Technical Bulletin No. 24

The Mungbean Green Revolution in Pakistan

Mubarik Ali
Ilyas Ahmad Malik
Hazoor Muhammad Sabir
Bashir Ahmad

Asian Vegetable Research and Development Center

Technical Bulletin No. 24

The Mungbean Green Revolution in Pakistan

[1]Mubarik Ali
[2]Ilyas Ahmad Malik
[3]Hazoor Muhammad Sabir
[4]Bashir Ahmad

Collaborating institutions
[1]Asian Vegetable Research and Development Center, Taiwan
[2]Nuclear Institute for Agriculture and Biology, Faisalabad
[3]Ayub Agriculture Research Institute, Faisalabad
[4]University of Agriculture, Faisalabad
National Agricultural Research Centre, Islamabad

P.O. Box 42, Shanhua 741
Taiwan
ROC

Ali, M., Malik, I.A., Sabir, H.M., and Ahmad, B. 1997. The Mungbean Green Revolution in Pakistan. Technical Bulletin No. 24. AVRDC. Shanhua, Taiwan, ROC. 66 p.

Cover: A farmer in Mianwali stands in his field of improved-variety mungbean.

AVRDC publication no. 97-459
ISBN: 92-9058-109-3

Collaborating Institutions
Asian Vegetable Research and Development Center, Taiwan
Nuclear Institute for Agriculture and Biology, Faisalabad
Ayub Agriculture Research Institute, Faisalabad
University of Agriculture, Faisalabad
National Agricultural Research Centre, Islamabad

Acknowledgements

We deeply appreciate the continuous support, interest, and persuasion of Dr. Samson C. S. Tsou, the Director General of AVRDC, throughout the completion of this report. His valuable critiques and suggestions always guided us. Without the personal interest of Dr. Sayed Hassan Mujtaba Naqvi, Director General, Nuclear Institute for Agriculture Biology, we would not have been able to initiate this study. We appreciate his guidance and encouragement throughout this study. We also acknowledge the help of Dr. Muhammed Akbar, Chairman, Pakistan Agriculture Research Council, Islamabad, and Dr. Bashir Ahmed, Pulses Coordinator, National Agricultural Research Centre, Islamabad, in providing collaborative support in the field survey. The authors would also like to extend their appreciation to Mr. David Abbass for editing the manuscript, to Ms. Chan Chiu-Wei for typing and formatting the document, to Ms. Wu Mei-huey for assisting in analysis, and to Dr. Charles Y. Yang for his valuable administrative support. Our sincere appreciation goes to the extension workers in the mungbean growing areas who facilitated the field survey, and to the mungbean growing farmers who did not hesitate to provide us information, even related to their household belongings and family members.

Foreword

Agricultural research requires a long-term commitment. Goals are set, plans are made, resources are committed. People dedicate years of their lives and the better part of every waking day to see that a crop's yield is increased, to see that it won't wither in the field, or be eaten on the vine by countless predators. All so that a farmer might have a crop to sell, to give sustenance to families, to communities, and to whole populations waiting in confident reliance on the steady work of agricultural researchers.

But breakthroughs in agricultural research are celebrated quietly. A handshake across a row of beans or a picture of a pristine leaf spared the ravages of disease cannot compete for show with space walks or the carnage of war. This might change. Agricultural research could soon make the news as a sidebar to stories of famine and doom if funding to agricultural research continues to decline.

For now, AVRDC is enjoying a quiet celebration. Some 20 years ago a goal was set, a plan was made, and resources were committed to a humble crop, still virtually wild, that might someday feed protein-hungry masses. For even then, it was obvious that the Green Revolution in grains would surely cause a reduction in land devoted to protein-rich pulses and that the result would be protein-deficiency. Mungbean, it was reasoned, stood the best chance of fitting profitably into the modern, high-yielding grain systems of Asia. But first, much work would need to be done to remove or improve the traits that had relegated mungbean to marginal lands. Among these was asynchronous maturity – farmers were harvesting their mungbean crops several times and harvest labor accounted for a major part of the crop's total cost of production. Others were low yield, long duration, and susceptibility to disease.

The mungbean program was nicknamed SHE by its first principal researcher, Dr. Hyo-Guen Park of Korea. *S* for stability brought by disease resistance, *H* for high yield to make the crop a competitive alternative, and *E* for early maturity to fit mungbean in rotation with intensive grain systems.

From the start, the mungbean program held special significance: it would be AVRDC's mission brought to fruition and it would be a model for future work. The program would deliver nutrition to the poor in developing countries, it would be a sustainable advance making soils more productive, it would deliver true benefits to farmers as well as consumers, and it would be good for the environment, diversifying cropping patterns. What's more, the program would be a collaboration of AVRDC and developing-country scientists. It was, in fact, AVRDC's Pakistani research partners who in the early 1990s supplied a critical improvement, namely resistance to mungbean yellow mosaic virus. If AVRDC mungbean lines were to bring the same impressive gains to South Asia (where the bulk of mungbean is grown) that they had already brought to East and Southeast Asia, then resistant or tolerant lines had to be developed.

And so today, quietly, improved mungbean is taking back land lost to grain production. It is being grown on land once left fallow. And it is nestling in to tight, high production rotations with grains and other cash crops, supplying healthy immediate returns and boosting fertility for the benefit of successive crops. It is a Green Revolution that has put farmers, consumers, and the environment all on the winning side.

The next step is to spread the benefits of modern mungbean to other countries in the region. The mungbean working model, however, has already proved its worth. It has for years inspired and guided efforts into the Center's other mandate crops.

Please share in the spirit of our most recent quiet celebration by praying that agricultural research finds soon the wise champions it deserves.

Dr. Samson C. S. Tsou
Director General
Asian Vegetable Research and Development Center

1. Introduction

Mungbean (*Vigna radiata* (L.) Wilczek) is an important short-duration pulse crop in Pakistan, supplying a substantial portion of protein to the cereal-based diet of the poor. It is regarded as a quality pulse for its rich protein seed and excellent digestibility, especially when combined with cereals (Thirumaran and Seralathan, 1988; Singh, Chhabra, and Kharb, 1988; Rachie and Roberts, 1974). [1] And mungbean's low requirement for inputs, and its ability to restore soil fertility through symbiotic nitrogen fixation (Firth *et al.*, 1973) make it particularly important to resource-poor farmers.

Mungbean was cultivated on 167,900 ha producing 69,300 t in 1993-94. This represented 11% of the country's total pulses area (1.5 million ha) and production (0.61 million t).[2] The province of Punjab accounted for 88% of mungbean area and 83% of total mungbean production in 1993-94. Cultivation is concentrated in Layyah, Bhakar, and Mianwali districts of Punjab, contributing 72% of the total area and 75% of the country's mungbean production (Figure 1).

Lax policy regarding food legumes and introduction of high-yielding, input-responsive varieties of cereals during the late 1960s and 1970s pushed pulse cultivation, including mungbean, to marginal lands. For example, the districts of Layyah, Bhakar, and Mianwali, all relatively marginal cereal growing areas, accounted for just 3% of the area planted to mungbean in Pakistan in 1970. By 1993, the three districts accounted for 70% of the country's mungbean area (Figure 2). Pulses production decreased from 836,000 t in 1973 to 614,000 t in 1993, while its share in total cropped area dropped from 8.8% to 6.8%. Unlike the other pulses, mungbean has experienced a turnaround. Since the mid-1980s, the crop has had years of dramatic increase.

While pulse production has declined, population has exploded. Domestic per capita production of legumes decreased from 9.5 kg per annum in 1970 to 3.4 kg per annum in 1993 (Table 1). Attempts to halt the decline have so far failed and the government has been forced to spend much-needed foreign exchange on imports to supplement domestic production. Pulse imports have risen from nil in 1975 (Government of Pakistan 1978) to 254,000 t in 1993 (Government of Pakistan 1995).[3] And pulse prices have jumped compared to other food items, such as wheat (Figure 3). As a result, the diets of the poor

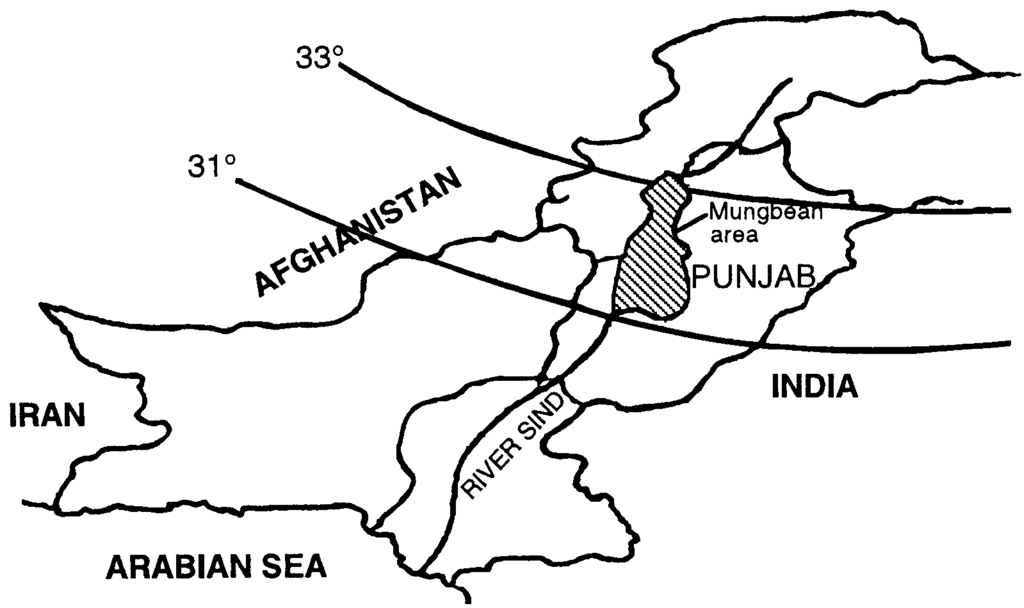
[1] The relative deficiency of sulphur amino acids in legumes is compensated for by the relative surplus in the cereals, while the relative deficiency of lysine in the cereals is likewise compensated for by a relative surplus in legumes (Thirumaran and Seralathan, 1988).

[2] Other major pulses are black gram (*Cajanus cajan and Cicer arietinum*), lentil (*Lens esculenta or Lens culinaris*), and mash (*Vigna mungo*).

[3] Similar trends were observed in other countries where Green Revolution in cereals was pushed hard. For example, in India, which is one of the major pulses producing countries in the world, total pulses area declined from 23.6 million ha in 1960 to 22.4 million ha in 1993, and the share of pulses in total foodgrain area dropped from 20% to 18%; total production remained stagnant at around 12-13 million t, but per capita availability declined from 65.5 g/day to 37.0 g/day in the corresponding period (Government of India, 1994). Pulses prices increased 40% more than cereal prices just during 1982-93 (Government of India, 1995).

have suffered As well, soils have deteriorated in the intensive cropping systems lacking a pulse in rotation.

Figure 1. Map of mungbean growing area in Pakistan

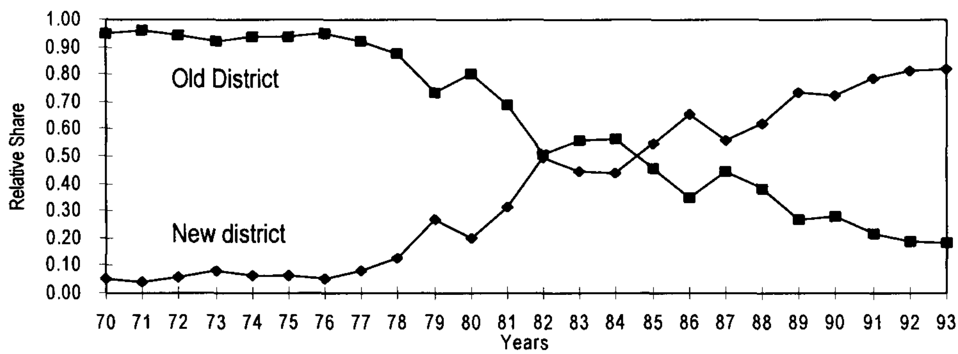


Green Revolution research turned to mungbean in the early 1980s. Collaborative research programs launched by the Asian Vegetable Research and Development Center (AVRDC) resulted in release and adoption of a number of high-yielding, disease resistant, and superior quality varieties. These new varieties have had favorable implications for both per capita consumption of mungbean and mungbean prices. Although per capita availability (from production data) has been constant at 0.5 kg (Table 1), consumption as reported in the Household Income and Consumption Expenditure Surveys has increased from 1.08 kg per capita in 1984-85 (Government of Pakistan 1989) to 1.32 kg in 1990-91 (Government of Pakistan 1995). Moreover, mungbean prices increased only moderately compared to a sharp increases for other pulses (Figure 3).

On the other hand, technological innovation in mungbean expanded its production to new areas. Mungbean area more than doubled within a decade (Table 1). Because of the soil-improving characteristics of the crop, this has had favorable implications for agriculture production in these areas.

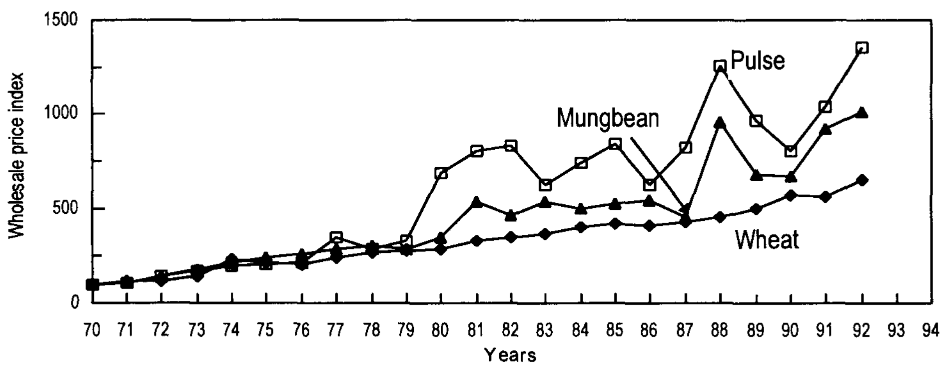
The technological innovations in mungbean cultivation are so important for sustainable production and human nutrition in Pakistan that researchers and policy makers needed to understand the process that has led to the crop's improvement and its implications for different sectors of the society. The main objective of this bulletin is to highlight the technical advances achieved in mungbean and report on what the improved crop has meant to farmers and consumers. The next chapter explains how problems in the pre-innovation era led to refinement of research objectives, and it describes approaches taken to solve those problems. Chapter 3 describes the farm-level performance of the improved mungbean. Specifically, the chapter describes the environment of mungbean growing areas, traces the adoption pattern of modern technologies, quantifies the achievable potential of these technologies, ranks production constraints, measures the sustainability impact of mungbean cultivation, and quantifies the gains generated by the improved crop. The final chapter summarizes findings, and suggests implications for future research.

Figure 2. Share of the old and new mungbean growing districts in mungbean area



Note: New districts are Layyah, Bhakar, and Mianwali, while old districts are all others.

Figure 3. Mungbean, pulses, and wheat prices in Pakistan



Note: The pulses prices are weighted average of wholesale prices of gram (Lahore), lentil (Faisalabad), and mash (Multan). The relative share in total production was used as weights. Mungbean prices are wholesale prices in Karachi market.

Source: Government of Pakistan (1972), Government of Pakistan (1983), Government of Pakistan (1995b).

Table 1. Area (000 ha), production (000t), average yield (kg/ha), and per capita availability (kg) of all pulses and mungbean, and mungbean share in production (%) in Pakistan, 1973-1993

	Mungbean				All Pulses				Mungbean share
Year	Area	Production	Yield	Availability	Area	Production	Yield	Availability	in all pulse production (%)
1973	68.6	32.0	461	0.42	1626.8	836.3	514	9.20	3.83
1974	62.5	28.6	466	0.37	1376.9	715.6	520	7.55	4.00
1975	67.3	31.9	470	0.40	1476.5	783.7	531	8.03	4.07
1976	64.7	29.7	459	0.36	1533.3	843.5	550	8.38	3.52
1977	65.5	30.8	470	0.36	1544.7	811.6	525	7.85	3.79
1978	65.9	30.0	454	0.34	1676.6	735.8	439	6.96	4.08
1979	69.0	32.7	473	0.36	1550.9	512.2	330	4.86	6.38
1980	67.0	31.8	475	0.34	1252.5	525.5	419	4.80	5.35
1981	65.6	31.6	482	0.33	1321.1	488.2	369	4.37	5.00
1982	79.0	39.6	501	0.40	1335.4	693.7	520	5.85	5.92
1983	91.0	41.8	459	0.41	1306.7	709.9	543	5.76	6.96
1984	93.6	44.6	476	0.42	1415.3	725.5	513	5.73	6.64
1985	104.2	48.8	468	0.45	1451.5	796.7	549	6.08	7.17
1986	114.2	55.3	484	0.49	1521.6	790.9	520	5.85	7.49
1987	94.1	43.3	460	0.38	1222.3	556.1	455	4.07	7.69
1988	96.6	41.1	425	0.35	1394.9	641.8	460	4.50	6.96
1989	143.8	57.0	396	0.46	1496.4	768.5	514	5.20	9.63
1990	141.6	56.5	399	0.45	1538.2	732.1	476	4.81	9.23
1991	125.8	50.9	405	0.39	1420.4	706.2	497	4.50	8.87
1992	146.8	62.1	423	0.46	1453.1	547.1	377	3.47	10.11
1993	167.9	69.3	413	0.50	1480.9	614.0	415	3.75	11.35

Per capita availability of mungbean was estimated by subtracting 10% of its production for seed requirements. In the case of all pulses, the seed requirement for gram was assumed to be 31%, and 10% for all other pulses.
Source: (Government of Pakistan 1978 and 1995 issues)

2. Mungbean Research for Sustainability

2.1 Available material

Before the start of varietal research in mungbean, the two major types of local or Desi mungbean available were: i) photoperiod sensitive, and ii) photoperiod insensitive. The photoperiod sensitive "Desi moong" varieties were low yielding (250-500 kg/ha), asynchronous, and late maturing (95-115 days). They had spreading growth, small pods (5-6 cm) and small seed size (20-25 g/1000 seeds). The color of seed was usually green, either dull or shiny. Strong response of these varieties to day length forced farmers to postpone their sowing, which delayed the sowing of the following wheat crop. They were susceptible to both mungbean yellow mosaic virus (MYMV) and cercospora leaf spot (CLS) diseases.[4] The photoperiod insensitive Desi varieties gave relatively better yield (400-600 kg/ha). They had erect growth habit and took 90-95 days to mature in summer (kharif) and about 80 days when sown in spring. They had comparatively bigger pods (7-8 cm) and medium size seed (25-30 g/1000 seeds) with a green, but dull seed coat. They were, for the most part, also susceptible to MYMV and CLS. The variety 6601 (land race) released by the Department of Agriculture, Punjab, in 1971, was in this category and remained the only approved variety of mungbean until 1983.

Long-duration and unsynchronized maturity created strong competition with other crops for land and labor. Low yield eventually threw mungbean out of the competition. Susceptibility to diseases made 6601 a risky crop, and its dull color made it unattractive to consumers. The challenge for researchers was to overcome these constraints and make mungbean an economically viable option for a wide range of cropping systems. The sustainability advantages of the crop would follow.

