EVALUATING INTRA-TERRACE WATER HARVESTING IN POLY-LINED TANK AND ITS PRODUCTIVITY

THESIS

By

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IN

PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF

DOCTOR OF PHILOSOPHY
(SOIL SCIENCE)

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Dedicated

to

My Parents

and

Elders of my family

Dr. C.L. Acharya, FISSS, FAAS
Director, Indian Institute of Soil Science (ICAR),
Nabi Bagh, Berasia Road,
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CERTIFICATE - I

This is to certify that the thesis entitled "**Evaluating Intra-terrace Water Harvesting in Poly-lined Tank and Its Productivity**", Submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy (Agriculture)** in the subject of **Soil Science** to Himachal Pradesh Krishi Vishvavidyalaya, Palampur, is a bonafide research work carried out by Sh. Sanjay Sharma (A_{94}-40-13) son of Sh. A.C. Sharma 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.

(C.L. Acharya)
Chairman,
Advisory Committee

Place : Palampur
Dated : the June 10, 1998.

CERTIFICATE - II

This is to certify that the thesis entitled **"Evaluating Intra-terrace Water Harvesting in Poly-lined Tank and Its Productivity"**, Submitted by **Sh. Sanjay Sharma** to Himachal Pradesh Krishi Vishvavidyalaya, Palampur in partial fulfilment of the requirements for the degree of **Doctor of Philosophy (Agriculture)** in the subject of **Soil Science,** has been approved by the advisory committee after an oral examination of the same in collaboration with the external examiner.

7.9.98

Chairman,
Advisory Committee

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Perhaps, it is inevitable that some error of facts, interpretations and emphasis will be found, but I trust no one will attribute these to anyone, but me myself.

9/6/98

(SANJAY SHARMA)

CONTENTS

List of Symbols

Symbol	Explanation
a	empirical constant
@	at the rate of
b	empirical constant
BSSH	bright sunshine hours
°C	degree Celsius
cat.	category
CD	critical difference
CEC	cation exchange capacity
CPE	cumulative pan evaporation
CRI	crown root initiation
CSDD	cumulative stress degree days (°C)
DAS	days after sowing
E	east
et al.	and associates
etc.	*et cetera* (and so on)
ETP	evapo-transpiration
F	flowering
FB	frenchbean
Fig.	figure
FYM	farmyard manure
G	ginger
g	gram(s)
GI	galvanised iron
h	hour(s)
ha	hectare(s)
HP	Himachal Pradesh
HPKV	Himachal Pradesh Krishi Vishvavidyalaya
I	accumulated intake (mm)
i	infiltration rate (m/s or mm/h)
IW	irrigation water

K	Potassium
kg	kilogram(s)
km	Kilometer(s)
kPa	kilopascal
M	maize
m	metre(s)
m^2	square metre(s)
m^3	cubic metre(s)
Max.	maximum
Mg	megagram(s)
Min.	minimum
MPa	megapascal
mm	millimetre(s)
MWD	mean weight diameter
N	normal, north, nitrogen
n	empirical constant
Na_2CO_3	sodium carbonate
NaOH	sodium hydroxide
No.	number(s)
NS	nonsignificant
O	onion
OC	organic carbon(%)
P	phosphorus
PEC	pan evaporation coefficient
PEI	pre-emergence irrigation
pH	soil reaction
PSI	pre-sowing irrigation
R	radish
r	regression coefficient
Re	rupee
RF	rainfed
RH	relative humidity (%)
RMD	root mass density (kg/m^3)
Rs.	rupees
RV	root volume ($m^3/100m^3$)

s	second
SA	stable aggregates
SW	standard week
t	tonne(s), time
var.	variety
vs.	versus
viz.	videlicet (namely)
W	wheat
WUE	water use efficiency
WV	wind velocity (km/h)
x	empirical constant
XWP	xylem water potential
Y	variable
%	per cent
θ	volumetric moisture content ($m^3/100m^3$)
ψ	matric potential (-kPa)
Σ	sigma (summation)
μ	mu (micron)

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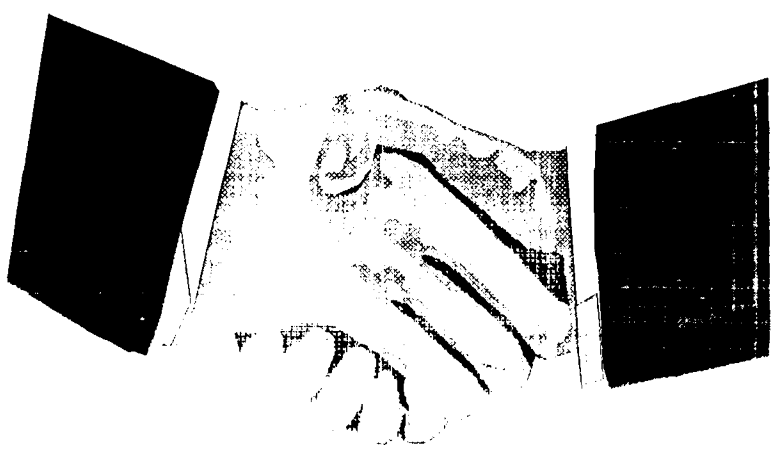
CHAPTER - 1

INTRODUCTION



Chapter-1

Introduction

Water is the life line in the realm of global environment. As in other fields, water is scanty in agri-business and one has to act like a true economist to allocate this scarce resource against greater demand of soil, for optimum use. The major portion of world's cultivated area is under rainfed agriculture and there is not much hope for irrigation expansion due to technological, economical and socio-political limitations. The ground water does not fulfil all the requirements of soil as much of it is either saline or too deep to be put under use. Stability of food production in many countries is strongly linked with crop yields in the rainfed areas. Developing countries, predominantly thrive on agriculture for thrust in their economies.

In hills of India, although, the magnitude of rainfall in almost all the regions varies, yet the pattern of rainfall receipt remains more or less the same. Himachal is one of the hilly states where 82 per cent of the cropped area is rainfed. Except for the cold desert areas of the state, where most of the precipitation is received in the form of snow, all the regions receive more than 1000 mm of annual rainfall. In mid-hills sub-humid zone, rainfall varies from 1500-3000 mm. In spite of so much of rain, crop failures are not uncommon as 80 per cent of this rain is received from mid June to mid September. Such high rainfall areas also exhibit periods of water scarcity and crops experience water stress at critical growth stages. Farmers even have to transport water from long distances to raise nursery and establish seedlings of vegetable/cash crops. During October to mid December and April to mid June evaporation exceeds precipitation (Fig.1). This desiccates the seed-zone of its moisture reserves and makes it difficult to do timely sowing of both rabi and *kharif* crops.

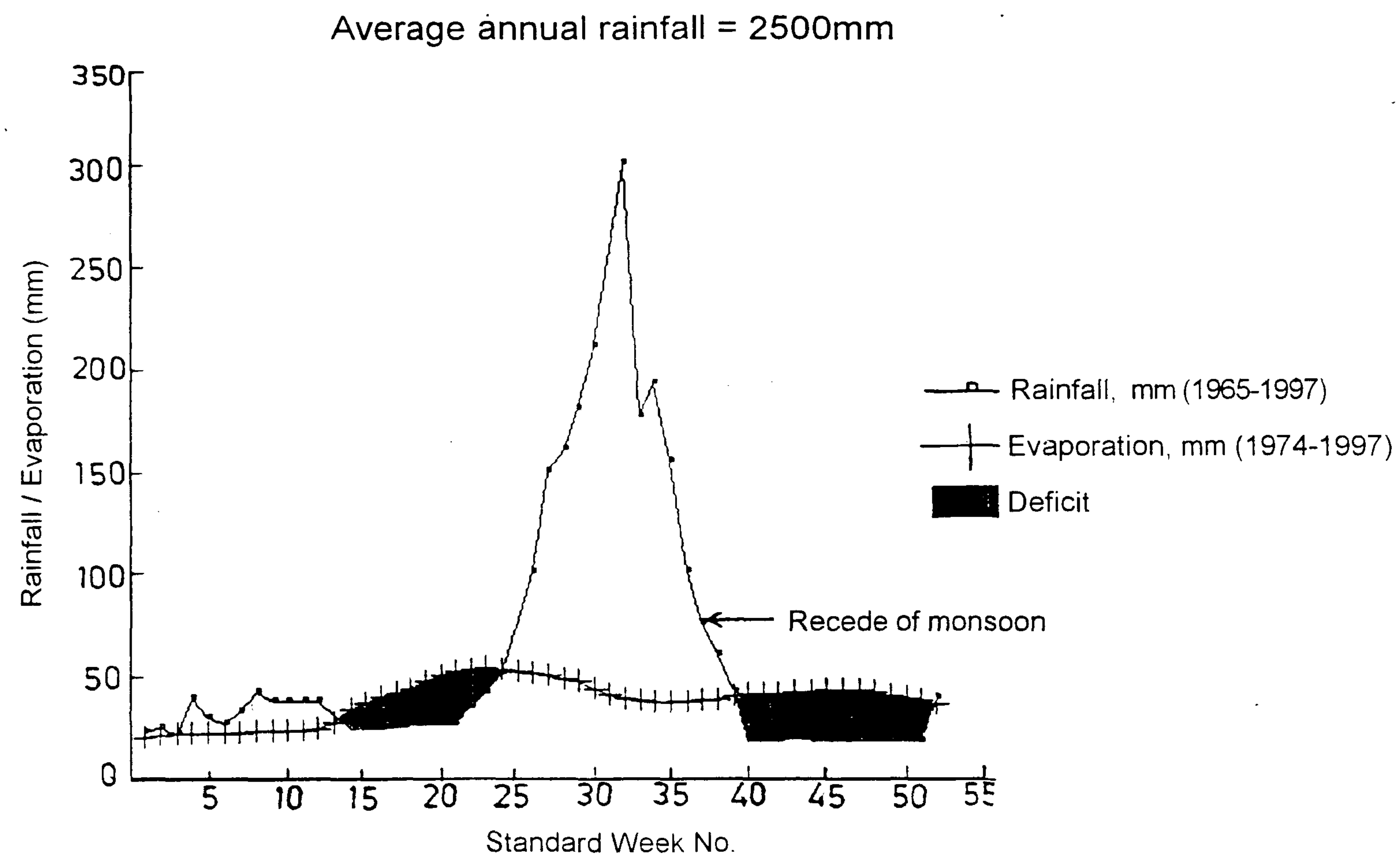


Fig. 1. Weekly rain-water balance for Palampur

Increasing demand for agricultural production in rainfed areas engineers the generation of other means to provide supplemental amounts of water to crops at critical growth stages for obtaining optimum yields. Because of these limitations farmers in rainfed areas do not take risk of applying costly inputs like fertilizers and plant protection measures. The modern technologies like artificial rain etc. are neither feasible nor are within the economic boundaries of the developing nations.

In Himachal Pradesh most of the farmers (82%) fall in the category of small and marginal with average holdings of less than 0.5 ha. About 62 per cent of them have holdings less than 0.3 ha. They are doing cultivation on the terraced lands which do not normally conform to soil and water conservation measures. Under such situations methods have to be devised for improvisation of local talent and resources which are cheap and easy to comprehend for the peasants. The excess water flowing as run-off can be harvested, stored and recycled to provide pre-sowing/protective/supplemental irrigation. This has, however, to be done on a watershed basis. Promising technologies for harvesting rain-water and run-off are being developed and further, need to be developed to mitigate the problem of water scarcity in rainfed agriculture followed in hilly areas. In the watershed development programme emphasis is given to harvest and store water in natural depressions. This is primarily done for the convenience of the available site for water storing rather than convenience of water application for irrigations. Invariably very little water is left at the time when it is required to be applied. This is due to boulder-ridden nature and shallow depth of soil which results in excessive percolation losses. Because of small land holdings, the poor farmer is not in a position to afford a large piece of land to construct a water harvesting reservoir. Furthermore, to lift water stored in deep depressions is beyond his means owing to technical reasons and energy inputs not available at his command. However, it is possible for him to afford a small piece of land to construct a small water harvesting tank at the end of a terrace. The run-off can be diverted to this tank with minor land shaping. Even water from some small *Kuhl* (small gravity stream), when not in use, can be diverted to the tank.

The cement-concrete lined tanks are not only costly but also less effective in storing water due to development of cracks, particularly at soil-cement boundary. Lining of tanks with polyethylene sheet seems promising to minimise seepage losses. This sheet, however, has to be protected from the effect of direct sunlight. Dry pitching with stones (Srivastava and Tandon, 1984), bricks (Acharya and Kapur, 1998) and providing cover of fabric sheet or even cover made of discarded empty cement bags (Acharya and Kapur, 1997) have been found effective in increasing life of polyethylene sheet.

The water so harvested and stored in the tank can be judiciously utilized for growing crops. The data on such aspects on water harvesting in small poly-lined tank and its judicious use for growing crops/cash crops are meagre. The water productivity of the limited water thus harvested and stored can be evaluated with respect to growing of cereals, vegetables, cash crops etc. The possibility of rearing fish in the tank, may be for small period, can also be explored with an approach for suggesting diversification in agriculture rather than growing only of traditional non-remunerative crops. The present investigation, therefore, was undertaken for growing rainfed maize based cropping sequence with the following broad objectives.

(i) To monitor periodical changes in water storage in a poly-lined tank.

(ii) To determine water use under limited irrigation to wheat grown in a maize - wheat sequence.

(iii) To evaluate the possibility of growing vegetables and introducing pisciculture in the poly-lined tank for increasing water productivity and its economic viability.

CHAPTER - 2

REVIEW OF LITERATURE

Chapter-2

Review of Literature

This chapter covers a brief review of literature on water harvesting and its efficient management under water deficit conditions for wheat and vegetable crops under the following heads:

2.1 Water harvesting.

2.2 Effect of irrigation on growth and yield of wheat.

2.3 Effect of irrigation on growth and yield of vegetable crops.

2.1 Water harvesting

Most parts of mid-Himalayan region receive good amount of rainfall but its occurrence is restricted primarily to the monsoon periods. During the remaining part of the year, the frequency of rainfall is erratic which makes the growing of crops round the year a risky job. Even during the rainy season occurrence of dry spell is quite frequent which adversely affects crop yields. If crop production levels are to be stabilized at enhanced levels, then water flowing from heavy precipitation must be harvested and stored for use during deficit periods. Water harvesting is defined as a practice of collecting water from an area treated to increase runoff from rainfall and snow melt (Myers, 1964).

According to Joshi *et al.* (1989a) collection of surface runoff during the periods of excess rainfall and its use during the subsequent dry periods helps in crop production. In small watersheds, the land management practices could be so planned that all the surface run-off is diverted *through* grass water ways to a collection point. Verma (1983) suggested inter and intra-plot water harvesting for small areas in surface reservoirs.

Grewal *et al.* (1989) worked on earthen reservoirs and showed that during drought periods, harvested water had the potential to save crops. El-Samani *et al.* (1996) reported the occurrence of water harvesting structures in Red Sea Hills of northern Sudan. The water so harvested is utilized for growing sorghum and millet. Prinz (1996) described six types of water harvesting viz. roof top harvesting, microcatchment water harvesting, water harvesting for animal consumption, inter-row water harvesting, medium-sized catchment water harvesting and large catchment water harvesting. The water harvesting was based on the utilization of surface run-off and required run-off area and a storage area. Sharda and Shrimali (1994) reported that due to temporal and spatial variations in the rainfall, the crops suffer from moisture stress conditions during critical stages of plant growth. For this reason they emphasised the essentiality of water harvesting ponds in arid and semi-arid regions. They further, suggested the possibility of increasing crop yields two to three folds by providing supplemental irrigation from the harvested water. Goyal *et al.* (1995) utilized the harvested water on ber (*Zizyphus mauritiana)* and reported a cost : benefit ratio of 1.672 indicating that, in order to provide stability to agricultural production on rainfed lands in arid and semi-arid areas, farm ponds were a suitable mean to achieve the goal.

Verma *et al.* (1994) suggested that for successful production of *rabi* crops like wheat, the water harvested in tanks during rainy season should be used for irrigation purpose. They further revealed that in order to get good germination and initial plant stand, it was essential to provide a pre-sowing irrigation to wheat crop. Verma and Sarma (1990) while working on water harvesting tank reported that tanks designed on the basis of seasonal run-off and used for pre-sowing irrigation to wheat, were most beneficial when the benefit cost ratio ranged from 1.6 to 4.6 for catchment areas of 1 to 100 hectare. Khan (1992) reported that in order to get maximum run-off into the water harvesting tank, jet emulsions followed by sodium carbonate spray were the most effective sealants. To reduce evaporation from these tanks he suggested the sealing of the water surface with polyethylene sheet. Karpiscak *et al.* (1984, 1988) suggested the use of plastic film cans as a mean of reducing evaporation loss from a water harvesting reservoir in Arizona. According to a data recorded by Lebdi *et al.* (1989) the evaporation accounted for 70 per cent of the monthly rainfall in Siliana, Tunisia. They assessed this to be a major constraint for water storage to be utilized for irrigation of cereals from April to June.

According to Hegde and Pandurangaiah (1989), the high intensity run off resulting from rains in Karnataka, India, could be stored in dug-out farm ponds. The results showed that with two supplemental irrigations to ragi, the yield increased to 1.38 t/ha as compared with 0.82 t/ha under no irrigation. Further, they suggested that harvested water could also be used as a source for raising fish. The gain in body weight of fingerlings over a period of 6 months was reported to be 750g. Bhardwaj *et al.* (1989) revealed that on a watershed basis the harvested water in earthen reservoirs resulted in an increase in water table despite of tremendous increase in the total number of electrified wells. They argued that this was due to the reason that all the run-off was retained within the watershed boundaries.

Mittal and Dhruva Narayana (1989) reported an increase in the crop yields by 78 per cent as a result of combined effect of water harvesting and soil conservation in Himachal Pradesh, India. The earthfill was constructed to store a volume of 9.66 ha-m run-off water from 41 hectares of hilly catchment. Similarly, Singh *et al.* (1989) reported an increase in wheat yield by 100 per cent from Bunga village of Haryana, India, where a water harvesting reservoir of 60 ha-m capacity was constructed for supplemental irrigation and controlling excessive run-off. Rai *et al.* (1989) reported the construction of water harvesting reservoirs in Mirizapur, India. They suggested that the water storage not only increased the crop yields but also checked the soil erosion, thus increasing the crop productivity. Talashilkar (1989) observed that the water harvesting technology applied at the Kumbhave watershed in Konkan (Maharashtra), India miraculously increased the ground water level and also increased the soil wetness of the neighbouring fields of the *Nallah* (reservoir) particularly during the dry spells of monsoon. The water harvesting made it possible to use the high yielding varieties where there was substantial increase in the crop yields over the traditional varieties. Hazra (1989) reported that in Tejpura (Madhya Pradesh), India different reservoirs had a capacity to store 15 ha-m water sufficient to irrigate 300 ha. of land once in *kharif* season. Also, due to recharge of the water through percolation and late rains, it was estimated that irrigation to rabi crops in about 450 ha area was made possible. According to Gupta (1989) the integrated watershed management approach which also included water harvesting as one of its aspects increased the fertilizer consumption and crop yields which went up as much as by 500 per cent in Malwa (Madhya Pradesh) India. Bhatia *et al.* (1989) observed that seven water retention dams constructed with stone pitching had a storage capacity of about 9 ha-m in Haryana (India). Three water harvesting ponds were constructed at different places with a total water storage capacity of about 2.5 ha-m. This resulted in the rise of water table of the tube wells situated near the constructed ponds even in the years of severe drought during 1987-88. In another study made by Umrani *et al.* (1989), the construction of 11 *nallah* checks (dams) increased the irrigation potential in Maharashtra, India inspite of low rainfall during 1987-88. A good recharge of ground water was also noticed. There was an increase in the irrigated area as a result of this type of water harvesting. A detailed analysis of water use pattern revealed that about 2.70 ha-m water was used for irrigating *rabi* crops in 1986-87. During the subsequent year, it was estimated to be about 6.00 ha-m which was more than double the previous year. Thus, water conserving and harvesting structures recharged the ground water.

Singh and Sharma (1989) revealed that storage of rainwater served as a catalytic agent in watershed development programme. They suggested that run-off harvesting tanks might, therefore, be constructed at a suitable location. They could be small-sized tanks like dug-out ponds lined or unlined depending upon the situation.

Cooley *et al.* (1978) applied paraffin wax (53°C melting point) @ 0.92 Kg/m^2 to the surface of catchment area for enhancing surface run-off. This application resulted in an increase in the surface run-off towards the water harvesting structure. The water was collected in a 300 m^3 tank with surface evaporation controlled by a floating close-cell synthetic rubber cover 0.6 inch in thickness. For increasing surface run-off Murthy *et al.* (1978) used different water proofing surface covers for water harvesting in Rajasthan. These included soil-bentonite plaster, soil-cement, mud-plaster, compacted lime concretions, Na_2CO_3 treated tank silt, Janta emulsion treatment and grass cover. Janta emulsion treatment (Esso product) and the application of tank silt sprayed with Na_2CO_3 were found to be most effective treatments. The later was cheaper of the two and the grass cover was least effective. Pratt (1980) also suggested treating soil surface to increase run-off while gathering water generated from the seasonal rains.

In sandy soils, however, Shanan *et al.* (1980) used a buried plastic membrane for generating run-off in Sahelian region of Isreal. Laborde and Morel (1991) stated that collection of rain water for drinking was a very old technique, which was presently gaining ground, especially in developing countries and in areas of scattered settlements, where this technique was practically suitable. The guidelines for water harvesting in North Cameroon were based on potential consumption, collection from roof top area and tank volume. The results showed that rain water collection in North Cameroon were technically feasible and economically viable provided that the rainfall regime was not subjected to very wide fluctuations.

