EFFECT OF IRRIGATION AND PHOSPHORUS LEVELS ON SEED PRODUCTION OF GARDEN PEA (*Pisum sativum* L.)

THESIS

By

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Submitted to

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PALAMPUR - 176 062 (H.P.) INDIA

IN

Partial fulfilment of the requirements for the degree

OF

DOCTOR OF PHILOSOPHY IN AGRICULTURE

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(2009)

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CERTIFICATE - I

This is to certify that the thesis entitled **"Effect of irrigation and phosphorus levels on seed production of garden pea (*Pisum Sativum* L.)"** submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy (Agriculture)** in the subject of **Vegetable Science** of Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, is a bonafide research work carried out by **Mr. Gurpreet Singh Khalsa (A-2004-40-14)** son of **S. Kuldip Singh Khalsa** under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

(Vidyasagar)
Chairman
Advisory committee

Place: Palampur
Dated: April 23, 2009

CERTIFICATE II

This is to certify that the thesis entitled **"Effect of irrigation and phosphorus levels on seed production of garden pea (*Pisum sativum* L.)"** submitted by **Mr. Gurpreet Singh Khalsa (A-2004-40-14)** son of **S. Kuldip Singh Khalsa** to the Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur, in partial fulfilment of the requirements for the degree of **Doctor of Philosophy (Agriculture)** in the subject of **Vegetable Science**, has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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Needless to say, all omissions and errors are mine.

Place: Palampur
Dated: April 23, 2009 — ***(Gurpreet Singh Khalsa)***

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CSK HIMACHAL PRADESH KRISHI VISHVAVIDYALAYA PALAMPUR – 176 062 (H.P)
DEPARTMENT OF VEGETABLE SCIENCE AND FLORICULTURE

THESIS ABSTRACT

Title of the thesis:	Effect of irrigation and phosphorus levels on seed production of garden pea (*Pisum sativum* L.)
Name of the student:	Gurpreet Singh Khalsa
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Major Advisor:	Dr. Vidyasagar

Abstract

Garden pea is one of the most leading off-season vegetables in the Himachal Pradesh. Irrigation water is a limiting factor in the hilly regions. Availability of phosphorus is somewhat restricted in the acidic soils. Quality seed is the basic input in any of the production programme. Irrigation and phosphorus are important to improve the seed yield as well as its quality. Hence, the present investigation entitled " Effect of irrigation and phosphorus levels on seed production of garden pea (*Pisum sativum* L.)" was conducted in the Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur (H.P) during *rabi* 2005-06, 2006-07 and 2007-08, to study the response of irrigation and phosphorus levels on growth and development, yield attributes and yield, seed quality, plant/soil chemical studies and water use efficiency of garden pea. The treatment combinations comprised of five main-plot treatments (irrigation levels *viz*., I_1: water-seeding, I_2: I_1 + irrigation (1cm) at vegetative stage, I_3: I_2 + irrigation (1cm) at 75% flowering, I_4: I_3 + irrigation (1cm) at 75% podding and I_5: recommended 5cm irrigation at all the stages *viz*., pre-sowing, vegetative stage, 75% flowering and 75% podding) and three sub-plot treatments (phosphorus levels *viz*., P_1: 40kg P_2O_5/ha, P_2: 60kg P_2O_5/ha and P_3: 80kg P_2O_5/ha). In all there were 12 treatment combinations. The field experiments were conducted in split-plot design with three replications.

The results revealed that water-seeding (0.43cm irrigation water applied within the rows before sowing) proved better than pre-sowing irrigation of 5cm depth in early emergence of seedlings. Early flowering and seed maturity were recorded in the treatments receiving limited irrigation water at one or more of the critical growth stages (I_1 to I_4) as compared to the recommended (I_5).The irrigation levels I_5 (recommended) and I_4 (water-seeding + 1cm irrigation water along the rows at all the critical stages) were at par with each other and both were significantly superior over rest of the irrigation levels with respect to growth, yield attributes, seed yield and quality traits and nutrient uptake. Water use efficiency was the highest with I_4. The highest phosphorus dose P_3 (80kg P_2O_5/ha) was the best for early maturity, yield attributes, seed yield and quality and nutrient uptake. In general, the I X P interactions were non significant. In conclusion, the best irrigation schedule and phosphorus dose proved to be I_4P_3.

(Signature of the student with date) (Signature of the Major Advisor)

Head of Department

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ABSTRACT FOR BOARD OF MANAGEMENT

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P_3 (80kg P_2O_5/ha) were the best for growth, yield attributes, seed yield and quality traits and nutrient uptake. Water use efficiency was the highest in irrigation level I_4 during all the years of experimentation. In conclusion, the best irrigation schedule and phosphorus dose proved to be I_4P_3.

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Chapter I

INTRODUCTION

Garden pea (*Pisum sativum* L.), a member of the family Fabaceae, is one of the most important cool season vegetable crops grown throughout the world. In India, it is cultivated over an area of about 3,14,000 ha with an annual production of 25,60,000 tonnes (Anonymous, 2007-08). It occupies a position of considerable worth because of its importance in agricultural economy of the country. Ethiopia is probably the main centre of origin of the garden peas. It is very palatable and nutritious for human consumption and is taken fresh, canned, frozen or in dehydrated form. It contains higher proportion of digestible proteins alongwith carbohydrates, vitamins and mineral matter (Choudhary, 1996). Green tender foliage of garden pea is also used as vegetable in parts of Asia and Africa. Leaves are used as a pot herb in Myanmar and parts of Africa (Kay, 1979). Garden pea is a cool season crop and is mainly grown in Uttar Pradesh, Bihar, Haryana, Himachal Pradesh and Punjab. However, Uttar Pradesh accounts for 70 per cent of the total out put of peas in India (Singhal, 2003).

In Himachal Pradesh, the districts of Lahaul and Spiti, Kinnaur, Shimla, Kullu and Mandi are the major pea producing areas. The area under pea crop in Himachal Pradesh is 16,348 hectares with an annual production of 1,77,036 metric tonnes (Anonymous, 2006). With steady increase in acreage and production over the years, it has occupied the position of the most leading cash crop especially in the high (zone III and zone IV) and mid hills (zone II), from where the green pods are available during the period April to October and they find ready market in the plains bringing remunerative returns to the growers. In zone IV, garden pea cultivation is under assured irrigation conditions only. In zone III and II, majority of the area is either rainfed or has limited irrigation water. The main season garden pea varieties are sown during November (zone II and III) and March – June (zone IV) and inadequate soil moisture is usually a limiting factor in ensuring proper germination. Quality seed has been well recognized as the basic input in any production programme. Availability of water and nutrients especially phosphorus in legumes in acidic soils is of great significance in improving not only the seed yield but also the seed quality. About 81 per cent of the total cultivated area in the state is rainfed (Anonymus, 2004) and there exists limited opportunity for new water development projects for expanding irrigated area.

Water is an important natural resource and its efficient management is a key to success in augmenting crop production. During the 21st century, water would be a crucial factor in enhancing food production, in meeting food deficit experienced by almost two-thirds of the world's population since irrigated farming is expected to continue to develop intensively in future (UNESCO, 2000). Judicious management of irrigation water resources is important not only for enhancing and sustaining crop production but also for prevention of salinity, alkalinity, water logging and degradation of environment. For farmers with a limited supply of water, improving productivity is a chance to improve incomes and livelihoods (Sharma, 2002). Irrigation water being a scarce and economically high cost input, especially in hilly areas, its optimality in pea cultivation is crucial to realize the maximum yield as well as improve the water use efficiency.

The growth of plants depends on the availability of nutrients from soil which has to be supplied by appropriate use of fertilizers for sustenance of growth. Phosphorus is an essential constituent of several enzymes and co-enzymes which are involved in basic reactions of photosynthesis. It has specific action on encouraging root development in many legume crop species (Brady, 1984). The most essential function of phosphorus in plants is in energy storage and transfer. Adenosine di- and triphosphates (ADP and ATP) act as "energy currency" within plants. Phosphorus is associated with early maturity of crops (Tisdale *et al*., 1995). However, deficiency of phosphorus in Indian soils is widespread and majority of soils are unable to furnish sufficient quantities of phosphorus for higher yield on a sustained basis (Tandon, 1987). Limited study, investigating the role of irrigation water and phosphorus nutrient on garden pea, has been carried out earlier under mid-hill (zone II) conditions of Himachal Pradesh. Therefore, there is a need for technological intervention, which will help in sustaining the precious resources and maximizing crop production.

Keeping in view the above facts, the present study was planned and executed to economize irrigation water and phosphorus nutrition on one hand and optimize seed yield along with improved seed quality on the other, with the following objectives:

1. To study the effect of irrigation and phosphorus levels on growth, seed yield and quality of garden pea.
2. To determine water use efficiency (WUE) of garden pea.
3. To find the best irrigation schedules and phosphorus level for garden pea.

Chapter III

MATERIALS AND METHODS

The present investigation was undertaken to ascertain the "Effect of irrigation and phosphorus levels on seed production of garden pea (*Pisum sativum* L.)" during the *rabi* seasons of 2005-06 to 2007-08 at the Experimental Farm of the Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur. The details of experimental site, materials used and the methods employed have been presented in this chapter under the following heads:

3.1 General description of the experimental site

3.1.1 Experimental site

The experiment was conducted at the Experimental Farm of the Department of Vegetable Science and Floriculture, Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya, Palampur. The experimental site is situated between 32.6^0 N latitude and 76.3^0E longitude and at an altitude of 1290m above mean sea level.

3.1.2 Climate and weather

Agroclimatically, the experimental site falls in the sub-temperate mid-hill zone which is endowed with mild summer and cool winters along with high rainfall during monsoons. The weekly meteorological data recorded at the Meteorological Observatory of the Department of Agronomy, during the field experimental period of the years 2005-06, 2006-07 and 2007-08 have been given in Appendix I, II and III and illustrated in Fig.3.1a, Fig.3.1b and Fig.3.1c, respectively.

3.1.3 Soil characteristics

Soil samples were drawn from 0-15cm depth. These representative soil samples from different locations of the experimental area were mixed, dried, sieved and composite sample was drawn for determining various physico-chemical properties. The results of various soil physico-chemical properties, before the start of experiment, and the methods employed are given in Table 3.1.

Table 3.1 Physicochemical properties of soil of experimental site

Parameters	Value			Method employed
	Depth (cm)			
	0-15	15-30	30-60	
Mechanical analysis				
Sand (%)	22.2	-	-	International pipette method (Piper, 1966)
Silt (%)	43.2	-	-	
Clay (%)	32.7	-	-	
Texture	Silty clay loam			
Bulk density (g/cm^3)	1.06	1.19	1.22	Core sample technique (Singh, 1980)
Soil moisture content (%) (Before pre-sowing irrigation)	13.71	15.62	19.17	Gravimetric method
Chemical analysis				
Organic carbon (%)	0.95	-	-	Walkley and Black's rapid titration method (Piper, 1966)
Soil pH	5.9	-	-	1:2.5 soil water suspension glass

				electrode method (Jackson, 1967)
Available Nitrogen (kg/ha)	292.0	-	-	Alkaline potassium permanganate method (Subbiah and Asija, 1956)
Available phosphorus (kg/ha)	17.2	-	-	Olsen's method (Olsen *et al.,* 1956)
Available potassium (kg/ha)	263.2	-	-	Ammonium acetate method using flame photometer (Jackson, 1967)

The soil analysis data showed that the soil of the experimental field was silty clay loam in texture, acidic in reaction (pH 5.9) and medium in organic carbon, available nitrogen, phosphorus and potassium (ranges given in Appendix IV).

