Enhancing soybean productivity and production in sub-Saharan Africa

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Summary

This project was on "Enhancing soybean productivity and production in drought-prone areas in sub-Saharan Africa". The emphasis of the first and second phases were on improved soybean productivity through the development of improved germplasm, integrated crop management, marketing, commercialization, seed systems and other institutional issues that shape the adoption, use and retention of improved soybean varieties by smallholder farmers in the intervention areas. The main objective was to target crop breeding and seed delivery efforts so as to enhance the impact on the livelihoods of the poor in drought-prone regions of sub-Saharan Africa. The major objective was to quantify nodulation, biomass production, and grain yield characteristics of a set of best-bet, dual purpose and grain varieties, relative to a locally available variety in all five project sites. The dual purpose, promiscuous soybean that produce a substantial amount of grains and leafy biomass and do not require inoculation with specific *Rhizobium* spp. strains were developed by IITA and have increased resilience of farming while providing income to farmers. In some soils in Kenya, they have not been nodulating freely; and hence, there is a need for inoculation.

This project report covers the critical project objectives based on the activities included in the TL III proposal and justified as the challenges to be addressed in the TL III project. Addressing these challenges would help consolidate the positive achievements from the earlier two phases. The two phases have successfully led to the desired sustainable development and promotion of soybean in Kenya. The remaining issues include: (i) the need to influence supportive policy for soybean development and promotion in Kenya, (ii) integration of institutions at all levels in soybean value chain, (iii) building soybean-related skills and capacities of all stakeholders, (iv) fine-tuning of best agronomic practices with special attention given to overcoming the risk of growing soybean on degraded soils, (v) increased participation of the women networks in soybean enterprises, (vi) enhanced skills and capacity of the service providers, and (vii) ensuring that farmers obtain their soybean seeds from credible sources. These were followed by the key highlights of the project such as pilot cottage-level soybean processing sites, the concept of Soybean Resource Centers, Community Soybean Seed Payback System, the concept of commercial villages and soybean collection centres, other important developments following the project execution (the rising of interest-driven groups, several independent enquiries on how to get involved in soybean enterprises), overall impact of the project (impact on farm income, increase in number of soybean farmers and how the different associations, cooperatives, and other collective networks are contributing), challenges (branding, need for phosphorus (P), the problem of rust, poor soil fertility status, drought tolerance, limited access of farmers to farm and seasonal credit, etc.) as project innovations were scaled up. With the project, 11 soybean varieties were released officially in Kenya (DPSB19, DPSB8, Sc Squire, Sc Saga, Sc Salama, Nyala, Hill, Gazelle, Blackhawk, EAI3600 and 931/5/34).

Test existing soybean varieties and lines for their drought tolerance, promiscuity, disease resistance, low P tolerance, and processing/nutritional quality.

Milestone: At least 20 elite, early to medium maturity, soybean lines evaluated for drought tolerance, promiscuity, disease resistance, low P tolerance, and processing/nutritional quality, using farmer participatory approaches.

Mother Trial (March-August, 2008): Varieties used in the establishment of the mother trial in west Kenya were (i) varieties that had been tested and found best during earlier work in Kenya, led by CIAT and new materials from IITA; (ii) varieties and promising lines tested by the KARI; and (iii) widely available 'local' materials. The basis of selection of test genotypes from the IITA soybean breeding program was based on a prior superior performance in West Africa.

Key achievements

Select existing varieties

The Participatory Varietal Selection (PVS) was based on the mother trial established at the experimental farm of TSBF-CIAT at *Sidada* village in western Kenya. A total of 23 soybean varieties (comprising of 15 Tropical Glycine Crosses or the TGx series, 2 TGm varieties, 2 varieties that have earlier been recommended in Kenya, 1 local variety, and 3 other varieties that fell outside these four earlier categories) were planted and evaluated by 86 farmers (67% males and 33% females) drawn from eight districts (Bhukalarire, Busia, Butere, Ebuyangu, Migori, Mumias, Sidada, and Teso) in the recommendation domains in western Kenya.

