (KAT B1 and KAT B9) and CIAT drought tolerant lines (SAB 618, SAB 620 and SAB 659) in CIAT-Cali. They were evaluated in Kenya at two drought sites of Kambi ya Mawe and Katumani research fields. Yields at Katumani were relatively higher than those obtained in Kambi ya Mawe with an average yield of 2,191 kg ha^{-1} with a range of 1,305 kg ha^{-1} (AS 16468-006) to 2,730 kg ha^{-1} (AS 16372-013) in Katumani while at Kambi ya Mawe the yield ranged from 619 kg ha^{-1} (AS 16375-001) to 1,831 kg ha^{-1} (AS 16370-010) with an average yield of 1,028 kg ha^{-1}. Results were promising as all the lines yielded more than the national average yields of most commercially grown varieties (500 kg ha^{-1}). Twenty-five lines performed better than the best commercial check (GLP 1004, 1,638 kg ha^{-1}). Sixty-nine promising lines from the cross SCR 9 x INB 841 combining drought tolerant small red-seed type with the BCMV recessive resistance were selected on the basis of grain yield and grain filling trait. This population is a cross of *Phaseolius vulgaris* (SCR 9) with an interspecific cross derivative INB of *P. acutifolius.* Seventeen different populations consisting of 100 F_4 families with resistance to multiple constraints including BCMV, CBB and drought were received from CIAT-Colombia and evaluated for adaptability during the November 2012- February 2013 growing season at KARI Katumani. There were very minimal BCMV and CBB disease incidences noted in the field during the season and, therefore, were not scored. The grain yield ranged from 45-293 g per 1.5 m row. Progeny rows were planted at KARI Katumani and Thika during the long rainy season of April-July 2013, where further selection was done to produce the experimental lines. Selected lines were evaluated during the short rainy season of 2013. $F_{2.4}$ populations, developed for multiple stress tolerance, were advanced to the $F_{2.5}$ generation in Ethiopia. Most of the segregating populations are targeted drought tolerance.

Preliminary yield trials (PYT) and advanced yield trials (AYT)

In Northern Tanzania, Advanced Yield Trials (AYT) of 21 best lines and Preliminary Yield Trials (PYT) (2012) plus four checks were further evaluated at Selian Agricultural Research Institute (SARI), Arusha site in 2013 during the main rainy season. Twelve best lines of beans were selected from 21 lines (AYT in 2012) plus four checks were further evaluated at SARI and Machine Tools (Kilimanjaro) sites in 2013 during the main rainy season. All agronomic traits, yield components, and disease data were collected. All trials have been harvested and the seed processed. Data Analysis was also undertaken.

In Zimbabwe, PYT were conducted at two sites and AYT at five sites to supplement the data for variety selection and release. The five sites of AYT were a representative of the agro-ecological zones in Zimbabwe as required by the Variety Release Committee. A total of 25 entries were selected from SABYT and 20 lines of SARBEN were evaluated at PYT. PYT of SARBEN and four checks (NUA45, Gloria, Speckled Ice and PAN 148) were evaluated at Harare Research Station and Gwebi Variety Testing Center. Highly significant differences ($p<0.001$) were observed among the genotypes for grain yield after the combined analysis of the two sites. Eleven lines were selected from the PYT for further evaluation in intermediate variety trials (IVT) during the 2013-14 season. The best performing 25 lines selected from intermediate yield trial (IYT) (2012) were evaluated at Harare Research Station, Gwebi Variety Testing Center, Kadoma Research Station, and Save Valley Experiment Station during the 2012-13 season in the AYT. A total of 10 genotypes from the AYTs had more grain yields compared to the high yielding check varieties. A total of 24 on-farm trials were established to evaluate 15 promising bean genotypes including five check varieties in eight different locations. Genotypes showed highly significant differences for grain yield ($p<0.001$) under on-farm conditions. Five genotypes ie, SEQ 1001, ARA 4, DAB 51, DAB 52 and DAB 411 were selected for further evaluations. Two on-farm locations Chiota and Chivhu were characterized by dry spells, and this allowed for the identification of genotypes tolerant to drought. Seven varieties (SEQ 1001, ARA 4, MG 38, VTTT925/9/1/2, DAB 51, DAB 52 and DAB 411) performed well under the dry conditions giving an average yield of 0.7 t/ha.

In Malawi, PYTs with 30 entries and AYT with 20 entries were conducted at three sites (Chitedze, Bembeke, and Bvumbwe). The main objective of these trials were to test a selected number of promising bean varieties for better bean yield that were resistant to disease and adapted to different growing environments. At Chitedze, genotypes did not show any significant difference on seed yield ($p=0.09$) while at Bvumbwe and Bembeke, the genotypes showed significant differences ($p=0.004$) in relation to the grain yield. At both sites, several varieties produced higher yields as compared to the yield of the released check variety. These varieties were increased for further testing.

PVS trials and lines in the pipeline

The fast track activities were initiated in KARI, Katumani and were carried forward to dryland sites throughout eastern, central, and western Kenya. During the first season of 2009, five PVS were conducted, out of which three were in Central province and two in Rift Valley province. Both female and male farmers were invited to evaluate the test genotypes at physiological maturity stages using the ribbon method. During the exercise, 18 lines were selected. In the second season of 2009, 18 test genotypes and six checks (KAT B1, KAT B9, KAT X56, KAT x 69, GLP x 92, and GLP 1004) were evaluated in both on-farm and on-station trials. Eight on-farm trials were established, which was evaluated with farmers and the yield was estimated. On-station trials were grown under irrigation and under managed stress at KARI's Kiboko station in eastern Kenya. At the outset of the project, check varieties GLP x 92 and KAT B1 were identified as two better yielding varieties in farmers' hands. However in on-farm and managed stress at Kiboko, these varieties were found to be inferior to the new KARI varieties, being distributed in objective 8. Furthermore, lines being tested resulted in far better yield than the KARI varieties with an advantage of as much as 80% over the best check.

In phase II, KARI Thika conducted a PVS trial that included eight lines (ECAB 702, 703, 0019, 027, 241, K131, GLP 2 and GLPX92) at pod filling stage (R8) by a team of scientists from KARI Thika and Katumani. Twenty-six farmers (18 women and eight men) from Mla Jasho Yake self-help group and neighborhood participated in the selection process using the ribbon method. Some of the preferred traits, were many pods per plant, high yield in the midst of moisture stress, resistance to diseases, good seed and pod filling, good plant stand, and the seed color. The traits that were disliked included, few pods per plant, presence of insects and diseases, poor seed and pod filling, and seed size. Genotypes GLP X92, K 131, ECAB 702 and 703 were ranked as highest yield varieties amongst the farmers. GLP X92 was the most preferred genotype amongst the women, followed by ECAB 702 and ECAB 703. The most preferred genotype amongst men was ECAB 027, followed by GLP X92, K 131, and GLP 2. In general, women preferred the highest yielding lines in terms of the pod load and seed filling while the men preferred the large seeded types. Women did not mind the small-seeded types as long as the lines were high yielding, thereby, ensuring food security to their families. Men used the criteria of acceptability of the bean lines at the market place in their selection. The final yield data is still under analysis to compare the selection by the farmers and the actual yield performance of the lines.

