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1) Measured and predicted yield response of soybeans to simulated acid rain.

Modern soybean cultivars in the U.S. are highly related within the northern and within the southern maturity groups and they trace their genetic constitution to a small number of ancestral lines. On the other hand, there is much less genetic relationship between northern cultivars and southern cultivars. Examples of this can be seen in Figure 1, which shows the ancestral relationships among selected lines and cultivars developed from the northern and southern germplasm pools, respectively. Slightly more than 80% of the northern cultivars released during 1971-81 trace their genetic makeup to 10 accessions (Delannay et al., 1983). 'Mandarin', alone, accounts for more than 30% of the genes in the northern cultivar gene pool. Similarly, more than 80% of the genes in southern cultivars released during 1971-81 come from seven accessions. According to Delannay et al. (1983), CNS and S100 have contributed more than 50% of the genes in the southern cultivar gene pool. This narrow genetic base is a major concern to the breeders and geneticists due to vulnerability to diseases, insects, etc. On the other hand, the narrowness of the genetic base facilitates the assessment of future progenies' reactions to environmental changes. We are attempting to predict the response of soybean lines to acid rain on the basis of the reaction of the ancestral lines to acid rain.

Current knowledge concerning soybean response to acid precipitation is inconclusive in that stimulation, inhibition, or no effect on yield has been reported (Evans and Thompson, 1984; Evans et al., 1981; Heagle et al., 1983; Irving and Miller, 1981; Troiano et al., 1983). This uncertainty in response might be due to the differing growing conditions. Soybeans grown under optimum conditions might tend to overcome adverse effects of acid precipitation whereas stressful growing conditions might adversely affect productivity.

The objectives of our research were to evaluate: (1) yield response of ancestral lines and cultivars derived from them to Simulated Acid Rain (SAR); (2) interaction between environments and SAR for yield; and (3) predicted yield response to SAR of progeny from matings among ancestral lines.

Materials and methods: During 1985, the experiments were conducted at Knoxville and Milan, Tennessee. At each location, the 72 treatment combinations (optimum vs. sub-optimum soil fertility, three levels of SAR acidity, and 12 entries) were grown in a split-split strip block arrangement with three replications. The two soil fertility levels served as main strips, the three SAR treatments (pH 2.8, pH 3.2, and pH 4.3) served as the split-block and 12 entries served as the split-split block. The results of soil test were as follows: water pH of 5.9; buffer pH of 7.7; 46 kg/h P205; and 80 kg/h K20. In order to create two types of growing environments, lime (5.6 mt/h ground limestone) and fertilizer (89.6 kg/h P205 and 179.3 kg/h K20) were incorporated into the optimum strips to raise their fertility and soil pH to optimum levels. The sub-optimum strips did not receive any lime or fertilizer. Each experimental unit consisted of three rows 3 m in length with 0.9 m space between the rows.

The entries included eight ancestral lines ('AK Harrow', 'CNS', 'Manchu', 'Mandarin', PI 54610, 'Richland', S 100, and 'Tokyo') and four cultivars ('Amsoy 71', 'Essex', 'Lee 74' and 'Williams 82'). The SAR treatments were applied (spray-until-runoff) three times a week at Knoxville and two times a week at Milan from V2 until R7 stage. The amount of SAR represents mean weekly amounts of ambient rain based on the 30-year mean. The SAR solutions were made using the composition of rainfall as reported by Cogbill and Likens, a 1:1 mix of nitric and sulphuric acids substantiated with ammonium sulfate, calcium sulfate, sodium sulfate, potassium sulfate, and magnesium sulfate. The SAR was applied with a tractor-mounted sprayer at a pressure of 0.7 kg/sq cm using a PTO-driven diaphragm pump. The SAR quality was maintained by analysis of time of application samples for pH and other parameters.

