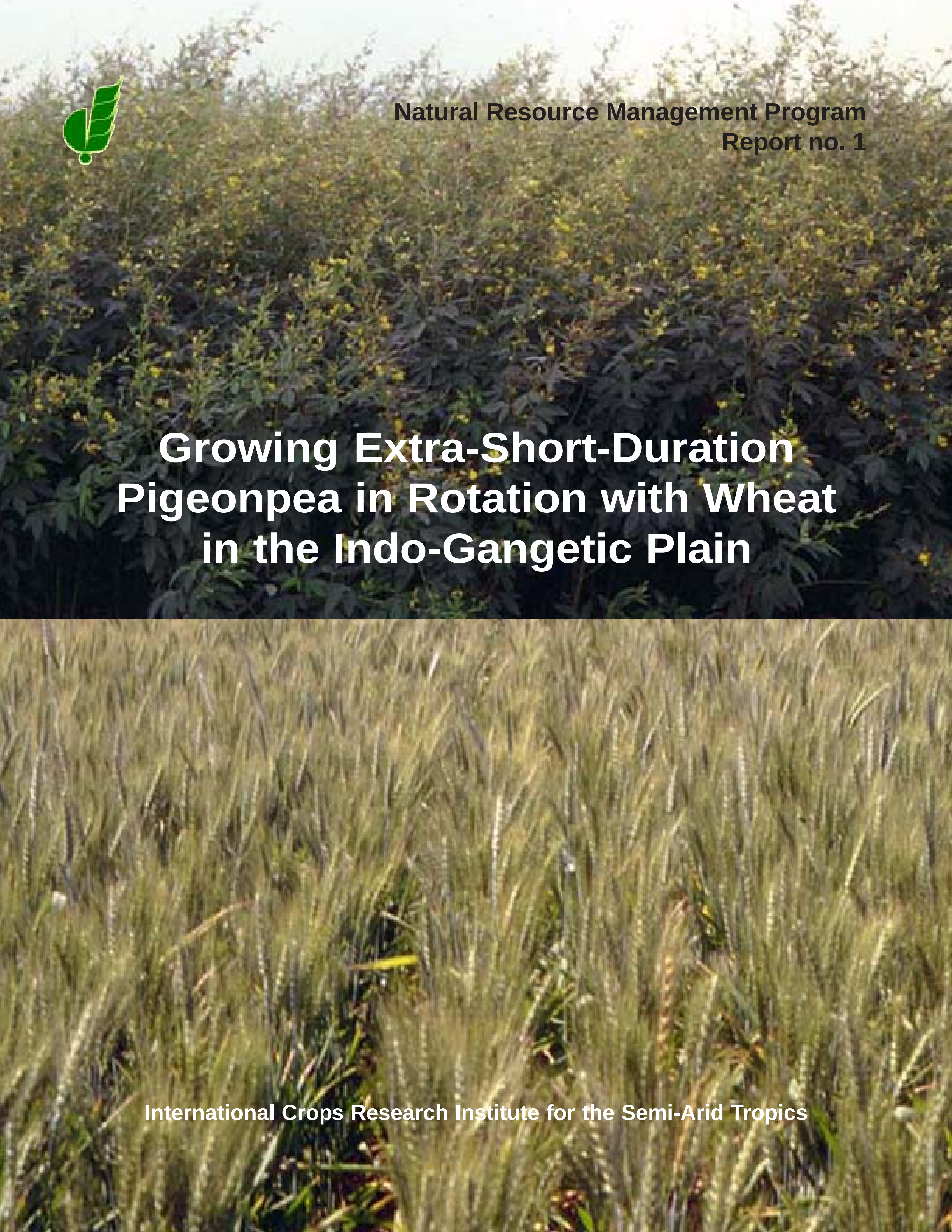

Natural Resource Management Program
Report no. 1

Growing Extra-Short-Duration Pigeonpea in Rotation with Wheat in the Indo-Gangetic Plain

International Crops Research Institute for the Semi-Arid Tropics

Abstract

Extra-short-duration pigeonpea [*Cajanus cajan* (L.) Millsp.] is a relatively new plant type, which has been primarily bred to replace short-duration pigeonpea (SDP) for cultivation in rotation with wheat in the western Indo-Gangetic Plain of South Asia. This book summarizes the experiences with on-farm testing of extra-short-duration pigeonpea (ESDP)-wheat rotation vis-a-vis SDP-wheat rotation conducted at three locations -- Sonepat, Ghaziabad, and Ludhiana in northwestern India, from 1995 to 2000. Extra-short-duration pigeonpea genotypes matured two to four weeks earlier than SDP cultivars, yet produced up to 16% higher yield. Yield of the following wheat crop was 0.75 to 1 t ha^{-1} more after ESDP genotypes than after SD cultivars or rice. Farmers preferred ESDP genotypes to SD cultivars because of increased yield and early maturity, enabling timely sowing of wheat. The realized mean yield of ESDP genotypes in farmers' fields was about 1.5 t ha^{-1}, which though greater than SDP cultivars was about half of their potential. The major abiotic, biotic, socio-economic constraints that limit realization of potential yield and widespread adoption of ESDP are discussed. Currently recommended practices for maximizing their yield and precautions to be taken for seed production and storage are also highlighted.

The research activities reported and cost of publication of this book were partly supported by the Asian Development Bank.

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Growing Extra-Short-Duration Pigeonpea in Rotation with Wheat in the Indo-Gangetic Plain

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Contents

Introduction

The introduction of high yielding cultivars of rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) and their intensive production technology since the 1960s has contributed greatly to increased food production in the Indo-Gangetic Plain (IGP) in South Asia. Popularly known as the “Green Revolution”, this appreciably increased the food security, reduced rural poverty, and increased affordability of food at cheaper prices. Inevitably, this encouraged large-scale sequential cropping of rice and wheat in millions of ha even in non-traditional areas for both crops. Unfortunately, this cereal monocropping is showing signs of fatigue and concerns are now being expressed about the sustainability of rice-wheat systems (Hobbs and Morris 1996). Continuous cultivation of rice and wheat is lowering soil fertility and organic matter (Yadav et al. 1998), depleting ground water resources in tube-well irrigated areas (Gulati 1999), and exacerbating weed, disease and pest problems (Pingali and Gerpacio 1997).

It has been suggested that if these systems could be appropriately diversified, especially with legumes, the system of sustainability could be enhanced and the process of land degradation reversed (Joshi 1998; Ali et al. 1998, 2000). In particular, legumes have potential to make substantial contributions to the nitrogen (N) economy, ability to extract nutrients from deep soil layers (Chauhan 1993), utilize insoluble or fixed P and make it available to succeeding crops (Ae et al. 1990), and improve physico-chemical properties of saline–alkali soils (Dhawan 1958). The ameliorative effects of legumes in the cropping systems are well known to farmers in the region, but legumes are relegated to marginal lands because of low profitability and high risks compared to rice and wheat (Joshi et al. 2000). During the last three decades, rice and wheat have replaced legumes in nearly 3 million ha area in the IGP (Kumar et al. 1999). Most traditional cultivars and land races of legumes take a long time to mature, and are unable to fit into rotation with either rice or wheat.

Development of high yielding short-duration cultivars of legumes has, however, created a fresh opportunity for the greater inclusion of legumes in the rice-wheat system. Such cultivars can be grown either as catch crop in rice-wheat (e.g., with mungbean (*Vigna radiata* (L.) Wilczek) and black gram (*Vigna mungo* (L.) Hepper), or in rotation with rice (e.g., with chickpea (*Cicer arietinum* L.) or wheat (e.g., with pigeonpea (*Cajanus cajan* (L.) Millsp.). Pigeonpea is one such legume in which breeding of high yielding short-duration cultivars has been highly successful (Singh 1996). Short-duration pigeonpea (SDP) cultivars have permitted establishment of a new pigeonpea-wheat cropping system in the northwestern plain of India. However, because wheat sowing is often delayed in this crop rotation, development of extra-short-duration pigeonpea (ESDP) cultivars that will mature 10-15 days earlier than SDP cutlivars has received attention (Singh et al. 1987). However, adoption of ESDP cultivars did not become visible.

Following the recommendations of a workshop on ESDP (Singh et al. 1996), ICRISAT coordinated joint on-farm research and development efforts in the northwestern Indo-Gangetic Plain (IGP) involving the Chaudhary Charan Singh Haryana Agricultural University (CCSHAU), Haryana; the Punjab Agricultural University (PAU), Punjab; the G.B. Pant University of Agriculture and Technology (GBPUA&T), Uttaranchal (previously Uttar Pradesh), with financial support from the Asian Development Bank, through the project on "Legume-based Technologies for Rice and Wheat Production Systems in South and Southeast Asia". This book, which is an outcome of these efforts, makes an appraisal of opportunities, constraints and farmers' perceptions for the ESDP-wheat rotation in the IGP.

Pigeonpea-Wheat Rotation

Pigeonpea is a rainy season crop, which requires little input of fertilizer, and due to its deep root system thrives well even under limited rainfall situations. It can provide considerable residual benefit for the succeeding crops such as wheat (Johansen et al. 1990). The crop has been traditionally grown as an intercrop or mixed crop with a number of cereals such as sorghum (*Sorghum bicolor* L.), pearl millet (*Pennisetum glaucum* L.), and maize (*Zea mays* L.) when sown at the beginning of rainy season (Fig. 1). Pigeonpea-wheat rotation is relatively new production system replacing rice or other rainy season cereals with pigeonpea (Fig. 1). The primary reasons why pigeonpea has been considered an remunerative break (diversification) crop for rice-wheat systems are: remunerative price for its grain, less requirement of water, fuel-wood yield and its ability to improve soil fertility. A number of short-duration pigeonpea (SDP) cultivars that can fit in rotation with wheat have been developed under the aegis of the All India Coordinated Pulses Improvement Project in the 1960s, and later at ICRISAT from 1972. The system that was based on SDP, however, could not find an anticipated adoption and the area stagnated at about 150,000 ha. The available SDP cultivars were susceptible to pests, had smaller seed size, low and unstable yields, and forced delayed wheat sowings. Their tall plant height made management of pests difficult. This necessitated development of extra-short-duration pigeonpea (ESDP) cultivars having bold seed size, and less susceptibility to insect pests and diseases for pigeonpea-wheat rotation.

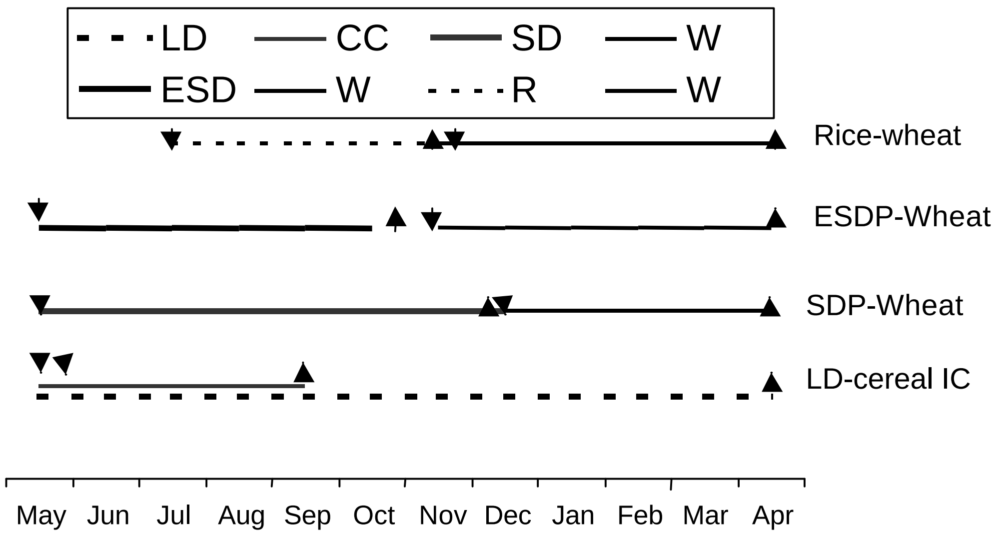

Figure 1. Pigeonpea, rice and wheat-based cropping systems in pigeonpea with approximate sowing (↓) and harvesting times (↑) of sequences; LD = long-duration pigeonpea, Cereal IC = cereal inter-crop; SD = short-duration pigeonpea; ESDP = extra-short-duration pigeonpea; and R = rice and W = wheat, CC = cereal crop.