Schemenauer and Cereceda (1991) reported another method of water harvesting in Chile. The source of water for harvesting was fog. They reported that fifty droplet collectors of 48 m^3 produced 7.2 m^3 water per day during the drought years. They also reviewed the results of fog water collection at 47 arid locations in 22 countries on six continents. Due to good quality of water, this could be used for drinking, domestic and agricultural purposes. Goncalves and Cunha (1992) also discussed the possibility of harvesting fog water in some regions of Cape Verde in order to supplement domestic water supply.

According to Reddy (1989), the decline of ground water levels in India by 5-10m was usually explained as a result of the increased number of tubewells and a decline in the average annual rainfall. He argued that the decline was the product of destruction of indigenous systems for storing run-off water, which were essential because rainy days are very few and erratic. These systems comprised tanks-small water reservoirs behind earthen embankments that conserved water for irrigation of nearby fields and facilitated recharge of ground water. For betterment, he suggested rejuvenation of these tanks.

Vijaya Lakshmi *et al.* (1989) stored a part of the run off water from sloping red soils of Andhra Pradesh (India) region for local irrigation of several crops. They claimed that this type of utilization of harvested water was unique in semi-arid tropics. Storms with a minimum of 20mm daily rainfall were associated with run-off volume exceeding 1000 m^3 from a large area.

The major problem in the earthen reservoirs/ponds is that seepage losses are very high and some times the water is not at all available for use during the dry spells. According to Osborn *et al.* (1978), although the stock of water in earthen tanks is a primary source of water in south western United States, in areas with calcareous soils, seepage rates from these ponds might be excessive, limiting the pond use to relatively short periods following run-off producing rainfall. They further, suggested the application of sodium salts, primarily sodium chloride which has been used for many years to reduce seepage. In laboratory tests, sodium carbonate (Soda ash) was the most effective and long-lasting sodium salt for dispersing. It was found that clay aggregated and fixed calcium as calcium carbonate. The field tests substantiated the lab tests. The guidelines suggested addition of soda regularly (every 2 or 3 years) to neutralise additional calcium carried into the pond in run-off. Verma (1983) and Dhruva Narayana *et al.* (1990) reported the use of very thin membranes like aluminium foil, polyethylene, poly vinyl floride, chlorinated polyethylene, acrylic and butyl rubbers etc. to reduce seepage. Further, they suggested many means to reduce seepage which included distribution of particles, puddling, sealing by compaction, clay blanket, bentonite treatment, soil defloculation, gleization, chemical sealants, membranes, soil-cement, concrete lining, brick tiles, stones etc. Maheshwari and Turner (1986) tested some low cost techniques for seepage control in earthen tanks in *Alfisols* and *Vertisols* in

India under both laboratory and field conditions. Use of soil dispersant, soil-cement lining and improvement in gradation of soil particles were compared. Preliminary cost estimates showed that all lining tried in *Alfisols* but not in *Vertisols* were justified economically on the basis of a yield increase due to supplementary irrigation using the saved water at the critical stage of moisture stress in sorghum, maize and *Pennisetum americanum*. Singh *et al.* (1983a) found that covering of 800 gauge polyethylene sheet 20 cm deep only in bottom of the tank and brick and cement lining for sides of the tank without polyethylene sheet underneath produced seepage losses through brick pores much above the tolerable limits. In order to avoid losses a low density polyethylene film tank has been suggested by Srivastava and Tandon (1984). They stated that in earthen tanks the seepage losses were to the tune of 300 to 400 litres/m^2/day. It was suggested that the sheet be buried 0.15m deep and sides be covered with stones.

In another study made by Kumar (1992) it was suggested that small seepage free reservoirs for rain water harvesting for supplementary irrigation should be developed. He stressed on roof top harvesting for domestic use. It was found that seepage was completely checked in poly-lined tanks. The poly-lined tanks were found to be technically feasible and economically viable in five mountain districts of Uttar Pradesh, India. In poly lining, mode of its placement and protective cover over the sheet is important. Dhruva Narayana *et al.* (1990) suggested that the film of polyethylene be buried under protective cover of earth. However, there are chances of its slippage from side of the tank. Dry pitching with bricks (Acharya and Kapur, 1998) and dry stone pitching (Srivastava and Tandon, 1984) have been found to be effective to provide a protective cover against direct sunlight. Recently, Acharya and Kapur (1997) recommended the use of fabric sheet over the polyethylene sheet to protect it from direct sunlight. They reported that cement-concrete tanks are not only costly but also less effective as they develop cracks, particularly at soil-cement boundary. The stored water can be used through gravity without involving costly inputs like pumping units, thus making them cost effective.

2.2 Effect of irrigation on growth and yield of wheat

The harvested and stored water must be utilized judiciously. According to Singh *et al.* (1980), 50mm irrigation applied to wheat before sowing and again at crown root initiation stage increased the yield over no irrigation. The interaction between irrigation and nitrogen levels was also found significant. According to Singh *et al.* (1983b), the greatest effect of water stress on grain yield of wheat was observed during planting to jointing stage indicating that if limited water supply was there, the crop should be irrigated during this period. From flowering to maturity, the effect of water stress on yield was not marked which suggested that this time was not an important stage for irrigation under limited water availability. Water use efficiency was highest with no stress and lowest with -1.5 MPa stress. The results reported by Hooker *et al.* (1983) showed that two irrigations applied at pre-plant and jointing gave significantly higher yield than irrigation at pre-plant or pre-plant and flowering stages. Chandrasekharaiah *et al.* (1985) reported that irrigation at 0.9 IW/CPE ratio with 60mm depth recorded 24 and 3 per cent higher grain yield of wheat over 0.3 and 0.6 IW/CPE ratios, respectively. Mittal *et al.* (1987) stated that in the absence of assured irrigation, the limited irrigation from harvested rain water as pre-emergence irrigation gave significantly higher yield of wheat than irrigation as pre-sowing irrigation. Further, they suggested that pre-emergence irrigation followed by one irrigation at CRI could be more beneficial and economical to cover large area with limited availability of harvested water. According to Zaman and Mallick (1987), it was possible to go in for double cropping with one pre-sowing irrigation (PSI) to wheat in an existing mono-cropping region. Grewal *et al.* (1989) in 10 years study found that water harvested during rainy season could provide one supplemental irrigation of 75mm to different crops and save crops by providing irrigation during drought periods. Prihar *et al.* (1989) in sub-montane of Punjab found that, within certain limits, irrigation substituted for nitrogen. The regressions generated from the data permitted recommendations of N in relation to stored water and seasonal rain with or without limited irrigation. However, Rajput *et al.* (1989) reported that six irrigations to wheat with recommended NPK dose gave best results over any reduction in irrigation. Singh *et al.* (1990c) reported that there were certain wheat varieties (C 306 and Wt 34) which were tolerant to moisture stress upto certain levels. These exhibited higher leaf water potential than the normal varieties. Brar *et al.* (1990) stated that complete suspension of irrigation after CRI stage in wheat resulted in low photosynthetic rate and ultimately all the physiological processes were adversely affected.

A number of small earthen dams constructed in shiwalik foot hills for rain water harvesting and recycling showed that crop yield can be subsequently increased if irrigation at pre-sowing stage (198%), two irrigations one as PSI and other at crown root initiation (CRI) stages (268%) and if possible, 3 irrigations one as PSI, one at CRI and one at tillering stage (430%) could be provided (Gupta *et al.*, 1990). In another study conducted by Mandal (1991) it was found that no effect of irrigation on wheat yield was observed on boron deficient soil in West Bengal. Patel *et al.* (1992b) found that under deep soil conditions, 120mm irrigation depth at an interval of 6 days was most beneficial for wheat in *Vertic Ustochrept* soil. Acharya (1992) suggested that under conditions of soil moisture deficit in the profile, scarcity of water for irrigation and delayed occurrence of post-sowing rain, light pre-sowing than heavy irrigation and application of remaining quantity of water at early post-sowing within 7-10 days of sowing proved more beneficial. Aggarwal and Sidhu (1992) reported that under limited irrigation one irrigation as PSI followed by another 4 weeks after sowing gave higher yield than with PSI and irrigation at 7 weeks after sowing. Sharma *et al.* (1992) found that water uptake by wheat was higher at higher N application rate and vice-versa. They further revealed that yield productivity was much better when nitrogen and water uptake at different growth stages were combined together. The highest yield was observed at an IW:CPE ratio of 1.2. Sharma and Acharya (1993) found that 120 kg N/ha and deep ploughing (0-0.30m) encouraged greater root growth of wheat and resulted in water extraction from sub-surface depths and thereby increased the grain and straw yield. Further, it was reported by Sharma and Acharya (1996) that changes in water contents, increase in hydraulic gradients and root water uptake were considerably more under the combination of 120 kg N/ha and deep ploughing. Water extraction was extended to lower depths with the increase in N level from 40 to 120 kg/ ha. The manipulation of water dynamics and higher water uptake by the crop roots at 120 kg N/ha and under deep ploughing was exhibited in root growth and yield of wheat. Patel and Upadhayay (1993) reported maximum yield of wheat at IW:CPE ratio of 1.6 (4.4 t/ha) than at IW:CPE ratio of 1.2 (4.3 t/ha) on loamy sand soil.

Sabry *et al.* (1994) found that bread wheat variety gave higher returns when one irrigation was applied to it at sowing time than the rainfed crop. Nikolov (1994) found that single irrigation of 50mm gave significantly higher grain yield of wheat over two or three irrigations of

40mm after ear formation or no irrigation treatments. Kumar *et al.* (1995) found that in sodic soil of Karnal, irrigation applied at IW:CPE ratio of 1.2 gave maximum yield even with high dose of 180 kg N/ha.

Singh (1995) reported an increase in leaf water content in wheat following irrigation. They also found that grain yield was positively correlated with morning time leaf water potential, particularly at later crop stage (late jointing onwards). Radder *et al.* (1995) found that in India supplemental irrigation increased the crop yield upto an extent of 33 to 92 per cent on medium black soils. For late sown crop one irrigation of 50mm was more beneficial than 2 irrigations of 25mm each under limited water supply. Mishra and Das (1995) reported that for medium altitude wheat crop the irrigation interval for best yield was 27 days and the frequency was reduced to half on upland soils. The irrigation requirement irrespective of soil type was found to be 437mm. Verma and Acharya (1996a) reported that the grain and straw yield of wheat with one PSI grown under conventional tillage was statistically at par with that obtained by tillage at harvest of previous growing rice crop and under conventional tillage with *Lantana* incorporation treatments.

Acharya and Kapur (1993) reported that at recede of monsoon the soil profile is wet and if the seed-zone moisture is conserved then it is possible to sow wheat without PSI and harvested and stored water can be applied later to effect its higher use efficiency. They suggested application of waste material, like wild sage (*Lantana camara* L.) to the previous standing maize at receding monsoon for moisture conservation and carry-over for wheat. They reported that this practice ensures timely sowing of wheat without irrigating the crop with 80mm water. Further, it was revealed that if we can ensure germination, then a good harvest of wheat can be expected as in hills of North-west India, the water irrigation to wheat was recommended at 30 days after sowing (Sharma *et al.*, 1985).

Dunbam (1988) observed non-significant differences in rooting pattern of wheat when irrigated at one or two weeks interval, although the rooting density was higher when the crop was irrigated at one week interval. Shaktawat and Joshi (1989) reported that with one irrigation to wheat at CRI stage the grain yield increased from 1.98 t/ha to 2.35 t/ha and with two irrigations at CRI and flag leaf stages it increased upto 2.89 t/ha. Nakhotre and Kewat (1989) observed no effect of irrigation on grain and straw yield of wheat, given one (20 DAS), two (20 and 60 DAS), three (20, 60 and 80 DAS) and four (20, 60, 80 and 95 DAS) irrigations. They attributed no effect due to occurrence of rain at most critical stages of CRI and flowering. Rao and Tomar (1989) reported a yield of 3.3 t/ha with 3 irrigations applied at CRI, maximum tillering and flowering stages against 2.41 t/ha obtained with irrigation at CRI stage only. The identification of most critical stages is, of course location specific. Joshi *et al.* (1989b) showed that three irrigations of 50mm each at CRI, tillering and flowering stages are necessary for optimising the wheat yield (4.0-4.2 t/ha). However, in case of resticted supply of irrigation water, only two irrigations either at CRI and tillering stages or at tillering and jointing stages depending upon the winter rains will be enough to achieve the optimum yield of wheat.

Singh *et al.* (1990a) showed that root weight density of wheat was higher with irrigation at 50 per cent soil water depletion than irrigation at CRI stage only. The higher root mass density in former case resulted in higher grain yield and water use efficiency than the later treatment. The yield was positively correlated with root mass density at 80 days after sowing. Buriro *et al.* (1990) found no significant effect of 3, 4 or 5 irrigations applied to wheat in Pakistan, However, 1000-grain weight was highest (46.77g) from crops irrigated 5 times. Upadhayaya and Dubey (1991) reported that the grain yield of wheat when one irrigation at CRI stage was applied remained statistically at par with that treatment where 2 irrigations one each at CRI and boot stages were applied meaning thereby that under limited irrigation water facility only one irrigation at CRI stage should be applied to wheat. On the other hand, Raghuwanshi and Verma (1991) observed that wheat crop irrigated twice, 30 and 60 DAS with 50mm water each time, gave higher yield and water use efficiency over no irrigation treatment. Lathwal *et al.* (1992) obtained yield of 4.22 t/ha with only one irrigation to wheat at CRI stage in sandy loam soil of Haryana. The yield increased upto 4.85 t/ha only with even 5 irrigations. Thompson and Chase (1992) concluded that where irrigation water supply was limited, the best strategy would be the avoidance of moisture stress during tillering to spike emergence stages of wheat. They observed that an effective rooting depth of 0.70 to 0.80m was extended upto more than 1.10m under severe moisture stress during grain filling, but at the expense of considerable yield. Rai and Sinha (1992) reported an increase in grain yield of wheat from 2.19 t/ha with no irrigation to 2.58 t/ha with one irrigation at CRI stage and 2.87 t/ha with two irrigations at CRI and boot stage in New Delhi, India. Singh and Uttam (1993) reported that in Kanpur, India, three irrigations at CRI, late tillering and flowering stages gave significantly higher grain yield (3.22 t/ha) than yield with one irrigation at CRI (2.08 t/ha) or with two irrigations at CRI and boot stages (2.81 t/ha). In Madhya Pradesh, India, Kostha *et al.* (1993) observed the highest yield of wheat with six irrigations at different growth stages alongwith 100 per cent NPK doses applied in splits, Abreu *et al.* (1993) suggested that for growing wheat in Lisboa, Portugal, late irrigation 4 and 20 days after anthesis increased the grain protein concentration and N uptake substantially over no irrigation treatment. Roy and Pradhan (1994) observed an increase in wheat yield with one irrigation at CRI stage and two irrigations applied at CRI and flowering stages over no irrigation treatment. The grain yields were 1.62 t/ha for unirrigated treatment, 1.70 t/ha for irrigation at CRI and 1.97 t/ha for irrigation at CRI and flowering stages. Debaeke and Hilaire (1995) reported an increase in grain yield of 4 wheat varieties by applying irrigation at pre-anthesis stage. The increase ranged from 0.3-3.0 t/ha over no irrigation treatment. Debaeke (1995) obtained results from a 44 years study on irrigation and observed that a single irrigation (50mm) during booting-milking grain stage resulted in an increase in yield by 0.5-1.0 t/ha under 45 per cent situations. Sharma (1995) observed higher water use efficiency of wheat when one irrigation at CRI stage was applied. He suggested that for irrigating wheat and mustard, the criteria based on physiological stages was more reliable than that based on IW:CPE ratio.

Abd-El-Gawad and Abo-Shetaia (1995) studied the effect of withholding irrigation on yield of wheat and found that withholding irrigation for more than 21 days adversely affected the wheat yield of Sakha 69 and Giza varieties of Egypt. In another study made by El-Far and Allam (1995) in Egypt it was concluded that missing irrigation at mid-tillering stage gave the lowest yield indicating that this was the crucial stage for irrigation rather than applying irrigation at all the stages, if irrigation water was scanty. They also found that drought at milk-ripe stage and at the beginning of heading stage gave highest protein content in wheat grains. Four irrigations applied at PSI, CRI, tillering and flowering stages were reported to give highest yield of wheat by over one, two or three irrigations applied at different growth stages by Sharma and Singh (1995). Abo-Shetaia and Abd-El-Gawad (1995) reported a reduction in grain yield of wheat by 37.7, 29.1, 23 and 10.8 per cent when irrigation was skipped at tillering, heading, milk ripe and dough ripe stages, respectively. Water use efficiency was maximum when plants were subjected to water stress at dough ripe stage. Jana and Mitra (1995) found that two irrigations at tillering and flowering stages produced the highest grain yield as compared to irrigation at CRI, flowering and dough stages individually or with their combinations. Water use increased and water use efficiency decreased with increase in number of irrigations. In alluvial soils, Singh *et al.* (1996) found that the grain yield was maximum with irrigation at PSI and CRI stages supplied with 150 kg N over control treatment. Highest yield was observed with irrigation of PSI treatment upto field capacity.

Hooda *et al.* (1985) studied the effect of 2,4 and 6 irrigations applied to wheat on N and P contents in grains and N and P uptake by the crop. It was found that irrigation did not affect N or P content in wheat grains whereas increasing irrigation frequency significantly affected N uptake but not P uptake. Matsunaka *et al.* (1992) reported that irrigation from beginning of tillering to heading in Japan resulted in the production of a large number of effective spikes and higher grain yield than that obtained by applying irrigation during any other growth stage. It was concluded that the beneficial effects of irrigation from tillering to heading were due to promotion of N absorption by the crop, increase in number of tillers and increase in number of effective spikes. Ma *et al.* (1995) studied the correlation between leaf water potential and water content in lower soil layers. Both of them increased with age of the plant. A close correlation was also observed between leaf water potential and flowering and yield. It was suggested that allowing early water stress to save water, although reduced leaf water potential, could still allow high yields to be achieved. Sharma and Acharya (1994) studied the effect of tillage on water stress in wheat in relation to nitrogen and found that xylem water potential increased with increase in N from 40 to 120 kg/ha and was also higher under deep ploughing than under conventional tillage.

Liu and Liu (1995) suggested that the difference in temperature between air and canopy in the range of -1 to 0°C could be a critical indicator of water stress. Sharma and Acharya (1994) found that cumulative stress degree days (CSDD), which is the sum of difference between crop canopy and air temperatures, decreased with increase in N application from 40 to 120 kg/ha. They attributed this to be a result of better root growth which extracted higher amount of water and maintained higher xylem water potential and kept the canopy cooler at 120 kg N/ha than with 40 or 80 kg N/ha.

2.3 Effect of irrigation on growth and yield of vegetable crops

In general cash crops require light irrigations. Therefore, raising cash crops requires them to be irrigated more frequently. The pertinent literature on the vegetable crops like onion, radish, frenchbean and ginger raised with harvested and stored water in the present study is briefly reviewed in the subsequent paragraphs.

2.3.1 Effect of irrigation on growth and yield of onion

For raising yield levels of onion a time interval of 3 weeks between two irrigations was suggested by El-Tabakh *et al.* (1979). This however, varies with soil type and climatic conditions. Singh *et al.* (1987) found that highest yield of onion crop was obtained with four irrigations of 50mm each by flood irrigation at 20 days interval under sodic soil conditions. Among various cultivars tried by Kaniszewski and Perlowska (1988) it was concluded that onion be irrigated between 0.02 to 0.04 MPa suction to get highest bulb yield. Chung (1989) studied the effect of irrigation on yield and quality of onion bulbs and found that applying irrigation throughout the season increased the total bulb yield from 52 to 84 t/ha while, withholding the last two irrigations prior to maturity, produced 51-70mm sized bulb yield from 57 to 44 t/ha. No effect of irrigation was observed on incidence of bulb defects such as skin cracking, doubles, thick neck and on chemical composition of the bulb.

Pfulb and Zangerle (1990) reported that water requirement was low for onion seedlings, but after 60 days it increased sharply and then diminished as the shoots ceased to grow.

Palled *et al.* (1988) found that water use efficiency of onion increased with increasing irrigation efficiency. The maximum water use efficiency (38.3 kg/ha/mm) reduced and yield increased with IW:CPE ratio of 0.7 over that of 0.9, 0.5 and no irrigation treatment from a trial of two years. Whereas, Patel *et al.* (1992a) found that onion bulb yield was maximum with an IW:CPE ratio of 1.4 (32.5 t/ha). Pandey *et al.* (1992) reported net returns of Rs. 10420/ha with yield of 25.2 t/ha when irrigation was applied at IW:CPE ratio of 1.25. In another study made by Galbiatti *et al.* (1992) it was suggested that highest yield of onion can be obtained if the crop is irrigated with 100 to 150 per cent of the daily evapotranspiration. Rajas *et al.* (1992, 1993) reported that the total volatile sulphur content of harvested dry bulb of onion was highest with a combination of 80 kg sulphur per hectare and irrigation at an interval of 5 days rather than 10 or 15 days.