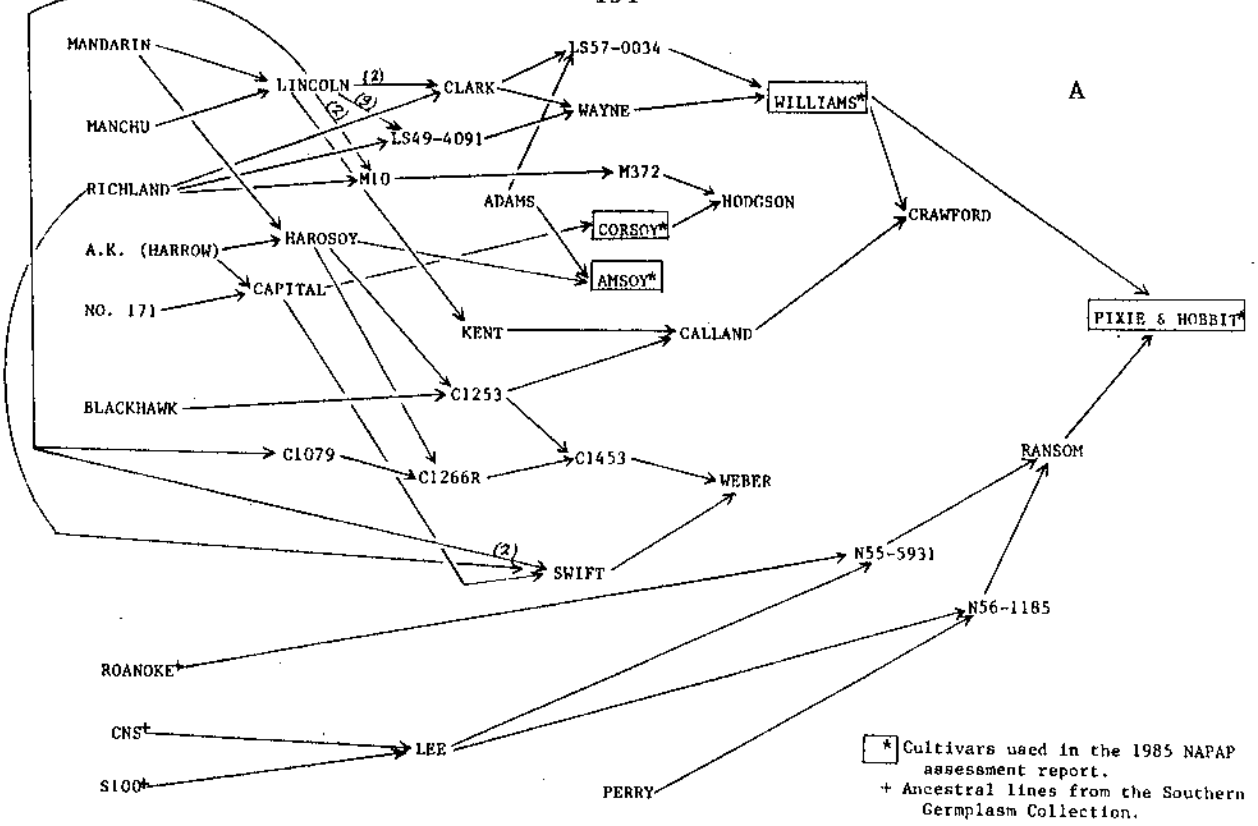
The entries were hand-harvested and threshed in a plot thresher and their yields were recorded. The data were analyzed using SAS procedures (SAS Institute, Inc., Box 8000, Cary, North Carolina 27511-8000). The yields of four cultivars (Amsoy 71, Essex, Lee 74, and Williams 82) were predicted from ancestral lines' yield response and the covariance relationships among ancestral lines and these cultivars by using mixed models procedure (Henderson, 1975; Hill and Rosenberger, 1985). The covariance matrix for relationship among ancestral lines and cultivars was generated by using 'PROC INBREED' procedure in SAS. The ratio of phenotypic variance to genetic variance (the heritability of yield in soybeans assumed to be .4) was superimposed on the covariance matrix. We used a generalized inverse of covariance matrix to obtain Best Linear Unbiased Prediction (BLUP) for yield response of cultivars to different environments. The yield data of these cultivars was eliminated, one cultivar at a time, before obtaining the BLUP estimate. The BLUP estimates of yield were compared to the actual yield of these cultivars.

Results and discussion: There was significant interaction between locations, entries, soil fertility levels, and acidity levels of SAR. At both locations, there was significant interaction between entries, soil fertility levels, and acidity levels of SAR except between entries*soil fertility levels and soil fertility levels*acidity levels of SAR at Knoxville.

At Knoxville, an increase in the acidity of SAR from pH 4.3 to pH 2.8 significantly decreased the yield of Manchu (28.8%) at optimum soil fertility and significantly increased the yields of Mandarin (51.4%) and Tokyo (36.5%) at sub-optimum soil fertility (Table 1). At Milan, an increase in the acidity of SAR from pH 4.3 to pH 3.2 significantly increased the yield of AK Harrow (124.7%) and significantly decreased the yield of Amsoy 71 (9.8%) under optimum soil fertility and any further increase in the acidity of SAR did not have any significant effect. The increase in the acidity of SAR from pH 4.3 to pH 2.8 significantly increased the yields of Richland (171.3%) and Tokyo (22.5%) at optimum soil fertility.

