I. Progress Report 2005

A. Cover Page

Project Title:

Adaptation of Soybean to Low Phosphorus Soils of Tropical and Subtropical South China: A Radical Approach

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Executive Summary

In 2005, we continued to make excellent progress and successfully concluded the first 4-year phase of the project, having achieved most of the research and training objectives. The following progress and results were specifically achieved during the past year: 1) Our germplasm screening and breeding work continued to produce phosphorus-efficient, high-yielding soybean lines, among which 17 promising lines were submitted for the 2nd year to the China National Regional Variety Trials in 2005. Five of our breeding lines that performed well in most of the regional trials for two consecutive years will apply for the National Official Variety Certification and will be officially released in 2006. 2) Physiological studies both in China and USA were continued to identify important root traits as well as other physiological parameters contributing to phosphorus efficiency in soybean. 3) Genetic studies were continued for mapping and cloning of genes conferring superior root traits and phosphorus efficiency. More QTLs conferring root traits and/or P efficiency were identified with the molecular linkage map constructed previously, and some candidate genes previously isolated were further analyzed for their possible functions in phosphorus efficiency and/or root development. 4) Agroecological studies were continued both in the field of South China and in central America (Costa Rica) to study the ecological impacts of improved soybean germplasm. 5) Data from agroeconomic and social survey were continued to be analyzed for likely economic impacts of improved soybean germplasm in South China. 6) Joint-training programs continued with more trainees sent to the US universities. As the first phase of the project concludes, a new partnership is formed for an extended effort in increasing phosphorus efficiency and production of grain legumes in China and Africa.

B. Research and Training Progress (by Module)

1. Module 1: Germplasm Screening and Conventional Breeding

In 2005, our conventional breeding programs continued in the three breeding nurseries located at SCAU, Boluo, and Guangxi using different approaches previously described (i.e., hybridization breeding, recurrent breeding, and mutation breeding. See Annual Reports 2002, 2003， 2004). This has continuously resulted in more phosphorus-efficient, high-yielding soybean lines. Following the 18 new lines selected last year, 17 more lines were selected to participate in the China National Regional Variety Trials in 2005. Among them are 8 Spring-sowing varieties and 9 summer-sowing varieties. The trials were carried out at 15 sites across the South China's 6 provinces. The results are summarized in Tables 1 and 2. It can be seen from the tables that 5 out of our 8 Spring breeding lines tested were better than the official "best check" variety in the spring-sowing south region (Table 1); while all of our Summer breeding lines tested were significantly better than the official "best check" variety (Table 2). In addition, we selected 5 breeding lines with possibly broader climate adaptability to participate in the Regional Trial in the northern region of South China (or central China). Interestingly, in spite of the climatic effect, 3 of our 5 Spring breeding lines tested were better than the official "best check" variety in the northern region, indicating that some of our breeding lines have the potential of being extended beyond areas in the Southern part of South China.

Based on the results from two years' national regional trials, 5 of our breeding lines (2 Spring lines and 3 Summer lines) that performed well in most of the regional trials for two consecutive years will be submitted to for the National Official Variety Certification to be held in April 2006. Once certified, they will be officially released in July, 2006.

Table 1. Average yield of selected soybean Spring breeding lines in the National Regional Variety Trials (Southern Region, Spring, 2005)

Lines	Plot yield（kg/10m^2）	Multiple Comparison		Estimated Yield（kg/ha）	Increase over CK（%）
		p=0.05	p=0.01		
Gui 0120-1	2.55952	a	A	2560.8	20.49
Yuechun 03-4	2.46571	ab	AB	2466.9	16.07
Yuechun 04-1*	2.42619	ab	AB	2427.5	14.21
Yuechun 03-5	2.23476	cd	CD	2235.9	5.20
Gui 0118-1*	2.21524	cd	CDE	2216.4	4.28
Liudou 1(CK)	**2.12429**	de	DE	**2125.4**	—
Yuechun 03-3	2.07810	e	DEF	2079.2	-2.17
Yuechun 04-2*	1.90190	f	FG	1902.9	-10.47
Gui 980702)*	1.86333	f	G	1864.2	-12.28

Note: Values in the table are means of 9 trial plots located in 5 different provinces of South China. **Liudou 1** is an official "best check" Spring soybean variety for tropical regions in China. * Lines for the first-year in this trial.

Table 2. Average yield of soybean Summer breeding lines in the National Regional Variety Trials (Southern Region, Summer, 2005)

Lines	Plot yield (kg/10m^2)	Multiple Comparison		Estimated Yield (kg/ha)	Increase over CK (%)
		p=0.05	p=0.01		
Gui 0114-2	2.73810	a	A	2739.5	33.76
Yuexia 03-3	2.72810	a	AB	2729.4	33.27
Gui 0114-1	2.64810	ab	ABC	2649.5	29.36
Yuexia 03-5	2.55857	bc	CD	2559.9	24.99
Yuexia 03-1	2.45429	cd	DE	2455.5	19.89
Gui 0103-1	2.42619	de	DEF	2427.5	18.52
Gui 0104-1	2.38286	def	EF	2384.1	16.40
Yuexia 03-4	2.33762	def	EF	2338.8	14.19
Yuexia 03-2	2.27762	f	F	2278.4	11.26
Genqing 82(CK)	**2.04714**	**g**	**G**	**2048.1**	**-**

Note: Values in the table are means of 9 trial plots located in 5 different provinces of South China. **Gengqing 82** is an official "best check" summer soybean variety for tropical and sub-tropical regions in China.