In a study conducted by Pandey *et al.* (1993) it was suggested that the time of first light irrigation to onion at transplanting was watering eight hours before transplanting which resulted in significantly higher yield (28.5 t/ha) over other treatments watered either before or after transplanting. An experiment carried out by EL-Oksh *et al.* (1993) in tafla and sand mixture revealed that plant height, number of leaves, chlorophyll content, fresh and dry weight of onion increased with increasing soil moisture level from 40 to 100 per cent of field moisture capacity. However, the bulb total protein concentration and N contents increased significantly with decreasing soil moisture levels (El-Gizaway *et al.*, 1993). The findings made by Martin de Santa-Ollala *et al.* (1994) indicated that in Spain, for optimum yield, onion required at least 355 mm of irrigation water in seventeen applications. Similarly Prashar *et al.* (1994) found that the onion crop should be irrigated when the available soil moisture to a depth of 0.20m had been depleted by 40 per cent, to get maximum yield. Rana and Sharma (1994) found that the bulb yield of onion with 14-16 irrigations (IW:CPE = 1.25) was statistically at par with the yield obtained by applying 19-21 irrigations (IW:CPE = 1.75). The water use efficiency was highest (50.3 kg/ha/mm) at 1.25 IW:CPE ratio.

2.3.2 Effect of irrigation on growth and yield of radish

Park and Fritz (1984) reported that increasing irrigation from 50 to 90 per cent of field moisture capacity in radish had little effect on root pithiness but decreased root Vitamin C, sugar and dry matter contents and increased plant nitrate content. Hegde (1987a,b) observed that frequent irrigations to radish crop at -20 kPa soil water potential increased relative water content, leaf water potential, osmotic potential, yield, evapotranspiration and water use efficiency and decreased canopy temperature when compared with irrigation at -40 and -60 kPa. Mehta *et al.* (1987) found no difference in nitrogen requirement of radish at IW:CPE ratio of 0.4 and 0.6, respectively. Prasad and Prasad (1992) reported the higher yield of radish when it was irrigated at an IW : CPE ratio of 0.6 or 0.8 over 0.4 in Bihar Sharma and Raina (1993) found that on a sandy loam soil in

Himachal Pradesh, India, the seed yield and uptake use efficiency and recovery of N was found to be maximum when radish was irrigated at 90 per cent CPE alongwith 75 kg N/ha. Finch Savage *et al.* (1994) reported that a single 12.5mm irrigation after sowing produced higher percentage of seedling emergence of radish over pre-sowing or no irrigation.

Joung Keun and Semisi (1995) found that a combination of mulching and irrigation at 10 days interval showed a remarkable improvement over "mulch alone" treatment giving a root diameter of 73mm and length of 25mm of leafy radish. Mulching and irrigation also reduced the boron deficiency and root cracking in western Samoa. A study undertaken by Gura and Dhaka (1997) revealed that irrigation applied at a value of 1.6 pan evaporation co-efficient (PEC) alongwith 50 ppm cycocel (chlormoquat) produced the higher yield of radish cv. Pusa Reshmi in Jobner, Rajasthan and significantly affected all growth attributes except dry weight of leaves, chlorophyill content of leaves, diameter of roots and root to shoot ratio over irrigation at 1, 1.2 or 1.4 PEC.

2.3.3 Effect of irrigation on growth and yield of frenchbean

For a good harvest of frenchbean it was suggested that the crop be irrigated at pre-flowering and during flowering stages (Muirhead, 1979; Gunton and Evenson, 1980). Similarly, Megalhaes *et al.* (1979) while working on frenchbean irrigation concluded that the beginning of flowering was most critical period for water stress which at this stage caused a seed yield reduction of 36.85 per cent. The stress at flowering stage reduced seed yield by 33.68 per cent. Irrigation of frenchbean by several families around victoria lake have been reported by Singh and Agnihotri (1984). They further reported that dry conditions limit crop growth in all months except April and May. For growing frenchbean they suggested dimensions of the economic waterholding tank from 10 to 20m². Hegde and Srinivas (1987) suggested that the frenchbean gave highest green pod yield (15.57 to 16.97 t/ha) and water use efficiency when the crop was irrigated at -45 kPa matric potential. Le-Dellinu and Dellinu (1989) found that in South-west France irrigation of freanchbean after flowering at a rate equivalent to 120 per cent evapotranspiration (ETP) increased pod number and improved pod quality (less strings, less seeds, high moisture content) compared with irrigation at 100 per cent ETP. At 100 per cent ETP, pod quality was better with two than with four irrigations for the same volume of water applied. Hegde and Srinivas (1989) observed the highest green pod yield of 12.43 to 13.23 t/ha when frenchbean crop was irrigated at -45 kPa matric potential alongwith 120 kg N per hectare. However, Singh *et al.* (1990b) found no significant differences in seed yield of frenchbean given 1, 2 or 3 irrigations when the water table was 1m deep. Hegde and Srinivas (1990), further reported that the difference in pod yield between irrigation scheduled at -25 and -45 kPa matric potential at 0.15m depth was non-significant. However, dry matter production, green pod yield, nutrients uptake and water use efficiency were significantly higher when the crop was irrigated at -45 kPa matric potential than at -65 or -85 kPa matric potential. Dahatonde *et al.* (1992) suggested that for maximum seed yield of frenchbean, the best combination was 90 kg N/ha alongwith six irrigations (IW:CPE ratio of 1.2). Gupta *et al.* (1996) found that during winter season frenchbean irrigated at an IW:CPE ratio of 0.75 in Uttar Pradesh, India gave the highest seed yield.

2.3.4 Effect of irrigation on growth and yield of ginger

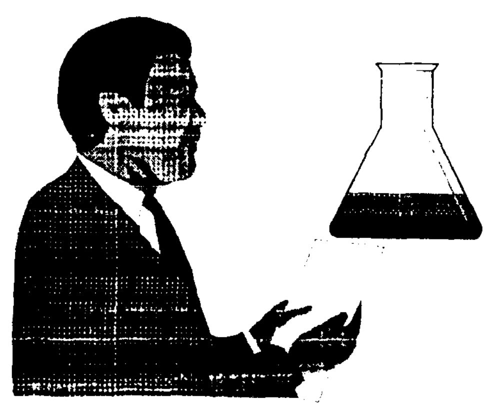
Anderson *et al.* (1990) suggested that the ginger crop should be irrigated when the suction at 0.3m soil depth reaches -20 kPa. Pawar

(1990) found that the highest yields of green ginger were obtained with mulches (Sugarcane trash @ 5 t/ha or polyethylene mulch) and irrigation at 60 or 80 mm CPE. Pawar and Govande (1992) reported maximum N content in ginger when it was irrigated at 60 mm cumulative pan evaporation whereas, N and P contents were unaffected by irrigation at 60, 80 or 100 mm cumulative pan evaporation. Uptake of N, P and K was found to be highest when crop was irrigated at 60 CPE.

Sabur and Rahman Molla (1993) reported that an increased application of fertilizers and irrigation resulted in higher yield of ginger in Bangladesh.

CHAPTER - 3

MATERIALS AND METHODS



Chapter-3

Materials and Methods

3.1 General

The present study entitled "Evaluating Intra-terrace Water Harvesting in Poly-lined Tank and its Productivity" was conducted at the experimental farm of Himachal Pradesh Krishi Vishvavidyalaya, Palampur during the year, 1995-96 and 1996-97.

3.1.1 Location

Palampur lies at 32°6' N latitude and 73°3' E longitude at an elevation of 1300 m above mean sea level.

3.1.2 Climate

Annual average rainfall of the place is about 2500 mm. The monsoon rains start from mid June and withdraw in mid September. More than 80 per cent of annual rainfall is received during this period only. Winter rains are meagre and erratic. Soil temperature drops as low as 2°C and frost incidences are common. The research farm lies in mid-hills, sub-humid zone (Anonymous, 1997). The weekly weather data from July 1995 to June 1997 are given in Appendix-I.

3.1.3 General soil characteristics

The soil of the experimental site is silty clay loam (0 - 0.15 m). Average values of physico-chemical and chemical properties of the surface soil (0 - 0.15 m) are pH, 5.6; CEC, 14C mol (P^+)/100g and organic carbon, 0.80 per cent. The soil is medium in available N, P and K (264, 15 and 224 kg/ha, respectively). At 33 and 1500 kPa suctions, soil retains about 0.31 and 0.16 m^3/m^3 moisture. Mean weight diameter of the aggregates for surface layer is large (2.28 mm) with the result that the retentivity of the soil for water is poor and infiltration is high (5×10^{-6} m/s.). The soil is generally rich in clay content with accumulation of sesqioxides in the sub-surface layers and are classified as *Alfisol*, Typic Hapludalf (Verma, 1979).

3.2 Determination of soil physical and physico-chemical properties

These included the determination of particle size distribution, aggregate analysis, bulk density, infiltration, soil physico-chemical properties and soil water retention characteristics.

3.2.1 Particle size distribution

The particle size distribution was done by international pipette method (Piper, 1950). Texture of surface soil was determined by using textural triangle given by International Society of Soil Science.

3.2.2 Aggregate analysis

Aggregate size analysis was performed with the help of Yoder's apparatus (Yoder, 1936). The apparatus was calibrated to give ¾ inch stroke for 29 strokes per minute. Air dried samples collected from study area were broken by hand into small crumbs and fractioned by sieving through 8mm sieve. The material retained in 4mm sieve was analysed for aggregate size distribution after saturating it overnight. The sieve net (standard of Geologists Syndicate India, Ltd., Calcutta) was immersed in water at about 22±0.5°C.

The apparatus was run for 20 minutes. Resulting samples on respective sieves were oven dried at 105°C and weighed. Different sized fractions were calculated. The results were calibrated for coarse primary particles retained on each sieve to avoid designating them falsely as aggregates. This was done by dispersing the material collected from each sieve using dispersing agent (1 N NaOH), stirring it mechanically and finally washing the material back through the same sieve. The weight of retained aggregates after the second sieving was substracted from the total weight of the dispersed material after the first sieving and percentage of stable aggregates (SA) was calculated using the relation (Kemper, 1965) as follows:

$$\% \text{ SA} = \frac{\text{Weight retained - weight of sand}}{\text{Total weight of sample - weight of sand}} \times 100$$

The mean weight diameter (MWD) was computed with the help of procedure as outlined by Van Bavel (1949).

$$\underset{(\text{mm})}{\text{MWD}} = \sum_{i=1}^{n} \text{di Wi}$$

Where, 'di' is the mean diameter of each size fraction (mm) and 'Wi' is the weight of that fraction in the sample (g).

3.2.3 Bulk density

The bulk density was determined by core method (Singh, 1980) using a metallic core (0.115 m height and 0.08 m internal diameter). The core had a sharp edge at the bottom to facilitate easy penetration into the soil and 0.01m thick open circular cap fitted on the edge of the core at the top. The core was driven into the soil by hammering with a centre weight concentrated hammer. Three cores for each depth were removed and the soil was freshly weighed and moisture content determined by thermo-gravimetric methoa. The dry bulk density was calculated using mass volume relationship.

3.2.4 Infiltration

Infiltration behaviour of the study area was studied using double ring infiltrometers. The infiltrometers were ponded with water and water intake was measured as a function of time until a steady state arrived. The water intake (i) as well as accumulated intake (I) were plotted on a simple scale as a function of time. Infiltration data were analysed according to the relationship given by Kostivakov (1932)

$$I = a\ t^b$$

Where I is accumulated intake, 't' is time and 'a' and 'b' are constants.

3.2.5 Soil physico-chemical properties

Soil pH was determined in 1:2.5 soil : water suspension and organic carbon was estimated by wet digestion method (Walkley and Black, 1934).

Available N was determined by alkaline permanganate method (Subhiah and Asija, 1956), available P by Olsen's method (Olsen *et al.,* 1954) and available K by neutral normal ammonium acetate method (Merwin and Peach, 1951).

3.2.6 Soil water retention characteristics

Undisturbed soil core samples, drawn in metal rings (0.03m long and 0.05m diameter), were collected in triplicate from 0 - 0.15m depth with the help of core sampler (Cat. No. 200A, manufactured by Soil Moisture Equipment Corporation, Santa Barbara, California, USA). The samples were wrapped in polyethylene bags and stored in refrigerator for further use.

Moisture content (θ) at different suctions (ψ) ranging from 0 to 1500 kPa was determined with the help of pressure plate apparatus. Soil samples were saturated for 24 hours and then equilibrated against applied pressure.

The water content was determined thermo-gravimetrically and converted into volumetric water content by multiplying with bulk density of the corresponding depth. Soil moisture retention curves were drawn for surface depth (0-0.15m) by plotting suction (ψ) vs. water content (θ) on a simple scale.

3.3 Experimental

3.3.1 Rain water harvesting and storage structure

3.3.1.1 Construction of poly-lined tank

3.3.1.1.1 Site selection

The site where the pond was constructed was selected three bench terraces above the area where the crops were grown and irrigated. The site for construction was selected at the end of terrace where maximum water could be harvested. The area of the catchment (terrace) was 350 m^2.

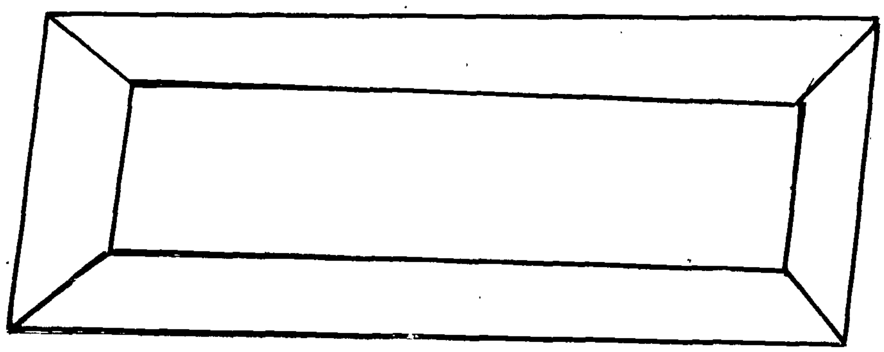
3.3.1.1.2 Excavation of soil

The tank was made by excavating soil of the selected site. Surface area of the tank was 75.1m^2 with 13.9m length and 5.4m width. It was 11.3m long and 2.85m wide at bottom with an area of 32.2m^2. The provision for outlet was also kept by installing G.I. pipe at the bottom of the tank which was further connected with the delivery pipe through a sluice valve for regulating the flow of water. The irrigation water, whenever necessary, was applied through gravitational flow with the help of garden pipe.

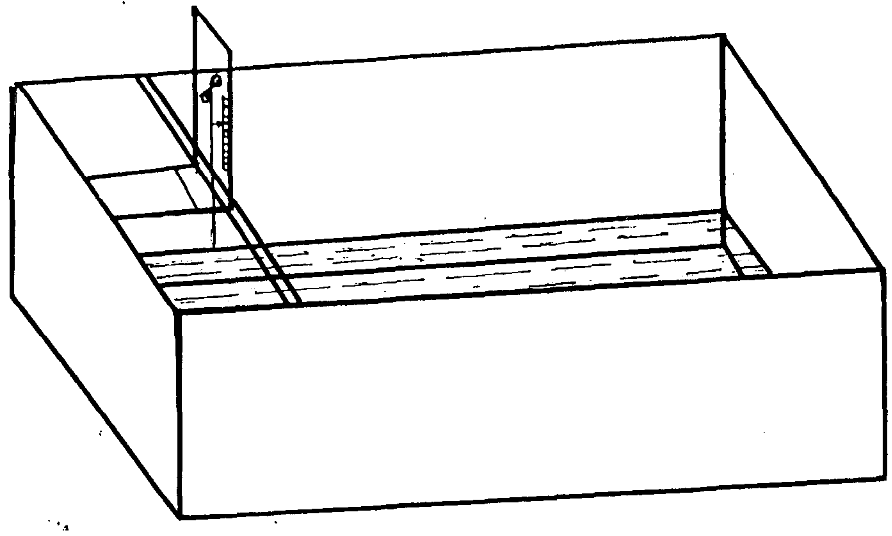
All the protruding stones and grass roots from the inside surface of the tank were removed and it was smoothened by plastering with mud.

3.3.1.1.3 Spreading of polyethylene sheet

250 μ (1000 gauge) thick black polyethylene sheet 17.5m long and 8.5m wide covering an area of 150 m^2 was spread in the tank and about



(a)

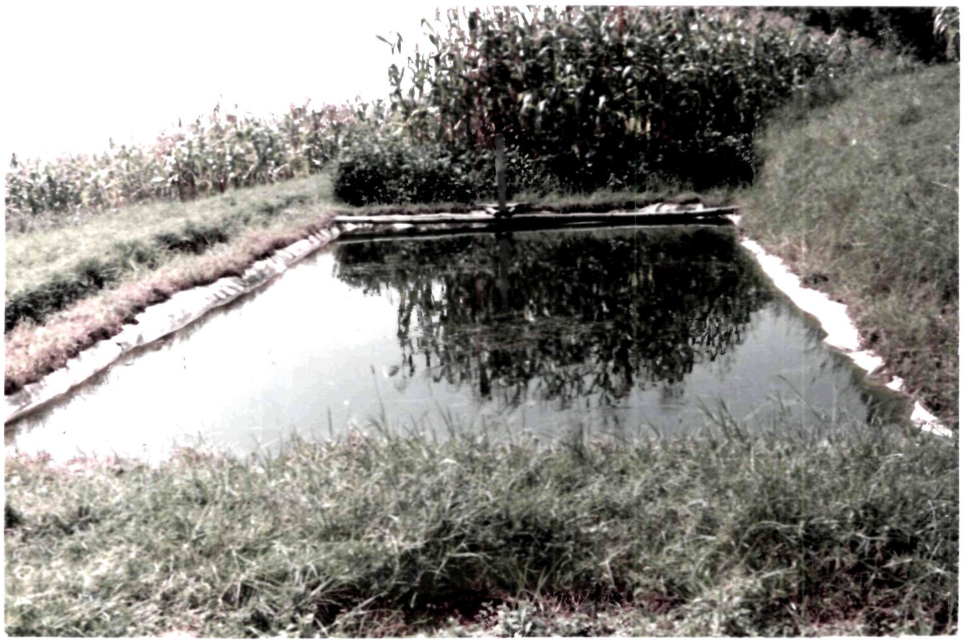


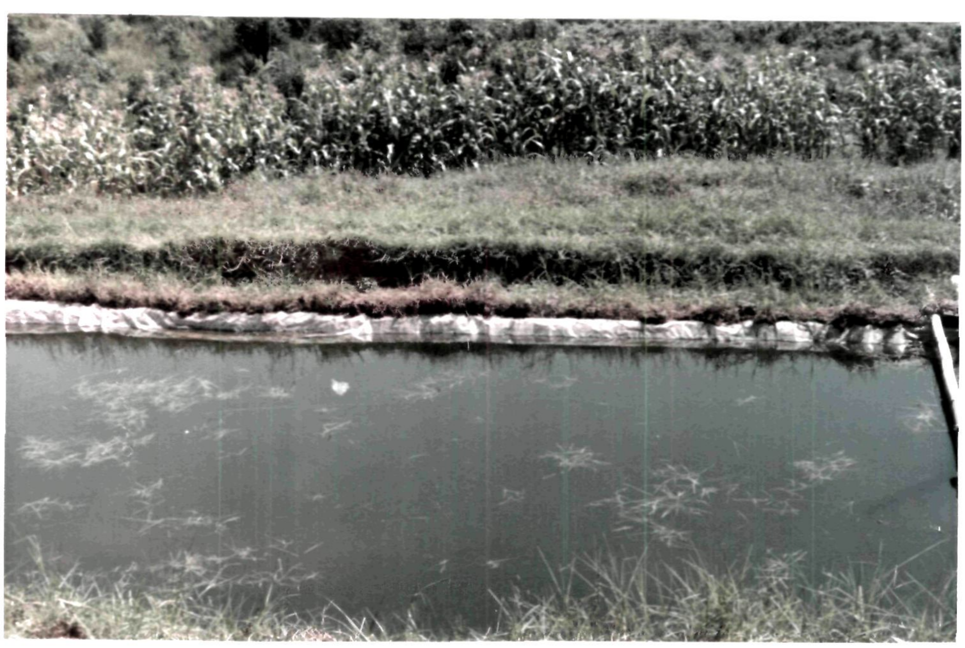
(b)

Fig. 2. Sketch of poly-lined tank,
(a) Top view
(b) Lateral view

Plate-1 Poly-lined tank for intra-terrace water harvesting

Plate-2 A view of poly-lined tank and command area for growing crops





20mm soil layer was laid uniformly on the sheet at the bottom of tank. A trench about 0.15m deep was dug around the tank at the top and excess sheet was buried in it. At one end, the sheet was kept unburied so as to allow entrapped air to escape at the time of entry of water. This end was buried later on when the tank became full of water.

A hole was made at the outlet point of the tank at the base. This point was made leak proof by placing rubber seals on each side of the G.I. pipe and the polyethylene sheet and was tightened with the help of a clamp. A white opaque fabric sheet 40 m in length and one metre wide was spread on the top upper inside periphery of the polyethylene sheet to protect it from the direct sunlight.

3.3.1.1.4 Costs involved

The weight of 150 m^2 polyethylene sheet was 41.65 kg costing Rs. 3750 @ Rs. 90 per kg. The cost of fabric sheet was Rs. 240 and that of earthwork Rs. 2600. The costs of 6.13m long having 63.35mm diameter GI pipe and 12.67mm diameter sluice valve were Rs. 1000 and Rs. 55, respectively. Thus, the total cost for the construction of the tank was approximately Rs. 7655. This does not include the cost of 18.39m long having 12.5mm diameter GI pipe (costing Rs. 900) and of 32.5m long flexible garden pipe (costing Rs. 195) for providing measured amount of minimal irrigation to crops.