Out of 427 DAB lines, 191 most adapted lines were selected and further evaluated during the April-July 2013 growing season at both KARI Katumani and Thika. Thirty-six out of the 191 lines were further evaluated at the farmers' fields at Nyeri, Kirinyaga, and Machakos. A PVS was conducted at Machakos, where 46 farmers selected the best performing lines. Data entry and analysis is still in progress. The best performing lines are currently being evaluated in multiple locations with PVS in the October 2013 - February 2014 season.

In phase II at Zimbabwe, the Agronomy Research Institute carried out PVS trials in two agro-ecological zones and the farmer/consumer preferences were captured. Ten dry bean varieties (PAN 148, MG 38, DAB 411, VTTT 925/9/1/2, Bounty, Speckled Ice, Gloria, SAN-1, Cardinal, and NUA 45) were tested on-farm and on-station in agro-ecological zones II, III and IV. The sugar bean types such as Gloria, VTTT 925/9/1/2, DAB 411, and Speckled Ice were the mostly preferred varieties. Farmers cited that these varieties were potentially easy to market as compared to the Calima types. Most female farmers preferred DAB 411 more because of its drought tolerance attributes, which is good for ensuring the food security of the region.

The SARI team in Arusha received lines of the fast track nursery from the University of Nairobi, and followed it up with several cycles of testing. Lines were divided into two groups ie, bush and indeterminate vining types, which were yield-tested on-farm in three regions. Lines were also subjected to PVS evaluation with farmers using colored ribbons to express favorable or unfavorable opinions on the materials. Lines including F9 Kidney selection (15), F8 Drought line (36), and Dwarf climber (6) expressed better yields and were also rated well by farmers.

Pre-released and released varieties

In Zimbabwe, three promising drought tolerant, high yielding, red speckled, and large seeded sugar bean varieties were submitted for distinct, uniform and stable (DUS) test in November 2013. These are as follows; DAB 51, DAB 52 and DAB 411. In Ethiopia, eight seed varieties were submitted to the release committee for release. They included five small white varieties (Ecabunci cross 4, Ecabunci cross 8, Ecabunci cross 11, Ecabunci cross 12 and Ecabunci cross 13) that out-yielded the standard check Awash-1 with a yield advantage of 10-15% and three small red *varieties* (SER 125, SER 128 and SER 194) that out-yielded the standard check (Dinknesh) with a yield advantage of 6-8%. Three varieties, KAT B1, KAT B9 and Navy-87 were approved for release. KAT B1 and KAT B9 were released in Kenya. KAT B1 was the best in seed color (yellow) and will be the first of the seed type. Considering all locations with similar maturity group as checks, KAT B9 gave more than 20% average grain yield advantage over Batu and 45% over Red Kidney. KAT B1 showed 8% yield advantage over the Batu and 32% over Red Kidney. Out of all these varieties, 22 were released (2009-2014) for drought areas whereas others were in the last stages of the development pipeline along with the six that were reported in phase I. This totals up to 28 varieties that were released directly with TL II project support in the period 2007-2014 (Tables 33 and 34). Most of the released lines had the yield advantage of 10-54% over the commercial varieties in on-farm trials with the additional trait of resistance to key pests and diseases and/or high grain Fe and Zn content. For example, the two varieties released in Zimbabwe were found to have an additional trait of high Fe content. It was probable that the other released varieties and lines in the pipeline had additional traits that needed to be identified and communicated for use in the seed delivery systems. In Zimbabwe, two bean varieties MG 38 (Cherry) & VTTT 925/9/1/2 (Sweet Violet) were released in Jun 2013 by the Crop Breeding Institute. MG 38 has an oval seed shape, drought tolerant, a red mottled seed coat pattern, and an acceptable seed size (44 g/100 seeds). The variety also recorded an attainable yield of 1,400 – 3,200 kg ha^{-1}. Sweet Violet was a very large seeded (55g/100 seeds) and red speckled sugar bean variety with an attainable yield of 1,400 – 3,300 kg ha^{-1}. Both MG38 and VTTT925/9/1/2 have high levels of tolerance to CBB and ALS. Seed-co also released one red speckled sugar bean variety, called SCBV07001, which performs well under irrigated conditions. In Kenya, two varieties were released by KARI, namely KAT-RM 001 and KAT-SR 01.

However in total, there are 73 newly released varieties in the six TL II participating countries ie, Ethiopia, Kenya, Malawi, Tanzania (N & S), Uganda and Zimbabwe in the period of 2007-2014 (Table 34). For the purpose of completeness, we have reported all the released varieties in this period realizing that a number of the released varieties were supported from other projects with or without leverage from TL-II with the same interest. Notably, the projects were Alliance for a Green Revolution in Africa (AGRA) and Pan African Bean Research Alliance (PABRA) that involved a number of donors but with an interest to the seed system's objective of the Tropical Legumes project. For instance, the varieties released in Uganda and South Tanzania were released before these countries were integrated into the TL II project while a number of varieties released in Kenya were supported by PABRA. In Kenya, from evaluation of 20 small red germplasms, five varieties were entered in NPT in the year 2014. Four varieties with root rot resistance from KARI Kakamega materials are at the DUS stage.

Table 33. Varieties released under TL II project (2007-2014).

No.	Variety Code	Year of release	Country	On-farm yield (t ha^{-1})	Yield advantage over check (%)
1	SUG 131 (Deme)	2008	Ethiopia	2200	116
2	A19 x OMNAZCr-02-11 (Batu)	2008	Ethiopia	2070	110
3	SNNRP-120 (Hawassa Deme)	2008	Ethiopia	2500	NA
4	GLP 2	2011	Ethiopia	2770	116
5	ECAB 0056	2011	Ethiopia	2617	110
6	02-04-11-4-1 (SARI-1)	2011	Ethiopia	2500	NA
7	ECAB 0060	2013	Ethiopia		
8	K132	2013	Ethiopia		
9	ECAB 0203	2013	Ethiopia		
10	ECAB 0247	2013	Ethiopia		
11	RXR 10	2013	Ethiopia		
12	ACC 4	2013	Ethiopia		
13	KAT B9	2014	Ethiopia		20-45
14	KAT B1	2014	Ethiopia		8-32
15	Navy 87	2014	Ethiopia		17-28%
16	KAT-SR 01	2012	Kenya		
17	KAT-RM-001	2013	Kenya		
18	VTTT 924/4-4	2012	Malawi	1.0	
19	SER 124	2013	Malawi		
20	VTTT 925/9-1-2	2013	Malawi		
21	SER 83	2013	Malawi		
22	BF 13607-9	2013	Malawi		
23	CIM 9314-17	2012	Zimbabwe		
24	SUG 131	2012	Zimbabwe		
25	Gloria (PC652-SS3)	2012	Zimbabwe	1.5 – 1.8	
26	NUA 45	2012	Zimbabwe	1.3 – 1.6	
27	MG 38	2013	Zimbabwe	0.8-1.1	
28	VTTT 925/9/1/2	2013	Zimbabwe	0.8-1.1	

Table 34. Varieties released in TL II project supported countries over a seven-year period (2007-2014).