Table 3. Average yield of selected soybean Spring breeding lines in the National Regional Variety Trials (Northern Region, Spring, 2005)

Lines	Plot Yield (kg/10m^2)	Multiple comparison		Estimated yield (kg/ha)	Increase over CK (%)
		p=0.05	p=0.01		
Yuechun 04-5	2.15952	a	A	2160.6	11.10
Guizao 2	1.98905	b	B	1990.1	2.33
Gui 0118-1	1.95714	bc	B	1958.1	0.69
Zhechun 3(CK)	**1.94381**	bc	B	**1944.8**	—
Gui 980702	1.94048	bc	B	1941.5	−0.17
Yuechun 04-6	1.20381	d	C	1204.4	−38.07

Note: Values in the table are means of 7 trial plots located in 6 different provinces of South China. **Zhechun 3** was the official "best check" spring soybean varieties for central regions in China.

It should be pointed out that soils in most of the field sites for the regional variety trials were deficient or modestly deficient in P, and therefore the better performance of our breeding lines might be mainly due to a higher P efficiency. In fact we have run independent field experiments to grow these lines in several typical soil types of South China (ultisol, oxisol) with or without P application. Our preliminary results indicated that most of our breeding lines have a relatively higher P efficiency (as indicated by the ratio of Low P Yield / High P Yield), especially for the Summer varieties. The results are being summarized and will be reported when the data are ready.

2. Module 2: Physiological Mechanisms and Root Trait Identification

Physiological studies both in China and USA were continued to identify important root traits as well as other physiological parameters contributing to phosphorus efficiency in soybean.

At SCAU, we continued to characterize root traits of contrasting genotypes both in the field and in the lab using the paper pouch growth system, sand culture system and the phytotron-rhizotron system, with focus on phosphorus-induced changes in root morphology (root hairs) and root architecture and their relationship to soybean's ability in response to altered P nutrition. In a study with two contrasting soybean genotypes and their F_9-derived recombinant inbred lines (RILs), we found that root hair traits, including root hair density, average root hair length, and root hair length per unit root varied significantly among different genetic materials and these variations were highly associated with P status in soybean. However, the root hair traits are possibly controlled by quantitative trait loci (QTLs) and therefore are subject to great environmental influence (Fig. 2). Further studies are being conducted to elucidate the molecular mechanisms of P-induced root hair growth and development and their relationship to P efficiency in soybean.

As to root architecture, our study employing a new "applied core collection" of soybean germplasm provided the first-hand evidence for a close relationship between root architecture and P efficiency in soybean (Fig. 3). Shallow root architecture had better spatial configuration in the P-rich cultivated soil layer thus higher P efficiency and soybean yield. Interestingly, there seems to be a co-evolutionary pattern among shoot type, root architecture and P efficiency. The bush cultivated soybean had a shallow root architecture and high P efficiency, the climbing wild soybean had a deep root architecture and low P efficiency, while the root architecture and P efficiency of semi-wild soybean were intermediate between cultivated and wild soybean. The co-evolutionary relationship between root architecture and P efficiency might be attributed to the long-term effects of topsoil fertilization.

Studies were also conducted to characterize the physiological and molecular mechanisms of P-induced root exudation and its significance in phosphorus efficiency. We showed that soybean genotypes contrasting in P efficiency differ in the type and quantity of organic acids excreted from the roots under P stress, which contributes to greater P uptake in P-efficient genotypes. Further studies demonstrated that organic acid exudation is differentially induced by -P and +Al in soybean plants, with specific induction of oxalate and malate by -P and citrate by +Al, indicating their Specific functions in P efficiency and Al resistance. Such specificity could be attributed to membrane ion channels controlling citrate efflux, which appeared to be associated with the plasma membrane H^+-ATPase in soybean roots. Our collaborative work with Prof. Leon Kochian at Cornell University also demonstrated that P-efficient genotypes may be able to enhance Al tolerance not only through direct Al-P interactions but also through indirect interactions associated with stimulated exudation of different Al-chelating organic acids in specific roots and root regions.

We also investigated some other aspects of soybean root traits which could affect P efficiency and plant growth. We found that significant positive N and P interactions were found in field-grown soybean which might be related to genetic attributes of root morphological and nodular traits. Such a positive N and P interaction in the field might have resulted from better nodulation, longer root length, and shallower root architecture and these traits could be considered as selection criteria in further breeding programs for better nutrient efficiency in legumes. P addition had great impacts on rhizobium symbiosis and biological N_2 fixation of some genotypes by increasing nodule formation and nitrogenase activity on the upper parts of the roots. This at least in part explains the observations in the field experiment and may imply that selecting soybean genotypes with shallow root systems would not only increase P uptake efficiency but also facilitate biological N_2 fixation.

At PSU, graduate student Catalina Posada continued to evaluate genetic variations of root hair traits in soybean using a soybean collection from USDA. Root hair images were collected for all (approximately 300) genotypes in our soybean core collection. Images are being analyzed to quantify root hair length, density, and distribution.

