~~THE USE~~ OF AGROCHEMICAL INPUTS IN PRODUCTIVE AND SUSTAINABLE TROPICAL CROP PRODUCTION SYSTEMS OF RICE, COMMON BEANS AND MAIZE

by

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The paper is being circulated for critical comments and suggestions. The paper will be submitted for publication in an appropriate journal.

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1 INTRODUCTION

Improving efficiency in the use of external inputs in agricultural production systems has been an issue and the focus of agricultural research in both developed and developing countries for many decades The need to decrease the cost of production per unit of output has been the main motivation in the past Over the same period however there has been an alarming increase in the global use and abuse of agricultural chemicals, particularly plant protectants Reports from Eastern Europe suggest that in the cotton growing regions of the USSR and in neighbouring countries the situation has now reached catastrophic proportions The seriousness of the problem varies in different agroecosystems depending on environmental and socioeconomic factors but tropical production systems generally are particularly susceptible since the life cycle of biotic constraints is not interrupted by cold temperatures

Environmental degradation associated with the overuse and abuse of agricultural chemicals and the ever increasing need to develop sustainable agricultural production systems which will continue to provide solutions to world food demand have more recently placed particular emphasis on finding lasting solutions which imply increased efficiency or more importantly a reduction in the use of applied agricultural chemicals particularly plant protectants

Proponents of this trend have come from both the environmentalists (e g Bramble, 1989) and the agriculturalists (e g Bellotti et al, 1990) Unfortunately the polemic which has developed on the subject has often created misunderstandings which have not been constructive in moving ahead on the issue Failure to differentiate between plant protectants as a group on one hand and fertilizers on the other, has been a contributing factor in these disagreements The 'minimum input' philosophy (Nickel, 1984) which CIAT has followed is often misunderstood, particularly by some economists and soil scientists, who suggest that such a philosophy leads to unsustainable exploitation of soil nutrient reserves Proponents of low-input agriculture are often criticized by those concerned with world food supplies who suggest that low-input equals low-output One of the main reasons for the controversies surrounding this subject is also the failure to distinguish between agricultural research and agricultural production Research should attempt to develop technological solutions which provide a much wider set of environment friendly options in terms of input use The final outcome in production terms, i e with respect to input use, will then be determined by the market place to a large extent

Developing sustainable agricultural production systems which will provide lasting solutions to the ever increasing demand in developing countries for food, feed and fiber, must begin with agricultural research which is specifically oriented towards developing technology components and associated production systems which will both conserve the resource base and allow for increased productivity This is the critical challenge facing us, as researchers, as we enter the last decade of this century

This presentation is intended to highlight selected examples of specific agricultural research which are focused on finding lasting solutions and hopefully will throw some light on the subject The focus is mainly on the Latin American tropics and sub-tropics and on three basic staple food crops, i e rice, beans and maize, and concentrates mainly on the work of the international crop networks catalyzed by the IARCs working with national partners and advanced public sector research laboratories in developed and developing countries

The concepts developed in the paper apply equally well to temperate agriculture, i e there is nothing particularly exotic about tropical agriculture The environmental conditions may be different but the principles remain the same The paper stresses research directed mainly at the small farm sector, particularly in the case of maize and beans, but it is clear that the outcomes of the research reviewed in this paper are of equal value to more well endowed farmers in the tropics and sub-tropics The discussion opens with a clear differentiation between 'plant protectants' on one hand and 'fertilizers' on the other

2 ARGUMENTS FOR REDUCING USE OF PLANT PROTECTANTS

The 'plant protectants' group includes insecticides, acaricides, fungicides, bacteriacides, nematocides and herbicides The main arguments in favor of research directed at developing technology components and associated production systems which will effectively permit a reduction in the use of plant protectants can be summarized as follows

a) Such technologies will lead to a reduction in the cost of production per unit of output

b) They will facilitate improved technology adoption by producers with limited resources, particularly the small farmers of the third world

c) They will contribute to a reduction in the importation by poorer nations of ever more costly agricultural chemicals which are rarely produced in developing countries

d) They will lead to a reduction in the level of environmental contamination

e) They will reduce the possibilities of direct toxic effects of agrochemicals on the human population, i e both producers and consumers

f) They will contribute to a maintainance of the natural biological balance thereby encouraging beneficial organisms, e g bacteria, fungi, insects, arthropods, viruses and annelids, which are native to the particular environment

g) They will facilitate the introduction of a wide range of novel biological control agents from the groups mentioned in (f) above

h) They will increase the efficiency of fertilizer use through a reduction in the toxic effects of applied agrochemicals on beneficial bacterial, (e g *Rhizobium*), and mychorrizal associations as well as reducing the limiting effects of biotic constraints generally

The critical criteria which defines the effectiveness of these research outcomes is the degree to which productivity is increased while simultaneously allowing a reduction in the use of plant protectants The main avenues for research are (a) development of resistant or tolerant crop cultivars, (b) the development of adoptable integrated pest control methodologies leading to fully integrated systems of crop production and (c) biological control methodologies involving the exploitation of beneficial organisms including insects, arthropods, bacteria, fungi and viruses

3 ARGUMENTS FOR INCREASING THE EFFICIENCY OF FERTILIZER USE

For the purposes of this paper the 'fertilizer' group includes chemical formulations containing the major elements (nitrogen, phosphorus and potassium), and/or a range of important minor elements as well as soil conditioners such as gypsum and dolomitic limestone In this group naturally occurring phosphate (Leon and Arregoces, 1987) and feldspar rocks are receiving increasing attention as possible lower-cost sources of phosphorus and potassium and other minor elements The very important issue of organic manures for third world agriculture is a larger subject than cannot be tackled in this paper

The overuse of fertilizers, particularly nitrogen sources, in temperate agriculture has lead to serious environmental problems which are well recognized In more tropical and sub-tropical environments and with most small farmers in developing countries the situation is most often the reverse, i e there is a critical need to increase nutrient input into traditional food production systems The generally lower fertility of most tropical soils compared to those used for broad scale agriculture in temperate latitudes and the relative degree of poverty experienced by most third world farmers are obvious contributing factors to this latter trend

The main arguments in favor of research aimed at developing technology components which will permit more efficient use of fertilizers in tropical environments are rather straight forward, i e (a) reduction in the cost of production per unit of output, (b) increased opportunities for small farmers to adopt the use of fertilizers and associated improved cultivars in their production system and (c) a reduction in environmental contamination in particular, but rather limited, situations

Research to increase fertilizer use efficiency and/or crop productivity at lower native soil fertility, normally involves an integrated approach taking into account soil type, crop, climate and other associated constraints The following avenues for research have proved effective

a The development of crop cultivars which are more responsive at low levels of fertilizer application

b The development of crop cultivars tolerant to soil toxicity problems e g aluminium and manganese, in many tropical soils c The development of crop cultivars which are more tolerant of particular limiting major and minor element deficiencies, e g phosphorus and zinc

d The formulation of more efficient fertilizer types and/or the use of organic sources of nutrients appropriate to particular cropping systems and soil types

e The development of novel and adoptable cropping systems which are more effective in soil fertility conservation and improvement than is the case in the existing traditional systems

f The development of cultivars resistant to other prevailing biotic constraints (e g insects and diseases) and soil-water deficits thus contributing to more efficient fertilizer responses

The critical criteria for measuring the efficiency of fertilizer use is increased output per unit of input particularly at comparatively lower rates of application, i e thus placing the technology more within the economic reach of the vast majority of farmers in developing countries

4 ANALYSIS OF THE RESEARCH PROCESS

The analysis which follows traces a path usually followed by researchers in the development of new cultivars in a typical crop Figure 1a simulates three typical fertilizer responses in unimproved land races in tropical production systems Point A being a typical yield under zero inputs, i e the normal situation in many tropical systems Fertilizer responses can be positive (Curve 1) but maximum yields are still quite low due to low yield potential of the land races In many situations (Curve 2) one can observe positive responses to a certain level and/or followed by a yield decline (Curve 3) caused typically by

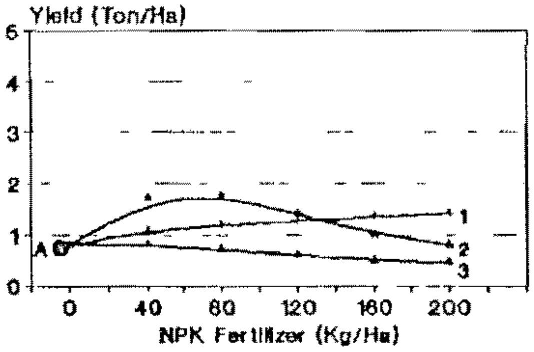

Figure 1a

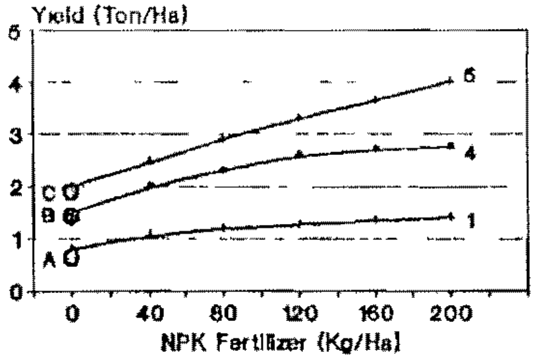

Figure 1b

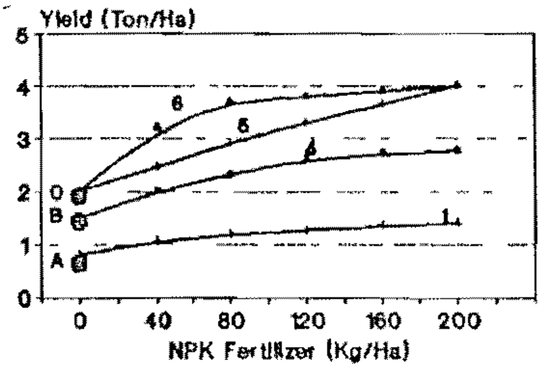

Figure 1c

Simulated response to fertilizers at three stages in the process of crop improvement Point A represents a typical average yield of a land race cultivar grown in a traditional cropping system without fertilizer inputs Point B represents the yield of an improved cultivar with disease resistance while point C simulates the yield of an improved cultivar with both disease resistance and improved plant type The explanation of the six fertilizer response curves are given in the text increased lodging, by increased disease incidence and/or due to excessive early vegetative development which leads to increased late season water stress

Point B in Figure 1b simulates the yield of a typical genetically improved crop cultivar incorporating disease and/or insect resistance but without a large alteration in plant type This class of cultivar often shows slightly more respectable yield responses to fertilizers (Curve 4) Point C simulates the yield of an improved cultivar with both improved plant type as well as genetic resistance to key biotic constraints Curve 5 shows a typical fertilizer response of many modern cultivars i e an almost linear response to the critical limiting element(s) over a wide range of application rates This type of response is very common and usually implies extremely high economically optimum rates of fertilizer application which more well endowed farmers are not slow to take advantage of In the discussion which follows on the three crops examples will be given which illustrate the linearity of fertilizer response often observed in modern cereal varieties Curve 6 is unfortunately far less commonly observed under field conditions, i e modern varieties with more efficient responses to lower application rates of key elements, implying lower economic optimum rates of application