S. No	Country	Varieties	Total number
1.	Kenya	KAT-SR 01, KAT-RM-001, §KK 15, §MN 14, §MN 17, §MN 19, *MAC 13, *MAC 34*, *MAC 64, §KK14, *Embean 118, *Embean 14, *Embean 7*, §Cardinal	14
2.	Ethiopia	ECAB 0060, K 132, ECAB 0203, ECAB 0247, RXR- 10, ACC4, KATB9, KATB1, Navy 87, ECAB 0056, GLP 2, DA-NAZCR-02-12, RXR 10, SARI 1	14
3.	Zimbabwe	CIM 9314-17, SUG 131, Gloria, NUA 45, MG38, VTTT 925/9/1/2, SCBV 07001	7
4.	Malawi	VTTT 924/4-4, SER 124, VTTT 925/9-1-2, SER 83, BF 13607-9, §KK03/KK25/68/S-F, §KK25/MAL/19/S-F, §MAL/KK25/9/S-F, §MAL/KK35/443/S-L, §K25/MAL/112/S-F, §NAG/KK25/168/S-F, §KK25/NAG/184/S-L, *NUA 45, *NUA 59	14
5.	§Tanzania	Njano-Uyole, Wanja Cross, NRI 06 E13, NRI 05 P200, Roba-1, Calima, Uyole, Pasi, Fibea, Rossela	10
6	§Uganda	NABE 15, NABE 16, NABE 17, NABE 18, NABE 19, NABE 20, NABE 21, NABE 22, NABE 23, NABE 26C, NABE 27C, NABE 28C, NABE 29C	13
	Total		73

*Partial funding from TL II (other support were from PABRA and AGRA)
§PABRA and/or AGRA support

Lessons learned

- Factors affecting the photosynthate remobilization to grain are key in determining drought resistance and probably yield potential as well. Pod Harvest Index (seed weight / total pod weight including seed) was found to be a viable selection criterion for drought resistance with positive effects on non-drought yield as well. While the conventional selection for stress tolerance or resistance was known to limit the yield potential, our work suggests that drought resistance traits can contribute to yield in favorable environments. Thus, drought resistance does not have a yield penalty.
- Even highly vulnerable farmers grow for the market. While one might expect that farmers living "on the edge" might be primarily concerned with food security, the baseline study showed that they are equally concerned with markets for income. Moreover, they maintain a "drought inferior" variety with the hope of selling some beans, and maintaining a preferred culinary type for home consumption. Thus, obtaining the drought resistance in types with best grain size and color in the market poses a major challenge to the breeders. Farmers are well aware of the genetic differences in drought resistance varieties and rank drought resistance as one of the highly considered traits for a preferred variety.
- Market opportunities have a dramatic influence on the usage of inputs and total yields. The case of Ethiopia is striking, where an assured market condition, combined with effective extension and seed systems, led the farmers to improve crop management and double national yields within eight years.
- On the down side, the benefits of degree training were limited because of staff instability. Only one scientist who had achieved higher degrees is currently working in the respective programs (although one may still reincorporate). Further, all but one studied in African universities. Therefore, this is not a cure for this enduring problem. Efforts for training technicians need to be intensified, as they are typically more stable in their posts than scientists.
- Farmers are willing to adopt new varieties once they are convinced that the variety will meet their requirements. In addition, their awareness about bean production and productivity systems as well as sensitization on the type and kinds of varieties enables the creation of market for seed companies especially for the new varieties. This has also triggered increased interest of individual farmers, private farms and farmers groups to venture in bean farming as a mode of business. However, they require remedial training after some years for enhancing their technical capacity and adopting multi-crop approach as both farmers and seed companies require several crops at a go. For instance, the seeds produced by the trained seed entrepreneurs are of good quality, and are highly demanded and such activities should be expanded.

Gaps in achieving intended outcomes

- Data recovery was inadequate both for GIS analysis and for gauging with statistical precision. It requires improvement in order to be more systematic in targeting the outputs and creating impact.
- The process of evaluating the potential of the sister species (*Phaseolus acutifolius* and *P. lunatus*) was not advanced enough for either determining their utility or identifying promising materials, which is still being addressed.
- Advances in combining drought tolerance trait with other traits in Andeans (nutrition) were slow, especially on the side of bio fortification and difficulties were encountered in obtaining adequate levels in bush types (Greatest progress is in climbing types of the Andeans).
- Consumer demand for energy efficiency was not considered during breeding both in rural and urban areas (eg, short cooking time).

- To increase bean productivity, the market should play a bigger role in breeding priorities. For example, yellow bean varieties are in high demand due to good palatability /short cooking time.
- Though several degree trainings were offered to the NARS scientists, the retention of newly graduated staff was limited.

Vision

From the phase I research, it became clear that target strategies along the value chain are required to address the problem of drought, declining soil fertility and in overcoming the constraints in seed and grain markets. Such investments are inter-related and are required to achieve a combined effect. In other words, issues related to germplasm improvement, management practices or extension and marketing need to be addressed in order to achieve maximum beneficial and equitable impacts.

In the course of phase I, drought research was firmly established as a research priority within PABRA at all levels. Field testing was practiced on a routine basis. Equipment was put in place for more detailed evaluation. In collaboration with TL I, the scientific capacity was enhanced through the post-graduate training. In phase II, the impact of TL II was expanded by involving other partner countries within PABRA with focus on enhancing the capacity by understanding G x E within drought trials, in conjunction with TL I. Breeding continued to address both terminal and intermittent types of drought while minimizing the trade-offs between large harvests and good culinary traits or marketability. The biodiversity of the *Phaseolus* genus through interspecific crosses and direct use, for both biotic and abiotic stress tolerance required more exploitation. Emphasis was laid on creating farmer-, market- and consumer-acceptable germplasm with multiple stress tolerance and enhanced nutritional value. Important culinary traits (eg, less cooking, low flatulence, keeping quality or taste) and market preferences (eg, seed shape and color) in Ethiopia were identified through the baseline studies. Currently, seed color and seed shape are the key attributes considered while grading beans available in the market for export in Ethiopia and are likely to become more important determinants of variety choice by farmers in the near future while the existing varieties with flat shape or less brilliant color could be disadopted.

Soil fertility is clearly a major confounding factor in the evaluation of drought lines and should be dealt with in a complementary fashion ie, by exploiting both genetic and crop management techniques to assure that drought tolerance is fully expressed. In phase II, there is a need to expand beyond the varietal introductions and focus on fertilizer associated with specialized seed production. In other words, improvement in soil fertility is key for all zones, especially stressed ones. Thus, N fixation, moderate use of P and manures (green and organic) might be among the themes to be pursued (in conjunction with the use of drought-tolerant varieties).