Meanwhile, research was continued to investigate physiological parameters other than root traits that may contribute to phosphorus efficiency in soybean. In this regard, PSU graduate student Eric Nord completed a greenhouse trial of maturity time effects on response to P stress. In addition, a field trial was also carried out, where P fertilization treatments produced significant differences in biomass for all genotypes. A simple computer model of the relationship between timing of reproduction and ultimate fecundity was developed. With further development, this model may yield useful insights into the effects of maturity time on P efficiency of soybean.

3. Module 3: Molecular Biology of Root Traits and Development of Genetic Systems for Improving Root Traits and P Efficiency

1) Gene Mapping

At SCAU, a soybean genetic map was constructed last year for tagging of QTLs associated with P efficiency, using a F_2 population with 110 individuals derived from a cross between BD2 and BX10. In 2005 we conducted a field experiment to quantify some important phenotypic parameters related to P efficiency and/or root traits, including shoot and root biomass, shoot and root P content, root volume, root width/depth ratio (as an indication of root shallowness), root length, root surface area and so on. At the meantime we screened 500 Simple Sequence Repeats (SSR) markers, of which 150 markers with polymorphisms were used to construct a new map. Then the above traits were tagged to the map using the interval mapping approach. The results are being summarized and QTLs identified will be added to the map that we reported last year. Meanwhile construction of several permanent mapping populations with recombinant inbred lines is underway with some of the populations advanced to the F_6 generations in 2005.

At PSU, a genetic map of Essex × Forrest based on 181 RAPD and RFLP markers plus 240 microsatellite markers was employed by graduate student Catalina Posada for identification of QTL related to root hair traits in soybean. Root hair images have been collected for 100 recombinant inbred lines of the 'Essex' × 'Forrest' population of soybean, a population that has been developed and genetically mapped at Southern Illinois University at Carbondale. Upon completion of analyzing these images, we will be able to genetically map the root hair phenotypes.

2) Gene Cloning

At SCAU, more candidate genes for root traits and/or P efficiency were identified using both suppression subtraction hybridization (SSH) and homology cloning approach. In addition, two cDNA libraries for both soybean and common bean were constructed in collaboration with Prof. Raghothama at Purdue University, with many interesting candidate genes putatively related to root traits and/or P efficiency identified from these libraries. The cDNA clones identified are being characterized for their spatial and temporal expression patterns as related to their functions in P efficiency.

After returning from PSU, Mr. Yingxiang Wang and Dr. Chuxiong Zhuang continued to conducted functional analysis of a candidate gene *GmMAPK1*, which is now renamed as *GmWNK* from our new understandings of this gene. We employed *in situ* hybridization and other techniques to study the possible function of this gene in relation to root growth and development. Soybean transformation system is being established at SCAU for both gene functional analysis and possible transgenic approach to improving P efficiency in soybean (Fig 4).

4. Module 4: Agroecological Analysis

1) Phosphorus-efficient Soybean Genotypes in Different Cropping Systems

In 2005, a fourth-year field experiment was continued at the Boluo field site with previously identified soybean genotypes contrasting in P efficiency to study the effects of P-efficient genotypes on the crop yield in a soybean-maize intercropping/rotation system. Our results of the fourth year continued to provide evidence for the beneficial effects of P-efficient genotypes on plant growth and soil fertility maintenance. It is interesting to note that soybean root architecture might not only affect P efficiency of soybean *per se* but also affect the N and P nutrition of maize in a soybean-maize intercropping system (Tang et al., 2005). The shallow-rooted and P-efficient genotype had significantly greater advantages over the deep-rooted and P-inefficient genotype when intercropped with maize. The nutrient acquisition efficiency of maize intercropped with shallow-rooted soybean genotype was significantly greater than that with deep-rooted soybean genotype.

Meanwhile, we continued to conduct greenhouse experiments at SCAU using both root growth container (RGC) and minirhizotrons to study the root dynamics of different soybean genotypes. Our preliminary results indicated that the P-efficient genotype distributed more root length and percentage of root length at top 30cm than the P-inefficient genotype both at the early stage and throughout the growth period, resulting in a more shallow root architecture (Fig. 5).

The possible effects of plant interactions with mycorrhizal symbioses were also investigated. Our preliminary results indicated that soybean genotypes differ in their ability in mycorrhizal infection and this appeared to be associated with root shallowness and P efficiency of soybean, although the specific mechanisms of Plant-AM interactions are largely unknown and thus deserve future investigation.

2) Phosphorus Cycling

In 2005, another field experiment was continued at the Boluo field site using run-off and leachate collection facilities installed in field plots to study the impacts of adopting P efficient genotypes on nutrient cycling in low-P red soils. Four soybean genotypes (2 P-efficient and 2 P-inefficient) were planted in the field with both low and high P treatments. The P input (P from seeds, irrigation water, fertilizers, rain etc.) and P output (P from run-off, percolation, etc) were analyzed to estimate phosphorus budgets in the field. This year's result continued to indicate that the P-efficient genotype tend to reduce P losses from both run-off water and leaching into the subsoil, particularly in the low P treatment (Table 4).