2.2 International Mungbean Research

In 1971, AVRDC assumed responsibility for improving mungbean productivity. The research objectives were to develop high- and stable-yielding, uniform-maturing, disease- and insect-resistant varieties that made efficient use of solar energy and soil nutrients (AVRDC 1977). The starting point was to collect germplasm. By 1996 the Center had collected 4000 entries in its germplasm bank (AVRDC 1997). The germplasm is regularly evaluated. Preliminary, intermediate, and advanced yield trials are also regularly conducted. Lines with desirable characteristics have been selected from advanced yield trials and distributed to national programs for further evaluation and crosses. Pakistan benefited from the advanced lines of VC1482, VC1560, VC1628, VC1973, VC2719, VC2768, VC3726, VC2754 VC2771, VC2778 and VC3902. The characteristics of some of the selected lines are reported in Table 2.

[4] In Pakistan, mungbean is rarely grown in the winter season, thus powdery mildew is less a problem.

Table 2. High yielding lines in the International Mung Nursery, Spring and Summer, 1983, AVRDC

AVRDC no.	Parentage or variety name	Yield (t/ha) spring	summer	mean	Ist harvest (% of total)	Disease CLS	PM	100-seed wt. (g)	Lodging[1] index
VC 2768 A	VC 1482 A/VC 1628 A	1.98	2.73	2.35	72	MR	MR	5.8	1.4
VC 1482 C	EG-MD-6D/ML-3	2.08	2.52	2.30	65	MR	MR	4.7	1.0
1628 A	CES ID-21/ PHLV 18	2.24	2.14	2.19	73	VS	VS	5.4	1.4
VC 2719 A	Shanhua 1/VC1163A	2.11	1.99	2.05	65	MR	MR	4.8	1.2

[1] Rated on a scale of 1 for no lodging to 5 for all lodging;
MR = moderately resistant; VS = very susceptible; CLS = cercospora leaf spot; PM = powdery mildew.
Source: AVRDC (1985), page 177

2.3 History of Mungbean Breeding Research in Pakistan

In the past, like many other grain legumes, mungbean received very little research attention in Pakistan. Breeding work was limited to selections from land races or from the cultivators' improved stocks. This was mainly due to the scarcity of genetic variability in local germplasm.

Work on the improvement of mungbean in Punjab was intensified in the early 1970s at the Ayub Agricultural Research Institute (AARI), Faisalabad, and further expanded in 1980-81 with the involvement of the National Agricultural Research Center (NARC), Islamabad. Genetic variability in the local germplasm was created through induced mutations at the Nuclear Institute for Agriculture and Biology (NIAB). In 1980, the Pakistan Agricultural Research Council began a coordinated research program on pulses improvement with support from the International Development Research Center (IDRC), Canada. More than 1600 mungbean lines were assembled in collaboration with AVRDC.

A hybridization program was started in 1980. Research got a boost in 1981 with collaboration between NARC, NIAB, AARI, and AVRDC. Crossing work, involving local mungbean cultivars/mutants resistant to MYMV and large-seeded varieties resistant to CLS, was started at NIAB and NARC.

To contain the spread of MYMV, which is transmitted by the insect vector white fly (*Bemisia tabacci Genn*), AVRDC and National Agricultural Research Centers (NARCs) in the country agreed in 1992 to collaborate in a regional network. The object of the network was to develop and screen mungbean populations for MYMV resistance as well as other important plant characteristics. The NARC at Islamabad, including other national and provincial organizations engaged in mungbean research (especially NIAB in Faisalabad) joined the network. A large number of mungbean lines resistant to MYMV, developed at NIAB, were sent in 1992 to the Asian Regional Center (ARC) of AVRDC, located in Thailand, for evaluation and selection. AVRDC maintained the supply of segregating material derived from crosses between AVRDC accessions and local mungbean lines. This would be used to select new, high yielding, large-seeded varieties having improved plant type and resistance to MYMV.

The hybridization and generation advancement at AVRDC and selection for MYMV and other important plant characteristics under strong biotic stress at NIAB accelerated the research efforts. To identify, using RFLP techniques, the genes conferring resistance to MYMV and bruchids (a serious insect pest of grains in storage) a collaborative program involving the University of Minnesota, NIAB, and AVRDC was initiated in 1992.

2.4 Breeding Strategies

The mungbean improvement efforts concentrated on the following:

1. Higher yield and wider adaptability to fit intensive cropping systems
2. Earliness, uniform maturity, and non-shattering pods
3. Insensitivity to photoperiod
4. Erect and determinate plant type
5. Short reproductive phase
6. Higher harvest index
7. Improvement in seed size and shiny coat
8. Resistance to pests and diseases such as MYMV and CLS

2.5 Breeding Approaches

To achieve these goals the following breeding techniques were used:

2.5.1 Induced mutations

Objectives. The objectives were to create genetic variability within the local germplasm for desired plant characteristics and to provide improved varieties to the farmers as soon as possible.

Methods. A vast amount of genetic variability was created in the local cultivar 6601 and strains Pak17, Pak22, Pak32, RC71-17, and RC71-27 by treating the seeds with various doses of gamma rays (5KR-80KR) at NIAB. Seeds of various genotypes were obtained from the Directorate of Pulses, AARI, Faisalabad. In 1977, a large number of plants (mutants/variants) having desired characteristics were selected from the M2 generation of the treated populations grown under conditions epiphytotic for MYMV. Further selections were made in the M3 generation and promising mutants were subjected to microplot yield trials and seed protein analysis. Selection was continued in the advanced generations (M5-M6) and only seven superior mutants were carried forward and subjected to multi-locational trials and national uniform yield trials for a period of three years. The mutants also remained under study for their reaction to MYMV and CLS diseases under the artificially created epiphytotic conditions as well as under ordinary field conditions.

Important Characteristics of the Mutants. The characteristics of the selected mutants and parental varieties were studied in multilocation trials for three years (Table 3). The mutants had short stature with erect and determinate growth. They matured earlier by a margin of 2-4 weeks and yielded 15-44% higher compared to the standard. The mutants were also superior to the parental types in number of pods per plant, 1000-seed weight, harvest index, and per day productivity. The mutants were, however, similar to their parents in traits such as pod length, seeds per pod, seed color and surface, and seed protein content. The high harvest index of the mutants indicated their improved physiological efficiency in partitioning a major portion of photosynthates toward grain formation. The higher per day productivity of the mutants (100-185%) per unit area was important for profitability, particularly in the areas where land holdings are very small. The mutants also showed a high level of tolerance to MYMV and wide adaptability when grown under different agroclimatic conditions. Their early maturity fit them in a number of crop rotations and intercropping systems

Achievements. Based on their performance, five mutants were approved by the Punjab Seed Council as commercial varieties. Mutant NIAB Mung 28 was released in 1983. Mutants NIAB Mung121-25, 19-19, 20-21, and 13-1 were released in 1986 for general cultivation in both summer and spring. Mutant NIAB Mung 20-21 and 13-1 were also recommended for a catch crop in the fallow period (May-June) between wheat harvest and rice/maize planting (Malik *et al.*, 1986, 1988b, 1989).

2.5.2 Hybridization and Irradiation of Hybrids

Background. Large seed size in mungbean (60-75 g/1000 seed) is important to consumers and producers. Although the local mungbean cultivars are invariably small-seeded (20-30 g/1000 seed), some of them are well adapted to both spring and summer crop seasons and fairly tolerant to MYMV. The large-seeded varieties developed at AVRDC have higher yield potential, but fail to thrive in summer (kharif season), the major crop season, largely due to MYMV disease. When grown in the spring, most suffer pod shattering at maturity, requiring two to three hand pickings. However, some possess resistance to CLS and powdery mildew which are also serious diseases of mungbean.

Objective. The main objectives of the program were to further improve yield potential, increase seed size, and incorporate resistance to CLS into the local cultivars (varieties/mutants), and to transfer resistance to MYMV and the nonshattering pod characteristic into the large-seeded AVRDC varieties.

Methods. A hybridization program involving local cultivars and large-seeded high yielding varieties developed at AVRDC was initiated in 1980. A local small-seeded (30 g/1000 seed) variety 6601, tolerant to MYMV but susceptible to CLS, was crossed with AVRDC large-seeded (70 g/1000 seed) variety VC1973A, susceptible to MYMV but tolerant to CLS. The F1 seeds were also irradiated with a 10 KR dose of gamma rays to enhance their variability. The F1/M1 generation was raised in the spring of 1981. The F2/M2 generation (along with parents) was grown in the following summer under artificially created epiphytotic conditions for both the diseases. The plants with desired characteristics were isolated. These plants were further evaluated in F3/F4 generations for their breeding behavior in plant progeny rows. Selection for higher yield, and other desirable characteristics, was continued in successive generations (F7-F8), and only the superior lines were advanced and evaluated in 1985-1989. Yield trials were arranged at various locations through the Department of Agriculture Punjab, and the Pakistan Agricultural Research Council. These included trials with progressive farmers.

Table 3. Comparison of important plant characteristics of mungbean gamma-irradiation-induced mutants and varieties (3 years average of summer and spring crop seasons 1980-82)

Mutant/ Variety	Parent	Days to mature	Plant height (cm)	No. of pods	1000-seed wt.(g)	Harvest index (%)	Seed protein	Yield(kg/ha)[a] summer	Yield(kg/ha)[a] spring	Reaction to[b] MYMV	Reaction to[b] CLS
NM121-25	RC71-27	70	65	33	31.5	26.8	23.6	1393	1409	MR	MS
NM19-19	Pak22	66	62	36	30.3	30.3	23.3	1311	1293	R	MS
NM20-21[c]	"	64	60	31	29.6	33.9	22.8	1274	1265	R	MS
NM13-1	6601	62	65	29	32.3	31.2	23.5	1169	1312	MR	MS
NM131-37	RC71-27	74	71	29	31.3	23.3	23.3	1277	1310	MR	MS
NM94-73	Pak22	71	68	30	29.8	22.5	23.7	1118	1218	MR	MS
NM131-98	"	75	68	31	29.6	21.3	22.7	1152	1254	T	MS
St. RC71-27		86	78	26	29.3	14.4	22.7	1038	1113	MT	HS
St. RC71-17		87	81	25	29.7	15.5	23.0	1019	1046	T	HS
St. Pak22		88	77	24	29.7	13.2	22.9	1010	1163	MT	S
St. Aum233		96	88	23	29.9	8.1	22.4	835	878	MR	S
Var. 6601[d]		89	84	22	29.3	16.1	22.7	968	1150	MT	S

a At 42 out of 44 locations the yield among the entries was significantly different from the standard treatment.

b MYMV = mungbean yellow mosaic virus, CLS= cercospora leaf spot, R = resistant, MR = moderately resistant, T = tolerant, MT = moderately tolerant, S = susceptible, HS = highly susceptible

c Approved varieties NM20-21 is a mutant induced strain of Pak22 (at 40 KR dose of gamma rays).

d Standard treatment

Source: Malik, *et al.* (1988a), Malik, *et al.* (1989), and Malik, (1992)

Important Characteristics. The important characteristics of the superior lines are presented in Table 4. Varieties NIAB Mung 51 and 54 have 21-36% higher yield than the standard variety NM121-25. They are short in stature with erect and determinate growth habit. They mature early (64-72 days) and uniformly and bear large pods, mostly on the plant top. Their pods do not shatter. Their seeds are green and shiny and almost double the size of the local cultivars. They are resistant/tolerant to MYMV and CLS and thrive in spring and summer. They are also suitable for mechanical harvesting and threshing.

Table 4. Comparison of important plant characteristics and yield performance of large-seeded mungbean lines (4 years average of summer and spring crops 1985-88)

Mutant/ Variety	Days to mature	Plant height (cm)	No. of pods	Seeds per pod	1000-seed wt.(g)	Harvest index (%)	Seed protein	Yield(kg/ha)[a] summer	Yield(kg/ha)[a] spring	Reaction to[b] MYMV	Reaction to[b] CLS
NM51[c]	67	72	34.7	12.0	46.0	30.6	24.1	1536	1714	HR	MT
NM54[c]	65	68	30.4	12.3	56.1	25.9	24.2	1517	1482	T	T
NM18	72	72	31.4	12.2	53.2	28.9	24.7	1544	1727	HR	T
NM36	64	57	32.1	12.2	52.7	31.4	24.4	1488	1651	HR	T
VC1973A[d]	78	52	18.5	10.7	72.1	36.1	23.5	-	1690	HS	T
6601[e]	90	94	23.2	11.2	30.4	17.6	24.0	990	1049	T	S
NM121-25 (check)	67	59	31.5	11.7	33.3	27.6	24.5	1232	1262	MR	S

a The number of locations in summer and spring experiments were 91 and 69, respectively. In 150 out of 160 locations the yields among the entries were significantly different.
b MYMV: mungbean yellow mosaic virus, HR = highly resistant, MR = moderately resistant
CLS: cercospora leaf spot, T= tolerant, MT = mod. tolerant, S = susceptible, HS = highly susceptible
c Released as commercial varieties in 1990.
d AVRDC large-seeded parents failed to thrive in summer; data from spring crop at NIAB are presented as reference.
e Local small-seeded parent.
Source: Malik (1991)

Achievements. Four promising lines, namely NIAB Mung 51, 54, 18, and 36, were proposed to the Punjab Seed Council for their approval as commercial varieties. Of these, NIAB Mung 51 and NIAB Mung 54 were approved by the Council and were released in 1990 for general cultivation (Malik 1991).

2.5.3 Use of induced mutants in hybridization

Objectives. To further improve the yield potential of mungbean varieties and enchance resistance to both MYMV and CLS

Methods. The three mutants induced in local cultivars were crossed with four promising AVRDC accessions. The crossing work was carried out mainly at AVRDC and partly at

NARC and NIAB during 1980-82. The details of NARC work can be seen in Bashir et al. 1988 and AVRDC 1987. At NIAB, the segregating populations were raised during summer 1983 under artificially created epiphytotic conditions for both MYMV and CLS. A large number of segregants (from 10 crosses) with desired plant traits and resistance to diseases were isolated. The selected plants were carried through to successive generations in plant progeny rows. The superior lines were tested through preliminary and macroplot yield trials.

Important Characteristics. The yield potential, disease reaction, and other important characteristics of the promising lines are presented in Table 5. Most of the lines exhibited significantly higher yield and a greater degree of resistance to MYMV and CLS. They are shorter in stature, earlier and uniform maturing, non-shattering, and larger seeded compared to the local parents.

Table 5. Performance of mungbean advanced lines (exotic varieties x induced mutants x local varieties) for yield and other important plant characteristics (summer crop season, 1983)

Entry	Pedigree [a]	Days to		1000-seed wt. (g)	Harvest index (%)	Yield (kg/ha)	Reaction to [b]	
		Flower	Mature				MYMV	CLS
5-80	VC1973A x NM19-19	38	65	46	30	1786	R	R
7-114	VC2719A x NM13-1	38	64	46	23	1573	MR	R
7-134	"	36	60	44	27	1656	MR	R
8-151	VC2719A x NM19-19	39	68	38	26	1538	MR	R
9-180	VC2719A x NM20-21	40	73	43	24	1670	MR	R
10-12	VC1482E x NM20-21	35	58	53	36	1789	HR	R
10-22	"	40	63	42	28	1888	R	R
10-43	"	35	61	40	30	2138	R	R
1-13	VC1560D x NM13-1	40	68	48	23	1413	MR	R
NM13-1	Local parent	38	62	34	25	1216	MR	S
NM19-19	"	37	65	32	28	1344	R	MS
NM20-21	"	37	62	31	26	1395	R	MS

a Acc. VC1973A, VC2719A, VC1560D, VC1482E: large-seeded varieties developed by AVRDC fail to thrive in summer due to MYMV attack.
NM13-1, 19-19, 20-21: small-seeded varieties developed at NIAB

b MYMV: mungbean yellow mosaic virus
CLS: cercospora leaf spot

Source: Malik (1993)

Achievements. Entries 10-43 (NM89) and 10-12 (NM88) in particular are not only high yielding (2138 kg/ha, 1789 kg/ha) and early maturing genotypes but are also resistant to both the diseases. NM89 was crossed with 15 promising AVRDC accessions. From the F2 populations of these crosses, about 550 segregants with the desired plant traits were isolated during the summer of 1994 at NIAB and sent to AVRDC, Thailand, for generation advancement and further evaluation.

2.5.4 Back crosses/three-way crosses

Objective. Begun in 1987, the program of backcrosses and three-way crosses strives to further improve the desirable characteristics, and, above all, develop the short stature plant type.

Methods. The varieties NM54, 51, and 36 (derivatives of 6601 x VC 1973A) were crossed with several AVRDC large-seeded promising lines, such as VC2768A, VC2768B, VC3726A, VC2754A, VC2771A, VC2778A, VC1973A, VC1560D, with marked differences in their morphological attributes.

Important Characteristics. The yield and other important plant characteristics of elite lines derived from some of the crosses are presented in Table 6. They have short plant type, along with all the other desirable characteristics.

The performance of four derived lines – NM92, 93, 96, and 90 – have also been studied at NIAB in trials over the past 3-4 years (Appendix 1), as well as in multilocation yield trials arranged by the Arid Zone Research Institute, Bhakar, in the Thal region (Appendix 2). All four lines have shown good performance in various agroclimatic conditions, but NM92 maintained its superiority over its counterparts in yield and other important agronomic characteristics.

Achievements. Varieties such as NIAB Mung 92 (derivative of NM36 x VC2768B) and NIAB Mung 93, 94 (derivatives of NM36 x VC2768A) are the outcome of this program. Of these, NIAB Mung 92 was approved as a commercial variety by the Punjab Seed Council in 1996.

2.5.5 Shuttle Breeding Through AVRDC Collaborative Network

A shuttle breeding program was started in 1991 through a collaborative network of national programs and AVRDC. NARC and NIAB participated in the collaboration.

Objectives. The main objective of the program was to develop MYMV resistant genotypes with other desirable characteristics and having wider adaptability across Southeast Asia and South Asia.

Table 6. Performance of mungbean advanced lines (derivatives of three-way crosses) for yield and other important plant characteristics

Entry	Pedigree [a]	Days to maturity	Height (cm)	1000-seed weight (g)	Yield (kg/ha)	Reaction to [b] MYMV	CLS
21-1	NM36 x VC2768B	60	59	56	1749	R	R
21-2	"	62	63	58	2057	R	R
21-3	"	58	55	57	2185	HR	HR
21-15	"	60	60	55	2004	MR	T
21-17	"	64	62	49	1814	R	R
21-18	"	66	65	61	1703	MR	R
20-1	NM36 x VC2768A	66	69	53	1842	HR	R
20-2	"	65	78	56	1856	HR	MR
20-4	"	64	67	55	2087	HR	MR
20-11	"	61	62	53	1777	R	MR
20-12	"	62	71	56	2182	R	MR
18-8	NM36 x VC3726	66	77	56	2259	HR	MR
18-9	"	62	66	52	1995	R	MR
18-12	"	66	67	52	2120	R	MR
18-13	"	61	67	54	2356	R	MR
18-14	"	64	80	49	2526	HR	MR
NM36	6601 x VC1973A	72	79	50	1775	HR	T
NM51	"	67	80	46	1680	HR	T
(check)				CD 5%	122		
				1%	166		

a VC2768B, VC2768A, VC3726, VC1973A are AVRDC large-seeded accessions susceptible to MYMV but resistant to CLS (VC3726 susceptible to CLS).
b MYMV is an abbreviation for mungbean yellow mosaic virus, and CLS for cercospora leaf spot
Source: Malik (1993)

<u>*Methods*</u>. In the 19th International Mungbean Nursery (IMN) trial conducted during the summer of 1992 at AVRDC, variety NIAB Mung 92 out-yielded the check (VC1973A) and other entries in the trial, matured in just 55-60 days, and had the highest percent of first-harvest yield. Based on its performance, NM92 was crossed with five large-seeded lines (VC3902A, VC1560A, VC1628A, VC1973A, VC2768A) at AVRDC in 1991. The F1 and F2 generations were raised at AVRDC and the F3 populations were sent to NIAB for MYMV screening. The MYMV resistant recombinants with desired plant traits were

selected at NIAB and F4 populations were sent to ARC/AVRDC, Thailand, for two generation advances. The F6 populations were again screened for MYMV resistance/tolerance at NIAB in 1993. The resistant homozygous lines and some single plants were sent back for further evaluation. Seventeen promising lines in F7 generation were evaluated at ARC in the dry season of 1994. The same set of lines in F8 generation was evaluated at NIAB in the summer (rainy season) of 1994.