Pests and diseases like BSM, *Macrophomina,* CBB, BCMV and aphids (etc.) were of major importance in the drought-prone zones. Lessening their effects was recognized as a means to stabilize and increase the production. TL II in phase II linked up with the ongoing integrated pest and disease management research under PABRA to integrate good practices in managing these constraints. Lines developed for BSM, CBB, *Zabrotes* sp and "bc3" gene were deployed and evaluated in phase II. Further, with the development of new populations and wider evaluation techniques to identify resistance QTLs, this has turned to be an ongoing activity. With the development of SNP marker for a number of key diseases, the widespread application of markers for biotic stresses in both bush and climbing bean types required continuous promotion. Thus, the prospects of effective implementation of marker assisted selection (MAS) for drought per se continue to depend on obtaining relevant and reliable phenotypic data.

Seed systems

Common bean seed systems

Using innovative institutional arrangements to catalyze the sustainable production and supply of quality seed of improved bean seed varieties by small holders in SSA

Tropical Legumes II seed system activities were mainly implemented in Ethiopia, Kenya, Tanzania and Uganda where a pluralistic bean seed system, based on multiple but complementary seed producers (individual seed entrepreneur, companies, parastatals and farmer groups), was deployed with very limited support (training of seed producers). Seed system activities were also expanded to Malawi and Zimbabwe (TL II countries involved in breeding). The seed producers were also supported by a range of public–private partners (NGOs, farmer organizations and public extension) providing complementary services, eg, skills and knowledge enhancement/training, awareness creation, seed quality control, and financial and material support depending on the respective country/region specificities. Partners developed joint work plans for project research and implementation, and agreed upon its roles and responsibilities. Many of the partners also signed formal Memoranda of Understanding (MoU) and several incorporated TL II work plans in their own organizational yearly program plans. Bean Seed systems activities under TL II were, thus, implemented as part of country-led and nationally owned legume research for development plans (eg, seed road maps) and strategies. The engagement of the private sector by the TL II project (companies, individual seed entrepreneurs, NGOs and farmers' organizations) greatly enhanced the prospects for sustainability of the project outcomes. However, support from NARS and empowerment of development partners will remain essential in building an effective role of the private sector. Bean production and market opportunities are growing and attracting an increasing number of players, who are getting involved and establishing a strong and durable linkage in the bean innovation system across TL II countries.

Partnership in seed systems

More than 106 partners were involved in TL II bean seed systems in phase I, including NARS, private sector companies, specialized seed producers, governmental and non-governmental organizations, community- and faith-based organizations, and grain traders. In phase II, common bean seed systems in Ethiopia, Kenya, Uganda and Tanzania involved 67 farmer groups, 585 seed entrepreneurs, 15 seed companies, and 22 government organizations/institutions. Some of the successful bean seed system models practiced in phase I included three foundation seed production models (direct production through and by NARS seed unit with contractual farmers, private seed companies, and farmer cooperatives), four models of decentralized seed production (district/government officers supporting individual farmers, NGOs supporting individual farmers, farmer cooperatives/unions, and community-based seed production), and six seed delivery models (small pack sales at open markets, country stores, agro-dealers, and seed/grain traders, exchange system through seed loans and direct farmer-to-farmer diffusion).

Skills and knowledge enhancement

One of the pillars of expanding and sustaining the outcomes/outputs of the project is to build skills and knowledge of partners along the bean value chain. During phase I of the TL II project, training for trainers in the areas of bean seed production/post-harvest management and general bean agronomy were carriedout for 549 trainers (Ethiopia: 350 and Kenya: 189), who trained 35,943 farmers (women: 17,877 and men: 18,066). Further, a total of 54,733 farmers (women: 23,642 and men: 31,091) gained knowledge on bean production by attending a total of 193 demonstrations and seed fairs. Similarly, in phase II, a total of 135 trainings were conducted for 6,618 farmers/bean seed producers and 694 extension officers (4,596 in Tanzania, 1,302 in Kenya, 595 in Uganda, and 442 in Ethiopia). Improved variety awareness programs were implemented in Ethiopia, Uganda and Tanzania. For instance, 11,360 leaflets with information on bean seed production (6,000 in Uganda, 5010 in Tanzania and 350 in Ethiopia) were distributed. Through financial support from PABRA in Zimbabwe and Malawi, TL II bean team (from Kenya) extended the seed system's training and enhancement of skills and knowledge.

Awareness creation

A multi-media communication strategy and user-friendly tool for variety promotion and training manuals were adapted/developed/produced and shared with partners across the participating countries. Training modules, manuals, leaflets/flyers, and information bulletins were also produced. For instance, about 2,507 bean seed production/business manuals in four languages were produced and shared with partners in Ethiopia (Amharic), Kenya (Oromifa), Tanzania (Swahili), and Uganda (Luganda). Mass communication was also used to disseminate knowledge about new bean varieties and their seed source through several radio programs (12 in Ethiopia and 30 in Tanzania); TV programs (7 in Ethiopia, 15 in Tanzania, and 1 in Uganda); 3 articles in local newspapers on bean varieties in Ethiopia, and leaflets in Tanzania. Farmer field schools, field days, and seed fairs were carried out at selected learning centers annually. In Tanzania, field days (10 per season), open days and seed fairs (6), farmer field schools (8) had become regular tools for creating awareness about new varieties. Over 11,206 farmers/legume seed producers (1,990 in Tanzania, 5,535 in Uganda, 2,300 in Ethiopia and 1,381 in Kenya) participated in field days and farmers' fairs held on-farm locations. Strategies that create variety awareness were also implemented in private sector companies and farmer cooperatives. The partners included Dodoma Transport, Kilimo Markets, Beula Seed Co. Ltd, Tanseed International Co. Ltd, Stormy Hall Seed Growers, ARI-Uyole farm operation in Tanzania, several Farmers' Cooperative Unions (FCUs), Oromo and Southern Seed Enterprises, Alemayehu Farm and Haile Wako in Ethiopia, and several other companies (CEDO, Pearl, FICA and Victoria) and farmers' organizations in Uganda.

Seed production and supply

As a result of a strong partnership, supported by appropriate capacity building and availability of improved and user preferred varieties, seed production and supply significantly increased**.** Between 2007 and 2013, during phase I (2007-2010) and the first two years of phase II (2011-2013), 42,238 tons of assorted seed classes were produced across the implementing countries, as illustrated in Table 35. As a result of the lessons learned and the functional partnership established in the first phase (2007-2010), seed quantity increased drastically in the second phase (30,882.9 tons).

Table 35. Tons of bean seed produced across target countries (2008-2013).