3.1.4 Cropping history

Before start of the experiment in *rabi* 2005-06 field was under brinjal crop. Details during the experimental period are given below:

Season	Crop
Rabi 2005-06	Garden pea seed crop
Kharif 2006	Okra
Rabi 2006-07	Garden pea seed crop
Kharif 2006	Fallow
Rabi 2007-08	Garden pea seed crop

3.2 Experimental details

3.2.1 Field preparation and layout

The experimental field was prepared with the help of tractor driven disc plough, cultivation and harrow at the time of start of experiment. The experimental plots were prepared manually. During the subsequent seasons the experimental field was ploughed with tractor driven cultivator ensuring minimum displacement of soil and thereafter the experimental plots were prepared manually. The layout has been shown in Figure 3.2.

3.2.2 Details of treatments

A. **Irrigation levels (Main-plot)**

I_1 Water seeding (0.43cm) *viz*., irrigation within the rows before sowing.

I_2 I_1 + irrigation (1cm) during vegetative stage.

I_3 I_2 + irrigation (1cm) at 75% flowering.

I_4 I_3 + irrigation (1cm) at 75% podding.

I_5 Recommended irrigation schedule (5cm depth) pre-sowing + vegetative + 75% flowering + 75% podding stage.

B. Phosphorus levels (Sub-plot)

P_1 40kg P_2O_5/ha

P_2 60kg P_2O_5/ha

P_3 80kg P_2O_5/ha

Treatment combinations	:	15
Replications	:	3
Total number of plots	:	45
Spacing	:	45 X 10cm
Plot size	:	3.15m X 2.0m = 6.3m^2
Design	:	Split-Plot
Variety	:	Palam Priya.

3.2.3 Application of manures and fertilizers

The entire recommended dose of nitrogen (50kg/ha), potassium (60kg/ha), FYM (20t/ha) and phosphorus fertilizer as per sub-plot treatments were applied and mixed with in furrows before water seeding. The fertilizers used were composite (12:32:16 NPK), urea (46% N) and muriate of potash (60% K_2O).

3.2.4 Sowing

Palam Priya variety of garden pea was procured from Vegetable Farm, CSKHPKV, Palampur. Seeds were soaked in bavistin (0.1%) solution for 24 hours before sowing. Seed sowing was done manually by placing 30 seeds/row at equidistance. Chlorpyriphos @ 2.5ml/litre of water was sprayed with in the rows before covering the seeds with soil to protect seed from soil born insects.

3.3 Crop management

3.3.1 Intercultural operations and plant protection

The recommended package of practices was followed to raise the crop. Thinning was carried out to maintain the required plant population of 140 plants/plot with in 35 DAS. Hoeing and weeding operations were carried out from time to time in each plot of the experiment. No prominent disease/insect-pest was observed in pea seed crop. However, bavistin (0.1%) sprays (one in each crop season) were given as a prophylactic measure. Besides, one spray of rogor (0.1%) insecticide was done during 2006-07 only to control leaf miner. More details are given in Appendix V.

3.3.2 Harvesting/Threshing

The seed crop was harvested treatment and replication wise manually at maturity. The harvested produce was sun dried for about a week. Threshing was carried out by enclosing the sun-dried produce within a threshing sheet followed by light beating with the help of a wooden stick at the threshing floor.

3.4 Observations recorded

Observations recorded on various traits in garden pea are described as follows:

3.4.1 Growth and development

3.4.1.1 Days to 50 per cent emergence

The experimental plots were visited every day. Days to 50 per cent germination were recorded treatment wise as the number of days taken from the date of sowing to the day when 50 per cent of the seedlings had emerged.

3.4.1.2 Days to 50 per cent flowering

Days to 50 per cent flowering were recorded treatment wise as the number of days taken from the date of sowing to the day when 50 per cent of the plants had flowered.

3.4.1.3 Plant height (cm)

Ten plants were taken at random in each treatment. The height of these plants were measured from the soil surface to the apex and averaged as mean plant height (cm).

3.4.1.4 Leaf area index (LAI)

In the active growth stage (peak podding stage) three plants per experimental plot were marked at random, uprooted and brought to the laboratory to measure the leaf area of entire plants with the area measurement system, MK-2 (Delta-T Dereces Ltd. Burrvell, Cambridge, England). These values were then converted to total leaf area per plant (cm^2). Leaf area index (LAI) was calculated as per formula given by Redford (1967):

$$LAI = \frac{Leaf\ area}{Ground\ area}$$

3.4.1.5 Leaf water potential (-kPa)

Leaf water potential was also recorded in the active growth stage using a portable pressure chamber apparatus (Waring and Cleary, 1967). A fully exposed compound leaf along with tendril, third from top of the plant, was taken for this purpose. Three such leaves from three plants in each treatment were used for determination of leaf water potential (in -bars). Values were averaged for each treatment and converted into -kPa by multiplying with 100.

3.4.1.6 Root nodules per plant

Root nodules were not visible at the time of seed maturity. Hence, the data on this trait could not be recorded.

3.4.2 Yield attributes and yield

3.4.2.1 Effective plant population

The effective plant population was recorded at the time of harvesting by counting number of plants in each plot of the experiment and compared with the plant population of 140/plot maintained after the thinning operation.

3.4.2.2 Days to seed maturity

The data on the days to seed maturity were recorded as the number of days from the date of sowing to the day when ≥75% of the pods on plants in an experimental plot had turned yellow in colour.

3.4.2.3 Biological yield (g/plot or q/ha)

The plants were harvested manually in each experimental plot above the ground level at maturity and weighed in g/plot with the help of a weighing balance. The biological yield was converted into q/ha by multiplying the net plot yield by the factor 0.01587.

3.4.2.4 Number of pods per plant

Ten plants were taken at random on the day of harvest, total pods were counted and average values were worked out.

3.4.2.5 Number of seeds/pod

Ten pods were taken at random from 3.4.2.4. The numbers of seed were counted after shelling and the average seeds/pod were recorded.

3.4.2.6 Seed yield (g/plot or q/ha)

The harvested plants from each experimental plot were sun-dried for about a week and threshed. The threshed seeds were cleaned and sun dried for a couple of days before weighing. The seed yield then converted into q/ha by multiplying the net plot seed yield (g/plot) by the factor 0.01587.

3.4.3 Seed quality parameters

3.4.3.1 100-seed weight (g)

A random sample of 100-seeds was drawn from each treatment and weighed on electronic balance.

3.4.3.2 Seed germination (%)

A random sample of 100-seeds per treatment was drawn and seeds were placed in between the germination papers (BP) and incubated at 25 ± 1^0C. Data on germination were recorded based on ISTA rules on the 8th day of incubation (Agrawal, 1986).

3.4.3.3 Seed vigour

Total length (root+shoot) of all the germinated seeds (3.4.3.2) were recorded and average length was calculated by dividing the total length of all the seedlings with the total number of the germinated seeds. The seed vigour index was calculated as per Abdul-Baki and Anderson (1973) as follows:

Seed vigour index = Seedling length x germination percentage.

3.4.3.4 Crude protein content (%)

Crude protein content in garden pea seed was estimated by multiplying the nitrogen content (%) by the factor 6.25.

3.4.4 Plant/soil Chemical studies

3.4.4.1 Preparation and analysis of plant samples

The sun dried seed and straw samples were powdered separately and kept in paper bags for further analysis. The detail of chemical analysis is given below:

3.4.4.2 Total nitrogen content

Powdered straw and seed samples were digested with concentrated H_2SO_4 using digestion mixture and total nitrogen was determined by micro-Kjeldhal's method (Jackson, 1967).

3.4.4.3 Total phosphorus content

Straw and seed samples were digested with diacid mixture of HNO_3 and $HClO_4$ in the ratio of 9:4 and the extract was made to a definite volume. Total phosphorus was determined by Vanadomolybdate phosphoric acid yellow colour method at 470nm (Jackson, 1967).

3.4.4.4 Total potassium content

It was determined by using flame-emission spectrophotometer from the extract obtained by digestion with diacid mixture (Chapman and Brown, 1950).

3.4.4.5 Nutrient uptake

The concentration of nitrogen, phosphorus and potassium were determined in straw and seed samples and uptake was calculated as follows:

Uptake (kg/ha) = % concentration of nutrient X sun dried straw/seed yield of crop (kg/ha)

Total uptake was calculated as follows:

Total uptake = uptake in straw + uptake in seed

3.4.4.6 Available phosphorus in soil

Plot wise soil samples were drawn from 0-15cm depth after harvest of crop during all the three seasons whereas plot wise soil samples before sowing were drawn only during 2006 and 2007. The available soil phosphorus in the soil was determined by using Olsen's method (Olsen *et al.,* 1956).

3.4.5 Water studies

3.4.5.1 Soil water content (%)

The changes in soil water content during the crop season at different profile depths (0-15, 15-30 and 30-60cm) were monitored at about 15 day's interval by using gravimetric method. The soil water content was calculated by the following formula:

$$W = \frac{Ms - Md}{Md} \times 100$$

Where,

W : Soil water content (%)

M_s : Fresh mass of soil sample (g)

M_d : Oven dried mass of soil sample (g)

The volumetric moisture content (θ) was worked out as follows:

$$\theta = W \times \rho$$

where, ρ = bulk density

3.4.5.2 Total water use

The total water use by the pea crop was computed from the effective rainfall (ER), seasonal moisture depletion from 60cm profile (ΔS_{60}) and irrigation water applied (cm) as per treatment (I), all in centimeter unit by using the following equation:

$$\text{Total water use} = ER + \Delta S_{60} + I$$

3.4.5.3 Water use efficiency

The water use efficiency (WUE) was computed as:

$$\text{WUE(kg seed/ha/cm water used)} = \frac{\text{Seed yield (kg/ha)}}{\text{Total water use (cm)}}$$

3.5 Statistical analysis

The average data recorded treatment wise and replication wise on various parameters were subjected to statistical analysis using split-plot design as follows:

3.5.1 Analysis of variance for split-plot design

The ANOVA table for Split-Plot Design as explained by Gomez and Gomez (1984) is given in Table 3.2.

Table 3.2 ANOVA table for Split-Plot Design

Source of variation	Degree of Freedom (df)	Sum of Squares (SS)	Mean Sum of Squares (MS)	Computed 'F'	Tabulated 'F' (P=0.05)
Replication	(r-1)	R_{ss}	$R_{ss}/(r-1) = R_{ms}$	R_{ms}/E_{ams}	
Main-plot factor (a)	(a-1)	M_{ss}	$M_{ss}/(a-1) = M_{ms}$	M_{ms}/E_{ams}	3.84 at 4 and 8 df
Error (a)	(r-1) (a-1)	E_{ass}	$E_{ss}/(r-1)(a-1) = E_{ams}$		
Sub-plot factor (b)	(b-1)	S_{ss}	$S_{ss}/(b-1) = S_{ms}$	S_{ms}/E_{bms}	3.49 at 2 and 20 df
					2.45 at 8

axb	(a-1) (b-1)	I_{ss}	I_{ss}/(a-1) (b-1) = I_{ms}	I_{ms}/E_{bms}	and 20 df
Error (b)	a (r-1) (b-1)	E_{bss}	E_{bss}/a(r-1) (b-1) = E_{bms}		
Total	rab-1				

Where, a = main-plot factor; b = sub-plot factor; r = replication; E = error

In a split-plot design, with two variable factors and two error terms, there are four different types of comparisons. Each requires its own set of CD values. These comparisons are as follows:

1. Comparison between two main-plot treatment (irrigation levels) means averaged over all sub-plot treatments.
2. Comparison between two sub-plot treatment (phosphorus levels) means averaged over all main-plot treatments.
3. Comparison between two sub-plot treatment means (phosphorus levels) at the same main-plot treatments (irrigation levels).
4. Comparison between two main-plot treatment (irrigation levels) means at the same or different sub-plot treatments (phosphorus levels).

