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BEAN IMPROVEMENT FOR LOW FERTILITY SOILS IN AFRICA

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ABSTRACT

Bean (*Phaseolus vulgaris* L.) production in Africa is constrained by edaphic stresses. A pan-African effort, Bean Improvement for Low Fertility in Africa (BILFA), was initiated in 1990 to screen beans for tolerance to several edaphic stresses. In the first cycle, 280 entries consisting primarily of promising or released materials from African bean breeding programmes, were evaluated for tolerance to low availabilities of soil N, P and K, and toxicities of Al and Mn. Several entries were identified as tolerant for each of the stresses but especially promising are: RWR 382, RAO 55, ACC433, XAN 76 and MMS 224 for low P tolerance; ICA Pijao and EMP 84 for low K tolerance; Muhinga, Ntekerabsilimu and 7/4 ACC for tolerance to Al toxicity; and MCM 5001 and XAN 76 for tolerance to Mn toxicity. Several varieties, including XAN 76, RAO55, and OBA 1 have performed well under a number of edaphic stresses. The Rwanda breeding programme appears to be a good source of materials for low N and high Mn tolerance. The Uganda breeding programme appears to be a relatively better source of low P tolerance materials. The Great Lakes Region is apparently the best source of tolerance to Al toxicity. Problems encountered during implementation of the BILFA are discussed.

Key Words: ***Phaseolus vulgaris* L., edaphic stress, Aluminium and Manganese toxicity**

RÉSUMÉ

La production d'haricot (*Phaseolus vulgaris* L.) en Afrique est limitée par des stress édaphiques. Un effort panafricain portant sur l'amélioration du haricot pour les sols peu fertiles d'Afrique (BILFA) était initié en 1990 pour trier les haricots selon leur tolérance à plusieurs stress édaphiques. En premier cycle, 280 entrées comprenant premièrement des matériels prometteurs ou diffusés en provenance des programmes africains d'amélioration de haricot étaient évaluées pour leur tolérance à la faible disponibilité de N, P et K et aux toxicités en AL et Mn. Plusieurs entrées étaient identifiées comme étant tolérantes à chacun de stress. Les plus prometteurs de tous étaient: RWR 382, RAO 55, 533, XAN 76 et MMS 224 pour la tolérance aux faibles teneurs en P; ICA Pijao et EMP 84 pour la tolérance aux faibles teneurs en K; Muhinga, Ntekerabsilimu et 7/4 ACC pour la toxicité AL; et MCM 5001 et XAN 76, RAO 55 et OBA 1 se sont bien comportées en présence d'un certain nombre des stress édaphiques. Le programme Rwandais d'amélioration de haricots semble être la bonne source de matériels tolérants aux faibles teneurs en N et à la toxicité en Mn. Le programme d'amélioration de l'Ouganda semble être relativement la bonne source pour les matériels tolérant des faibles teneurs en P tandis que la région des grands lacs est apparement la meilleure source de tolérance pour la toxicité Al. Les problèmes rencontrés durant l'exécution de BILFA sont abordés dans ce papier.

Mots Clés: ***Phaseolus vulgaris* L., stress édaphique, toxicité en aluminium et manganèse**

INTRODUCTION

Bean (*Phaseolus vulgaris* L.) is a major source of protein and calories in Eastern and Southern Africa (Pachico, 1993). However, bean production in Africa is often constrained by low availability of soil nutrients, N, P and K and the toxicity complex of Al and Mn, resulting in annual losses of bean production estimated to be 1.2, 1.0, 0.3, and 0.5 million metric tonnes, respectively (Wortmann and Allen, 1994). The production of bean in Africa is primarily by small-scale farmers who use little or no fertilizer or soil amendments. Cultivars that are efficient in uptake and use of available nutrients are needed to give good performance in cases of low nutrient supplies and to use applied nutrients efficiently.

Studies of the genetics of tolerance of bean to various edaphic constraints have been reviewed (Singh, 1991; Aggarwal, 1994). Results demonstrate the feasibility of selection and breeding for tolerance to certain edaphic constraints.