	Assorted seed produced (tons) between 2008-2013							
Country	2007/8	2008/9	2009/10	2010/11	2011/12	2012/13	2013/14	Total
Ethiopia	386.2	2128.0	7557.0	2820.3	5133.2	5591.70	NT	23616.45
Kenya	377.4	452.8	453.6	574.0	710.0	2074.0	NT	4641.92
Malawi	NA	NA	NA	1044.5	863.7	1168.0	NT	3076.20
Tanzania	NA	NA	NA	538.9	678.9	735.8	NT	1953.6
Uganda	NA	NA	NA	1067.0	3559	4229.0	NT	7788
Zimbabwe	NA	NA	NA	350.0	353	458.9	NT	1161.9
Total	763.56	2580.93	8010.68	5327.70	11297.8	14257.4	NT	42238.0

NT: No data as yet
NA: Not applicable

Uganda and Tanzania joined TL II seed systems in 2010/11 as anchoring countries while Zimbabwe and Malawi only received limited technical support in the form of training. TL II experiences were shared by PABRA resource people from the anchoring country, particularly, Kenya (KARI) and CIAT.

Innovative approaches to target the poor and women farmers

Several innovative approaches were tested to avail seeds to poor farmers. The use of small seed packs is based on the field insights that farmers want to have access to new varieties, and some also were willing to pay for the certified seeds at affordable prices. This implies that seed simply has to be marketed at affordable size and price in places that can be easily accessible to farmers and by farmers' trusted vendors (or who may be held accountable to buyers). For instance, small seed packs (of 0.05, 0.1, 0.25, 0.5, 1, 2, 5, 10 and 25 kg sizes) were extensively used in bean seed dissemination in all the target countries (Table 36). The small pack approach gained popularity as the most efficient and cost-effective means of reaching more farmers with affordable quantities of seed and wide range of preferred varieties. For instance in Kenya, Dry-land Seed Company/FreshCo Seed Company, and KARI Seed Unit packed and sold 89 tons of seed of drought-tolerant bean varieties in 0.1 kg, 0.5 kg, 1 kg and 2 kg packs. This approach, which was initiated by NARS (public sector) bean seed system, has been extensively adopted by the private sector to enhance the extent of reach to the smallholder bean farmers who otherwise could not have access to the quality bean seeds. Moreover, PABRA is expanding the use of small packs to other countries (eg, Burundi, Cameroon, Madagascar and Rwanda) as well as crops other than beans. In Rwanda, more than 50 tons of bean seeds were sold to the smallholder farmers in small affordable packs.

Table 36. Amount of small bean seed packs distributed, by crop per country during 2007- 2013.

Country	Number of Small seed packs
Ethiopia	176,858
Uganda	20,129
Tanzania	3,045
Kenya	108,500
Total	308,522

In Kenya, seed loan (pay back) approach was implemented in partnership with 12 NGOs and ten district agricultural offices. More than 3 tons of drought tolerant bean seeds were supplied by TL II Project and 80 tons by Ministry of Agriculture, reaching over 1 million farmers.

Decentralized production of quality declared seed was also adopted to reduce the cost of accessing seed, especially in the areas not reached through the formal system. The premise is that, farmers are capable of producing high-quality seed when provided with technical support and sufficient start-up seeds. The neighboring farmers prefer purchasing seeds from known sources. Moreover, the farmers do not incur extra costs in accessing such seeds.

Variety use

The use of improved varieties is the key to increasing crop productivity in the context of smallholder farmers. Out of 132 bean varieties released before 2007, 67 are still in seed production phase while out of 87 varieties released after 2007, 56 are still in production, which indicates a retention rate of 50.76% for the varieties being used that were released before 2007 and 64.37% of varieties released after 2007 (Table 37). This demonstrated that a pluralistic and integrated seed system would be efficient in getting new varieties in the hands of farmers and replacing the older ones.

Table 37. Number of bean varieties released by period of release, varieties in production during 2007-2013.

Country	Total number of varieties released ***before 2007***	Number of varieties released ***before 2007*** which are in seed production	Total number of varieties released ***after 2007***	Number of varieties released ***after 2007*** which are in seed production
Ethiopia	37	5	16	8
Uganda	16	8	13	13
Tanzania	38	32	10	3
Kenya	16	14	30	17
Malawi	20	6	10	7
Zimbabwe	5	2	8	8
Total	132	67	87	56

Evolution of bean seed producers

Successful bean seed systems need to be sustainable and carried out by several partners/actors who respond to the farmers' seed demand. During phases I and II of the TL II project, there was a progressive evolution of four major categories of bean seed producers (private seed companies, public seed enterprises, individual seed entrepreneurs, and farmers' organization/ cooperatives) supported by government and NGOs. For instance, the number of individual seed entrepreneurs increased by 383% (from 186 to 899) while the number of farmers organizations increased by 341% (from 98 to 432) between 2007 and 2013 (Table 38).

Table 38. Evolution of the number of bean seed producers per partners/actors category per country (2007-2013).

	2007 (start of TL-2)				2013			
Country	PSC	PSE	Indiv	FO/C	PSC	PSE	Indiv	FO/C
Ethiopia	1	3	5	13	8	4	14	18
Uganda	20	1	0	54	27	1	0	92
Tanzania	7	1	0	4	7	1	2	8
Kenya	2	1	30	20	4	3	230	300
Malawi	3	1	150	3	5	1	650	7
Zimbabwe	6	1	1	4	8	2	3	7
Total	39	8	186	98	59	12	899	432

*PSC=Private seed companies, PSE= Private seed enterprises (University/Parastatals), Indiv= Individual seed enterprises, FO/C= Farmers organizations/ cooperatives supported by Government or NGOs, farmers crop

Lessons learned

Seed systems and delivery

- Introducing and popularizing new varieties require collaboration with partners and stakeholders. Therefore, the need to identify effective partners who share the same vision and interests is very important. For instance, strong partnerships are cemented through the formation of innovative platforms resulting in more effective and efficient bean seed system.
- The small pack seed dissemination approach has worked well in view of popularization and testing of new varieties while also targeting the farmers with all sizes of land (small to large). For instance, in Ethiopia, in the past, improved bean seed were only sourced from seed enterprises that had the capacity to meet less than 10% of the seed demand. Decentralized bean seed production and use of small seed packs have improved the seed supply capacity, which is currently estimated to meet more than 50% of seed demand. Whereas, in Kenya the seed loan and small seed packs approaches have proved popular for variety promotion and dissemination especially in case of poor farmers and women in particular. However, there is a need for a joint public-private initiative with a progressive vision of empowering the private sector to sustain and expand this approach.
- Integrated monitoring and evaluation systems helped to track the changes and scaled up good practices.
- Level of investment in seed systems and institutions is an important factor for determining the progress. Inadequate funds can slow down up-scaling of seed production activities and can even break the seed chain (considering that building up again would need substantial time and resources).
- Informal seed systems cannot be sustained without addressing the seed storage needs, both at the individual and community levels by farmer groups involved in seed production.
- Given the challenges of bulky nature and storage of groundnut seed, building the seed production supply chain between the seasons of two locations can be considered as a good option. This will also cut down the transportation charges thus bringing down the input cost.
- New organizational arrangements are needed for up-scaling the seed production, as partnerships with government agencies that are involved in seed production, certification and distribution are critical for success.
- More robust seed system models are needed for up-scaling the adoption of new varieties. The community seed bank system that relies on the use of quality declared seed can improve the technology reach of the project and needs further improvement. This is currently being investigated in Tanzania.
- Impact-oriented core team for a program is key for developing the seed systems in drought-prone regions, which should be geared to reach the poor. A program cannot be impactful unless the leader and the team devise strategies for solving the bottlenecks and reaching the end users. Otherwise, a program might end up with results like 'lots of seed produced' on the supply side.
- The professional and transparent engagement of partners is crucial for the widespread success of a program. This includes formal clarification of expectations and responsibilities and clear budget allocations. Productive partnerships require ongoing facilitation. Moreover, effective partners, private sector, NGO, unions and beyond, who shall continue production and deliver beyond the project need to be identified (after TL II exit). A better characterization of successful partner attributes could be useful.