3.3.2 Depth-capacity relationships of the tank

The depth-capacity relations of the tank were calculated for each 1cm height. These values are given in Table 3.1. Its capacity to retain water was 3.96 m^3 at 0.10m from botom, 22.03 m^3 at 0.50m, 52.23 m^3 at 1m and with full capacity of 70.11 m^3 at a height of 1.25m from the bottom.

Table 3.1 Depth-capacity relations of the Polyethylene lined tank

Height from bottom (m)	Cumulative volume (m^3)	Height from bottom (m)	Cumulative volume (m^3)	Height from bottom (m)	Cumulative volume (m^3)
0.00	0	0.42	18.04	0.84	41.63
0.01	0.39	0.43	18.53	0.85	42.27
0.02	0.78	0.44	19.01	0.86	42.92
0.03	1.18	0.45	19.49	0.87	43.57
0.04	1.57	0.46	20 00	0.88	44.23
0.05	1.96	0.47	20.51	0.89	44.88
0.06	2.36	0.48	21.01	0.90	45.53
0.07	2.76	0.49	21.52	0.91	46.19
0.08	3.16	0.50	22.03	0.92	46.72
0.09	3.56	0.51	22.52	0.93	47.52
0.10	3.96	0.52	23.06	0.94	48.18
0.11	4.36	0.53	23.58	0.95	48.85
0.12	4.78	0.54	24.09	0.96	49.53
0.13	5.18	0.55	24.61	0.97	50.20
0.14	5.59	0.56	25.15	0.98	50.88
0.15	6.00	0.57	25.69	0.99	51.55
0.16	6.42	0.58	26.22	1.00	52.23
0.17	6.84	0.59	26.76	1.01	52.92
0.18	7.25	0.60	27.30	1.02	53.60
0.19	7.67	0.61	27.86	1.03	54.29
0.20	8.09	0.62	28.41	1.04	54.97
0.21	8.52	0.63	28.97	1.05	55.66
0.22	8.95	0.64	29.52	1.06	56.36
0.23	9.39	0.65	30.08	1.07	57.06
0.24	9.82	0.66	30.65	1.08	57.76
0.25	10.25	0.67	31.23	1.09	58.46
0.26	10.69	0.68	31.80	1.10	59.16
0.27	11.14	0.69	32.38	1.11	59.87
0.28	11.58	0.70	32.95	1.12	60.58
0.29	12.03	0.71	33.55	1.13	61.30
0.30	12.47	0.72	34.16	1.14	62.01
0.31	12.92	0.73	34.76	1.15	62.72
0.32	13.38	0.74	35.37	1.16	63.45
0.33	13.83	0.75	35.97	1.17	64.18
0.34	14.29	0.76	36.59	1.18	64.90
0.35	14.74	0.77	37.21	1.19	65.63
0.36	15.21	0.78	37.83	1.20	66.36
0.37	15.68	0.79	38.46	1.21	67.11
0.38	16.14	0.80	39.08	1.22	67.86
0.39	16.61	0.81	39.72	1.23	68.61
0.40	17.08	0.82	40.36	1.24	69.36
0.41	17.56	0.83	40.99	1.25	70.11

3.3.3 Monitoring periodical changes in water storage

The variations in water storage in poly-lined tank were monitored daily. A monitoring device was fabricated where a long pointer which touched the water surface was attached to a thread. The thread on the other end was attached to a pulley having free movement. A needle and a 0.30m scale was also attached for making corresponding measurements in water level (Fig. 2, Plate 3).

3.3.4 Raising of Pisciculture

One hundred fish, fifty each of common carp (mirror carp) and grass carp were raised during, July 1995 and again in July 1996. The fish were harvested in December 1995 and December 1996, respectively. Feed and grass were regularly supplied and the data on input and output was recorded for both the years.

3.4 Experimental plan

3.4.1 Treatment details

The experiment was conducted during *kharif* (1995 and 1996) and *rabi* (1995-96 and 1996-97). Six crops viz. maize (var. Parvati), wheat (var. Aradhna), ginger (local selection), radish (var. Japanese white), green onion (Var. N-53) and frenchbean (var. Contender) were grown under maize-wheat, maize + ginger - wheat and maize - radish - onion (green) - frenchbean (green pods) sequences. The following treatments were imposed in sequence after rainfed maize grown as a general crop under recommended practices.

T_1 - Wheat as rainfed crop. **M-W(RF).**

T_2 - Pre-emergence irrigation to wheat in the absence of rain. **M-W(PEI).**

T_3 - Pre-sowing irrigation to wheat. **M-W(PSI).**

T_4 - T_3 + irrigation at crown root initiation stage to wheat. **M-W(PSI+CRI).**

Plate-3 Showing device for monitoring periodical changes in water storage

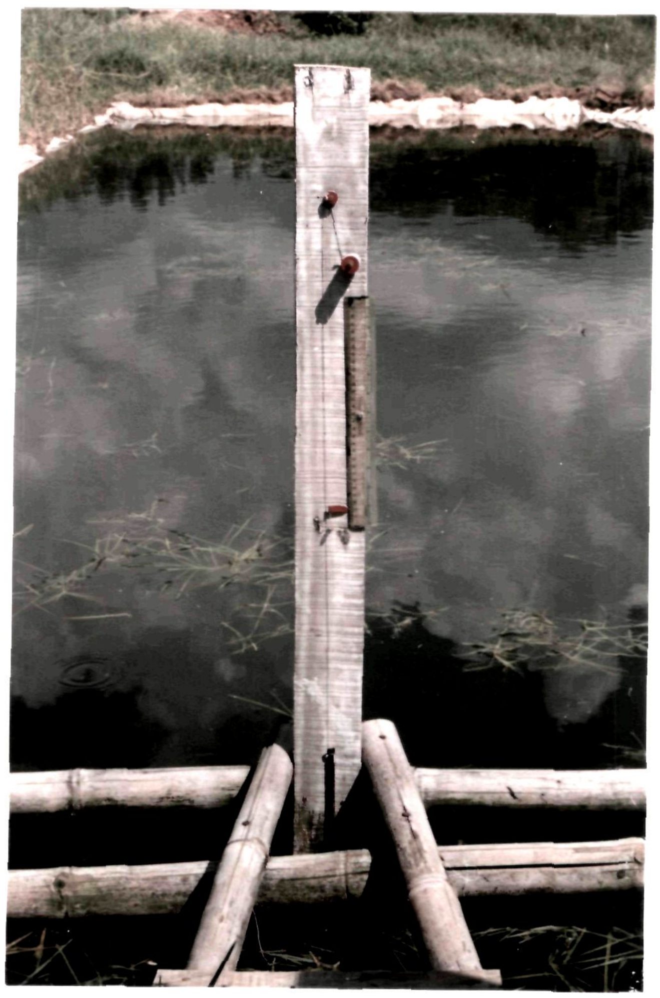
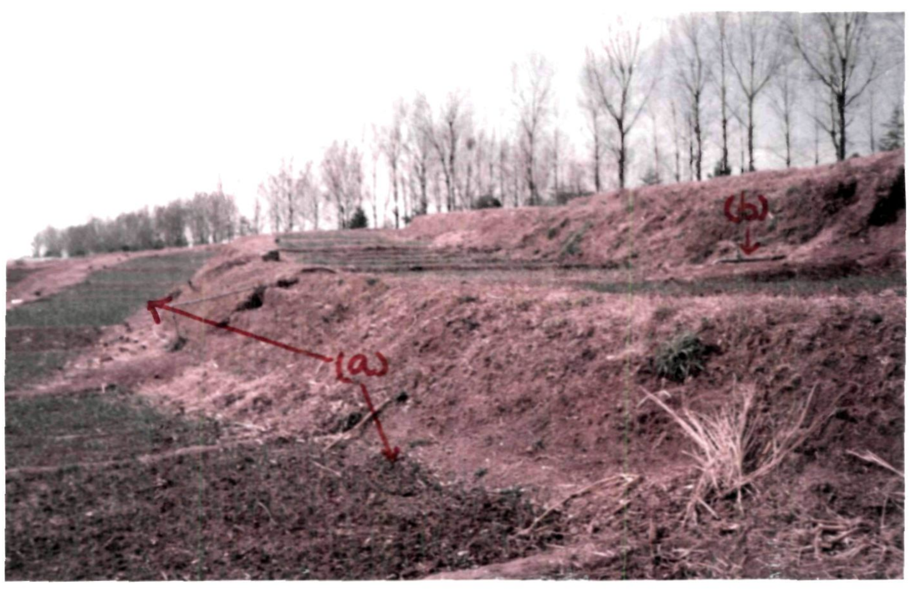


Plate-4 Showing pipelines for providing minimal irrigation to crops

Plate-5 A general view of growing crops (a) and device for regulating water supply (b)


(b)
(a)

T_5 - T_4 + irrigation at flowering stage to wheat. **M-W(PSI+CRI+F).**

T_6 - Maize + ginger - wheat with PSI. **M+G-W(PSI).**

T_7 - Maize - radish - onion (green) - frenchbean (green pods) **M-R-O-FB.**

Ginger was sown on June 6, 1995 and June 4, 1996 and harvested on November 15, 1995 and November 19, 1996. During these two years maize was sown on June 13 and 15 and harvested on November 10 and 7, respectively. Under M+G-W (PSI) treatment, maize was sown in between lines of ginger. Under M-R-O-FB treatment, radish was sown in standing maize to utilize residual moisture on September 20, 1995 and September 12, 1996. The last harvests were taken on December 5, 1995 and November 26, 1996. Onion was transplanted on December 13, 1995 and December 2, 1996 and harvested as green onion. The last harvests were made on May 6, 1996 and April 29, 1997. Frenchbean was dibbled in between lines of onion on March 6, 1996 and February 28, 1997 at optimum moisture. A layer of dry FYM was spread on lines to minimise crust formation and elevate minimum soil temperature during germination. The green pods were harvested till July 8, 1996 and June 28, 1997. Maize seeds in this treatment were sown in between the rows of frenchbean as per the sowing schedule. Maize was raised as a general crop. Wheat was sown on November 27, 1995 and November 20, 1996 and harvested on May 14, 1996 and May 17, 1997. The treatments were replicated four times in a randomised block design with a plot size of 12 m^2 (4m x 3m).

3.4.2 Manures and Fertilizers

Maize, ginger, radish, onion and frenchbean were grown under recommended doses (Table 3.2) of manures and fertilizers, whereas, wheat was grown with 50 per cent of recommended NPK alongwith 10 t/ha FYM.

Plate-6 Ginger as intercrop with maize

Plate-7 Showing radish after harvest of maize

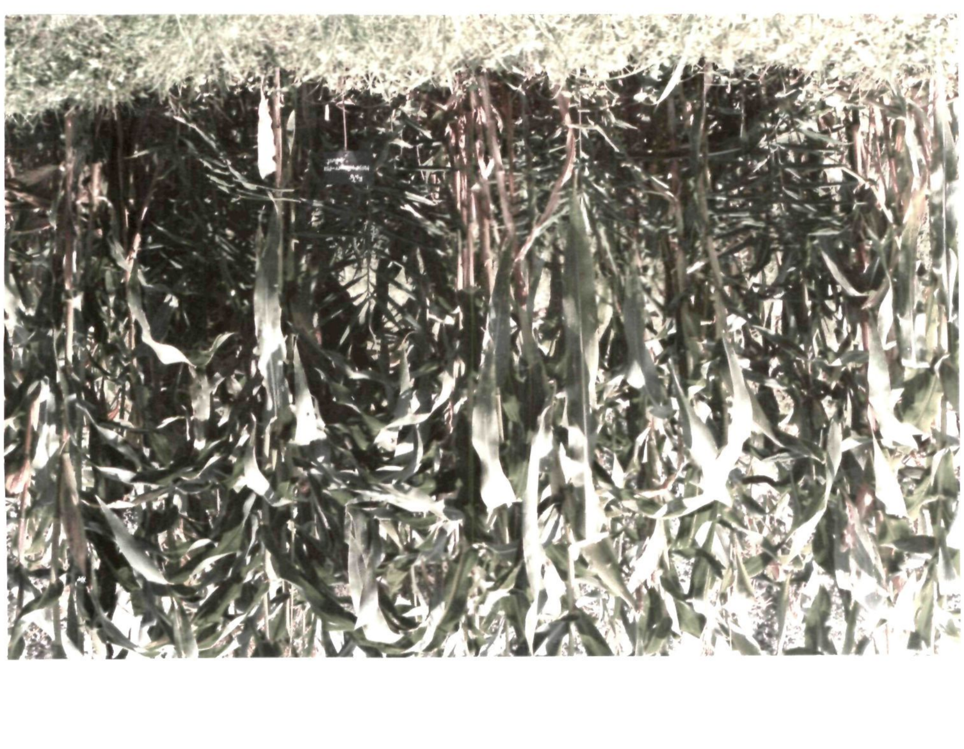


Table 3.2 FYM, fertilizer doses and spacing under different crops

Crop	FYM (t/ha)	N	Fertilizer dose P_2O_5	K_2O	spacing (m)
			kg/ha		
Maize	10	120	60	40	0.60X0.20
*Wheat	10	60	45	15	0.22
Ginger	30	100	50	50	0.45x0.20
Radish	10	100	50	50	0.30X0.075
Onion	25	125	75	60	0.15X0.075
Frenchbean	20	50	100	50	0.60X0.15

* 50 per cent of recommended NPK.

3.4.3 Irrigation of crops

The vegetable crops were applied minimal irrigation when the potential in mercury manometer type tensiometers installed at 0.15 m depth reached -25 ± 5 kPa. Minimal irrigation was applied on lines to wheat and vegetable crops with a garden pipe connected to the outlet of the tank. During 1995-96, 4.1 mm irrigation to wheat was required to bring the seed zone in the lines under all PSI related treatments to field capacity before sowing. A 7.5 mm irrigation was required under W (PEI) treatment 7 days after sowing (DAS) to moisten the whole plot. During 1996-97, 5.8 mm irrigation as PSI was required under all PSI related treatments before sowing and 12.5mm under W (PEI) treatment again 7 DAS. W (PSI+CRI) and W (PSI+CRI+F) treatments received 10 mm irrigation at 21 and 28 DAS at CRI stage during 1995-96 and 1996-97, respectively. W (PSI+CRI+F) treatment was given 20 mm irrigation on 143 and 157 DAS during these two years, respectively.

Plate-8 Showing minimal irrigation application to wheat as pre-sowing irrigation

Plate-9 Showing onion ready to harvest and frenchbean germinating between the rows

3.5 Soil water determination

3.5.1 Soil water content

The changes in soil water content at sowing and during growth of wheat and vegetables for 0-0.60m depth were monitored by thermo-gravimetric method at weekly interval. Volumetric water content (θ) for different depths was calculated by multiplying the water content (mass basis) with pre-determined bulk density for the respective depth.

3.5.2 Soil water potential

Mercury manometer type tensiometers were installed in duplicate at 0.15 and 0.30 m depths in one of the replications to monitor the changes in soil water potential and hydraulic gradients during growing of wheat and vegetable crops (1995-96 and 1996-97).

3.6 Seedling emergence count

The number of wheat seedlings emerging from one metre row length at two different sites in each plot were counted daily from sowing till it became constant in all the treatments and the data were converted into per square metre.

3.7 Xylem water potential

Xylem water potential (XWP) of wheat was recorded using a portable pressure chamber apparatus (Waring and Cleary, 1967). Observations were taken on a clear day at morning (0800 h), mid day (1200 h) under full sunlight and evening (1800 h). These observations were taken at maximum tillering (104 DAS during 1995-96 and 122 DAS during 1996-97) and at flowering stage (144 DAS during 1995-96 and 158 DAS during 1996-97). Fully exposed leaf, second from the top was taken for measurement of XWP. Three leaves per plant per treatment were sampled at each time of the day.

3.8 Root studies

Root growth parameters, viz. root mass density (RMD) and root volume (RV) at different depths were determined after flowering stage of wheat during 1995-96 and 1996-97. Metallic cores (0.103m internal diameter and 0.134m height) were excavated from previously randomly selected rows.

The cores were kept in water overnight and then roots were made free from soil by washing with fine spray of water. Roots were collected on fine sieve (1 mm) for a final washing with microjet tap.

Volume of roots was determined by displacement method and divided by the volume of the core to compute root volume per unit volume of soil. Roots were then transferred to a filter paper and pressed gently in its folds to remove imbibed water. Roots were then dried in an oven at 60°C to a constant weight and finally the dry weight was taken. The dry weight was divided by the volume of the core to compute the root mass density.

3.9 Crop yields

The grain and straw yields of maize and wheat, rhizome yield of ginger, root yield of radish, green onion yield and green pod yield of frenchbean were recorded during 1995-96 and 1996-97.

3.10 Economic studies

Gross expenditure, gross returns and net profit were calculated for each crop and crop-sequence during both the years of study.

3.11 Post harvest studies at the end of experimentation

These included determinations on bulk density, mean weight diameter (MWD), soil moisture retention characteristics, infiltration, soil organic carbon, soil pH and available NPK status of the soil at the end of study during 1996-97.

3.12 Meteorological parameters

The weekly weather data (Appendix-I) were procured from meteorological observatory of HPKV, Palampur, situated at about 200m from the experimental site.

3.13 Statistical analysis

The experimental data were analysed using standard statistical techniques described by Cochran and Cox (1963).

CHAPTER - 4

EXPERIMENTAL RESULTS

Chapter-4

Experimental Results

The experimental results are presented under the following heads:

4.1 Soil physical, chemical and physico-chemical properties

These include particle size distribution, aggregate analysis, bulk density, soil moisture retention characteristics, infiltration, pH, organic carbon, available nitrogen (N), phosphorus (P) and potassium (K) contents of the soil of the experimental site.

4.2 Run-off entry to the tank

This includes rate of entry of run-off to the tank from a specified area and per cent rainwater harvested during different rainfall episodes.

4.3 Periodical changes in water storage in polyethylene lined tank

These include volume of water stored in polyethylene lined tank at weekly interval during growing of maize, wheat and vegetable crops (July 1995 to June 1997).

4.4 Volume of water used from the tank

This includes the volume of water utilized from the tank on monthly basis, for irrigating wheat and vegetable crops.

4.5 Soil and plant studies during crop growth

These include changes in soil water content, soil water potential and hydraulic gradients during growth of wheat, seedling emergence parameters of wheat during 1995-96 and 1996-97.

4.6 Evaluation of xylem water potential

This includes the evaluation of xylem water potential of wheat during 1995-96 and 1996-97.

4.7 Root studies in wheat

These include root mass density and root volume of wheat after flowering stage during 1995-96 and 1996-97.

4.8 Water use in crops

This includes the water use in wheat, radish, onion and frenchbean during their growth cycle.

4.9 Crop yields

These include grain and straw yields of maize and wheat, rhizome yields of ginger, root yields of radish, green onion yields and green pod yields of frenchbean.

4.10 Water use efficiency

This includes water use efficiencies of wheat and vegetable crops.

4.11 Economic studies

These include gross and net returns from growing different crops in Maize-Wheat and Maize-Vegetables sequence.

4.12 Post harvest studies

These include bulk density, mean weight diameter, soil moisture retention characteristics, infiltration, soil organic carbon, pH and available nitrogen, phosphorus and potassium status of the soil at the end of experimentation.

4.13 Input and output data on fish culture

This includes the inputs allocated to and additional outputs obtained from the fish component in the polyethylene lined tank.

4.1 Soil physical and physico-chemical properties

The particle size distribution, textural class, bulk density, mean-weight diameter of aggregates, soil moisture retention curve, steady state infiltration, pH, soil organic carbon and available nitrogen, phosphorus and potassium contents of soil are given in Table 4.1.

4.1.1 Particle size distribution

The data in Table 4.1 revealed that in the surface (0-0.15m) soil depth, silt content was highest (49.7%) followed by clay (30.2%) and sand (20.1%). The textural class (ISSS) was silty clay loam.

4.1.2 Mean weight diameter

The mean weight diameter (MWD) ranged from 2.23 to 2.33 mm with a mean value of 2.28 mm.

4.1.3 Bulk density

The bulk density values for different depths showed an increasing trend with the depth. Maximum bulk density value (1.29 Mg/m^3) was obtained for 0.45-0.60 m soil layer and minimum (1.17 Mg/m^3) for 0-0.075 m depth.

4.1.4 Soil moisture retention characteristics

Soil moisture retetion characteristics for undisturbed soil sample are depicted in Fig. 3 whereas, the water retention at some selected values is given in Table 1. The volumetric water content (θ) decreased with increase in suction (ψ). The values of 'θ' at 10, 33 and 1500 kPa suction were 34.2, 28.9 and 13.2 $m^3/100m^3$, respectively. There was an abrupt decrease in 'θ' with an increase in 'ψ' upto a value of 10 kPa and beyond this value, the decrease in 'θ' was gradual with increase in 'ψ'.

4.1.5 Infiltration

The steady state infiltration rate was 5.0 x 10^{-6} m/s

4.1.6 pH

The soil was acidic in reaction with a pH of 5.6.