Tolerance to low soil N has seven basic components (Lynch and White, 1992) including: rate and duration of N acquisition, efficiency of N use in vegetative growth, timing of the transition to reproductive growth, rate and duration of N accumulation in seeds, and efficiency of N use in seed formation. Varieties differ in these characters but are largely influenced by the environment (Lynch and White, 1992). Differences in N fixing capacity have been observed where bush types fix less than indeterminate and climbing types (Graham, 1981; Rennie and Kemp, 1983), but there is much genetic variability within growth types for N fixing capacity (Kipe-Nolt and Vargas, 1988; CIAT, 1989). Leaf longevity is important but shoot architecture apparently is not important to N-use efficiency of individual leaves (Lynch and Rodriguez, 1994).

Several morphological (root and shoot dry weight) and physiological (P acquisition and utilisation) characters have been identified as important to low P tolerance in bean (Whiteaker *et al.*, 1976; CIAT, 1987; Gerloff, 1987). Bean root architecture may be important in P acquisition capacity by plants (Lynch and van Beem, 1993). Lindgren *et al.* (1977) used excised roots to identify lines of beans with different capacities for P absorption and estimated heritabilities derived from parent offspring regression to be around 40%. Fawole *et al.* (1982b) found root development, as an indicator of efficiency of P utilisation, to be controlled by quantitative inheritance patterns. Dominance variance was more important than additive variance in four out of six families and broad sense heritability estimates were between 0.69-0.89. In another study, Fawole *et al.* (1982a) found that epistasis, notably additive x additive and dominance x dominance, played a major role in efficiency of P utilisation. Additive and dominance gene effects were also significant with narrow sense heritability estimates of 0.45-0.76. Through regression of F_3 families on the corresponding F_2's, heritability for yield under low P was found to be 0.61 (Urrea and Singh, 1988). Phosphorus use efficiency has been transferred from an exotic germplasm to an adapted variety by Schettini *et al.* (1987) using a backcross method, and several tolerant lines were derived from the efficient P donor parent (PI 206002) combined with the desirable recurrent parent 'Sanilacl'.

Shea *et al.* (1968) determined efficiency of K use in beans to be simply inherited and largely influenced by the k_e gene. The frequency of occurrence of the k_e gene in commonly used bean germplasm is not known.

Varietal differences for Al tolerance have been reported for several crop species, including bean (Foy *et al.*, 1967, 1972; CIAT, 1985, 1987). Tolerance to Mn toxicity in bean has been less studied. Morris and Pierre (1948) found lespedeza and sweetclover to be relatively sensitive, cowpeas and soybeans intermediate, and peanuts to be relatively tolerant to high Mn. Peanuts were able to endure high concentrations of Mn within the plant.

The strategy of the BILFA has a number of features (CIAT, 1994):

(i) It is a pan-African effort to screen beans for tolerance to low availability of the important soil nutrients and to Al and Mn toxicities by screening independently for each of the four stresses rather than for a complex of stresses.

(ii) Entries of good agronomic type and/or known

reaction to soil fertility problems are collected from national and CIAT breeding programmes to be screened for the stresses.
(iii) Screening is done at primary sites for two seasons, rejecting 50% of the entries based on the first season results and another 30-40% based on the second season results.
(iv) Confirmation testing is to be done at additional stress sites.
(v) Screening is done at moderate stress levels allowing 40-50% of the yield of non-stress conditions due to expression of yield potential and good adaptation, together with tolerance.
(vi) The primary selection criterion is seed yield under stress.

This paper presents results of advanced level testing of genotypes identified as promising during the first cycle of the BILFA for either tolerance to low availability of soil N, P or K, or to toxicity of either Al or Mn. The proposed scheme for future BILFA germplasm evaluations is presented.