The 15 TGx soybean varieties were: TGx 1440-1E, TGx 1448-2E, TGx 1485-1D, TGx 1740-2F, TGx 1835-10E, TGx 1908-8F, TGx 1910-14F, TGx 1844-4F, TGx 1951-4F, TGx 1895-33F, TGx 1895-49F, TGx 1889-12F, TGx 1893-10F, TGx 1871-12E and TGx 1903-1F. The two TGm varieties were TGm 1420 and TGm 1360. While Gazelle and Sable were the two varieties that have earlier been recommended in Kenya and included in the PVS, the local variety was *Nyala*. The three other varieties that fell outside these four earlier categories were named 931/5/34, 915/5/12, and 917/5/16.

Overall, the three most preferred soybean varieties were TGx 1440-1E (occupying first position across gender), TGx 1844-4F (occupying second position across gender), and TGx 1951-4F (occupying third position across gender). It is important to note that the two soybean varieties earlier recommended in Kenya (Gazelle and Sable) and the local check (Nyala) were out-performed.

Baby trials (March-September 2009)

In western Kenya, a total of 29 baby trials were implemented in Busia (5 farmers), Teso (6 farmers), Butere (5 farmers), Mumias (6 farmers), and Migori (7 farmers).

Participatory varietal selection

The PVS is based on baby trials established in Migori, Mumias, Butere, Busia, and Teso in western Kenya. A total of 17 soybean varieties (comprising of 8 TGx series (TGx 1835-10E, TGx 1871-12E, TGx 1895-33F, TGx1893-10F, TGx 1740-2F, TGx 1448-2E, Namsoy 4a, TGx 1903-1F, 3 local varieties (Nyala, EAI 3600, Gazelle), and six grain varieties (931/5/34, Sable, SCS1 from KARI, Njoro H1, H8, H11 from Moi University that fell outside these two earlier categories) were planted (Table 85). These varieties were then evaluated by 320 farmers (52% males and 48% females) from five districts (Busia, Butere, Migori, Mumias, and Teso) in West Kenya.

Overall, farmers in western Kenya used a total of 24 criteria (grain size, number of pods, filling of pods, size of pods, number of seeds per pod, disease free pods, grain yield, early maturity, biomass (number of leaves, size of leaves and number of branches), color of leaves, disease resistance, hardness of pods to shattering, plant height, uniformity in height, size of stem, ease of uprooting, ease of threshing, uniformity in maturity, pest resistance, drought resistance, growth in poor soils, vigor of plant (standability), wind resistance and resistance to heavy rain) to evaluate the 17 soybean varieties.

Table 85. Soybean varieties selected for baby trials in western Kenya.

Variety type	TSBF-CIAT codes	Breeder codes	Source
Promiscuous varieties	SB3	TGx 1835-10E	IITA, NIGERIA
	SB4	TGx 1871-12E	IITA, NIGERIA
	SB8	TGx 1895-33F	IITA, NIGERIA
	SB17	TGx 1893-10F	IITA, NIGERIA
	SB18	TGx 1894-3F	IITA, NIGERIA
	SB19	TGx 1740-2F	IITA, NIGERIA
	SB20	TGx 1448-2E	IITA, NIGERIA
	SB25	Namsoy 4a	NAMULONGE, UGANDA
	SB37	TGx 1903-1F	IITA, NIGERIA
Grain varieties	SB69	931/5/34	KARI, NJORO
	SB73	Sable	KARI, NJORO
	SB96	SCS 1	KARI, NJORO
	SB92	H 11	MOIUNIVERSITY
	SB90	H 8	MOIUNIVERSITY
Local checks	SB23	Nyala	KARI, NJORO
	SB97	EAI 3600	KARI, NJORO
	SB72	Gazelle	KARI, NJORO

Farmers ranked the 17 varieties (on a scale of 1 to 10, where 1 was the best score or the most preferred on specific criterion basis while 10 was the least score or the least preferred, on each of the criteria that applied.

Comments given by farmers based on gender.