The reasons why Curve 5 would appear to be a more common phenomena can be traced in large part to the soil fertility conditions under which many breeding programs are conducted both in developed and developing countries The tendency to apply excessive fertilizer levels over many years on experiment stations is often compounded by the individual scientist who, for reasons to be discussed later in this paper, often reports that his or her work was conducted at 'optimum' fertilizer rates, i e on top of the already high soil fertility levels prevailing Cultivars developed under these conditions show linear fertilizer responses because there was no selection pressure on the parents or the progeny at low levels of fertilizer input and/or native soil fertility

5 RICE PRODUCTION SYSTEMS AND INPUT USE

Rice production in Latin America and the Caribbean is derived from irrigated (59%) and upland systems (41%) Regional production now stands at 18 million tons and has grown by an average of 3 1% per year since 1966 reflecting mostly the introduction of modern cultivars and new cultural practices into the irrigated and favored upland systems Conservative demand growth projections suggest that regional production will need to increase to 32 5 million tons by the year 2010 representing an annual growth of 3 0% over the next 20 years if regional self-sufficiency is to be assured (CIAT, 1989c) Most of this increased production will probably have to come from the upland sector given the present very low investment in major irrigation systems in the region

5 1 The Case of Irrigated Rice in Colombia

Colombia has the highest average national rice yield in Latin America (4 53 ton/ha, 1985-89) This high productivity has been associated with extremely high levels of agrochemical use particularly in irrigated rice Modern disease resistant dwarf cultivars, such as CICA 8, have changed the face of rice production in the irrigated sector and there has been a spillover into favored-upland systems on fertile soils Similar trends are presently in progress throughout most of the irrigated sector in Latin America with very rapid adoption of modern cultivars with increased yields and improved disease and insect resistance

In Colombia fertilizers, herbicides, insecticides and fungicides were all applied at very high rates in order to maximize yields and to resolve mainly secondary constraints, e g fungicides for grain discoloration The yield response of CICA 8 and IR 42 to nitrogen fertilization (8 levels of N from 0 to 210 kg/ha) in transplanted and broadcast treatments at CIAT-Palmira is shown in Figure 2 The almost linear response in CICA 8 implies an economic optimum rate of nitrogen application of 185 kg of elemental nitrogen or 400 kg of urea at a yield

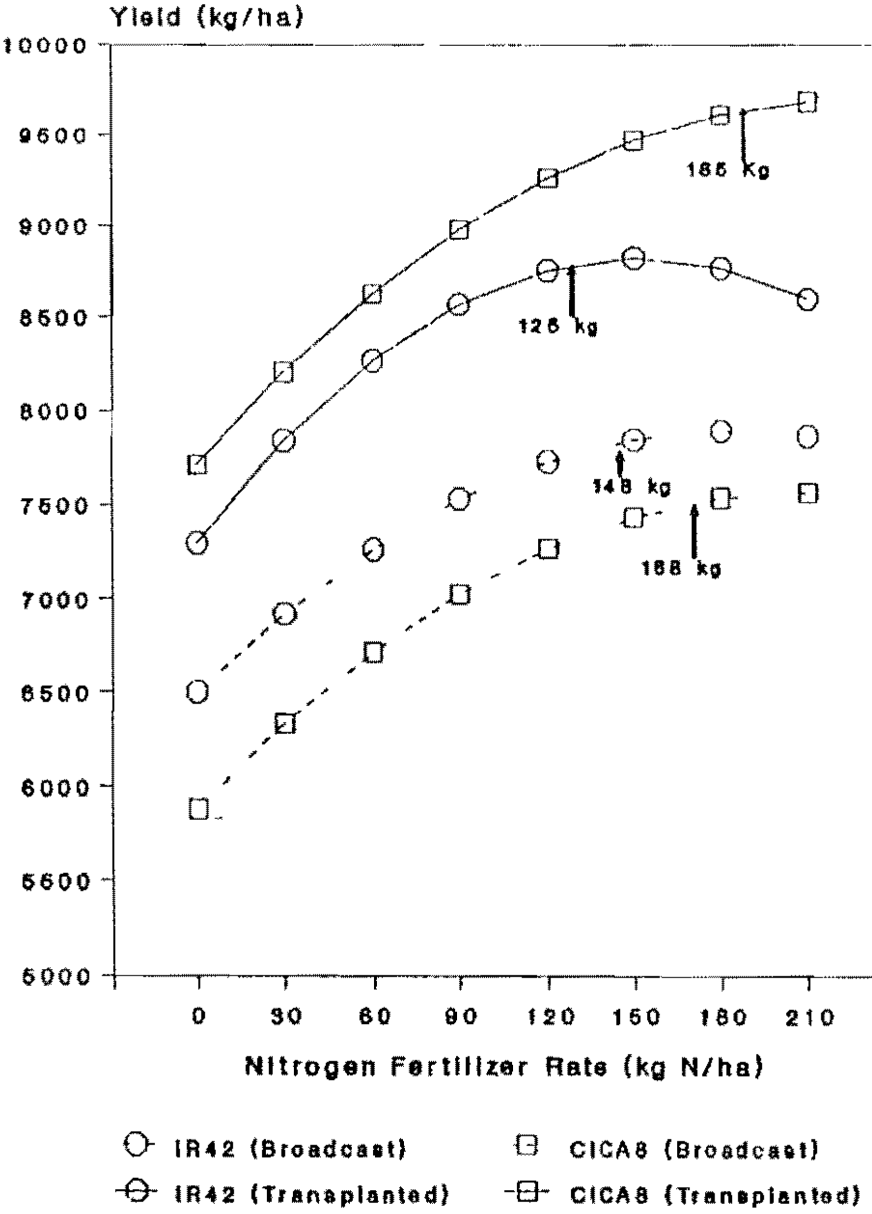

Figure 2 Nitrogen response (paddy yields) of two modern rice cultivars at CIAT-Palmira under irrigation in broadcast and transplanted treatments Data reworked from unpublished M Sc Thesis of Rolando Rubi, University of Louisiana, 1982 Data points show predicted values from quadratic fits, (r^2 from 0 72 to 0 92) Vertical arrows refer to the economic optimum N rate at a nitrogen (N) grain price ratio of 1 90 1 0

potential of almost 10 t/ha in the transplanted treatment CICA 8 was selected under CIAT-Palmira conditions where the yield potential is very high even without fertilizer (see Figure 2) IR 42 was selected in Asia by IRRI for adaptation to lower fertility conditions and to variation in water supply Under the more rustic broadcast production conditions IR 42 outyielded CICA 8 and had lower optimum fertilizer rates than CICA 8 in both treatments CICA 8 has been adopted in many countries and would still be much more widely grown had not its resistance to blast disease broken down Other high yielding cultivars have since been developed with a wider range of fungal disease resistances and tolerance to the rice white leaf virus (RHBV)

Table 1 Comparison of production costs for rice (expressed in terms of kg/ha of rice) in the Department of Tolima, Colombia data from surveys conducted in 1984-85 (National Rice Plan, PNA) and in 1988 (National Rice Census, ENA)[a]

Cost factors	PNA 1984-1985	ENA 1988	Difference
Land preparation	322	217	-105
Sowing	640	532	-108
Fertilizers	830	630	-200
Plant protection	1315	595	-720
Irrigation	372	276	- 96
Harvesting	330	617	+287
Total	3809	2867	-942

[a] Data source Fedearroz, ICA and CIAT

Concerned with these high costs of production CIAT, ICA (Colombian Agricultural Institute) and the Colombian rice growers federation (FEDEARROZ) in 1984-85 surveyed the national rice production situation prior to a collaborative research and extension program designed to reduce input use generally and particularly to introduce integrated pest control methodologies The earlier survey results (Table 1) compared to the recent rice census in the Tolima Valley suggest this program has been highly effective with an apparent reduction in production costs (particularly in plant protection) for irrigated rice of 25% or the equivalent of about 1 t/ha of rice production without any reduction in yield

The future profitability of irrigated rice in Latin America will depend on continuing collaborative efforts (Zeigler and Cuevas, 1990) to reduce the costs of production through the development of more efficient disease and insect resistant cultivars which are also tolerant of key edaphic problems, e g Fe toxicity, and the further refinement of integrated crop production systems which will permit even further reductions in input use More attention to yield response at lower fertilizer levels in irrigated rice breeding programs would seem to be justified

5 2 The Case of Upland Rice on Infertile Soils in Colombia

The availability of well watered fertile land for upland rice production in Latin America is limited while there is an abundance of acid and highly infertile savanna soils which are comparatively robust in ecological terms (i e less susceptible to nutrient loss since they already have low nutrient status and the relatively flat terrain reduces the potential for erosion) and with adequate rainfall (Lopes et al, 1977, Cochran et al 1984, Tanaka et al, 1989) CIAT in 1984 began a program of breeding acid soil tolerant upland rice cultivars The strategy adopted was firstly to screen a wide range (n = 1400) of exotic germplasm at zero and moderate applications (0 and 3000 kg/ha) of dolomitic limestone and a basal low-input fertilizer rate The germplasm which was screened included land races and improved cultivars from West Africa and from Brazil which were expected to have some degree of acid soil tolerance The screening was carried out on an acid Oxisol in the Colombian Llanos at ICA-La Libertad with a pH of 4 5 and aluminum saturation of 80% and extremely low soil fertility (available soil P 5 0 ppm) The criteria for parent selection was superior performance at both input levels These materials were crossed with disease and insect resistant sources in a pedigree breeding system Selection continued to homogeneity at a range of fertility levels which were considered to be both appropriate scientifically and economically feasible given the prevailing conditions

Table 2 Rice (paddy) yields of selected disease resistant (rice blast, leaf scold, brown spot, grain discoloration and white leaf virus) and acid soil tolerant semi-dwarf cultivars evaluated under two levels of fertilizer and lime treatments on an acid infertile Oxisol[a] of the Colombian Llanos at Matazul, 1989

Line or Cultivar	Yield kg/ha	
	Fertilizer Input Treatment	
	Moderate[b]	Low[c]
CT 7244-9-2-1-52-1[d]	3694	2964
CT 7079-43-1-4-1-1M	3521	2508
CT 7242-16-9-4-3-5M	3397	1981
CT 7332-5-3-7-1P-3M	3249	1524
CT 6946-2-5-3-3-2M	3037	2272
Control - IAC 165	2673	2667
Control - Oryzica 2	1632	1167
L S D (P 0 05)	812	

[a] Soil pH 4 8, 89% aluminium saturation, Al = 3 1 meq/100 gr of soil, 2 6 p p m available P, and 1710 mm of growing season rainfall

[b] Moderate fertilizer rate equivalent to 500 kg of dolomitic lime and 80 43 83 kg/ha of NPK