The predicted and actual yields of four cultivars are presented in Table 2. The predicted yields of Essex, Lee 74, and Williams 82 were always lower than their actual yields in both locations. The predicted yields of Amsoy 71 were always higher than its actual yields except at pH 3.2 with optimum soil fertility at Knoxville. At Milan, the predicted yields of Amsoy 71 were either greater than or similar to its actual yields. Based on their genetic background, Essex, Lee 74, and Williams 82 were expected to yield lower than their actual yields, indicating that they were not detrimentally affected by the acid rain. On the other hand, Amsoy 71 did not yield as expected from its genetic background, indicating that it might be sensitive to acid rain.

The comparison of actual yields (Table 1) did not give conclusive results but still gives an indication that Amsoy 71 is sensitive to acid rain under some growing conditions. The parents of this cultivar (Figure 1) are Harosoy and Adams. The parents of Harosoy, AK Harrow and Mandarin, were not detrimentally affected by SAR (Table 1). Therefore, the sensitivity of Amsoy 71 apparently was not inherited from either AK Harrow or Mandarin. Since Adams



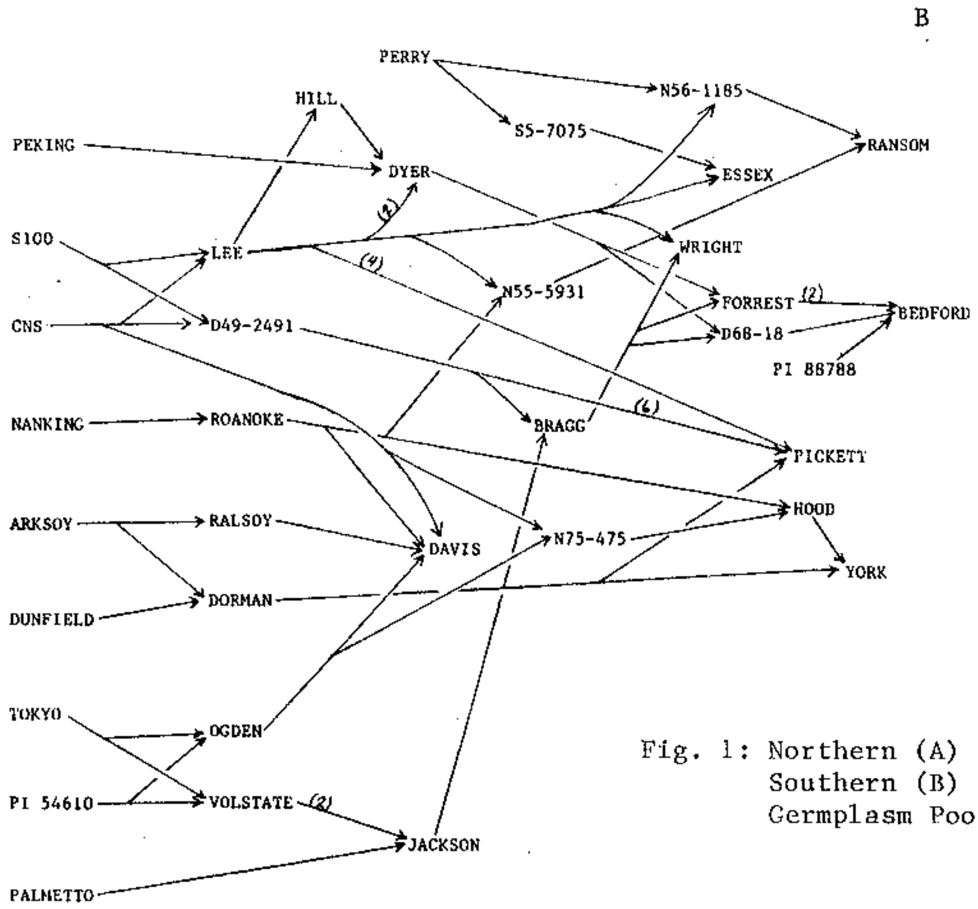


Fig. 1: Northern (A) and Southern (B) Soybean Germplasm Pools.

Table 1. Mean yield (g/plot) of eight ancestral soybean lines and four cultivars with three pH levels of simulated acid rain