Women choose varieties that are early maturing, large-sized grain and with moderate yields for following reasons:

- They bring food on the table early at a time when hunger is biting hard - focus on food security.
- Large-sized varieties are most preferred in the local market.
- Give sufficient time for farm operations before the on-set of short rainy season (window period between rainy seasons is short).
- Tend to be short in height; hence, preferred for intercropping with the cereals.
- They mature early to escape drought conditions.

Men choose medium varieties because of the following reasons:

- They can improve soil fertility (high biomass accumulation and nitrogen fixation properties); hence, costs of farm inputs are cut down.
- Give higher yields; hence, better returns to the farmer.
- Good for environmental conservation (soil moisture and organic matter build-up).

Desired traits for grain varieties: - early maturity, large-sized grain, high pod load, and medium height.

Desired traits for promiscuous varieties: - early maturity, large-sized grain, higher height and longer viability, high biomass and good nodulation.

Farmers proposed a soybean growing strategy, to grow one grain variety and one promiscuous variety every season, in order to meet the household needs - food security and soil fertility improvement.

Milestones

1. At least 15 lines were evaluated for drought tolerance and biological nitrogen fixation (BNF);
2. At least 10 lines for rust resistance using FPVS trials; and
3. At least 35 lines (20 varieties, 15 lines) assessed for quality traits (protein, oil content) every year (Y1, Y2, Y3).

Evaluation of rust tolerant germplasm 1

Evaluation trial was established in Sidada, Siaya district (N 00˚00' 32.4"; E 034˚25' 25.8"; 1329 masl) and Kokare, Teso district (N 00˚ 36' 21.5"; E 034˚ 18' 48.4"; 1185 masl) with the following materials: NYALA (check), TGx 1740-2F, TGx 1835-10E, TGx 1987-10F, TGx 1987-11F, TGx 1987-17F, TGx 1987-18F, TGx 1987-20F, TGx 1987-23F, TGx 1987-25F, TGx 1987-28F, TGx 1987-31F, TGx 1987-32F, TGx 1987-34F, TGx 1987-62F, TGx 1987-64F, TGx 1987-65F, TGx 1987-6F, TGx 1987-8F and TGx 1987-9F.

All the varieties, except the first three varieties, were new breeding lines developed in the context of the TL II project. The varieties were screened with and without the application of P fertilizer in three replicates per site. Almost all the varieties responded to the P application at both sites. Yields were higher in Sidada than in Kokare and most of the new lines produced well in Sidada while in Kokare, about 3 lines outperformed the other materials (with P applied). Best yields were higher than 3 t/ha in Sidada and above 2 tons ha^{-1} in Kokare.

Total aboveground biomass at podding responded to P application for almost all varieties at both sites. Biomass was higher in Sidada than in Kokare and most of the new lines produced well in Sidada while in Kokare, the biomass production of new lines was not substantially higher than that of the earlier lines. Best yields were higher than 3 tons ha^{-1} in Sidada and above 2 tons ha^{-1} in Kokare.

Nodulation responded significantly to P application in Sidada for most lines with large variation in the total nodule numbers. Nodulation was very low to nil at Kokare. Most new lines noduled well at Sidada.

Rust scores at R6 were slightly lower for about 7 lines in Sidada compared to the earlier lines and some newer lines. At Kokare, over half of the new lines showed considerable improvements against rust damage compared with the earlier lines and with variety TGx 1835-10E, which has been released in Uganda as a rust-tolerant variety.

Evaluation of rust tolerant germplasm 2

Evaluation trials were established at Lolwe (N 00˚08' 22.6"; E 034˚24' 51.7"; 1331 masl) during short rain season 2012 and Mwadi (N 00˚ 08' 26.7"; E 034˚ 25' 42.6"; 1322 masl) during long rain season 2013 in Siaya County with the following materials: NYALA (check), TGx 1990-5F, TGx 1989-20F, TGx 1990-57F, TGx 1990-15F, TGx 1990-8F, TGx 1990-59F, TGx 1990-3F, TGx 1989-19F, TGx 1990-97F, TGx 1990-29F, TGx 1989-41F, TGx 1989-4F, TGx 1990-2F, TGx 1989-21F, TGx 1988-5F and TGx 1987-129F. All, except Nyala, were new breeding lines developed in the context of the TL II project. All varieties were screened with and without application of P fertilizer in 3 replicates per site.