[c] Low fertilizer rate equivalent to 300 kg of dolomitic lime and 80 28 50 kg/ha of NPK

[d] The pedigree of this breeding line includes 4 parental sources for following factors a) acid soil tolerance (improved upland line from IITA), b) white leaf virus and grain quality (Colombian land race), c) a mutant of an African land race with tolerance of acid soils and disease resistance and d) a widely adapted tall upland cultivar from Brazil

Yield testing of advanced semi-dwarf lines derived from this program (Table 2) was carried out in large plots in 1989 at various locations and at two levels of lime and fertilizer application on a virgin Oxisol (typically with pH of 4 7 and aluminium saturation of 89%) The experimental area was previously covered by native savanna grasslands and was first cultivated 68 days prior to sowing The very low levels of

300 and 500 kg of dolomitic lime are considered as a fertilizer source for Ca and Mg rather than as a soil conditioner to increase soil pH The results at one location for the five leading lines at that location compared to IAC 165 (classical tall improved Brazilian upland variety for the Cerrado) and to Oryzica 2 (Colombian irrigated and favored upland variety) clearly show the success of the strategy, i e excellent yields at both low and moderate fertility levels This response to fertilizer application approaches that simulated by Curve 6 in Figure 1c The results of this work clearly demonstrate the utility of parent and progeny selection under a realistic range of soil fertility conditions

Acid soil tolerant and disease resistant semi-dwarfs grown on relatively well watered savannas may prove to be the main source of the increased Latin American rice production which will be required to satisfy demand, i e to ensure regional self sufficiency over the next 10 to 20 years CIAT is presently considering the potential regional strategic impact of these new savanna rice cultivars in combination with improved tropical grass and legume pasture technologies and other acid soil tolerant crop cultivars such as grain sorghum (Gourley and Salinas eds , 1987) Sustainable farming systems integrating these technology components could stimulate accelerated development and closer settlement of the well watered savanna frontier areas of Latin America This in turn would stimulate economic development in areas adjacent to the tropical rainforests of the Amazon basin Conceivably these developments would in turn reduce the pressure on land resources and, hopefully, the present destruction of the rainforests for crop and pasture production

6 BEAN RESEARCH AND INPUT USE

Common bean (*Phaseolus vulgaris* L) production in tropical and sub-tropical developing countries is 7 2 million tons (78% of total world production) annually produced on 12 7 million hectares (86% of total world area) Production in the tropics and sub-tropics is concentrated in Latin America (60%) and sub-Saharan Africa (33%) Production in developing countries is overwhelmingly in the hands of small scale producers most of whom are commercial in the sense that they sell excess production Bean yields are generally low in tropical and sub-tropical developing countries (500-700 kg/ha) and are constrained by a wide range of climatic, biotic, edaphic and socioeconomic problems (Schwartz and Pastor-Corrales ed 1989, Sere et al, 1989) Beans are produced in associated systems involving a wide range of other species ([illegible] 1984) Low apparent yields in many situations are due to the competitive efforts of the associated crop The yield of the system however is often greater, in economic terms, than the separate monoculture of the constituent species (Francis, 1988a, 1989b)

Obviously agricultural researchers cannot be expected to resolve all of these problems through improved technology components It is clear however that there are researchable solutions to many of the problems and these will be highlighted in the discussion which follows Notwithstanding the fact that beans are essentially a small farmer crop there are many areas where plant protectants are being used and and even abused, particularly in snap bean production (Henry and Janssen, 1989), and in some cases this has been associated with possible clinically toxic effects on producers (Cojocaru, 1989)

6 1 Combining Yield Potential and Disease Resistance

The immediate strategy agreed upon by CIAT and its collaborators in national programs (CIAT, 1973, CIAT, 1978, CIAT, 1981) was to jointly develop genetic resistance to the most important biotic constraints and to gradually incorporate these resistances into materials with higher yield Research on yield potential, edaphic constraints and water stress tolerance have recently received increased emphasis (White and Izquierdo, 1990) Progress in pyramiding different disease resistance genes into higher yielding materials has been remarkable (Amezquita and Voysest, 1989)

Table 3 Progress in combining high yield potential with multiple disease resistance yield data for superior lines[a] entered into final stages of evaluation during the period 1984-86 measured at CIAT-Palmira and CIAT-Popayan under optimum level of fertilizer application, which included liming at CIAT-Popayan and without disease control

Attribute	n	Mean bean yield (kg/ha) Popayan[b]	 Palmira[c]
Lines with high yield	42	3327	3123
Lines with high yield and resistance to			
Anthracnose (ANT)	33	36[illegible]6	3312
Bean Common Mosaic (BCM)	35	3208	3121
Angular Leaf Spot (ALS)	22	3360	3347
Bean Rust (RUS)	26	3484	3220
ANT-ALS-BCM	15	3966	3775
ANT-RUS-BCM	16	3859	3723
RUS-ALS-BCM	14	3398	3401

[a] Lines with highest yields at both locations selected from the 317 entries
[b] CIAT-Popayan Altitude 1750m, mean temperature 17 5°C
[c] CIAT-Palmira Altitude 1000m, mean temperature 23 8°C

Superior fixed lines (n = 317) entering the final stage of collaborative testing during the period 1984-86 were yield tested at CIAT-Palmira and CIAT-Popayan under 'optimum' soil fertility conditions (Table 3) Of those lines 42 were high yielders at both of these climatically contrasting locations (i e implying wide adaptation to temperature and soil conditions) These 42 lines have different degrees and combinations of disease resistances In Table 3 the 15 lines (of the 42) with combined resistance to anthracnose, angular leaf spot and common bean mosaic showed very high average yields (3966 and 3775 kg/ha) at the two locations with similar results for other groups of lines with different combinations of genetic resistance appropriate to different production areas Data not shown for lines entered for common bacterial blight resistance indicate a generally lower yield level for these materials

Table 4 Progress in pyramiding for multiple disease resistance in common beans resistance evaluations[a] for five major diseases[b] in superior lines selected from advanced materials entering initial selection in 1989 at CIAT Palmira, Quilichao and Popayan

Line	BCMV	ANT	ALS	CBB	RUS
ZAA 44	R	R	I	R	R
ZAA 93	R	R	I	R	R
BAT 1769	R	R	I	R	R
AFR 188	R	R	I	R	R
XAN 195	R	R	I	R	R

[a] R = resistant (scores 1-3 on a 9 scale), I = intermediate (scores 4-6)
[b] BCMV = common bean mosaic, ANT = anthracnose, ALS = angular leaf spot, CBB = common bacterial blight and RUS = bean rust

More recent progress on multiple resistance breeding in beans demonstrated in Table 4, shows data for the evaluations of five advanced high yielding lines with combined resistance to five of the most critical diseases affecting beans including common bacterial blight (CIAT, 1989b) Pyramiding for disease resistance is clearly a highly successful strategy which requires international cooperation for its implementation due to the need to evaluate the resistance sources across many environments

6 2 Breeding for Insect Resistance in Beans

Progress in insect resistance breeding has been particularly remarkable in two areas both involving collaboration between CIAT and other agencies[1] The case of bean bruchids (Zabrotes subfaciatus) has been the most remarkable in that resistance was found in a wild related Phaseolus species collected privately in Mexico by Oscar Norvell sometime

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[1] Collaborating institutions include the University of Wisconsin in the U S A, and the University of Durham and ODNRI in the U K

during the period 1952-68 The collection was passed to the USDA at Pullman, Washington, by the wife of Norvell at his death and the USDA in turn passed the collection to CIAT for inclusion in the world collection The resistance trait to the bruchids was transferred into commercial grain types through normal breeding methodologies (Cardona *et al*, 1990) A series of protein bands, denominated as Arcelin, have been shown to be the factor associated with the resistance (Osborn *et al*, 1988, Cardona *et al*, 1989) Approved biosafety evaluations (CIAT, 1989) have been conducted on this protein and the data shows that there are no negative effects on mammals associated with this trait Similar work is in progress on the other bruchid species affecting common beans (*Acanthocelides obtectus*) (Kornegay and Cardona, 1990) This work on the bruchids will eventually have highly significant effects on bean productivity (i e through improved farmers' seed quality after on-farm storage) as well as improved consumer acceptance of the beans

The other area where progress has been particularly significant is in relation to collaborative research[2] to develop resistance to the pod weevil *Apion godmani* which is a very serious pest in Central America and Mexico (Díaz, 1988) Yield testing (Table 5) by the Honduran national program of six superior lines compared to regional controls further demonstrates the feasibility of breeding for critical constraints such as *Apion* The alternative in the case of *Apion* control is insecticide applications which are well beyond the economic capacity of most bean farmers in Central America Similar observations apply to the collaborative development by ICTA (Guatemala) and CIAT of Bean Golden Mosaic Virus (BGMV) tolerant bean cultivars in Central America The only other solution to the latter problem would have been the ever increasing application of insecticides to control the white fly vector (*Bemisia tabaci*) of the virus

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[2] Collaborating agencies include Secretariat of Natural Resources in Honduras, ICTA in Guatemala, CENTA in El Salvador and INIFAP in Mexico

Table 5 Progress in breeding beans for resistance to the bean pod weevil (Apion godmani) yield testing[a] of six advanced lines under field conditions compared to commercial cultivars grown in Honduras

Genotype	Bean Yield (kg/ha)	Pod damage %
APN 102	2009	22
APN 99	1915	22
APN 101	1781	32
APN 107	1788	23
APN 83	1616	5
APN 106	1611	27
Catrachita[b]	825	65
Desarrural[c]	669	75

[a] Yields from six on-farm experiments in Honduras in 1989

[b] Catrachita was recently released and is being rapidly adopted by farmers in Honduras for reasons of disease resistance, yield and commercial grain acceptability The cultivar is highly susceptible to Apion

[c] Honduran land race typical of many other Type III small red seeded

Adoption of disease resistant cultivars of beans has been widespread in many countries in Latin America and Africa and national production is beginning to increase, e g Costa Rica, Guatemala, Nicaragua and Argentina (Pachico and Borbon, 1987, CIAT, 1989a) The adoption trends suggest that the strategy of beginning on disease and insect resistance has paid off The research results clearly show that real progress is now being made in combining higher yield potential with resistance to biotic constraints

6 3 Simultaneous Breeding for Soil Stress and Disease Resistance

CIAT research (Singh et al, 1989) designed to evaluate a breeding strategy for low input systems was carried out over the period 1981 to 1986 at Popayan on a very infertile Inseptisol (pH 5 0) The basic idea was to simultaneous select for disease resistance and for yield under a certain degree of soil stress (soil pH and available phosphorus) and disease pressure and to compare that strategy with selection under optimum conditions Results in Table 6 show the mean yields for the best six fixed lines derived from each of three different crosses (which combined different gene pools) and selected under either high or moderate input levels The results show that selecting under moderate levels of input is clearly advantageous when lines are yield tested at moderate input levels while not disadvantaging these same lines when tested at high input levels High input bean yields of more than 5 t/ha in 100 days of growing season are probably some of the highest ever obtained in bush bean research The response of the Mesoamerican x Jalisco genepool progenies selected at moderate input levels approaches that shown by Curve 6 in Figure 1c