Important Characteristics. The data of some of the lines evaluated at both AVRDC and NIAB are presented in Table 7. The genotypic environmental interaction of the entries grown under two diverse agroclimatic conditions is clearly manifested in yield and other

Table 7. Performance of mungbean advanced lines at AVRDC, Thailand, and NIAB Pakistan, 1994-95

			AVRDC (spring)				NIAB (summer 1994)			
S.No.	Entry	Pedigree	Days to maturity	Plant height (cm)	1000-seed weight (g)	Yield (kg/ha)	Days to maturity	Plant height (cm)	1000-seed weight (g)	Yield (kg/ha)
1	VC6158-B-5-B-3-1-B	VC2768A x NM92	52	58	74.3	1803	66	67	67.3	1345
4	VC6158-B-31-B-3-1-B	"	52	58	59.8	1565	67	62	56.0	1463
5	VC6158-B-15-B-2-1-B	"	59	63	59.4	1313	72	57	54.6	1248
7	VC6158-B-22-B-2-1-B	"	53	53	75.5	1811	69	51	73.3	1373
9	VC6153-B-31-2B-1-B	VC3902A x NM92	54	63	70.1	1865	68	57	67.0	1872
10	VC6153-B-32-2B-1-B	"	55	61	64.7	1526	65	55	63.0	1290
14	VC6168-B-19-2B-1-B	VC1628A x NM92	50	55	71.8	2113	72	50	66.8	1193
16	VC6173-B-22-2B-3-B	VC1560A x NM92	54	59	78.2	1836	70	67	73.4	1387
18	NM92		54	50	50.2	1416	67	51	53	1650
19	KPSI (VC1973A)		58	58	70.6	1322	Fail to thrive due to MYMV attack			
20	NM51 (Standard)		Not studied				74	72	43.0	1532
21	NM54 (Standard)		Not studied				67	57	57.0	1414

Source: Unpublished data

plant attributes. Some entries, such as S. No. 1, 7 and 14, which gave higher yield at AVRDC (1803-2114 kg/ha), did not perform well at NIAB (1193-1373 kg/ha). However, there were certain entries, such as S.No. 9 (VC6153-B-31-2B-1-B, a derivative of VC3902A x NM92), which gave higher yield both at AVRDC (1865 kg/ha) and at NIAB (1872 kg/ha), expressive of wider adaptability. Most of the lines showed marked improvement in their seed size. All the entries exhibited a high level of resistance/tolerance to MYMV and CLS diseases at NIAB. With these crosses, a vast amount of variability has been created offering immense scope for further gains in potential yield and other agronomic traits of economic importance.

Achievements. The shuttle breeding program has been largely successful in studying genotype-environment interaction, and in developing new material with desired plant characteristics and wider adaptability. NM92 was tested for its wider adapability. The variety is performing very well, not only in Pakistan (Chapter 3), but in other countries (AVRDC 1994; Chadha 1996). More importantly, a large number of recombinants with improved plant traits have been identified. These are being further evaluated.

3. Technology, Farmers, and the Environment

Along with past neglect of varietal research, little was known of the technological options available to farmers, the biophysical environments in which pulses are grown, and farm-level constraints in their cultivation. This lack of knowledge impeded research and development aimed at improving the production and productivity of pulses. The objective of this chapter is to fill this gap, so that future research and policies can be targeted to solve important issues. The specific objectives of the chapter are to:

- describe the socioeconomic and physical environments of the mungbean-growing districts
- describe the characteristics of mungbean farmers in terms of household composition, farm size, and asset ownership
- identify the cropping system in which mungbean is being cultivated, and evaluate the potential for its cultivation to be extended, given recent innovations
- describe farm management practices, labor and non-labor input use in mungbean cultivation
- estimate the economics of mungbean cultivation
- quantify the residual impact of mungbean cultivation on the following crop
- investigate major constraints to mungbean cultivation
- assess the impact of modern technologies on productivity and farmers' incomes
- segregate the welfare generated by scientific innovations to consumers, producers, and to the whole society

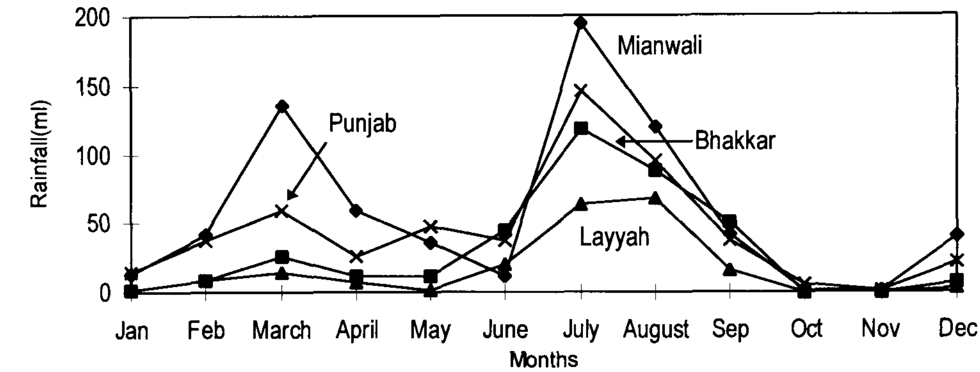
3.1 Socio-Physical Environment

The three major mungbean-growing districts of Mianwali, Bhakar, and Layyah are western districts of the Punjab province lying on the right bank of the River Sind, between 31° and 33° latitude (see Figure 1).

3.1.1 Climate

Mianwali experiences a bimodel rainfall pattern: one peak of rain in March and the other in July. Bhakar and Layyah receive one peak in July. Layyah is relatively dry compared to other mungbean growing districts (Figure 4). Mungbean is cultivated at the end of July, after the monsoon, on fallow land after wheat. By harvest time in October, however, the weather is completely dry, with almost zero possibility of rain. Supplemental irrigation with surface water and groundwater is required.

Figure 4. Monthly average (1987-95) rainfall in the mungbean growing districts



Source: The data used here were taken from official files of the Land Record Office, Lahore

3.1.2 Infrastructure

Average farm size in the mungbean growing districts is bigger than in the rest of the Punjab, mainly because of a relatively low land productivity index. A higher proportion of the total area is rented out in these districts compared to the rest of Punjab. Supporting infrastructure — such as proportion of irrigated area and number of tube wells (except in Layyah), number of tractors, literacy ratio, (except in Mianwali), and length of roads — is less developed compared to other parts of Punjab. All these factors result in low cropping intensity and lower yields of major summer crops (Table 8). This makes a place for a low-return and low-input crop, such as mungbean.

3.2 Survey and Sampling Procedure

To generate information on farm management practices, a detailed mungbean production survey was conducted in 1994 by AVRDC in collaboration with NARC, NIAB, AARI, and the University of Agriculture, Faisalabad (UAF). Agricultural economists, agronomists, and plant breeders representing these international, national, and provincial institutions collaborated in the study.

Punjab was selected as the study area because it accounts for more than 80% of Pakistan's total mungbean area. A total of 250 representative farmers were randomly selected from the province. The random sampling was done in the following three stages:

In the first stage, the total sample was allocated to different districts based on their relative share in the total mungbean area of the province. Seventy-five percent of the total sample was allocated to the three major mungbean growing districts of Layyah, Bhakar, and Mianwali, which account for about 75% of the total mungbean growing area. The rest of the sample was assigned to all Other districts. The sample allocated to the three major mungbean growing districts was distributed proportionately based on each district's relative share in area (districts Layyah, Bhakar, and Mianwali contributed 40, 17 and 20% of the total area under mungbean respectively in Punjab in 1991-92). To represent all of the minor districts, seven districts of the Punjab, Sahiwal, Khanewal, Pakpattan, Okara, Gujranwala, Sheikhupura, and Sialkot, were visited. Each accounted for less than 5% of the total mungbean area in the province. No specific allocation to each minor district was made; rather the selection was purposive as mungbean farmers in these districts are scattered, and hard to find. The sampling distribution across the three major mungbean growing districts and the Other districts is shown in Table 9.

Table 8. Socioeconomic environment in the mungbean growing districts of Punjab, Pakistan

	Layyah	Bhakar	Mianwali	Punjab
Farm size (ha/family) [a]	5.1	7.4	5 .4	3.7
Area owned (% of the farm area) [a]	68.1	65.4	67.4	72.1
Area rented (% of the farm area) [a]	31.9	34.6	32.6	27.9
Irrigated area (% of the cropped area) [c]	87.0	45.0	61.0	86.0
Tube well per 1000 ha[c]	41	13	11	33
Tractor per 1000 ha[c]	7	4	4	14
Literacy ratio of farm families (%) [a]	59.0	47.0	61.0	60.0
Average village distance from paved road (km)[b]	3.1	3.4	2.8	2.7
Cropping intensity (%) [c]	120.9	105.4	94.1	125.3
Cotton yield (t/ha) [c]	1.1	0.98	0.7	1.4
Sugarcane yield (t/ha) [c]	32.3	28.5	35.9	37.3
Maize yield (t/ha) [c]	1.1	1.2	1.2	1.3

Source: [a]Government of Pakistan (1994) published these data for 1990; [b] Estimated as the middle point of the distance-ranges multiplied by the frequency of villages in each range for 1988 (Government of Pakistan 1991); [c]Data for 1993-94 from the official files of the Crop Reporting Section, Lahore.
Note. Rice which is another major crop in Punjab is not cultivated in these districts, thus not reported here.

In the second stage of sampling, 10 villages each from Bhakar and Mianwali, and 20 from Layyah were selected at random. The allocated number of sample farmers for each district was proportionately distributed among the randomly selected villages based on the farm population in these villages. The village selection in Other districts was not random, but depended upon the distribution of mungbean growing farmers in these districts.

In the third stage of sampling, the village sample in the major mungbean growing districts was randomly selected from a list of all mungbean-growing farmers in the village. In the villages of Other districts, if more than five mungbean farmers were available, they were randomly selected. In cases where there were less than five, all were included in the sample.

In Other districts, 12 out of 50 farms experienced mungbean crop failure in a very early stage due to flood, poor germination, or other problems. These farmers shifted to other crops in this early stage, and thus were excluded from further analysis. This was the situation on one farm each in Mianwali and Bhakar. The operational sample left after deleting these cases is given in Table 9.

Table 9. Sample distribution by district and variety

	Operational sample	No. of parcels by variety				
		Desi	NM19-19	NM54	NM92	Total
Layyah	98	44	28	20	35	127
Bhakar	49	5	10	13	28	56
Mianwali	49	1	11	22	30	64
Others	38	0	1	0	32	33
Overall	234	50	50	55	125	280

3.3 Data Collection

A structured questionnaire was used to gather data on farm management practices, cropping pattern, input use, varietal adoption, cost and return, and production constraints in mungbean cultivation.

Data on household characteristics, such as operational holding, family size, education, household and livestock inventory, source of information, etc., were collected to judge the relative wealth status of mungbean farmers.

Data on all aspects of crop management practices were collected by variety. If one respondent had more than one variety, a separate questionnaire was filled for each. In this way, data were obtained for a total of 280 varietal parcels. The distribution of the sampled fields by variety and district is also shown in Table 9.

After a preliminary survey of the area, it was found that wheat followed mungbean in 90% of fields. To understand the residual impact of mungbean cultivation on the following wheat crop, the survey questionnaire incorporated a separate investigation about input use and yield of wheat in wheat-mungbean, wheat-fallow, and wheat-other crop rotations.

3.4 Household Characteristics of Sample Farmers

3.4.1 Household Structure

Average family size of the sample farmers was 6.7 members with 3.7 adults and 3 children. A large family size in Other districts and Layyah district might be due to a preference for living in extended families, rather than bigger nuclear families, in these districts. The average number of schooling years of the members of sample farm families was 6.4, with the highest in Other districts (7.5), and lowest in Mianwali (5.6) and Bhakar (5.6). Thus although the literacy ratios of Mianwali and Layyah districts were almost equal to overall Punjab (Table 8), the average number of schooling years in these districts was far below that of Punjab (Table 10).

Table 10. Household structure and belongings of farm families by district, 1994-95

Family characteristics.	Layyah	Bhakar	Mianwali	Others	Overall
Family size (number)	6.9	6.2	6.1	7.6	6.7
Adult members (number)	3.8	3.6	3.7	4.0	3.7
Children (number)	3.1	2.7	2.4	3.6	3.0
Average education of all adult family members (years of schooling)	6.8	5.6	5.6	7.5	6.4
% of farmers having Important household belongings					
Radio	59	55	40	64	55
Cassette recorder	36	24	29	44	33
TV	14	31	38	41	27
Fan	45	59	83	64	60
Refrigerator	12	31	33	44	25
Bicycle	74	65	56	82	70
Motorcycle	21	37	25	38	28
Pickup	10.	10	0	23	10

3.4.2 Household Inventory

Farmers in the major mungbean-growing districts are less well off than farmers in the Other areas. See wealth indicators such as ownership of radios, electric fans, refrigerators, cassette recorders, bicycles, pickup trucks, TVs, and motorcycles in Table 10.

3.4.3 Land Ownership

The average operational cultivated area per family of the mungbean farmers varied from the smallest of about 4.9 ha in Mianwali to 8.6 ha in Bhakar (Table 11). The average size of holding estimated in this study was slightly higher than reported in the Agricultural Census of Pakistan (Table 8) for all districts.

Table 11. Size of holding and source of irrigation of the sample farmers by district

Farm characteristics	Layyah	Bhakar	Mianwali	Others	Overall
Operational holdings (ha)	5.8	8.6	4.9	4.7	6.2
Source of irrigation					
Canal irrigated area (%)	58.8	81.3	72.1	91.4	72.5
Tube well irrigated area (%)	40.9	18.7	25.6	4.2	26.5
Both sources (%)	0.3	0.0	2.3	4.4	1.1

3.4.4 Source of Irrigation

All of the cultivated area of mungbean farmers was irrigated, most by canal. In Layyah, 41% of the total cultivated area was under tube well irrigation. In Other districts the proportion was much smaller (Table 11).

3.4.5 Agricultural Machinery and Livestock

Overall, 35% of farmers were found to own a tractor and cultivator, but only 26% of farmers owned a trolley to haul agricultural outputs and inputs to and from the market centers. A relatively small number of farmers in mungbean growing districts, compared to their counterparts in Other districts, owned other agricultural machinery, apart from manual sprayers and chaff cutters (Table 12). This suggests that mungbean cultivation is concentrated in areas with less access to mechanical technology.

On average, three buffaloes, two cows, three young stock, four goats, and five chickens were kept by every farm family. More buffaloes but fewer cows, goats, and poultry were kept in Other districts. The large numbers of goats in Layyah and Bhakar were probably due to the availability of more free grazing land in these districts (Table 12).

3.4.6 Source of Information

Most farmers in Layyah and Bhakar relied on fellow farmers, while most farmers in Mianwali cited the extension agent as their first source of information (Table 13).

Table 12. Agricultural machinery ownership and livestock inventory of the mungbean-growing farmers by district, 1994-95

	Layyah	Bhakar	Mianwali	Others	Overall
Farm machinery (% of farmers)					
Tractor	25	37	40	51	35
Trolley	17	28	25	44	26
Tube well	47	55	48	41	48
Thresher	15	22	12	31	20
Ridger	12	6	6	21	11
Manual sprayer	33	29	29	18	29
Power sprayer	3	8	6	33	10
Manual chaff cutter	68	57	54	51	60
Power chaff cutter	27	39	42	31	35
Livestock (number per farm)					
Draft animals	0.69	0.38	0.87	1.12	0.77
Buffaloes	3.22	2.48	2.03	5.63	3.34
Cows	2.24	2.64	2.42	1.43	2.18
Young stocks	2.53	3.3	2.85	3.28	2.99
Goats	7.18	5.26	2.91	1.48	4.21
Poultry	7.43	3. 12	9.77	0.53	5.21

Table 13. Source of information about modern mungbean varieties (frequency of farmers)

Source of information	Layyah	Bhakar	Mianwali	Others	Overall
Fellow farmers:					
Ist priority	67	78	31	56	60
2nd priority	11	12	25	5	13
Extension agents:					
Ist priority	36	24	69	33	40
2nd priority	12	14	6	8	11
Others:*					
Ist Priority	2	0	2	10	1
2nd priority	1	0	0	0	0

* = Radio, research institute, newspaper, and television, etc

3.4.7 Soil Type

The major mungbean-growing districts have light soils, such as sandy loams, compared to the soils in Other districts, which are predominantly clay loam (Table 14). This indicates that mungbean is cultivated on relatively light soils, which are considered marginal for cultivation of other crops. In fact, farmers told the survey team that most of the area under mungbean cultivation was newly established, within the past 15-20 years.

Table 14. Soil types of the mungbean growing farms (frequency) by district, 1994-95

	Layyah	Bhakar	Mianwali	Others
Clay	4.8	0.0	4.7	3.0
Clay loam	3.2	5.4	9.4	60.6
Loam	4.0	0.0	6.3	36.4
Sandy loam	88.0	94.6	79.7	0.0

3.5 Cropping Pattern

Two cropping seasons can be defined in the study area. The summer season from May to October is called *kharif* season and crops grown in this season are called kharif crops. The dry winter season from November to April is called *rabi* season and the crops cultivated in this season are called rabi crops. In the study area, wheat, gram, and fodder are important rabi crops. In the kharif season, mungbean, cotton, and sugarcane are important.

Wheat occupied most of the total cropped area in all districts. The relatively low share of wheat area in Bhakar is due to the higher area devoted to gram (13%), which in turn is explained by the high proportion of sandy soils in this district.

The proportion of mungbean in the total cropped (kharif and rabi season) area in the major growing districts ranged from 24% in Layyah to 33% in Mianwali, while it occupies a major share in the kharif season in these districts. Of the selective sample farmers in the Other districts, about 8% of the total cropped area and 16% of the kharif area was occupied by mungbean (Table 15). [5]

The average yields of crops competing with mungbean—such as cotton, sugarcane, and maize—in the three major mungbean growing districts, were below the provincial average, indicating that these kharif crops are not economically competitive in these

[5] It should be noted that while the cropping pattern on the sample farms in the major mungbean-growing districts was representative of the whole district, the cropping pattern in Other districts represented only the pattern practiced on sample farms and was not generally representative of the cropping pattern in the Punjab province.

districts (Table 8). Indeed, all farmers in these districts agreed that they grow mungbean because it best suits their environments. In Other districts, however, it is unlikely that farmers will substitute mungbean for their main commercial crops, such as cotton, sugarcane, rice, and maize.