Mother and baby trials were installed during short rains 2012 to evaluate soybean yield potential in different agroecological zones of western Kenya, response to inoculation with rhizobia, effect of inoculation on rust severity, tolerance of improved germplasm to rust and drought.

Milestone for phase I

There was an annual exchange of at least 20 lines between TL II and N2 Africa projects in five overlapping countries, including information about BNF and other agronomically important traits for at least 15 lines.

Presently, the exchange of soybean lines between TL II and N2AFRICA stands at 8. TGx 1740-2F, Namsoy 4M, Maksoy 1N, Sc Squire, Sc Sequel, Sc Samba, Sc Saga, and EAI 3600. Joint set up trials on BNF and agronomy were also set up in the region.

Milestone for phase II

At least 20 elite lines were distributed to partners in five countries each year (Y1, Y2, Y3).

Seventeen elite lines received by CIAT-TSBF from IITA in January 2011 continue to be evaluated at KARI Njoro. The lines are from TGx 1987 series namely 6F, 8F, 9F, 10F, 11F, 16F, 17F, 18F, 20F, 23F, 25F, 28F, 31F, 32F, 34F, 63F, 64F. On the other hand, CIAT-TSBF received 20 elite lines from IITA in February 2012. The new lines are from TGx 1987 (86F, 88F and 129F); from TGx 1988 series (3Fand 5F); from TGx 1989 series (4F, 8F, 19F, 20F, 21F and 41F); and from TGx 1990 series (2F, 3F, 5F, 8F, 15F, 29F, 57F, 59F, and 97F). The lines are being evaluated on station for adaptability to Kenyan conditions.

Milestone: At least 2 varieties submitted to the variety release authorities in the target countries. Ten grain type varieties (EA1300, Gazelle, Black Hawk, Hill, Nyala, Sc Squire,Sc Saga,Sc Salama, DPSB8 and DPSB19) and two dual purpose soybean varieties [DPSB19-TGx 1740-2F; DPSB8-TGx 1895-33F] have been released in Kenya.

Milestone: At least 20 *Rhizobium/ Bradyrhizobium* strains screened for efficient biological N fixation in farmer-preferred varieties This activity has been fully implemented through active linkages with the N2Africa project operating in Kenya. A formal implementation plan of N2Africa details relationships between TL II and N2Africa around the main principles: (i) N2Africa will use the best soybean varieties selected by TL II, and (ii) TL II will have access to the best *Rhizobium* strains, identified by N2Africa.

Within the TL II project, a study was conducted to assess the nodulation and nitrogen fixation of a set of nine indigenous *Bradyrhizobium* strains inoculated on three promiscuous soybean varieties grown under greenhouse conditions. Seedlings of three promiscuous soybean varieties (SB 8, SB 9 and SB 19) were inoculated with 3 ml each (10^8 cell mL^{-1}) of pure indigenous *Bradyrhizobium* strains (TSBF 404, TSBF 101, TSBF 131, TSBF 531, TSBF 534, TSBF 331, TSBF 442, TSBF 344, TSBF 3360). Negative and positive (98 kg ha^{-1} equivalent) controls were also included. The seedlings were grown in 2 kg sand filled polybags, kept at field capacity by alternate day watering with double distilled water and Broughton (Broughton and Dilworth, 1970) solution in a greenhouse at approximately 12/12 light and 25°C/32°C. Seedlings were harvested at R1 (Fehr et al. 1971) for each of the genotypes and nodule number and shoot biomass was recorded. All samples were dried to constant weight for 48 h at 70°C. Nodule dry weight and shoot dry weights were recorded. Dry shoot weights were used as proxy for nitrogen fixation (Abaidoo et al. 2000). The Effectiveness index (E) was calculated as described by Ferrera and Marques (1992):

$$E_J = (X_J - X_{TO}) / (X_{TN} - X_{TO})$$

where J is the shoot dry weight of the inoculated test strain, TO is the non-inoculated control while TN is the nitrogen control. Strains were arranged in ascending order and grouped into classes of effectiveness as described by Beck et al. (1994).