Table 4.1 Basic physical and physico-chemical properties of the experimental site

1. Particle size distribution (%) for surface 0-0.15 m depth		
(i)	Clay	30.2
(ii)	Silt	49.7
(iii)	*Sand*	*20.1*
	Textural class(ISSS)	Silty clay loam
2. Mean-weight diameter (mm) for 0-0.15m depth		: 2.28 ± 0.05
3. Bulk density (Mg/m^3)		
i)	0- 0.075 m	1.17 ± 0.04
ii)	0.075-0.15 m	1.19 ± 0.03
iii)	0.15-0.30 m	1.22 ± 0.02
iv)	0.30-0.45 m	1.25 ± 0.03
v)	0.45-0.60 m	1.29 ± 0.04
4. Moisture content (θ) for 0-0.15m depth ($m^3/100m^3$)		
i)	Saturation	62 ± 4
ii)	10 kPa suction	34 ± 3
iii)	33 kPa suction	29 ± 2
iv)	1500 kPa suction	13 ± 2
5. Steady state infiltration (m/s)		: 5.0×10^{-6}
6. pH		: 5.6
7. Organic carbon (%)		
i)	0-0.075m	1.00 ± 0.04
ii)	0.075-0.15m	0.89 ± 0.03
iii)	0.15-0.30m	0.78 ± 0.03
8. Available NPK (kg/ha) for 0-0.15 m depth		
i)	Nitrogen	279 ± 12
ii)	*Phosphorus*	*13 ± 2*
iii)	Potassium	203 ± 10

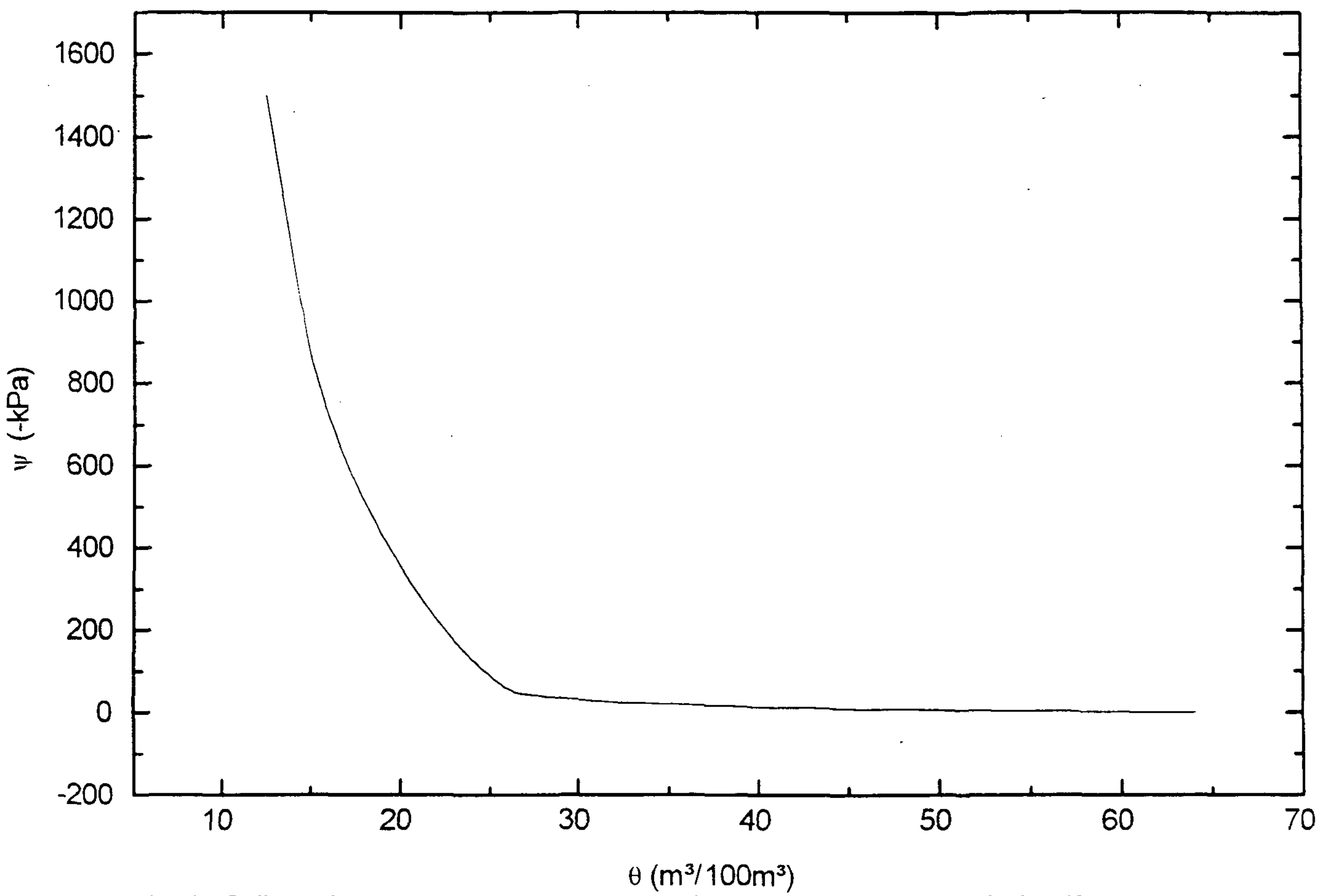


Fig. 3. Soil moisture retention characteristics of the experimental site (0-0.15m)

4.1.7 Organic carbon

The organic carbon content of the soil decreased with increase in depth. It was highest (1%) in 0-0.075m soil layer and lowest (0.78%) in subsurface layer (0.15- 0.30m).

4.1.8 Available NPK

The soil was medium in available nitrogen (N), phosphorus (P) and potassium (K) contents with values 279, 13 and 203 kg/ha, respectively, for 0-0.15m depth.

4.2 Run-off entry to the tank

The rate of entry of run-off to the tank and per cent rain harvested from a specified area during different rainfall episodes are given in Table 4.2. It was observed that continuous occurrence of rainfall yielded more amount of water per unit time as compared to the sporadic rains. The volume of water collected per unit time was higher in the month of August 1996 than June and July 1996. During August the run-off rate ranged from 6 to14 litres per minute, whereas, it varied from 5 to 8 litres per minute and 2 to 9 litres per minute in the months of June and July 1996, respectively. The data also indicated that higher amount of rainfall resulted in higher volume of water per unit time during 1996 as well as during 1997. It was observed that the volume of water collected per unit time was generally higher during summer monsoon months as compared to the winter months. During September 1996, it ranged from 1 to 8 litres per minute, during January to April 1997, it varied from 2.5 to 4.5 and during May to June 1997, it varied from 3.5 to 5 litres per minute. The per cent of rainwater harvested was highest in July 1996 (67.4 per cent) and lowest in February 1997 (12.8 per cent).

Table 4.2 Run-off rate and per cent rain harvested in the water harvesting tank from a specified area during different rainfall episodes

Date	Rainfall episode (mm)	Rate of entry (Litre/minute)	Maximum water that could have been harvested/day (m^3)	Actual water harvested/day (m^3)	Per cent rain harvested/ day
13.6.96	45.8	8.0	19.47	5.92	30.4
4.7.96	18.3	6.0	7.78	3.20	41.1
9.7.96	7.0	2.0	2.98	1.32	44.3
22.7.96	38.5	8.5	16.36	11.02	67.4
6.8.96	22.5	6.0	9.56	3.97	41.5
13.8.96	85.8	14.0	36.47	tank filled	-
22.8.96	13.0	6.5	5.53	--do--	-
2.9.96	21.5	7.5	9.14	--do--	-
9.9.96	25.0	8.0	10.63	--do--	-
12.9.96	5.0	1.0	2.13	--do--	-
9.1.97	36.0	4.5	15.3	3.44	22.5
20.1.97	17.0	3.0	7.23	2.03	28.1
9.2.97	12.0	2.5	5.10	0.65	12.8
15.3.97	23.7	4.0	10.07	1.97	19.6
18.3.97	17.2	3.5	7.31	1.29	17.7
9.4.97	18.0	3.5	7.65	1.94	25.4
7.5.97	23.2	4.0	9.86	1.54	15.6
20.6.97	16.0	3.5	6.8	1.21	17.7
23.6.97	29.0	5.0	12.33	2.43	19.7

4.3 Periodical changes in water storage in polyethylene lined tank

The periodical changes in water storage in polyethylene lined tank are graphically presented in Fig. 4 on standard week basis. Each value depicted is the volume present in the tank on the first day of respective standard week (SW). During 1995, the volume of water in the tank was 50.20 m^3 on SW 30, which increased to its maximum capacity (70.11m^3) on SW 31. The tank remained filled upto its full capacity from SW 30 to SW 38. On SW 44, after irrigating radish the volume was 63.52 m^3. This volume reduced to 55.45 m^3 on SW 48 (26 November, 1995) after irrigating radish and wheat. It further reduced to 48.65m^3 on SW 52 after irrigating onion as well as wheat in W (PSI+CRI) and W (PSI+CRI+F) treatments at CRI stage in December 1995.

During 1996, the volume was 48.05m^3 on SW 5. No irrigation was required for onion in February and March 1996. The volume was 56.99 m^3 on SW 13. Water was utilized for irrigating onion and wheat (W) in W (PSI+CRI+F) treatment in April 1996. The volume was 46.06 m^3 on SW 18. Frenchbean required irrigation in May and June 1996. The volumes on SW 22 and SW 26 were 35.13 an 43.18 m^3, respectively. The volume increased to 69.96 m^3 on SW 27 due to rains. No irrigation was required from August to September 1996. The tank regained its maximum capacity on SW 30. It reduced to 67.41 m^3 on SW 40. After irrigating radish and ginger in October 1996 the volume was 48.45 m^3 on SW 49 (3 December, 1996). The volume after irrigating onion from December 1996 to February 1997 was 42.10 m^3 on SW 10. The volume was 42.79 m^3 on SW 14 which reduced to 40.80 m^3 after irrigating frenchbean and W (PSI+CRI+F) treatment of wheat. After irrigating frenchbean in May 1997 the volume was 33.01 m^3 on SW 23. Finally on SW 27 the volume was 37.46 m^3.

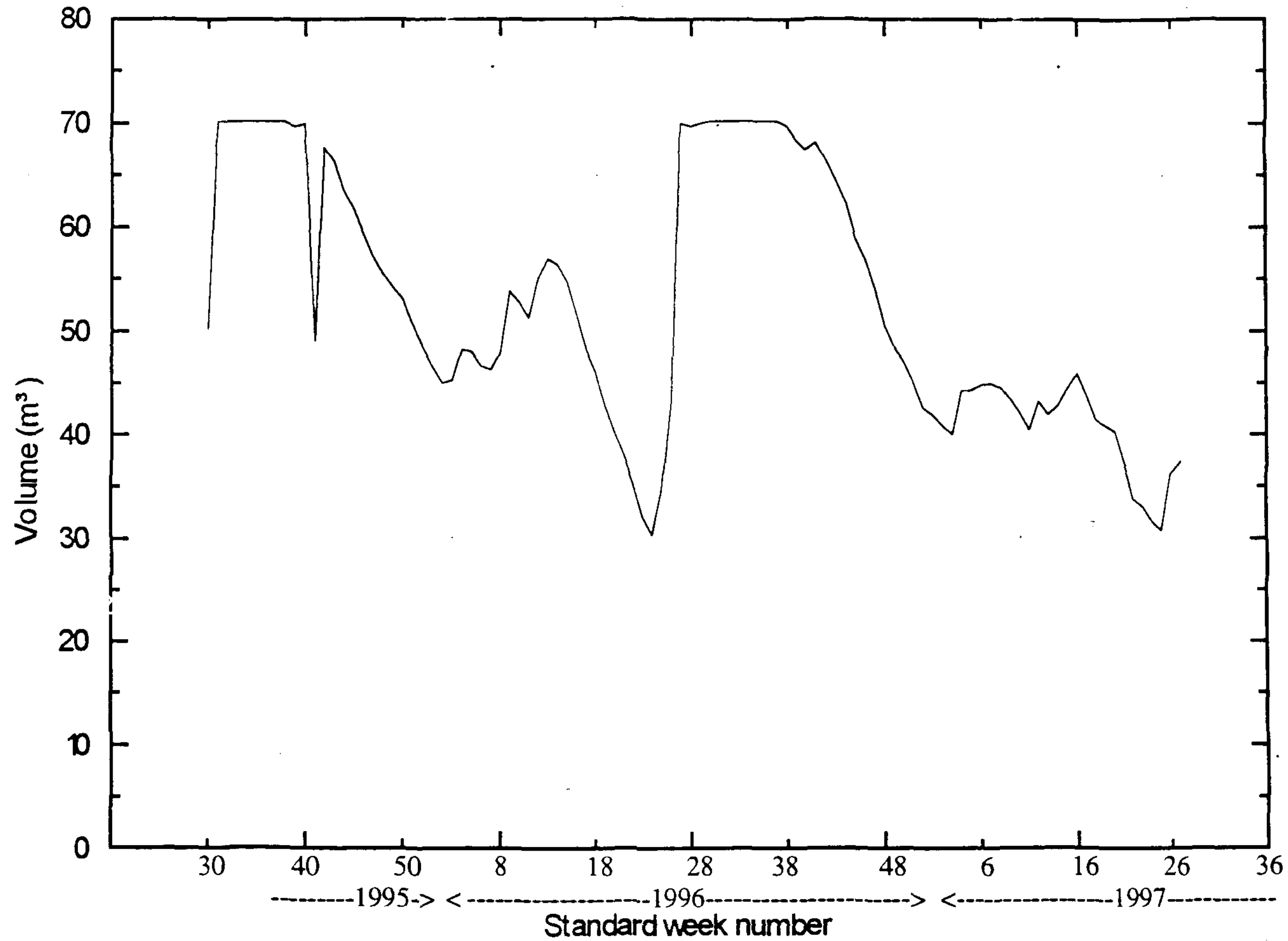


Fig. 4. Volume of water in the tank (July,1995- July 1997)

4.4 Volume of water used from the tank for irrigation

The monthly water utilisation from the tank during the course of study is given in Table 4.3. No water was required for irrigation in the months of July, August and September 1995. In October 1995, radish was irrigated with a total of 32.3 mm lowering the storage by 1.55 m^3. In November 1995, irrigation to radish and wheat lowered the volume by 3.15 m^3. In December 1995 W (PEI), W (PSI+CRI) and W (PSI+CRI+F) treatments were irrigated which reduced water volume by 1.32 m^3 and irrigation to onion lowered the storage by 2.68 m^3 water. Thus, a total of 4.00 m^3 of water was consumed in December 1995. For onion, 1.34 m^3 water was utilized from the tank in January 1996. No irrigation was required in February and March 1996. In April 1996 onion and wheat were irrigated which lowered the water storage by 3.16 m^3. A total volume of 3.54 m^3 water was applied to frenchbean in May 1996 for providing different irrigations. In June 1996, ginger and frenchbean utilized 0.84 m^3 of water from the tank. No irrigation was required in July , August and September 1996 from the tank. Irrigation applied to radish and ginger decreased water volume by 3.18 m^3 in October 1996. In November 1996, onion and wheat resulted in a total water expenditure of 7.08 m^3 from the tank. Onion and wheat reduced storage by 4.79 m^3 in December 1996, whereas onion alone utilized 0.56, 0.28 and 0.42 m^3 water in January, February and March 1997, respectively. Irrigation applied to wheat in W (PSI+CRI+F) treatment and frenchbean decreased the storage by 1.94 m^3 in April 1997. In May 1997, 2.78 m^3 water was utilized for irrigating frenchbean. No water was required in June 1997.

During 1995-96 cropping sequence, no irrigation was required by ginger whereas, 81.6mm irrigation was applied to radish in 10 irrigations which utilized 3.92 m^3 water from the tank. Onion consumed 6.23 m^3 water from the tank for irrigation in 21 irrigations with a total depth of irrigation equal of 129.7mm. Frenchbean was irrigated 10 times with 82.5mm of total irrigation utilizing 3.96 m^3 water from the tank.

Table 4.3 Monthwise water utilization (m^3) for irrigation from the water harvested in polyethylene lined tank (July,1995 to June,1997)

Treatment	1995	1996	1997
January		1.34	0.56
February		-	0.28
March		-	0.42
April		3.16	1.94
May		3.54	2.78
June		0.84	-
July	-	-	
August	-	-	
September	-		
October	1.55	3.18	
November	3.15	7.08	
December	4.00	4.79	

Total water used (m^3)

	Ginger	Radish	Onion	Frenchbean	Wheat	G. Total
1995-96	-	3.92	6.23	3.96	3.07	17.18
1996-97	1.35	7.47	4.94	3.76	3.63	21.15

During 1996-97 crop sequence 28.1mm water was applied to ginger in 3 irrigations utilizing 1.35 m^3 water and again 10 irrigations were applied (total 155.7mm water) to radish consuming 7.47 m^3 water from the tank. Onion utilized 4.94 m^3 water from the tank in 14 irrigations with a total irrigation depth of 102.9mm. Frenchbean alone was applied 7 irrigations with total of 78.4mm water accounting for 3.76 m^3 volume from the tank.

Wheat under different treatments consumed 3.07 m^3 water during 1995-96 and 3.63 m^3 during 1996-97 from the tank.

4.5 Soil and plant studies during crop growth

4.5.1 Soil water content during wheat growth

The volumetric moisture content (θ) upto 0-0.30 m depth during various stages of wheat growth for 1995-96 is presented graphically in Fig. 5 for 0-0.075 m soil depth, Fig. 6 for 0.075-0.15 m from 0 to 91 DAS; Fig. 7 for 0-0.15 m from 112 to 169 DAS and Fig. 8 for 0.15-0.30 m depth. These data for the year 1996-97 are presented in Fig. 9, Fig. 10, Fig. 11 and Fig. 12 for 0-0.075 m depth from 0 to 110 DAS, 0.075-0.15 m from 0 to 110 DAS; for 0-0.15 m; for 122 to 178 DAS and for 0.15 - 0.30 m for 0 to 178 DAS, respectively. For 0.30-0.45 and 0.45-0.60 m depths during 1995-96 and 1996-97, it is presented in Appendix-II and III, respectively. During both the years, the results for 'θ' with respect to different treatments of wheat were nonsignificant below 0.30m depth.

During 1995-96 at sowing (27.11.95), 4.1 mm irrigation to wheat under pre-sowing irrigation (PSI) related treatments increased the 'θ' of these treatments significantly over rainfed wheat W (RF) and pre-emergence irrigation W (PEI) treatments. The values for 'θ' ranged from 22.1 to 26.3 $m^3/100m^3$ for PSI related treatment, 8.3 $m^3/100m^3$ for W (RF) and 11.1 $m^3/100m^3$, for W (PEI) treatments respectively, for 0-0.075 m depth. On 2 DAS, the 'θ' increased due to 6.8 mm rainfall (Appendix-I) in all the treatments, but the trend for moisture content remained the same as on first day of sowing after irrigation. On 7 DAS, an irrigation of 7.5 mm irrigation significantly increased 'θ' of W (PEI) treatment over other treatments, W (RF) treatment was, however, significantly lower in 'θ' than all the treatments. The values of 'θ' were 18.4, 33.0, 24.0-26.8 $m^3/100m^3$ for W (RF), W (PEI) and different PSI related treatments, respectively for 0-0.075 m depth.

Ten mm irrigation applied to wheat at crown root initiation stage (CRI) under W (PSI+CRI) and W (PSI+CRI+F) treatments, 21 DAS increased 'θ' of these two treatments at all the depths (0-0.30 m) significantly over other treatments. The values of 'θ' for W (RF), W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G- W (PSI) treatments were 8.8, 20.3, 12.4, 28.9, 29.4, and 14.0 $m^3/100m^3$ for 0-0.075 m depth; 10.4, 21.7, 16.3 28.8, 29.2 and 19.1 $m^3/100m^3$ for 0.0.75-0.15 m and 10.7, 18.5, 17.3, 25.8, 27.4 and 19.3 $m^3/100\ m^3$ for 0.15-0.30 m depths, respectively.

On 38 DAS W (PSI+CRI) and W (PSI+CRI+F) treatments exhibited significantly higher moisture content than all other treatments. The differences were nonsignificant on 52, 61, 77 and 91 DAS in all the treatments. On 112 and 126 DAS, W (PEI) treatment contained higher 'θ' than all the treatments, whereas, W (RF) treatment was significantly lower in 'θ' than all the treatments. The remaining treatments were statistically at par with one another. On 143 DAS, due to 20 mm irrigation applied at flowering stage to W (PSI+CRI+F) treatment, 'θ' was significantly higher under this treatment over all other treatments. The values of 'θ' under W (RF) , W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments were 17.1, 24.6, 20.4, 20.7, 35.9 and 22.0 $m^3/100m^3$ for 0-0.15 m depth and 20.0, 26.7, 23.0, 24.3, 33.7 and 23.5 $m^3/100m^3$, for 0.15-0.30 m depth, respectively. The same trend of statistical significance was observed on 155 DAS. At harvest W (PSI+CRI+F) treatment was significantly higher in 'θ' than allother treatments which were statistically at par with one another.