The Standard Error (SE) of Mean Difference for each of these types of pair comparisons are computed as follows:

Type of pair comparison		SE_d±	Tabulated ‘t’ at P=0.05
Number	Between		
1.	Two main-plot means	$(2E_{ams}/rb)^{1/2}$	t_a

	(averaged over all sub-plot treatments)		
2.	Two sub-plot means (averaged over all main-plot treatments)	$(2E_{bms}/ra)^{1/2}$	t_b
3.	Two sub-plot means at the same main-plot treatments.	$(2E_{bms}/r)^{1/2}$	t_b
4.	Two main-plot means at the same or different sub-plot treatments	$[2\{(b-1) E_{bms} + E_{ams}\}/rb]^{1/2}$	t_w

These SE_d values were then multiplied by tabular standard t-values for the calculation of CD values except for the comparison which involved more than one error term like type-4 comparison. For such comparison SE_d was multiplied with weighted tabular t-value which was computed by the formula given below:

$$\text{Weighted Tabular t-value } (t_w) = [(b-1) E_{bms}t_b + E_{ams}t_a]/ [(b-1)E_{bms} + E_{ams}]$$

The critical difference (CD) also called as least significant difference were calculated as follows:

$$CD1 = SE_{d1} \times t_a$$

$$CD2 = SE_{d2} \times t_b$$

$$CD3 = SE_{d3} \times t_b$$

$CD4 = SE_{d4} \times t_w$

3.5.2 Analysis of variance for Randomized Block Design (RBD)

Water use efficiency (WUE) was analysed as per randomized block design since irrigation levels were in main plots. The ANOVA table for RBD is given in Table 3.3.

Table 3.3 ANOVA table for Randomized Block Design

Source of variation	Degree of Freedom (df)	Sum of Squares (SS)	Mean Sum of Squares (MS)	Computed 'F'	Tabulated 'F' (P=0.05)
Replication	(r-1)	R_{ss}	$R_{ss}/(r-1) = R_{ms}$	R_{ms}/E_{ms}	4.303 at 2 and 8 df
Treatment	(t-1)	T_{ss}	$T_{ss}/(t-1) = T_{ms}$	T_{ms}/E_{ms}	2.776 at 2 and 8 df
Error	(r-1) (t-1)	E_{ss}	$E_{ss}/(r-1)(t-1) = E_{ms}$		
Total	(rt-1)				

Where, r = replication; t = treatment; E = error.

For the treatment comparisons, the critical difference (CD) value was computed as follows:

$CD = SE_d \times t_{0.05}$

Where $SE_d = (2E_{ms}/r)^{½}$.

Chapter IV

RESULTS

The effect of different irrigation and phosphorus levels on various growth and development parameters, yield attributes and yield, seed quality traits, plants/soil chemical studies were studied in field experiments during *rabi* season of 2005-06, 2006-07 and 2007-08. The details of results obtained have been presented below:

4.1 Analysis of variance

Analysis of variance for the experimental design (Appendix VI, VII and VIII) revealed that mean sum of squares due to main treatment (irrigation levels) during 2005-06 were significant for days to 50 per cent emergence, days to 50 per cent flowering, leaf area index (LAI), plant height (cm), days to seed maturity, pods/plant, seeds/pod, biological yield (g/plot or q/ha), seed yield (g/plot or q/ha), 100-seed weight (g), seed germination (%), seed vigour index, crude protein content (%), NPK-uptake (kg/ha) and water use efficiency (kg/ha/cm) whereas these were non-significant for the effective plant population and available soil-phosphorus (kg/ha). In the same year (2005-06) mean sum of squares due to sub-plot treatments (phosphorus levels) were significant for all the traits except days to 50 per cent emergence and effective plant population. However the irrigation x phosphorus interaction was non-significant for all the traits studied.

During 2006-07, mean sum of squares due to main treatment (irrigation levels) were significant for all the traits studied except days to 50 per cent emergence, days to 50 per cent flowering, effective plant population, 100-seed weight (g), seed germination (%) and available soil-phosphorus (kg/ha) after seed harvest. Mean squares due to sub-plot treatments (phosphorus levels) were also significant in this year for all the traits except days to 50 per cent emergence, days to 50 per cent flowering and effective plant population. However irrigation x phosphorus interaction was significant for the traits *viz*., leaf area index (LAI), days to seed maturity and seed yield (g/plot or q/ha).

During 2007-08, mean sum of square values due to main treatments (irrigation levels) were significant for all the traits except effective plant population. Mean sum of squares due to sub-plot treatment (phosphorus levels) were also significant for all the traits except days to 50 per cent emergence and effective plant population. The irrigation x phosphorus interaction was significant for the traits biological yield (g/plot or q/ha), crude protein content (%), N and K-uptake (kg/ha) and available soil-phosphorus (kg/ha) after harvest.

4.2 Growth and development

4.2.1 Days to 50 per cent emergence

The effect of different irrigation and phosphorus levels on days to 50 per cent emergence are presented in Table 4.1. Irrigation levels were significant during 2005-06 and 2007-08 but non-significant during 2006-07. The irrigation treatments I_1, I_2, I_3 and I_4 took significantly less number of days during 2005-06 (21.33 to

22.33) and 2007-08 (19.89 to 21.00) as compared to I_5 (recommended) which took 23.78 and 25.56 days, respectively. The irrigation treatments I_1, I_2, I_3 and I_4 were at par with each other. The influence of phosphorus levels as well as irrigation x phosphorus interactions were non-significant in all the three years.

Table 4.1 Effect of irrigation and phosphorus levels on days to 50 per cent emergence in garden pea.

Treatment	Days to 50% emergence		
	2005-06	2006-07	2007-08
Irrigation (I)			
I_1	21.33	13.22	21.00
I_2	22.33	13.22	19.89
I_3	21.78	13.44	20.44
I_4	21.44	13.22	20.22
I_5	23.78	13.56	25.56
CD(P=0.05)	1.43	NS	1.41
Phosphorus (P)			
P_1	22.40	13.27	21.47
P_2	22.13	13.40	21.60
P_3	21.87	13.33	21.20
CD(P=0.05)	NS	NS	NS
IxP interaction	NS	NS	NS

NS = Non-significant

4.2.2 Days to 50 per cent flowering

The effect of different irrigation and phosphorus levels on days to 50 per cent flowering were significant during 2005-06 and 2007-08 but not during 2006-07 (Table 4.2). The irrigation level I_4 took the minimum number of days (83.78 and 98.11) and was significantly earlier to I_5 (recommended). The irrigation level I_4 during all the study years was at par with I_1, I_2 and I_3 levels except with I_2 during 2007-08. The phosphorus level P_3 took significantly less number of days to 50 per cent flowering (83.80 and 98.60) but was at par with P_2 level during 2007-08 (99.47) which in turn was at par with P_1 level (99.93). The interaction irrigation x phosphorus was non-significant in all the three years.

Table 4.2 Effect of irrigation and phosphorus levels on days to 50 per cent flowering in garden pea.

Treatment	Days to 50% flowering		
	2005-06	2006-07	2007-08
Irrigation (I)			
I_1	84.33	93.44	98.67
I_2	84.67	93.44	99.89
I_3	84.67	93.22	98.67
I_4	83.78	92.44	98.11
I_5	86.11	93.78	101.33

CD(P=0.05)	0.98	NS	1.36
Phosphorus (P)			
P_1	85.67	93.67	99.93
P_2	84.67	93.4	99.47
P_3	83.80	92.73	98.60
CD(P=0.05)	0.66	NS	0.90
IxP interaction	NS	NS	NS

4.2.3 Leaf area index (LAI)

The effect of different irrigation and phosphorus levels and their interaction on LAI are presented in Tables 4.3a and 4.3b respectively. The irrigation treatment I_4 (7.08, 7.27 and 7.51) and I_5 (7.22, 7.14 and 7.45) recorded the highest leaf area index during all the three years which were significantly higher than other irrigation levels except I_3 during 2006-07. Among the phosphorus levels, P_3 resulted in the maximum leaf area index (6.37, 7.16 and 6.76) during all the three years which were at par with P_2 (6.25, 6.64 and 6.57) except during 2006-07. Irrigation x phosphorus interaction was significant during 2006-07 only. The phosphorus level P_3, P_2 and P_1 were at par with each other at irrigation level I_5 whereas at I_4, only P_3 and P_2 were at par. However at I_1, I_2 and I_3, the highest phosphorus level (P_3) gave significantly higher leaf area index over rest of the phosphorus levels. The irrigation levels I_3, I_4 and I_5 at P_1, P_2 and P_3 phosphorus levels were at par with each other except I_4P_2 and I_3P_2 being significantly different with each other. The leaf area index was the maximum in I_4P_3 (7.61) which was at par with treatment combinations I_3P_3, I_4P_2, I_5P_2 and I_5P_3.

Table 4.3a Effect of irrigation and phosphorus levels on leaf area index in garden pea

Treatment	leaf area index		
	2005-06	2006-07	2007-08
Irrigation (I)			
I_1	5.04	5.98	4.84
I_2	5.25	5.94	6.07
I_3	6.38	6.95	6.96
I_4	7.08	7.27	7.51
I_5	7.22	7.14	7.45
CD(P=0.05)	0.29	0.42	0.11
Phosphorus (P)			
P_1	5.97	6.17	6.35
P_2	6.25	6.64	6.57
P_3	6.37	7.16	6.76
CD(P=0.05)	0.27	0.25	0.23
IxP interaction	NS	S	NS

S= Significant

Table 4.3b Interaction effect of irrigation and phosphorus levels on leaf area index in garden pea during 2006-07

Treatment	2006-07		
	Phosphorus (P)		
Irrigation (I)	P_1	P_2	P_3
I_1	5.50	5.93	6.52
I_2	5.14	5.73	6.96
I_3	6.61	6.79	7.44
I_4	6.75	7.45	7.61
I_5	6.87	7.30	7.27
CD(P=0.05) to compare different phosphorus (P) levels at same level of irrigation (I)			0.57
CD(P=0.05) to compare different irrigation (I) levels at same or different levels of phosphorus (P)			0.62

4.2.4 Leaf water potential (-kPa)

The effect of irrigation levels on leaf water potential are illustrated graphically in Fig. 4.1. The plants under irrigation level I_5 (recommended) recorded the highest leaf water potential (-287.0, -279.0 and 262.7kPa) followed by I_4 (-339.3, -288.0 and -287.7 kPa), I_3 (-361.0, -355.0 and -334.0 kPa), I_2 (-393.7, -371.0 and -370.3 kPa) and I_1 (-408.7, -410.3 and -384.7 kPa) during 2005-06, 2006-07 and 2007-08 respectively.