Table 15. Cropping pattern (% of the total cropped area) on the mungbean growing farms, 1994-95

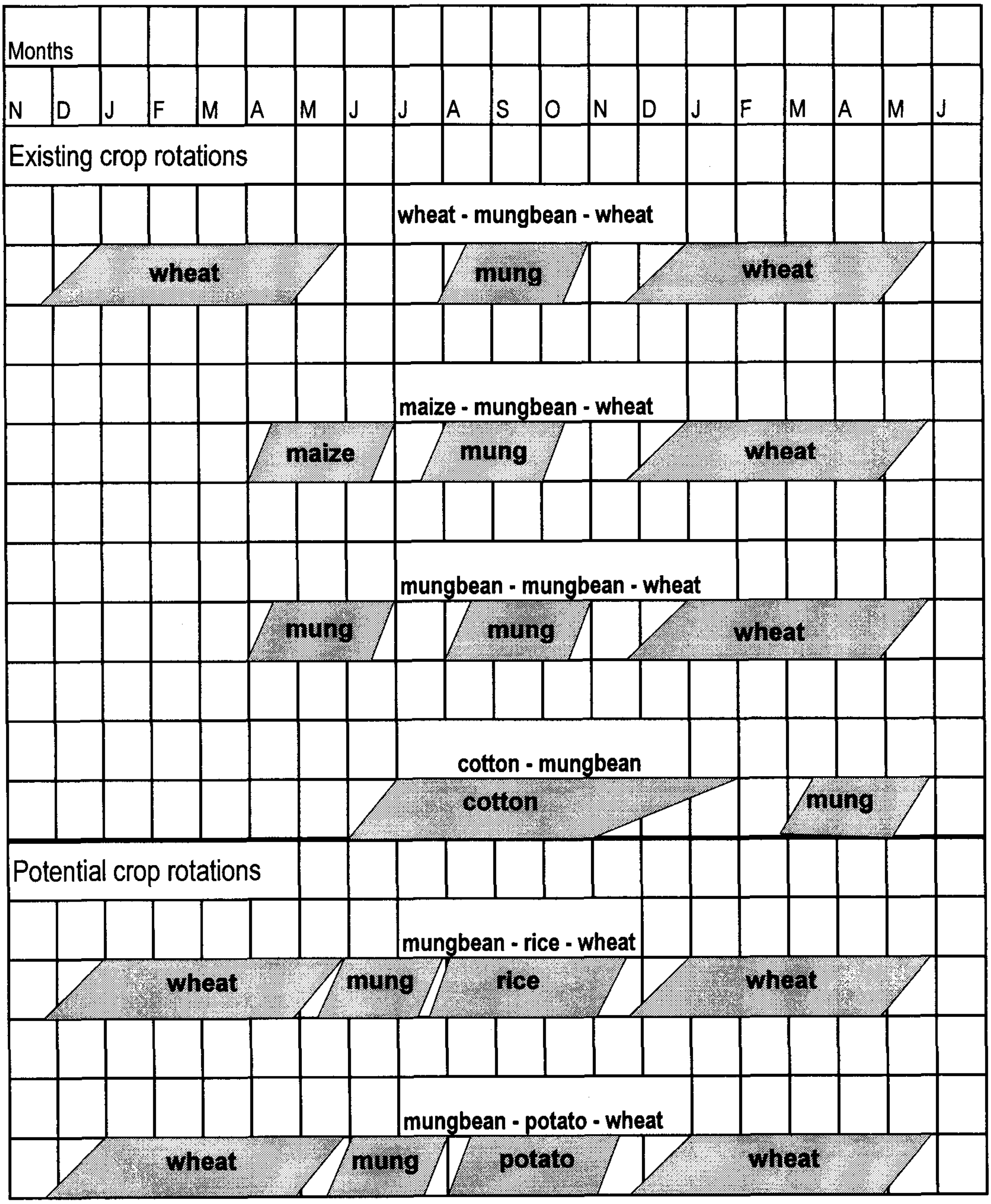
	Layyah	Bhakar	Mianwali	Others	Overall
Kharif crops	44.0	52.7	45.9	53.7	48.8
Cotton	7.3	0.6	0.5	21.7	8.0
Sugarcane	6.9	19.2	6.6	10.9	10.9
Rice	0.0	0.0	0.0	4.5	1.1
Maize	0.0	0.0	0.0	4.0	1.0
Mungbean	24.1	29.4	32.5	8.5	23.0
Kkarif fodder	5.7	3.5	6.3	4.1	4.8
Rabi crops	56.0	47.3	54.1	46.3	51.2
Wheat	46.3	30.7	44.4	42.1	41.1
Gram	3.3	13.3	4.2	0.1	5.2
Rabi fodder	3.8	2.9	3.9	3.9	3.6
Other rabi crops	2.6	0.4	1.6	0.2	1.3
Total cropped area	100.0	100.0	100.0	100.0	100.0

3.6 Crop Rotation

The major existing and potential mungbean-based cropping rotations in Pakistan are shown in Figure 5. Although mungbean can be grown in a variety of cropping systems, wheat-mungbean-wheat (for short, mungbean-wheat) was the dominant cropping rotation in the three major districts. After wheat harvest in April-May, mungbean was cultivated in July-August and harvested in October, followed by wheat planting in November-December.

Maize-mungbean-wheat was well known in Sahiwal and Khanewal Districts. Maize was cultivated in April-June, and mungbean occupied the field from mid-July to mid-October, followed by wheat in November-December.

Figure 5. Mungbean-based crop rotations in Pakistan



Some farmers whose rice or cotton crop failed, or who could not cultivate these crops for various reasons, reaped two mungbean crops in the kharif season. The first crop was cultivated as a spring crop in April-June, while the second was in the field as a summer crop in August-October. Wheat followed at its usual time.

In Multan District, a few farmers were observed to follow a cotton-mungbean rotation. Mungbean was cultivated in March after the cotton harvest in November-February. This rotation was practiced when farmers extended cotton harvesting to a fourth picking in February due to its high yields or good prices. In this situation, wheat could not be planted in the usual cotton-wheat rotation (Byerlee *et al.* 1987).

Amir (1985) suggested mungbean after harvest of short-duration rice in September in the rice-wheat system. This was not observed. But it should be noted that the area devoted to short-duration rice in Punjab has reduced substantially (Sharif *et al.* 1988).

The only way to introduce mungbean in the intensive system is to utilize the brief period between kharif and rabi crops; for example, after wheat harvest and before the transplanting of rice (mid May to mid July), or after wheat harvest and before maize cultivation (mid May to end of July). Farmers and extension agents in the area expressed eagerness to fill this niche with the short-duration and uniform-maturing mungbean varieties now available. The main reasons given for not adopting this rotation were the unavailability of new variety seed, early monsoon rains at the time of mungbean harvest, and the competition for labor drawn to wheat harvesting and rice cultivation. Farmers were unaware of recent developments in mungbean production technology, especially the early and uniform maturing varieties.

3.7 Adoption of Mungbean Varieties

Four varieties, Desi, NM19-19, NM54[6] and NM92, were grown in the sample area during the survey year. While Desi variety was grown by about 80% of farmers in 1988, it was grown on just 10% of farms in 1994. The adoption of NM19-19, released in 1986, remained in the range of 18-32%, reaching a maximum in the period 1990-92; NM19-19 was then replaced by NM54 which was officially released in 1990. Its adoption reached a peak of 37% of farms in 1992. Although NM92 was officially released in 1993, its seed slipped to farmers through the on-farm yield trials in 1992. Its adoption was rapid and reached 51% of the sample farms in 1994. The fast rate of adoption of NM92 can be taken as indication of its superiority over other varieties (Figure 6).

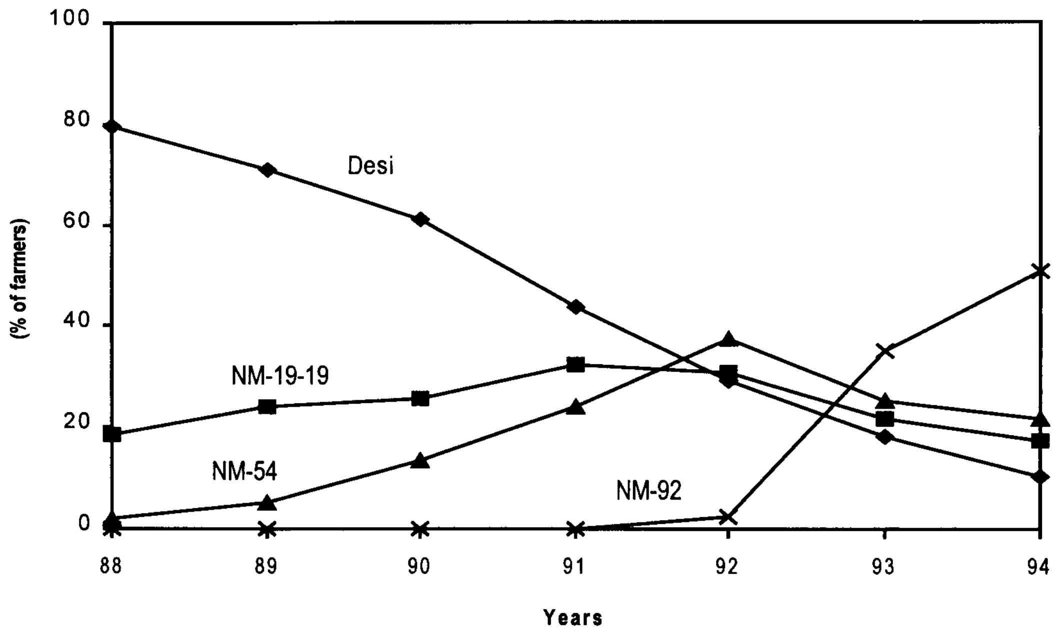
By 1994, the Desi variety had almost completely disappeared from Bhakar, Mianwali, and Other districts. Layyah was the only district where Desi was cultivated on a significant area in 1994-95 (Table 16), but the variety was in sharp decline, being replaced by NM92. As explained, the profitability of competing crops was higher in other districts. So only those farmers with access to the new mungbean varieties experimented with the crop.

[6] NM54 actually represents two closely related varieties, viz NM51 and NM54.

Table 16. Varietal distribution of mungbean area (% of sample area) during 1994-95

Districts	Desi	NM19-19	NM54	NM92
Layyah	29	27	14	29
Bhakar	3	7	11	79
Mianwali	0	11	31	58
Others	0	0	0	100
Overall	10	17	22	51

Figure 6. Mungbean varietal adoption curve in Pakistan



3.8 Management Practices

One third of NM-92 was sown in rows (19% by seed drill behind tractor or bullock-drawn plow, 9% by manual drill, called kerah, and 4% by dropping the seed in rows, called porah. In the case of the Desi variety, 90% was broadcast. A lower proportion of the other varieties were broadcast compared to the Desi variety, but a higher proportion compared to NM92 (Table 17). This suggests that the modern varieties were a catalyst to improved cultivation methods.

Table 17. Input use on mungbean (% of farmers) by variety, 1993-94 and 1994-95

Inputs	Variety				
	Desi	NM19-19	NM54	NM92	Overall
Sowing method:	100	100	100	99	100
Broadcast	90	88	70	67	76
Drill	2	10	20	19	15
Kerah	8	2	7	9	7
Porah	0	0	2	4	2
Used purchased seed	3	54	53	75	59
Applied farm manure	0	4	7	6	5
Used fertilizer	47	44	44	46	46
Urea	22	36	54	23	27
DAP	25	8	20	24	22
Canal irrigation	67	50	48	66	60
Tube well irrigation	47	50	57	45	49
Manual weeding	61	42	46	29	40
Used herbicide	16	10	13	10	11
Applied insecticide	29	40	52	58	50

About three fourths of farmers growing NM92 purchased seed, while only 3% of farmers growing Desi mungbean used purchased seed. The proportion of purchased NM19-19 and NM54 ranked between Desi and NM-92 (Table 17). The proportion of seed purchased by farmers growing NM-92, not for the first time, was also higher than was the proportion of seed bought by farmers growing the Desi variety. Thus, new varieties also induced farmers to purchase seed from the market, rather than keep seed from the previous year's production.

A few modern variety parcels received farm manure, compared to none for Desi. A little less than half of the sample farmers applied either urea or diammonium phosphate (DAP), but very few used both. Fertilizer and irrigation use patterns do not seem to relate to the adoption pattern of new varieties. More Desi parcels were treated by manual and chemical weeding than were new variety parcels, but the reverse is true for insecticide application.

3.9 Input Use

3.9.1 Non-Labor Inputs

The levels of input use by varieties are shown in Table 18. As Desi and NM19-19 are small-seeded varierties, low seed rates were used to cultivate these varieties. Application of fertilizer and farm manure was found to be slightly higher for modern varieties. The insecticide spray was highest for NM92, while weeding number was highest for Desi varieties. The higher weeding for Desi might be due to the use of weed-contaminated seed saved from the previous year. No significant difference in plowing and irrigation was observed across varieties. The average of two irrigations is consistent with what is recommended for mungbean.

Table 18. Physical inputs per hectare on mungbean by variety, 1994-95

Input quantities	Units	Desi	NM19-19	NM54	NM92
Seed	kg.	17.0^{a}	17.3^{a}	19.3^{b}	20.3^{b}
Plowing	no.	5.2^{a}	5.0^{a}	5.2^{a}	5.3^{a}
Farm yard manure	donkey bags	0^{a}	100^{b}	200^{c}	105^{b}
Total fertilizer	kg	22.8^{a}	23.0^{a}	27.4^{b}	29.7^{b}
Nitrogen (N)	kg	$11.\ 3^{a}$	16.1^{b}	$14.\ 8^{b}$	14.8^{b}
Phosphorus (P)	kg	$11\ 5^{a}$	6.9^{b}	12.6^{a}	14.9^{c}
Insecticide	no.	0.3^{a}	0.6^{b}	0.7^{b}	0.7^{b}
Hand weeding	no.	0.6^{a}	0.5^{a}	0.4^{b}	0.2^{c}
Irrigation	no.	1.9^{a}	1.9^{a}	1.9^{a}	1.7^{a}

Different superscript in a row implies that the hypothesis of equal input use across variety was rejected, while the same superscript in a row implies that the hypothesis of equal input use cannot be rejected at the 10% level using the t-test for unequal variance.

3.9.2 Labor Input

On average, 128 labor hours/ha (or 16 labor days) were required for mungbean cultivation. The newest variety (NM92) required less labor compared to earlier modern (NM19-19, NM54) or traditional (Desi) varieties, mainly because of less weeding time required. Harvesting time for the modern varieties was slightly higher due to higher yield. Planting time was higher for the newer varieties, as more farmers drilled these crops (Table 19).

Table 19. Labor use (hours/ha) in mungbean by variety, 1994-95

Inputs	Desi	NM19-19	NM54	NM92	Overall
Land and seedbed preparation	6.9[a]	6.9[a]	7.4[a]	7.4[a]	7.2
Planting	0.9[a]	1.5[b]	1.6[b]	1.9[b]	1.5
Irrigation	11.1[a]	11.4[a]	11.6[a]	10.8[a]	11.5
Weeding	46.6[a]	38.9[b]	38.8[b]	17.1[c]	27.5
Harvesting	65.2[a]	66.3[a]	70.4[c]	73.1[c]	70.1
Others*	1.3[a]	3.5[b]	6.9[c]	4.9[b]	4.6
Total	132.0[a]	128.5[a]	136.7[a]	115.2[c]	128.0

*Others include labor for fertilizer and farm yard manure application, and plant protection.
Different superscript in a row implies that the hypothesis of equal labor input across variety was rejected, while the same superscript in a row implies that the hypothesis of equal labor use cannot be rejected at the 10% level using the t-test for unequal variance.

About fifty percent of total labor was used for mungbean harvesting in all varieties. The high labor requirement for harvesting mungbean is critical when mungbean is to be followed immediately by another crop. When mungbean is to be incorporated in a rice-wheat rotation, for example, harvest might overlap with rice transplanting. Mechanical harvesting would be needed to alleviate this constraint.

Other labor-demanding operations in mungbean cultivation were weeding and irrigation. However, labor used in these operations competes less with other crops, even if mungbean is introduced in an intensive cropping system.

3.10 Yield

The average mungbean yield of all varieties in all areas was 840 kg/ha (Table 20), which was about 100% higher than the figure reported in government statistics for 1994 (Government of Pakistan 1995).[7]

[7] The average yield observed here was 100% higher than reported in government statistics. The under-estimation of mungbean production can also be seen from the estimated 150,000 t of mungbean utilized in the country assuming 1.32 kg/capita/annum consumption reported in the household surveys for the year 1990-91 (Government of Pakistan, 1995) as compared to 59,000 t mungbean production reported in the same source for the same year. Therefore, methods to estimate pulses production, especially for mungbean production, need to be revised.

The yields of modern varieties were statistically higher than the traditional variety in all districts, except NM19-19 in Mianwali district. Average yield of the latest variety, NM92, was about 55% higher than the average yield of the Desi variety; 12% higher than NM19-19, and 4% higher than NM54.[8] NM19-19 and NM54 also out-yielded the Desi variety on average by 38% and 49%, respectively. NM54 out-yielded NM19-19 in all districts.

Table 20. Mungbean yield (kg/ha) by variety, 1994-95

District	Desi	NM19-19	NM54	NM92	Overall
Layyah	575 [a]	825 [b]	899 [c]	1023 [d]	813
Bhakar	627 [a]	851 [b]	962 [c]	855 [b]	864
Others	-	791 [a]	-	1019 [b]	1019
Mianwali	618 [a]	629 [a]	793 [b]	797 [b]	777
Overall	579 [a]	801 [b]	865 [c]	900 [c]	840

Different superscript in a row implies that the hypothesis of equal yield across variety in a district was rejected, while the same superscript in a row implies that the hypothesis of equal yield cannot be rejected at the 15% level using the t-test for unequal variance.

Mungbean yield in Other districts was highest. This might be due to better infrastructure (such as roads, which contribute to the timely supply of seed and fertilizer), and/or because of better management practices spurred by competition with other crops in these districts. Bhakar had the next highest average yield (864 kg/ha), followed by Layyah (813 kg/ha) and Mianwali (777 kg/ha) (Table 20). Yield of all varieties improved in 1994-95 compared to 1993-94 (Figure 7).

3.11 Economics of Mungbean Production

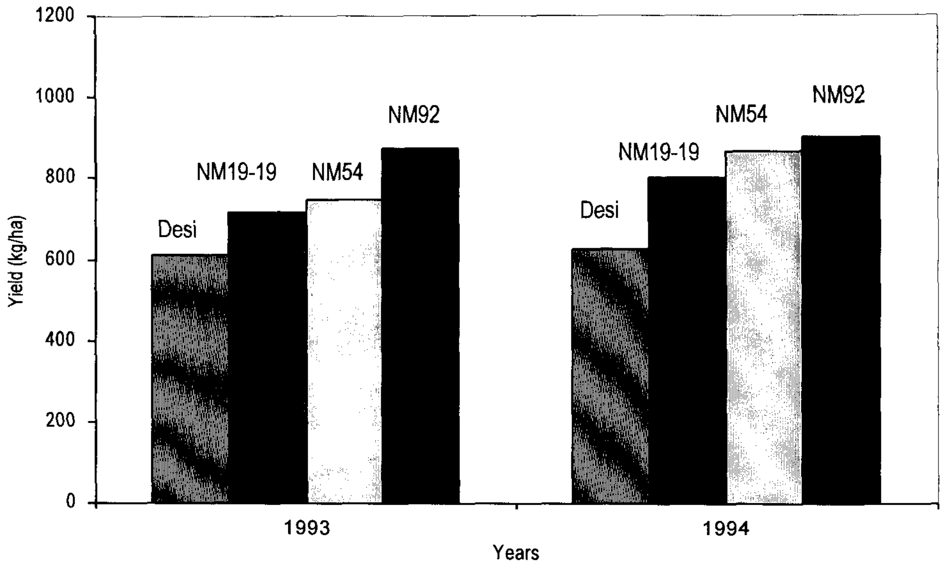
3.11.1 Estimation Procedure

The costs of marketable inputs were estimated at farm-specific input prices. In the case of inputs produced at home, such as seed and farm yard manure, these were valued at the prevailing market prices in the area as perceived by farmers. Similarly, the value of

[8] This variety out-yielded Desi and NM19 in all districts, and in Layyah its yield was significantly higher than NM54. However, NM54 performed relatively better in Bhakar, and the performances of NM51, 54, and NM92 were almost on par in Mianwali. The low yield of NM-92 in Bhakar might be due to mixing of NM92 seed with other varieties as many farmers complained, or due to special bio-physical conditions more suited for NM51, 54 than NM92. More research is needed to establish relative superiority of NM92 over NM51, 54 in different areas.

family labor was assessed the prevailing wage rate in the area, at the time of survey as perceived by each farmer.