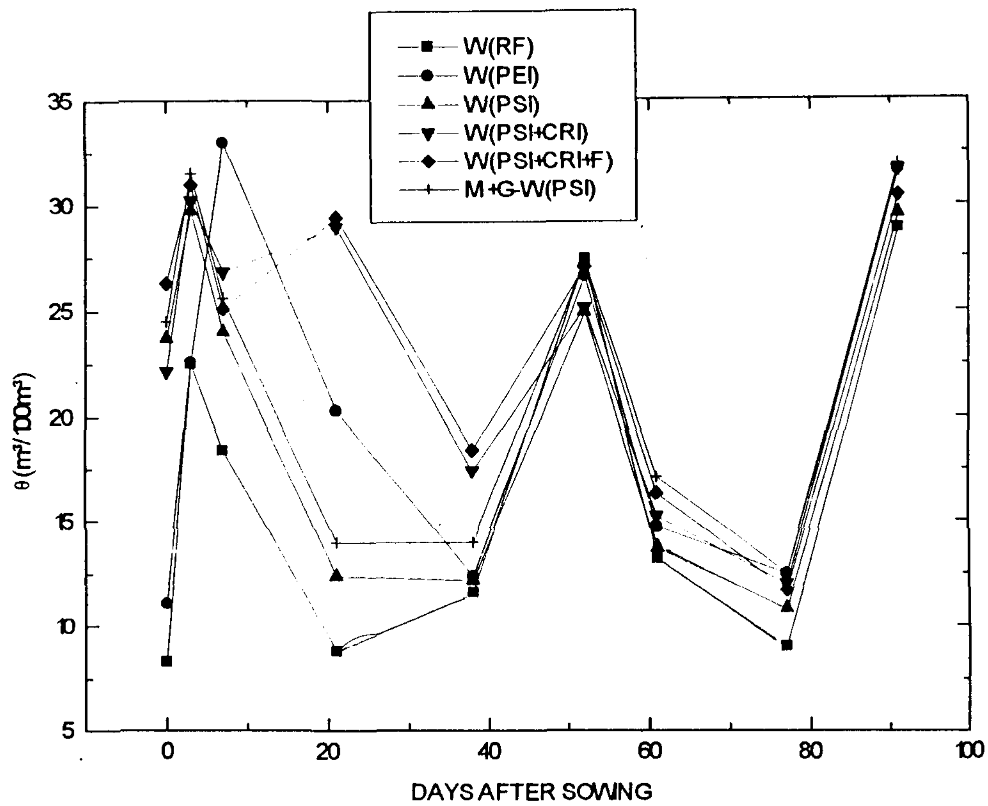


Fig. 5. Soil moisture content under different treatments (0 - 0.075 m) during growth of wheat (1995-96)

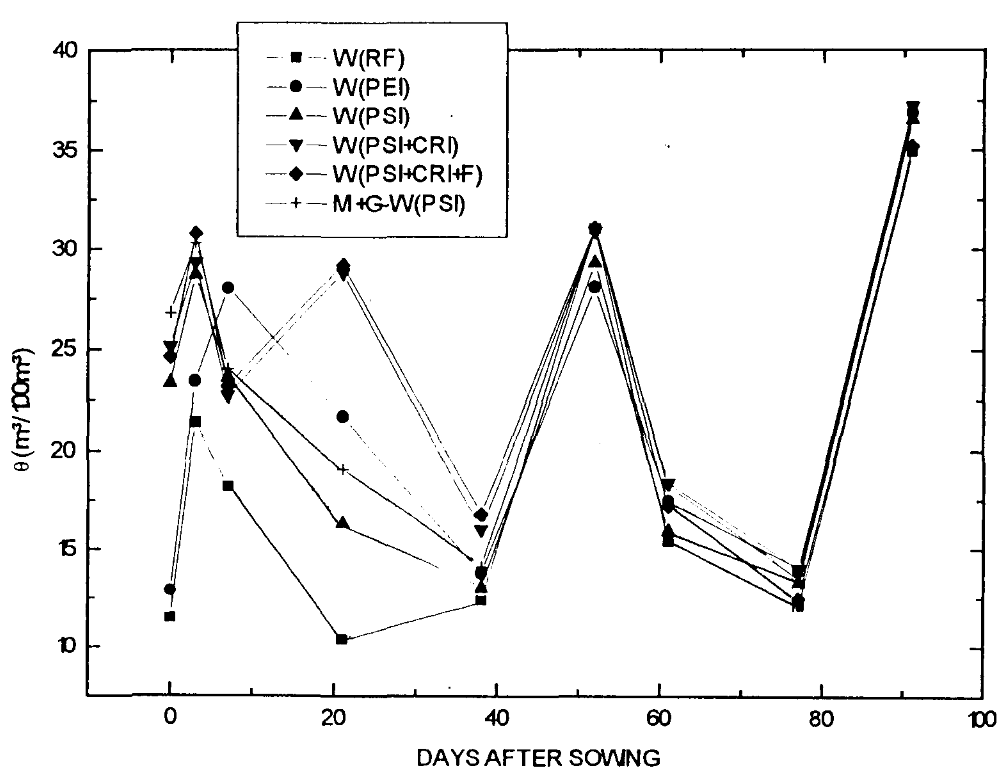


Fig. 6. Soil moisture content under different treatments (0.075-0.15 m) during growth of wheat (1995-96)

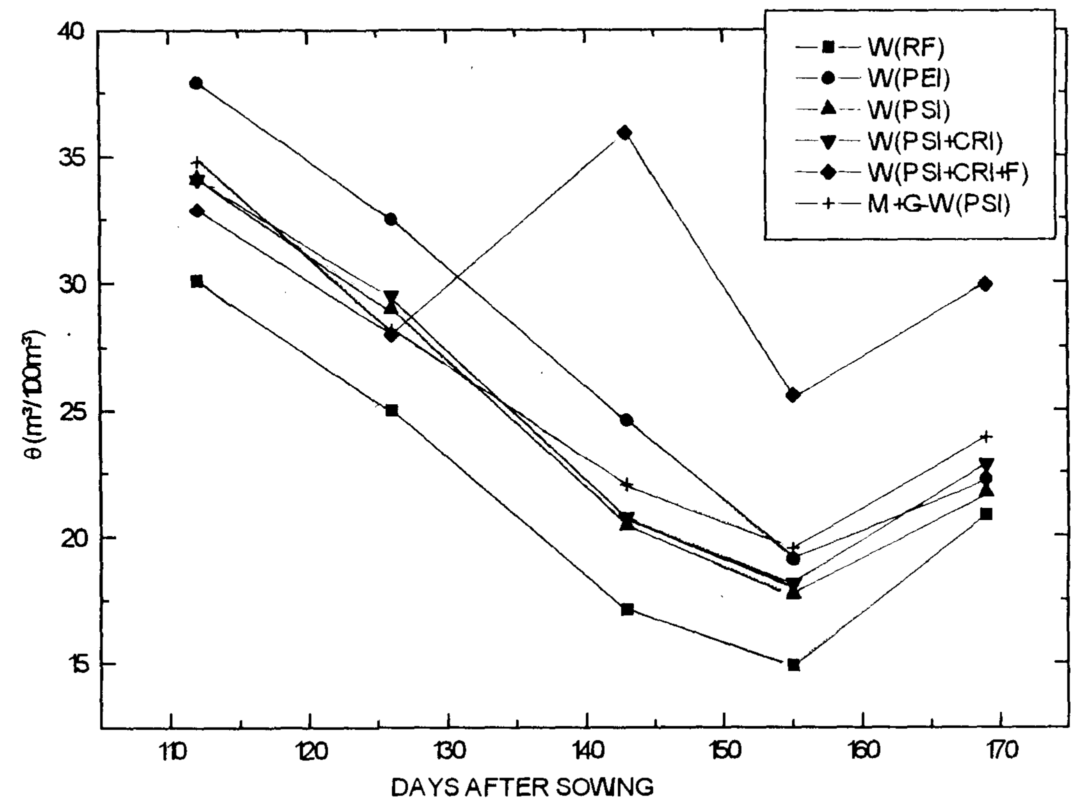


Fig. 7. Soil moisture content under different treatments (0-0.15m) during growth of wheat (1995-96)

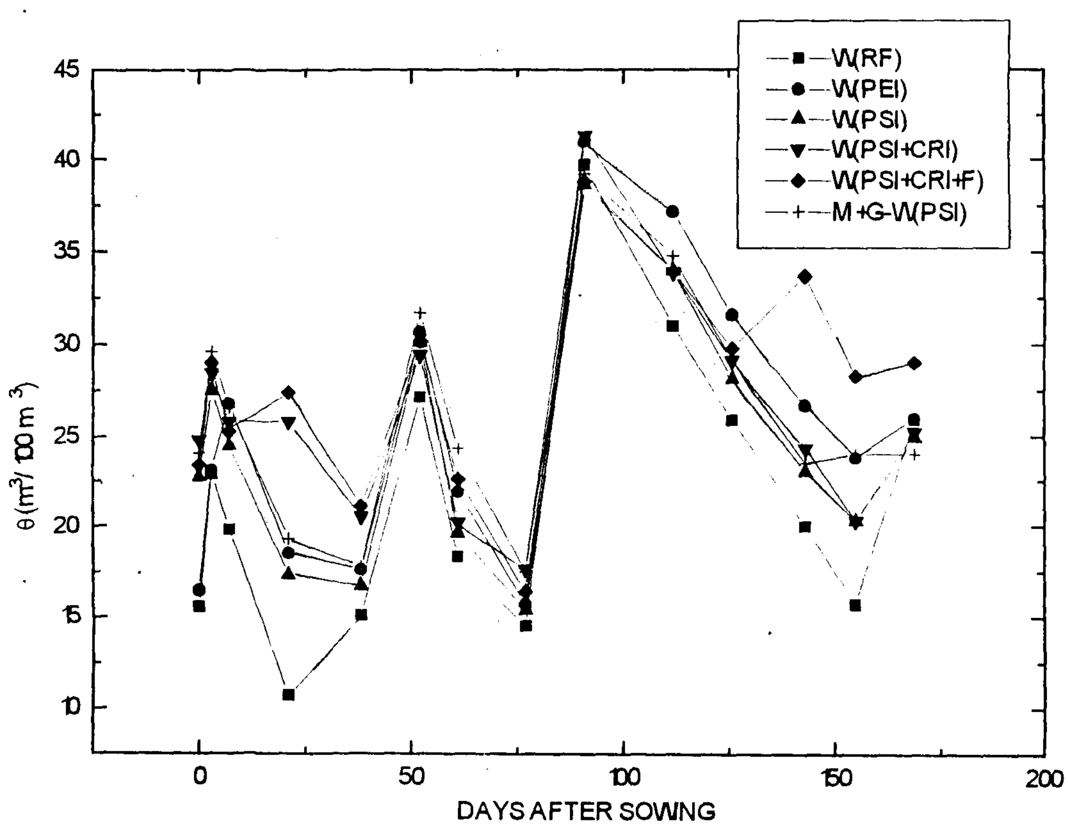


Fig. 8. Soil moisture content under different treatments (0.15-0.30 m) during growth of wheat (1995-96)

During 1996-97, an irrigation of 5.8 mm before sowing to all PSI related treatments significantly increased 'θ' of these treatments over W (RF) and W (PEI) treatments at all the depths (0-0.30 m). The value of 'θ' in W (RF), W (PEI) and various PSI related treatments were 10.3, 10.6 and 24.2 to 29.6 $m^3/100m^3$ for 0-0.075 m depth and 11.4, 13.0 and 25.1 to 27.6 $m^3/100m^3$ for 0.075-0.15m soil depth, respectively. On 8 DAS in the absence of rain 12.5 mm irrigation was applied to W (PEI) treatment which significantly increased 'θ' of this treatments over all the treatments. 'θ' values for all the treatments were, however, significantly higher that W (RF) treatment. The values of 'θ' under W (RF), W (PEI) and PSI related treatments were 9.2, 29.9 and 20.6-24.2 $m^3/100m^3$ for 0-0.075 m depth and 10.8, 28.8 and 21.7-22.6 $m^3/100m^3$ for 0.075-0.15 m depth, respectively. On 28 DAS, 10 mm irrigation applied to W (PSI+CRI) and W (PSI+CRI+F) treatment resulted in an increase in 'θ' of these treatments at all depths. At this stage W (RF), W (PEI) and W (PSI) treatments showed significantly lower 'θ' than M+G-W (PSI) (the treatment in which ginger was grown as inter-crop with maize), W (PSI+CRI) and W (PSI+CRI+F) treatments. The values of 'θ' were 17.3, 20.9, 19.7, 31.5, 33.5 and 26.6 $m^3/100m^3$, in 0-0.075 m depth for W (RF), W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments, respectively. The same treatments contained 18.9, 22.7, 21.9, 34.7, 35.1 and 26.9 $m^3/100m^3$ 'θ' in 0.075-0.15 m depth, respectively. On 61 DAS, M+G- W (PSI) treatment was significantly higher in 'θ' that all other treatments. Same trend followed on 75 and 83 DAS. Maize (M) + ginger (G) - wheat (W) with PSI [M+G-W (PSI)] treatment showed significantly higher and W (RF) treatment significantly lower 'θ' than all other treatments on 99 DAS. W (PEI), W (PSI) and W (PSI +CRI) treatments were statistically at par with one another. Same trend was observed on 110 and 122 DAS. On 134 DAS, all the treatments showed nonsignificant differences in 'θ'. On 148 DAS, all the treatments yielded significantly higher 'θ' than W (RF) treatment. On 157 DAS, 20 mm irrigation was applied to

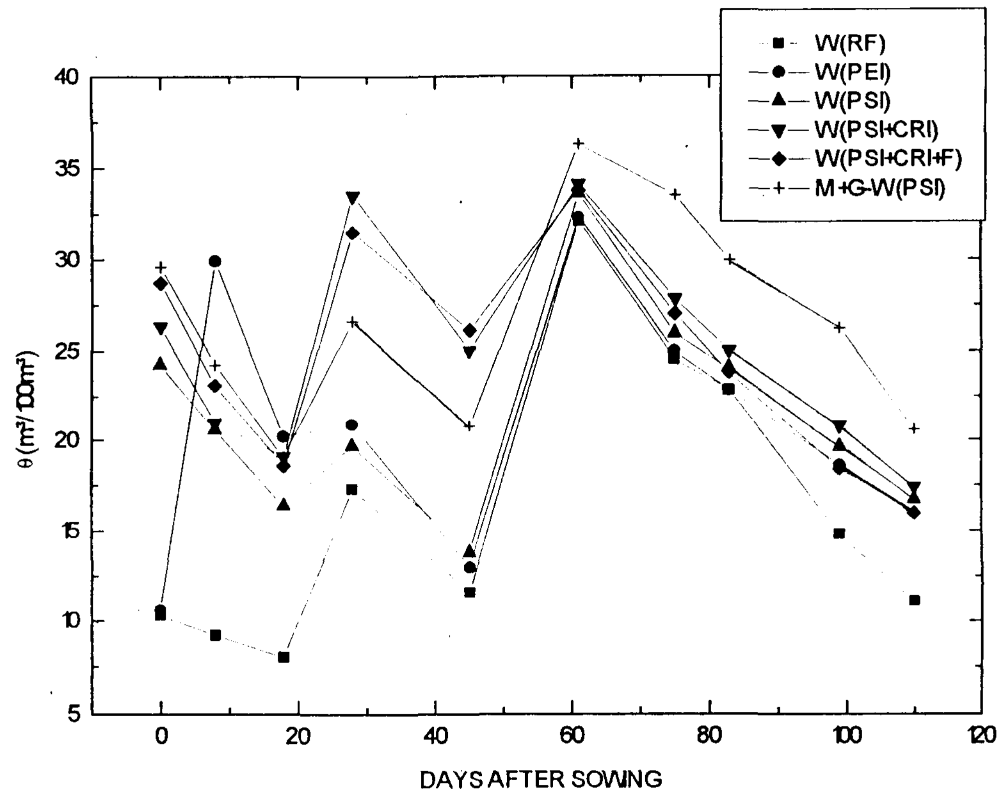


Fig. 9. Soil moisture content under different treatments (0-0.075 m) during growth of wheat (1996-97)

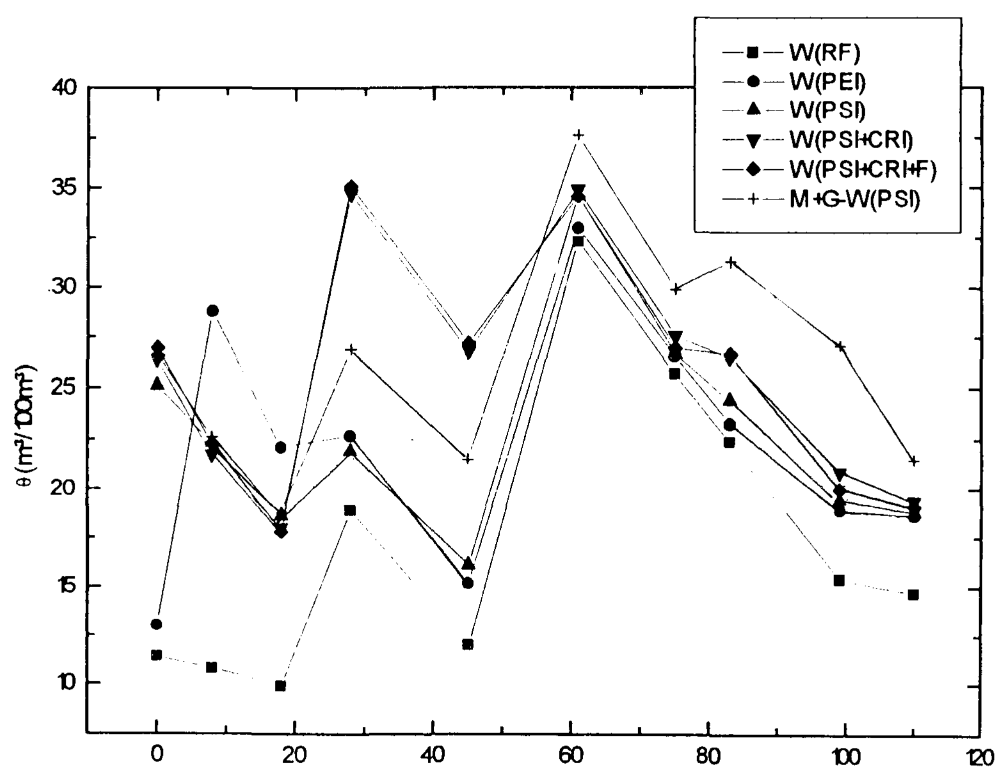


Fig. 10. Soil moisture content under different treatments (0.075-0.15m) during growth of wheat (1996-97)

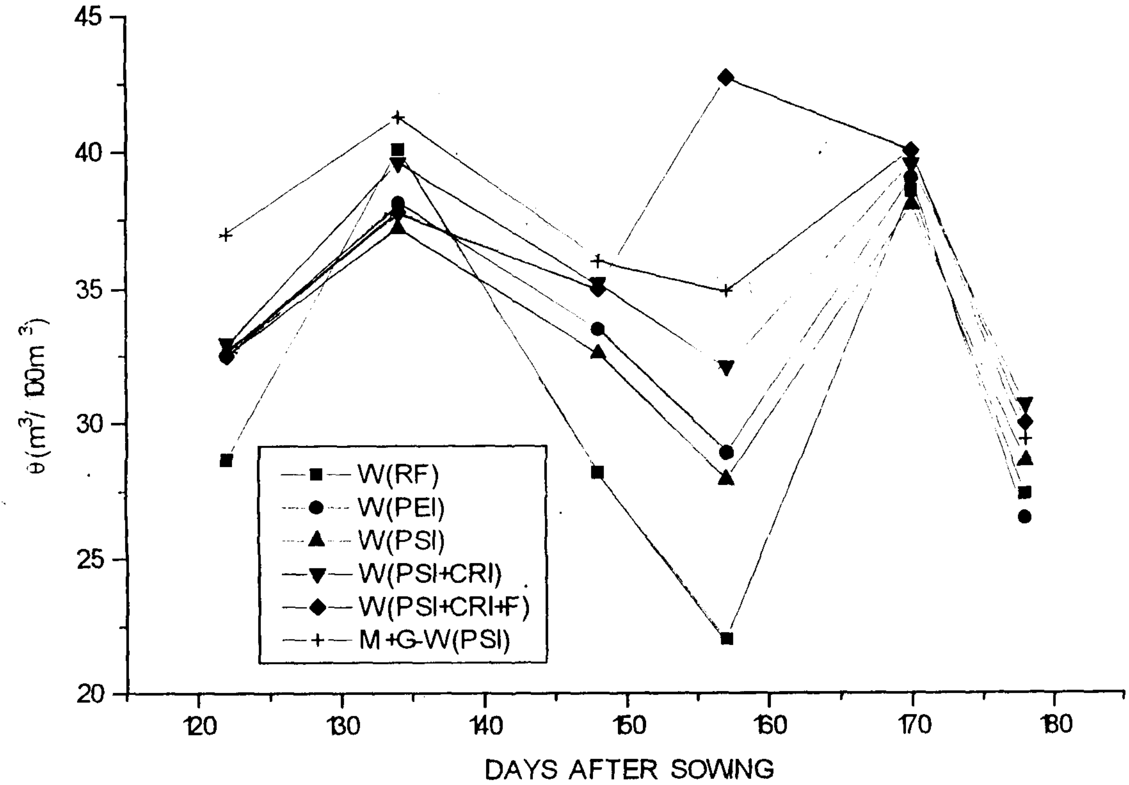


Fig. 11 Soil moisture content under different treatments (0-0.15 m) during growth of wheat (1996-97)

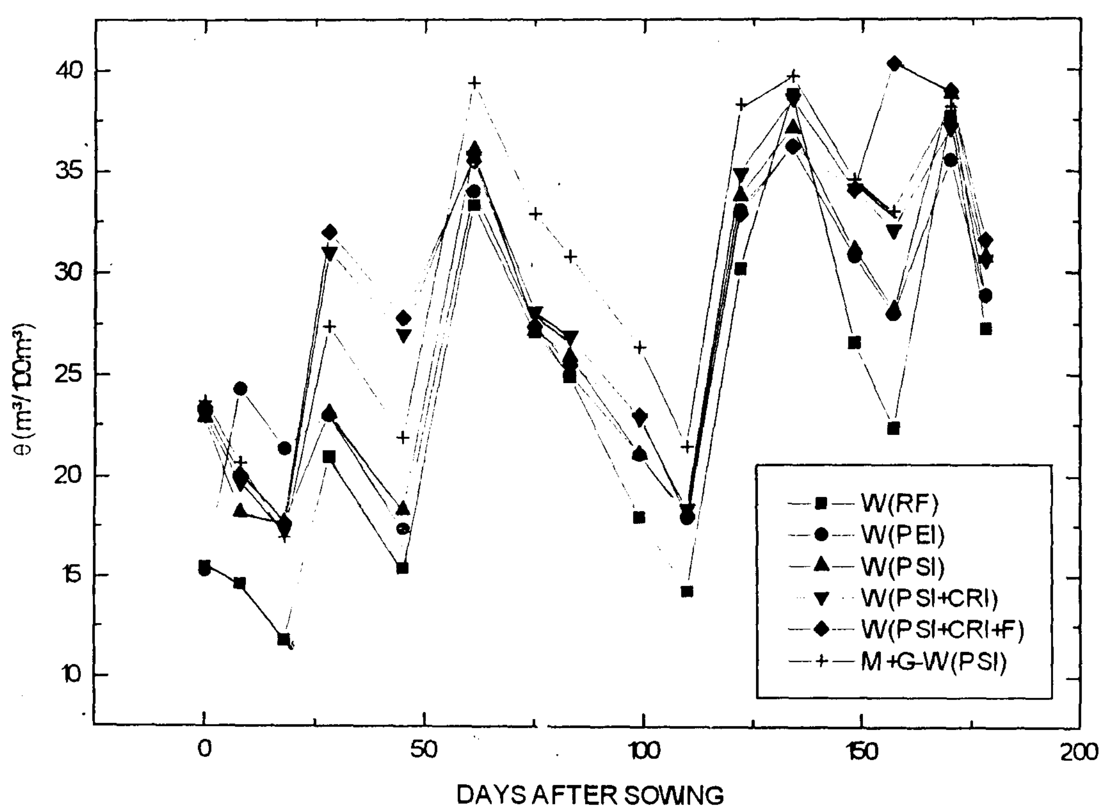


Fig. 12. Soil moisture content under different treatments (0.15-0.30 m) during growth of wheat (1996-97)

W (PSI+CRI+F) treatment which significantly increased 'θ' of this treatment over other treatments. The remaining treatments showed significantly higher 'θ' values than W (RF) treatment. The values of θ in 0-0.15m soil layer were 22.0, 28.9, 27.9, 32.1, 42.7 and 34.9 $m^3/100m^3$ and for 0.15-0.30 m depth the values of 'θ' were 22.4, 28.0, 28.2, 32.1, 40.3 and 33.0 $m^3/100$ m^3, for W (RF), W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments, respectively. The results were found to be nonsignificant on 170 and 178 DAS.