- Unavailability and access to basic or certified seeds remains a bottleneck. Despite high demand and interest of the the drought-tolerant varieties, basic seed production is slowly being opened to the private producers for example, in Ethiopia, EIAR/ Melkassa has actively engaged two private seed farms who produce basic seed of two most popular varieties, Nasir and Awash Melka. These two producers make the basic seed available to the other producers of certified and quality declared seed in Ethiopia.
- Emergency seed distribution can clash with the project goals. Emergency supply orders directly compete with the project needs for foundation or certified seed. Further, free distribution of seeds clash with the project objectives of selling seed and creating demand among the small farmers. Emergency and Development efforts in the seed system development need to be better coordinated and designed to complement each other. Some major improvements have been made in Kenya wherein the Government of Kenya will be substituting seed loans for direct free distribution, at least in the eastern drought-prone areas.

Gaps in achieving intended outcomes: Seed systems and delivery

- Although much efforts have been employed to introduce new varieties in order to meet the seed road map requirement, the cultivation of obsolete varieties (low yield and susceptible to diseases) and non-availability of quality seed of improved varieties still remains a challenge in the quest for higher productivity.
- Though there is an increasing participation of seed companies, the limited commercial perspective of legume seed poses a hindrance for the involvement of private sector on very large scale.
- The majority of seed companies do not want to invest in the popularization of new varieties. Their interest in the legume seed increases mainly when the varieties are already popular.
- In some countries, seed policies and certification procedures have not changed substantially in favor of the informal seed sector. There is need to engage policy makers to recognize the role of the informal seed sector especially in the supply of legumes seed.
- With the increasing demand of seed varieties, the basic seed tends to be a limiting factor especially in some countries where its production is still centralized and remains under the control of NARS or other public institutions.
- In some areas, inadequate marketing and promotion strategies hinder the sustainability and viability of farmer seed entrepreneurs.
- Though good efforts have been deployed and encouraging results have been achieved, a mass legume production to enable the commercialization of grain legumes in many countries has not yet been achieved.
- There is need for continuous training and creation of awareness about the new varieties, quality seed production, safe storage and use of small seed packs.
- The price of certified seed (CS) marketed by the companies increase with the increasing distance to the rural localities thus making it unaffordable for the poorest farmers.
- Need for creation of assured irrigation facilities at the NARS level for producing the basic and breeder seeds in order to maintain the uninterrupted flow of seed production cycles
- The adoption of farmer-preferred varieties in the target locations is at different levels and restricted to the project pilot sites.
- The supply of seeds to the target locations is not sufficient to meet the target of achieving 20% replacement with the quality seed of improved varieties.

What worked

- Linking the breeding and seed systems accelerated the timely delivery and usage of improved varieties.
- Institutionalizing partnership in the production and delivery of bean quality seeds across the countries and increasing the efficiency in using resources effectively.
- Skills and knowledge enhancement along the value chain helped to expand and sustain the project results.
- Institutionalizing the seed delivery system through appropriate channels improved the production and delivery of quality seed.
- Though the alignment to seed road maps was a new concept, it remains as the seed systems guide.
- Involving the agri-development NGOs in up-scaling the technologies and seed delivery system worked well.
- Involving seed certifying agencies in monitoring the seed production areas held by the smallholder farmers that produce pure seeds of various seed classes, which would fetch higher price and help in entrepreneurship.
- Some community seed producers were transformed into seed cooperatives leading to increased seed delivery.

What did not work

- Generally, the situation of national seed systems in the target countries varies considerably and therefore a country-specific approach is needed. Success requires engaging policy makers, and institutional innovations in linking the farmers with the markets through collaborative research.
- In most target countries, the availability and access to basic seeds acts as a bottleneck. It remains solely in the hands of the NARS, limiting the speed of accessing the new varieties and initial seed by seed companies or other seed producers.
- Lack of resources and infrastructure of NARS is a major challenge to handle large scale breeder or basic seed production to feed other classes of seed.

Capacity building

Our goal was to establish a working group, within the PABRA network, with expertise in drought research. While formal degree training formed a part of this plan, an equally important part dealt with aquiring skills in field management and physiological analysis. All progress in abiotic stress resistance and drought resistance must be dependent on the reliable field evaluation. This also applies to prospects for marker assisted selection, which must be initiated with reliable phenotypic data. Trials for managed drought must incorporate calibration of drought stress, starting with quantification of the amount of moisture in the soil. While scientists must understand the principles, they should also appreciate the methods and logistics of field management to be able to supervise effective field research. Technicians should be fully capable of executing the field studies, assuring uniformity across the field, and mastering the logistics of the field work (eg, physiological sampling), so that the study could be carried out efficiently with minimum errors. Often the technicians are the most stable element within a research program, as scientists, should dedicate time to administrative duties. Thus, in addition to the formal degree training, we also made an effort to establish capacity among both the scientists and technicians of the region for practical field oriented drought research. Practical skills included quantification of soil moisture content, sampling of field grown plants, distribution of plant biomass in different plant parts, biomass drying, and data analysis.

Two field workshops were held in January 2008 at Katumani and in May 2008 at Malawi. Additionally, a physiology assistant from CIAT-Colombia visited each participating country to supervise the on-site work, and to give advice on phenotyping protocols and data analysis.

Degree and technician training was undertaken with four PhD degrees and six MSc degrees granted scholarships. Until now, three PhDs have been completed and one MSc degree has been awarded. Degree training proved to be an excellent bridge between the TL I and TL II projects as several theses were derived from the topics of TL I or were closely akin to the themes developed in the project.