While this strategy demonstrates the feasibility of breeding under moderate input conditions the problem of enormous diversity of production systems and biotic, edaphic and climatic conditions in bean areas in Latin America and Africa demands a more decentralized and specific breeding approach to each major edaphic constraint in a similar fashion to the successful strategies adopted with respect to the wide range of biotic constraints, i e screening for variation for particular desirable traits in the world collection of Phaseolus and then exploiting that variation under an appropriate selection strategy in close collaboration with national partners taking advantage of diverse environmental conditions whenever possible

6 4 Research on Edaphic Constraints in Beans

The Agroecological Studies Unit at CIAT has estimated the relative importance of different combinations of edaphic constraints in bean growing soils in Latin America The data base required includes information on the microregions of production of beans throughout the continent and the main soil types in those microregions Figure 3 shows the relatively greater importance of potential deficiencies of nitrogen, phosphorus, calcium and magnesium, and of aluminium toxicity in various combinations depending on soil type The relative unimportance of potential potassium deficiency in bean soils is notable in these data

Table 6 Simultaneous selection for disease and soil stress yield of bean lines derived from three crosses representing different gene pools lines selected separately to F_7 under high and moderate input environments at CIAT Popayán, Colombia, and then evaluated for yield in both environments over three growing seasons (1984-1986)

Crosses	Bean mean yield[a] (kg/ha) High[b] input	Moderate[c] input
Mesoamerica x Jalisco		
A114 x (Flor de Mayo x AB 136)		
Selection at high inputs	5166	3212
Selection at moderate inputs	5090	3711
Mesoamerica x Mesoamerica		
A175 x (G2333 x A62)		
Selection at high inputs	3745	2551
Selection at moderate inputs	3882	2674
Mesoamerica x Nueva Granada		
A140 x (G3038 x G1274)		
Selection at high inputs	2705	1886
Selection at moderate inputs	3019	2097
Parental mean yield	3050	2041
Control mean yield	3221	2512
Environmental mean yield[d]	3671	2549
LSD (0 5)	295	232

[a] Mean yield of the six highest yielding lines in each environment and for each cross measured over three growing seasons on an infertile Inseptisol

[b] High input 5000 kg/ha lime and 127, 157 and 100 kg/ha NPK plus full disease and insect control

[c] Moderate input 2000 kg/ha lime and 60, 79 and 50 kg/ha NPK with plots inoculated with pathogenic isolates of anthracnose in order to encourage disease epidemics

[d] Yield of all lines and parents over three growing seasons in the two environments including data from three other crosses not reported here

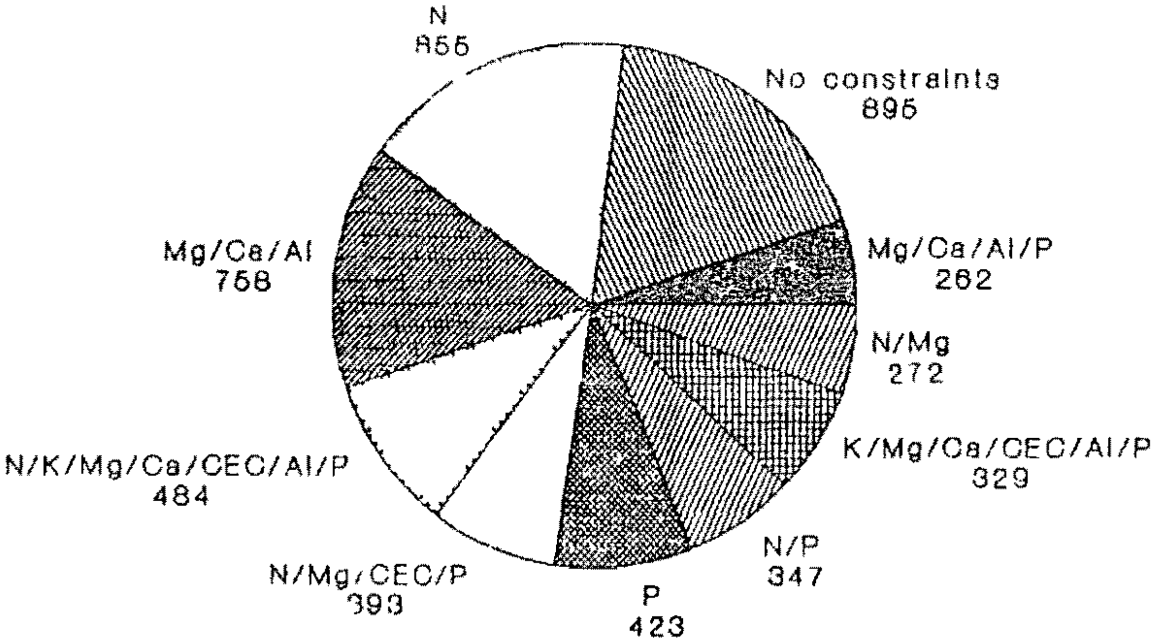

Figure 3 Estimates of the relative importance of the 10 most frequent combinations of edaphic constraints in Latin America covering 82% (i e about 5 million hectares) of the total regional bean area data derived from the data bank developed by the Agroecological Studies Unit, CIAT The numbers opposite each segment represent thousands of hectares of common bean area in Latin America which are grown on soils with the particular set of constraints indicated CEC refers to low cation exchange capacity

6 4 1 Improving Nitrogen Fixation

Land race bean cultivars, along with many other grain legumes in their native environments, have a reputation for low nitrogen fixation through a combination of low inherent genotypic capacity for fixation combined with the frequent incidence of highly competitive and relatively ineffective native Rhizobium strains in most bean soils Improving nitrogen fixation is clearly justified on economic and environmental grounds CIAT has approached the problem from the viewpoint of the plant and the bacteria in order to achieve a more efficient symbiosis Breeding (CIAT, 1985) for higher nitrogen fixation with effective strains has been successful (Table 7) Specific traits such as nitrogen harvest index and continued fixation after flowering are characters being evaluated in further work (CIAT, 1989b)

Table 7 Progress in breeding for nitrogen fixation data from ^{15}N studies[a] on a range of genotypes selected for high N fixation (RIZ) compared to genotypes unselected for this trait at CIAT-Palmira (1985)

Genotype	Total N[b] uptake kg N/ha	N-fixed kg N/ha	% N from fixation
A 268[c]	78	47	47
RIZ 30	76	45	45
RIZ 36	75	43	43
BAT 332[d]	63	35	35
BAT 1554[d]	56	32	32

[a] ^{15}N isotope dilution methodology under optimum soil conditions except for soil nitrogen availability which was reduced by cultural practices

[b] Total plant (shoots and roots) nitrogen uptake at 56 days from planting

[c] A268 was originally selected under low input conditions, i e not specifically for N fixation per se

[d] Lines with high yield under 'optimum' production conditions

Rhizobium research often has to be conducted on farmers' fields because of the high fertility conditions prevailing on most experiment stations On-farm testing in Rwanda (Table 8) shows the effects of

Table 8 Effect of inoculation with an effective Rhizobium strain on the yield of two genotypes on contrasting soil types on-farm research[a] results from Rwanda, 198[illegible]

Treatment	Bean Yield (kg/ha)			
	Poor Soils[b]		Fertile Soils	
	Tostado[c]	Rubona5	Tostado	Rubona5
Minus inoculation	202a	232a	1570a	2585a
Plus inoculation	454b	285a	2531b	2540a

[a] Mean results from _____ farms in the N E of Rwanda

[b] Soil fertility influenced mainly by acidity, phosphorus status and aluminium toxicity, with differences exacerbated by sheet erosion The extremely low yields being recorded on farmers' fields under infertile conditions in the highland Great Lakes region of Africa is well illustrated by these data

[c] Bean cultivars Tostado (G______), Rubona 5 (Diacol, Calima, G______)

Table 9 Effects of bean inoculation with effective Rhizobium strains compared to uninoculated controls and nitrogen fertilization in on-farm research in three countries in Latin America bean yields in kg/ha

	El Salvador[a]	Brazil[b]	Costa Rica[c]
Nitrogen fertilizer	2476a	471a	1166a
Inoculation	2224a	535a	941ab
Control (-N, -Inoc)	1654b	280b	694b

[a] Pineda, 1987 mean yields of five genotypes on one farm

[b] Moura et al, 1989 mean yields of eight genotypes on one farm

[c] Uribe et al, 1987 mean yields of one genotype on three farms

Rhizobium inoculation on two contrasting genotypes on both infertile and fertile soils Experiments reported by network collaborators in Latin America (Table 9) show that on-farm inoculation can be particularly effective compared to nitrogen fertilizer applications On-farm results from Peru (Table 10) show strong evidence of positive responses in associated maize yields to increased nitrogen fixation in beans inoculated with an effective strain of *Rhizobium* Reduced competition for nitrogen in this highly nitrogen limited maize-bean production system has been postulated as the reason for these large yield responses in associated maize to bean inoculation These on-farm results clearly demonstrate the importance of considering the bean plant and the associated bacteria The data also demonstrates that inoculation can be very effective and can be highly economic compared to the costs of nitrogen fertilizer use

Table 10 Effects of inoculation of beans with three strains of *Rhizobium* compared to the uninoculated control and nitrogen fertilized treatment yields of maize and associated climbing bean system in on-farm research in the Cajamarca area of Peru

Treatment	Grain Yield (kg/ha)[a]	
	Beans[b]	Maize[c]
+ Nitrogen (180 kg urea)	728	3858a
+ Inoculation (strain 7001)	861	2508b
+ Inoculation (strain Cus 6)	805	2503b
+ Inoculation (strain 632)	814	2397b
- Nitrogen, - Inoculation	741	1270c

[a] Mean data for four on-farm experiments at approximately 2600m altitude
[b] Mean data for two bean genotypes
[c] Landrace maize adapted to region

The challenge remains to develop more effective genotypes for a wider range of growing conditions and to develop inoculum production and distribution systems which can provide effective strains to large numbers of small farmers Cuba has now adopted a policy of inoculation in commercial bean production and the results will be carefully monitored

6 4 2 Improving Low Soil Phosphorus Tolerance

Phosphorus availability is a critical constraint to bean production in both Africa and Latin America In many areas the degree of yield response to phosphorus application is limited by soil acidity, i e simultaneous applications of lime, which reduces aluminum toxicity, can result in higher phosphorus responses (Le Mare, 1975)

Genotypes tolerant of low soil phosphorus availability have been identified and the land race Carioca adapted to low P soils in Brazil has been considered the standard for some years Recent screenings (CIAT, 1990) at CIAT-Popayan have identified climbing bean land race accessions from the Mexico highlands (e g G14508) with excellent adaptation to P limiting conditions