Figure 7. Mungbean yield by variety in Pakistan 1993 and 1994



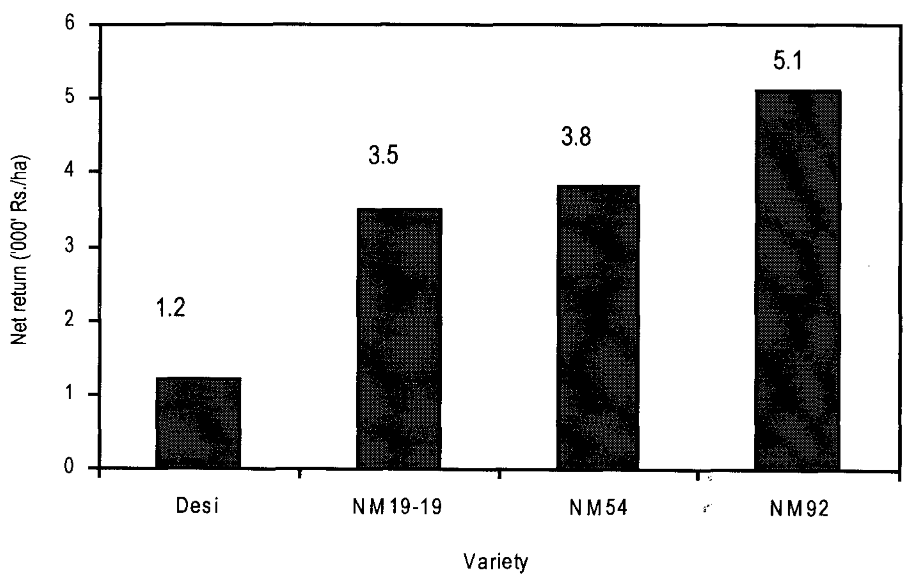
In major mungbean districts, land rent for mungbean growing is 50% of the farmers' total annual rent. Wheat, the only other crop grown in the year, accounts for the other 50%. In Other districts, 25% of the annual land rent was included in calculating the rental cost of mungbean, as maize or cotton was usually cultivated in rotation with mungbean and mungbean took only one fourth of the total time during the year. Output was evaluated at market prices, even though some of the output was consumed at home.

The gross revenues from mungbean cultivation were estimated by multiplying the farm-level output prices by the total output. Total cost included cost of land and seedbed preparation, the cost of seed and its sowing, fertilizer, farm yard manure, irrigation, and their application costs, the cost of weeding and hoeing, plant protection, and harvesting costs. Net income was defined as gross revenue less total cost. Inputs, costs, gross revenue, and net income were estimated on a per-hectare basis by dividing the total values of these parameters for the whole farm with total farm area of the sample farmers. Cost per unit of output was calculated by dividing the total cost by the yield (both on a per ha basis). The benefit-cost ratio is the gross revenue divided by total cost.

3.11.2 Costs, Gross and Net Revenues, and Benefit-cost Ratio

The cost of production per ha was significantly higher in NM54 and NM92 than in NM19-19 and Desi. NM92 gave the highest gross revenue followed by NM54, NM19-19, and Desi. Although the yield difference between NM92 and NM54 was insignificant (only 4%), the NM92 variety produced 16% higher gross revenue because it obtained a significantly higher output price than other varieties due to its prominent seed with attractive shiny green coat (Table 21).The modern varieties cost slightly more to produce, but they returned a higher net income (Figure 8). The net income of NM92, for instance, was four times higher than that earned from Desi. Similarly, NM54 and NM19-19 returned three times more income than did Desi.

Figure 8. Mungbean net returns by variety



The cost of production per kg was lower for the new varieties: Rs 6.8 for Desi and Rs 4.7 for NM92 (Table 21). This has obvious favorable implications for the diets of the poor.

The benefit-cost ratio in NM92 cultivation was highest at 2.21. This suggests that every rupee invested in NM92 cultivation returned the investment and generated an additional Rs 1.21. The benefit-cost ratios for other modern varieties were also higher than that of Desi (Table 21).

3.11.3 Factor Share

The study found land rent to be the major cost. It accounted for half of all costs in all varieties. Labor cost (land preparation, sowing, harvesting, and weeding and hoeing) accounts for about one third of the total cost. The cost for plant protection as a share of

Table 21. Economics of mungbean cultivation (Rs/ha) by varieties, 1994-95

Inputs	Desi	NM19-19	NM54	NM92	Overall
Cost of production	3961 [a]	4012 [a]	4236 [b]	4224 [b]	4161
Land preparation	637 [a]	625 [a]	650 [a]	726 [b]	688
Sowing	33 [a]	47 [b]	63 [c]	100 [d]	78
Seed	248 [a]	241 [a]	281 [b]	306 [d]	285
Farm manure	0 [a]	13 [b]	52 [c]	30 [d]	27
Fertilizer	271 [a]	244 [a]	311 [b]	333 [c]	308
Irrigation	207 [a]	210 [a]	229 [a]	203 [a]	209
Weeding and hoeing	298 [a]	285 [a]	167 [b]	103 [c]	165
Plant protection	109 [a]	196 [b]	321 [c]	258 [d]	239
Harvesting	322 [a]	316 [a]	325 [a]	328 [a]	325
Land rent	1836 [a]	1836 [a]	1836 [a]	1836 [a]	1836
Gross revenue	5176 [a]	7512 [b]	8055 [c]	9333 [d]	8296
Yield (kg/ha)	579 [a]	801 [b]	865 [c]	900 [c]	840
Price (Rs/100 kg)	894 [a]	938 [b]	931 [b]	1037 [d]	988
Net income	1215 [a]	3500 [b]	3819 [c]	5109 [d]	4135
Benefit-cost ratio	1.31 [a]	1.87 [b]	1.90 [b]	2.21 [c]	1.99
Cost per unit of output (Rs/kg)	6.84 [a]	5.00 [b]	4.91 [b]	4.69 [c]	4.90
Improvement (%) due to modern technologies					
Yield	-	38.2	49.4	55.4	45.0
Price (Rs/100 kg)	-	5.0	4.2	16.0	10.6
Gross revenue	-	45.1	55.6	80.3	60.3
Total cost	-	1.3	7.0	6.6	5.1
Cost/kg	-	26.9	28.2	31.4	28.4
Net income	-	188.0	214.3	320.5	240.3
Benefit-cost ratio	-	43.3	45.5	69.1	52.6

Different superscript in a row implies that the hypothesis of equality in parameter values across varieties was rejected, while the same superscript in a row implies that the hypothesis of equal parameter value cannot be rejected at the 15% level using the t-test for unequal variance.

total cost was higher for modern varieties, while the weeding cost for Desi was higher. A slightly higher proportion of the total cost went to sowing NM92. The higher costs of seed and fertilizer application in the variety were not statistically significant (Table 22). Among the variable cost items, harvesting was the major cost, accounting for about 8%

of the total cost in all varieties. This was followed by weeding and hoeing costs in Desi, and fertilizer and insecticide costs in the NM54 and NM92 varieties (Table 22).

Table 22. Factor share (%) in total cost

Inputs	Desi	NM19-19	NM54	NM92	Overall
Land preparation	16.1[ac]	15.4[a]	15.3[a]	17.2[c]	16.5
Sowing	0.8[a]	1.2[ab]	1.5[bd]	2.4[d]	1.9
Seed	6.3[a]	6.0[a]	6.6[a]	7.3[a]	6.9
Farm yard manure	0.0[a]	0.3[b]	1.2[c]	0.7[cb]	0.7
Fertilizer	6.8[a]	6.1[a]	7.3[a]	7.9[a]	7.4
Irrigation	5.2[a]	5.2[a]	5.4[a]	4.8[a]	5.0
Weeding and hoeing	7.5[a]	7.1[a]	3.9[b]	2.4[b]	4.0
Plant protection	2.7[a]	4.9[b]	7.6[c]	6.1[c]	5.8
Harvesting	8.1[a]	7.9[a]	7.7[a]	7.8[a]	7.8
Land rent	46.4[a]	45.8[a]	43.3[a]	43.5[a]	44.1
Total	100.0	100.0	100.0	100.0	100.0

Different superscript in a row implies that the hypothesis of equal factor share across varieties was rejected, while the same superscript in a row implies that the hypothesis of equal factor share cannot be rejected at the 15% level using the t-test for unequal variance.

3.12 Production Function Analysis

A variant of the Cobb-Douglas production function was used to quantify the response of production to technological options.[9] The variables and parameters estimated are defined in Table 23. As some variables have many zero observations (such as nitrogen and phosphorus application), the Tobit Model (TM) rather than the Ordinary Least Square (OLS) estimation method is more appropriate in this case (Madala, 1977). The results of the TM estimation are reported in Table 24.

The log-likelihood value in the TM estimates was highly significant. The coefficients for the varieties were positive and highly significant, indicating that modern varieties gave higher yield than the traditional Desi variety even after controlling the level of input use.

[9] Interaction of variety was assumed only with the inputs that were expected to interact with varietal technology, such as nitrogen, phosphorus, irrigation, and number of days the crop was in the field. This type of model has been used by Ali and Velasco (1995), Lin (1988), Pingali and Xuan (1992) to explain the productivity difference of modern technologies in Pakistan, China, and Vietnam, respectively.

However, all the three high-yielding varieties were equally productive as their coefficients are not significantly different from each other.

Table 23. Definition of the variables used in the mungbean response function

Variable symbol	Parameter symbol	Definition
Y_m		Mungbean output in kg
X_0	a_0	Intercept having a value of one for all observations
V	a_1, a_2, a_3	Variety dummies for NM19-19, NM54, and NM92 having a value one for a variety, and zero otherwise (Desi was the base variety with which other varieties were compared)
D	a_4, a_5, a_6	District dummies for Layyah, Bhakar, and Others having a value of one for the district and zero otherwise (Mianwali was the base district with which other districts were compared)
N	a_7	Nitrogen in kg
P	a_8	Phosphorus in kg
S	a_9	Seed in kilogram
PL	a_{10}	Number of plowings
PPC	a_{11}	Plant protection cost
<u>Interaction terms</u>		
NxV	a_{12}, a_{13}, a_{14}	Nitrogen interacted with varietal dummy
PxV	a_{15}, a_{16}, a_{17}	Phosphorus interacted with varietal dummy
IRxV	a_{18}, a_{19}, a_{20}	Number of irrigations interacted with varietal dummy
DAYxV	a_{21}, a_{22}, a_{23}	Number of days crop was in the field minus recommended maturity days interacted with varietal dummy

Note: All the variables except dummies were transformed into logarithm form. The function was estimated on per-hectare basis by converting all variables except dummies into per-hectare. For the zero observations, the logarithm of the variable was censored to zero. To keep the function manageable, only plausible interaction terms were included. The error term was assumed to be randomly and normally distributed.

The interactions of phosphorus and nitrogen with varieties were not significant in any case, except phosphorus with NM92, which was positive and significant at the 5% level. This suggested that none of the improved varieties was responsive to nitrogen, and except for NM92, all were insensitive to phosphorus application as well. Plowing labor contributed positively to yield, and was significant at the 10% level in the TM. Additional seed did not influence production, because most of the respondents were using the recommended seed quantity. An important result: delay in harvesting can significantly lower yield of NM19-19 and NM92, perhaps due to pod shattering.

Table 24. The Tobit mode (TM) estimates of the mungbean production function in Pakistan, 1994-95 (dependent variable = logarithm of mungbean yield)

Variable	Variable symbol	Parameter symbol	TM	
			Parameter	Standard error
Intercept	X_0	a_0	1.317***	0.258
NM19-19	V_1	a_1	0.660****	0.254
NM54	V_2	a_2	0.544***	0.267
NM92	V_3	a_3	0.561****	0.174
Layyah	D_1	a_4	0.188****	0.064
Bhakar	D_2	a_5	-0.000	0.072
Other districts	D_3	a_6	0.112	0.101
Nitrogen	N	a_7	0.013	0.046
Phosphorus	P	a_8	-0.015	0.044
Seed	S	a_9	-0.041	0.117
Plowing	PL	a_{10}	0.165**	0.085
Plant protection cost	PPC	a_{11}	0.026****	0.010
Nitrogen x NM19-19	NxV_1	a_{12}	-0.015	0.062
Nitrogen x NM54	NxV_2	a_{13}	-0.072	0.065
Nitrogen x NM92	NxV_3	a_{14}	-0.044	0.057
Phosphorus x NM19-19	PxV_1	a_{15}	0.005	0.078
Phosphorus x NM54	PxV_2	a_{16}	0.081*	0.056
Phosphorus x NM92	PxV_3	a_{17}	0.110***	0.053
Irrigation x NM19-19	$IRxV_1$	a_{18}	-0.093	0.128
Irrigation x NM54	$IRxV_2$	a_{19}	-0.065	0.122
Irrigation x NM92	$IRxV_3$	a_{20}	-0.071	0.088
Day x NM19-19	$DAYxV_1$	a_{21}	-0.133**	0.077
Day x NM54	$DAYxV_2$	a_{22}	-0.008	0.082
Day x NM92	$DAYxV_3$	a_{23}	-0.034*	0.022
Log-likelihood value			108.0***	15.34
Number of observations		n	278	

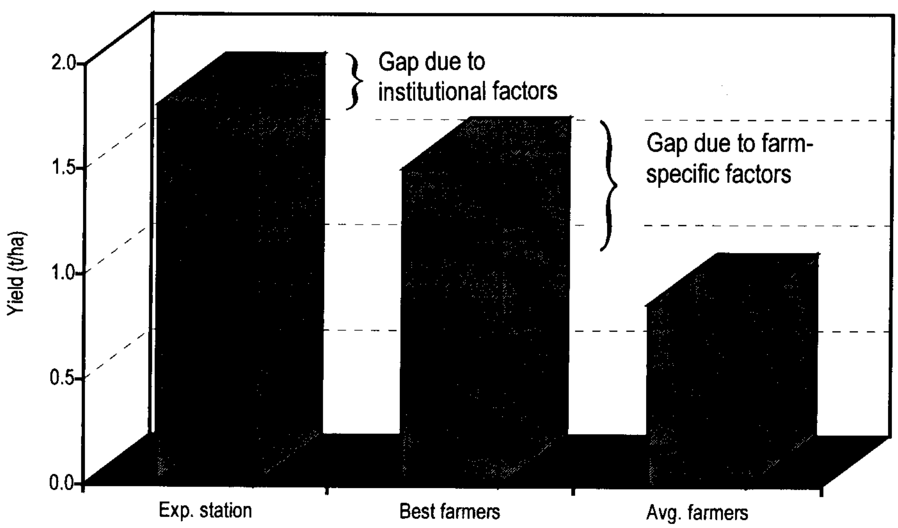
****, ***, **, ** imply that the coefficients are significant at the 1%, 5%, 10%, and 15% level, respectively.

3.13 Production Efficiency

Introduction of research-based technologies generates a disequilibrium as farmers shift from old to new ways of cultivation. It takes time to learn new technologies (Schultz, 1979). Until farmers learn to achieve the potential of new technologies, a low level of technical efficiency is expected. Technical efficiency is defined as the ability to obtain maximum possible output from a given resource (Farrell, 1957).

There are indications of inefficiency in mungbean cultivation. While the yield of the top 5%, progressive farmers, approached the experimental potential yield, average farmers are getting only half the potential yield (Figure 9). The gap between average and potential yield on the progressive farms might be due to "technical efficiency", "allocative efficiency", or both. Technical efficiency is the ratio of the current yield and the maximum achievable yield at the existing level of inputs; and allocative efficiency is defined as yield loss due to less than optimum use of inputs (Farrell, 1957). To achieve allocative efficiency, additional input costs are required. For this reason, economists and policy makers are first concerned with technical efficiency, which was quantified in this study by estimating the frontier production function.

Figure 9. Yield gaps in mungbean cultivation in Pakistan



Many approaches are available to estimate frontier function from which technical efficiency is quantified (Ali and Byerlee, 1991). The approach used in this analysis is explained in Appendix 1.

The frontier function was estimated using the maximum likelihood estimation (MLE) procedure. The estimation shifted the intercept without much change in the coefficients (although standard errors have reduced), implying that farmers on the frontier obtain higher efficiency by an upward shift in the production function as opposed to changes in input elasticities. The mean population efficiency was 65%, implying that average farmers are obtaining less than two thirds the yield of progressive farmers, both at the same levels of input use (Table 25).