MATERIALS AND METHODS

During the first cycle of the BILFA, 280 agronomically promising bean genotypes were obtained from national and CIAT breeding programmes. The entries were evaluated for low N at Nakasongola and Kawanda in Uganda, low P at Nakasongola and Ikulwe in Uganda, low K at Kawanda in Uganda, high Al at Mulungu in Zaire and high Mn at Buikwe and Ssempa in Uganda. Soils at most screening sites were highly weathered oxisols (Table 1). Screening methods varied slightly, but were generally similar. Stress levels were intended to allow 40-50% of the yield achieved when nutrient supply was adequate. Fertilizers and amendments were applied as necessary to alleviate other disorders. Evaluations at primary screening sites were carried out only under stress conditions for two seasons with yield under stress as the main selection criterion. Plots were of 2.4 or 3.9 m^2 with two or three replicates. Climbing and non-climbing bean types were tested separately. In some cases, check varieties, G2333 for the climbers and either Carioca and K20 for the non-climbing varieties, were planted in every seventh plot to account for variation in stress levels across the field. In other cases, plot values were adjusted by the mean yield of the two or four nearest plots to account for variation in stress levels.

After two seasons of evaluation, 80-90% of the entries were rejected, and a set of promising varieties was compiled for each edaphic stress. Confirmation testing was done in more environments usually in plots of 2 x 4 m^2 with three replicates in either a lattice or a randomised complete block design. The check varieties used at this stage were well-adapted varieties in the test locations, but generally not recognised as tolerant to specific nutrient deficiencies or toxicities.

RESULTS AND DISCUSSION

Some check varieties performed well compared to the mean of the entries selected as promising for tolerance to particular stresses. MCM 5001, MCM 2001 and CAL 96 are high-yielding, well-adapted varieties in Uganda selected under moderately low soil fertility conditions. Their good adaptation probably contributes to their capacity to perform well under low fertility conditions (Tables 2-4, 6). Carioca, a check variety in the low P trials, is well adapted in Uganda and is known to have tolerance to certain types of low P conditions. K20, an older and widely grown variety in Uganda capable of moderately good yields under farmers' conditions, generally performed poorly under stress compared to the varieties selected as promising for tolerance.

Nitrogen. The check varieties were superior under low N stress to most entries in the first cycle of the BILFA, and compared well with the 33 varieties selected as most promising for tolerance (Table 2). Still, several varieties performed significantly better than the checks under low N stress including RWR 382, RAO 55, ACC433 and BAT 85. These varieties also performed well under less stress in the Kawanda 1992b trial suggesting the capacity to utilise available N well, either from the air or from the soil. Preliminary results from Malawi tend to confirm the tolerance of several varieties to a complex of low soil N and P.

Phosphorus. The check varieties varied in performance under low P stress (Table 3). MCM

5001 and Carioca performed relatively well compared with the varieties selected for tolerance to low P. K20 performed poorly. Several varieties promising for tolerance, although not always superior to MCM5001 and Carioca, performed well under the low P conditions in Uganda. Especially promising are BAT25, RAO55, XAN76, and MMS224. Several promising of the varieties performed well under low soil N and P in Malawi.

Potassium. Results are available from one site only for 33 varieties selected from the original 280 for tolerance to low K (Table 4). EMP84, ICA Pijao, and RAO52 appear to have good levels of tolerance to low K. BAT1220 is of particular

TABLE1. Characteristics of surface soils at test sites of the first cycle of the BILFA

Site	Altitude (m asl)	Texture	pH:H_2O (1:2. 5)	SOM (%)	Avail. P (mg kg^{-1})	Ex.Ca (cmol. kg^{-1})	Ex.K^+	Ex. Mn^{2+} (mg kg^{-1})	% Al^{3+} sat.
Nakasongola	1130	SL	6.1	1.5	4	2	0.3	n.a	n.a
Kawanda (low N)	1190	SCL	5.5	2.1	20	2	0.5	n.a	n.a
Kawanda (low K)	1190	SCL	5.3	3.3	10	2	0.2	n.a	n.a
Ikulwe	1200	SCL	5.2	2.8	3	4	0.8	n.a	n.a
Buikwe	1200	SCL	5.4	n.a	32	2	0.5	488	n.a
Sempa	1200	SCL	6.1	n.a	33	3	1.1	445	n.a
Kavumu	1730	n.a	4.6	5.6	7	2	0.1	n.a	68
Burhale	1730	n.a	4.6	2.0	4	1	0.1	n.a	68
Mumbumbano	1730	n.a	5.1	3.7	neg.	2	0.1	n.a	56
Nyamunyunye	1730	n.a	4.7	3.9	1	3	0.1	n.a	42
Mulungu	1730	n.a	5.0	n.a	1	n.a	n.a	n.a	n.a