Extra-short-duration Pigeonpea Plant Type

The ESDP takes about 120 to 150 days to mature compared to 180 to 270 days taken by the traditional medium- and long-duration types. Some ESDP genotypes, irrespective of latitude, mature up to about three weeks earlier than SDP cultivars (Gupta et al. 1989). The subtropical environment of the IGP favors better growth and dry matter production of ESDP than the tropics. The flat-topped canopy of determinate ESDP genotypes make them more vulnerable to pests, but efficacy of pesticide application is somewhat higher due to shorter height and pods in clusters (Gupta et al. 1991). In contrast, the indeterminate ESDP genotypes tend to be taller, but generally suffer less damage from pod-and flower-damaging insect pests, and produce more fuel-wood. However, determinate genotypes may be marginally more productive under pesticide protected conditions whereas indeterminates may be superior under unprotected conditions. There is no physiological advantage of determinate growth habit in terms of dry matter partitioning, yield and maturity period among cultivars of comparable phenology. However, the advantage of determinate ESD types in escaping terminal drought and superiority over other tropical legumes has been documented (Nam et al. 1993; Chauhan et al. 1999). There has, however, been little effort made to compare the productivity of determinate and indeterminate ESDP plant types in wheat-based production systems for which it was initially designed (Singh 1996).

Methodology Used for Participatory On-farm Testing

The on-farm trials were conducted at three benchmark locations, in Sonepat district (28^{o}N) in Haryana, in Ghaziabad district (28^{o} N) in Uttar Pradesh (now Uttaranchal) and in Ludhiana district (30 ^{o}N) in Punjab (all in India) to determine the suitability of ESDP genotypes (ICPL 88039 and 85010) vis-à-vis SDP cultivars in rotation with wheat, and to identify constraints to their production. Farmer participatory testing of ESDP or SDP cultivars/genotypes was done by offering farmers a number of cultivars/genotypes for them to identify acceptable genotypes through farmers' field evaluation. This provided information on the consequences of including these genotypes in actual production systems, farmers' preferences, and likely benefits to them. The other advantage of on-farm testing was the direct exposure of genotypes to the complexity of social and natural environments. A simple indicator of preference was the farmer's intention to grow a particular cultivar/genotype in the next season. For a non-performing cultivar/genotype quick fading of interest by farmers became clearly evident. Farmers managed the trials with technical inputs from scientists.

Sonepat (Haryana, India)

Sonepat is a typical wheat growing area in the Haryana state. Short-duration pigeonpea (SDP) was grown in the district prior to the introduction of extra-short-duration pigeonpea (ESDP). The district typically receives about 650 mm annual rainfall, with wide fluctuations (Fig. 2). In order to examine the potential of the ESDP genotypes, ICPL 85010 (determinate, ESDP), ICPL 88039 (indeterminate, ESDP) and control cultivar Manak (SDP, indeterminate) were offered to the farmers for testing in their fields (0.4-0.6

ha per farmer). Each field was further subdivided into as many plots as were the genotypes. The number of locations each genotype was tested is given in Table 1. Each on-farm trial constituted an individual replication. Pre-sowing irrigation was usually given at each trial site for better preparation of fields and ensuring adequate moisture in the seeding zone. The crop was given a basal fertilizer of 18 kg N and 20 kg P ha^{-1} and seed rate of 15 kg ha^{-1} was used. The trials were sown in rows at 40 cm spacing and a plant population of 10-12 plants m^{-2} maintained. Sowing dates of different trials varied from 25 to 27 June in 1995, 1 May to 18 June in 1996, 8 May to 20 June in 1997, 22 May to 28

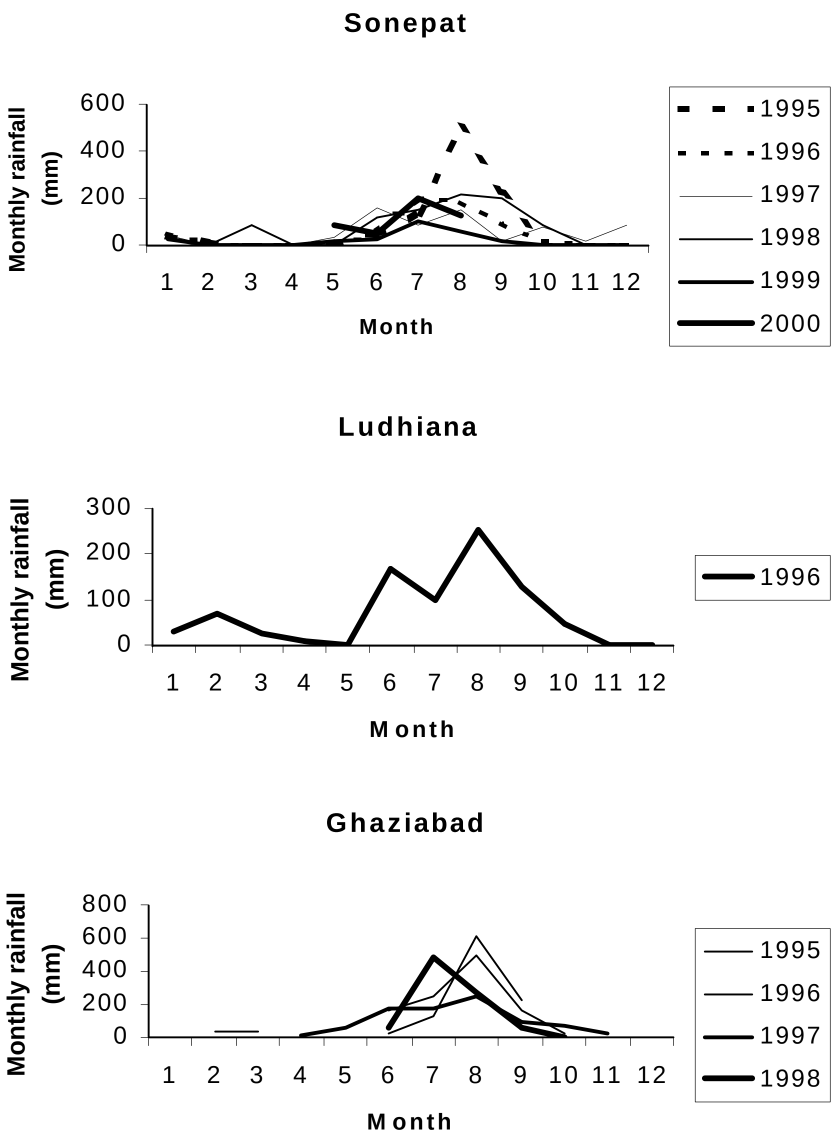

Figure 2. Monthly rainfall data of Sonepat (1995-2000), Ludhiana (1996) and Ghaziabad (1995-98), India.

June in 1998, 19 May to 22 June in 1999, and 25 May to 15 June in 2000. One hand weeding was done at about one month after sowing to keep the fields weed free.

Besides a pre-sowing irrigation, irrigation was applied at the flowering or pod formation stage to overcome the adverse effects of protracted drought in 1999 and 2000 rainy seasons. The ESDP genotype ICPL 88039 (indeterminate) and SDP cultivar Manak (indeterminate) were not sprayed at all for the control of pod borer (*Helicoverpa armigera*). However, ESDP genotype ICPL 85010 (determinate) was sprayed with endosulfan (0.07%) at pod initiation stage and the spray was repeated with cypermethrin (0.04%) after 10 days of the first spray for the control of pod borer. Blister beetle (*Mylabris pustulata*) attack was sporadic and localized; therefore, the pigeonpea crop was sprayed with diclorovos (0.05%) at flowering stage only at a few sites. A wheat crop in each trial followed pigeonpea. However, data on wheat (cultivar HD 2329) yield was recorded from 1997/98 only. Wheat was sown after pre-sowing irrigation using a seed cum fertilizer drill at a row spacing of 20 cm, with seed rate of 125 kg ha^{-1}. A fertilizer dose of 120 kg N and 60 kg P ha^{-1} was given to the wheat crop. The full dose of P and one-third dose of N were applied as a basal dose at sowing, and the remaining N was applied in two equal doses, coinciding with the first and second irrigations. Five irrigations were applied to wheat at about tri-weekly intervals after sowing.

Table 1. Grain Yield (t ha^{-1}) of extra-short-duration genotypes and short-duration pigeonpea cultivars grown during 1995-2000 at Sonepat, Haryana, India.

	ESDP genotypes		SD cultivar
Year	ICPL 85010	ICPL 88039	Manak
1995	1.46 ± 0.103 (4)[a]	---- [b]	1.32 ± 0.065 (4)
1996	1.28 ± 0.078 (10)	1.42 ± 0.091(8)	1.19 ± 0.088 (9)
1997	1.48 ±0.050 (5)	1.65 ± 0.079 (11)	1.56 ± 0.087 (9)
1998	----	1.20 ± 0.045 (24)	0.90 ± 0.038 (11)
1999	-----	1.46 ± 0.039 (15)	1.32 ± 0.073 (10)
2000	------	1.65 ± 0.023 (25)	1.40 ± 0.019 (25)
Mean	1.41	1.48	1.28
CV(%)	7.83	12.7	17.4

[a] Number of locations

[b] Indicates not tested in that year

Four additional on-farm trials to compare rice-wheat, SDP-wheat and ESDP-wheat systems were conducted in 1998 and 1999. Rice (cultivar Tarawari Basmati), SDP (Manak) and ESDP (ICPL 88039) were followed by wheat (cultivar PBW 343). Pigeonpea sowing dates ranged between 28^{th} May and 7^{th} June and other packages followed were the same as in other trials. Rice was transplanted in a puddled field during the second week of July and was grown by maintaining 35-40 plants m^{-2} and fertilized with 125 kg diammonium phosphate (DAP) and 125 kg urea (to give 93 Kg N, and 25 kg P ha^{-1}), and 25 kg of $ZnSO_4$ ha^{-1}. Full doses of DAP, $ZnSO_4$ and half dose of urea were applied at the time of sowing. The remainder of nitrogen was applied in two equal doses at 25 and 42 days after transplanting. The rice crop was irrigated to maintain a water level at around 3-4 cm at above the soil surface throughout the crop season. Wheat after rice and pigeonpea was sown after preparing the land by disking and planking to break clods. The sowing dates of wheat after ESDP were 20 to 25 November in 1998, and 18 to 24 November in 1999; whereas after SDP and rice, wheat was sown from 6 to 10 December in 1998 and from 5 to12 December in 1999. For wheat, all the crop practices followed were as specified earlier.

To find out the effect of diversification of a rice-wheat cropping system (RWCS) through inclusion of pigeonpea, particularly on weed intensity (*Phalaris minor*) in the wheat crop, observations were recorded in three farmers' fields. Rice-wheat sequence was continuously followed in the preceding four cropping cycles (1995/96 to 1998/99), and during the fifth cycle (1999/2000) it was replaced by ESDP-wheat rotation. The observations were recorded at each site from 1 x 1m quadrants.