4.2.5 Plant height (cm)

The effect of different irrigation and phosphorus levels on plant height (cm) are presented in Table 4.4 and illustrated graphically in Fig. 4.2 (a & b). The maximum plant height (47.78cm, 53.64cm and 48.98cm) was recorded in the irrigation level I_5 (recommended) but it was at par with I_4 (45.62cm, 52.70cm and 48.89cm). Both I_4 and I_5 were significantly higher as compared to remaining irrigation levels (I_1, I_2 and I_3) during all the three years. The highest phosphorus level P_3 resulted in maximum plant height (43.68cm, 48.70cm and 45.88cm) which were at par with P_2 (42.56cm and 47.64cm) during 2005-06 and 2006-07 but significantly superior (45.88cm) during 2007-08. Both P_3 and P_2 were significantly superior to P_1 during all the three years.

Table 4.4 Effect of irrigation and phosphorus levels on plant height (cm) in garden pea.

Treatment	Plant height (cm)		
	2005-06	2006-07	2007-08
Irrigation (I)			
I_1	37.25	40.95	35.80
I_2	36.44	43.06	41.86
I_3	41.37	46.00	44.20
I_4	45.62	52.70	48.89
I_5	47.78	53.64	48.98
CD(P=0.05)	2.52	1.84	2.98

Phosphorus (P)			
P_1	38.84	45.47	42.05
P_2	42.56	47.64	43.90
P_3	43.68	48.70	45.88
CD(P=0.05)	1.86	1.43	1.68
IxP interaction	NS	NS	NS

The irrigation x phosphorus interactions were non-significant during all the three years.

4.2.6 Days to seed maturity

The effect of different irrigation and phosphorus levels and their interaction on days to seed maturity are presented in Tables 4.5a and 4.5b, respectively. The irrigation treatments I_1, I_2 , I_3 and I_4 took significantly less number of days (136.44-137.89 days and 140.44-142.33days) in comparison to I_5 (141.44 and 144.56 days) during 2005-06 and 2006-07, respectively.

Table 4.5a Effect of irrigation and phosphorus levels on days to seed maturity in garden pea

Treatment	Days to maturity		
	2005-06	2006-07	2007-08
Irrigation (I)			

I_1	136.44	140.44	144.89
I_2	136.89	141.56	147.00
I_3	136.78	142.33	147.33
I_4	137.89	141.67	146.89
I_5	141.44	144.56	151.00
CD(P=0.05)	1.81	2.08	1.15
Phosphorus (P)			
P_1	138.87	142.40	148.47
P_2	138.07	142.80	147.47
P_3	136.73	141.13	146.33
CD(P=0.05)	1.34	0.95	0.84
IxP interaction	NS	S	NS

During 2007-08, the irrigation treatments I_1, I_2, I_3 and I_4 were significantly earlier to $I_{5.}$ Also, I_1 was significantly earlier to I_2, I_3 and I_4 treatments. The phosphorus level P_3 resulted in earlier maturity (136.73, 141.13 and 146.33 days) as compared to lower levels but was at par with P_2 (138.07) during 2005-06. The irrigation x phosphorus interaction was significant during 2006-07 only. All the phosphorus levels were at par at the irrigation levels I_1, I_2 and I_5 whereas the phosphorus level P_3 took significantly lesser number of days (139.33 and 140.00 days respectively) as compared to P_2 and P_1 levels at the irrigation levels I_4 and I_3.

Table 4.5b Interaction effect of irrigation and phosphorus levels on days to seed maturity in garden pea during 2006-07

Treatment	2006-07		
	Phosphorus (P)		
Irrigation (I)	P_1	P_2	P_3
I_1	140.00	141.67	139.67
I_2	140.67	141.67	142.33
I_3	144.33	142.67	140.00
I_4	142.33	143.33	139.33
I_5	144.67	144.67	144.33
CD(P=0.05) to compare different phosphorus (P) levels at same level of irrigation (I)			2.13
CD(P=0.05) to compare different irrigation (I) levels at same or different levels of phosphorus (P)			2.71

The irrigation levels I_1, I_2, I_3 and I_4 at different phosphorus levels took less number of days as compared to I_5 and were at par with each other except I_3P_1 and I_2P_3 which in turn were at par with I_4P_1 and I_5P_1 and I_1P_3 and I_5P_3, respectively. The treatment combination I_4P_3 took minimum number of days (139.33) to seed maturity which was at par with I_1P_1, I_1P_2, I_1P_3, I_2P_1, I_2P_2 and I_3P_3.

4.3 Yield attributes and yield

4.3.1 Pods/plant

The effect of different irrigation and phosphorus levels on number of pods/plant are presented in Table 4.6.

Table 4.6 Effect of irrigation and phosphorus levels on number of pods/plant in garden pea.

Treatment	Pods/plant		
	2005-06	2006-07	2007-08
Irrigation (I)			
I_1	10.40	8.53	7.79
I_2	10.40	8.74	8.46
I_3	12.14	13.03	12.17
I_4	12.73	13.13	13.78
I_5	13.17	13.48	14.19
CD(P=0.05)	0.48	0.36	0.69
Phosphorus (P)			
P_1	10.91	10.42	10.79
P_2	11.93	11.37	11.28
P_3	12.47	12.36	11.75
CD(P=0.05)	0.44	0.45	0.40
IxP interaction	NS	NS	NS

The recommended irrigation level I_5 recorded the maximum number of pods/plant (13.17, 13.48 and 14.19) during all the three years but was at par with irrigation level I_4 (12.73, 13.13 and 13.78 pods/plant) and both were significantly higher as compared to the other irrigation treatments except I_3 which was at par with I_4 during 2006-07. The phosphorus level P_3 resulted in significantly higher number of pods/plant (12.47, 12.36 and 11.75) as compared to P_2 and P_1 levels during all the three years. The irrigation and phosphorus interaction was non-significant during all the three years.

4.3.2 Seeds/pod

The effect of different irrigation and phosphorus levels on number of seeds/pods are presented in Table 4.7.

Table 4.7 Effect of irrigation and phosphorus levels on number of seeds/pod in garden pea

Treatment	Seeds /pod		
	2005-06	2006-07	2007-08
Irrigation (I)			
I_1	6.30	6.02	5.73
I_2	6.39	6.27	6.28
I_3	6.88	6.77	7.20
I_4	7.48	7.71	7.46
I_5	7.61	7.83	7.53

CD(P=0.05)	0.26	0.30	0.31
Phosphorus (P)			
P_1	6.31	6.61	6.58
P_2	6.73	6.97	6.81
P_3	6.88	7.18	7.13
CD(P=0.05)	0.23	0.21	0.27
IxP interaction	NS	NS	NS

The irrigation level I_5 (recommended) recorded the maximum number of seeds/pod (7.61, 7.83 and 7.53) during all the three years but were at par with the irrigation level I_4 (7.48, 7.71 and 7.46) and both were significantly higher as compared to the other irrigation treatments *viz.,* I_1, I_2 and I_3 except I_3 which was at par with I_4 during 2007-08. The phosphorus level P_3 resulted in significantly more number of seeds/pod (6.88, 7.18 and 7.13) as compared to P_1 and P_2 levels during all the three years except P_2 which was at par with P_3 during 2005-06.

4.3.3 Biological yield (g/plot and q/ha)

The effect of different irrigation and phosphorus levels and their interaction on biological yield (g/plot and q/ha) are presented in Tables 4.8a, 4.8b and 4.8c, respectively and illustrated graphically in Fig. 4.3a and 4.3b, respectively.

Table 4.8a Effect of irrigation and phosphorus levels on biological yield/plot (g) in garden pea

Treatment	Biological yield/plot (g)		
	2005-06	2006-07	2007-08
Irrigation (I)			
I_1	2258.33	2208.33	2090.56
I_2	2255.56	2341.67	2275.00
I_3	2316.67	2525.00	2633.33
I_4	2716.67	2938.89	2858.33
I_5	2733.33	2958.33	2877.78
CD(P=0.05)	74.70	37.52	106.47
Phosphorus (P)			
P_1	2380.00	2476.67	2462.67
P_2	2456.67	2631.67	2568.33
P_3	2531.67	2675.00	2610.00
CD(P=0.05)	55.48	47.50	38.67
IxP interaction	NS	NS	S

The irrigation level I_5 (recommended) recorded the highest biological yield/plot (2733.33g, 2958.33g and 2877.78g) during all the three years but were at par with irrigation levels I_4 (2716.67g, 2938.88g and 2858.33g) and both were significantly higher yielding over rest of the irrigation levels *viz.,* I_1, I_2 and I_3. Among the phosphorus levels, P_3 was higher in biological yield (2531.67g, 2675.00g and

2610.00g) during all the three years and was significantly higher over P_2 and P_1 levels except P_2 in 2006-07. Irrigation x Phosphorus interaction was significant during 2007-08 only. The phosphorus levels P_3 and P_2 were at par at irrigation levels I_5, I_4 and I_1 whereas P_3 gave significantly higher biological yield (g/plot) over P_2 and P_1 at I_2 and I_3 irrigation levels. The irrigation treatments

Table 4.8b Effect of irrigation and phosphorus levels on biological yield (q/ha) in garden pea

Treatment	Biological yield (q/ha)		
	2005-06	2006-07	2007-08
Irrigation (I)			
I_1	35.84	35.05	31.96
I_2	35.80	37.17	34.92
I_3	36.77	40.08	41.05
I_4	43.12	46.65	45.37
I_5	43.39	46.96	45.25
CD(P=0.05)	1.19	0.59	1.67
Phosphorus (P)			
P_1	37.78	39.31	38.01
P_2	38.99	41.77	40.16
P_3	40.18	42.46	40.96
CD(P=0.05)	0.88	0.75	0.62

IxP interaction	NS	NS	S

I_4 and I_5 were at par irrespective of the phosphorus levels. The treatment combinations I_4P_2 and I_5P_3 gave the highest biological yield/plot (2908.33g) and were at par with I_4P_1, I_4P_3, I_5P_1, and I_5P_2 (2791.67g, 2875.00g, 2783.33g and 2866.67g respectively).