SOM= Soil organic matter; n.a. = data not available, neg. = negligable or trace amounts

TABLE 2. Performance (kg ha^{-1}) under low N stress of best of 33 varieties selected for tolerance from 280 adapted entries plus three check varieties

Variety	Nakasongola 92b	Kawanda[1] 92b	Kawanda 93a	Kawanda 94a
RWR382	633	1361	275	1177[2]
XAN76	500	1253	335	599
RWK8	408	1475	269	963
RWK5	300	1542	355	971[2]
RAO55	508	1583	389	971[2]
RAB476	325	1174	336	913
433	908	1367	341	916[2]
BAT85	962	1531	330	894[2]
PEF2	375	1342	167	976
MMS224	483	1308	334	899
MCM5001 (check)	400	1404	199	—
CAL96 (check)	—	—	164	643
MCM2001 (check)	358	1267	218	726
Mean of 36 entries	423	1153	272	580
LSD(0.05)	252	326	124	172

[1]The Kawanda 1992b site had generally adequate N levels.
[2]These varieties were in the top 10% of 350 varieties screened at Bembeke, Malawi on a site severely deficient in N and P during the 1993-4 season (Aggarwal *et al.*, 1994).

interest since it was selected from on-farm variety trials conducted in Uganda in 1987-8 and adopted by farmers who continue to grow it on low K soils.

Aluminium. Yield results from five environments in Zaire are presented for the best entries selected for tolerance to Al toxicity from the original set of 280 entries (Table 5). Stress levels were severe at these sites and some of the entries failed to produce seed. Under such severe stress levels, tolerance is probably the main determinant of yield and effects of yield potential and good adaptation are suppressed. A well-adapted local variety in the Mulungu area, 7/4 ACC, appears to have the greatest tolerance to Al toxicity. All of the most promising varieties selected for tolerance to these levels of Al toxicity originated in the vicinity of Eastern Zaire, Rwanda and Burundi suggesting this Region as a likely source of genetic diversity for this characteristic.

TABLE 3. Performance (kg ha^{-1}) under low P stress of best of 33 varieties selected for tolerance from a set of 280 adapted entries, plus three check varieties

Variety	Nakasongola 92b	Ikulwe 94a
BAT85	667	225[1]
BAT25	658	543
ACC433	650	340[1]
RAO55	575	447
XAN76	515	670
MMS243	500	369
MMS224	492	505
DOR375	450	297
AFR544	233	701
A 321	225	699[1]
OBA 1	175	567[1]
MCM 5001 (check)	608	343[1]
K 20 (check)	212	214
Carioca (check)	367	629
Mean of 36 entries	359	427
LSD (0.05)	222	289

[1] Varieties were in the top10% of 350 varieties screened at Bembeke, Malawi on a site severely deficient in N and P during the 1993-4 season (Aggarwal *et al.*, 1994).
[2]Preliminary evaluation of several of these varieties on a volcanic soil with extremely low available P at Darien, Colombia indicate that BAT85, RAO55, RAO52, MMS243, DOR375, AFR544, MCM5001, K20 and Carioca are not tolerant under these conditions. XAN76, A321 and OBA1 performed well.

Manganese. MCM5001 gave the best performance under high Mn conditions (Table 6). XAN76 and Urugezi also appeared to tolerate Mn toxicity, as did several Rwandan varieties of the RWR series.

Multiple tolerances. Several varieties appeared to tolerate multiple deficiencies (Table 7). BAT85, ACC433, RAO52, RWR382 and XAN76 appear to be relatively tolerant to low soil N, P and K availability, suggesting these have the capacity to perform well despite the scarcity of other nutrients. MCM5001, RWR382, OBA1, and XAN76 performed well in the high Mn trials while having tolerance to low levels of two or more nutrients. Only Urugezi, and possibly AFR476, appear to tolerate both Al and Mn toxicities.