There was no interaction between strains and varieties on shoot dry weight (Figure 10). However, there was a highly significant ($P<0.001$) difference among strains on shoot dry weight. Shoot weight ranged from 0.1380 g per plant for negative control to 0.731 g per plant for TSBF 442. TSBF 442 had five times more shoot dry biomass than the negative control while it recorded 2.5 times more shoot biomass than the control strain (USDA 110). The control strain USDA 110 produced significantly less dry shoot biomass and nodules than all tested strains in all three varieties. All varieties fixed significantly higher amounts of nitrogen when inoculated with all indigenous strains but TSBF 131.

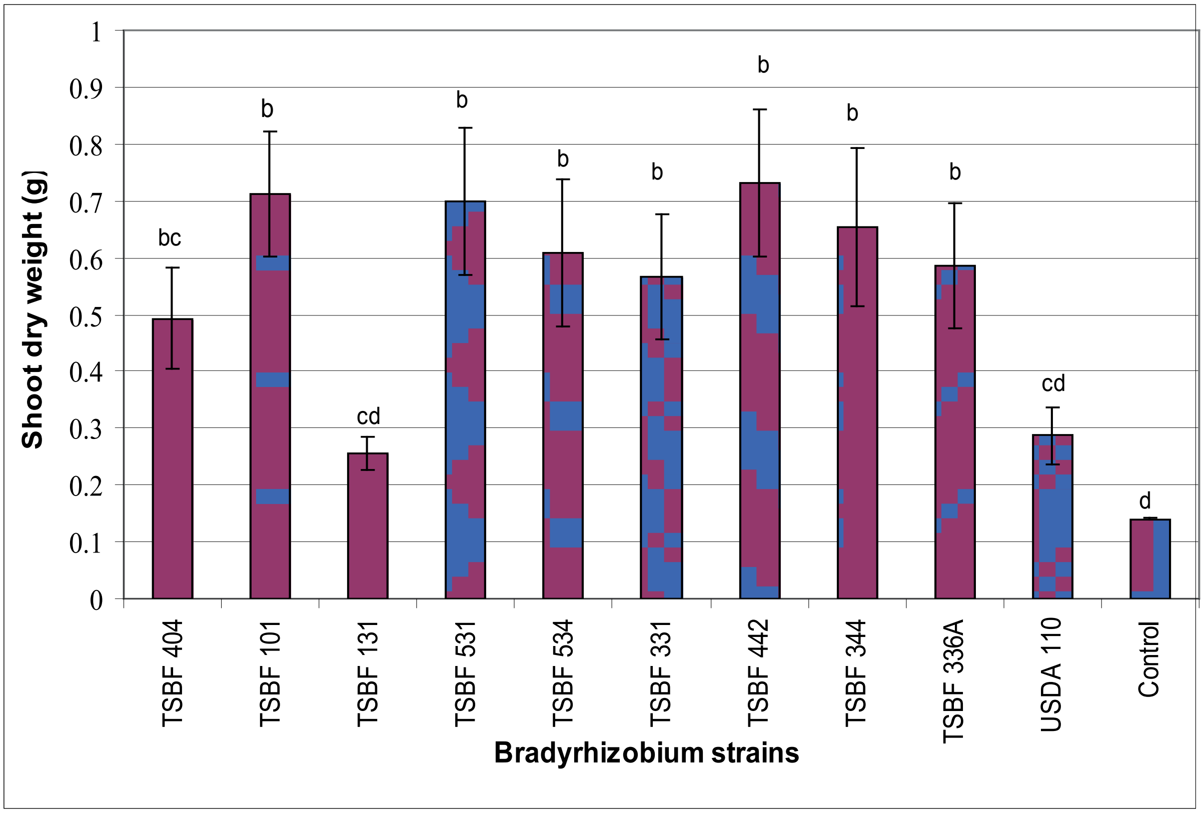

Figure 10. Dry weight of three promiscuous soyabean varieties grown in sand under greenhouse conditions.