Table 4. Soluble P content (μg/L) in the run-off water and leachate in the field planted with two contrasting soybean genotypes

Soybean Variety	Low P Treatment		High P Treatment	
	Runoff	Leachate	Runoff	Leachate
BX 10 (P efficient)	189.67±14.05 a	18.94±5.16 a	330.43±73.87 a	31.05± 7.22 a
BD 2 (P inefficient)	259.35±44.58 b	22.71±8.14 a	300.40±17.80 a	30.78±16.98 a

Note: Values in the tables are means of 4 replicates with standard errors. Values with the same letter in the same column are not significantly different (p=0.05).

While at PSU, a runoff study was repeated by graduate student Amelia Henry in 2005 using a rainfall simulator to compare deep and shallow-rooted beans and soybeans and their effects on runoff with different genotypes that were expected to show more contrasting root architecture. Samples are currently being analyzed.

Meanwhile, two field sites were chosen in Veracruz, Costa Rica to investigate the effects of phosphorus efficiency and root architecture on nutrient (particularly P) cycling for both soybean and common bean. Runoff samples were collected by local farmers, filtered, and shipped to Penn State University for total, particulate and dissolved phosphorus and analyses. Several local women conducted filtration of runoff using a water aspirator pump. Daily rain-gauge readings were also conducted. Sediment concentration of runoff is being determined by evaporation of unfiltered samples. We are also analyzing phosphorus levels in leaves, stems, and pods before and at harvest. Soil cores were taken to a depth of 45 cm. Roots were washed from 15-cm segments of each core. Total root length in each segment was determined to compare differences in root architecture and correlate them with differences in phosphorus efficiency. Percent cover was determined by computer analysis of overhead digital images. Preliminary results showed differences in percent leaf cover between genotypes and phosphorus treatments (Fig. 6). Percent cover of three phosphorus-efficient common bean genotypes (L-88) were higher than local varieties in the low phosphorous soil treatment and equal to or higher than those supplemented with fertilizer. Differences in yield were also observed (Fig. 7).

Also at PSU, graduate student Raul Jaramillo continued his efforts in the assessment of crop growth and phosphorus cycling employing simulation models. Progress was made to communicate the SimRoot model (an explicit root-growth model) with the CROPGRO model, a widely used model of photosynthesis assimilation and grain yield production. We attained the variables that determine root carbon allocation in CROPGRO and inserted them in the regular output of the program. Figure 7 shows the pattern of carbon allocation in CROPGRO; the graph was made with weather information obtained from Guangdong Province in South China for soybean.

At the same time we modified SimRoot to have a measure of construction costs (Mass) and maintenance (Respiration); the carbon used for this now corresponds to the values generated by CROPGRO. Our newest SimRoot now grows roots not only based on geometry and architecture parameters, but also can limit the expansion of the roots based on carbon availability. SimRoot now can also calculate the root distribution per soil layers that correspond to the soils description used in CROPGRO.

The current version of CROPGRO, does not consider phosphorus stress. We could identify a research group that developed an alternative version of the model with phosphorus-limited growth. We are currently working at ways to use this version, and be able to assess more completely the effects of root carbon economy, root architecture and resource acquisition on the yield of legumes.

In addition to the work with models we are currently trying to collect more information on the distribution of soils deprived of phosphorus. This information can contribute latter to estimate the impacts of phosphorus-efficient crops for different areas in the world.

5. Module 5: Agroeconomic Studies and Impact Assessment

At PSU, efforts were continued by Dr. R. Weaver and his Ph.D. student Lin Zhang to analyze the data collected previously during field work in China at the beginning of the project. This analysis resulted in a paper presentation and poster presented at the Vaals, NL McKnight conference. The quality of data collected allowed estimation of the competitiveness of soybeans relative to other crops at the household level based on current technology, germplasm, and prices. An effort was made to characterize the new technology based on new varieties produced by the project. Field trial data was requested for new variety trials as well as production input use and labor use recorded during the field trials. While this data has not been available as yet, upon availability it will serve as an important basis for calibrating and validating farm household survey data to be collected in the next field mission.

Progress made in this module included development of a household survey and a rapid reconnaissance approach to support development of two levels of models. Lin Zhang worked with to develop initial drafts of these models. The models include: 1) A math programming model supported by cross-section based econometric functions to analyze Chinese rural household crop selection, labor use, crop production, and change in supply of available nutrition, and 2) A market model of the village and regional market impacts of introduction of the new variety of soybeans developed by the project. The first of these models is planned to be implemented based on household survey data that will support nonparametric estimation of household technology to be used as part of the household production and consumption model, this model will be developed in the course of survey implementation during the May 2006 mission. These models were developed to final form by Dr. Weaver following an extensive review of potential data that could be collected as well as experience in other analogue projects. The second model will allow analysis of the household impacts of adoption of the new variety of soybeans including labor demand, demand for traction services, demand for seeds, changes in crop selection, and change in food supply. The second model of market effects was to complement the farm household model by establishing village and regional level market impacts of adoption of the new varieties. Of particular interest will be simulation of wage and price effects for labor, seeds, fertilizer, and crop outputs. This model was to be developed based on rapid reconnaissance method data developed by Lin Zhang during the summer of 2005.