Sources of tolerance. The results indicate that the Rwanda bean breeding programme is a relatively good source of materials with tolerance to low N and high Mn. Proportionately more entries submitted by the Uganda breeding programme are promising for low P tolerance. Lines with apparent low K tolerance came from numerous sources. Rwanda, Burundi and eastern Zaire appear to be good sources of tolerance to Al toxicity. Tolerance to nutrient deficiency occurred relatively more frequently in small seed types than with medium or large seed types. Tolerance

TABLE 4. Performance (kg ha^{-1}) under low K stress at Kawanda, Uganda of the best of 33 varieties selected for tolerance from 280 adapted entries, plus three check varieties

Variety	Yield in 1994A
EMP84	542
ICAPijao	399
RAO52	371
MUS97	346
DOR335	318
Porrillo Sintetico	311
DOR375	286
ARA4	262
BAT1220	247
XAN76	109
MCM5001(check)	153
CAL96 (check)	162
K20 (check)	88
Mean of 36 entries	217
LSD (0.05)	141

TABLE 5. Yield (kg ha^{-1}) under high Al stress of eight bean varieties selected for Al tolerance from 280 entries in trials in Zaire

	1993a season		1993b season		
Varieties	Kavumu	Burhale	Kavumu	Burhale[1]	Mubumbano[1]
7/4 ACC	751	250	170	131	432
Muyinga	395	175	225	179	596
Ntekerabasilimu	571	29	150	62	79
EM 24/6	178	92	166	92	300
IZO 0201461	144	83	208	96	242
Ubusosera	272	42	317	12	17
ACV 22	375	33	62	112	87
AFR 476	187	112	17	58	229
Mean[2]	296	49	180	2 8	56
LSD 0.05	193	106	189	42	114

[1] Several varieties gave no yield at the Burhale and Mubumbano sites in 1993b.
[2] The mean of 50 varieties selected from 280 for tolerance to Al toxicity.
Modified from: Lunze (1994).

TABLE 6. Yield (kg ha^{-1}) under high Mn stress of 10 bean varieties selected for Mn tolerance from 280 entries in trials conducted in Uganda

	Buikwe 1992b	Sempa 1993a	Matugga 1993b
MCM 5001	1268	1133	1256
XAN 76	1394	707	1290
Urugezi	1094	727	1000
RWR 960	826	1093	1046
RWR 982	846	770	—
RWR 382	1241	590	—
RWR 221	1248	65	—
A 120	1217	453	—
KID 54	939	897	—
AND 871	1003	680	—
K 20 (check)	467	410	793
Carioca (check)	617	190	—
LSD 0.05	378	—	—

Modified from: Ochwoh (1994).

to Mn and Al toxicity was less dependent on seed size.

SCHEME FOR FUTURE BILFA EVALUATIONS

An important issue encountered in the BILFA is that of tolerance versus adaptation with yield potential as it has implications for setting optimal levels of stress for effective screening, site selection and number of selection sites. Another issue has been that of screening for single stresses versus complexes of edaphic stresses.

BILFA evaluations have generally been done at moderate stress levels in order to allow tolerance as well as adaptation and yield potential to contribute to plant performance. This approach allows for efficient selection of genotypes to be used as cultivars. However, selection at more severe stress levels would probably be better for identifying breeding parents with high levels of tolerance. A problem with evaluation under moderate stress is that often another abiotic or biotic stress affects the crop and prevails over the stress of interest. An alternative to screening at moderate stress levels is to evaluate entries both under severe stress and non-stress conditions, but this would require more resources. Also, increasing stress increases susceptibility to other stresses. The current BILFA scheme is to conduct the primary evaluations for two seasons at moderate stress levels. Confirmation testing is done at more locations at both moderate stress and no stress levels, while these promising genotypes are also evaluated under severe stress at the primary screening sites only (Table 8).