Table 4.8c Interaction effect of irrigation and phosphorus levels on biological yield (g/plot or q/ha) in garden pea during 2007-08

Treatment	Biological yield (g/plot) 2007-08			Biological yield (q/ha) 2007-08		
	Phosphorus (P)					
Irrigation (I)	P_1	P_2	P_3	P_1	P_2	P_3
I_1	1873.33	2091.67	2075.00	29.74	33.20	32.94
I_2	2050.00	2225.00	2325.00	32.54	35.32	36.90
I_3	2475.00	2558.33	2725.00	39.29	40.61	43.25
I_4	2791.67	2908.33	2875.00	44.31	46.16	45.64
I_5	2783.33	2866.67	2908.33	44.18	45.50	46.16
CD(P=0.05) to compare different phosphorus (P) levels at same level of irrigation (I)			86.46			1.38
CD(P=0.05) to compare different irrigation (I) levels						

at same or different levels of phosphorus (P)	127.61	2.02

4.3.4 Seed yield (g/plot and q/ha)

The effect of different irrigation and phosphorus levels and their interaction on seed yield (g/plot and q/ha) are presented in Tables 4.9a, 4.9b and 4.9c and illustrated graphically in Fig. 4.4a and 4.4b, respectively. The irrigation treatment I_5 (recommended) recorded the highest seed yield/plot (865.56g, 886.67g and

Table 4.9a Effect of irrigation and phosphorus levels on seed yield/plot (g) in garden pea

Treatment	Seed yield /plot (g)		
	2005-06	2006-07	2007-08
Irrigation (I)			
I_1	700.00	548.33	530.56
I_2	696.67	595.00	539.44
I_3	722.22	667.78	595.00
I_4	837.22	860.00	831.67
I_5	865.56	886.67	845.00
CD(P=0.05)	33.65	34.12	36.10
Phosphorus (P)			
P_1	720.67	648.00	633.00
P_2	764.33	719.33	676.33
P_3	808.00	767.33	695.67

CD(P=0.05)	16.80	24.18	23.22
IxP interaction	NS	S	NS

Table 4.9b Effect of irrigation and phosphorus levels on seed yield (q/ha) in garden pea

Treatment	Seed yield (q/ha)		
	2005-06	2006-07	2007-08
Irrigation (I)			
I_1	11.11	8.70	8.42
I_2	11.06	9.44	8.56
I_3	11.46	10.60	9.44
I_4	13.29	13.65	13.20
I_5	13.74	14.07	13.41
CD(P=0.05)	0.53	0.54	0.57
Phosphorus (P)			
P_1	11.44	10.29	10.05
P_2	12.13	11.42	10.74
P_3	12.83	12.18	11.04
CD(P=0.05)	0.27	0.38	0.37
IxP interaction	NS	S	NS

845.00g) during all the three years but were at par with irrigation level I_4 (837.22g, 860.00g and 831.67g) and both were significantly higher seed yielding as compared to the other treatments *viz*., I_1, I_2 and I_3. The phosphorus level P_3

resulted in the highest seed yield/plot (808.80g, 767.33g and 695.67g) during all the three years and was significantly higher than P_2 and P_1 levels except P_2 during 2007-08. Irrigation x phosphorus interaction was significant during 2006-07 only. The phosphorus level P_3 gave significantly higher seed yield in comparison to P_2 and P_1 at irrigation levels I_5 and I_4 whereas the phosphorus

Table 4.9c Interaction effect of irrigation and phosphorus levels on seed yield (g/plot or q/ha) in garden pea during 2006-07.

Treatment	Seed yield (g/plot) 2006-07			Seed yield (q/ha) 2006-07		
	Phosphorus (P)					
Irrigation (I)	P_1	P_2	P_3	P_1	P_2	P_3
I_1	521.67	540.00	583.33	8.28	8.57	9.26
I_2	551.67	613.33	620.00	8.76	9.74	9.84
I_3	625.00	680.00	698.33	9.92	10.79	11.08
I_4	765.00	861.67	953.33	12.14	13.68	15.13
I_5	776.67	901.67	981.67	12.33	14.31	15.58
CD(P=0.05) to compare different phosphorus (P) levels at same level of irrigation (I)			54.08			0.86
CD(P=0.05) to compare different irrigation (I) levels at same or different levels			55.74			0.88

of phosphorus (P)

levels P_3 and P_2 were at par at the irrigation levels I_3, I_2 and I_1. The irrigation level I_4 was at par with I_5 at all the levels of phosphorus. The treatment combination I_5P_3 gave the highest seed yield (981.67g/plot) and was at par with I_4P_3 (953.35g/plot).

4.3.5 Effective plant population (at harvest)

Data given in Appendix XIV showed that the effect of irrigation and phosphorus levels and their interactions on effective plant population at harvest was non-significant. This indicated the maintenance of required plant population throughout the crop season in all the years.

4.4 Seed quality

4.4.1 100-seed weight (g)

The effect of different irrigation and phosphorus levels on 100-seed weight are presented in Table 4.10. Irrigation levels were significant except during 2006-07. The maximum 100-seed weight were in I_5 (21.86g) during 2005-06 and I_4 (19.89g) during 2007-08 and these treatments were at par with each other. I_3 was also at par with I_4 and I_5 during 2007-08. The phosphorus level P_3 resulted in more 100-seed weight (21.10g, 19.46g and 19.74g) and was at par with P_2 (20.97g, 19.39g and 19.71g) and both were significantly higher over P_1 during all the three years. The irrigation and phosphorus interaction were non-significant.

Table 4.10 Effect of irrigation and phosphorus levels on 100-seed weight (g) in garden pea.

Treatment	100 seed weight (g)		
	2005-06	2006-07	2007-08
Irrigation (I)			
I_1	20.04	18.62	19.01
I_2	20.11	18.89	19.16
I_3	20.25	19.34	19.60
I_4	21.79	19.64	19.89
I_5	21.86	19.89	19.82
CD(P=0.05)	0.66	NS	0.44
Phosphorus (P)			
P_1	20.35	18.98	19.04
P_2	20.97	19.39	19.71
P_3	21.10	19.46	19.74
CD(P=0.05)	0.56	0.35	0.26
IxP interaction	NS	NS	NS

4.4.2 Seed germination (%)

The effect of different irrigation and phosphorus levels on seed germination are presented in Table 4.11. Irrigation levels were significant during 2005-06 and 2007-08 only. Irrigation levels I_4 and I_5 resulted in higher seed germination (86.89%) during 2005-06 and 2007-08, respectively but these were at par with each other. Both the treatments (I_4 and I_5) recorded significantly higher seed germination as compared to the remaining irrigation levels (I_1, I_2 and I_3). The phosphorus level P_3 gave the maximum seed germination (86.47%, 82.27% and 86.00%) but was at par with P_2 in all the years except during 2005-06. Both (P_3 and P_2) resulted in higher germination over P_1 during all the three years. Irrigation x phosphorus interactions were non-significant.

Table 4.11 Effect of irrigation and phosphorus levels on seed germination (%) in garden pea.

Treatment	Seed germination (%)		
	2005-06	2006-07	2007-08
Irrigation (I)			
I_1	84.11 (9.17)	80.78 (8.99)	83.44 (9.13)
I_2	83.78 (9.15)	79.56 (8.92)	84.22 (9.18)
I_3	84.11 (9.17)	80.33 (8.96)	85.11 (9.23)
I_4	86.89 (9.32)	82.67 (9.09)	86.67 (9.31)
I_5	86.44 (9.30)	82.78 (9.10)	86.89 (9.32)
CD(P=0.05)	1.90 (0.10)	NS	1.03 (0.06)
Phosphorus (P)			

P_1	83.80 (9.15)	79.80 (8.93)	84.20 (9.18)
P_2	84.93 (9.22)	81.60 (9.03)	85.60 (9.25)
P_3	86.47 (9.30)	82.27 (9.07)	86.00 (9.27)
CD(P=0.05)	1.05 (0.06)	1.34 (0.07)	0.90 (0.05)
IxP interaction	NS	NS	NS

Values in parenthesis are square root transformed values.

4.4.3 Seed vigour index (SVI)

The effect of different irrigation and phosphorus levels on seed vigour index (SVI) are presented in Table 4.12.

Irrigation level I_5 (recommended) resulted in the maximum seed vigour index (1387.88, 1378.93 and 1457.19) but was statistically at par with I_4 (1374.03, 1374.97 and 1450.81) during all the three years and I_3 (1320.79 and 1406.88) during 2006-07 and 2007-08. The phosphorus level P_3 recorded the maximum seed vigour index (1306.13, 1337.86 and 1434.05) followed by P_2 (1283.60, 1333.78 and 1404.15) and both were at par but significantly superior to P_1 during all the three years. The irrigation x phosphorus interaction were non-significant.

Table 4.12 Effect of irrigation and phosphorus levels on seed vigour index in garden pea.

Treatment	Seed vigour index (SVI)		
	2005-06	2006-07	2007-08
Irrigation (I)			
I_1	1115.71	1197.01	1249.13

I_2	1196.84	1255.81	1326.23
I_3	1254.48	1320.79	1406.88
I_4	1374.03	1374.97	1450.81
I_5	1387.88	1378.93	1457.19
CD(P=0.05)	91.66	88.87	69.13
Phosphorus (P)			
P_1	1207.63	1244.87	1295.95
P_2	1283.60	1333.78	1404.15
P_3	1306.13	1337.86	1434.05
CD(P=0.05)	44.21	39.87	45.66
IxP interaction	NS	NS	NS

4.4.4 Crude protein content (%)

The effect of irrigation and phosphorus levels and their interaction are presented in Tables 4.13a and 4.13b, respectively.

Table 4.13a Effect of irrigation and phosphorus levels on crude protein content (%) in garden pea.

Treatment	Crude protein (%)		
	2005-06	2006-07	2007-08
Irrigation (I)			

I_1	18.99	19.10	19.20
I_2	19.33	19.20	19.42
I_3	19.58	19.71	19.70
I_4	19.37	19.98	20.24
I_5	19.56	19.92	20.22
CD(P=0.05)	0.35	0.41	0.08
Phosphorus (P)			
P_1	18.75	19.13	19.38
P_2	19.63	19.70	19.79
P_3	19.72	19.92	20.10
CD(P=0.05)	0.40	0.25	0.21
IxP interaction	NS	NS	S

Table 4.13b Interaction effect of irrigation and phosphorus levels on crude protein content (%) in garden pea during 2007-08.

Treatment	2007-08		
	Phosphorus (P)		
Irrigation (I)	P_1	P_2	P_3
I_1	19.19	18.90	19.50
I_2	18.88	19.50	19.90
I_3	18.88	20.23	19.98
I_4	19.94	20.25	20.52
I_5	20.00	20.06	20.58

CD(P=0.05) to compare different phosphorus (P) levels at same level of irrigation (I)	0.47
CD(P=0.05) to compare different irrigation (I) levels at same or different levels of phosphorus (P)	0.39

The maximum crude protein content of seed was in I_3 (19.58%) during 2005-06 and this was at par with I_2, I_4 and I_5. The protein content was the highest in I_4 (19.98% and 20.24% during 2006-07 and 2007-08 respectively) and this was at par with I_5 and also I_3 during 2006-07. Irrigation levels I_2 and I_3 during 2005-06 and I_3 during 2006-07 were also at par with I_4 and I_5. Among the phosphorus levels, P_3 gave the highest crude protein content (19.72%, 19.92% and 20.10%) and was at par with P_2 (19.63% and 19.70%) during 2005-06 and 2006-07 respectively. Irrigation x phosphorus interaction was significant in 2007-08 only. The phosphorus level P_3 was significantly higher over P_2 and P_1 at irrigation level I_5. At I_2, I_3 and I_4 irrigation levels, P_3 and P_2 were at par but at I_1, P_3 was at par with P_1. The irrigation levels I_4 and I_5 were at par with each other irrespective of the phosphorus levels. Irrigation level I_3 was also at par with I_4 and I_5 at phosphorus level P_2. Among the different treatment combinations, the highest crude protein content was recorded in I_5P_3 (20.58%) and was at par with I_3P_2 (20.23%), I_4P_2 (20.25%) and I_4P_3 (20.52%).

4.5 Plant/soil chemical studies

4.5.1 N-uptake (kg/ha)

The different irrigation and phosphorus levels and their interaction effect on N-uptake are presented in Tables 4.14a and 4.14b. The irrigation level I_5 (recommended) resulted in the maximum N-uptake/ha (109.48kg and 107.60kg) in 2005-06 and 2007-08 and I_4 (103.56kg) in 2006-07 but both were at par and significantly higher over rest of the irrigation levels *viz*., I_1, I_2 and I_3 during all the three years. The phosphorus level P_3 led to more N-uptake/ha (100.96kg,

Table 4.14a Effect of irrigation and phosphorus levels on N-uptake (kg/ha) in garden pea.