Unfortunately Lin Zhang was not able to complete the mission of further field survey due to personal reasons and she has been arranged to be taken off the project funding by Dr. Weaver. Therefore the effort has been rescheduled in 2006 with recruitment of a new Chinese student, Xun Bian. A SCAU economist will be identified to actively participate in the team to complete remaining tasks for this module.

6. Module 6: Joint-Training, Communication and Management

1) Joint training

Two trainees from SCAU were sent to US universities for collaborative research in 2005. Dr. Hong Liao visited Prof. Leon Kochian’s lab at Cornell University from June to August 2005 to work on P and Al interactions in soybean, with interesting results obtained (see description in Module 2). Her work not only opens a new area of research tackling important problems in acid soil areas but also begins actual collaborations with the other CCRP team led by Dr. Schaffert in Brazil.

Another trainee from SCAU, Dr. Jiang Tian, was sent to Prof. Raghothama's lab at Purdue University for collaborative work on molecular biology of P efficiency in soybean and common bean. Prof. Raghothama is also a member of another CCRP team led by Dr. Schaffert in Brazil. Dr. Tian was scheduled to stay from June 2005 to June 2006. To date he has made significant progress in finding some interesting candidate genes putatively related to root traits and/or P efficiency identified from two cDNA libraries of soybean and common bean. He is now characterizing these candidate genes for their spatial and temporal expression patterns as related to their functions in P efficiency.

2) Communications and Management

As usual, the two PIs representing SCAU and PSU partnerships, Drs. Xiaolong Yan and Jonathan Lynch, have been in regular contact through email and telephone calls during the past year to discuss scientific and management issues related to the project. At both SCAU and PSU, the sub-committee met periodically, sometimes on module basis, to report project progress and discuss problems and constraints encountered.

In June 2005, Dr. Xiaolong Yan from SCAU, Mr. Magalhaes Miguel from the Agricultural Research Institute of Mozambique and Dr. Jonathan Lynch met at PSU to finalize a renewal proposal entitled “Increasing Phosphorus Efficiency and Production of Grain Legumes in China and Africa”, which was later approved by the McKnight Foundation in October. As the first phase of the project concludes, a new partnership is formed for an extended effort in increasing phosphorus efficiency and production of grain legumes in China and Africa.

C. List of Publications in 2005

1. Peer-reviewed papers

1) Kuang R., Liao H., Yan X. et al., 2005. Phosphorus and nitrogen interactions in field-grown soybean as related to genetic attributes of root morphological and nodular traits. *Journal of Integrative Plant Biology*, 47(5): 549-559
2) Tang JC, Mborehal IA, She LN, et al., 2005. Nutritional effects of soybean root architecture in a soybean/maize intercropping system. *Scientia Agricultura Sinica.* 38(6):1196-1203
3) Shen H, He LF, Sasaki T, et al., 2005. Citrate secretion coupled with the modulation of soybean root tip under aluminum stress: up-regulation of transcription, translation and threonined-oriented phosphorylation of plasma membrane H^+-ATPase. Plant Physiology 138：287-296

2. Papers in Proceedings

1) Xiurong Wang, Hong Liao and Xiaolong Yan, 2005. Variations for protein and oil content of soybean germplasm from an applied core collection as related to phosphorus availability. In: C.J. Li et al., eds., Plant Nutrition for Food Security, Human Health and Environmental Protection, Tsinghua University Press, pp414-415
2) Jinxiang Wang, Xiaojie Cai, Hong Liao, Xiaolong Yan, 2005. Adventitious Root Formation Is Highly Regulated by phytohormones in Soybean Cuttings. In: C.J. Li et al., eds., Plant Nutrition for Food Security, Human Health and Environmental Protection, Tsinghua University Press, pp518-519
3) Zhuoping Cai, Eric Nord, Jonathan Lynch, Xiaolong Yan, 2005. Relationship between Plant Maturity and Root Traits as Related to P Efficiency in Soybean. In: C.J. Li et al., eds., Plant Nutrition for Food Security, Human Health and Environmental Protection, Tsinghua University Press, pp482-483
4) Suqin Fang, Zhiyuan Li, Minghao Chen, Tonglin Zhu, Xiaolong Yan, 2005. Quantification of 3D Root Architecture in Plants with an Image Capture and Reconstruction System. In: C.J. Li et al., eds, Plant Nutrition for Food Security, Human Health and Environmental Protection, Tsinghua University Press, pp494-495
5) Wenbing Guo, Jing Zhao, Chuxiong Zhuang, Xiaolong Yan, 2005. Pi-inducible changes and cloning of related genes in soybean. In: C.J. Li et al., eds, Plant Nutrition for Food Security, Human Health and Environmental Protection, Tsinghua University Press, pp498-499
6) Cuiyue Liang, Hong Liao, Jiang Tian, Xiaolong Yan, 2005. APase Properties as Related to P Availability and Purification of an APase in Common Bean. In: C.J. Li et al., eds, Plant Nutrition for Food Security, Human Health and Environmental Protection, Tsinghua University Press, pp504-505
7) Nige Liu, Hong Shen and Xiaolong Yan, 2005. Variation of metabolic products in root tissues and root exudates of soybean in response to phosphorus starvation. In: C.J. Li et al., eds, Plant Nutrition for Food Security, Human Health and Environmental Protection, Tsinghua University Press, pp506-507
8) Liu Peng, Wang, Jinxiang, Liao Hong and Yan Xiaolong, 2005. Effect of phosphorus status and decotyledonning on root growth of soybean and common bean. In: C.J. Li et al., eds, Plant Nutrition for Food Security, Human Health and Environmental Protection, Tsinghua