4.5.2 Matric Potential

The changes in matric potential (ψ) of soil during wheat growth at 0.15 and 0.30m depths for a period of 44-169 DAS during 1995-96 and for 44-178 DAS during 1996-97 are depicted in Fig.13, 14 and Fig.15, 16, respectively.

During 1995-96 on 44 DAS the 'ψ' was almost similar in all the treatments (Fig.13 and 14) on 54 DAS, it was higher in all the treatments than W (RF) treatment at both the depths. It's values on 84 DAS for W (RF), W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments were -18.7, -13.3, -14.6, -14.6, -13.8 and -13.8 kPa at 0.15 m depth and -10.8, -7.0, 7.3, -7.3, -6.3 and -6.6 kPa at 0.30 m depth, respectively. On 89 and 94 DAS, the values of 'ψ' increased due to occurrence of rains and again decreased on 104 and 109 DAS in all the treatments at both the depths. Due to rains 'ψ' increased on 114 DAS. The value was maximum under W (PEI) treatment (-6.4 kPa for 0.15 m depth and -9.3 kPa for 0.30 m depth). The values decreased on 143 DAS in all the treatments, except for W (PSI+CRI+F). The value increased due to 20 mm irrigation to this treatment. 'ψ' values were -67.7, -62.8, -66.5, -66.5, -19.2 and -66.1 kPa for 0.15 m depth and -50.9, -47.8, -52.6, -52.6, -52.6, -20.6 and -52.2 kPa for 0.30 m depths in W (RF), W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments, respectively. These 'ψ' values further either increased or decreased depending upon rains or dry spells till the harvest of crop.

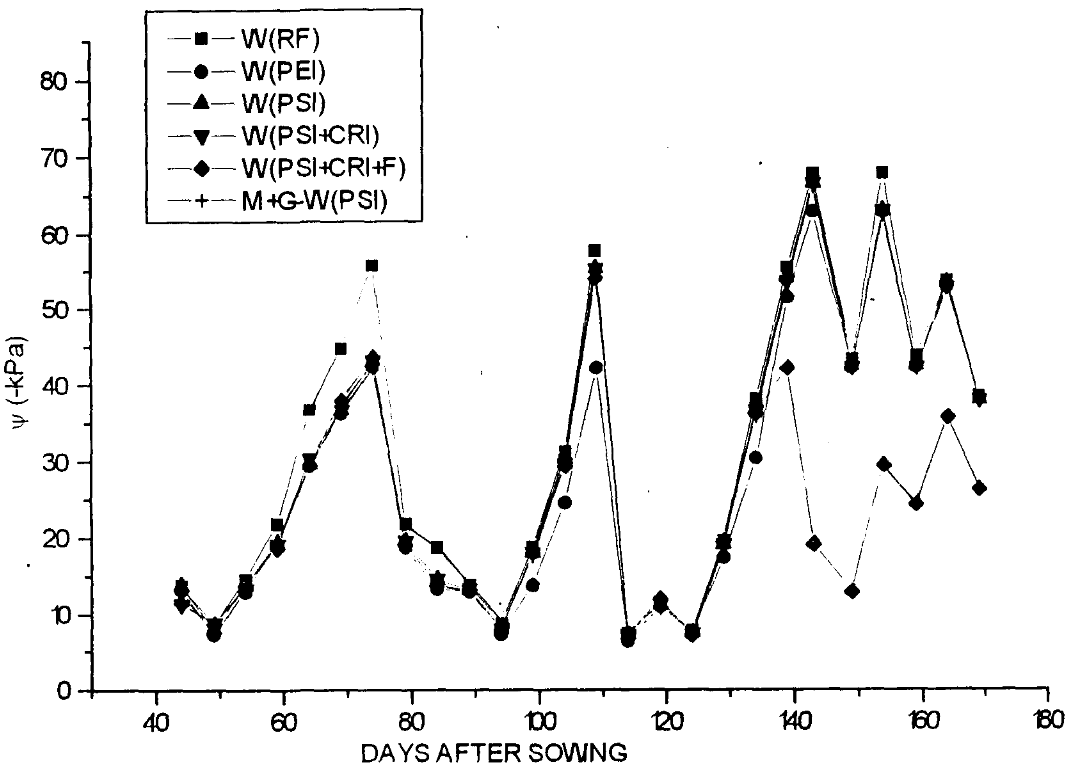


Fig. 13. Matric potential at 0.15m depth under different treatments during growth of wheat (1995-96)

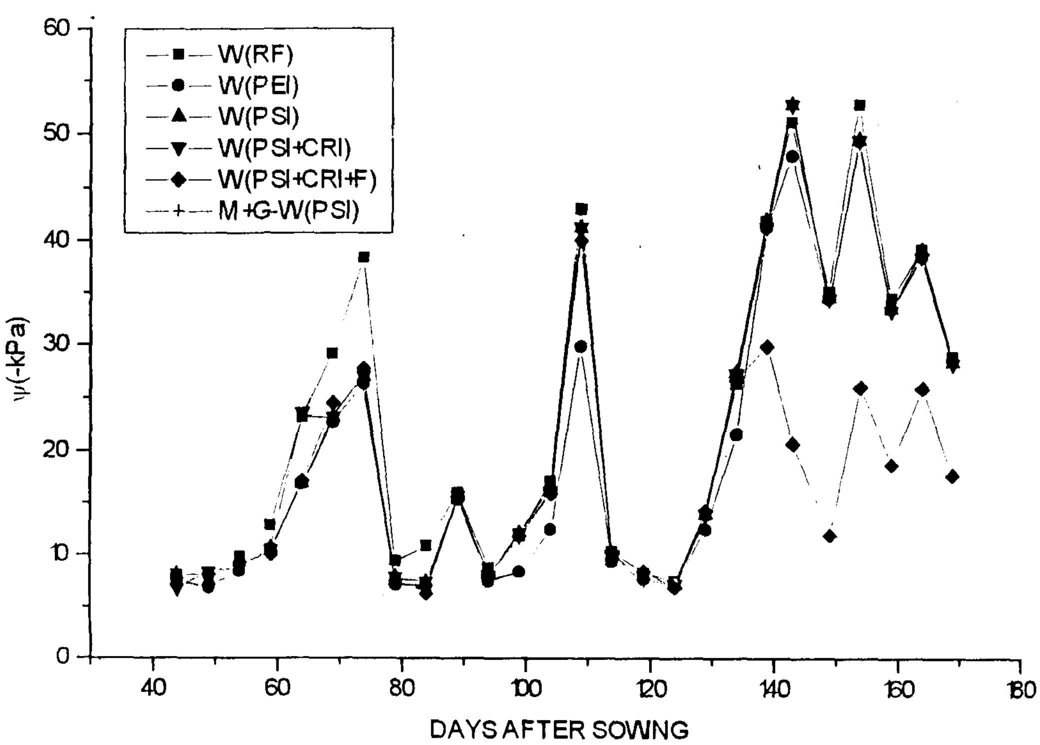


Fig. 14. Matric potential at 0.30 m depth under different treatments during growth of wheat (1995-96)

During 1996-97 the values of 'ψ' were lower in W (RF) treatment than all other treatments (Fig. 15 and 16). These further, decreased on 59 DAS at both the depths. On 64 and 69 DAS, 'ψ' increased due to rains under all the treatments. It decreased on 94 DAS in all the treatments and increased on 99 DAS. The values of 'ψ' on 104 DAS were -28.8, -26.2, -26.3, -24.7, -25.2 and -16.1 kPa for 0.15 m depth and -21.3, -18.9, -19.0, -17.7, -18.2 and -10.4 kPa for 0.30 m depth in W (RF), W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments, respectively. On 122 DAS, 'ψ' was highest in M+G-W (PSI) and lowest in W (RF) treatment. The values of 'ψ' for 0.15 m depth were -19.0 and -11.3 kPa and for 0.30 m depth were -15.0 and -8.5 kPa under W (RF) and M+G-W (PSI) treatments, respectively. The 'ψ' values for other treatments were almost similar. On 157 DAS 20 mm irrigation applied to W (PSI+CRI+F) treatment increased the 'ψ' of this treatment. The 'ψ' in W (RF) treatment was lowest and almost similar in remaining treatments. At harvest (178 DAS), the values of 'ψ' for W (RF), W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments were -19.6, -18.6, -19.0, -19.5, -19.4 and -18.4 kPa for 0.15 m depth and -13.9 -13.1, -13.5, -14.0, -13.9 and -13.0 kPa for 0.30 m depth, respectively.

4.5.3 Hydraulic gradients

The hydraulic gradients between 0.15 and 0.30 m depth from 44 to 169 DAS during 1995-96 and from 44 to 178 DAS during 1996-97 for wheat are depicted in Fig 17 and Fig 18, respectively. The hydraulic gradients during 1995-96 were upward on 44 DAS (Fig 17) . Their values on 44 DAS for W (RF), W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments were - 2.9, -2.8, -2.9, -2.1, -2.0 and -2.7 m/m, respectively. These values became downward on 49 DAS and again became upward with the advancement of period from 59 DAS to 74 DAS. On 89 and 94 DAS, these were downward in all the treatments due to rains. From 99 to 119 DAS, these were again

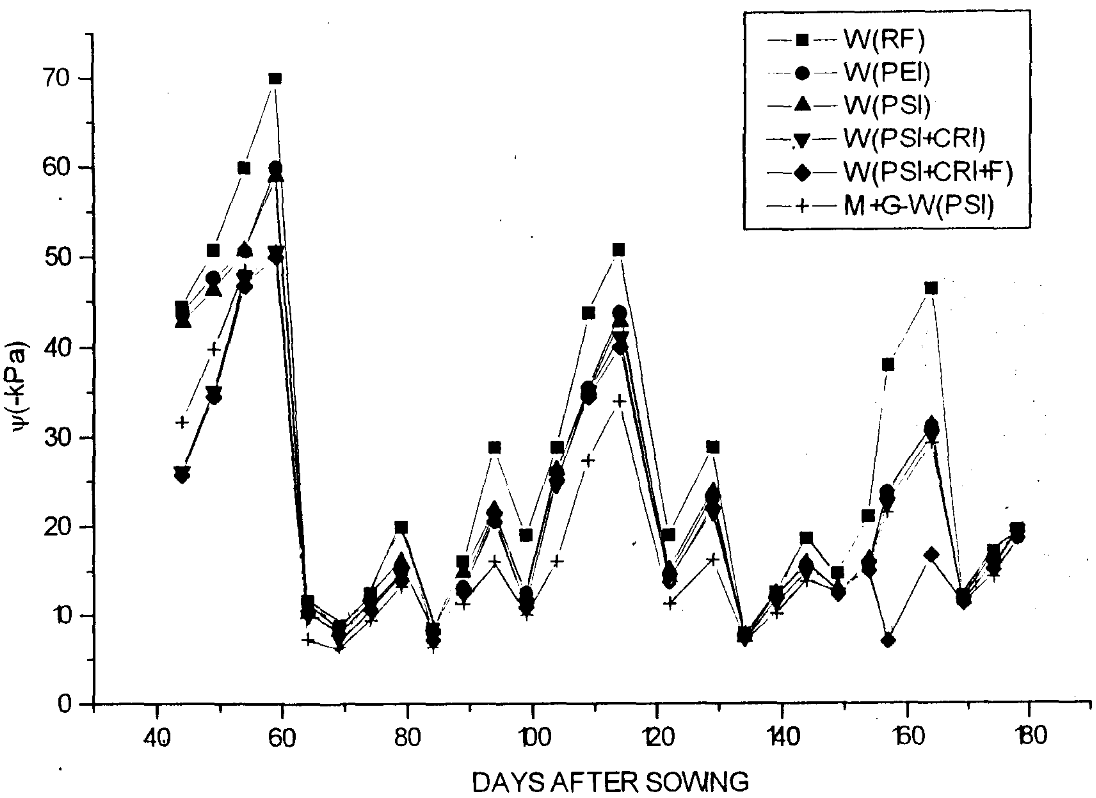


Fig. 15. Matric potential at 0.15 m depth under different treatments during growth of wheat (1996-97)

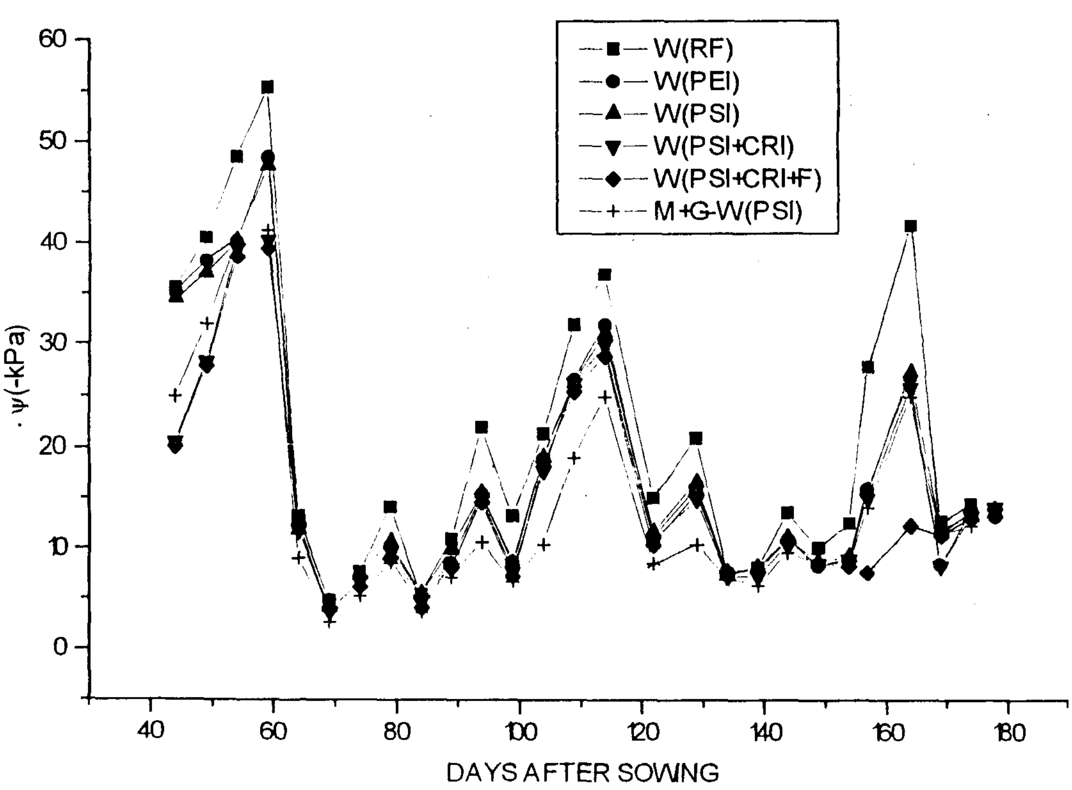


Fig. 16. Matric potential at 0.30 m depth under different treatments during growth of wheat (1996-97)

upward. The values for W (RF), W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) on 119 DAS were -1.3, -1.2, -1.3, -1.3, -1.4 and -1.2 m/m, respectively. These were downward on 124 DAS. The value further, decreased on 139 DAS. Due to 20 mm irrigation to W (PSI+CRI+F) treatment, these become downward under this treatment and remained upward for the remaining treatment on 143 DAS. Their values for W (RF), W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments were -4.5, -4.2, -4.3, -4.3, 0.3 and -4.2 m/m, respectively, on 149 DAS.

During 1996-97, the hydraulic gradients on 44 DAS were upward and their values were higher under W (PSI+CRI) and W (PSI+CRI+F) treatments than all other treatments (Fig. 18). These values were -4.8, -4.6, -4.5, -2.8, -2.8 and -3.5 m/m for W (RF), W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments, respectively. The values further, decreased on 49, 54 and 59 DAS. Due to rains, these were downward on 64 DAS under all the treatments. From 69 to 129 DAS, these remained upward. The values on 134 DAS for the same treatments were 0.8, 0.9, 0.9, 0.9, 1.0 and 1.0 m/m, respectively. These were upward upto 154 DAS. On 157 DAS, due to 20mm irrigation to W (PSI+CRI+F) treatment, the hydraulic gradients became downward under this treatment but upward under other treatments. These remained downward on 169 DAS and upward at harvest (178 DAS) under all the treatments.

4.5.4 Seedling emergence parameters of wheat.

The seedling emergence parameters viz. seedling emergence count/m^2, days taken for initiation of emergence and for attaining constant emergence during wheat 1995-96 and 1996-97 are presented in Fig. 19 and 20, and in Table 4.4.