Treatment	N-uptake (kg/ha)		
	2005-06	2006-07	2007-08
Irrigation (I)			
I_1	82.64	75.74	73.06
I_2	83.70	81.01	78.64
I_3	91.94	90.66	93.34
I_4	107.62	103.56	106.12
I_5	109.48	102.46	107.60
CD(P=0.05)	2.00	2.73	1.77
Phosphorus (P)			
P_1	87.88	84.31	86.14
P_2	96.39	92.12	94.14
P_3	100.96	95.63	94.97
CD(P=0.05)	2.10	3.16	1.43

IxP interaction	NS	NS	S

Table 4.14b Interaction effect of irrigation and phosphorus levels on N-uptake (kg/ha) in garden pea during 2007-08.

Treatment	2007-08		
	Phosphorus (P)		
Irrigation (I)	P_1	P_2	P_3
I_1	65.89	76.67	76.62
I_2	72.58	80.42	82.92
I_3	87.81	94.26	97.96
I_4	101.60	111.15	105.62
I_5	102.81	108.22	111.76
CD(P=0.05) to compare different phosphorus (P) levels at same level of irrigation (I)			3.20
CD(P=0.05) to compare different irrigation (I) levels at same or different levels of phosphorus (P)			3.15

95.63kg and 94.97kg) and was significantly higher over lower levels except P_2 in 2007-08. The irrigation x phosphorus interaction was significant in 2007-08 only. The phosphorus levels P_3 and P_2 gave significantly the highest N-uptake (111.76 and 111.15kg/ha) at irrigation levels I_5 and I_4 respectively. The irrigation levels I_4 and I_5 were at par with each other at P_1 and P_2 whereas I_5 was significantly higher than I_4 at P_3 level. Among all the treatment combinations, I_5P_3 resulted in the highest N-uptake (111.76kg/ha) and was at par with I_4P_2 (111.15kg/ha).

4.5.2 P-uptake (kg/ha)

The effect of different irrigation and phosphorus levels are presented in Table 4.15.

Table 4.15 Effect of irrigation and phosphorus levels on P-uptake (kg/ha) in garden pea.

Treatment	P-uptake (kg/ha)		
	2005-06	2006-07	2007-08
Irrigation (I)			
I_1	11.17	11.40	10.18
I_2	11.23	12.60	11.33
I_3	12.05	13.89	13.44
I_4	14.56	16.84	15.26
I_5	14.57	16.62	15.88
CD(P=0.05)	1.00	0.61	0.87
Phosphorus (P)			
P_1	11.24	13.47	12.00
P_2	13.20	14.36	13.48
P_3	13.70	14.98	14.17
CD(P=0.05)	0.64	0.50	0.38

IxP interaction	NS	NS	NS

The irrigation levels I_5 (14.57kg, 16.62kg and 15.88kg) and I_4 (14.56kg, 16.84kg and 15.26kg) resulted in maximum P-uptake/ha and were at par with each other but significantly higher as compared to lower levels. Among the phosphorus levels, P_3 gave significantly higher P-uptake/ha (13.70kg, 14.98kg and 14.17kg) as compared to lower levels during all the years except P_2 (13.20kg) in 2005-06. The irrigation x phosphorus interaction was non-significant during all the three years.

4.5.3 K-uptake (kg/ha)

The effect of different irrigation and phosphorus levels and their interaction on K-uptake (kg/ha) are presented in Tables 4.16a and 4.16b.

Table 4.16a Effect of irrigation and phosphorus levels on K-uptake (kg/ha) in garden pea.

Treatment	K-uptake (kg/ha)		
	2005-06	2006-07	2007-08
Irrigation (I)			
I_1	42.69	45.89	43.02
I_2	43.45	48.42	48.22
I_3	44.49	53.96	55.98
I_4	53.64	62.36	61.35
I_5	53.68	61.84	61.82
CD(P=0.05)	2.29	1.40	2.77

Phosphorus (P)			
P_1	45.84	51.69	52.06
P_2	47.36	55.09	54.62
P_3	49.57	56.69	55.56
CD(P=0.05)	1.38	1.69	1.23
IxP interaction	NS	NS	S

Table 4.16b Interaction effect of irrigation and phosphorus levels on K-uptake (kg/ha) in garden pea during 2007-08.

Treatment	2007-08		
	Phosphorus (P)		
Irrigation (I)	P_1	P_2	P_3
I_1	39.50	45.30	44.27
I_2	44.28	48.90	51.49
I_3	53.86	53.58	60.49
I_4	61.17	64.03	58.84
I_5	61.48	61.28	62.71
CD(P=0.05) to compare different phosphorus (P) levels at same level of irrigation (I)			2.74
CD(P=0.05) to compare different irrigation (I) levels at same or different levels of phosphorus (P)			3.56

The irrigation level I_5 (recommended) recorded the maximum K-uptake/ha (53.68kg and 61.82kg) during 2005-06 and 2007-08 whereas I_4 recorded the maximum (62.36kg/ha) during 2006-07 but both were at par with each other and significantly higher than lower levels during all the three years. The phosphorus level P_3 resulted in maximum K-uptake/ha (49.57kg, 56.69kg and 55.56kg) which were at par with P_2 (55.09kg and 54.62kg) during 2006-07 and 2007-08 but significantly higher during 2005-06. The irrigation x phosphorus interactions were significant during 2007-08 only. The phosphorus levels P_3 and P_2 were at par at the irrigation levels I_5, I_2 and I_1 whereas P_3 and P_2 resulted in significantly higher K-uptake/ha at the irrigation levels I_3 and I_4 respectively. The irrigation levels I_5 (recommended) and I_4 were at par to each other at the phosphorus levels P_1 and P_2. I_5 was significantly higher than I_4 at P_3. The maximum K-uptake/ha was recorded in the treatment combination I_4P_2 (64.03kg) and it was at par with I_3P_3, I_4P_1, I_5P_1, I_5P_2 and I_5P_3 (60.49kg/ha, 61.17kg/ha, 61.48kg/ha, 61.28kg/ha and 62.71kg/ha).

4.5.4 Available soil phosphorus (kg/ha)

The effect of different irrigation and phosphorus levels and their interaction on available soil phosphorus after the harvest of garden pea seed crop are presented in Table 4.17a and 4.17b,

Table 4.17a Effect of irrigation and phosphorus levels on available soil phosphorus (kg/ha) after harvesting of seed crop in garden pea.

Treatment	Available soil phosphorus (kg/ha)		
	2005-06	2006-07	2007-08
Irrigation (I)			
I_1	19.73	21.32	22.68
I_2	20.09	21.32	22.95
I_3	19.84	20.93	22.36
I_4	19.44	20.46	21.68
I_5	19.38	20.71	21.78
CD(P=0.05)	NS	NS	0.70
Phosphorus (P)			
P_1	18.66	20.31	21.45
P_2	19.87	20.79	22.17
P_3	20.55	21.74	23.25
CD(P=0.05)	0.39	0.45	0.52
IXP interaction	NS	NS	S

Table 4.17b Interaction effect of irrigation and phosphorus levels on available soil phosphorus (kg/ha) after harvesting of the seed crop in 2007-08.

Treatment	2007-08
	Phosphorus (P)

Irrigation (I)	P_1	P_2	P_3
I_1	21.84	22.03	24.16
I_2	22.22	22.71	23.91
I_3	21.02	23.02	23.03
I_4	21.42	20.77	22.85
I_5	20.75	22.31	22.28
CD(P=0.05) to compare different phosphorus (P) levels at same level of irrigation (I)			1.17
CD(P=0.05) to compare different irrigation (I) levels at same or different levels of phosphorus (P)			1.18

Whereas the status of plot wise soil-phosphorus before sowing are presented in Appendix IX. The effects of different irrigation levels on available soil phosphorus were significant during 2007-08 only. Irrigation level I_2 had maximum available soil-phosphorus (22.95kg/ha) and was at par with I_1 and I_3 (22.68kg/ha and 22.36kg/ha) whereas I_3 was in turn at par with I_4 (21.68kg/ha). Among the phosphorus levels, the highest level P_3 resulted in significantly more available soil phosphorus (20.55kg/ha, 21.74kg/ha and 23.25kg/ha) over rest of the phosphorus levels during all the three years. The irrigation x phosphorus interaction was significant during 2007-08 only. The phosphorus level P_3 was significantly higher over P_2 and P_1 at I_4, I_2 and I_1 irrigation levels whereas P_2 was at par with P_3 at I_3 and I_5 irrigation levels. The irrigation levels I_1, I_2 and I_4 were at par at phosphorus level P_1 but I_1, I_2 and I_3 were at par with each other at P_2 and P_3 levels. I_5 was also at par with I_1, I_2 and I_3 at P_2 level. Among the treatment combinations, I_1P_3 had the highest available soil phosphorus (24.16kg/ha) and was at par with I_2P_3 (23.91kg/ha), I_3P_2 (23.02kg/ha) and I_3P_3 (23.03kg/ha).

4.6 Water studies

4.6.1 Soil moisture content

The data on soil moisture content on volumetric basis (θ) during the subsequent periods of crop season during 2005-06, 2006-07 and 2007-08 in profile depths of 0-15cm, 15-30cm and 30-60cm are given in Appendix XV and illustrated graphically in Fig. 4.5, 4.6 and 4.7, respectively. The 'θ' values in 0-15cm, 15-30cm and 30-60cm were the maximum with the irrigation level I_5 (recommended) as compared to rest of the irrigation levels *viz.,* I_1, I_2, I_3 and I_4.

4.6.2 Water use efficiency (kg/ha/cm)

The effect of different irrigation levels on water use efficiency (WUE) in seed production of garden pea are presented in Table 4.18 and illustrated graphically in Fig. 4.8. Whereas the total water use by the crop during 2005-06, 2006-07 and 2007-08 are given in Appendix X (a), X (b) and X (c). The irrigation level I_4 resulted in significantly higher water use efficiency (kg/ha/cm) (78.43, 41.22 and 45.30) over rest of the irrigation levels *viz.,* I_1, I_2, I_3 and I_5 (recommended) during all the three year.

Table 4.18 Effect of irrigation levels on water use efficiency (kg/ha/cm) in garden pea.

Treatment	Water use efficiency (kg/ha/cm)		
	2005-06	2006-07	2007-08
Irrigation (I)			
I_1	71.95	27.79	31.22
I_2	70.83	28.74	30.24
I_3	70.43	32.48	32.25
I_4	78.43	41.22	45.30
I_5	45.51	28.68	29.30
CD(P=0.05)	3.06	1.31	1.97

Chapter V

DISCUSSION

Garden pea (*Pisum sativum* L.) is the most leading cash crop of Himachal Pradesh. Except the districts of Lahaul-Spiti and Kinnaur (zone-IV) and valley areas, its cultivation is primarily under rainfed/limited irrigation conditions. Inadequate soil moisture at sowing time in mid (zone-II) and high (zone-III) hills results in suboptimal plant stand thereby resulting in reduced green pod and seed yields. Phosphorus is known for healthy root development which in turn proves beneficial in better utilization of soil moisture and nutrients and ultimately enhances yield and quality. Since the scope of increasing irrigation potential in the state is restricted, economic/optimal use of every drop of water is highly desired. As only a limited studies on the economic use of irrigation water and phosphorus nutrient on garden pea have been carried out earlier under mid hill conditions, the present investigation was planned and executed to study the effect of irrigation and phosphorus levels on growth, seed yield and quality of garden pea coupled with determining water use efficiency (WUE) and also to suggest the best irrigation scheduling and phosphorus level. The results obtained are discussed as follows.

5.1 Growth and development

Proper growth and development are the prerequisites to realize optimum yields and these are ensured through the various seed and plant characters such as days to emergence, flowering and seed maturity, leaf area index, leaf water potential and plant height.