University Press, pp496-497

9) Yutao Liu, Hong Liao, Xiaolong Yan, 2005. Shallow roots are better for phosphorus efficiency in soybean: evidence from the field evaluation of an “Applied Core Collection”. In: C.J. Li et al., eds, Plant Nutrition for Food Security, Human Health and Environmental Protection, Tsinghua University Press, pp508-509
10) Bingbo Mo, Nige Liu, Cunyi Yang, Hong Shen and Xiaolong Yan, 2005. Al signal transduction was involved in the synthesis of citrate in soybean leaves. In: C.J. Li et al., eds, Plant Nutrition for Food Security, Human Health and Environmental Protection, Tsinghua University Press, pp786-787
11) H Shen, X. L. Yan and H Matsumoto, 2005. Possible involvement of plasma membrane H+-ATPase in the aluminum-induced secretion of citrate from arabidopsis roots. In: C.J. Li et al., eds, Plant Nutrition for Food Security, Human Health and Environmental Protection, Tsinghua University Press, pp742-743
12) Jianghua Shi, Hong Liao, Xiaolong Yan, 2005. Cloning and functional analysis of genes involved in root gravitropism in soybean as related to P availability. In: C.J. Li et al., eds, Plant Nutrition for Food Security, Human Health and Environmental Protection, Tsinghua University Press, pp514-515
13) Y. X. Wang, Y. H. Wan, H. Liao, C. X. Zhuang, H. Ma and X. L. Yan, 2005. Cloning and functional characterization of a novel *GmMAPK1* gene in soybean root. In: C.J. Li et al., eds, Plant Nutrition for Food Security, Human Health and Environmental Protection, Tsinghua University Press, pp516-517
14) Xiaolong Yan, 2005. The roots of p-efficient soybean: theories and practices. In: C.J. Li et al., eds, Plant Nutrition for Food Security, Human Health and Environmental Protection, Tsinghua University Press, pp36-37
15) C.Y. Yang, Y.X. Wang,H Shen, X.L. Yan, 2005. Cloning and characterizaton of the novel root-specific putative phosphate transporter in soybean (*Glycine max* (L.) Merr.). In: C.J. Li et al., eds, Plant Nutrition for Food Security, Human Health and Environmental Protection, Tsinghua University Press, pp172-173

3. Theses

1) Mboreha IA. 2005. Nutritional Effects of Soybean Root Architecture in a Soybean-Maize Intercropping System. Ph.D. Thesis, South China Agricultural University, Guangzhou, China, 86 pp
2) Fu JB. 2005.Genetic and Evolutionary Analysis of Soybean Root Morphological and Architectural Traits as Related to Phosphorus Availability. M.S. Thesis, South China Agricultural University, Guangzhou, China, 48 pp
3) Kong FL. 2005. Phosphorus Acquisition and Utilization from Various Phsophate Compounds in Growth Media by Transgenic Tobacco with a Phytase Gene from *Bacillus subtilis*. M.S. Thesis, South China Agricultural University, Guangzhou, China, 41 pp
4) Zhang MG. 2005. Effects of Salt and Low P Coupled Stresses on Soybean Growth and Ion Homeostasis. M.S. Thesis, South China Agricultural University, Guangzhou, China, 65 pp.

D. Emails from PIs

1. An Email From Dr. Jonathan Lynch (PI-PSU)

----- Original Message -----

From: Jonathan Lynch

To: Xiaolong Yan

Sent: Monday, February 06, 2006 3:23 AM

Subject: 2005 annual report

Dear Xiaolong,

this message is to confirm that I endorse the 2005 annual report.

Best

Jonathan

Jonathan Lynch
Dept. Horticulture
Penn State University
University Park, PA, 16802
814-863-2256, fax 3-6139
http://www.personalpsu.edu/faculty/j/p/jpl4/

2. An Email From Dr. Yaoguang Liu (coPI-SCAU)

----- Original Message -----
From: <ygliu@scau.edu.cn>
To: <xlyan@scau.edu.cn>
Sent: Saturday, February 04, 2006 5:40 PM
Subject: Re:McKnight Annual Report 2005

Xiaolong:

Thank you for the report. The report was well prepared and I agree with the contents.

Yaoguang

Yaoguang Liu
Professor of Molecular Biology
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3. An Email From Dr. Hong Ma (coPI-PSU)

----- Original Message -----

From: Hong Ma
To: xlyan
Sent: Saturday, February 04, 2006 10:29 AM
Subject: Re: McKnight Annual Report 2005

Dear Xiaolong:

Thank you very much for sending the report. I have read the report, and I agree with the content.

I just made a few very minor spelling corrections.

Happy Chinese New Year!

Hong

Hong Ma
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Appendices (Figures) 2005

Fig. 1. One of our soybean breeding lines, Yuexia03-3, performed very well as compared to the check variety (background in the right) in the National Regional Variety Trials. This line, together with 4 others from our breeding work, will be submitted for National Variety Certification in 2006.