There was a significant interaction between soybean varieties and indigenous *Rhizobium* strains for nodulation. SB8 nodulated best with strain TSBF 336A and least with TSBF 131, SB9 with strain TSBF 344 and least with TSBF 534, and SB19 nodulated best with TSBF 442 and least with TSBF 131. All tested indigenous strains nodulated significantly better than the introduced strain (USDA 110) on all promiscuous soybean varieties under greenhouse conditions. Nodulation did not necessarily result in high N_2 fixation. This study indicates that the indigenous rhizobia strains can be deployed to replace/ supplement introduced USDA 110 that is currently used in soybean inoculants in Kenya.

Create segregating populations for drought tolerance, promiscuity, disease resistance, and low P tolerance

Milestone: A total of 100-200 accessions screened for low P tolerance. The variation in P uptake among different species and genotypes was caused by a range of factors that are mostly related to specific root traits such as root architecture and root hair development (see Gahoonia and Nielsen 2004). However, the selection of P efficient varieties is a difficult process since direct screening requires large-scale field experiments including a large number of varieties. Hence, it would be desirable to develop screening techniques that would enable breeders to identify P efficient varieties in early stages of plant development. This research therefore, aims at developing such screening technique through the identification of 'early root traits' related to P efficiency. This will be accomplished by (i) qualitative and quantitative evaluation of root traits in early plant growth stages of a varied set of soybean varieties, through the use of innovative screening techniques and (ii) field testing of the same set of varieties to evaluate possible correlations between early root traits and efficiency under field conditions.
A multi-locational field trial was established during the short rains of 2009 in 10 locations of south-