The effect of irrigation levels proved significant on days to 50 per cent emergence during the first (2005-06) and third (2007-08) year. Water seeding treatments (I_1, I_2, I_3 and I_4) proved better than the recommended practice (I_5) in earlier emergence of seeds which suggests that the moisture in the near vicinity of the seed is available in adequate quantities for a longer period ensuring earlier emergence as compared to recommended practice of pre-sowing irrigation in the entire plot followed by seed sowing at field condition. The irrigation levels proved non-significant during the second year (2006-07) which may be attributed to natural rainfall of 1.74 cm on 22.11.2006 just after four days of sowing (18.11.2006). Phosphorus levels proved non-significant in all the years probably on account of the fact that the germinating seeds get the initial energy from the cotyledons and the roots are to develop and absorb phosphorus in due course of time. The irrigation x phosphorus interaction proved non-significant in all the years.

As expected, days to 50 per cent flowering also followed the same trend as for days to 50 per cent emergence. Variety and the seed lot being the same, the seeds germinating at an earlier date are also likely to flower earlier. In contrast, phosphorus levels proved significant during first (2005-06) and third (2007-08) years. The highest phosphorus level of P_3 @ 80kg

P_2O_5/ha resulted in earlier flowering and this was at par with P_2 level during 2007-08 which may be attributed to increase in available soil phosphorus at the sowing time of third year (Appendix IX). The beneficial response of phosphorus on early flowering in garden pea is on account of the fact that phosphorus application plays a pivotal role in energetic metabolism and biosynthetic reactions as a component of ATP, NAD, NADP and RNA, which govern cell multiplication resulting in rapid completion of vegetative growth (Kanaujia *et al*., 1997). The present findings are similar to Kanaujia *et al.* (1998) and Sinha *et al.* (2000) who have also observed earlier flowering with higher phosphorus dose. Non-significant effect of phosphorus levels during the second year (2006-07) may be due to more natural rainfall soon after sowing.

Leaf area index is an important growth parameter as productivity rates increase somewhat with LAI because of more total light interception **(**Salisbury and Ross, 1986). The recommended irrigation (I_5) was at par with water seeding plus limited water supply at the critical stages (I_4) in all the three years but these were at par with I_3 as well during 2006-07. Higher phosphorus levels (P_3 and P_2) also resulted in higher LAI values but P_3 was significantly higher to P_2 during 2006-07. This shows the favourable response of recommended irrigation/limited irrigation at all the critical stages as well as higher dose of phosphorus nutrient. Similar findings have also been reported by Yadav *et al.* (1993) and Kasturikrishna and Ahlawat (2000) while working on pea. Barky *et al.* (1985) have also observed reduction in leaf area with the omission of one irrigation at any one of the stages (vegetative, flowering and pod formation). The interaction I x P was significant during the second year only when there was natural rainfall soon after sowing.

Higher leaf water potential (LWP) in the plants implies the absence of water stress within the plant system for various metabolic functions. The pea plants receiving the recommended irrigation (I_5) recorded the highest leaf water potential followed by I_4, I_3, I_2 and I_1 during all the crop seasons. This may be attributed to higher soil moisture with increase in irrigation frequency and quantity of water (I_4 and I_5) leading to more water uptake by the plants in such treatments. Similar views have been expressed by Arora *et al.* (1991) and Gajri *et al.* (1991) while working in corn and wheat respectively.

Plant height is one of the most important growth characters which governs the ultimate yield of plants. Like LAI, the recommended irrigation (I_5) and water seeding plus limited irrigation at all the critical stages (I_4) resulted in more plant height and these were at par with each other in all the three years. Similarly, the highest phosphorus level (P_3) recorded the maximum plant height and this was at par with P_2 except in third year. The interactions I x P were non-significant in all the years. The explanation given earlier in the attribute LAI holds true for plant height as well. The present findings are in agreement to those of Rathi *et al.* (1995) and Bahadur and Singh (1990) with respect to irrigation and phosphorus on field pea and garden pea respectively. Reddy and Ahlawat (1998) have also observed that two irrigations at branching and pod development stages markedly contributed to increase in plant height as compared to no irrigation (control) in chickpea.

Early seed maturity is a desirable attribute in garden pea. Reduction of irrigation water at all the critical growth stages (I_4) and also omitting limited irrigation water at one or more of the critical stages, except water seeding, led to earlier seed maturity as compared to the recommended irrigation (I_5). Higher dose of phosphorus (P_3) also induced earlier seed maturity. This implies that more water quantity in plant system will lead to physiological activity for a longer period and higher dose of phosphorus will accomplish the same at an earlier date. The interaction I x P was significant during the year 2006-07 only in which besides natural rainfall soon after sowing there were adequate rains thereafter as well. The findings are in line with those of Sinha *et al.* (2000) who have also observed earlier seed maturity with the application of higher phosphorus dose.

5.2 Yield attributes and yield

Number of pods per plant is one of the direct components of seed yield. The recommended irrigation (I_5) resulted in the maximum number of pods/plant but was at par with water-seeding plus limited irrigation water at all the critical growth stages (I_4) during all the three years. Similarly, the highest dose of phosphorus nutrient (80 kg P_2O_5/ha) gave significantly more pods/plant. The interactions I x P were non-significant in all the years. This suggests that plants with no or minimal moisture stress maintain superiority at all the phenological stages (Kasturikrishna and Ahlawat, 2000). Similarly phosphorus has a key role in rapid cell division and elongation in the meristematic regions, root development and proliferation and enhancing flowering, pod setting and seed formation. The present findings are in consonance to those of Rathi *et al.* (1995), Singh *et al.* (2001) and Kaushik and Chaubey (2003) with respect to the role of irrigation water on pods/plant and Uddin *et al.* (2001), Bhatt *et al.* (2002) and Dass *et al.* (2005) with respect to phosphorus. Tewari and Singh (2000) have also reported more pods/plant in French bean with the application of higher doses of P_2O_5.

Number of seeds/pod is also an important trait which contributes towards seed yield directly. Like number of pods/plant, the recommended irrigation (I_5) as well as water-seeding plus limited irrigation at all the critical stages (I_4) resulted in the maximum number of seeds/pod and both were significantly superior to other irrigation levels but were at par with each other. Similarly, the highest phosphorus level (P_3) also proved significant in getting more number of seeds/pod except during 2005-06 which may be attributed to the improvement in available phosphorus in the soil in subsequent years (Appendix IX). The present findings on account of favourable response of irrigation on seeds/pod are in conformity with those of Singh *et al.* (2001). Bhatt *et al.* (2002) and Dass *et al.* (2005) have also reported favourable response of phosphorus on number of seeds/pod in field and vegetable pea respectively.

Biological yield is of practical relevance in garden pea especially in the hill regions where besides the usage of seeds for sowing, vegetable and pulse-purposes, the green as well as dry foliage are fed to the cattle. Like pods/plant and seeds/pod, the irrigation treatments I_5 (recommended) and I_4 (water-seeding plus limited watering at all the critical stages) proved significantly superior in getting higher biological yield but both were at par with each other. Similarly, the highest phosphorus level proved the best except in second year (2006-07) when the natural rainfall was more including rain soon after sowing. The I x P interactions were non-significant except in third year. Rathi *et al.* (1995) have reported favourable response of irrigation water applied at branching + flowering + pod development stages as well as higher dose of phosphorus in field pea. Dubey *et al.* (1999) in pea and Dhar and Singh (1995) in French bean have also observed beneficial effect of irrigation at critical stages on vine and straw yield respectively. Dass *et al.* (2005) have noted positive response of higher P-nutrient on straw yield in vegetable pea.

Higher seed yield alongwith better seed quality is the ultimate goal in a seed production programme. Like pods/plant, seeds/pod and biological yield, the irrigation treatment I_5 and I_4 proved significantly superior in getting higher seed yield and both happened to be at par with each other. Similarly, the highest phosphorus level (80kg P_2O_5/ha) gave significantly higher seed yields as compared to lower levels except in the third year when P_3 was at par with P_2 (60 kg P_2O_5/ha) level. The I x P interaction was significant during second year (2006-07) only, when there was natural rain soon after sowing. The present findings on the desirable effect of irrigation on seeds/pod yield are in accordance with earlier researchers *viz.,* Singh *et al.* (2001), Kaushik and Chaubey (2003) and Masand *et al.* (2006). Uddin *et al.* (2001), Bhatt *et al.* (2002) and Masand *et al.* (2006) have also recorded higher seeds/pod yields with the application of higher doses of phosphorus nutrient.

5.3 Seed quality

Seed quality attributes are important not only for good germination but also for germination at a faster rate so as to ensure proper growth and development within a given period. 100-seed weight is an indicator of the boldness of the seed. The recommended irrigation (I_5) and water seeding plus limited watering at all the critical stages (I_4) proved significantly superior over all other irrigation levels during the first (2005-06) and third year (2007-08) but these were at par with each other. During 2006-07, all irrigation levels were at par primarily due to more natural rainfall including rain just after four days of sowing. The phosphorus levels P_3 and P_2 were at par with each other but significantly higher over the lower level (P_1). The interaction I x

P were non-significant all throughout. This implies that irrigation/limited watering at all the critical growth stages coupled with at least 60kg P_2O_5/ha is needed to improve 100-seed weight. These findings are in broad agreement to those of Dhar and Singh (1995), Nandan and Prasad (1998), Kumar and Puri (2002) and Prashant *et al.* (2006) in French bean and Sinha *et al.* (2000) in garden pea.

Seed germination is one of the most important seed quality characters and its significance can be judged from the fact that as per seed legislation its mention is a must on the seed container. The irrigation treatment I_5 (recommended) and I_4 (water-seeding + limited watering at all the subsequent critical stages) gave significantly higher seed germination as compared to other irrigation levels receiving lesser amount of water that too not at all the critical growth stages (I_1 to I_3) during the first and third year and both were at par with each other. Like 100-seed weight there were no significant differences in seed germination on account of irrigation levels during the second year (2006-07). The phosphorus levels P_3 and P_2 also ensured better seed germination and they were at par except in the first year (2005-06). I x P interactions were non-significant in all the years. Shukla and Kohli (1991) in garden pea and Prashant *et al.* (2006) in French bean have reported higher seed germination (%) at higher doses of phosphorus nutrient. However, there is no earlier report in literature on the effect of irrigation water on seed germination of garden pea and other legume crops as well.

Seed vigour index (SVI) gives an indication of rapidity of seed germination and subsequent plant growth and development. Irrigation level I_5 (recommended) and I_4 (water-seeding plus limited watering at all the critical growth stages) resulted in the maximum seed vigour index and were at par with each other including I_3 during 2006-07 and 2007-08. The phosphorus levels P_2 and P_3 were at par but were significantly superior over the lower level (P_1). Like 100-seed weight and seed germination, the interactions I x P were non-significant. In literature, higher phosphorus levels have been reported to enhance seed vigour index in pea (Shukla and Kohli, 1991 and Amjad *et al.,* 2004). Like seed germination, there is no earlier report on the effect of irrigation treatments on seed vigour index.