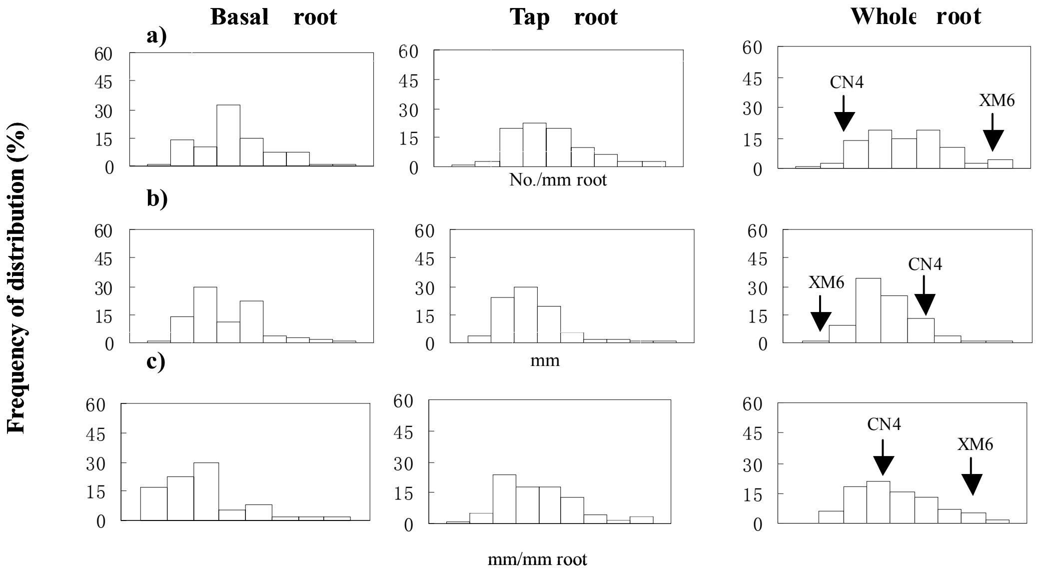

Fig. 2. Frequency distribution of the three root hair traits in a recombinant inbred line population derived from two contrasting soybean parents. a) root hair density (RHD); b) average root hair length (ARHL); c) root hair length per unit root (RHLUR). Note that the two parents are contrasting in three root hair traits measured and their progenies follow a normal distribution, indicating a quantitative nature of inheritance (Wang et al., 2005).

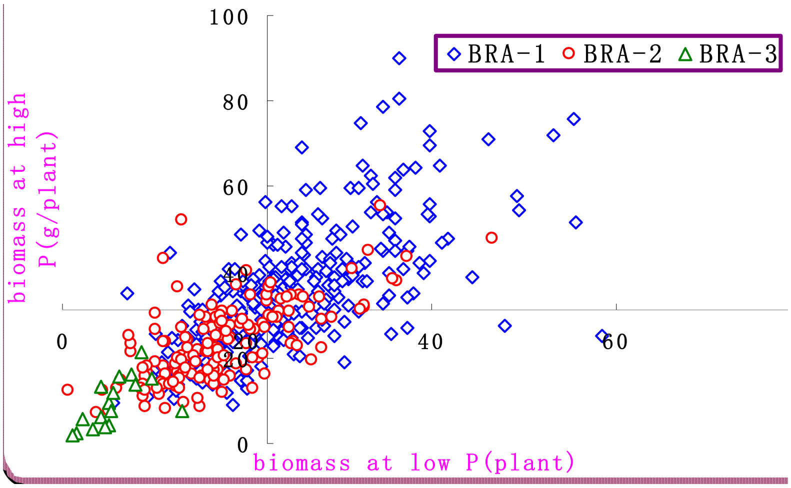

Fig. 3. Relationship between root architecture and soybean biomass under both low P (X axis)and high P (Y axis) conditions in the Boluo field site in South China. Symbols in the figure represent 500 individuals of the core collection of soybean germplasm. Blue diamond: shallow root architecture; Green triangle: deep root architecture; Red circle: intermediate root architecture (Liu et al., unpublished)

Fig. 4. Soybean transformation system is being established at SCAU for both gene functional analysis and possible transgenic approach to improving P efficiency in soybean.

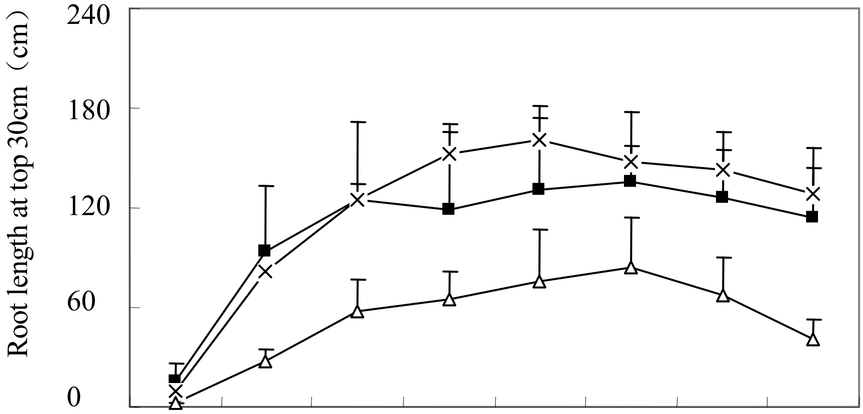

Fig. 5. Dynamics of root length distribution observed with a minirhizotron facility for three soybean genotypes with different root architecture. Cross: CN4 (P-efficient genotype); Open triangle: XM6 (P-inefficient genotype); Solid square: R51 (intermediate genotype). (Fu et al., unpublished)