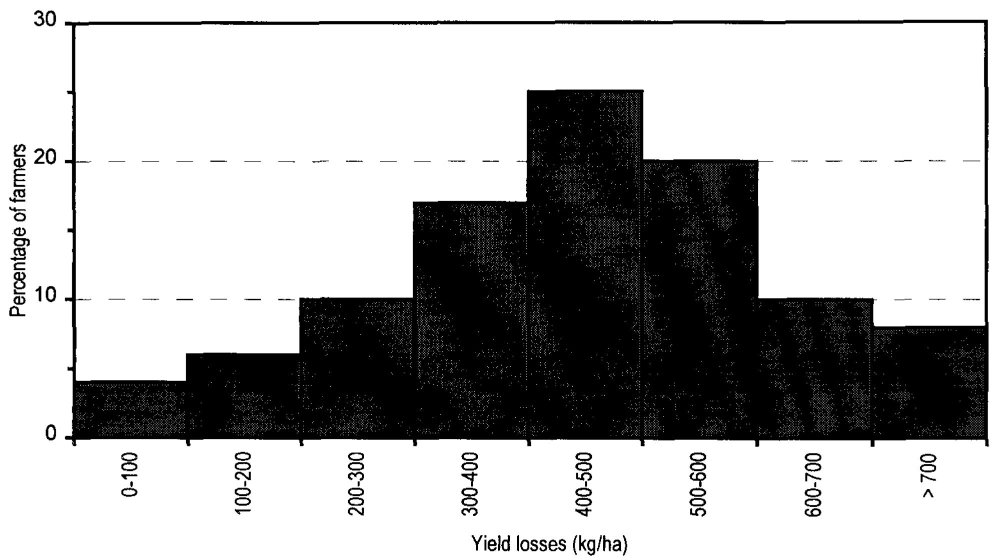
Table 25. The MLE estimates of the frontier production function for mungbean in Pakistan, 1994-95 (dependent variable = logarithm of mungbean yield)

Variable	Variable symbol	Parameter symbol	Parameter	Standard error
Intercept	X_0	a_0	1.985****	0.282
NM19-19	V_1	a_1	0.850****	0.247
NM52, 54	V_2	a_2	0.461**	0.281
NM92	V_3	a_3	0.536****	0.165
Phosphorus	D_1	a_4	-0.031	0.055
Phosphorus x NM19-19	D_2	a_5	0.018	0.090
Phosphorus x NM52,54	D_3	a_6	0.080	0.083
Phosphorus x NM92	N	a_7	0.125***	0.061
Nitrogen	P	a_8	-0.011	0.050
Nitrogen x NM19-19	S	a_9	-0.001	0.065
Nitrogen x NM52,54	PL	a_{10}	-0.022	0.067
Nitrogen x NM92	PPC	a_{11}	-0.020	0.057
Layyah	NxV_1	a_{12}	0.177****	0.057
Bhakar	NxV_2	a_{13}	-0.037	0.069
Other districts	NxV_3	a_{14}	0.053	0.091
Seed	PxV_1	a_{15}	-0.087	0.114
Plowing	PxV_2	a_{16}	0.105**	0.064
Insecticide cost	PxV_3	a_{17}	0.025****	0.009
Irrigation x NM19-19	$IRxV_1$	a_{18}	-0.136	0.104
Irrigation x NM52,54	$IRxV_2$	a_{19}	-0.068	0.150
Irrigation x NM92	$IRxV_3$	a_{20}	-0.042	0.085
Day x NM19-19	$DAYxV_1$	a_{21}	-0.156***	0.077
Day x NM52,54	$DAYxV_2$	a_{22}	-0.000	0.109
Day x NM92	$DAYxV_3$	a_{23}	-0.032**	0.023
Variation explained by efficiency (%)		$\sigma^2_u/(\sigma^2_u+\sigma^2_v)$	92.20	-
Log-likelihood value		$E(u/v)$	99.45	-
Mean value of population efficiency (%)			0.65	-
Number of observations		n	278	-

****, ***,**,* imply that the coefficients are significant at the 1%, 5%, 10%, and 15% level, respectively.

The distribution of farm-specific yield losses due to inefficiency is shown in Figure 10. The mean yield loss over the sample was 500 kg/ha, indicating a clear potential to improve productivity at the given level of resources. More than one third of the sample farmers lost 500 kg/ha or more, and one fourth of farmers lost 400-500 kg/ha. Only 4% of farmers were losing 100 kg/ha or less.

Figure 10 Yield losses due to technical inefficiency in mungbean production in Pakistan



3.14 Mungbean Production Constraints

Farmers' perceptions about the percentage yield losses due to insects, diseases, and weeds, by variety, are presented in Table 26. Weeds are the most serious problem. According to farmers, weeds caused a yield loss of 17% in Desi, and about 11% in NM-92. Again, modern varieties had less loss due to weeds, mainly because most of the seed was purchased, while most of the seed of the Desi variety was home produced and contaminated with weed seeds. The most frequently occurring weed in the area was Hazar Dani (*Phylanthus nitruri*).

The mixing of seed of different varieties negatively affected production. Being a new variety, NM-92 had high demand. The Punjab Seed Supply Corporation, responsible for supplying pure mungbean seed, produced only a small fraction of the seed required in the country. To meet the gap in supply and demand, many unscrupulous seed dealers have begun dealing in the mungbean growing areas. Their mixed seed decreased the potential of modern varieties. The yield of NM-92 was greatly affected by this practice — mixing up to 40% with other varieties was observed. The survey team felt that pure seed would increase yield of NM-92 by at least 10%.

Table 26. Farmers perception of yield losses (%) due to various factors

Causes	Desi	NM19	NM54	NM92	Overall
Weeds	17.2	14.1	12.4	10.5	12.7
Diseases	4.2	5.7	4.6	4.4	4.7
Insects	9.0	11.1	14.8	14.0	12.7

Loss due to insect infestation was another important problem in mungbean cultivation. According to farmers, insects caused more losses in modern varieties than in traditional varieties. About 14% yield losses were perceived by farmers growing NM-92 compared to 9% growing Desi. The overall average was 13%. The most important insects observed in the field, in order of their intensity, were caterpillar (*Spodotera litura*), white fly (*Bamisia tabaci*), and pod borer (*Helicoverpa armigera*). The farmers' perception of losses due to insect infestation matched with higher pesticide use on modern varieties.

The perceived losses due to disease were found to be minimal at about 4-6%, depending upon variety. The Desi variety was infested with MYMV. The highest yield losses in the modern varieties were due to cercospora leaf spot on the late-sown crop.

3.15 Residual Impact of Mungbean Cultivation on Wheat

3.15.1 Input Use on Wheat

The residual impact of mungbean on the following wheat crop was studied by investigating input use and yield of wheat under three rotations: mungbean-wheat, fallow-wheat, and other-wheat crop rotations.

Land preparation for wheat when it followed mungbean required significantly fewer plowings compared to land preparation for wheat when it was preceded by fallow. A more significant difference was observed in the use of inorganic fertilizer. About 40% less nitrogen (N) was applied to wheat after mungbean compared to the application in the other two rotations.[10] Farm yard manure application to wheat following mungbean was also significantly lower than that in the other-wheat rotation. However, it was significantly lower in the fallow-wheat rotation compared to the mungbean-wheat rotation, perhaps because keeping land fallow, with its resulting natural vegetation, might have helped improve organic matter more than was contributed by incorporating mungbean debris. The number of weedings (either manual or chemical) in wheat was lower in mungbean-wheat rotations, compared to that in other-wheat crop rotations. No significant differences in seed requirement and number of irrigations to the wheat crop across rotations were observed. (Table 27).

[10] In addition, total fertilizer applied to a total one-year rotation, including fertilizer given to the mungbean crop, was reduced significantly with the cultivation of mungbeanin the rotation.

Table 27. Physical inputs use (per ha) on wheat by rotation, 1994-95

Inputs	Mungbean-wheat	Fallow-wheat	Other-wheat	Overall
Plowing (number)	4.5 [a]	5.0 [b]	4.7 [ab]	4.6
Seed (kg)	119 [a]	114 [a]	124 [a]	119
Farm yard manure (donkey, bags)	400 [a]	100 [b]	600 [c]	0.4
Total fertilizer (kg)	138 [a]	191 [b]	189 [b]	151
Nitrogen (N)	84 [a]	119 [b]	116 [b]	95
Phosphorus (P)	53 [a]	73 [b]	73 [b]	60
Irrigation (number)	5.2 [a]	5.2 [a]	5.7 [a]	5.2
Weeding (number)	0.56 [a]	0.53 [a]	0.67 [b]	0.58

The same superscript in a row implies that the hypothesis of equality in input use across rotations was accepted at the 15% level using the t-test with unequal variance, and not accepted when they are different.

3.15.2 Economics of Wheat Cultivation in Alternative Crop Rotation

The procedure to estimate cost, gross return, and net return for wheat is similar to that for mungbean explained earlier. Wheat following mungbean produced significantly higher yield and gave higher gross return and net income than wheat in other rotations. Total cost per ha and cost per kg of wheat production were lower, while the benefit-cost ratio improved in the mungbean-wheat rotation compared to the other two rotations (Table 28). Thus, it can be concluded that mungbean improves sustainability because it helps reduce the use of external inputs and enhances land productivity.

Higher gross returns and lower cost of wheat cultivation in the mungbean-wheat rotation almost doubled net income compared to other rotations. The benefit-cost ratio of wheat cultivation in the marginal areas of Pakistan improved from 1.30 in the wheat-other crop rotation to 1.77 in the wheat-mungbean rotation. This implies that every rupee invested in wheat cultivation gave 77% return in the wheat-mungbean rotation compared to 30% in the wheat-other crop rotation. The cost of wheat production per kg reduced from Rs 3.17 in the wheat-other crop rotation to Rs 2.33 in the wheat-mungbean rotation.

3.15.3 Production Function Analysis for Wheat

Another way to analyze how mungbean affected wheat cultivation is by estimating the production function for wheat, including rotation as a variable in the function. A Cobb-Douglas response function was estimated for this purpose. The variables included in the function are reported in Table 29. The function was estimated using the OLS method, and the results are reported in Table 30.

Table 28. Economics of wheat cultivation by crop rotation, 1994-95

Inputs	Mungbean-wheat	Fallow-wheat	Other-wheat	Overall
Yield (kg/ha)	2799 [a]	2649[b]	2718 [c]	2758
Price (kg/ha)	4.13[a]	4.13[a]	4.12[a]	4.13[a]
Gross revenue (Rs/ha)	11560 [a]	10940 [b]	11198 [c]	11387
Total cost (Rs/ha)	6524 [a]	8209 [b]	8603 [b]	7986
Net income (Rs/ha)	5036 [a]	2731 [b]	2595 [b]	3402
Benefit-cost (ratio)	1.77 [a]	1.33 [b]	1.30 [b]	1.43
Cost per unit of output (Rs/Kg)	2.33 [a]	3.10 [b]	3.17 [b]	2.90

The same superscript in a row implies that the hypothesis of equality in the parameter across rotation was accepted at the 15% level using the t-test with un-equal variance, and vice versa when they are different.

Table 29. Definition of the variables included in the wheat response function

Variable symbol	Parameter symbol	Definition
Y_w		Wheat output in kg
X_0	β_0	Intercept having a value of one for all observations
PL	β_1	Number of plowings
S	β_2	Seed in kg
FYM	β_4	Farm yard manure in tons
N	β_5	Nitrogen in kg
P	β_6	Phosphorus in kg
IR	β_7	Number of irrigations
W	β_8	Number of times field was weeded
R	β_9, β_{10}	Rotation dummies for the mungbean-wheat and fallow-wheat rotations having a value of one for a particular rotation, and zero otherwise. The base rotation with which these rotations were compared is other-wheat.
D	$\beta_{11}, \beta_{12}, \beta_{13}$	District dummies for Layyah, Bhakar, and Others having a value of one for the district, and zero otherwise. The base district with which these districts were compared is Mianwali.

Note: All the variables except dummies were transformed into logarithm form. The function was estimated on a per-ha basis by converting all variables except dummies into per ha. For the zero observations, the logarithm of the variable was censored to zero. To keep the function manageable, only plausible interaction terms were included. The error term was assumed to be randomly and normally distributed.

Wheat yield was significantly higher in the wheat-mungbean rotation than in the fallow-wheat and other crop-wheat rotations for the same level of inputs. The yield was 17.5% higher in mungbean-wheat than in the other crop-wheat rotation. There was no significant difference between wheat yields in fallow-wheat and other crop-wheat as the coefficient for the former is not significant (Table 30).

Table 30. Wheat response function on the mungbean growing farms (dependent variable = logarithm of yield in kg per ha), 1994-95

Variables	Variable symbol	Parameter symbol	Coefficient	Standard error
Intercept	X_0	β_0	1.755****	0.545
Plowing	PL	β_1	0.032	0.057
Seed	S	β_2	0.296***	0.138
Farm yard manure	FYM	β_4	0.010**	0.006
Nitrogen	N	β_5	0.012*	0.008
Phosphorus	P	β_6	-0.004	0.009
Irrigation	IR	β_7	0.161****	0.054
Weeding	W	β_8	0.001	0.004
Mungbean-wheat	R_1	β_9	0.175****	0.045
Fallow-wheat	R_2	β_{10}	0.036	0.0534
Layyah	D_1	β_{11}	-0.049	0.056
Bhakar	D_2	β_{12}	-0.066	0.063
Other districts	D_3	β_{13}	0.161***	0.073
R2		R^2	0.24	-
F-Value		F	4.96****	0.526
Number of observations		n	374	

****, ***,**,* imply that the coefficients are significant at the 1%, 5%, 10%, and 15% levels, respectively.

As mungbean yield and biomass in a variety might be correlated, so would be their effect on wheat productivity. To test this hypothesis, the projected mungbean yield from the model in Table 24 was included in the wheat response function, and the function was re-estimated only for those wheat parcels which followed modern mungbean.[11] The variable related to crop rotation (R) was excluded from the function.

[11] The projected, rather than actual, mungbean yield was included in the function to control the simultaniety in the yields of both crops due to management factors.

A positive relationship (albeit significant at only 15%) was observed between wheat yield and mungbean productivity. A 10% increase in the latter, and keeping all inputs constant, would enhance wheat yield by 0.14% (Table 31). Therefore, research aimed at improving management practices in mungbean will have positive implications for wheat productivity.

Table 31. Response function for wheat in the wheat-mungbean rotation

Variables	Variable symbol	Parameter symbol	Coefficient	Standard error
Intercept	X_0	β_0	1.938****	0.739
Plowing	PL	β_1	0.070	0.078
Seed	S	β_2	0.222**	0.142
Farm yard manure	FYM	β_4	0.010*	0.007
Nitrogen	N	β_5	0.011*	0.006
Phosphorus	*P*	β_6	-0.010	0.010
Irrigation	*IR*	β_7	0.144***	0.068
Weeding	*W*	β_8	0.002	0.005
Layyah (Dummy)	D_1	β_{11}	-0.099***	0.055
Bhakar (Dummy)	D_2	β_{12}	-0.048	0.067
Other districts (Dummy)	D_1	β_{13}	0.231***	0.0986
Mungbean yield	MY	β_{14}	0.140*	0.100
F-value	R^2		3.053****	0.273
R-square	*F*		23	
Number of observations	*n*		208	

****, ***, **,* imply that the coefficients are significant at the 1%, 5%, 10%, and 15% levels respectively.

3.16 Miracles of Modern Technologies

We are now in a position to quantify the benefits produced by the introduction and adoption of modern technologies in mungbean cultivation. The main question in this section is how much welfare was generated by the scientific innovations and who mainly benefited from the adoption of these innovations. Producers and consumers are the two main parties considered in this analysis. The productivity gains of modern technologies estimated in the previous section are the basis for estimating welfare gains, while supply and demand elasticities reported elsewhere (Ali 1996) are critical in segregating the total gains among producers and consumers.

The theoretical model, estimation procedure, and assumptions used in the estimation of welfare gains are explained in Appendix 4. The total gains were segregated into i) production effect, defined as the benefit generated from the increase in mungbean production, ii) quality improvement effect, defined as the benefits generated due to improvement in mungbean quality, and iii) residual effect, defined as benefits from the expanded mungbean cultivation on the fallow lands after wheat. The gains generated from increased mungbean production were further segregated into a) expansion effect, defined as benefits generated from the expansion in mungbean area, and b) substitution effect, defined as benefits generated by replacing the area under the low-yielding Desi variety with modern varieties.

The data used in quantifying the impact of modern technologies are reported in Appendix 5. The welfare generated on various accounts is shown in Table 32. About US$20 million were being generated annually by the improvement in mungbean cultivation through these innovations. The consumers share in total welfare was 38%, compared to the producers share of 62%.

Table 32. Consumers' and producers' surplus (million US$) generated through research innovations in mungbean production in Pakistan, 1994-95

Type of effect and surplus	Value	Percentage
Total effect	19.7	100.0
Consumers' surplus	7.5	38.0
Producers' surplus	12.2	62.0
i) Production effect	9.0	45.5
a) Substitution effect	5.3	27.1
Consumers' surplus	3.4	17.1
Producers' surplus	2.0	10.0
b) Expansion effect	3.6	18.4
Consumers' surplus	2.3	11.6
Producers' surplus	1.3	6.8
ii) Improvement in quality effect	4.4	22.2
Consumers' surplus	1.8	9.3
Producers' surplus	2.5	12.9
iii) Residual effect	6.4	32.4
Consumers' surplus	0.0	0.0
Producers' surplus	6.4	32.4

The estimated surplus in million Rs was converted into million US$ by using the official exchange rate during 1994-95, Rs 30.85 equal to one US dollar (Government of Pakistan, 1996).

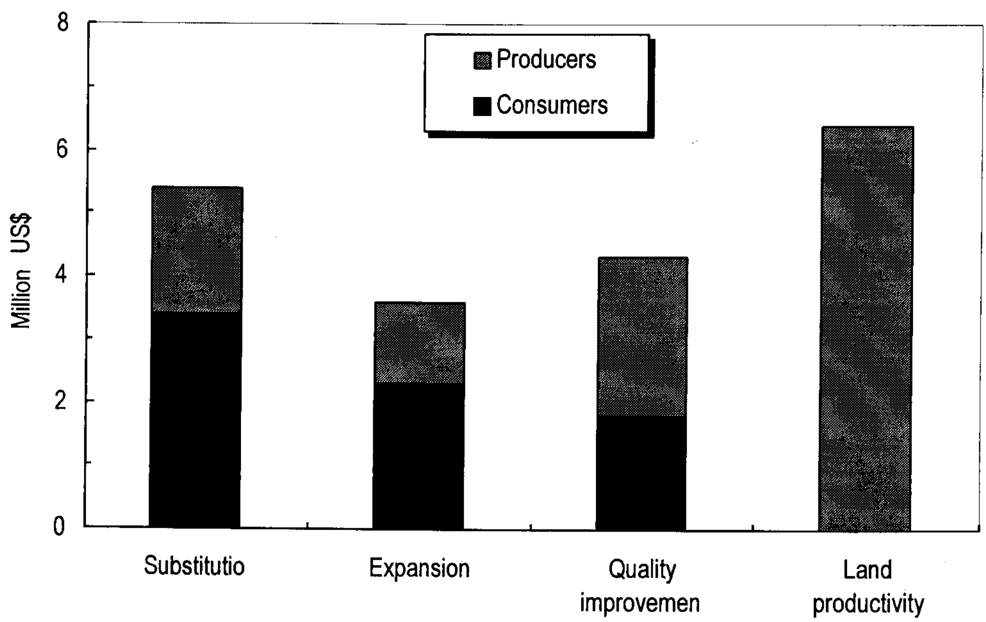
The distribution of the research benefits among consumers and producers was sharply different than for cereal crops, such as rice or wheat, where most if not all gains go to consumers. Actually the gains to producers have been shown to be negative in some cases (Evenson and Flores 1978, Scobie 1978, Hayami and Herdt 1977). These results are due to high demand elasticities of mungbean compared to the very inelastic nature of demand for cereals.

3.16.1 Production Effect

The improvement in mungbean production contributed less than half of the total effect at about US$9 million per annum. This effect can be divided into substitution effect and expansion effect as follows.

<u>*Substitution effect*</u>. This produced US$5.3 million per annum. The substitution effect contributed 27% in the total welfare generated. The effect was relatively small as mungbean cultivation covered only a small area before the introduction of modern technologies. The share to consumers was 63%, while producers shared 37% of the gain (Figure 11).

Figure 11. Distribution of welfare generated by modern mungbean varieties among consumers and producers



Expansion effect. Total welfare generated due to area expansion amounted to US$3.6 million in 1994-95. About 63% of this went to consumers, and 37% to producers. Expansion effect contributed 18% of the total surplus generated from research innovation. (Figure 11)

3.16.2 Improvement in Quality

The large and shiny seed of the new varieties raised mungbean prices at the farm gate and at the wholesale level. This produced a surplus of US$4.4 million, about 22% of the total surplus generated through research innovations. The consumers' and producers' shares were 42 and 58%, respectively (Figure 11).

3.16.3 Residual Effect

The land productivity effect of mungbean on the following wheat crops on the expanded mungbean-wheat rotation areas generated US$6.4 million per annum, which is about 32% of the total surplus generated. As the improvement in wheat yield due to mungbean in the rotation affects only a small proportion of the total wheat area, this will not affect the price of wheat. Therefore, the total benefit goes to producers (Figure 11).