Higher crude protein content in seeds is an index of better seed quality. The irrigation treatments I_5 and I_4 produced seeds with higher crude protein content and were at par with each other during all the three years. These were at par with I_3 (2005-06 and 2006-07) and I_2 (2005-06) and this may be attributed to the differences in natural rainfall pattern received during the conduct of field experiment spread over three cropping seasons (2005-06, 2006-07 and 2007-08). The highest phosphorus level (P_3) also resulted in the highest crude protein content in seeds but it was at par with P_2 during the first two years. The I x P interaction was significant during third year only probably due to increase in the availability of phosphorus in the soil at the start of third year of field experiment. There is no earlier report in literature on the effect of irrigation on crude protein content in seeds of pea or any other legume crop but Rathi *et al.* (1993) and Prashant *et al.* (2006) have observed increase in crude protein content with higher phosphorus nutrient in field pea and French bean seeds, respectively.

5.4 Plant/soil chemical studies

Nitrogen, phosphorus and potassium are the primary nutrients required by the plants in larger quantities. Nitrogen plays a significant role in the plant system and plants absorb it either in the form of nitrate or ammonical form. It is an essential constituent of different proteins, nucleic acids and many other organic molecules such as chlorophyll. The irrigation treatments I_5 and I_4 resulted in more N-uptake (kg/ha) by the plants and were at par with each other in all the years. Rathi *et al.* (1993) and Dubey *et al.* (1999) have also observed better N-uptake by pea plant at higher irrigation frequency. The N-uptake (kg/ha) was also the maximum in the treatment receiving the highest dose of phosphorus nutrient (80kg P_2O_5/ha) but this was at par with P_2 during 2007-08. The interaction I x P was significant during third year only. The favourable response of phosphorus in N-uptake by the plants may be attributed to development of better root system. The present findings are in consonance with Dubey *et al.* (1999) in pea and Reddy and Ahlawat (1998) in chickpea and Parmar *et al.* (1999) in French bean.

Phosphorus plays a significant role in the energy transfer reactions and oxidation-reduction processes. Like N-uptake, P-uptake was the maximum in I_5 and I_4 both being at par and significantly higher over I_1, I_2 and I_3 irrigation levels. This may be attributed to the availability of adequate moisture around the root zone at all the critical growth stages in the treatments I_4 and I_5. The highest phosphorus level P_3 (80kg P_2O_5/ha) also revealed significant increase in P-uptake by the pea plants but was at par with P_2 (60kg P_2O_5/ha) during the first year probably due to availability of phosphorus in reduced quantity at the start of the field experiment during 2005-06. These findings are in agreement to those of Rathi *et al.* (1993) with respect to the beneficial response of irrigation and Dubey *et al.* (1999), Reddy and Ahlawat (1998) and Parmar *et al.* (1999) with respect to favourable response of higher doses of phosphorus application in P-uptake by the plants.

Potassium is readily mobile within plant tissues. It affects the rate of transpiration and water uptake through regulation of stomatal opening. Like N- and P-uptake, the same trend was observed in K-uptake by pea plants with respect to irrigation levels (I_5 and I_4 being the top best and at par) in all the years. The phosphorus level P_3 (80kg P_2O_5/ha) led to significant increase in K-uptake during 2005-06 but was at par with P_2 (60kg P_2O_5/ha) during the second (2006-07) and third (2007-08) years. Like N-uptake, the I x P interaction was also significant during the third year only. The present findings are in accordance with those of Dubey *et al.* (1999) who have also observed favourable response of higher phosphorus doses on K-uptake in pea plants. However, there is no report in literature with respect to the effect of irrigation on K-uptake by the plants.

Available soil-phosphorus is the amount of phosphorus which is available to plants. Plants absorb phosphorus in the form of soluble phosphorus such as $H_2PO_4^-$ and HPO_4^{2-} (orthophosphate ions). In soil, phosphorus gets fixed and this problem is more in acidic soil. Hence, the available soil-phosphorus is of great significance in nutrient studies. Irrigation treatments were significant during 2007-08 only. In general, the available soil-P after crop harvest decreased corresponding to the increase in irrigation water at the well recognized critical stages irrespective of the quantity (I_5 and I_4). Relatively lower quantities of available soil-P after crop harvest in the treatment I_4 and I_5 may be ascribed to more biological and seed yields obtained in these treatments. However, the non-significant differences in available soil-P after crop harvest in first year are difficult to be explained whereas the rainfall was more during the second year (2006-07). In contrast, the available soil-P after crop harvest increased with the corresponding increase in the phosphorus dose applied at the time of sowing of pea crop in all the years. Like the main treatments (irrigation levels), the I x P interaction was significant during the third year only. It is quite likely that available soil-P after harvest will increase with the application of more phosphorus at the sowing time as was observed in this study. The findings of the present study related to increase in available soil-P after each crop harvest are in accordance with those of Singh and Singh (1986) and Reddy and Ahlawat (1998).

5.5 Water studies

Water use efficiency (WUE) indicates the quantum of the economic yield obtainable per unit of area per unit of water used. The water use efficiency in the treatment I_4 (water seeding plus limited water supply at all the critical stages) was the maximum and significantly higher than all other treatments. Comparison among the years suggested that the water use efficiency (WUE) values were the highest during the first year followed by the third and the second years. This situation may be attributed to the fact that the natural rainfall was the minimum in first year and the maximum in second year and in between in third year. The water use efficiency (WUE) was the least in the recommended irrigation (I_5) which implies that even 1 cm irrigation along the rows is comparable in getting economic yield at par with irrigation of 5 cm depth applied at all the critical growth stages when the natural rainfall during the cropping season was 24.75cm, 48.59cm and 35.44cm during 2005-06, 2006-07 and 2007-08 respectively. Besides, the recommended method of irrigation (I_5) also leads to more weed intensity. Nandan and Prasad (1998) have also observed that increase in irrigation frequency decreased water use efficiency in French bean.

Chapter VI

SUMMARY

Garden pea is one of the most leading off-season vegetables in Himachal Pradesh. Quality seed is the basic input in any of the production programme. Irrigation water is a limiting factor in the hilly regions. Irrigation and phosphorus are important to improve the seed yield as well as its quality. Hence, the present investigation 'Effect of irrigation and phosphorus levels on seed production of garden pea (*Pisum sativum* L.)' was planned and executed at the experimental farm of the Department of Vegetable Science and Floriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur during *rabi* 2005-06, 2006-07 and 2007-08 to study the effect of irrigation and phosphorus levels on growth, seed yield and quality of garden pea, determine water use efficiency and find the best irrigation schedule and phosphorus level. The treatments consisted of five irrigation levels *viz*., I_1 (water-seeding), I_2 (I_1 + irrigation (1cm) at vegetative stage), I_3 (I_2 + irrigation (1cm) at 75% flowering), I_4 (I_3 + irrigation (1cm) at 75% podding) and I_5 (recommended irrigation schedule of 5cm depth at pre-sowing + vegetative + 75% flowering + 75% podding stages) in main-plots and three phosphorus levels *viz*., P_1 (40kg P_2O_5/ha), P_2 (60kg P_2O_5/ha) and P_3 (80kg P_2O_5/ha) in sub-plots. The field experiment was conducted in split-plot design with three replications. The main season, powdery mildew tolerant variety 'Palam Priya' was used in this study. Observations were recorded on the traits *viz*., days to 50 per cent emergence, days to 50 per cent flowering, leaf area index (LAI), leaf water potential (-kPa), plant height (cm), days to seed maturity, pods/plant, seeds/pod, biological yield (g/plot or q/ha) and effective plant population at harvest, 100-seed weight (g), seed germination (%), seed vigour index, crude-protein content (%), NPK-uptake (kg/ha), available soil-phosphorus (kg/ha) and water use efficiency (kg/ha/cm).

Earliness with respect to 50 per cent emergence of seedlings, 50 per cent flowering and seed maturity was recorded in the treatments receiving limited irrigation water at one or more of the critical growth stages (I_1 to I_4) as compared to the recommended irrigation (I_5). Plant height and leaf area index (LAI) were the maximum in the irrigation treatments I_5 (recommended) and I_4 (water-seeding + 1cm irrigation along the rows at all the critical stages) and both were at par. Leaf water potential was the maximum in I_5 followed by the lower irrigation levels in descending order. There was no effect of phosphorus on days to 50% emergence. The highest phosphorus level (P_3 @ 80kg P_2O_5/ha) resulted in earlier 50% flowering and days to seed maturity and the highest values of leaf area index and plant height but was at par with lower level (P_2 @ 60kg P_2O_5/ha) in some of the years. In general, the irrigation x phosphorus interactions were non-significant.

Seed yield and its attributes *viz*., pods/plant, seeds/pod and biological yield were significantly higher in the irrigation treatments I_5 (recommended) and I_4 (water-seeding + limited irrigation at all the critical stages) and both were at par with each other. Similarly, the highest phosphorus level (P_3) recorded significantly higher seed yield and yield attributes but was at par with P_2 for the traits seeds/pod, biological yield and seed yield during 2005-06, 2006-07 and 2007-08 respectively. In general, irrigation x phosphorus interactions were non-significant.

Like seed yield and its attributes, seed quality traits *viz*., 100-seed weight, seed germination (%), seed vigour index (SVI) and crude-protein content recorded the highest values in the irrigation treatments I_5 (recommended) and I_4 (water-seeding + limited irrigation supply at all the three critical stages) and both were at par with each other. These treatments were also at par with I_2 and I_3 in some years for one (crude-protein) and two (seed vigour index and crude-protein) traits respectively. The highest phosphorus level P_3 was also the best for improving seed quality attributes but quite often this was at par with P_2 level. In general, I x P interactions were non-significant.

Nitrogen, phosphorus and potassium-uptake by the plants from the soil were the maximum in the irrigation treatment I_5 (recommended) and I_4 (water-seeding + 1cm irrigation at all the critical stages). Similarly the highest phosphorus level also resulted in the highest N, P and K-uptakes. The lower phosphorus level P_2 was at par with P_3 for P (2005-06) and K-uptake (2006-07 and 2007-08). In general, I x P interactions were non-significant. Available soil-phosphorus status at the end of the third year of pea seed crop was the highest in the irrigation levels I_1, I_2 and I_3. With the highest phosphorus level, the available soil-phosphorus was the maximum at the end of pea seed crop in all the three years. I x P interactions were significant during 2007-08 only.

Water use efficiency (WUE) was significantly higher in the irrigation level I_4 (water-seeding + 1cm irrigation at all the critical growth stages) as compared to I_1, I_2 and I_3 as well as recommended irrigation (I_5). The irrigation level I_4 resulted in saving of irrigation water to the extent of 82.85% (16,57,000 litres/ha) as compared to the recommended irrigation practice (I_5) when the natural rainfall received by the crop was 24.75cm, 48.59cm and 35.44cm during *rabi* 2005-06, 2006-07 and 2007-08 respectively.

CONCLUSIONS

1. Water-seeding (0.43cm irrigation water applied within the row before sowing) proved better than pre-sowing irrigation of 5cm depth in early

emergence of seedlings. Besides, there was less weed intensity in water-seeding treatments (I_1 to I_4).

2. The irrigation levels I_5 (recommended irrigation of 5cm depth at all the critical stages) and I_4 (water-seeding + 1cm irrigation water along the rows at all the critical stages) along with the highest phosphorus level P_3 (80kg P_2O_5/ha) were the top best for growth, seed yield and quality traits and nutrient uptake.
3. Early to flowering and seed maturity were recorded in the treatments receiving limited irrigation water at one or more of the critical growth stages (I_1 to I_4) as compared to the recommended (I_5).
4. In general I x P interactions proved non-significant implying that higher phosphorus dose will not prove beneficial under water stress conditions.
5. Water use efficiency was the highest in irrigation level I_4.
6. The best irrigation schedule and phosphorus dose proved to be I_4P_3.

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