The primary evaluations of the first cycle of the BILFA were conducted at one location only to identify promising materials to be tested more widely throughout Africa. The importance of good adaptation, especially to altitude, has become apparent to the expression of tolerance. The BILFA strategy has been modified to have primary screening sites for each stress at both high and intermediate altitudes (CIAT, 1994).

TABLE 7. Reactions of varieties selected from a set of 280 entries to various soil fertility related constraints

Variety	Low N	Low P	Low K	High Al	High Mn
ACC433	T	MT	T	S	S
6088	T	S	T	S	S
7/4ACC	S	S	S	VT	S
AFR403	T	S	MT	S	S
AFR476	S	S	S	T	T
AFR544	MT	T	S	S	T
BAT25	S	VT	T	S	S
BAT85	T	T	MT	S	S
Black Dessie	S	MT	S	S	T
Carioca	T	T	S	S	S
DOR 375	S	T	T	S	S
GLP 585	MT	T	S	S	S
Ikinimba	T	MT	S	S	S
MCM 5001	MT	S	S	MT	VT
MMS 224	T	T	S	S	S
Muhinga	S	T	S	VT	S
MUS 97	VT	S	T	S	S
Ntekerabsilimu	S	S	S	VT	S
OBA 1	T	T	S	S	T
PAI 112	T	T	S	S	S
Porrillo Sin.	T	S	T	S	S
RAO52	MT	T	T	S	S
RAO55	VT	T	s	MT	S
RWK5	T	T	S	S	S
RWK8	T	S	S	T	S
RWR382	T	T	T	s	T
RWR960	S	S	S	S	T
RWR982	S	S	S	S	T
ICA Pijao	S	S	VT	S	S
Urugezi	S	S	S	T	T
XAN 76	VT	VT	T	S	VT

[1] S, MT, T, VT indicate susceptible (in the lower 85% of the original set), moderately tolerant (upper 15%), tolerant (upper 8%) and very tolerant (upper 1%), respectively, in reaction to the edaphic stress.

Soil fertility problems often occur as complexes of deficiencies and/or toxicities, but these complexes vary with location. Because of the variability of complexes, it was thought that genotype by complex interaction effects would delay selection progress. The BILFA strategy has been to screen for tolerance to single stresses, e.g. low soil P or Al toxicity, rather than for tolerance to complexes. This strategy was slightly modified to focus on tolerance to low soil N at moderate pH, to low soil P at moderate pH, and to the low pH complex which has Al and Mn toxicity and low P and base availability as common characteristics (CIAT, 1994).

TABLE 8. Procedure for future screening bean germplasm for tolerance to soil fertility related stresses

Season	Details	Plot size/number	Stress level
	Stage I		
A	360 entries; Primary sites only; Criteria: yield under stress; Select best 50%	Single row, 2 replications	Moderate stress
B	180 entries; Primary sites; Criteria: yield under stress; Select 40-50 lines	2 row plots, 2 replications	Moderate stress
C	50 lines; Primary and Secondary sites; Criteria: yield	2-4 row plots, 3 replications	Moderate stress and no stress
D	20-35 lines Primary and secondary sites; Criteria: yield root,shoot ratio, total nutrient uptake	4 row plots, 3 replications	Moderate stress and no stress
	Stage II		
C2	50 lines, Primary and secondary sites; Criteria: yield, biomass, root/shoot ratio	2-4 row plots, 3 replications	High stress

Source: CIAT (1994).

Both tolerance and good adaptation are important to performance under stress. The promising varieties are generally expected to be less well- adapted than the check varieties which were selected because of their good performance in the test countries. Therefore, good performances by promising varieties is probably because these have significant levels of tolerance to the stress in question.

CONCLUSION

The BILFA has successfully identified varieties which perform well despite certain edaphic constraints. Experiences gained have been useful in improving the evaluation strategies and the modified scheme is being applied with the second cycle of the BILFA. The promising varieties are available for use by national bean breeding programmes. The ultimate test of the BILFA will be through further testing of the varieties in more locations and subsequent reactions of farmers to the varieties, and through the use of more tolerant genotypes as breeding parents.

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