Sixty three small size farm-holders (<3 ha) comprising 62 men and 1 woman farmers who had grown ESDP and SDP during the preceding five years were interviewed at the end of year 2000 rainy season about their perceptions on ESDP-wheat rotation vis-à-vis SDP-wheat rotation. The spouses and other family members assisted farmers in framing opinions about the fuel-wood potential and taste of ESDP. The information from each farmer was compiled using a structured questionnaire.

The yield potential of pigeonpea and wheat were determined using the pigeonpea and wheat modules of the Agricultural Production Systems Simulator (APSIM) Model (McCown et al. 1996). The daily rainfall, solar radiation, maximum and minimum temperatures used for predicting yield of pigeonpea was from Delhi (near to Sonepat).

Ludhiana (Punjab, India)

An on-farm trial was conducted on sandy loam soil during 1996/97. The annual rainfall for the year was around 827 mm (Fig. 2). ESDP genotypes (ICPL 88039, ICPL 85010 and AL 201) and SDP cultivar (T 21) were sown on 7 June 1996 in rows (50 cm x 25 cm) giving about 8 plants m^{-2}. The individual plot measured about 0.1 ha. There were three replications. The standing crop of pigeonpea was irrigated four days before uprooting to allow soil to become soft for land preparation for wheat sowing. Immediately after uprooting pigeonpea, land was prepared and wheat (cv. HD 2329) was sown. Only four irrigations were given at 22, 53, 72 and 108 days after wheat sowing. Fertilizer doses, application method and other packages were similar as described for Sonepat.

Ghaziabad (Uttar Pradesh, India)

The annual average rainfall was about 1000 mm with wide fluctuations (Fig. 2). The ESDP genotypes (ICPL 88039 and ICPL 85010) and SDP cultivars (UPAS 120, Manak, Pusa 33 and ICPL 151) were tested in on-farm trials conducted on sandy loam soils. The number of trials conducted for each cultivar is given in Table 2. Sowing dates varied from 13 May to 27 June in 1995, 20 May to 13 June in 1996, 28 May to 14 June in 1997 and 9 May to 26 May in1998. Pre-sowing irrigation was given to establish crop in May. Sowings were done through broadcasting, and thinning was done to maintain the optimum plant population at about 10-12 plant m^{-2}. The other packages followed for pigeonpea were as described for Sonepat. The plot size was about 1000 m^2.

Data Collection and Analysis

Data on pigeonpea and wheat yields (where recorded) were collected from the entire plot at the maturity of respective crop. A few plots that were badly damaged in 1996-97 at Sonepat and Ghaziabad by blue-bull grazing and waterlogging in the early stages, were rejected. The individual farmer's field was considered a replication. The standard error of means for each cultivar within each season was then calculated for particular location. Farmers' perceptions were expressed as percentage of total respondents. Pod borer damage as percentage of bored pods was recorded during 1996-97 from a sub-sample of 100 pods on the basis whether they had a hole in them or not.

Table 2. Grain Yield (t ha^{-1}) of extra-short-duration (ESD) and short-duration (SD) pigeonpea cultivars during 1995-1998 at Ghaziabad, Uttar Pradesh, India.

	ESD genotypes		SD cultivars	
Year	ICPL 85010	ICPL 88039	UPAS 120	Manak
1995	1.18 ± 0.088(13)[a]	1.80	1.04 ± 0.075(7)	1.08
1996	1.54 ± 0.137(8)	1.29 ± 0.097(8)	-	-
1997	1.31 ± 0.071(6)	-[b]	1.10 ± 0.086(2)	-
1998	0.87 ± 0.050(5)	-1.00 ± 0.072 (3)	-	
Mean	1.22	1.54	1.05	1.08
CV(%)	13.87		3.0	

[a]. Figures in parantheses represents the no. of trials/observations. Only one observation on Manak during 1995. [b]. Not grown by farmers due to limitation of seed.

Potential Productivity of Pigeonpea-Wheat Rotation

The APSIM model prediction of mean pigeonpea yields for four cropping seasons (from 1995 to 1998) under non-limiting moisture supplies were about 3.1 t ha^{-1} for May sowing and 2.2 t ha^{-1} for June sowing (Fig. 3). The highest recorded yield from the ESDP from the IGP in large plots was about 3 t ha^{-1} at Hisar (29^{o} N). The greater yield potential in the May sowing was largely due to greater growth resulting in more pods plant^{-1}. The comparative yield potential of SDP was 2.5 t ha^{-1} for May sowing and 1.6 t ha^{-1} for June sowing. The APSIM predicted 4.7 t ha^{-1} yield of wheat after the May-sown crop of ESDP and 3.0 t ha^{-1} after the June-sown crop. Comparative predicted yields of wheat were 4.2 t ha^{-1} after SDP after the May-sown crop and 3.2 t ha^{-1} after the June-sown crop. ESDP yielded better irrespective of sowing date, and wheat yields were high after May-sown ESDP. The potential of the entire system, however, remained to be verified in farmers' fields.

Time to Maturity of ESDP and SDP in Farmers' Fields

The ESDP genotypes ICPL 88039 and ICPL 85010 matured about two to three weeks earlier than SD cultivar Manak (Fig. 4). The differences in maturity time tended to be slightly smaller in later sowings (data not shown). The earlier maturity of ESDP is of vital importance for farmers as it provides them sufficient time to prepare their lands for timely wheat sowing, whereas wheat sowing is invariably delayed after SDP cultivars.

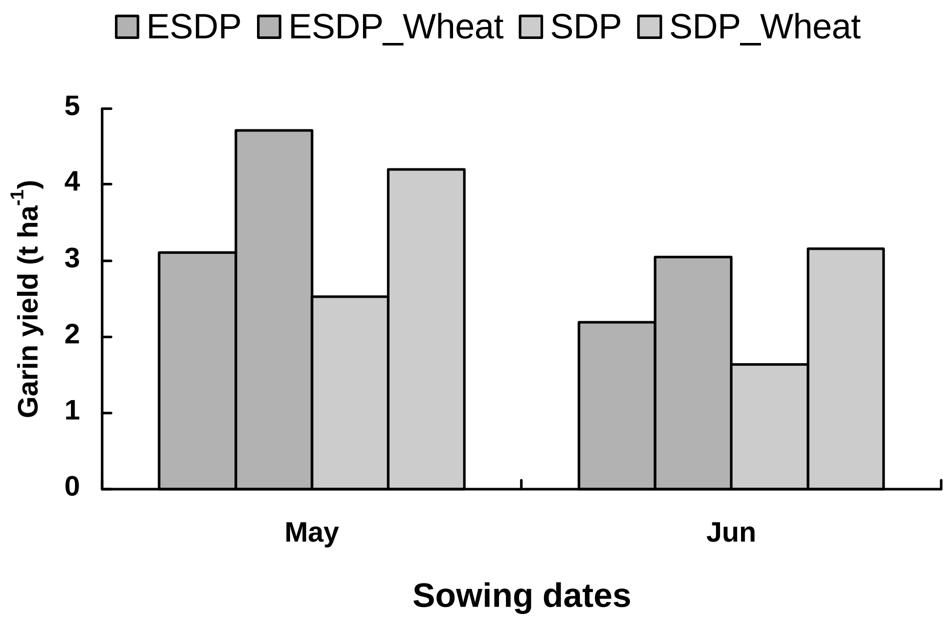

Figure 3. The yield potential (t ha^{-1}) of extra-short-duration pigeonpea genotype and wheat as predicted by the Agricultural Production Systems Simulator (APSIM) model for the Sonepat environment.

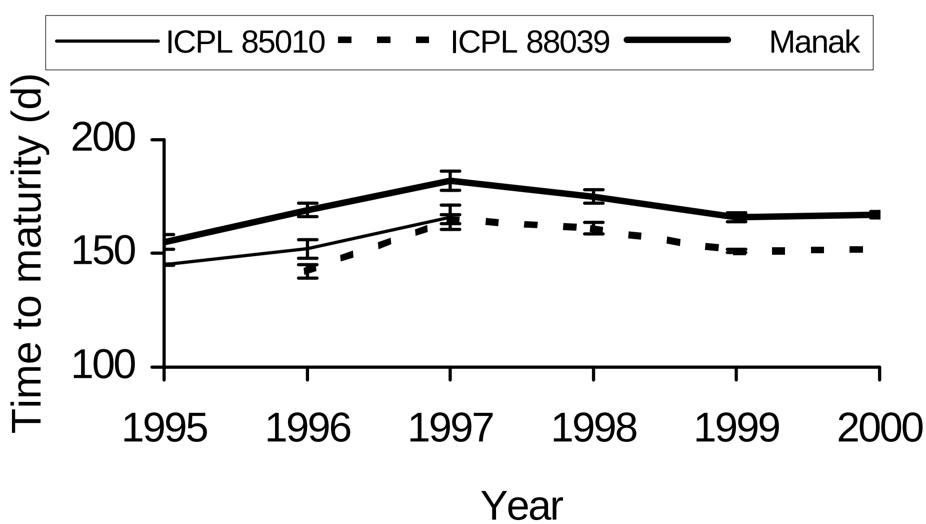

Figure 4. Time to maturity of extra-short-duration pigeonpea genotypes ICPL 85010 and ICPL 88039 and short-duration pigeonpea cultivar Manak in different years at Sonepat, India. Standard error of means are shown for individual year observations for each genotype.

Realized Yield of Pigeonpea in Farmers' Fields

At Sonepat (Haryana, India), ESDP genotype ICPL 88039 gave the highest yield which was 5% more than ICPL 85010 and 16% more than SDP control cultivar Manak (Table 1). Higher yield of ICPL 88039 as compared to Manak correlated with lesser damage by *Helicoverpa armigera* (Fig. 5). Less pod damage in ICPL 88039 may be attributed due to early maturity (Fig. 4) or other tolerance mechanisms. This is a crucial advantage of this genotype considering that it grows profusely making insecticide application very difficult (Fig. 6). Its early flowering may also allow relatively better soil moisture conditions during the reproductive phase; soil moisture becomes limiting, especially for SDP, if the monsoon withdraws early. Its seed size was also bigger than that of Manak (Fig. 7). ICPL 85010 also yielded more than cultivar Manak even though it had highest pod-borer damage (Fig. 5) and plant measures were applied. Being a determinate plant type, it required greater insecticide protection due to its determinate nature (Gupta et al. 1991).

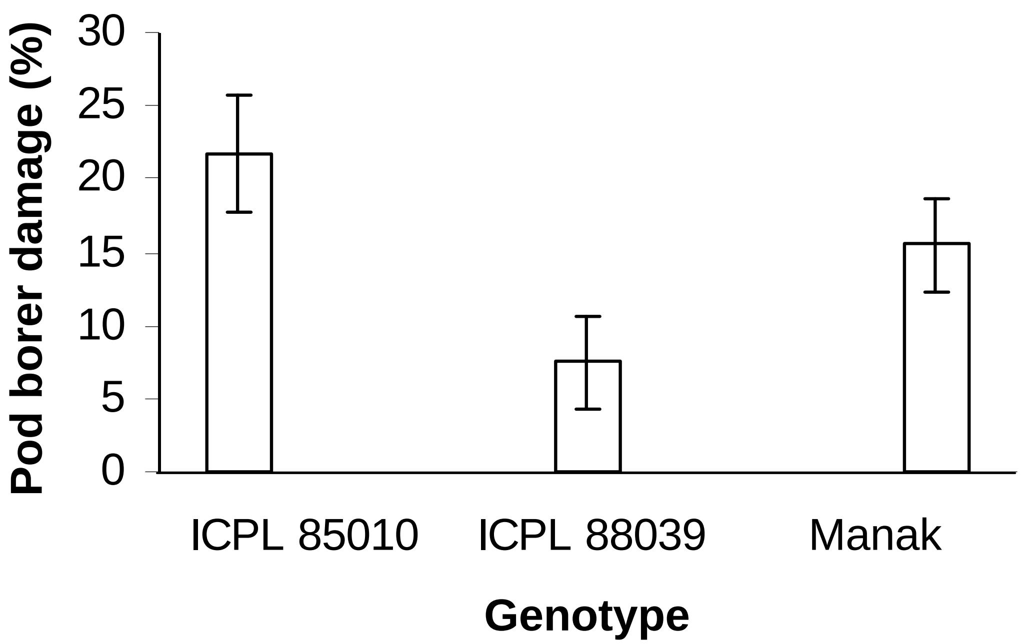

Figure 5. Mean relative pod borer damage in extra-short-duration pigeonpea genotypes ICPL 85010, ICPL 88039 and short-duration pigeonpea cultivar Manak grown in farmers` fields during 1996-97 at Sonepat, Haryana, India.