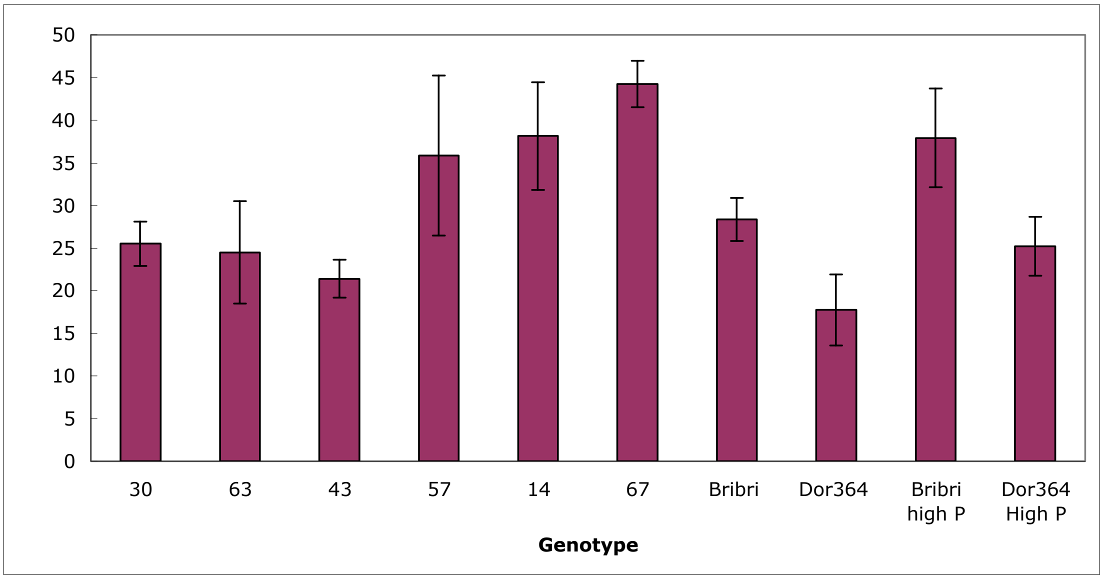

Fig. 6. Percent leaf cover 35 days after planting of L-88 RILS selected for differing root architecture, local phosphorus-efficient variety Bribri, and phosphorus-inefficient variety DOR 364. (Henry et al., unpublished)

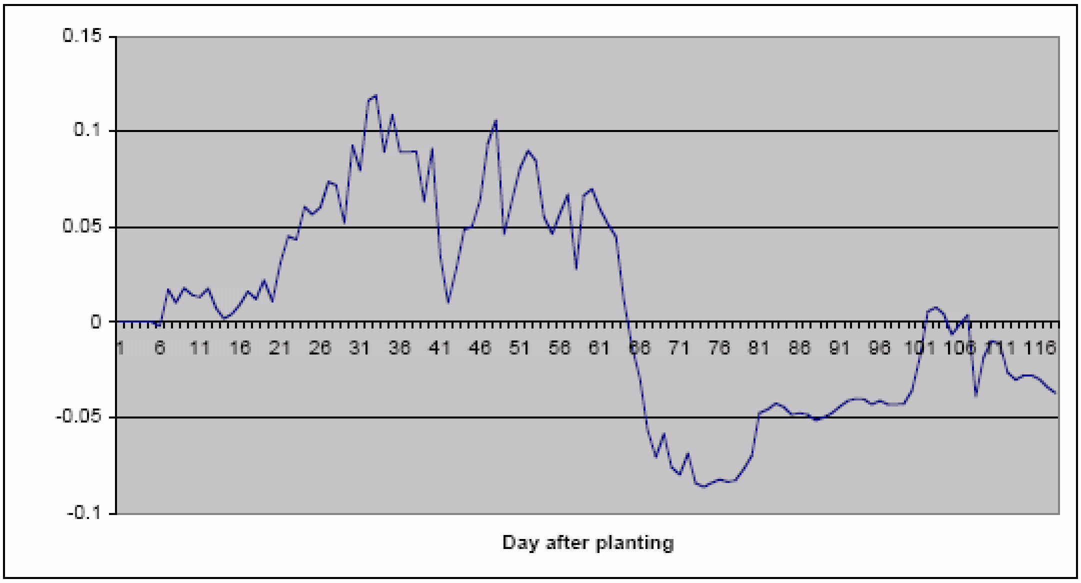

Fig. 7. Estimation of carbon (sucrose) allocation in the root for soybean grew in Guandong Province.

Fig. 8. Percent leaf cover 35 days after planting of L-88 RILS selected for differing root architecture, local phosphorus-efficient variety Bribri, and phosphorus-inefficient variety DOR 364. (Henry et al., unpublished)