Berhanu Amsalu of Ethiopian Institute of Agricultural Research (EIAR), Melkassa Research Center completed his PhD study at the University of Pretoria, Republic of South Africa. His study focused on the aspects of nitrogen fixation in common bean under drought conditions, focusing on the activity of protease inhibitors as indicators of nodule health. As known, when legumes come under stress, the nodules start degrading under the influence of proteases that break down the proteins including nitrogenase. Lower activity (or conversely, more activity) of protease inhibitors indicates the nodule health, especially under stress when fixation tends to decline. Berhanu initiated a greenhouse study of soybean (his thesis topic and its results), which could be relevant for biological nitrogen fixation (BNF) of soybean under stress as well. Subsequently, Berhanu continued the greenhouse studies on common bean with the high nitrogen fixing line BAT 477, the poor fixer DOR 364, and their progenies. He also carried out a field trial with the same genotypes. Finally, he executed a trial looking at the interaction of drought x P levels under the hypothesis that the protease degradation of nodules is a generalized mechanism in response to the stress, and BAT 477 will show low activity of proteases under both moisture and low P stress. He is currently assaying the protease activity to test this hypothesis.

Godwill Makunde of Zimbabwe also completed his PhD study at Free State University, RSA. His university expenses were financed under TL II project and his research was supported mostly by TL I. His research involved a physiological analysis of the TL I reference collection, which is a sub-set of 202 accessions from the CIAT core collection. The re-selection was based on detailed molecular analysis by employing a more focused attention onrace Durango from Mexico and Andean types. These two groups were emphasized with an ideology that race Durango might yield new sources of drought resistance and one could utilize the variability existing in the Andean types for more improvement. Godwill executed the physiological sampling and analyzed the reference collections in CIAT-Colombia under intense terminal stress. He also conducted root phenotyping studies at CIAT-Colombia on selected genotypes from the reference collection. With data from several sites and seasons, Godwill performed an analysis on the association mapping using the SNP data generated at UC-Davis in the group of Doug Cook. This will be the first such attempt in common bean varieties.

Felix Waweru graduated from the University of Nairobi, Kenya with an MSc degree in a study shared with TL I project. Felix carried out a field phenotyping of RILs of a cross of BAT 881 x G21212. BAT 881 is sensitive to abiotic stress and G21212 is relatively resistant. G21212 was first recognized to be tolerant to low soil P and subsequently it also proved to have a good response to drought and aluminum toxicity. It also presents an excellent remobilization of photosynthate to grain under stress, which appears to be its mechanism of multiple stress resistance. A genetic map exists for this population, and the data of Felix could help to elucidate further the inheritance of this trait. Felix also analyzed a regional collection of landraces and lines, compiled under TL I project.

Lizzie Kalolokesya of Malawi completed an MSc degree at the University of Zambia. Lizzie was brought on board when Isaac Fandika withdrew to study in New Zealand. Lizzie carried out MAS for disease resistance in collaboration with TL I project. Lizzie had the opportunity to carryout a part of her research in the installations of ARC-Potchefstroom in South Africa, which helped in broadening her perspectives and working in collaboration with an ongoing practical breeding program.

Mable Nabatregga: Mable is doing her Master's degree at Makerere University in Uganda. Her study is directed at determining the genetic basis of phenotypic traits associated with the drought tolerance ability in common bean using the SEQ1027 x BRB191 population and the identification of molecular markers linked to these traits. She will be setting up trials at Namulonge research station of NACRRI.

Others were Daniel Ambechew, Scholastica Wambua, Yetagesu Tebeka, Bikara innocent and Alemeyahu Fitsum (Table 39).

Table 39. Degree level training supported in TL I and TL II.

Name of student	Degree	Gender	Field	Country	Current status
Waweru Felix Muchiri	MSc	M	Plant breeding	Kenya	Finished
Susan Gachania	MSc	F	Plant breeding and Physiology	Kenya	Incomplete
Lizzie Kalolokesya	MSc	F	Plant Breeding	Malawi	Finished
Mable Nabatregga	MSc	F	Plant Breeding	Uganda	Ongoing
Daniel Ambechew	MSc	M	Plant Breeding	Ethiopia	Ongoing
Scholastica Wambua	MSc	F	Agri-business/Seed systems	Kenya	Finished
Yetagesu Tebeka	MSc	M	Agricultural Economics/Seed systems and objective 1	Ethiopia	Ongoing
Bikara innocent	MSc	M	Agricultural Economics/seed systems and objective 1	Uganda	Ongoing
Makunde Godwill	PhD	M	Plant Breeding/Physiology	Zimbabwe	Finished
Alemeyahu Fitsum	PhD	M	Plant Breeding/Physiology	Ethiopia	Ongoing
Teshale Assefa	PhD	M	Planting breeding	Ethiopia	Finished
Berahanu Amsalu	PhD	M	Planting breeding	Ethiopia	Finished

Degree training: operational support

Teshale Assefa, formerly of EIAR, Melkassa, Ethiopia, completed his PhD degree at the University of Padua in Italy. Teshale worked on the drought tolerance and canning quality of navy beans, analyzing the RIL of the cross SXB 405 x ICA Bunsi developed at CIAT. The former genotype is a rustic and low fertility tolerant line developed for drought tolerance. The latter is a small white canning type developed years ago in the national bean program of Colombia. Teshale selected 78 lines based on the grain type and planted them under managed drought and irrigated conditions in Melkassa Station. A physiological analysis showed that the parameters of both biomass accumulation and PHI contributed to the final yield, again validating the role of remobilization of photosynthate to grain as an important drought resistance mechanism. Teshale also involved farmers and traders in the evaluation process, bringing farmers on station for this activity. Finally, an evaluation of canning quality was carried out on eight elite lines. As a result, it was found that most of the lines were acceptable and one of the most drought resistant lines was also rated excellent for its canning quality. Lines were distributed throughout the region for evaluation by other partner countries. Teshale also received training in CIAT-Colombia on evaluation of bruchid resistance.

Susan Gachania received support towards her MSc degree research at the University of Nairobi. Susan worked on the physiological analysis of the fast track nursery. Unfortunately, Susan left her studies before finishing her degree.

Table 40. National program scientists trained under the TL II project in phase I.

Country	Name	Gender	Position	Institute
Ethiopia	Amsalu Berhanu	Male	Agronomist	EIAR
	Gebeyehu Setegn	Male	Research Physiologist	EIAR
Kenya	Gachania Susan		Student	University of Nairobi
	Musyoki Robert	Male	Researcher biotechnologist	Kenya Seed Company
	Okwuosa Elizabeth	Female	Researcher Breeder	KARI
	Wachira Geofrey	Male	Research Assistant	University of Nairobi
	Macharia David	Male	Breeder	KARI
Malawi	Fandika Isaac	Male	Agronomist/Physiologist	DAR
	Kalolokesya Lizzie	Female	Research Assistant	CIAT – Chitedze
	Chisale Virginia	Female	Breeder	DAR
Tanzania	Msaky John	Male	Agronomist	SARI
	Slumpa Simon	Male	Entomologist	SARI
	Kweka S.O.	Male	Breeder	SARI
Zimbabwe	Makunde Godwill	Male	Breeder	Crop Breeding Institute

In addition to the graduate level training, high priority was placed on technicians for their role in the daily execution of the field trials. Thirteen technicians were trained in the first year in the basic techniques of crop physiology and monitoring the soil water content (Table 41). Plant sampling was also practiced to estimate the biomass level at mid-pod fill and the components of harvest index at harvest time. However, this is an activity that must continue and be reinforced, as the technicians are the backbone of every research program. Expanded effort should be given to this area in the near future.