Figure 6. Under normal conditions, the extra-short-duration grow profusely in the Indo-Gangetic Plain posing difficulty in insecticide protection. Genotype ICPL 88039 seems to be less susceptible to pod borers requiring few insecticide sprays.

Figure 7. Seed size differences between short-duration cultivar Manak (right) and extra-short-duration genotype ICPL 88039 (left). A 30% seed size advantage of ICPL 88039 enables farmers to realize a better market price of their produce.

At Ludhiana (Punjab, India), the grain yield of SDP and ESDP genotypes was similar, at about 1.6 t ha^{-1} (Table 3). However, genotypes ICPL 85010, ICPL 88039 and AL 201 matured about four weeks earlier than SDP cultivar T 21, which matured in 170 days. The seed size of ICPL 88039 was about 30% more (9 g 100-$seeds^{-1}$) than that of T 21 or AL 201 (Table 3). Farmers prefer pigeonpea genotypes having about 10 g 100-$seeds^{-1}$ weight because of better price. Small seed size results in low *dhal* recovery and thus overall profitability to millers is less (Singh and Jambunathan 1981). Bolder seeds have additional advantages of tolerance to high temperature and ability to emerge from deeper sowings (Srivastava et al. 1998).

At Ghaziabad (Uttar Pradesh, India), mean yield across four seasons was highest for the ESDP genotype ICPL 88039 (1.54 t ha^{-1}), followed by ICPL 85010 (Table 2). ICPL 88039 was grown in only two seasons, as the required quantity of seed could not be made available to farmers. The yields of SDP cultivars Manak and UPAS 120 were almost similar (1 t ha^{-1}). There were wide variations in yield over the years (relating to fluctuations in rainfall), but the SDP cultivars were generally low yielding than the ESDP genotypes.

Table 3. Performance of short-duration and extra-short-duration pigeonpea genotypes in 1996 at Ludhiana, India.

Genotypes	Days to maturity	Yield (t ha^{-1})	Seed mass (g 100-$seed^{-1}$)
ICPL 85010	144	1.58	8.8
AL 201	144	1.60	6.8
ICPL 88039	144	1.69	9.0
T 21 (control)	170	1.66	6.8
SE (±)	6.5	0.025	0.59

Performance of Wheat grown after ESDP vs SDP

In trials conducted at Sonepat (Haryana, India) during the three cropping seasons 1997-99, the mean wheat yield was 4.51 t ha^{-1} when sown after ESDP genotype ICPL 88039 as compared to 3.79 t ha^{-1} after SDP cultivar Manak (Table 4). The higher yield of wheat after ICPL 88039 was due to timely sowing of wheat. These actual yield values are close to the APSIM predicted yield of wheat (Fig. 3). Wheat yield was lowest (3.64 t ha^{-1}) when it followed rice. There was a delay of two to three weeks when wheat was sown after SDP Manak or rice (Tarawari Basmati). However, yield of the wheat crop was marginally higher after Manak than after rice (Table 4). This might be attributed to addition of organic matter through senesced leaves and decaying roots, and residual N effect (of biological N-fixation) of pigeonpea on the succeeding wheat crop (Kumar Rao et al. 1983).

Table 4. Effect of rice (cultivar Tarawari Basmati), short-duration pigeonpea (SDP) cultivar Manak, and extra-short-duration pigeonpea (ESDP) genotype ICPL 88039 on the yield of following wheat crop during 1997-1999 at Sonepat, Haryana, India.

	Wheat yield (t ha^{-1})			
Cropping Systems	1997[a]	1998[b]	1999[b]	Mean
Rice-Wheat	---[c]	3.58±0.074	3.69±0.078	3.64
SDP-Wheat	3.93±0.076	3.67±0.066	3.76±0.062	3.79
ESDP-Wheat	4.68± 0.066	4.46±0.061	4.39±0.068	4.51

[a] wheat cultivar HD 2329 in 1997
[b] wheat cultivar PBW 343 during 1998-99
[c] not tested

At Ludhiana (Punjab, India) also wheat yield after SDP cultivar T 21 was up to 1 t ha^{-1} less than after ESDP genotypes (Fig. 8). This also confirmed that with the delay in harvest of pigeonpea due to longer maturity period, yield of wheat declined drastically. These results are consistent with the finding of Ortiz-Monasterio et al. (1994) who reported a reduction in wheat yield at the rate of 0.8% day^{-1} delay in sowing. The turnaround time between ESDP harvest and wheat sowing (Oct-Nov) seems to allow greater decomposition of senescent leaves and root residues than for SDP as it is favored by higher ambient temperature and moist soil during this period. This may cause greater residual benefit of ESDP to wheat.

An additional benefit of pigeonpea to wheat might have also come due to its suppressive effects on crop specific weed flora such as *Phalaris minor.* This weed has become a major problem in rice-wheat systems in South Asia (Hobbs and Morris 1996). Pingali and Gerpacio (1997) indicated that intensive mono-cropping of cereals increased the incidence of weeds. Observations made in the farmers' fields in Sonepat District (Haryana, India) also indicated that continuous cultivation of rice-wheat for four years

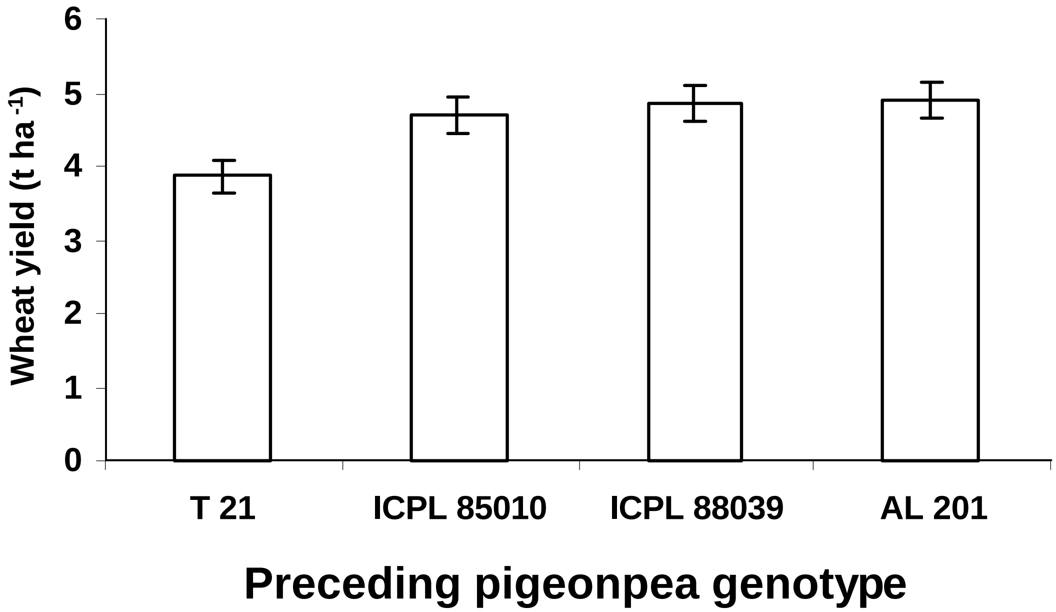

Figure 8. Performance of wheat crop after short-duration pigeonpea cultivar T 21 and extra-short-duration pigeonpea genotypes, ICPL 85010, ICPL 88039 and AL 201, Ludhiana, India, 1996/97.

(1995-1998) in sequence resulted in a considerable increase in the population of *P. minor* weed (from 17 to 84 plants m^2). Pingali and Shah (1999) suggested that disruption of a repeated cropping pattern could reduce the weed build-up. Indeed, the inclusion of pigeonpea in rotation with wheat in the fifth year as a break crop drastically reduced the *P. minor* population from 84 to 27 plants m^2 (Fig. 9). It is, however, not clear whether it is due to a break in crop sequence or an allelopathic effect of pigeonpea on *P. minor*. It was also observed that there was large-scale lodging in wheat when it was grown after rice. Though not quantified, visual observations indicated that lodging of wheat after pigeonpea was much less than after rice. It could be that rice fields develop hard pans, which can affect establishment of wheat and the subsequent strength of its root system in being able to support plant shoots. Pigeonpea roots are capable of breaking hard pans (Maurya and Lal 1980). Limited observations suggested that there was about 37% less wheat root mass per unit soil volume at maturity when it grew after rice as compared to when it followed pigeonpea. However, more studies are required to quantify and verify these observations.

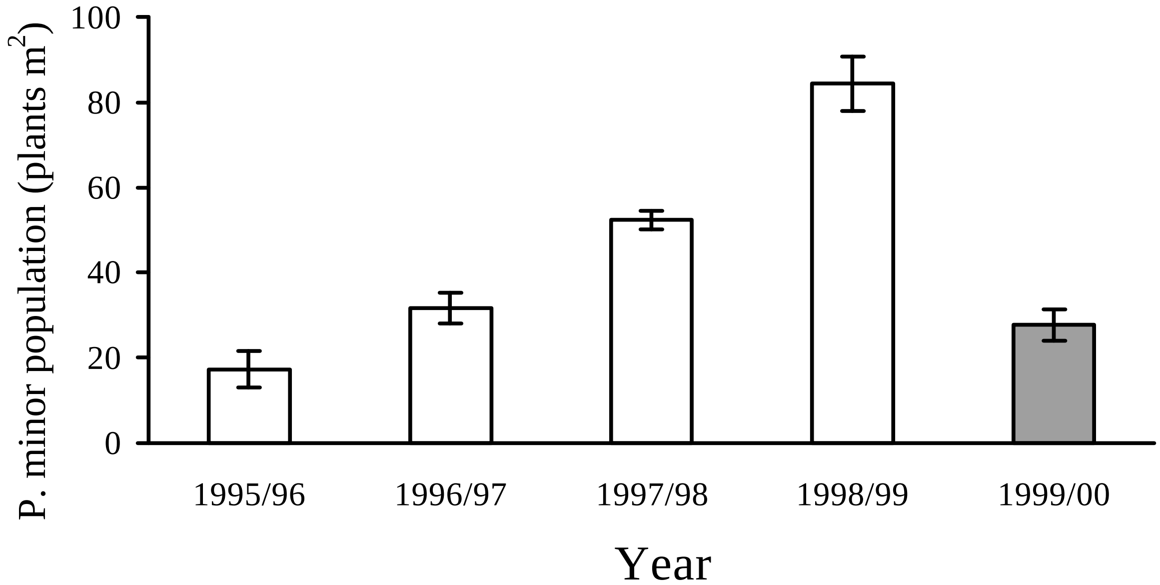

Figure 9. Mean Phalaris minor population in the wheat crop at three locations in farmers fields continuously cropped with rice-wheat during 1995-99 followed by pigeonpea-wheat in the rainy season 1999/00, Sonepat district, Haryana, India.