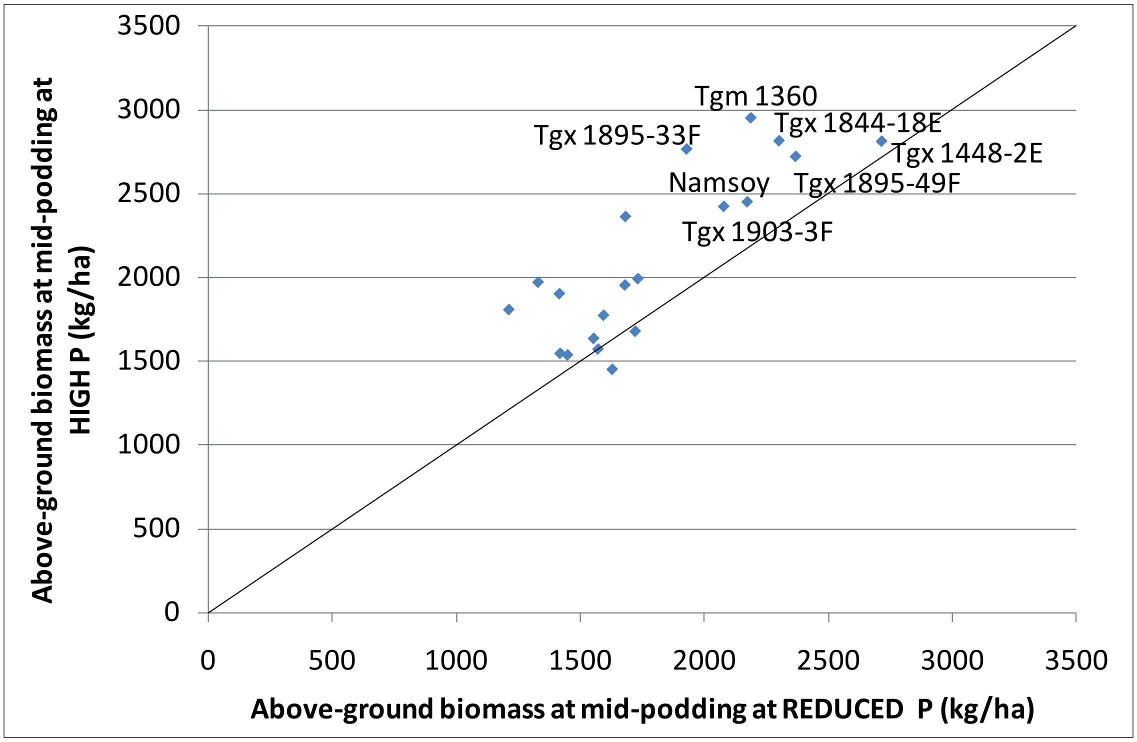

Figure 11. Relationship between above-ground biomass at mid-podding stage under reduced and high P application.

western Kenya (Migori district) and 10 locations of western Kenya (Siaya district). Twenty soybean varieties (10 dual-purpose varieties developed by IITA and 10 locally used varieties from different East African countries and China) were planted in combination with 50-60 kg P/ha (P at recommended rate, depending on area), a reduced P rate (40% of recommended rate), and a control treatment without P. All varieties were inoculated with Legumefix (Legume Technology Ltd).

The results of field screening showed substantial variability in P efficiency between varieties. In general, the dual-purpose varieties were superior in P efficiency compared to the locally used varieties (Figure 11). Varieties with good growth under low(er) P conditions showed larger root-shoot ratios, which indicates the importance of the root system for tolerance to low P conditions. Different groups of varieties could be distinguished based on their P efficiency in terms of biomass and/or harvest production under extremely low or reduced P rates. Only two varieties, TGx 1844-18E and TGx 1895-49F, produced well in terms biomass and harvest production under both, no and reduced P application, and can be considered superior in P efficiency.`

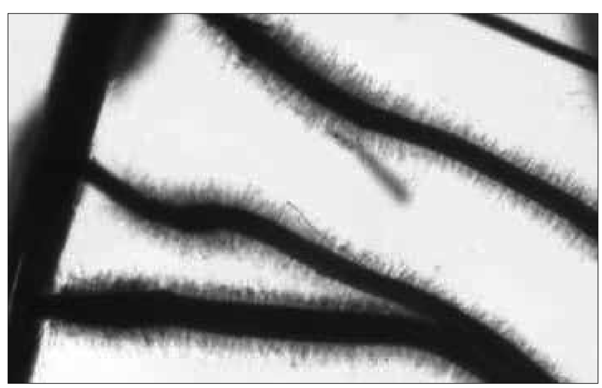

Figure 12. Evaluation of early root hair development in agar gel.

Early root traits of soybean varieties are currently being evaluated through the use of mini-rhizotrons filled with a mixture of sand and P adsorbed on aluminum oxides at different buffered P concentrations. Basal root angles, root length and diameter, and plasticity across P levels for these traits were assessed using WinRHIZO software. A method with agar gel containing aluminum-P as a growth medium was tested for evaluating root hair development. Figure 12 shows how early root architecture and root hair development under different buffered P concentrations can be closely followed-up in mini-rhizotrons and agar gel. These methods are currently being tested for different soybean varieties. It is hypothesized that certain 'early root traits' will appear to be indicative for P efficiency under field conditions. Two varieties contrasting in P efficiency under field conditions were screened in mini-rhizotrons filled with a mixture of sand and P adsorbed on aluminum oxides at low P availability (0.04 ppm) and moderate P availability (0.2 ppm) for 2 weeks. It was hypothesized that early root traits identified through the use of this screening technique would differ significantly between these varieties and would relate to their difference in P efficiency. In the early stages of growth, plant growth is strongly affected by the seed P reserve and to take this into account seeds of different sizes were selected for each variety.

Results showed that early root traits were influenced by the seed P reserve to such an extent that no useful conclusions could be drawn on the relation between early root traits and efficient P uptake in later stages (Figure 13). Young roots thus seemed to react strongly to the amount of P available in the seed which does not necessarily mean they will develop similar root traits after the seed P reserve has been used and that plants depend solely on the external P source. This finding interferes with our goal to identify differences in P efficiency in early plant growth stages. However, the mini-rhizotron technique was very promising for studying root architecture of a large number of varieties. The methods are currently being tested to compensate for the effect of seed P during early screening.