The interaction between phosphorus supply and nitrogen fixation in a range of bean genotypes has been studied at CIAT (Figure 4) Carioca, as the control, was compared to a group of improved materials including nine RIZ lines which were specifically selected under non-P limiting conditions for high nitrogen fixation (CIAT, 1986) The yield results at low phosphorus application (12 kg P/ha) on an infertile Ultisol at CIAT-Quilichao show remarkable differences in yield between the cultivars, e g compare RIZ 45 with the less efficient lines RIZ 50, 46 and 37 While there appears to be no overall genetic correlation between high and low P in beans it is the outlyers (high yield in both environments) which are of critical importance More recent work has identified BAT 271 as a highly efficient nitrogen fixer at low P levels as well as being highly tolerant of aluminium toxicity (see Figure 5)

Obviously selection for phosphorus efficiency in genotypes which are effective nitrogen fixers at low phosphorus is a key strategy The data in Figure 4 clearly demonstrates that genotypes can be selected which are efficient at both low and high P levels, e g Carioca and RIZ

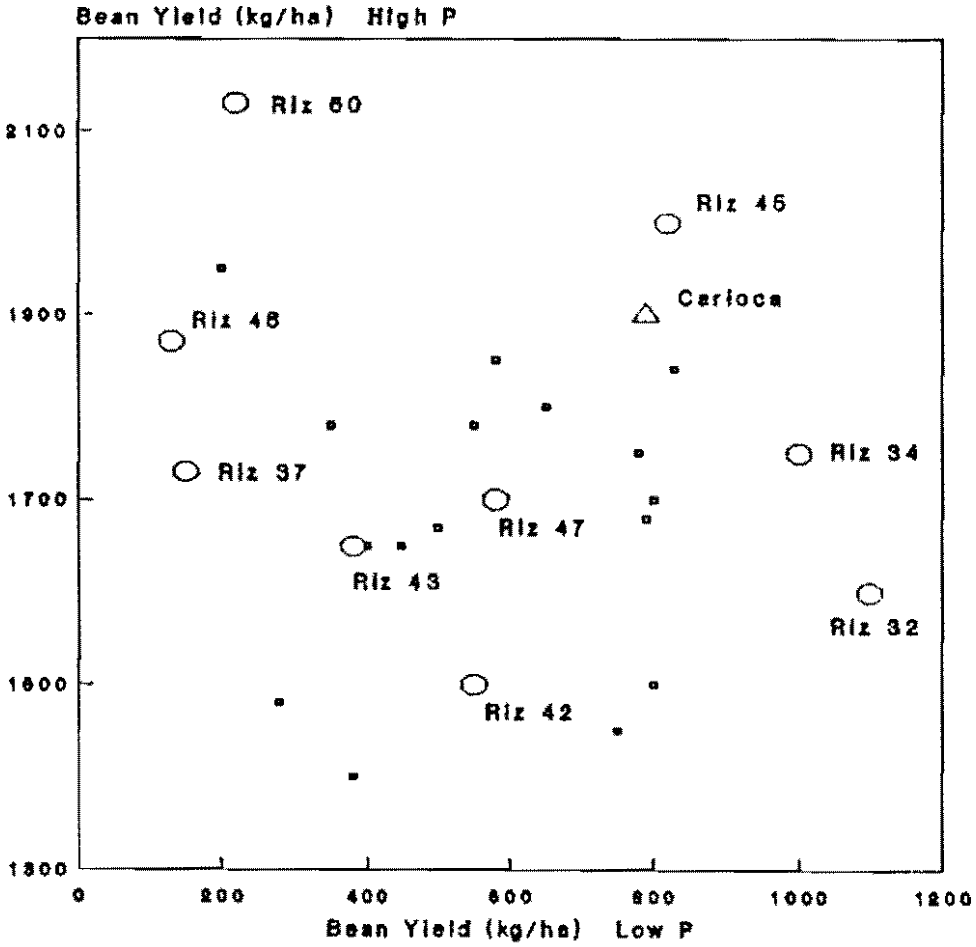

Figure 4 Yields, under low (12 kg P/ha) and high (120 kg P/ha) applications of soil phosphorus, of improved bean lines compared to cultivar Carioca all lines inoculated with an effective <u>Rhizobium</u> strain on a limed Ultisol at CIAT-Quilichao, 1986 RIZ lines were previously selected for high nitrogen fixation at high soil phosphorus status in separate screening experiments

45, thus detracting from the argument that low P adapted genotypes would also be low yielders at higher soil P status The physiological mechanisms for low soil phosphorus tolerance have yet to be identified in *Phaseolus* but particular root morphological characters appear to be associated with the trait[3]

6 4 3 Improving Aluminum and Manganese Toxicity Tolerance

Phaseolus accessions tolerant of aluminum and/or manganese toxicity have been identified (Foy, *et al* 1972, CIAT, 1990) and screening strategies in segregating populations have been developed Problems associated with breeding for Al and Mn toxicities are complicated by the phosphorus status and the *Rhizobium* symbiosis Obviously any successful strategy for breeding beans for acid soils will need to take into account all the above critical factors Normally low N fixation, low soil phosphorus and aluminum toxicity are often associated with an increased incidence of root diseases (e g *Fusarium* and *Phytopthera*) exacerbated by the acid soil conditions This latter situation is common to well watered Andisols particularly in central Africa and in the Andes and poses a particular challenge at this time CIAT is planning accelerated research on this complex of constraints

One of the key factors in this latter research will be the availability of materials with adaptation to both low soil phosphorus and aluminium toxicity The data in Figure 5 shows a scatter diagram for 36 lines yield tested in P and Al stress plots at CIAT-Quilichao in 1989 The five outlyers combine these traits As indicated earlier Carioca and Rio Tibagi are land race cultivars adapted to acid soils in Brazil, Ikinimba is a land race selected by women farmers in Rwanda for its adaptation to the poorer acid soils, BAT 271 (Mexico 309 x Porrillo Sintetico) is an improved line from the cross of Mexican highland climbing type with a

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[3] van Beem, J and J Lynch (1989) Personal communication results of root morphology studies on cultivars Carioca and Porrillo Sintetico CIAT, Cali, Colombia

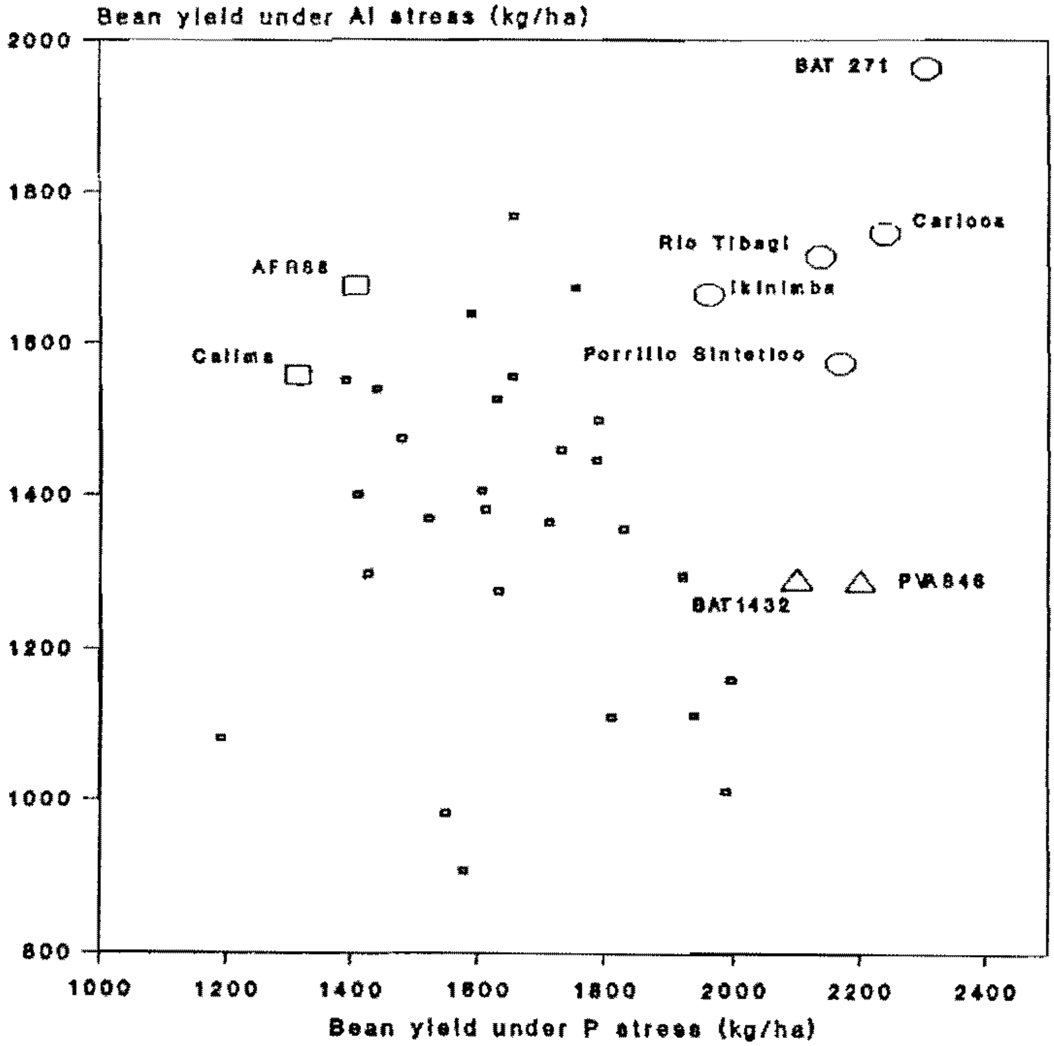

Figure 5 Screening for tolerance of aluminium toxicity and low soil phosphorus yield data for 36 land race and improved lines at CIAT-Quilichao (1989) on Al stress plots (pH 4 4, 20 ppm P, 3 1 meq/100 g Al, 60% aluminium saturation) and P stress plots (Ph 5 8, 6 5 ppm P, 0 15 meq/100 g Al, 2% saturation)

small seeded black accession from Mesoamerica which is also in this same group

Data in Figure 6 shows the control and stress yields for the same superior accessions for both aluminium toxicity tolerance and low P stress tolerance (Group A), compared to selected genotypes with only P or Al stress tolerance The scatter of data in Figure 5 clearly shows once again that while there is no relationship in the data between the two traits, materials do exist which combine both The control yield data in Figure 6 suggests that there is no sacrifice of yield under more optimum conditions The next step is to add root disease resistance to these sources and select for commercial grain types for highland areas which are normally larger seeded that the Group A genotypes in Figure 6

6 4 4 Improving Water Stress Tolerance in Beans

Estimates by Laing et al (1984) show that close to 60% of bean production in Latin America occurs in microregions with moderate to severe water deficits during some part of the growth cycle under average climatic conditions Tolerance of water stress has been identified in the world germplasm collection (Laing et al, 1983) and this has been proved to be associated with more efficient root system development particularly in deeper soil horizons (Sponchiado et al, 1989) Selection for stress tolerance has been in progress in contrasting soil types (White and Izquierdo, 1989) Figure 7 gives mean yields over six growing seasons for four cultivars in experiments conducted at CIAT-Palmira under full irrigation (control) and under various degrees of water stress (i e depending on season) commencing at or near flowering Cultivars such as BAT 85 and BAT 477 have consistently outyielded the susceptible lines under stress while mean yields in control plots are essentially the same BAT 477 has also been identified as being efficient in nitrogen fixation