Farmers Perceptions on SD vs ESDP-Wheat Rotation

Since ESDP-wheat is a new cropping system, its success will depend on how farmers perceive its benefits, notwithstanding the yield advantage that may be apparent. Of the sixty-three small farmers interviewed, 78% indicated that early maturity of ESDP was a major advantage, 87% suggested that pest damage was lower, and 77% indicated that they obtained higher yield of wheat when it was grown after ESDP (Table 5). Only 53% of the farmers indicated that ESDP *per se* has yield advantage over SDP. Since pigeonpea was not consumed in this region traditionally, most of the farmers were not able to express their taste preference. However, most of the farmers (34%) who consumed ESDP liked its taste over SDP cultivars they had consumed. Their views on taste were endorsed by their family members. Seventy-five percent of the farmers indicated their preference for indeterminate ESDP (ICPL 88039) whereas 15% indicated their preference for determinate ESDP (ICPL 85010). A large number of farmers were now switching over to ESDP in the study area of the Sonepat district, (Haryana, India). Nearly 37% of the farmers have grown ESDP in the last five years compared to only 11% who have grown SDP in the last five years in the study area of the district.

At times, the extent of adoption of new cultivar depends a great deal on the perception and requirement of the women members of the family. A seemingly high yielding pest resistant cultivar of pigeonpea did not find favor with women farmers in the Medak district of Andhra Pradesh since it had poor taste (Pimbert and Women Sanghams 1991). The adoption of SDP in the western IGP to an extent has been inspired by a requirement of fuel-wood for cooking. Without this, women have to undergo drudgery of collecting fuel-wood from far-off places (Fig. 10). The interviews with women indicated that in addition to grain yield, fuel-wood of pigeonpea has excellent burning quality, it produces less smoke and ignites with lesser efforts. Nearly 85% of farmers considered that fuel-wood yield of ESDP genotypes was similar to that of SDP cultivars (Table 5).

Table 5. Perception of sixty three small land holder farmers about extra-short-duration pigeonpea as compared to short-duration pigeonpea, 2000 in Sonepat, Haryana, India.

Trait	Better	Similar	Poor	Can't say
Yield	53	47	-	-
Seed size	98	-[a]	-	2
Price	37	61	-	-
Days to maturity	78	20	-	-
Pests	87	7	-	5
Fuel wood	-	85	7	7
Taste	27	7	-	65
Wheat crop	77	8	-	15

[a] No respondent

Constraints to ESDP Production

Even though the realized yield of ESDP is higher or similar to SDP (Tables 1-3), this was about half of the potential (Fig. 3), whereas the realized yield of wheat was close to the predicted yield for these environments. The big gap in realized and potential yields of ESDP types could be due to several biotic, abiotic, and socio-economic and policy constraints. On-farm research with ESDP-wheat rotation has helped in further clarification of these constraints, some of which are also common to SD pigeonpea.

Focusing of efforts to overcome these constraints can make the ESDP-wheat rotation even more attractive and more remunerative than rice-wheat system. These constraints and their possible alleviation are summarized below.

Figure 10. Collecting fuel-wood and fetching water from far-off places constitute drudgery for rural women. A farming couple discusses how extra-short-duration pigeonpea can reduce wife's burden by providing a ready source of fuel-wood.

Biotic constraints

Insect-pests: These represent the major constraint to yield and its stability in the IGP (Singh et al. 1996). Pod borers (*Helicoverpa armigera*, *Maruca vitrata)*, and blister beetle (*Mylabris pustulata)* are the major pests that cause severe damage to flowers and developing pods. The damage by pod borers is more severe in the determinate genotypes (such as ICPL 85010) because they bear pods in clusters. The indeterminate genotypes (such as ICPL 88039) are less susceptible to pod borers. Damage by blister beetle is generally localized, but can be devastating. These pests cause delayed maturity as they damage developing flowers and pods, and if attack is severe, the reproductive phase of the crop is delayed into winter (December), thus affecting overall prospects of the crop. There are integrated pest management (IPM) strategies available to permit effective management of pod borers in ESDP (Shanower and Romeis 1999), but farmers are generally unaware of these. Further, extension of this IPM technology is crucial for continued adoption of ESDP.

Diseases: The major disease limiting ESDP is *Phytophthora* stem blight, the incidence of which increases when rainfall is high and pigeonpea is sown in low lying areas prone to waterlogging (Reddy et al. 1990). It is a fungal disease caused by *Phytophthora drechsleri* f. sp. *cajani*. The ESDP is more sensitive to *Phytophthora* blight as compared to SDP. The affected plants show formation of brown to dark brown lesions on the stem near the soil surface. These lesions rapidly girdle the whole stem resulting into the drying of plant. The symptoms may be confused with the symptoms of wilt disease. Roots of *Phytophthora* infected plants don't show black streaks i.e., discolored xylem tissue. The affected plants cannot be easily pulled out, as these break at the affected stem position whereas wilt affected plants are easy to pull out. Ensuring seedling growth (to 20-cm plant height) on well-drained soil usually permits escape from this disease.

Wilt is a potentially important disease of ESDP caused by *Fusarium udum* (Reddy et al. 1990). The fungus survives on plant debris in the soil. The leaves of the affected plants become yellowish in color, and then drop and finally the whole plant dries. These types of symptoms can be easily confused with shortage of soil moisture. Wilt symptoms develop though there may be plenty of moisture in soil. *Fusarium* wilt can be diagnosed by examining the streaks (discolored xylem tissue) on the wood after removing the outer epidermal strip from the major roots. The ESDP usually escapes wilt, but its continuous cultivation in the same piece of land can increase disease severity in future years. Cultivars with resistance to wilt are available.

Sterility mosaic disease (caused by virus) is another potentially important disease of pigeonpea which spreads from plant to plant under field condition through *Eriophyid* mites (Reddy et al. 1990). The affected plants become light greenish in color, which can be easily differentiated from healthy dark green leaves. Leaves are reduced in size. Affected plants remain stunted and branch profusely, as a result of which they appear bushy. No flowers and fruits are borne (hence the name sterility mosaic) on such affected plants resulting in total loss of yield. Sometimes only a few branches in the plant are affected while others remain healthy and in such cases the yield reduction is partial. The disease is a major constraint for long-duration pigeonpea in the IGP, but ESDP tend to escape it. This could be partly due to the long break period between the two sowings of ESDP unlike the long-duration land races in which two sowings often overlap and plants from previous sowing serve as a source of infection.

Weeds: ESDP has very slow initial growth rate and is highly susceptible to weed competition in the early stages of its growth. Due to shorter period of its life cycle as compared to SDP and long-duration pigeonpea, it is more severely affected by weed competition. Weeds compete with the crop for incident light, nutrients, and moisture, and also give shelter to various pests that attack pigeonpea also. Yield losses up to 30% have been observed in un-weeded crop (Sekhon et al. 1996). The most serious weeds of ESDP in the IGP are '*santhi'* (*Trianthema monogyna*) and nutgrass (*Cynodon dactylon*). Most farmers find it difficult to arrange necessary resources for timely manual weeding and are ignorant about chemical weed management procedures for pigeonpea or are unable to use them for economic reasons.

Blue-Bull: Being a tall crop, pigeonpea provides a place to hide for the blue-bull (*Boselaphus tragocamelus*) also known as '*Nilgai*', a species of antelope in the western IGP. The animal grazes pigeonpea pods, especially those found in clusters at the top of the canopy (Gupta and Kapoor 1990). The damage is usually lesser in indeterminate types that are relatively tall and in which pods are more widely distributed throughout the canopy. Blue-bulls can cause severe loss in yields, and are difficult to protect against because most damage is done during nights. They are also protected animals under the Wild Life Acts of most countries.

Abiotic contstraints

Drought and waterlogging: Drought and waterlogging in the early vegetative phase cause yield loss and sometimes result in crop failure. ESDP genotypes escape terminal drought due to shorter life cycle. ESDP genotypes, however, are relatively more sensitive to intermittent drought stress (Nam et al. 2001). Occasional drought can occur at around the seedling stage.

Pigeonpea is highly sensitive to waterlogging, which could result in considerable loss in crop vigor and plant stand (Chauhan 1987). The risk of crop failure or yield reduction due to short-term waterlogging is particularly acute in ESDP genotypes because they have less time to recover from the stress compared to medium- or long-duration cultivars (Matsunaga et al. 1991).

Inadequate plant population: Uniformity of plant stand is an important yield-determining component in ESDP. Observation in farmers' fields at Sonepat revealed that plant population varied from 3 to 7 plants m^{-2} in several farmers' fields as against the optimum of 8 to 15 plants m^{-2} (Chauhan 1990). Use of the broadcast method of sowing as well as poor quality seed were mainly responsible for poor plant stand.

Nutrients: Pigeonpea generally exhibits no serious problem of nutrient deficiency. A basal dose of 100 kg di-ammonium phosphate seems to satisfy immediate N and P needs. Generally, N from N-fixation and use of residual nutrients in cropping systems are assumed to take care of additional requirement of nutrients.

Socio-economic and policy constraints

Most farmers tend to grow pigeonpea on marginal lands and under rainfed conditions, and the crop does not receive purchased inputs. Farmers have become market–conscious and prefer to grow crops that provide them assured returns on their more productive lands. Large fluctuations in market prices, depending upon the production, influence farmers to switch over from legumes to other crops such as rice. Pigeonpea is less profitable than rice in the western IGP under the existing policy regime and technological options (Malik 1994). Farmers generally view pigeonpea as relatively a more risky crop than rice during the rainy season, especially due to susceptibility to insect pests and waterlogging and lack of price support.

Farmers lack knowledge about the recently developed and released improved cultivars (Joshi 1998) and how to procure their seed. Cultivars such as AL 15, AL 201, ICPL 85010 and Paras, have not been well adopted in farmers' fields. Presently, private sector seed companies do not consider production of pigeonpea seed a remunerative business. Often, farmers use their own seed for the next season or exchange with other farmers. Infestation by bruchids (*Callosobruchus spp.*) during the crop season, harvesting and threshing generally result in seed damage. Improper storage conditions make the seed prone to damage by other insects and fungus. Rainfall at maturity may also damage seed quality. Thus, inferior seed results in poor germination, low plant stand and low yield. Research activities on development of pigeonpea genotypes and seed production are not linked to extension programs. Such linkages at early stages of technology are necessary for effective transfer of appropriate technology to farmers. This approach would enable farmers to acquaint with the latest technology that may suit their circumstances, and give researchers and extension personnel feedback on problems in the adoption of technology in their specific location.

ESDP is a new agro-technology; hence, agro-techniques need to be evaluated and fine-tuned for farmers' specific circumstances. Recommended practices are required to follow for higher yields. Lack of seed treatment, inappropriate fertilizer application, sowing time, population densities, and insufficient weeding lead to low yields. Post-harvest handling is a major constraint to the adoption of ESDP cultivars because seed need to be stored properly for a longer period. Storage and processing are often inadequate and losses can be heavy.

Production Practices for ESDP

Based on previously established (Chauhan 1990) and recent findings, following is a generic recommended package of practices for cultivation of ESDP in the western IGP. Of course, it would need some fine-tuning according to site-specific circumstances.

Ecological requirement

ESDP grows well in warm tropical and subtropical climates. It prefers warm weather (max 30-40 ^{o}C) during germination and pre-flowering growth, and a lower temperature (max 25-30 ^{o}C) during the flowering and pod filling stages. Waterlogging is very harmful for the crop and hence fields should be well drained and configured to allow better aeration for the root system.