4. Summary and Policy Implications

Laxity of policy makers concerning food legumes and introduction of high yielding, input-responsive cereal varieties in the 1960s and 1970s pushed pulses cultivation (including mungbean) to marginal lands, reduced its share in the cropping pattern, and caused per capita consumption to plummet. This created an imbalance in the diets of poor people and upset the balance of soil nutrients in intensive cropping systems.

Low yield, long duration, unsynchronized maturity, and susceptibility to diseases limited mungbean cultivation, and its sustainability advantages, to a small area. In the early 1980s, mungbean began to receive research attention. AVRDC played a pivotal role in the crop's advancement. The Center organized a collaborative network to share mungbean germplasm, which generated interest among national scientists, and it conducted training. These efforts resulted in the release and adoption of a number of high-yielding mungbean varieties, vis., NIAB Mung 28 introduced in 1983, NIAB Mung 121-25, 19-19, 20-21, 13-1 released in 1986, Mung 88 in 1988, NIAB Mung 51, 54 approved for cultivation in 1990, and NIAB Mung 92 introduced in 1992, and officially approved in 1996.

Mungbean research has concentrated mainly on developing high yielding, disease resistant, large seeded, and shiny coated varieties. Breeders in Pakistan have been successful in increasing the yield frontier by 100 percent, increasing the seed size by about 33%, developing resistance to MYMV and CLS, and in making the seed shinier. They have also shortened the crops duration from 90 days to about 60 days, and have synchronized maturity.

In Pakistan, mungbean is cultivated on relatively light soils, marginal for cereal cultivation. The mungbean growing districts of Punjab (i.e., Layyah, Bhakar, and Mianwali) have relatively poor infrastructure, and farmers have below average resources and household inventories. The province's major summer crops give low yield in the mungbean growing region, therefore the region's farmers cannot compete in these crops with farmers located elsewhere. These factors make a low-input summer crop such as mungbean suitable for the region.

Mungbean is a major kharif crop in these districts. It is grown in July-August and harvested in October, followed by wheat cultivation November through May. The region's climate is ideal for mungbean cultivation. In the early months, monsoon rains supply ample moisture, while at the end of the crop season the weather is quite dry. Supplementary water is available from surface and underground sources.

The major rotation in which mungbean is grown is mungbean-wheat, although some farmers practice a wheat-maize-mungbean rotation. It is also technically possible for mungbean to be grown after cotton when a late cotton harvest prevents growing wheat.

Modern mungbean varieties were quickly adopted by farmers. While the Desi variety was grown by about 80% of farmers in 1988, only 10% were using this variety in 1994.

The modern variety NM19-19 was grown by 17% of farmers, NM54 by 22%, and NM92 by 51% of the sample farmers in 1994.

The introduction of modern technologies brought about a series of changes in mungbean management practices. For example, most of the modern variety seed is purchased. But farmers growing the Desi variety usually sow home-produced seed which is often contaminated with weed seeds. Thus, Desi crops suffer high weed infestation and require more weeding operations compared to the modern variety crops. The adopters of modern varieties used various line planting methods such as sowing by drill, kerah, and porah, while almost all fields of the Desi variety were broadcast. Slightly higher fertilizer and farm manure doses were found to be used on the modern varieties compared to the Desi variety, although the differences were not significant, which might be due to the early stage of adoption. More farmers used chemical sprays on modern varieties compared to the Desi variety.

Research-based technologies enhanced mungbean productivity. The modern varieties produced significantly higher yield than the Desi variety. The average yield of NM92, for instance, was 55% higher. These varieties have shifted the production function upward, indicating that the new technologies gave higher yield, even as inputs remained unchanged. Compared to the Desi variety, NM92 generated four times higher return from one hectare of land, and reduced the cost by about one fourth.

Mungbean cultivation improved land productivity. Input use, especially nitrogen, plowing labor, and seed were significantly lower, and yield was significantly higher for wheat in the wheat-mungbean rotation than in wheat-other crops or wheat-fallow rotations. After controlling the level of inputs, the production function for wheat in the wheat-mungbean rotation was found to be about 19% higher compared to the other rotations. The cost of wheat production per kg has been reduced from Rs 3.17 in the wheat-other crop rotation to Rs 2.33 in the wheat-mungbean rotation. Higher mungbean yield helped to improve productivity of the following crop. As modern varieties have prompted mungbean cultivation on new areas or during the fallow period after wheat, the land productivity effect of mungbean also touched these lands.

Mungbean in rotation with wheat has given a boost to wheat production in marginal wheat producing districts (i.e., Mianwali, Bhakar, and Layyah). Wheat production increased 4.4% annually in these districts from 1986 through 1993, compared to an overall increase of 3.0% in the country (Government of Pakistan, 1990 and unpublished district level data of 1993 from the Crop Reporting Section, Ministry of Agriculture, Government of Punjab, Lahore).

Technological innovation also improved investment opportunities in the marginal areas. The benefit-cost ratio of NM19-19, NM54, and NM92 were 1.87, 1.90, and 2.21, respectively, compared to 1.31 for the Desi variety. This helped to expand mungbean area in the fallow period after wheat. Thus the higher benefit-cost ratio of wheat cultivation in the wheat-mungbean rotation (1.77) compared to that in the other-wheat crop rotation (1.30) was enjoyed by many more farmers.

The gains in productivity due to the adoption of science-based innovation resulted in a substantial increase in mungbean's share of the total pulses area, from 3% in 1980 to 11% in 1993-94. On the other hand, per capita consumption of mungbean increased from 1.08 kg/annum in 1984-85 to 1.32 kg/annum in 1991-92, while the consumption of some pulses, such as lentil, declined from 1.20 kg/annum to 1.08 kg/annum, and the consumption of others remained almost stagnant. Furthermore, no mungbean has been imported since the introduction of modern varieties, while imports of other pulses rose to 254,000 t in 1993.

The benefits to society from technological innovation were estimated to be about US$ 20 million per annum. These advantages came from i) substituting the area under Desi with high-yielding varieties, keeping the total mungbean area at the level before the adoption of the innovation (US$ 5.3 million), ii) an increase in mungbean area with the introduction of modern varieties (US$ 3.6 million), iii) improvement in quality (US$ 4.4 million), iv) residual effect of mungbean on the following wheat crop (US$ 6.4 million). Improvement in land quality contributed about one third of the total welfare generated.

New innovations not only enriched the quality of life of mungbean growers in the country who otherwise had meager income-generating opportunities, it also benefited consumers by supplying improved quality mungbean at lower prices. Thirty eight percent of the total benefits of the "Green Revolution" in mungbean were shared by consumers and 62% went to producers. This contrasts with cereals where most benefits of research accrue to consumers.

Although mungbean is currently grown in marginal areas in a mungbean-wheat rotation, the development of short-duration, uniform maturing varieties giving stable yields across regions (Malik, *et al.* 1989) has increased substantially the scope for integration of mungbean in intensive rice-wheat and wheat-maize rotations. A mungbean crop can be grown between wheat harvest and rice/maize planting. This would spread the sustainability advantage of mungbean. Our interviews with extension agents and farmers in the rice-wheat region also revealed a good possibility for integration of mungbean after the wheat harvest and before rice cultivation, if some technical constraints could be resolved. Among these are the competing labor demands for mungbean cultivation and wheat harvest, and mungbean harvest and rice cultivation. Because labor is a major input in mungbean cultivation, mechanization of some of the operation, such as rice transplanting and mungbean harvesting, could help remove this constraint. Perhaps plant physiologists can help further shorten mungbean's time to maturity. Shortening the duration of other crops in the rotation, through breeding, might be another way to resolve these conflicts, as was accomplished in wheat to facilitate the rice-wheat and wheat-cotton rotation in Pakistan (Byerlee, *et al.* 1987). Development of flood tolerant mungbean would also help facilitate its integration in the rice-wheat system, as rains would be expected to fall close to mungbean's harvest time when grown in the rotation. Availability of modern variety seed is a pre-condition for adoption.
Technical inefficiency, estimated using the frontier production function, revealed a substantial gap between average and progressive farm yields. This gap is expected to narrow given that progressive farm yield has already approached the yield at experiment stations. The average level of inefficiency was 35%, and yield loss due to inefficiency

was 500 kg/ha, which indicates that average yield could be improved by about 50% without increasing the input level.

The existence of such inefficiency is consistent with the hypothesis that farmers struggle with "disequilibrium" generated by the adoption of advanced cultivation methods (Schultz 1979). To help farmers to deal with this "disequilibrium", agronomic research should focus on developing expert management packages for various regions and environments. And farmers must be trained in how to use these packages. As its full potential is realized, the economics of mungbean cultivation will further improve, and its cultivation will expand into new cropping systems and ecoregions.

Apart from the need to improve management practices, many challenges lie ahead for policy makers and researchers. There is a need to reorganize the seed industry to provide clean and pure seed. The survey team observed pervasive mixing of mungbean seed of different varieties. This has further reduced the potential yield of modern varieties, especially of NM92. Farmers attribute 12% of yield losses to weeds and 12% to insects. The weed problem can be controlled by providing clean seed and promoting advanced weed management practices. Study into crop protection management, and the development of insect-pest-resistant varieties could help farmers to greatly increase mungbean yield.

References

Aigner, D. J., Lovel, C. A. K., and Schmidt, P. 1977. Formulation and estimation of stochastic frontier function models. Journal of Econometrics, 6, 21-37.

Ali, M., and Byerlee, D. 1991. Economic efficiency of small farmers in a changing world: A survey of recent evidence. Journal of International Development, 3, 1-27.

Ali, M. and Velasco, L. 1993. Intensification induced resource degradation in the crop sector of Pakistan. Los Baños, Laguna, Philippines, International Rice Research Institute, unpublished paper.

Alston, J.M., Norton, G.W., and Pardey, P.G. 1995. Science under scarcity: Principles and practice for agricultural research evaluation and priority setting. Ithaca and London, International Service for National Agriculture Research, Cornell University Press. 585 p.

Amir, P. 1985. Increasing the productivity of rice based farming systems of the Pakistan Punjab. Michigan, Michigan State University, unpublished Ph.D. dissertation.

AVRDC (Asian Vegetable Research and Development Center). 1976. AVRDC Mungbean Report '75, Shanhua, Taiwan, 72 p.

AVRDC (Asian Vegetable Research and Development Center). 1985. AVRDC 1983 Progress Report. Shanhua, Taiwan, AVRDC Publication No. 85-228, 444 p.

AVRDC (Asian Vegetable Research and Development Center). 1987. AVRDC 1985 Progress Report. Shanhua, Taiwan, AVRDC Publication No. 86-265, 471 p.

AVRDC (Asian Vegetable Research and Development Center). 1987. Mungbean Breeding - Germplasm Collection. AVRDC 1984 Progress Report. Shanhua, Taiwan, AVRDC Publication No. 86-264, pp: 165-176.

AVRDC (Asian Vegetable Research and Development Center). 1994. AVRDC 1993 Progress Report. Shanhua, Taiwan, AVRDC Publication No. 94-420, 537 p.

AVRDC (Asian Vegetable Research and Development Center). 1997. AVRDC 1996 Report. Shanhua, Taiwan, AVRDC Publication No. 97-460, 200 p.

Bashir, M., Zubair, M., and Malik, B.A. 1988. Disease resistance sources and utilization in breeding improved mungbean in Pakistan. In: Shanmugasundaram, S., and McLean, B.T. (ed.) Mungbean: proceedings of the second international symposium. Shanhua, Taiwan, Asian Vegetable Research and Development Center, AVRDC Publication No. 88-304, pp: 623-630.

Byerlee, D., Akhtar, M.R., and Hobbs, P.R. 1987. Reconciling conflicts in sequential cropping pattern through plant breeding: the example of cotton and wheat in Pakistan's Punjab. Agriculture System, 24, 291-304.

Chadha, M.L. 1996. Introduction and development of adaptive technologies for sustainable year-round vegetable production and consumption in Bangladesh: progress report 1996. AVRDC-USAID-Bangladesh Project, Shanhua, Taiwan, Asian Vegetable Research and Development Center, unpublished report.

Evenson R.E., and Flores, P.M. 1978. Social return to rice research. In: Economic Consequences of the New Rice Technology, Los Banos, Philippines, International Rice Research Institute, pp: 243-265.

Farrell, M.J. 1957. The measurement of productive efficiency. Journal of Royal Statistical Society, Series-A, Part 3, Vol. 120, 253-281.

Firth, P., Thitipoca, H., Suthipradit, S., Westselaar, R., and Beech, D.F. 1973. Nitrogen balance studies in the Central Plains of Thailand. Soil, Biology, Biochemistry, 5, 41-46.

Government of India. 1994. Economic Survey 1993-94, Ministry of Finance, Economic Division, New Delhi.

Government of India. 1995. Monthly Abstract of Statistics, Vol. 48, Number 2, Central Statistical Division, Department of Statistics, Ministry of Planning and Program Implementation, New Delhi.

Government of Pakistan. 1972. 25 Years of Pakistan in Statistics, 1947-72, Central Statistical Office, Ministry of Finance, Planning and Development, Karachi.

Government of Pakistan. 1978. Agricultural Statistics of Pakistan 1977, Ministry of Food, Agriculture and Cooperatives, Food and Agriculture Division (Planning Unit), Islamabad.

Government of Pakistan. 1983. 10 Years of Pakistan in Statistics, 1972-82, Central Statistical Office, Ministry of Finance, Planning and Development, Karachi.

Government of Pakistan. 1989. Agricultural Statistics of Pakistan 1988-89, Ministry of Food, Agriculture and Cooperatives, Food and Agriculture Division (Economic Wing), Islamabad.

Government of Pakistan. 1990. Crop Area and Production (By Districts), 1986-87 to 1988-89, Ministry of Food, Agriculture and Livestock, Food and Agriculture Division (Economic Wing), Islamabad.

Government of Pakistan. 1991. Pakistan Mouza Statistics 1988. Agricultural Census Organization, Statistics Division, Government of Pakistan, Gulberg-III, Lahore.

Government of Pakistan. 1994. 1990 Census of Agriculture: Province Report, Vol II Part-2, Punjab. Economic Affairs and Statistics Division, Agricultural Census Organization, Gulberg-III, Lahore.

Government of Pakistan. 1995. Agricultural Statistics of Pakistan 1993-94, Ministry of Food, Agriculture and Livestock, Food and Agriculture Division (Economic Wing) Islamabad.

Government of Pakistan. 1995b. Pakistan Statistical Year Book, Federal Bureau of Statistics, Economic Affairs and Statistics Division, Karachi.

Government of Pakistan. 1996. Economic Survey 1995-96, Finance Division, Economic Advisor's Wing, Islamabad.

Hayami, Y. and Herdt, R.W. 1977. Market price effect of technological change on income distribution in subsistence agriculture. American Journal of Agricultural Economics, 59(2), 245-56.

Jondrow, J., Lovel, C. A. K., Materov, I. S., and Schmidt, P. 1982. On the estimation of technical inefficiency in the stochastic frontier production function model. Journal of Econometrics, 19, 233-238.

Ladd, G.W., and Suvannut, V. 1976. A model for consumer goods characteristics. American Journal of Agricultural Economics, 58(2), 504-510.

Lin, J.Y. 1988. The household responsibility system in China's agricultural reform: A theoretical and empirical study. Economic Development and Cultural Change, 36(3), 199-224.

Madala, G.S. 1977. Econometrics (International Student Edition). New York, Mc Graw-Hill International Book Company.

Malik, I.A. 1991. Two improved varieties of mungbean in Pakistan. IAEA Mutation Breeding Newsletter, 37, 4.

Malik, I.A. 1992. Breeding for resistance to MYMV and its vector in Pakistan. In: Green, S.K. and Kim, D. (ed.) Mungbean Yellow Mosaic Disease: Proceedings of an international workshop, Bangkok, Thailand, 2-3 July, 1991. Shanhua, Taiwan, Asian Vegetable Research and Development Center, AVRDC Publication No. 92-373, pp: 41-53.

Malik, I.A. 1993. Improvement of mungbean, black gram, and lentil in yield, plant type, disease resistance, and nitrogen fixing capacity through induced mutation and conventional techniques. In: Proceedings of a regional coordination meeting on the use of isotopes in studies to improve yield and N_2 fixation of grain legumes in the tropics and subtropics of Asia, held at Tamworth, N.S.W., Australia, 29 Aug. - 3 Sept., 1993. FAO/IAEA

Malik, I.A., Ali, Y., and Sarwar, G. 1988a. Improvement of mungbean (*Vigna radiata* (L.) Wilczek) and black gram (*Vigna mungo* (L.) Heppy) in yield, plant type and resistance to diseases through induced mutations. In: Proceedings of FAO/IAEA workshop on improvement of green legume production using induced mutations, held at Pollman, Washington, U.S.A., 1-5 July 1986. IAEA, pp: 293-317.

Malik, I.A., Ali, Y., and Tahir, G.R. 1989. Yield stability of induced early maturing mutants of mungbean (*Vigna radiata* (L.) Wilczek) and their use in multiple cropping system. Field Crop Research, 20, 251-259.

Malik, I.A., Sarwar, G., and Ali, Y. 1986. Growing mungbean as a catch crop with early maturing and high yielding mutant varieties, IAEA Mutation Breeding Newsletter, 28, 14-16.

Malik, I.A., Sarwar, G., and Ali, Y. 1988b. High yielding and early maturing mutants in mungbean (*Vigna radiata* (L.) Wilczek). IAEA Mutation Breeding Newsletter, 32, 7-8.

Pingali, P.L., and Xuan, V.T. 1992. Vietnam: Decollectivization and rice productivity growth. Economic Development and Cultural Change, 40, 697-718.

Rachie, K.O., and Roberts, L.M. 1974. Grain legumes of the lowland tropics. Advances in Agronomy, 26, 62-77.

Schultz, T.W. 1979. The value of the ability to deal with disequilibria. Journal of Economic Literature, 13, 827-846.

Scobie, G.M. 1978. Comments on social returns to rice research. In: Economic Consequences of the New Rice Technology, Los Banos, Philippines, International Rice Research Institute, pp: 266-281.

Sharif, M., Longmire, J., Shafique, M., and Ahmad, Z. 1989. Adoption of Basmati 385: implications for time conflicts in the rice-wheat cropping system of Pakistan's Punjab, PARC/CIMMYT Paper No. 89-1. Islamabad, Pakistan Agricultural Research Council.

Singh, V.P., Chhabra, A., and Kharb, R.P.S. 1988. Production and utilization of mungbean in India. In: Shanmugasundaram, S., and McLean, B.T. (ed.) Mungbean: proceedings of the second international symposium. Shanhua, Taiwan, Asian Vegetable Research and Development Center, AVRDC Publication No. 88-304, pp:486-497.

Thirumaran, A.S., and Seralathan, M.A. 1988. Utilization of mungbean. In: Shanmugasundaram, S., and McLean, B.T. (ed.) Mungbean: proceedings of the second international symposium. Shanhua, Taiwan, Asian Vegetable Research and Development Center, AVRDC Publication No. 88-304, pp:470-485.

Unnevehr, L.J. Consumer demand for rice grain quality and return to research for quality improvement in Southeast Asia. American Journal of Agricultural Economics, 68(3), 634-641.