These results are highly encouraging Once other locations and collaborators can be identified, i e to diversify screening environments,

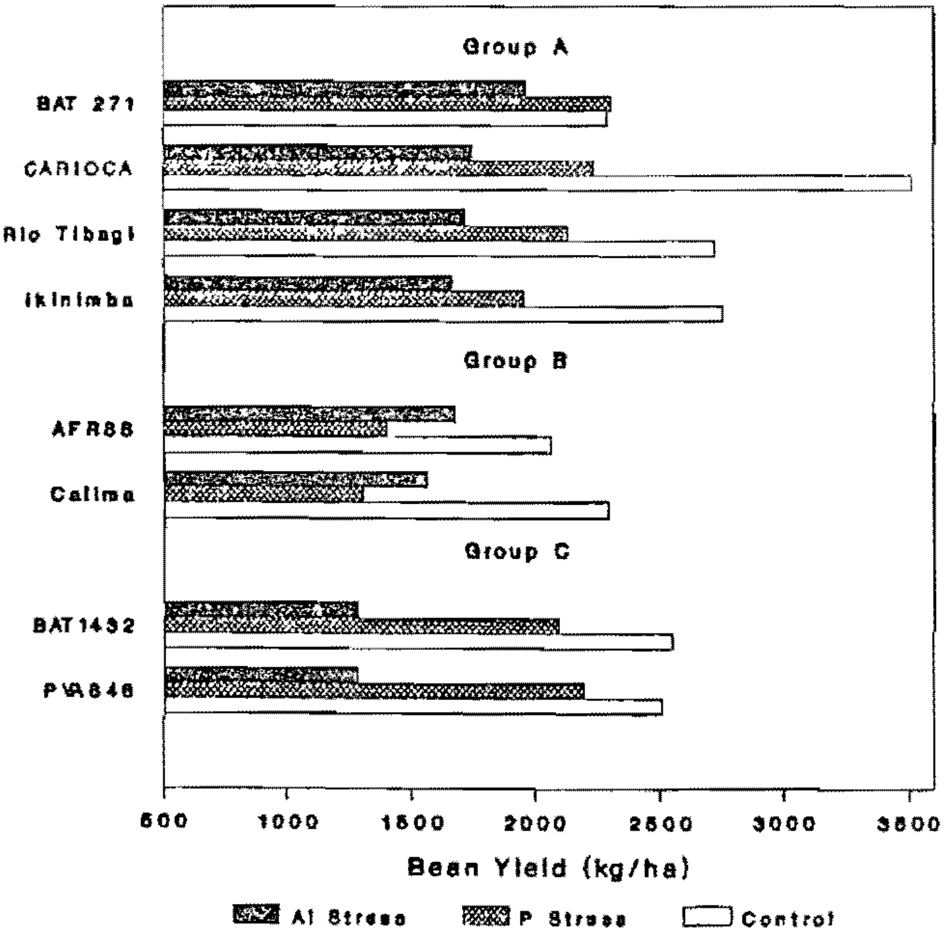

Figure 6 Yield of a range of selected bean accessions under conditions of aluminium and phosphorus stress and in limed control plots at CIAT-Quilichao, 1989 Group A are efficient under both Al and P stress, Group B are efficient only under Al stress and Group C efficient under P stress Definition of stress conditions are given in Figure 5

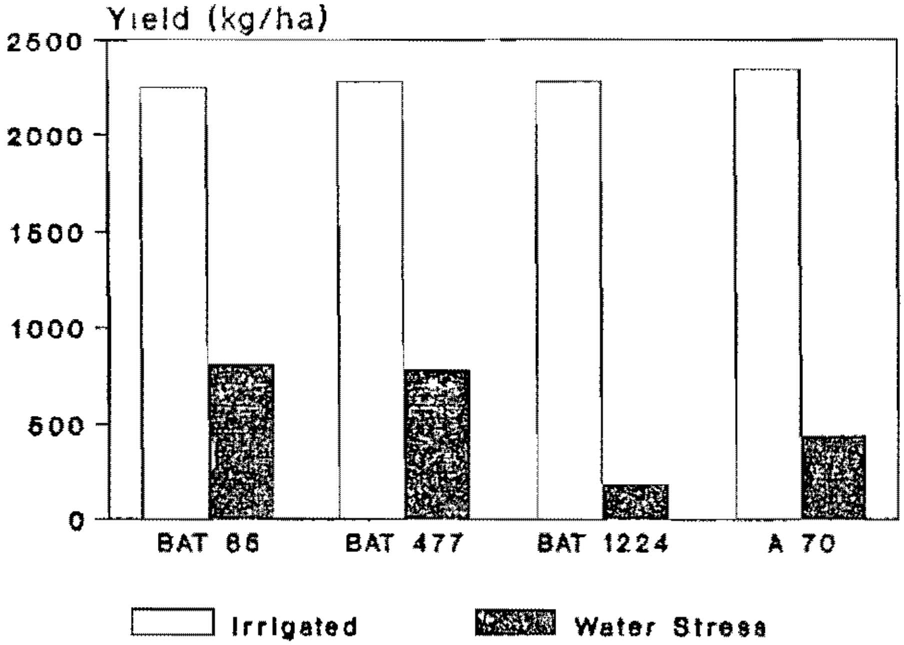

Figure 7 Mean yields of four bean lines at CIAT-Palmira over six growing seasons under full irrigation and under moderate to severe water stress during a major part of the growing season

progress will be more rapid in developing a wider range of water stress tolerant materials Water stress tolerance incorporated into commercial bean types would pave the way for a much higher level of fertilizer use efficiency by reducing the effects of this universal and critical constraint to productivity

7 MAIZE PRODUCTION RESEARCH AND INPUT USE

Tropical and sub-tropical maize production in developing countries, on the three continents, particularly the large proportion produced by small farmers, suffers a far wider range of climatic, edaphic and biotic constraints than that experienced in temperate latitudes and productivity is consequently much lower In addition much of the maize in developing countries is produced in a wide range of associated production systems particularly maize and beans, maize and yams and maize and cassava

The international maize network of CIMMYT working with its collaborators, has developed an effective research system and tropical maize no longer is considered to be inferior in yield potential Populations and hybrids with high yield potential and resistance to critical insect and disease pests have been developed The excellent work on maize streak (   ) in Africa and the continuing work on achaparramiento (Celado *et al*, 1990) in Central America are two examples of progress in virus disease resistance

The outstanding work at CIMMYT (Smith *et al*, 1987) in developing multiple resistance to insect pests shows the utility of gene pyramiding In this work 200 fullsib families from the MBR population were evaluated for resistance to a range of six important insect pests from the genera *Ostrinia*, *Diatraea*, *Chilo*, *Burseola* and *Spodoptera* Eighteen of these families were shown to be resistant to 3 insect species, 5 to 4 species and 1 to five species This work on insect resistance and that on leaf blight (Ceballos et al, 1990) and ear and stalk rot (De Leon and Pandev, 1989) point the way to further strategic pyramiding of genes for an even wider range of other biotic constraints limiting tropical maize yields in the third world

7 1 Improving Maize for Tolerance to Edaphic Constraints

Nitrogen is probably the key limiting factor, apart from water supply, in maize production throughout the tropics and sub-tropics Response to nitrogen fertilization in modern varieties and hybrids is highly economic and more well endowed farmers apply high rates of NPK applications On the other hand, the adoption of new maize technology in small farmer production systems would appear to be more constrained by the economic circumstances of individual farmers The tendency of many farmers to continue to utilize locally adapted open pollinated land race cultivars and low or zero input levels would suggest that the combination of modern cultivars and high fertilizer rates are beyond their economic reach in many cases This situation is particularly the case in Africa notwithstanding many years of intensive promotion of modern maize technology in that continent Kenya and Zimbabwe have been more successful but even in these countries the poorer farmers continue in their traditional systems

The earlier observation with respect to high input (particularly nitrogen) research environments for irrigated rice applies equally or even more so in the case of maize The results of research in Kenya provide a very good example of this trend (Allan and Darrah, 1978) These researchers selected parents in each cycle of selection at 110 kg N/ha and then crossed the original population (C_0) and each of three populations derived by selection over one, two or three cycles (C_1, C_2, and C_3) to a locally adapted hybrid Yields of the resulting population crosses were measured at 40, 140 and 240 kg N/ha (Table 11) While large yield gains were observed in C_3 at high N levels, yields of the four populations were virtually the same at 40 kg N/ha This low N rate is still probably higher than is economically feasible for most Kenyan small farmers The N response of C_3 is very close to that simulated by

Table 11. Yield testing of maize populations derived from three cycles (C_n) of selection compared to the original population (C_o) in Kenya Highlands: predicted yields (kg/ha) from a multiple regression equation at 44000 plants/ha ($r^2 = 0.83$) of H163(R)[a] at three N fertilizer levels. Combined data from three sites near Kitale, 1972

N level kg/ha	Cycle of Selection[b] C_o	C_1	C_2	C_3	Mean
40	5750	5790	5830	5870	5810
140	6720	6910	7090	7270	7000
240	6610	7050	7490	7930	7270
Mean	6360	6580	6800	7020	

[a] H163(R) is a top cross hybrid (F × G) Ecuador 573 R(C_n) where F and G are Kenyan inbreds derived from Kitale Synthetic III and C_n refers to the population crosses derived from each cycle of selection.

[b] Selection in each cycle carried out at sowing density of 44000 plants/ha and 110 kg N/ha.

Curve 5 in Figure 1c, i.e. linearity of N response. This work also begs a question, i.e. 'would the selection of parents at more realistic levels of N application have been more productive?'

The situation with respect to basic soil fertility and fertilizer application in maize breeding stations is similar to many other crops. One only has to observe the sheer beauty and comparative uniformity of many experiment stations to realize that something has been done to iron-out the natural soil variability, i.e. heavy applications of fertilizer.