	Knoxville						Milan					
	Sub-optimum†			Optimum			Sub-optimum			Optimum		
Entry	2.8‡	3.2	4.3	2.8	3.2	4.3	2.8	3.2	4.3	2.8	3.2	4.3
AK Harrow	392a*	388a	391a	446a	417a	441a	253a	266a	222a	241ab	346a	154b
Amsoy 71§	442a	428a	372a	593a	582a	575a	364a	370a	374a	392ab	378b	419a
CNS	399a	440a	455a	500a	398a	709a	288a	303a	291a	340a	338a	389a
Essex§	549a	735a	683a	831a	795a	821a	806a	619a	709a	831a	804a	659a
Lee 74§	524a	568a	556a	694a	617a	561a	476a	586a	521a	635a	718a	679a
Manchu	474a	378a	409a	430b	468ab	604a	337a	276a	268a	368a	304a	277a
Mandarin	480a	366b	317b	526a	402a	426a	294a	291a	281a	288a	278a	224a
PI 54610	473a	421a	546a	689a	739a	667a	364a	374a	484a	461a	529a	459a
Richland	377a	366a	357a	512a	429a	467a	278a	230a	225a	293a	209ab	108b
S100	--	--	--	--	--	--	438a	467a	390a	442a	449a	383a
Tokyo	864a	533b	633b	851a	588a	1043a	429a	428a	467a	604a	545ab	493b
Williams 82§	536a	567a	609a	813a	819a	730a	580a	559a	588a	710a	643a	597a

†Levels of soil fertility.

‡pH of simulated acid rain.

§Cultivar.

*Comparison of means to be made within locations, within each fertility level and separately for each entry (for example, in case of AK Harrow, the yields of three pH levels under sub-optimum fertility in Knoxville can only be compared with each other). Means followed by same letters are not different according to Duncan's Multiple Range Test (P = 0.05).

Table 2. Actual[†] and predicted[‡] yields (g/plot) of four soybean cultivars with three pH levels of simulated acid rain

	pH Levels of simulated acid rain											
	pH 2.8				pH 3.2				pH 4.3			
	KES*		MES[#]		KES		MES		KES		MES	
Entry	Sub[§]	Opt[¶]	Sub	Opt	Sub	Opt	Sub	Opt	Sub	Opt	Sub	Opt
Amsoy 71	442[†] (493)[‡]	593 (608)	364 (374)	392 (415)	428 (456)	582 (543)	370 (363)	378 (413)	372 (457)	575 (587)	374 (365)	419 (337)
Essex	549 (442)	831 (624)	806 (390)	831 (472)	735 (495)	795 (558)	619 (425)	804 (495)	683 (499)	821 (621)	709 (400)	659 (455)
Lee 74	524 (474)	694 (649)	476 (476)	635 (507)	568 (552)	617 (594)	586 (440)	718 (500)	556 (537)	561 (712)	521 (437)	679 (448)
Williams 82	536 (468)	813 (552)	580 (344)	710 (376)	567 (423)	819 (502)	559 (323)	643 (350)	609 (418)	730 (579)	588 (322)	597 (309)

*Knoxville Experiment Station.

#Milan Experiment Station.

§Sub-optimum soil fertility and pH.

¶Optimum soil fertility and pH.

was not included in this study, no definite statement can be made about its contribution to the sensitivity of Amsoy 71 but it remains a suspect. Adams and Manchu (another sensitive line) were involved in the pedigree of Williams 82, which was not detrimentally affected by SAR. It is possible that the contributions made by Mandarin and Richland to the pedigree of Williams 82 outweighed the sensitivity contributed by Manchu and/or Adams. Evans and Thompson (1984) also observed a decrease in the seed yield of Amsoy 71 with an increase in acidity of simulated acid rain. The actual yields of Amsoy 71 under optimum soil fertility conditions at Milan decreased with increasing acidity of SAR. The actual yields of Essex, Lee 74, and Williams 82 either increased with increasing acidity of SAR or were similar at all acidity levels.

The use of mixed models to predict the yields of future progeny seems quite worthwhile. It might be used successfully to predict the performance of future progeny under varying environmental conditions. This technique was compared with six other techniques by Hill and Rosenberger (1985) for estimating yields of lines included in a series of trials that did not contain all entries in equal numbers. They concluded that Best Linear Unbiased Prediction (BLUP) method was most desirable since it gave smallest prediction errors.

Besides yield, data on maturity and plant height were also recorded on all plots at both the locations. In addition, transpiration rate and stomatal resistance were recorded for AK Harrow, CNS, Essex, Mandarin, and Williams 82 at Knoxville. The effects of SAR on plant height and maturity were not significant. The transpiration rate of Essex decreased, whereas that of CNS increased with increasing pH of SAR.

The results from one year at two locations indicate that (1) Essex, Lee 74, and Williams 82 were not detrimentally affected by the acid rain; (2) Amsoy 71 seems to be sensitive to SAR at least under some growing conditions; (3) the growing environment seems to affect the response of soybean cultivars and lines to acid rain; and (4) the comparison of actual and predicted yields might be a useful criterion in assessing sensitivities of soybean lines and cultivars to acid rain.

Additional greenhouse (at Knoxville) and field experiments (at Knoxville and Milan, Tennessee) will be conducted during 1986 to further assess the impact of acid rain on soybean growth and yield.

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