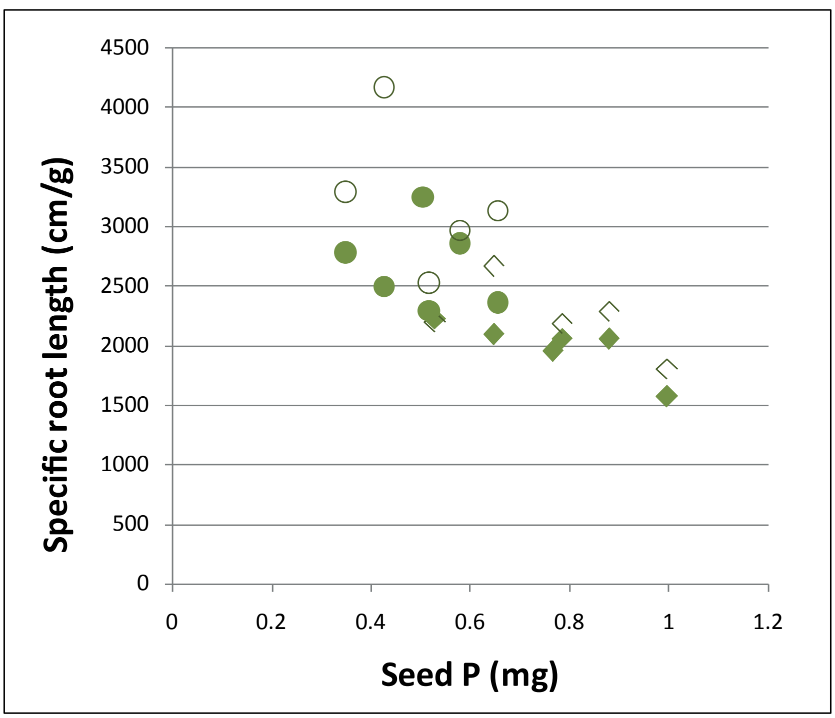

Figure 13. Specific root length of 2 soybean varieties grown in mini-rhizotrons filled with a sand-alumina-P medium (O: TGx 1895-49F;: TGx 1895-33F; filled marker points: 0.04ppm P; empty marker points: 0.2ppm P).*

Strengthen capacity of national agricultural research systems scientists, extension personnel, and farmers in the soybean value chain

Milestone: At least 3014 farmers trained in soybean participatory variety selection, processing, utilization, and/or agri-business following a training-of-trainers approach

Training of associations, women groups, youth groups, and other CBOs on pest and disease diagnosis and participatory variety selection.

Date	Venue	Duration	Topic	Participants	Attendance		
					Male	Female	Total
12-14/ 10/11	Maseno Club Hotel	3 days	• Integrated pest and disease management • Concept, methods and tools for participatory variety selection	Extensionists, farmer associations, women group, CBOs and youth groups	14	7	21
Mar- Aug, 2011	Butere Mumias Teso Busia Migori	1 day	• Methods and tools for participatory variety selectio	Extensionists, farmer associations, women group, CBOs and youth groups	160	110	270
Sep-Dec, 2010	Butere Mumias Teso Busia Migori	1 day	• Methods and tools for participatory variety selectio	Extensionists, farmer associations, women group, CBOs and youth groups	190	160	350
Mar-Aug, 2010	Butere Mumias Teso Busia Migori	1 day	• Methods and tools for participatory variety selectio	Extensionists, farmer associations, women group, CBOs and youth groups	170	130	300
Mar-Aug, 2009	Butere Mumias Teso Busia Migori	1 day	• Concept, methods and tools for participatory variety selectio	Extensionists, farmer associations, women group, CBOs and youth groups	167	153	320
Mar-Aug, 2008	Sidada	1 day	• Concept, methods and tools for participatory variety selection	Extensionists, farmer associations, women group, CBOs and youth groups	58	28	86
				Total:	759	588	1347