Research in Kansas by Muruli and Paulsen (1981) presents an alternative path for maize researchers concerned about appropriate technology for third world small farmers. These researchers began with a wide base of exotic germplasm (Mex Mix derived by CIMMYT) and screened S_1 lines at 0 and 200 kg N/ha in only one cycle of selection. The 10 highest yielding lines from each environment were then used as parents for two new populations which were yield tested at two locations at 0, 50, 100 and 200 kg N/ha The response curves in Figure 8 (meaned over two locations) show a 36% yield gain (i e about 1t/ha) of the population selected at 0 kg N/ha (P_1) over the one selected at 200 kg N (P_2) when tested at 0 N/ha, with a completely reverse trend (35% or 1 5t/ha) when the two populations were evaluated at 200 kg N The population selected at 200 kg N/ha showed a significantly linear response to N As Atlin and Frey (1989) observe these results show that the heritability of yield under low N conditions was sufficiently high to permit effective selection in this example

If one contrasts these results in Kansas with those presented in Table 2 for upland rice on acid soils in Colombia the question arises as to the most appropriate selection strategy for parents in order to achieve response curves such as Curve 6 in Figure 1c, i e rather than the "cross-over" type response in Figure 8 It is the contention of this author and those at CIAT who carried out the savanna breeding work, that their success was due to having selected individual parents that were superior in both environments, i e at moderate *and* low inputs This strategy implies beginning with a very wide range of exotic germplasm and having homogeneity of field conditions particularly at low input levels, in order to increase the reliability of selection The reader is referred to the very interesting paper by Atlin and Frey (loc cit) on the subject These authors argue that selection for low input agriculture under only low input conditions may be necessary if the genetic correlation is low or negative between high and low input environments, i e where different alleles are controlling yield in the two environments This paper gives many examples suggesting that it is indeed possible to select parents and progenies which yield well at lower inputs but have a high yield potential at high input levels Muruli and Paulsen (loc cit) conclude their paper by indicating that high and low N adaptation might be combined in the same genotype through selection of the few unique lines that yield well at extreme N levels, i e the outlyers

Research on acid soil toxicity tolerance in maize is underway in both Brazil by EMBRAPA and in Colombia by CIMMYT (Haag and Pandey,

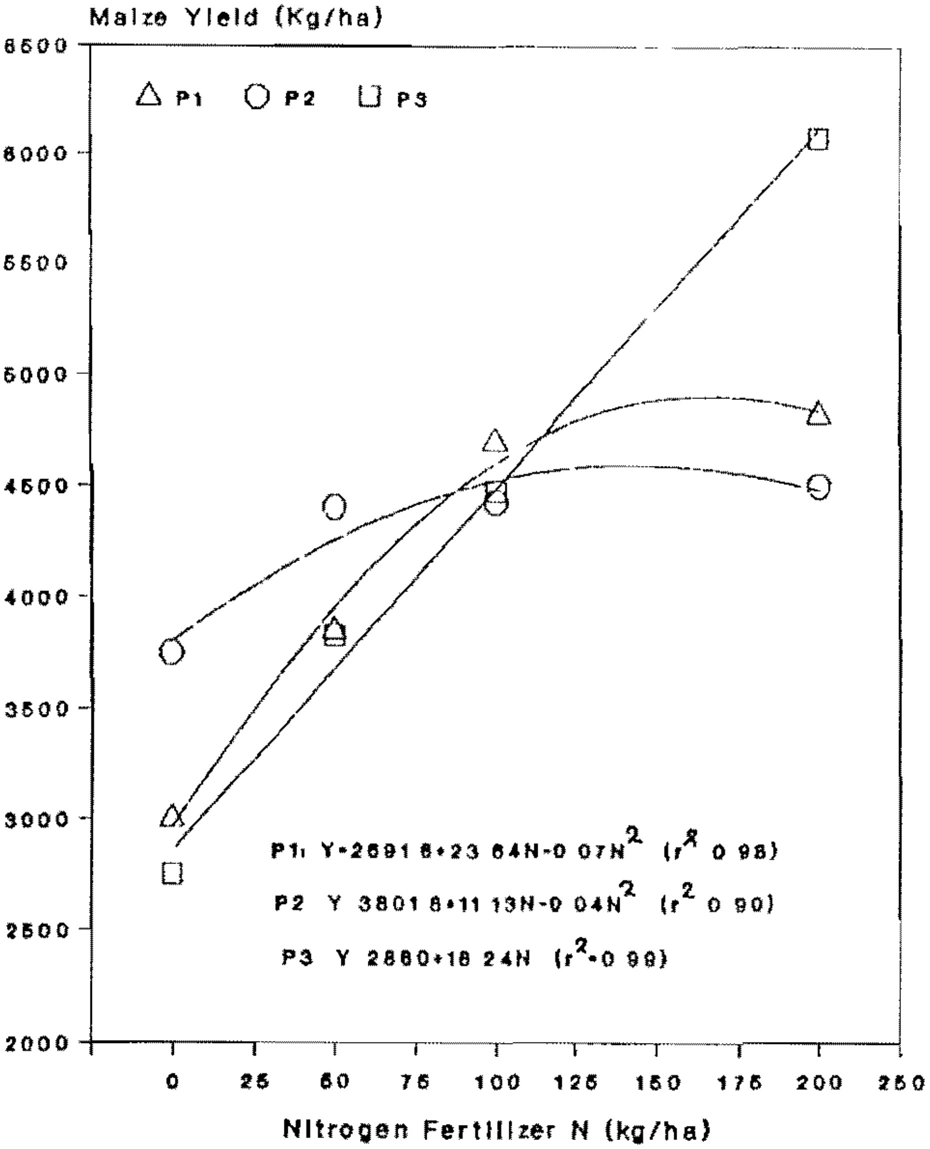

Figure 8 Nitrogen response of two synthetic varieties of maize developed from lines selected in once cycle of selection at low soil nitrogen status (0 kg N/ha, P2) and at 200 kg N/ha (P3) compared to the response of the original population (1) data reworked from the paper by Muruli and Paulsen (1981) (meaned over two locations in Kansas)

1988) Improved aluminium toxicity tolerance in maize would greatly improve the possibilities for more efficient fertilizer responses, i e without costly lime applications, in many tropical soils where maize is presently grown Similar work will be required to develop populations with tolerance for other important specific soil deficiencies, e g P and S and toxicities, e g Mn, in order to reduce the need for research on application of fertilizers and soil conditioners (Larios et al, 1990), to correct what appears to be a lack of 'edaphic' adaptation characteristics in presently available improved tropical maize populations

7 2 Improving Maize for Water Stress Tolerance

The principal factor limiting the degree of fertilizer response in maize is water supply in the tropics and sub-tropics under rain-grown conditions Improving water stress tolerance through recurrent selection in the widely adapted Tuxpeño population has shown highly significant progress (Fischer et al, 1989) The results in Table 12 illustrate the results of three cycles of selection, i e for C_0 and C_3, at three regimes of soil water deficits Grain yield increased by an average of 410 kg/ha per cycle (21 6%) when selection took place at severe soil moisture deficit levels

The authors confirm that adapted drought tolerant varieties outyielded all others by 500 kg/ha under severe moisture deficit but not at the expense of yield under well watered conditions These results have now been confirmed after eight cycles of selection of the same populations (Bolaños and Edmeades, 1989) with the stress tolerant Tuxpeño outyielding C_0 by 800-900 kg/ha over 12 locations at yield levels of C_0 of 500 to 8000 kg/ha The latest data confirm that yield gains were evident in populations selected under stress when evaluated under more optimum conditions The main character associated with this stress tolerance is the synchronization of tasselling and silking Studies on possible changes in root morphology are probably advisable to evaluate trends in this trait under selection pressure, i e particularly deep rooting characters The possibilities of combining water stress tolerance in maize with efficient nitrogen response at low N rates in the same populations should be explored. This combination could open new vistas for small farmers particularly in Africa and Latin America.

Table 12 Progress in selection for water stress tolerance in maize in Mexico: yields after three cycles (C_n) of selection in the Tuxpeño population under three moisture-deficit regimes (Tlaltizapan, 1981) through recurrent selection of full-sib families compared with selection for yield over many locations (International Progeny Testing Trials, IPTT)

Selection cycle	Grain Yield (kg/ha) Soil-moisture deficit Mild	 Medium	 Severe
Stress tolerance			
C_o	5860	1740	620
C_3	6180	2160[b]	1030[b]
EV[a]	6310	2340[b]	1100[b]
IPTT			
C_o	5610	1680	580
C_3	6460[b]	1890	680
cv (%)	12	19	23

[a] Experimental variety represents higher (10%) selection pressure in cycle 2

[b] Significantly different ($P < 0.05$) from original cycle (preplanned F-test)

These very encouraging results from CIMMYT in maize and those illustrated in Figure 7 for beans at CIAT support the view that water stress tolerance is now a more feasible objective for third world agriculture. This conclusion has important future implications for improved fertilizer use efficiency in rain grown maize and bean systems. Another possible implication of this work on water stress tolerance is the general concept that stress tolerance *per se* in many crops could allow a reduction in the amount of water required and/or the frequency of application in irrigated production systems thus increasing efficiency of water use and reducing salinity problems induced by excessive water applications and rising water tables The overall problems of sustainability in irrigated systems require urgent attention in many parts of the developing world

8 CROP PRODUCTION SYSTEMS RESEARCH AND INPUT USE

The need for more long term research on farming systems is now very pressing Lynam and Herdt (1989) have developed some excellent concepts on the criteria in relation to research on the sustainability of key cropping or farming systems The criteria imply a much longer time horizon in our research than has been possible in many farming systems research efforts in the past The plethora of FSR projects in developing countries during the 70s and 80s were usually constrained within the classical 'three year' project time frame imposed by the donors In many cases the results have been criticized as being location specific and thus not extrapolatable

A better understanding of some of the major food crops systems in the tropics and sub-tropics is vital to progress towards developing technology components which will contribute to sustainability Examples of such systems are the banana-bean association in the heavily populated highlands of eastern and central Africa and the maize and bean associations in the tropics and sub-tropics of Latin America and Africa One of the key issues in such long-term systems studies will be the nutrient balance of the system over time, i e the balance between gains and losses including soil loss Our ability to drastically improve fertilizer use efficiency, i e from inorganic or organic nutrient sources, will ultimately depend on a better knowledge base than we now have about those systems

Another and related aspect of cropping and farming systems research which is vital to the future of tropical agriculture (and fertilizer use efficiency) is the need for accelerated development of low input and low capital investment requiring technologies for controlling soil erosion and gradually improving soil fertility on tropical hillsides The comparatively invisible nature of sheet erosion that is taking place in heavily populated tropical highland or hilly regions such as the Great Lakes region of Central Africa and in Central America is truly alarming These are the comparatively well watered and thus higher potential areas for food production Rates of soil loss in traditional systems exceeding 500 tons/ha/year do not encourage one to be optimistic (CIAT,) Technologies such as living barriers using hardy species like vetiver grass (*Vetiveria zizanoides*) (World Bank, 1990) and alley cropping (Mulongoy and Kang, 1986) point the way forward Such systems will have to be adoptable by poor farmers otherwise the research outcomes remain as a set of interesting curiosities, i e like so many other 'novel' systems to be found only on experiment stations

Improving soil cover and reducing sheet erosion by more vigorous crop growth through increased fertilizer use is a critical interaction often observed in the field in the tropics particularly where rainfall intensities (mm/hour) are high The work described in this paper which would contribute to small farmer adoption of fertilizer use would also make an important contribution to soil conservation

9 BIOTECHNOLOGY AND INPUT USE

Modern biotechnological tools are becoming available across a broad spectrum of interrelated fields which will revolutionize the process of plant improvement over the next decade In this regard the new biology should be seen as a means of accelerating existing research efforts and as a means of solving specific problems which remain intransigent Some commentators seem to be suggesting that biotechnology is almost an end in itself Those who are putting biotechnology into practice realize that this is an erroreous view