Soil requirement

ESDP thrive best on well-drained loamy soils. Saline/alkaline, highly acidic (pH <5) and waterlogged soils are unfit for its cultivation as they adversely affect crop growth and nodulation (Johansen 1990).

Cultivars/genotypes

Only a few ESDP cultivars/genotypes have been developed relatively recently. The description of the most important ones is given below:

AL 201: This indeterminate cultivar has been released for cultivation in Punjab state of India. It has up to four weeks earlier maturity than T 21 commonly grown in the state, yet gives similar yield in farmers' fields. However, it has an unacceptable seed size of ~7 g 100-seeds^{-1}.

Paras: This indeterminate cultivar of semi-spreading habit has been released in Haryana State of India. It has slightly greater height and higher yield (1.6 t ha^{-1}) in farmers' fields and matures about a week earlier than SDP cultivar Manak; due to rapid growth it can be fitted into late sown conditions. The seeds are, however, small (~7 g 100-seeds^{-1}), smooth and brown in color.

ICPL 85010: This determinate cultivar has been released in Himachal Pradesh State of India. It matures in about 145 days in June sowing to allow wheat sowing at optimum time. The average grain yield obtained in farmers' field with plant protection is about 1.5 t ha^{-1}. Its pods are borne in clusters and require plant protection to reduce damage by pod borers. Its seeds are of bold size (~ 9.5 g 100-seeds^{-1}).

ICPL 84031: This determinate cultivar has been released, for cultivation in north Telangana region of Andhra Pradesh, India. It has a flat-topped canopy with pods in clusters. This cultivar has, however, not been tested in rotation with wheat. It gives about 1.5 t ha^{-1} in farmers' fields.

***ICPL 88039*:** This indeterminate genotype matures in about 150 days in June sowing, providing enough time to prepare the field for the sowing of wheat crop. This genotype is less susceptible to pod borers. Plants are medium tall. Its seeds are bold (9.0 g 100-seeds^{-1}). It gives an average yield of 1.65 t ha^{-1} under unsprayed conditions in farmers' fields. However, it sometimes requires protection from pod sucking bugs. It is more tolerant to drought during the reproductive phase.

Field preparation

ESDP establishes well in a properly tilled and well-drained seedbed. The soil surface should be graded such that no standing water remains after rains. A deep ploughing with a mold-board plough followed by two to three cross-harrowings, and proper leveling should be done to ensure uniform irrigation and good drainage. Planking (leveling) should follow final ploughing. These field operations are similar to those as recommended for SDP and long-duration pigeonpea.

Fertilizer application

Farmers are advised to add fertilizer on the basis of soil test values. In the absence of this information, a basal dose of 18 kg N and 20 kg P ha^{-1} ensures a good crop of pigeonpea. The entire dose of fertilizer should be mixed in top 15 cm of soil during land preparation. Fertilizer contact with seed should be avoided, as germinating pigeonpea seeds are sensitive to salt toxicity.

Seed treatment

Seed treatment with Thiram @ 3g kg^{-1} of seed is helpful to protect against dry root rot caused by *Rhizoctonia bataticola* and collar rot caused by *Sclerotium rolfsii* (Reddy et al. 1990). Inoculation of seed with an effective *Rhizobium* strain improves nodulation, nitrogen fixation that benefits pigeonpea and succeeding wheat. Seed should be first treated with fungicide/insecticide followed by *Rhizobium* application.

Time of sowing

This is the most important non-monetary agronomic input for realizing high yield from an improved cultivar. The optimum time for sowing ESDP in the western IGP is from the last week of May to mid-June. It is preferable to sow pigeonpea in early May, because the crop can then more effectively suppress *Trianthema monogyna* weed, escape from pod borer attack later in the season, and be harvested in time to ensure timely wheat sowing. In case early sowing is not possible due to lack of rainfall or irrigation, late-June and July sowings can be taken up with the on-set of rains. However, these are more prone to weed infestation and pod borer attack and the crop may not mature until after mid-November (Dahiya et al. 1999).

Sowing method and seed rate

Recommended seed rate is 12-15 kg ha^{-1}. ESDP seed should be sown behind a plough or with a seed drill at a depth of about 5 cm using row spacing of 40 cm and 15 to 20 cm distance from plant-to-plant to get 12-15 plants m^{-2}. Sowing through broadcasting, which is quite popular as it saves labor and time, leads to uneven plant stand.

Intercropping and rotations

During rainy season, short-duration cultivars of mungbean (*Vigna radiata*), black gram (*Vigna mungo*), and maize (*Zea mays*) can be inter-cropped in a normal plant stand of an ESDP cultivar, without appreciably reducing its grain yield. Field observations have revealed that inter-cropping of maize with pigeonpea (genotype ICPL 88039) has shown promise in Sonepat district (Haryana, India). For this purpose, one row of maize between the two rows of pigeonpea spaced 60 cm apart can be accommodated. The seed rate of component crops for inter-cropping should remain same as that of pure crop. ESDP fits well for rotation with wheat, late-sown potato (*Solanum tuberosum*) and *chickpea (Cicer arietinum*).

Water management

The crop sown in May needs a pre-sowing irrigation. There is no need of further irrigation after the start of monsoon rains, but irrigation may be quite beneficial in case of protracted drought during the reproductive phase. However, if rainfall is well distributed a mid-June sown crop may not require any irrigation.

Weed management

Manual weeding, once or twice, markedly increases the productivity of ESDP. Weeding at 25-30 days and at 45-50 days after sowing gives excellent weed control because the period of first 50 days is very critical for ESDP plant (Singh et al. 1980). Pre-emergence application of pendimethalin @ 1.0 kg a.i., ha^{-1} can effectively control weeds (Tomer and Ram Dhari 1996). However, chemical weed control in minor crops such as pigeonpea is not popular among farmers, being an expensive input.

Integrated Pest Management (IPM)

In the past few decades over-dependency and indiscriminate use of pesticides have resulted in development of pesticide resistance in pests, pest resurgence, secondary pest outbreaks, elimination of beneficial insects, environmental pollution (pesticide residues) and health hazards. Therefore, several components of pest management approaches are being used singly or in combinations for managing pests. An IPM approach, therefore, is the best mix of various pest control options such as cultural practices, biological control agents, and use of chemical sprays. The exploitation of host avoidance mechanism through manipulation of sowing dates, mixed/inter-cropping, utilization of pheromone trap for insect monitoring, use of nuclear polyhydrosis virus (NPV), and neem (*Azadirachta indica*) seed kernel extract (Schmutterer 1990; Ranga Rao and Shanower 1999), and development of resistant cultivars are some of the major components of IPM. Following practices may be effective in eco-friendly pest management of ESDP.

Cultural practices

- Deep ploughing in summer.
- Early sowings in May.
- Growing pest tolerant or relatively less susceptible cultivar.
- Inter-crop pigeonpea with maize. Sorghum on the borders of pigeonpea acts as bird perches that eat pod-borer larvae and also harbors natural enemies of pigeonpea pests.
- Cultivation of short statured, early maturity crops such as cowpea (*V. unguiculata*), mungbean and blackgram in the inter-row spaces of pigeonpea will suppress weeds. These crops can be harvested before flowering of pigeonpea, and the space left by these crops facilitates the spraying operations in the pigeonpea field.
- Grow trap crops such as marigold (*Chrysanthemum* spp.) on the border and in between rows as an inter-crop.
- Monitoring pests with pheromone trap. The septa of the pheromone trap consist of a chemical that attracts the male moths (Reed and Lateef 1990). Therefore, the use of sex pheromone trap at village or block level will predict the time when pest population will reach the threshold needing chemical/biological pesticide sprays.
- Blister beetles can be controlled manually by hand picking or collecting them with insect net and crushing them, since they are slow moving (Reed et al. 1989). Hand gloves should be used as otherwise the insect can cause blisters on the skin.

Biological practices

- Use of neem seed kernel extract 5% against pod borer in SDP and ESDP is quite effective.
- Spray HNPV (nuclear polyhedrosis virus that infects *H. armigera*) 250 LE (larval equivalent) ha^{-1} on noticing egg and first instar larva of *H. armigera* (2-3 eggs or 1 larva per 5 twigs of plants, which is the economic threshold level).
- Installing bird perches for attracting insectivorous birds that feed on larvae of *Helicoverpa* pod-borer.

Chemical control practices

More often, farmers apply insecticides after the devastation by the pests, thus losing the crop yield as well as money spent on insecticide application. Therefore, timely application of insecticides is essential with appropriate selection of chemicals, especially when resistance to insecticide is low (Reed and Lateef 1990). Insecticide application should be done only when the population of the insect has reached the threshold level, which may cause economic loss. For ESDP pigeonpea, application of insecticide is recommended when 15-eggs $plant^{-1}$ are observed. Sprays of monocrotophos 36 EC (0.04%) (1ml L^{-1} water) followed by Nimbicidine (0.3%) was best for the control of pigeonpea pests. Cypermethrin (0.004%), and endosulfan 35EC (0.07%) (2 ml L^{-1} water) are also effective for pod borers. Spraying should be done @ 600-1000 L of water ha^{-1} with knapsack sprayer or 200-300 L of water ha^{-1} with power sprayer.

Diseases identification and their management

A few diseases affect ESDP cultivars, however, diseases are not serious yield reducers for the crop in the western IGP. Diseases have been noticed sporadically, but caused no measurable economic damage. Therefore, following strategies should be quite effective in the management of some of the potentially important diseases of ESDP (Reddy et al. 1993).

Phytophthora blight:

Some of the suggested management options are:

- Select fields with no previous history of blight; avoid sowing pigeonpea in fields with low-lying areas prone to waterlogging.
- Seed dressing with Ridomil MZ® @ 3g kg^{-1} seed.
- Prepare raised seedbeds to ensure good drainage.
- Use wider (>50 cm) row spacing.
- Two foliar sprays of Ridomil MZ® at 15 days intervals starting from 15^{th} day after germination, if there is continuous rain (high humidity), and risk of infection.

***Fusarium* Wilt**

The simple avoidance measures are:

- Select a field with no previous record of wilt.
- Use seed from disease-free fields.
- Use wilt resistant/tolerant genotypes.
- Follow crop rotation; do not grow pigeonpea after pigeonpea in the same field.

Sterility mosaic disease

The simple management options are:

- Select a field well away from perennial or ratooned pigeonpea.
- Uproot infected plant at an early stage of disease development and destroy them.
- Grow sterility mosaic resistant culitvars
- Spray acaricides Kelthane® or Morestan® or Metasystox at 0.1% to control the mite vectors in the early stages of plant growth (in exceptional cases).

Seed Production

Availability of quality seeds of improved cultivars is considered crucial for realizing productivity and adoption of cultivars in different agro-climatic conditions. The quality of seed alone is known to account for at least 10-15% increase in the productivity (ICAR 1993). However, lack of quality seed continues to be one of the greatest impediments to bridging the vast yield gap. Therefore, to approach the potentially realizable yield of a cultivar, production and distribution of quality seed is essential.

The good quality seed should have the following characters:

- Genetic purity, and uniformity and should conform to the standards of the particular cultivar.
- Disease free, viable seeds.
- Free from admixtures of other crop seeds, weeds and inert matter.
- Acceptable uniformity with respect to size, shape and color.