Table 41. National program technicians trained under the TL II project.

Country	Name	Gender	Position	Institute
Ethiopia	Lemlem Micheal	Male	Technician	EIAR/MARC
	Jemal Abdulshikur	Male	Technician	EIAR
	Dagne Belete	Male	Technician	EIAR
Kenya	Mutinda Duncan	Male	Technician	KARI
	Mwangi John	Male	Technician	University of Nairobi
Malawi	Banda Raphael	Male	Technician	DAR
	Ngwira Evelyn	Female	Technician	DAR
	Chibwana Willard	Male	Technician	DAR
Rwanda	Mukankubana Domitilla	Female	Technician	RAB
	Gasigwa Evariste	Male	Technician	RAB
Tanzania	Kisamo Alex	Male	Technician	SARI
	Mawalla Rogast S	Male	Technician	SARI
Zimbabwe	Mudzamiri Clemence	Male	Technician	DRSS
	Gachange N.	Male	Technician	University of Zimbabwe

Capacity building was also a priority under the TL I project, which supported students financed under TL II with research topics and research costs. Non-degree training was also carried out through several workshops in order to prepare breeders for the application of molecular markers (Table 40). Seven-day training was conducted for introducing the SNP genotyping and the IBP as a new tool for breeders at CIAT-Kawanda in May 2013. The training included various aspects, like field experimentation, data analysis, multi-environment trials to test for local adaptation, disease phenotyping under controlled conditions, planning crosses, reviewing the bean/PABRA breeding strategy, etc. Twenty-nine bean scientists (breeders, pathologists and agronomists) from 13 countries (DRC East and South, Kenya, Zimbabwe, Ethiopia, Ghana, Mozambique, Rwanda, Burundi, Uganda, Zambia, North and South Tanzania, Malawi, and Madagascar) attended the training (Table 42). The training was facilitated by trainers from CIAT (Colombia, Malawi, Tanzania and Uganda) and Makerere University.

Table 42. National program scientists trained under the TL II project in phase II.

Country	Name	Gender	Position	Institute
Burundi	Eric Nduwagira	M	Student (MSc)	ISABU
DRC East	Antoine Lubobo Kanyenga	M	Researcher/Breeder	INERA/HP+
DRC South	Illunga Meshac	M	Researcher/Breeder	INERA
Kenya	Arunga Esther	F	Researcher/Breeder	Moi University
	Kamau Eliezah	M	Researcher/Breeder	KARI
	David Macharia	M	Researcher/Breeder	KARI
Ethiopia	Daniel Ambachew	M	Researcher/Breeder	EIAR
	Kassaye Negash	M	Researcher/Breeder	EIAR
	Kidane Tumsa	M	Researcher/Pathologist	EIAR
	Tedla Tazene Yayis	M	Researcher/Breeder	EIAR
Ghana	David Appiah Kubi	M	Researcher/Breeder	
Madagascar	Waltram Second Ravelombo	M	Researcher/Breeder	FOFIFA
Malawi	Virginia Chisale	F	Researcher/Breeder	DAR
Mozambique	Divage Belarmino	M	Student (MSc)	IIAM
Rwanda	Emma Uwera	F	Student (MSc)	RAB
	Floride Mukamuhirwa	F	Student (MSc)	RAB
	Justin Tuyiringire	M	Research Assistant	RAB
Tanzania	Luseko Chilagane	M	Student (PhD)	SUA
	Micheal Kilango	M	Researcher/Breeder	UARI
	Tryphone Muhamba	M	Researcher/Breeder	SUA
	Papias H. Binagwa	M	Research assistant	SARI
Uganda	Gabriel Ddamulira	M	Student (PhD)	NACRRI
	Mable Nabaterrega	F	Student (MSc)	CIAT/MUK
	Moses Kiryowa	M	Student (PhD)	NACRRI
	Paparu Pamera	F	Researcher/Pathologist	NACRRI
Zambia	Lorraine N Chilipa	F	Research assistant	ZARI
Zimbabwe	Bruce Mutari	M	Researcher/Breeder	CBI/DRSS

At the initiation of the TL II project, a consultant was contracted to review the state of infrastructure and the suitability of the experiment stations for drought research. A characterization of nine research stations was carried out to identify the strengths and weaknesses of each site with regard to the soil and water quality and infrastructure needs in order to make recommendations on planting dates for obtaining the desired level of stress. The sites included were Melkassa, Ethiopia; Thika, Kenya; Kabete, Kenya; Katumani, Kenya; Kiboko, Kenya; Kandiyani, Malawi; Kasinthula, Malawi; Chiredzi, Zimbabwe; Selian, Tanzania; and Madiira, Tanzania. The sites were evaluated for water quality, soil water holding capacity, existence and/or state of irrigational facilities, weather patterns, and implications for planting dates. A report on this study is available.

Installation of irrigational facilities and acquisition of drought phenotyping equipment

While equipment was offered to all programs, in the second year the Bean Program, Selian elected to forego more equipment purchase in favor of obtaining a better irrigational system to facilitate the managed drought nurseries by using an existing bore hole as a source of water. Options were studied and a solar powered pumping system was purchased as a more economical mode than tapping the local energy network (which would have been the most costly part of the installation). The system was installed only to discover that the bore hole at the site was not properly drilled and was unable to reach the water table. An appeal was made to the central authorities for additional funds to remake the bore hole; the system should be functional soon. In addition, irrigational facilities were installed at KARI Katumani to facilitate drought evaluation trials for which a number of phenotyping equipment were purchased and delivered to Kenya, Zimbabwe and Tanzania (Table 43).

Table 43. Equipment purchased for national research programs under the TL-2 project.

Equipment	Countries
Davis Vantage Pro2 Weather Station	Ethiopia, Kenya, Malawi, Tanzania and Zimbabwe
Laptop computer	“
Watermark soil moisture system with meters	“
Sensor for Soil moisture system	“
Ohaus Explorer Pro Toploading Balance	“
Ohaus Explorer Pro Toploading Balance	“
Digital camera SONY DSC-H50/B	“
ET Gauge	“
SPAD 502DL Chlorophyll meter	“
Soil Corers	“
SC-1 Porometer	Ethiopia, Kenya and Malawi
Turf-Tec Infrared Turf Thermometer with probe	“
Hand-held FluorPen with firmware upgrade	“
WHINRIZO Prosoftware on CDROM	“
Calibrate Color Optical Scanner	“
Root positioning system for STD scanners	“

Rain-out shelter in CIAT-Colombia:

A rain-out shelter was established at the CIAT headquarters to facilitate more detailed and controlled physiological studies, and confirm results under field conditions where the control of moisture was less precise.