Appendices

Appendix 1

Performance of mungbean elite lines for yield and other important plant characteristics in NIAB experiments

Entry	Pedigree	Days to mature	Height (cm)	1000-seed wt. (g)	Harvest index (%)	Yield (kg/ha)	Reaction to [a]	
							MYMV	CLS
NM92	NM36 x VC2768B	58	56	57	30	2189	HR	HR
NM93	NM36 x VC2768A	65	60	52	29	1777	R	MR
NM96	6601 x VC1973	67	73	62	25	1779	MR	MR
NM90	"	63	66	40	31	1951	HR	MT
NM36	"	70	75	51	21	1599	HR	MT
NM51 [b]	"	67	79	46	22	1687	HR	MT
NM54 [b]	"	66	71	61	24	1717	MR	MR
NM121-25 [b]	Mutant induced in St. RC71-27	70	70	31	25	1436	MR	MS
					CD 5%	132		
					1%	184		

a MYMV is the abbreviation for mungbean yellow mosaic virus, and CLS is the abbreviation for cercospora leaf spot.
b Approved varieties
Source: Malik (1993)

Appendix 2

Yield performance of promising mungbean varieties in multilocation trials conducted by the Arid Zone Research Institute, Bhakar, kharif season, 1992 and 1994

Entry	Locations during 1992				Overall average yield (kg/ha)	% increase of NM92 over other varieties
	chak 205 TDA	mushin kote	chak 29 TDA	Raizi shah		
NM92	1810.53	1047.14	1497.72	1016.26	1217.91	-
NM93	1216.37	231.48	1337.97	609.76	848.90	43.6
NM51	1730.99	610.26	1158.24	601.75	1027.19	18.6
NM121-25 (standard)	1637.43	521.88	1377.90	609.76	1036.74	17.5

Entry	Locations during 1992						Overall average yield (kg/ha)	% increase of NM92 over other varieties
	chak 49 TDA	chak 48 TDA	chak 205 TDA	moza kanari	chak 189 TDA	mushim kote		
NM92	1725	1344	1575	1727	1536	1489	1556.17	-
NM51	1463	1178	1350	1580	1293	1258	1353.67	16.00
NM121-25	1323	946	1100	1330	1112	931	1111.50	40.95

Entry	Locations during 1992						Overall average yield (kg/ha)	% increase of NM92 over other varieties
	A2R1 farm Bhakar	chak 36 TDA	notak nashaib	chak 211 TDA	chak 261 TDA	chak 49 TDA		
NM92	967	1910	1125	1035	700	2015	1292	-
NM90	918	1760	875	985	725	1252	1086	18.97
NM93	893	1559	1100	707	400	1524	1031	25.32
NM51	620	1408	700	1010	450	1252	907	42.45
NM121-25	670	1659	600	455	775	1415	929	39.10

TDA: Thal Development Authority
Source: Unpublished

Appendix 3 Estimation of Technical Inefficiency

The following stochastic production frontier was used in this analysis to estimate the frontier production function:

$$Y = f(X)\, e^{(v - u)} \tag{A3.1}$$

where Y is output and X is a matrix of all independent variables which are assumed to affect production. The error term has two parts; e^{v} and e^{-u} . The former is randomly and normally distributed while the latter is a ratio of actual yield to the maximum possible yield (i.e., technical efficiency), at the level of farm-specific variable inputs. If the value of e^{-u} is 1, the farmer is on the frontier of the production function and is efficient as management practices maximize output from the resources employed. If the value of e^{-u} is below 1, the farmer is below the frontier function.

The above equation can be estimated using the Maximum Likelihood Estimation (MLE) technique if the natures of the density functions for u and v are specified (Aigner, Lovel, and Schmidt, 1977). In this analysis, v is assumed to be normally distributed and u to have a truncated (half) normal distribution with zero mode. Given the value of v, the population (Maddala, 1977) and farm-specific (Jondrow et al. 1982) efficiency, can be estimated as follows:

Population efficiency $$E(u/v) = \sigma_u \sqrt{2/\Pi} \tag{A3.2}$$

Farm-specific efficiency $$E(u/v) = \sigma^{*}\left[\left(\frac{f(.)}{1 - F(.)}\right) - \left(\frac{R\lambda}{\sigma}\right)\right] \tag{A3.3}$$

where σ is standard deviation of the total error term $R=u+v$, $\sigma^{*}=\sigma_u.\sigma_v/\sigma$, $\lambda=\sigma_u/\sigma_v$, $\sigma=/\sigma u^2+\sigma v^2$, and $f(.)$ and $F(.)$ are respectively the standard normal density and distribution functions evaluated at $R\lambda/\sigma$, and Π is equal to 3.14159. R is obtained by substituting the farm-specific input use in the estimated function of equation (A3.1), σ_u^2 and σ_v^2 are respectively the standard errors of u and v, and are the outcome of the MLE estimation. Inefficiency is then measured as (exp($-u$)-1), and yield losses as inefficiency multiplied by the yield of the farmers on the frontier function.

The frontier function in A3.1 was estimated using the LIMDEP computer program which applies the Newton Raphson non-linear estimation technique.

Appendix 4 Theoretical Model to Estimate Consumer and Producer Surplus

Appendix 4.1 Standard Model

The Marshallian concepts of consumer and producer surplus can be applied to quantify the welfare generated through research. As a result of the adoption of high-yielding technology developed by research, the aggregate supply curve in Figure 12 shifts from S_0 to S_1. Assuming linear supply and demand functions, a parallel shift in the supply curve will produce a change in the "consumers' surplus" by the area AP_0P_1B. The same supply shift will produce a change in "producers' surplus" by the area BP_1S_1 minus AS_0P_0. The total change in "economic surplus (producers' plus consumers') will be the area BS_oS_1A. These effects due to technological development to improve yield can be expressed algebraically as follows (Alston, Norton, and Pardey, 1995).

Consumers' surplus due to yield improvement

$$=\nabla CS_m = P_{m0}\, Y_{m0}Z_m\,(1+0.5Z_m\varepsilon_m) \qquad \text{(A4.1)}$$

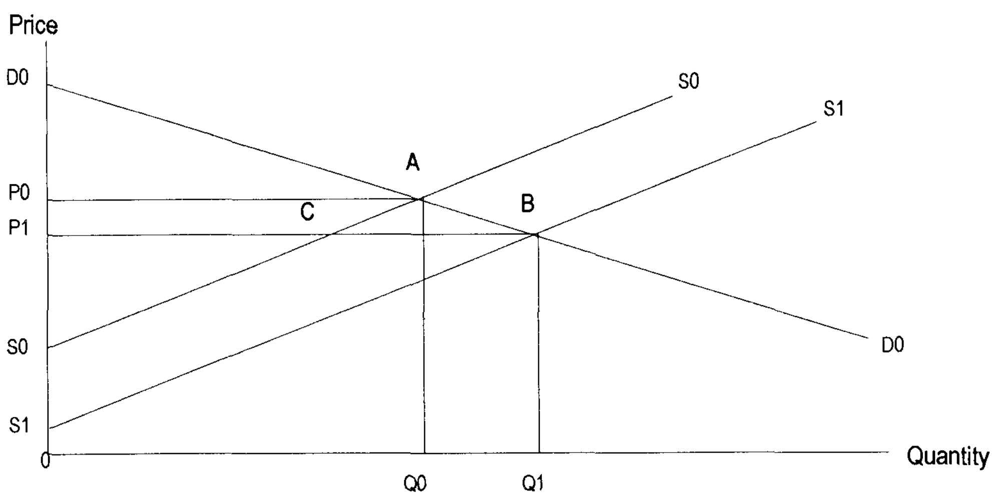
Producers' surplus due to yield improvement

$$=\nabla PS_m = P_{m0}Y_{m0}(k_m\text{-}Z_m)(1+0.5Z_m\varepsilon_m) \qquad \text{(A4.2)}$$

Total surplus due to yield improvement

$$=\nabla TS_m=\nabla CS_m+\nabla PS_m=P_{m0}Y_{m0}k_m(1+0.5Z_m\varepsilon_m) \qquad \text{(A4.3)}$$

Figure 12. Effect of high yielding mungbean technologies on consumers' and producers' surplus



Consumers' surplus=BD_0P_1 - AP_0D_0=AP_0P_1B
Producers' surplus=BP_1S_1 - $AP_0S_{0=}$ BCS_0S_1 - AP_0P_1C
Total surplus=BAS_0S_1

where subscript *m* connotes a particular crop, say mungbean in this case, k is the vertical downward shift in the supply function expressed as a proportion of the initial price, ε is the absolute value of the own-price elasticity of demand, α is the own-price elasticity of supply, and $Z = k\alpha/(\alpha+\varepsilon)$ is the reduction in price, relative to its initial (i.e., pre-research) value due to shift in supply. Y_0 and P_0 are respectively initial production and price before innovation started. If initial production (Y_{m0}) is defined as the existing mungbean area in the country multiplied by yield of Desi mungbean, it will give the *total* effect of modern technologies.

However, two scenario can be isolated by defining the values of Y_{m0} on which the effects of modern technologies are applied. In the first scenario, it was assumed that total mungbean area in the country remained unchanged at the pre-innovation level, but Desi area was replaced by high-yielding varieties. This is called *substitution effect.* In this case, the initial production, now called Y_{mi}, is estimated as the area before the start of the adoption multiplied by the yield of Desi mungbean.

In the second scenario, called *expansion effect,* the effect of the increase in production due to expansion in area was estimated. To quantify this effect, the substitution effect was subtracted from the total effect. Alternatively, one can quantify the expansion effect by estimating Y_{m0} as expanded area multiplied by the yield of Desi mungbean. The implicit assumption is that the profitability of the pre-innovation cultivation is equal to Desi mungbean cultivation, both in the case of expansion on virgin land and when mungbean replaces some other crops.

Appendix 4.2 Adaptation in the Standard Model

The above specifications to estimate the consumers' surplus, producers' surplus, and total surplus generated by research are oversimplified as they assume a closed economy in a static situation, they do not identify differences across ecoregions or socioeconomic group of consumers, and they overlook farmers and spillover effect. However, mungbean in Pakistan is neither imported nor exported, so the closed economy assumption is not restrictive.

Egalitarian issues and the spillover effect of modern technology will become increasingly important as mungbean area expands due to enhanced profitability. The above analysis can be extended to the regional level, and to socioeconomic groups of farmers and consumers by incorporating group- and region-specific elasticities. As enhanced mungbean supply increases the incomes of resource-poor farmers, and possibly improves the nutrition of the poor, such analysis would highlight the positive egalitarian effect of these technologies. However, due to lack of data on disaggregated supply and demand elasticities, we leave these issues for future research by our national partners.

Nevertheless, two special effects of mungbean research cannot be ignored. The first is quality improvement, evident from higher farm-gate and wholesale prices for modern varieties compared to Desi mungbean. The second is the residual impact of mungbean on the following wheat crop.

Appendix 4.2.1 Quality Improvement

Ladd and Suvannut (1976) have shown that such innovations in product quality lead to a rightward shift in the demand function. The effect of such a shift on the welfare of producers and consumers has been modeled by assuming a constant production cost (Unnevehr 1986) or assuming a higher cost for the better quality output (Voon and Edward). We follow the former approach, and assume that shifting from small-seeded, dull to large-seeded, shiny coated mungbean and keeping the yield constant (i.e., quality change at the same yield level) will give higher output prices, without involving additional cost. Therefore, as the demand curve shifts with quality improvement, the supply curve is assumed to be unchanged in this analysis. However, unlike Unnevehr (1986), the price is allowed to change as quality improves.

Figure 13 depicts the effect of improvement in quality which shifts the demand curve from D_0 to D_1, while the supply curve is unchanged at S_1. This will generate consumers' surplus equal to area D_0CAD_1 minus area P_1CBP_0 and producers' surplus equal to area P_1ABP_0. These areas can be estimated algebraically as follows:

Consumers' surplus by quality improvement in mungbean

$$=\nabla CS^*_m = P_{0m}Y_{0m}(k^*_m - Z^*_m)(1+0.5Z^*_m\alpha_m) \qquad \text{(A4.4)}$$

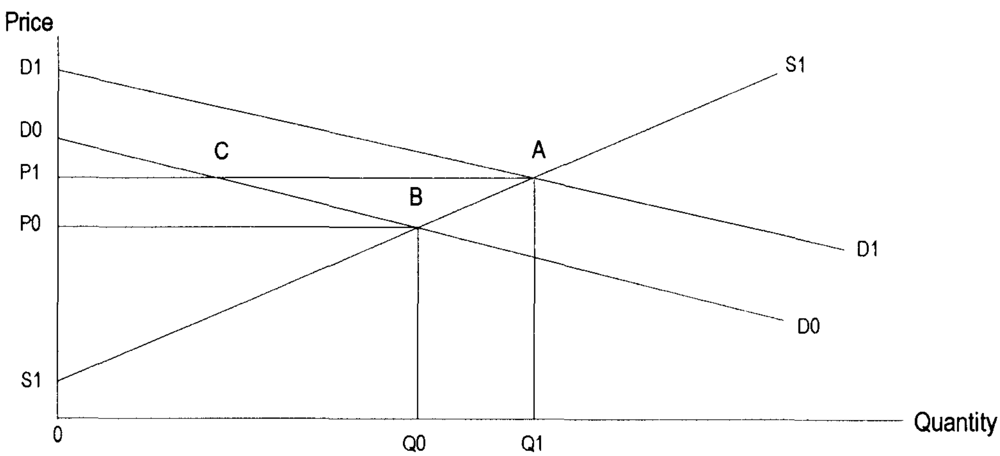
Producers' surplus by quality improvement in mungbean

$$=\nabla PS^*_m = P_{0m}Y_{0m}Z^*_m(1+0.5Z^*_m\alpha_m) \qquad \text{(A4.5)}$$

Total surplus by quality improvement in mungbean

$$=\nabla TS^*_m=\nabla CS^*_m+\nabla PS^*_m=P_0Y_0k^*_m(1+0.5\, Z^*_m\, \alpha_m) \qquad \text{(A4.6)}$$

Figure 13. Effect of improvement in mungbean quality on consumers' and producers' surplus



Consumers' surplus = $P_1A_1D_1 - P_0BD_0 = D_0CAD_1 - P_1CBP_0$
Producers' surplus $=P_1ABP_0$

where * represents the quality improvement change, k^* is the shift in the demand curve in proportion to the original price, and $Z^*_m = k^*_m \varepsilon/(\alpha+\varepsilon)$ is the increase in price after the demand shift.

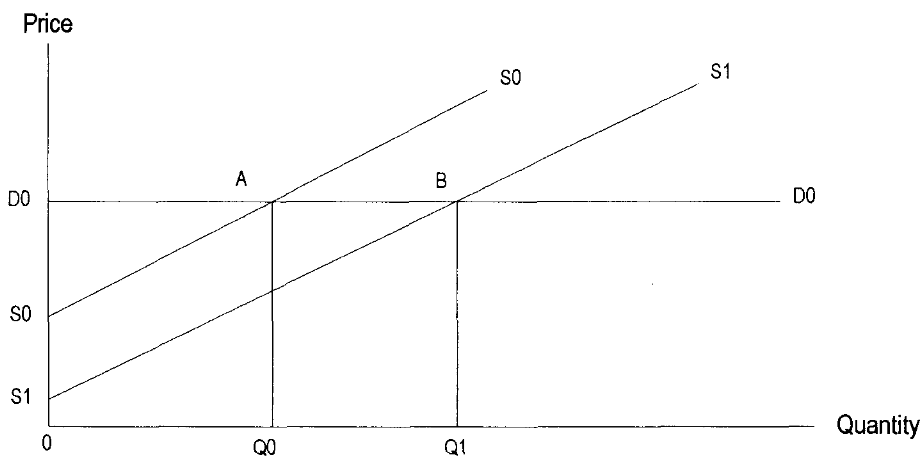
Appendix 4.2.2 Residual Effect

Because wheat cultivation after mungbean demands less inputs and produces higher yield per unit of land, mungbean-wheat rotation will improve the economics of wheat cultivation. This effect will be present whenever wheat follows mungbean, irrespective of the variety. However, improvement in mungbean yield induced an expansion in its cultivation, and increased the area under mungbean-wheat rotation in mungbean growing districts. Thus, the sustainability effect of mungbean on wheat cultivation expanded to new areas of mungbean cultivation. Previously, most of the wheat area in major mungbean growing districts was followed by fallow or other crops. There has been an increase in mungbean-wheat rotation.

It is assumed that the residual effect of mungbean will influence only two percent of wheat area in the country. Therefore, such an effect would not generate a substantial additional wheat supply, and is even less likely to change the wheat price (Figure 14). In estimating the spillover effect of mungbean expansion on wheat, it can be safely assumed that wheat producers in mungbean growing areas face a completely inelastic demand curve, which implies no change in prices and no effect on consumers. The producers' surplus in wheat generated through the spillover residual effect of the modern mungbean varieties and their accompanying technologies can be estimated using the equation (A4.7) by replacing *m* with *w*, and suppressing the value of *Z* to zero as follows:

Producers' surplus due to residual effect on wheat $= \nabla PS_W = P_{W0} Y_{W0}\, k_W$ (A4.7)

Figure 14. Producers' surplus generated through residual effect of mungbean on wheat



Producers' surplus = ABS_0S_1

where subscript w is the wheat crop, k_W is the shift in the wheat supply curve when wheat follows mungbean on the extended mungbean area. Y_{w0} is the wheat production from the extended mungbean area at the yield level observed in the other-wheat rotation, and P_{w0} is the prevailing wheat price at the time of survey.

Appendix 5 Data Used in Estimating the Gains From Mungbean Innovations

#	Parameter	Unit	Value	Source/remarks
1.	Price elasticity of mungbean supply (α_m)	%	1.178	Ali (1996)
2.	Price elasticity of mungbean demand (ε_m)	%	0.689	Ali (1996)
3.	Price elasticity of wheat supply (α_w)	%	0.327	Ali (1990)
4.	Demand elasticity of wheat (ε_w)	%	0.000	This is because mungbean effect is limited to relatively small wheat area.
5.	Yield of Desi mungbean	t/ha	0.579	Table 21
6.	Mungbean area before innovation started	ha	100000	Government of Pakistan (1995)
7.	Current area	ha	167900	Government of Pakistan (1995)
8.	Expansion in area during 1986-1993	ha	67900	Estimated as #7 - #6
9.	Production before the start of innovations(Y_{mi})	t	57900	Estimated as #5 x #6
10.	Production on the existing area with Desi variety (Y_{m0})	t	97248	Estimated as #5 x #7
11.	Cost/kg of Desi mungbean	Rs/kg	6.839	Table 21
12.	Cost/kg of modern variety mungbean	Rs/kg	4.791	The Weighted average cost of MV in Table 21
13.	Shift in cost or supply curve of mungbean (k_m)	%	29.9	(#11 - #12)/#11 x 100
14.	Proportion of area under modern variety	ha	0.88	Table 16
15.	Shift in supply curve of wheat (k_w)	%	26.5	Estimated as the percentage reduction in cost per kg of wheat when grown in mungbean rotation compared to in other-wheat crop rotation, both are given in Table 28.
16.	Price of Desi mungbean or initial price (P_{m0})	Rs/t	8940	Table 21
17.	Price of large-seeded mungbean	Rs/t	9960	Table 21
18.	Shift in mungbean demand function due to improvement in quality	(%)	0.114	(#17 - #16)/#16 x 100
19.	Price of wheat (P_{w0})	Rs/t	4129	Table 28
20.	Wheat yield in fallow-wheat rotation	t/ha	2.649	Table 28
21.	Wheat production (Y_{w0})	t	179867	Estimated as #18 x #19
22.	Official exchange rate	Rs/US$	30.85	Government of Pakistan (1996)