Maintaining seed quality and purity at farmers level

A study conducted by the National Seed Project revealed that samples in most cases of farmers-saved seeds were sub-standard in respect of physical (15-100%) and genetic purity (37-80%), germinability (15-100%) and seed health (ICAR 1993). Also, farmer's seed sample gave 2 to 80% lower yield than the certified seed in different crops. A considerable spread of released pigeonpea cultivars takes place through seed exchange among farmers. Therefore, care should be taken to avoid seed contamination with other cultivars due to outcrossing or mechanical mixing. Farmers should be educated to follow simple procedures to maintain seed purity at farm level through leaflets, videos and seminars and meetings conducted by 'Krishi Vigyan Kendras (KVK)' (centers for disseminating agricultural technology). Pigeonpea, being partially outcrossing crop, requires extra-precautions to maintain varietal purity. Some of the important steps that will help maintain purity and minimize seed contamination are listed below:

- Avoid delayed sowing for seed production as it may produce poor quality seed.
- The field should not have been sown with pigeonpea crop in the previous season to avoid emergence of dormant seeds of the previous crop.
- Seed production plots of ESDP cultivar should be grown at least 250 m away from other cultivar of pigeonpea with an overlapping flowering phase to prevent outcrossing.
- Remove all off-type plants before flowering. Even among the uniform looking plants, the late flowering plants should be removed to ensure that there is no drift of population towards later maturing plants.
- Prevent mechanical mixing and damage to seed. Care should be taken at the time of harvest to separate any off-type plants from the harvested bulk that might have been missed during roguing.

Seed Storage

Considerable post-harvest losses occur during storage of pigeonpea. The problem is more acute in case of ESDP, because the time between harvesting and next season's sowing is longer than for the other maturity groups. Many factors such as seed moisture, relative humidity, temperature and infestation by stored grain pests influence the viability of seed during storage and reduce the quality of seed. The seeds damaged by bruchids do not germinate well resulting in poor plant stand and consequently yield, and economic loss. This condition forces farmer to sell seed immediately after harvest even though the market price may not be remunerative at that time. Therefore, the following preventive and control measures are recommended.

Preventive measures

- Sun dry the seed thoroughly before storage as the seed containing moisture > 10% will attract storage pests and is likely to be damaged soon. The seed can also be solarized for couple of days before storing them in shade (Chauhan and Ghaffar 2001). High temperatures (~65 ^{o}C) in polythene bags due to sunrays will kill any living insect pest. Such bags can be stored for longer period without any chemical treatment and thus seed would remain safe for both sowing as well as consumption.
- Clean the seed store and remove old seed. Do not store new seed with old seed.
- Disinfect the floors and walls of stores well in advance by spraying with 1% malathion (50 EC).
- Plug all the cracks in floor or walls of store to prevent entry of vermin. Fumigate the store by Aluminum phosphide (celphos). While fumigating, care should be taken that the storeroom must be air tight as these chemicals are poisonous.
- Use new gunny bags lined with polythene to store seed in them. In case of old bags, disinfect them with 0.1% malathion 50 EC or with fenvelrate 20 EC. Dip the old gunny bags in this solution for 10-15 minutes and dry properly in shade before storing seed.
- Seed bags should be stored away from walls and they must not touch the floor. Seed bags should be placed on a thick layer of fine sand or cowdung ash as the layer acts as a repellent for insect pests.

- Grain earmarked for sowing should be mixed with 5% malathion dust at 250 g 100-kg^{-1} seed. Inspect the seed in store at regular intervals.
- For storage in seed bins (metal containers), disinfect the containers and place seed in them after proper drying. Spread 2-3 inches thick layer of dry coarse sand on the top of the seed and close the lid of the bin properly.
- In case of insect attack, fumigate the seed in store with aluminium phosphide (30 g celphos t^{-1} seed or 7-10 tablets of celphos 28-m^{-3}). The exposure period should be one week for best results.
- Seed can also be treated with 7.5 ml rapeseed (*Brasica spp.*) oil or groundnut (*Arachis hypogea*) oil per kg of seed. By this way, the seed can be kept safe for 8-9 months.

Future Needs

Genetic improvement

Even though, considerable advantage of ESDP over SDP is evident not only in terms of higher yield of pigeonpea and also of subsequent wheat, there is still a large yield gap. While it could partly be due to various biotic, abiotic and socio-economic constraints discussed above, there could still be other unknown constraints that may be affecting the realization of high yield. Multidisciplinary research efforts are needed for improving the yield and adaptation of ESDP for target production systems to make its cultivation more competitive with rice or other rainy season crops. The following is the list of researchable issues that could be addressed on priority:

-- Breeding of appropriate plant type, including rapid early growth, yield stability and increased harvest index under long photoperiod.

-- Intensification of development of ESDP hybrids based on cytoplasmic male sterility.

-- Breeding and selection of high yielding ESDP genotypes with multiple resistance/tolerance for pod borers, *Phytophthora* blight, *Fusarium* wilt and sterility mosaic diseases.

-- Developing genotypes with adaptability to waterlogging and intermittent drought.

Crop production technology

ESDP, being a recent introduction in cropping systems requires:

- Developing new, intensive and intercropping system that can fit in ESDP as a component.

- Use of simulation models that have been developed recently can help in resolving the complex management issues (M.J. Roberston, APSRU, Toowoomba, Australia, personal communication).
- Development of improved integrated pest management technologies for management of weeds, pests and diseases in ESDP.

Transfer of improved technologies

In view of declining water table and increased infestation of weed (*P. minor*) in rice-wheat system, is causing potential ecological threat. Following points need early attention:

- Farmers' participatory research on ESDP should be given top priority by KVK and state department of agriculture. This can help in better focus on the farmers' requirements of ESDP.
- Identification of profitable and viable cropping systems involving pigeonpea (mixed, sequential and inter-crops) in different agro-climatic conditions.
- Concerted efforts by agricultural extension staff to disseminate promising technologies to farmers through demonstrations, adaptation trials, and on-farm trials.
- Socioeconomic evaluation of technology, its appropriateness and acceptance by farmers.

Policy interventions

- Policies and procedures to produce seed and maintenance of seed purity at farmers' level.
- Assured minimum support price so as to compete with cereals.
- Incentives to produce good quality seed.
- Development of processing units near production centers.

Summary and Conclusions

The major objectives of introducing pigeonpea in the western IGP, in addition to increasing its production, have been to improve the sustainability of rice and wheat cropping systems. Since pigeonpea by itself requires little by way of purchased inputs and is known to improve soil fertility, it is ideally suited for cultivation in rotation with wheat. The failure of anticipated adoption of SDP in the western IGP for several reasons highlighted above has, however, not allowed this objective to be fully met. Development of ESDP has presented fresh opportunity to enhance cultivation of pigeonpea in rotation with wheat. The results of farmer participatory on-farm testing spread across six years at three locations in the western IGP clearly indicate a greater potential of ESDP in rotation with wheat than SDP. Farmers' perception has been favorable for indeterminate ESDP (such as ICPL 88039) and its adoption is beginning to increase. Its adoption could be catalyzed further if biotic, abiotic, and socio-economic and policy constraints that afflict legumes in general and pigeonpea in particular are urgently addressed to bridge the yield gap that currently exists. Pigeonpea as a break crop reduced weed (*P. minor*) population. This work has enabled several general recommendations for overcoming constraints, cultivation practices, seed production and storage for ESDP in the western IGP and their adoption would be crucial in making cultivation of ESDP more profitable. Further, fine-tuning of these to develop site-specific recommendations would greatly assist in increasing adoption of ESDP in rotation with wheat.

Acknowledgements

Our sincere gratitude to Dr. L S Suhag, Director, Extension Education, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana, India for providing necessary facilities and guidance in developing of this manuscript. We acknowledge whole heartedly the timely help and co-operation extended by Drs. S P Wani, K B Saxena, JVDK Kumar Rao and O P Rupela in preparation of this publication. Thanks are due to M/s G Mallesham, P Manohar and M Satyam for their technical help. The authors are thankful to Ms. J Nalini for her meticulous typing of this publication. Finally, special thanks are due to the farmers who participated actively in the execution of research trials on ESDP.

References

Ae, N., Arihara, J., Okada, K., Yoshihara, T., and **Johansen**, **C.** 1990. Phosphorous uptake by pigeonpea and its role in cropping systems of the Indian subcontinent. Science 248: 477-480

Ali, M., Mishra, J.P., Ahlawat, J.P., Kumar, Ravi, and **Chauhan, Y.S.** 1998. Effective management of legumes for maximizing biological nitrogen fixation and other benefits. Pages 107-128 *in* Residual effect of legumes in rice and wheat cropping systems of the Indo-Gangetic Plain (Kumar Rao, J.V.D.K., Johansen, C., and Rego, T.J., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics; and New Delhi, India: Oxford and IBH.

Ali, M., Joshi, P.K., Pande, S., Asokan, M., Virmani, S.M., Kumar, Ravi, and **Kandpal, B.K.** 2000. Legumes in the Indo-Gangetic Plain of India. Pages 35-70 *in* Legumes in Rice and Wheat cropping systems of the Indo-Gangetic Plain – constraints and opportunities (Johansen, C., Duxbury, J.M, Virmani, S.M., Gowda, C.L.L., Pande, S., and Joshi, P.K. eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics; and Ithaca, New York, USA: Cornell University.

Chauhan,Y.S. 1987. Screening for tolerance to salinity and waterlogging: case studies with pigeonpea and chickpea. Pages 93-103 *in* Adaptation of chickpea and pigeonpea to abiotic stresses. Proceedings of the consultants Workshop, 19-21 Dec 1984, ICRISAT, Hyderabad, India. Patancheru, Andhra Pradesh 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Chauhan, Y.S. 1990. Pigeonpea: optimum agronomic management. Pages 257-278 *in* The pigeonpea (Nene, Y.L., Hall, S. D., and Sheila,V.K., eds.) Wallingford, U.K.: CAB International.

Chauhan, Y.S. 1993. Pigeonpea. Pages 79-91 *in* Rooting pattern of tropical crops (Salam, A., and Wahid, W.A., eds.). India: Tata Mcgraw Hill Publishers.

Chauhan, Y.S., Atukorala, W.D., Perera, K.D.A., Joseph, K.D.S.M., Saxena, K.B., and **Johansen, C.** 1999. Potential of extra-short-duration pigeonpea in the short rainy season of a tropical bimodal rainfall environment. Experimental Agriculture 35:87-100.

Chauhan, Y.S., and **Ghaffar, M.A.** 2001. Solar heating of seeds - a low cost method to control bruchid (*Callosobruchus* spp.) attack during storage of pigeonpea. Journal of Stored Products Research (in press).

Dahiya, S.S., Johansen, C., Chauhan Y.S., and **Shanower, T.G.** 1999. Adjusting pigeonpea sowing time to manage pod borer infestation. International Chickpea and Pigeonpea Newsletter 6: 44.

Dhawan, C.L., Bhatnagar, B.B.L., and **Ghai, P.D.** 1958. Role of green manuring in reclamation. I. Proc. Natn. Acad. Sci. India 27A: 168-75.

Gulati, A. 1999. Globalization of agriculture and its impact on rice-wheat system in the Indo-Gangetic Plains. Pages 43-60 *in* Sustaining rice-wheat production systems: socio-economic and policy issues (Pingali, Prabhu L., ed.). Rice-Wheat Consortium Paper Series 5. New Delhi, India: Rice-Wheat Consortium for the Indo-Gangetic Plains.

Gupta, S.C., and **Kapoor, R.K.** 1990. Nilgai, a menace to extending pigeonpeas to nontraditional pigeonpea-growing areas of India. International Pigeonpea Newsletter 12: 28.

Gupta, S.C., Johansen, C., and **Singh, L.** 1989. Uniformity of nomenclature in short-duration pigeonpea. International Pigeonpea Newsletter 10:3-6.

Gupta, S.C., Lateef, S.S., and **Ariyanayagam, R.P.** 1991. Are determinates inferior to indeterminates in short-duration pigeonpeas? International Pigeonpea Newsletter 13:11-13.