In this paper a limited set of examples of new biological systems designed to solve old problems are highlighted to illustrate the exiting possibilities which lie ahead in terms of input use research

o 1 Biotechnology Research in Progress in the Staple Food Crops

Advanced genetic transformation systems are not yet applicable to *Phaseolus* and thus it has not yet been possible to create transgenic plants in these species Shimamoto *et al*, 1989, first reported the regeneration of fertile transgenic rice plants from transformed protoplasts Similar results were also recently reported for maize except that the resulting plants were infertile (Rhoades *et al*, 1988) Advanced biological systems being used for genetic transformation mostly involve the family *Solanaceae* Intensive research is in progress on other crop species in many laboratories and results can be expected soon In the meantime a wide range of other modern biotechnology techniques are being utilized in these food crops Some limited examples follow which demonstrate these latter efforts

In *Phaseolus*, work is in progress at CIAT on embryo rescue to facilitate crossing of P *vulgaris* with P *acutifolius* Data from field screening at CIAT for drought tolerance have confirmed that P *acutifolius*, originating in the drier southeast of the United States and northern Mexico, has very much higher yields than P *vulgaris* under severe stress Transferring the associated traits, probably tap root development, into P *vulgaris* will be a major breakthrough

In rice, anther culture is already being used in various breeding programs as a routine means of accelerating the process of obtaining homogeneity in recombinants This system is seen as being particularly useful in accelerating breeding in rice systems where only one crop cycle per year is possible Work is in progress at CIAT to resolve some limitations in the use of anther culture Homogeneous materials derived from anther culture (i e crosses of indica x japonica rice) are presently under field evaluation in Chile

The Rockefeller Foundation-funded network on rice biotechnology is catalyzing a very wide range of research around the world Given that a protocol now exists for producing transgenic plants in rice we can soon expect some highly significant developments in this critical world crop This network has particularly catalyzed the application of RFLPs to rice improvement

In maize much of the work is concentrated in the private sector in the USA with heavy emphasis on RFLPs The work on genetic linkage maps has been published (Helentjaris, 1986) Other workers (Lee et al, 1989) report the use of RFLPs as molecular markers to facilitate the improvement of agronomic traits in maize These workers conclude that RFLPs are a potential alternative to field testing for assigning maize inbreds to different heterotic groups Anther culture is being evaluated as a possible breeding tool in maize in order to reach homogeneity more rapidly, e g in the production of inbreds (Wan et al, 1989)

9 2 Future Applications with High Potential Impact

The highest priority constraints related to the topic and the focus of this paper which will most effectively be mediated through genetic transformation in the future are considered as follows

a) Weeds in tropical crop production systems

b) Insects for which resistance breeding has not been particularly successful

c) Diseases, particularly those caused by fungal organisms which are continually developing more virulent races

9 2 1 Developing Herbicide Resistance in Crops

Tropical weeds are one of the most critical constraints to increased small farm production The man or woman hours spent in the drudgery of hand weeding could be more usefully employed in other tasks, e g increasing the area cultivated or in soil conservation work, if more efficient weed control technologies were available Available herbicides are often toxic, e g Paraquat, and/or highly selective for monocots or dicots and are usually very expensive and are thus often inappropriate for mixed cropping systems on small farms Environment friendly systems which will act against a wide range of weed species simultaneously without damaging the crop are required Genetic transformation systems have recently been proposed which seem to fulfill these requirements

Phosphinothricin (PPT) is a potent inhibitor of glutamine synthetase in plants and is used as a non-selective herbicide A gene (bar) has been identified (De Block, 1987) which, when transferred to solanaceous species (tobacco, tomato and potato), conferred complete resistance to high doses of PPT The gene action is through a process of detoxification of the herbicide within the transgenic plants Another system proposed by Stalker et al, 1988, also involves a single gene (bxn) which confers complete resistance to the herbicide bromoxynil through a process of catabolic detoxification In both cases the genes were isolated and cloned from naturally occurring organisms, i e a streptomycete and Klebsiella ozaenae (natural soil bacteria species) respectively

A private company has announced the first success in generating an inheritable herbicide tolerance trait in maize through the use of cell culture technology This work involves the growing of maize protoplasts in in-vitro culture and subjecting the cells to formulations of the herbicide imidazolinore The resultant plants were resistant to herbicide concentrations ten times higher than that required to kill weeds The inheritance appears to be controlled by a single dominant gene (Shaner, 1985)

Another fascinating system coming from the private sector (Carlson, 1989) named Incide involves the use of naturally occurring endophytic bacteria (Clavibacter xyli subspecies cynodontis) Genes encoding for particular characters, e g controlling insecticidial traits or herbicide resistance, are inserted into the bacteria cells which are then cultured by normal fermentation procedures The commercial product is then infiltrated into the seed under vacuum and after a lag phase begins to protect the germinated plant Spraying has also been effective Theoretically once a cultivar has been treated in this way and the farmer retains his own seed the next crop should be also protected since the endophyte grows systemically in plant xylem tissue This 'vaccination' system holds particular interest for developing countries as a preventive rather than a curative system and progress will be watched with interest This particular system would appear to be environment friendly but each application will certainly have to run the guantlet of biosafety precautions prevailing in the United States and other countries The system would appear to be exploitable for a wide range of constraints

9 2 2 Transgenic Insect Resistance

Insect toxins produced naturally by Bacillus thuringiensis have been used for more than 20 years as a biological insecticide, i e as spore preparations, against Lepidoptera, Diptera and Coleoptera depending on the bacterial strain The bt2 gene which encodes for the toxins has been cloned from B thuringiensis and transferred into tobacco conferring high toxicity to insects in transgenic plants

Another system involving a gene encoding a cowpea trypsin inhibitor has been shown to confer some measure of field resistance to insect pests (Hilder, 1987) Another useful gene encoding a seed lectin in beans, which is very similar to Arcelin mentioned earlier, has been isolated and will certainly be the subject of transformation experiments in species where such protocols exist (Osborn et al, 1988)

Insect resistance systems such as those outlined here could be enormously effective in third world agriculture since they can be transferred to small farmers through the medium of new cultivars rather than through a spray nozzle

9 2 3 Durable Disease Resistance

Restriction fragment length polymorphisms (RFLPs) are providing breeders with a powerful new set of tools to (a) expedite the movement of desirable genes, (b) allow transfer of novel genes from wild related species, (c) facilitate the analysis of complex polygenic characters and (d) establish genetic relationships between sexually incompatible crop plants (Tanksley et al, 1989) The range of applications is virtually all of plant breeding but the particular application in facilitating pyramiding of genes for diverse constraints will greatly expedite the research outlined in this paper

Among the myriad of possibilities for RFLPs the development of more durable disease resistance to variable disease organisms, e g rice blast, through the pyramiding of major or minor genes ranks very high in terms of potential benefits to agriculture The efficiency of gene mapping and tracing using RFLPs is a quantum leap ahead of previous marker systems, i e isozymes The influence that this new tool will have in accelerating and reducing the size of modern breeding programs should begin to have a major effect on the cost of doing business in the next decade

Another system for virus disease resistance has recently been published (Cuozzo et al, 1988) which involves a system of cross protection in transgenic plants expressing the cucumber mosaic virus (CMV) coat protein gene (CP+) The CP gene of CMV has been cloned, sequenced and transferred into tobacco plants conferring resistance to CMV The system is now under intense study in many laboratories and offers exiting possibilities for the future

10 CONCLUSIONS

This paper set out to demonstrate through research examples, derived mainly from the international networks, that a drastic reduction in the use of plant protectants and an increase in fertilizer use efficiency is possible in tropical food crop production systems The examples selected show the following general trends

a) Progress towards pyramiding genetic resistance to a wide range of biotic constraints in the same genotype has been remarkably successful using conventional breeding approaches This work must eventually lead to a reduction in the use of external inputs in the plant protectant group provided that the new technology is adopted by farmers

b) Progress towards improved adaptation to edaphic constraints and hence higher fertilizer use efficiency at lower application rates has been less remarkable, particularly in tropical maize, but indications suggest that excellent work is in progress in this direction Improved fertilizer efficiency is seen as being critical in order to facilitate adoption of fertilizer use by resource poor farmers in dryland crop systems

c) Progress in the use of modern biotechnological tools to help resolve the more intransigent constraints and in the use of these tools to increase the efficiency of conventional breeding is now a reality Biotechnology will allow us to accelerate international efforts but is not seen as a general panacea The involvement of developing country scientists in modern biotechnology will be critical to progess in those countries and ways must be found to make this interaction possible

In relation to the three crops surveyed in this paper it is clear that challenges lay ahead which will involve a continued and concerted international effort Specifically more attention to fertilizer use efficiency in irrigated rice in Latin America seems justified There is critical need for an accelerated international effort on nitrogen response at lower N application rates and an associated improvement in the tolerance of tropical maize germplasm to key edaphic constraints In beans the main challenge is one of simultaneously pyramiding genes for biotic and edaphic constraints into higher yield potential backgrounds The particular challenge of the tropical acid soil complex in beans, rice and maize will test the ability of researchers to balance and take account of the variation in the interacting limiting factors involved

A more general challenge is the need to conduct certain critical work away from relatively polluted experiment stations and/or to find ways of doing good research in the face of soil variability in experimental fields (Frey, 1964, Byth et al, 1969, Pederson and Rathjen, 1981) The problems associated with measuring statistically significant differences between treatments in low input systems in tropical soils is a major constraint to progress Many researchers have opted for the so called 'optimum fertility' approach because of these problems Careful site selection and land preparation can assist enormously in this regard The devolution of particular international research responsibilities to specific national research programs which have both institutional and environmental comparative advantages is another model now being explored

One aspect of the work of the international research system which is highlighted throughout this paper is the critical importance of conserving and utilizing the world's germplasm resources The basic tenant of this paper is the key contribution that genetic diversity can make to resolving the problems associated with improving the sustainability of tropical food crop systems The contribution that the IARCs and national public agencies in developed and developing countries have made to genetic conservation is truely remarkable involving as it does true international cooperation (IBPGR, 1989) Free exchange of germplasm must continue and ways have to be found to limit the possible negative effects that privatized plant breeding could have in relation to the international and inter-institutional sharing of genes

11 CLOSING REMARKS

This paper opened with a short discussion on the controversy surrounding 'minimum' or 'low-input' research philosophies This highly selective survey of research in progress in rice, beans and maize strongly suggests that sustainability criteria are being applied in the international agricultural system by both IARCs and by collaborating national commodity programs Research results strongly suggest that a drastic decrease in the use of certain external inputs is possible while at the same time safeguarding yield and system sustainability Progress is probably far more advanced than many environmentalists would care to admit given their present understanding of the research process Communication on these issues is critical since the very existence of the international system depends on continued support from donor governments increasingly aware of the environmental lobby If international commodity and system based research of the type outlined in this paper is not encouraged the world will not be able to feed itself in the next century I trust this paper will help in that communication process

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