Hobbs, P., and **Morris, M.** 1996. Meeting South Asia`s future food requirements from rice-wheat cropping systems: priority issues facing researchers in the post-green revolution era. Pages 96-101 *in* Natural Resource Group Paper. Mexico: CIMMYT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1989. Annual report. Patancheru 502 324, Andhra Pradesh, India: ICRISAT.

ICAR (Indian Council of Agricultural Research). 1993. Report of Quinquennial Review Team on Seed Technology Research and Breeder seed Production under the National Seed Project, New Delhi, India: Indian Council of Agricultural Research (ICAR).

Johansen, C. 1990. Pigeonpea: mineral nutrition. Pages 209-231 *in* The Pigeonpea (Nene, Y.L., Hall, S.D., and Sheila, V.K., eds.) Wallingford, U.K.: CAB International.

Johansen, C., Kumar Rao, J.V.D.K., Rupela, O.P., and **Rego, T.J.** 1990. Contribution of pigeonpea to nitrogen economy of different cropping system. Page 259 *in* Proceedings of the International Symposium on Natural Resource Management for a sustainable agriculture, 6-10 Feb. 1990, New Delhi, India, New Delhi, India: Indian Society of Agronomy.

Joshi, P.K., Asokan, M., Datta, K.K., and **Kumar, P.** 2000. Socioeconomic constraints to legumes production in rice-wheat cropping systems of India. Pages 176-184 *in* Legumes in rice and wheat cropping systems of the Indo-Gangetic Plain – constraints and opportunities (Johansen, C., Duxbury, J.M, Virmani, S.M., Gowda, C.L.L., Pande, S., and Joshi, P.K. eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics; and Ithaca, New York, USA: Cornell University.

Joshi, P.K. 1998. Performance of grain legumes in the Indo-Gangetic Plain. Pages 207-225 *in* Residual effects of legumes in rice and wheat cropping systems of the Indo-Gangetic Plain (Kumar Rao, J.V.D.K., Johansen, C., and Rego, T.J., eds.). Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics; New Delhi, India: Oxford and IBH.

Kumar, P., Joshi, P.K., Johansen, C., and **Asokan, M.** 1999. Sustainability of rice-wheat based cropping systems in India: socio-economic and policy issues. Pages 61-77 *in* Sustaining rice-wheat production systems: socio-economic and policy issues (Pingali, P.L., ed.). Rice-Wheat Consortium Paper Series 5. New Delhi, India: Rice-Wheat Consortium for the Indo-Gangetic Plains.

Kumar Rao, J.V.D.K., Dart, P.J., and **Sastry, P.V.S.S.** 1983. Residual effect of pigeonpea (*Cajanus cajan* (L.) Millsp.) of different maturity groups. Plant and Soil. 99: 255-266.

Malik, R.P.S. 1994. Public policy and sustainable agricultural development -- a natural resource accounting approach. Indian Journal of Agricultural Economics 49(4): 569-578.

Matsunaga, R., Ito, S., Tobita, and **Rao, T.P.** 1991. Response of pigeonpea (*Cajanus cajan* (L.) Millsp.) to nitrogen application and temporary waterlogging. Pages 183-186 *in* Root ecology and its practical application: procedings of Second International Symposium on Root Research, Sept 1991, (Kutschera, L. Hubl, E. Lichtenegger, E. Persson, H. and Sobotic M. eds.). Verein fur Wurzelforschung, A-9020 Klagenfurt, Australia: International Society for Root Research.

Maurya, P.R., and **Lal, R.** 1980. Effects of no-tillage and ploughing on roots of maize and leguminous crops. Experimental Agriculture 16: 185-193.

McCown, R.L., **Hammer, G.L.**, **Hargreaves, J.N.G.**, **Holzworth, D.P.,** and **Freebairn, D.M.** 1996. A novel software system for model development, model testing, and simulation in agricultural systems research. Agricultural Systems 50: 255-271.

Nam, N.H., Chauhan, Y.S., and **Johansen, C.** 1993. Comparison of extra-short-duration pigeonpea with short-season legumes under rainfed conditions on Alfisol. Experimental Agriculture 29: 307-316.

Nam, N.H., Chauhan, Y.S., and **Johansen, C**. 2001. Effect of timing of drought stress on growth and grain yield of extra-short-duration pigeonpea lines. Journal of Agriculture Science, Camb. (in press).

Ortiz-Monasterio, J.I., Dhillon, S.S., and **Fischer, R.A.** 1994. Date of sowing effect on grain yield and yield components of irrigated spring wheat cultivars and relationship with radiation and temperature in Ludhiana, India. Field Crops Research 37: 169-184.

Pimbert, M.P., and **Women Sanghams**. 1991. Farmer participation in on-farm varietal trials: multilocation testing under resource poor conditions. RRA Notes 10: 3-8.

Pingali, P.L., and **Gerpacio, R.V.** 1997. Towards reduced pesticide use for cereal crop in Asia. Economics Working Paper No. 97-04. CIMMYT, Mexico, D.F., Mexico.

Pingali, P. L., and **Shah, M.** 1999. Rice-Wheat cropping system in the Indo-Gangetic Plains: policy re-directions for sustainable resource use. Pages 1-12 *in* Sustaining rice-wheat production systems: socio-economic and policy issues (Pingali, Prabhu L., ed.). Rice-Wheat Consortium Paper Series 5. New Delhi: Rice-Wheat Consortium for the Indo-Gangetic Plains.

Ranga Rao, G.V., and **Shanower, T.G.** 1999. Identification and Management of Pigeonpea and Chickpea insect pests in Asia. Information Bulletin No. 57. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

Reddy, M.V., Raju, T.N., Sharma, S.B., Nene, Y.L., and **McDonald, D**. 1993. Handbook of pigeonpea diseases. (In En. Summaries in En, Fr.) Information Bulletin no. 42. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 64 pp.

Reddy, M.V., Sharma, S.B., and **Nene, Y.L.** 1990. Pigeonpea: Disease Management. Pages 303-348 *in* The pigeonpea (Nene, Y.L., Hall, S.D., and Sheila, V.K. eds.), Wallingford, UK: CAB International, and Patancheru, Andhra Pradesh, India: ICRISAT.

Reed, W., and **Lateef, S.S.** 1990. Pigeonpea: pest management. Pages 349-374 *in* The pigeonpea (Nene, Y.L., Hall, S.D., and Sheila, V.K., eds.) Wallingford, UK: CAB International, and Patancheru, Andhra Pradesh, India: ICRISAT.

Reed, W., Lateef, S.S., Sithanantham, S., and **Pawar, C.S.** 1989. Pigeonpea and Chickpea Insect Identification Handbook. Information Bulletin no. 26. Patancheru, Andhra Pradesh, India: ICRISAT, 120 pp.

Schmutterer, H. 1990. Properties and potential of natural pesticides from the Neem tree, *Azadirachta indica*. Annual Review of Entomology. 35:271-297.

Sekhon, H.S., Sidhu, P.S., and **Phul, P.S.** 1996. Use of extra-short-duration pigeonpea in rotation with winter crops in Punjab. Pages 17-22 *in* Prospects for growing extra-short-duration pigeonpea in rotation with winter crops: proceedings of the IARI/ICRISAT Workshop and Monitoring tour,16-18 Oct 1995, New Delhi, India (Singh, L., Chauhan, Y.S., Johansen, C., and Singh, S.P., eds.). New Delhi 110 012 and Patancheru 502 324, Andhra Pradesh, India: Indian Agricultural Research Institute and International Crops Research Institute for the Semi-Arid Tropics.

Shanower, T.G., and **Romeis, J.** 1999. Insect pests of pigeonpea and their management. Annual Review of Entomology 44: 77-96.

Sharma, D., Reddy, L.J., Green, J.M., and **Jain, K.C.** 1981. International adaptation of pigeonpeas. Pages 71-81 *in* Proceedings of the International Workshop on pigeonpeas, volume 1. 15-19 December, 1980. Patancheru, Andhra Pradesh, India: ICRISAT.

Singh, H.P., Saxena, M.C., Yadav, D.S., and **Sharma, R.P.** 1980. Chemical and mechanical weed control in pigeonpea under humid-subtropical conditions of Pantnagar. Legume Research 3: 22-26.

Singh, J.P., Govil, J.N., and **Ram, H.** 1987. Role of early pigeonpea varieties in arhar-wheat rotation. Seeds and Farms. 13: 17-21, 24.

Singh, **L.** 1996. The development of and adoption prospects of extra-short-duration pigeonpea. Pages 1-5 *in* Prospects for growing extra-short-duration pigeonpea in rotation with winter wheat crops: proceedings of IARI/ICRISAT Workshop and Monitoring tour 16-18, Oct, 1995, New Delhi, India. (Singh, L., Chauhan, Y.S., Johansen, C., and Singh, S.P., eds.). New Delhi 110 012 and Patancheru 502

324, Andhra Pradesh, India: Indian Agricultural Research Institute and International Crops Research Institute for the Semi-Arid Tropics.

Singh, L., Chauhan, Y.S., Johansen, C., and **Singh, S.P.** (eds.). 1996. Prospects for growing extra-short-duration pigeonpea in rotation with winter wheat crops: proceedings of IARI/ICRISAT Workshop and Monitoring tour 16-18, Oct, 1995. New Delhi, India: Indian Agricultural Research Institute, Patancheru 502 324, India: International Crops Research Institute for the Semi-Arid Tropics, pp. 132.

Singh, U., and **Jambunathan, R.** 1981. A survey of the methods of milling and consumer acceptance of pigeonpea in India. Pages 419-425 *in* Proceedings of the International workshop on pigeonpeas, volume 2, 15-19 December 1980, Patancheru 502 324, Andhra Pradesh, India: ICRISAT.

Srivastava, S.K. 1993. Problems and prospects of boosting productivity of pigeonpea. International Pigeonpea Newsletter 18:22.

Srivastava, S.K. 1996. Extra-short-duration pigeonpea in Western Uttar Pradesh: problems and prospects. Pages 27-33 *in* Prospects for growing extra-short-duration pigeonpea in rotation with winter crops: proceedings of the IARI/ICRISAT Workshop and Monitoring tour, 16-18 Oct 1995, New Delhi, India (Singh, L., Chauhan, Y.S., Johansen, C., and Singh, S.P., eds.). New Delhi 110 012 and Patancheru 502 324, Andhra Pradesh, India: Indian Agricultural Research Institute and International Crops Research Institute for the Semi-Arid Tropics.

Srivastava, S.K., Kumar, M.S., and **Johansen, C.** 1998. Effect of soil temperature and seed placement on establishment of short-duration pigeonpea in Ghaziabad District, Uttar Pradesh. National Seminar on "Advances in the studies of physical environment for resource management and sustainable crop production, IARI, New Delhi, March 23-25,1998.

Tomer, Y.S., and **Ram Dhari** 1996. Extra-short-duration pigeonpea in Haryana. Pages 11-16 *in* Prospects for growing extra-short-duration pigeonpea in rotation with winter crops: proceedings of the IARI/ICRISAT Workshop and Monitoring tour,16-18 Oct 1995, New Delhi, India (Singh, L., Chauhan, Y.S., Johansen, C., and Singh, S.P., eds.). New Delhi 110 012 and Patancheru 502 324, Andhra Pradesh, India: Indian Agricultural Research Institute and International Crops Research Institute for the Semi-Arid Tropics.

Yadav, R.L., Dwivedi, B.S., Gangwar, K.S., and **Prasad, Kamata.** 1998. Overview and prospects for enhancing residual benefits of legumes in rice and wheat cropping system in India. Pages 207-225 *in* Residual effects of legumes in rice and wheat cropping systems of the Indo-Gangetic Plain (Kumar Rao, J.V.D.K., Johansen, C., and Rego, T.J., eds.). Patancheru 502 324 , Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics.

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