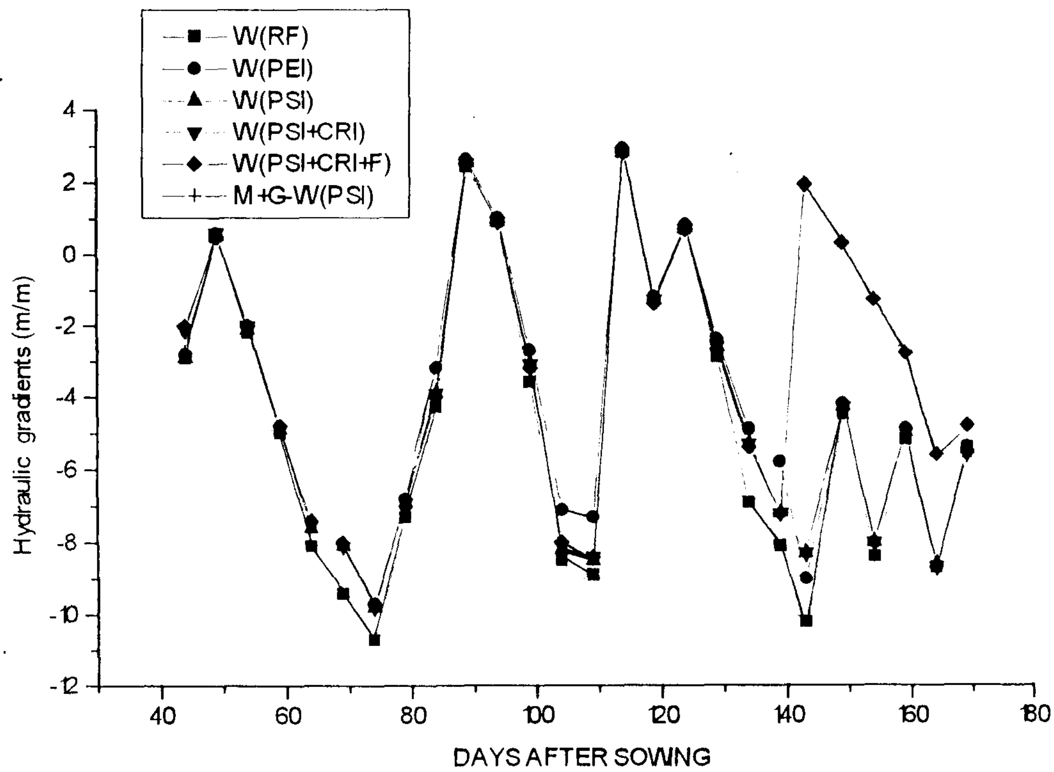


Fig. 17. Hydraulic gradients between 0.15 and 0.30 m depth during growth of wheat (1995-96)

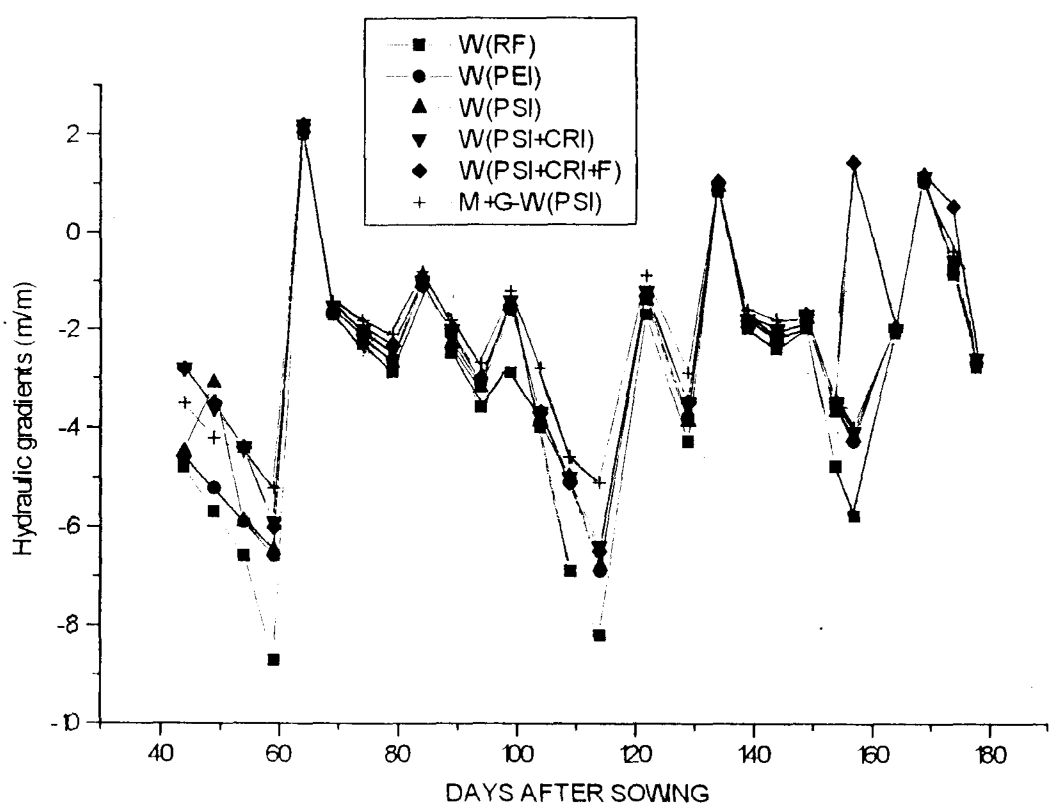


Fig. 18. Hydraulic gradients between 0.15 and 0.30 m depth during growth of wheat (1996-97)

4.5.4.1 Seedling emergence count

Fig. 19 indicates that during 1995-96, the emergence count per m^2 was higher under all PSI related treatments than W (RF) and W (PEI) treatments on 5 DAS. On 10 DAS the emergence count was significantly higher under W (PEI) treatment than all other treatments. The values on 10 DAS were 104.7, 165.2, 145.6, 150.2, 144.7 and 152.4 per m^2 for W (RF), W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments, respectively. On 40 DAS, it was significantly higher under W (PEI) and significantly lower under W (RF) treatments than under all other treatments.

During 1996-97 due to non receipt of rain after sowing, no emergence initiated under W (RF) treatment even at 20 DAS (Fig. 20). The emergence count was higher under all PSI related treatments than W (PEI) treatment on 20 DAS. It's values on 40 DAS were 81.0, 191.1, 197.0, 200.2, 199.3 and 219.8 for W (RF), W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments, respectively, On 80 DAS it was significantly higher under M+G-W (PSI) and significantly lower under W (RF) treatments than W (PEI) and other PSI related treatments.

4.5.4.2 Initiation of emergence

During 1995-96, a light rainfall of 6.8 mm 2 DAS initiated germination under all the treatments, however, all PSI related treatments took significantly less time for initiation of emergence than W (RF) and W (PEI) treatments. The seedling emergence occurred on 7.3, 7.0, 5.8, 5.5, 5.5 and 5.5 DAS under W (RF), W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments, respectively (Table 4.4).

During 1996-97, the initiation of emergence was earlier under all PSI related treatments than W (RF) and W (PEI) treatments. The seedling emergence occurred on 26.8, 13.8, 6.3, 6.8, 6.5 and 6.0 DAS under W (RF), W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments, respectively.

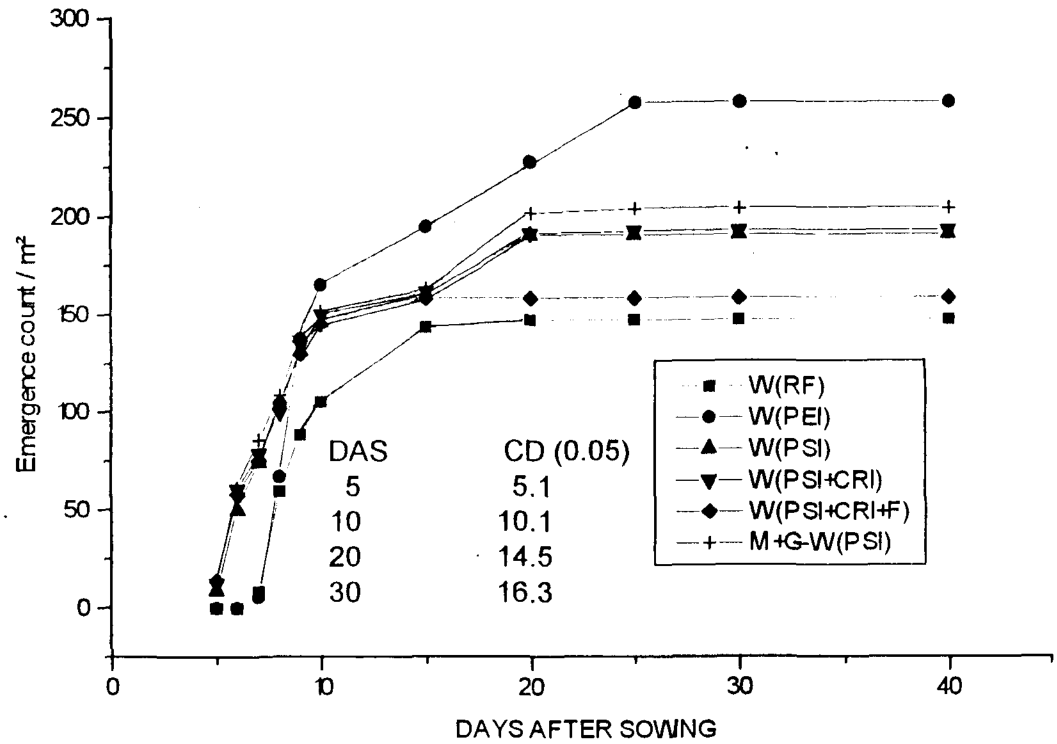


Fig. 19. Seedlings emergence count / m² of wheat under different treatments (1995-96)

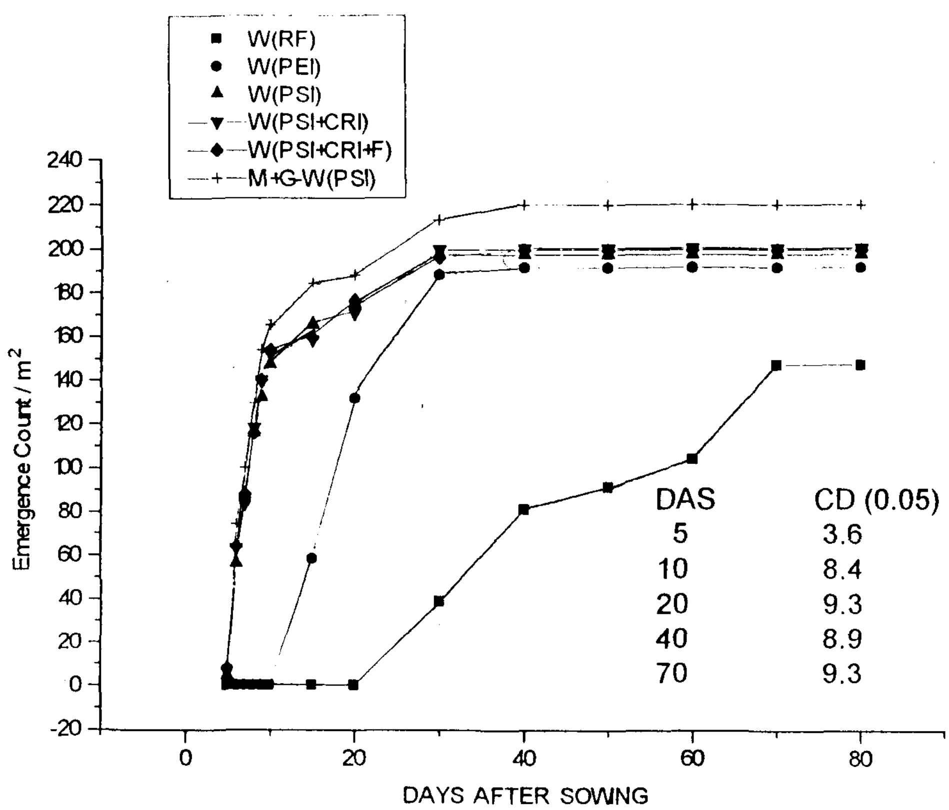


Fig. 20. Seedling emergence count / m² of wheat under different treatments (1996-97)

4.5.4.3 Constant emergence

During 1995-96, time taken for constant emergence was significantly lower under W (RF) treatment than all other treatments. W (PEI) treatment took significantly higher duration for constant emergence than all the treatments. Days taken for constant emergence under W (RF), W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments were 15.3, 24.8, 19.3, 20.8, 19.8 and 20.5, respectively.

Table 4.4 Effect of different treatments on seedling emergence parameters of wheat

Treatment	Initiation of emergence (day)		Constant emergence (day)	
	1995-96	1996-97	1995-96	1996-97
M-W (RF)	7.3	26.8	15.3	67.5
M-W (PEI)	7.0	13.8	24.8	39.8
M-W (PSI)	5.8	6.3	19.3	29.0
M-W (PSI+CRI)	5.5	6.8	20.5	30.3
M-W (PSI+CRI+F)	5.5	6.5	19.8	30.8
M+G-W (PSI)	5.3	6.0	20.5	32.5
CD(0.05)	0.8	4.9	3.2	7.2

During 1996-97, the time taken by W (PEI) treatment for constant emergence was significantly lower than W (RF) treatment but significantly higher than all PSI related treatments. All PSI related treatments were statistically at par with each other. The time taken for constant emergence by W (RF), W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments was 67.5, 39.8, 29.0, 30.3, 30.8 and 32.5 days, respectively.

4.6 Evaluation of xylem water potential

The xylem water potential (XWP) values of wheat during 1995-96 and 1996-97 on selected days at 0800, 1200 and 1800 hours are shown in Table 4.5. XWP under all the treatments was highest in morning hours and lowest in noon hours during both the years.

During 1995-96 the XWP of all the PSI related treatments was significantly higher than W (RF) treatment but significantly lower than W (PEI) treatments at 0800, 1200 and 1800 hours on 104 DAS. It's values on 104 DAS at 0800, 1200 and 1800 hours were -0.49, -1.18 and -0.73 MPa, for W (RF), -031, -086 and -057 MPa for W (PEI) and -039, -1.03 and -0.64 MPa for W (PSI+CRI) treatments, respectively. Due to 20 mm irrigation to W (PSI+CRI+F) treatment on 143 DAS, its XWP was found to be significantly higher than all the treatments on 144 DAS. The XWP values for W (PSI) and W (PSI+CRI) treatments were significantly higher than W (RF) but significantly lower than W (PEI) treatments.

During 1996-97 on 122 DAS, XWP was significantly higher under M+G-W (PSI) treatment than all other treatments at 0800, 1200 and 1800 hours. The XWP for the remaining PSI related treatments and W (PEI) treatment were statistically at par. However, under W (RF), XWP was significantly lower than all the treatments. The values for W (RF), W (PEI) and M+G-W (PSI) treatments at 0800 hours were -1.04, -0.64 and -0.52 MPa; -1.43, -1.10 and -0.82 MPa at 1200 hours and -1.23, -0.88 and -0.62 MPa at 1800 hours, respectively. On 158 DAS, XWP was significantly higher under W (PSI+CRI+F) treatment because it received 20 mm of irrigation on 157 DAS. XWP under (W (RF) treatment was significantly lower than all the treatments. W (PEI) and remaining PSI related treatments were statistically at par with each other.

Table 4.5 Effect of different treatments on xylem water potential (XWP) of wheat (-MPa) at different growth stages

Treatment	0800 (h)	1200 (h)	1800 (h)	0800 (h)	1200 (h)	1800 (h)
1995-96	------------*104 DAS*--------------			-------------*144 DAS*----------		
M-W (RF)	0.49	1.18	0.73	0.73	1.44	1.24
M-W (PEI)	0.31	0.86	0.57	0.51	1.11	0.82
M-W (PSI)	0.40	1.04	0.66	0.65	1.32	1.14
M-W (PSI+CRI)	0.39	1.03	0.64	0.62	1.34	1.16
M-W (PSI+CRI+F)	0.40	1.02	0.65	0.39	0.61	0.75
M+G-W (PSI)	0.38	0.98	0.63	0.62	1.26	1.10
CD (0.05)	0.06	0.10	0.05	0.06	0.08	0.07
1996-97	---------122 DAS-----------			--------------158 DAS----------		
M-W (RF)	1.04	1.43	1.23	0.97	1.44	1.24
M-W (PEI)	0.64	1.10	0.88	0.64	1.13	1.07
M-W (PSI)	0.67	1.04	0.82	0.70	1.11	1.06
M-W (PSI+CRI)	0.62	0.94	0.76	0.68	1.03	0.97
M-W (PSI+CRI+F)	0.61	0.99	0.81	0.49	0.76	0.61
M+G-W (PSI)	0.52	0.82	0.62	0.63	1.11	0.97
CD (0.05)	0.08	0.11	0.13	0.07	0.12	0.10

4.7 Root studies in wheat

The influence of different irrigation treatments on root growth parameters of wheat viz. root mass density (RMD) and root volume (RV) recorded after flowering stage for 0 - 0.075, 0.075 - 0.15 and 0.15 - 0.30m depths during 1995-96 and 1996-97 is shown in Table 4.6 and 4.7, respectively.

4.7.1 Root mass density

The effect of different irrigation treatments on RMD of wheat is presented in Table 4.6. A perusal of data indicated that during 1995-96, the RMD values for W (PSI), W (PSI+CRI) and M+G-W (PSI) treatments on 157 DAS were significantly higher than W (RF) but significantly lower than W (PEI) and W (PSI+CRI+F) treatments at all the depths. W (PEI) was statistically at par with W (PSI+CRI+F) treatment. The values of RMD for W (RF), W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments were 2.18, 3.45, 2.63, 2.88, 3.57 and 2.89 kg/m³ for 0-0.075 m depth; 0.40, 0.98, 0.61, 0.64, 1.02 and 0.75 kg/m³ for 0.075-0.15m depth and 0.10, 0.41, 0.22, 0.24, 0.43 and 0.30 kg/m³ for 0.15-0.30m depth, respectively.

Table 4.6 Effect of different treatments on root mass density (RMD) of wheat (kg/m³)

Treatment	1995-96			1996-97		
	157 DAS			168 DAS		
	0-0.075 (m)	0.075-0.15 (m)	0.15-0.30 (m)	0-0.075 (m)	0.075-0.15 (m)	0.15-0.30 (m)
M-W (RF)	2.18	0.40	0.10	1.16	0.73	0.22
M-W (PEI)	3.45	0.98	0.41	1.61	0.97	0.39
M-W (PSI)	2.63	0.61	0.22	1.58	0.94	0.34
M-W (PSI+CRI)	2.88	0.64	0.24	1.97	1.22	0.53
M-W (PSI+CRI+F)	3.57	1.02	0.43	2.18	1.42	0.58
M+G-W (PSI)	2.89	0.75	0.30	2.01	1.40	0.56
CD (0.05)	0.41	0.18	0.10	0.34	0.17	0.12

During 1996-97, the RMD on 168 DAS under W (PEI) and W (PSI) treatments was significantly higher than W (RF) treatments but significantly lower than the remaining treatments at all the depths. The values of RMD for W (RF), W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments were 1.16, 1.61, 1.58, 1.97, 2.18 and 2.01 kg/m^3 for 0-0.075m depth, 0.73, 0.97, 0.94, 1.22, 1.42 and 1.40 kg/m^3 for 0.075-0.15m and 0.22, 0.39, 0.34, 0.53, 0.58 and 0.56 kg/m^3 for 0.15-0.30m depth, respectively.

4.7.2 Root volume

The influence of different treatments on root volume (RV) of wheat during 1995-96 and 1996-97 recorded after flowering stage for 0-0.075; 0.075 -0.15 and 0.15-0.30m depths is shown in Table 4.7.

During 1995-96 on 157 DAS the RV of W (PSI), W (PSI+CRI) and M+G-W (PSI) treatments was significantly higher than W (RF) treatment but significantly lower than W (PEI) and W (PSI+CRI+F) treatments at all the depths. The RV of W (PEI) treatment was statistically at par with W (PSI+CRI+F) treatment. These values for W (RF), W ((PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments were 1.14, 1.54, 1.36, 1.38, 1.56 and 1.41 m^3/100m^3 for 0-0.075m depth, 0.43, 0.66, 0.52, 0.54, 0.70 and 0.56 m^3/100m^3 for 0.075-0.15m depth and 0.22, 0.38, 0.27, 0.29, 0.41 and 0.30 m^3/ 100m^3 for 0.15-0.30m depth, respectively.

During 1996-97, the RV of W (PEI) and W (PSI) treatments on 168 DAS was significantly higher than W (RF) treatment but significantly lower than W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments at all the depths. The values for W (RF), W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments for 0-0.075m depth were 1.07, 1.23, 1.21, 1.35, 1.40 and 1.42 m^3/100m^3; 0.25, 0.38, 0.35, 0.49, 0.54 and 0.52 m^3/ 100m^3 for 0.075 - 0.15 m depth and 0.12, 0.17, 0.16, 0.21, 0.24 and 0.22 m^3/ 100m^3 for 0.15 - 0.30 m depth, respectively.

Table 4.7 Effect of different treatments on root volume (RV) of wheat ($m^3/100m^3$)

Treatment	1995-96			1996-97		
	157 DAS			168 DAS		
	0-0.075 (m)	0.075-0.15 (m)	0.15-0.30 (m)	0-0.075 (m)	0.075-0.15 (m)	0.15-0.30 (m)
M-W (RF)	1.14	0.43	0.22	1.07	0.25	0.12
M-W (PEI)	1.54	0.66	0.38	1.23	0.38	0.17
M-W (PSI)	1.36	0.52	0.27	1.21	0.35	0.16
M-W (PSI+CRI)	1.38	0.54	0.29	1.35	0.49	0.21
M-W (PSI+CRI+F)	1.56	0.70	0.41	1.40	0.54	0.24
M+G-W (PSI)	1.41	0.56	0.30	1.42	0.52	0.22
CD (0.05)	0.11	0.07	0.04	0.10	0.08	0.03

4.8. Water use in crops

The water use under different treatments of wheat and under radish, onion and frenchbean during 1995-96 and 1996-97 is presented in Table 4.8.

During 1995-96 and 1996-97 maximum water use under wheat related treatments was observed under W (PSI+CRI+F) treatment followed by W (PSI+CRI), M+G-W (PSI), W (PSI), W (PEI) and W (RF) treatments, respectively.

The water use under radish, onion and frenchbean was 159, 378, 334.8 mm/ha grown in the M-R-O-FB sequence during 1995-96 and 224.3, 371.4 and 380.5 mm/ha during 1996-97, respectively.

Table 4.8 Water use (mm/ha) under different crops

Crop	Treatment	1995-96	1996-97
Wheat	M-W (RF)	194.4	235.5
Wheat	M-W (PEI)	204.4	248.0
Wheat	M-W (PSI)	229.9	265.9
Wheat	M-W (PSI+CRI)	241.1	275.9
Wheat	M-W (PSI+CRI+F)	245.5	298.0
Wheat	M+G-W (PSI)	233.4	274.6
Radish	-	159.0	224.3
Onion	-	378.0	371.4
Frenchbean	-	334.8	380.5

4.9 Crop Yields

The grain and straw yields of wheat, rhizome yields of ginger, root yields of radish, green onion yields and green pod yields of frenchbean are presented in Table 4.9 and 4.10.

In maize-wheat and maize-vegetables sequence the average yields of maize grain and straw were 4.58 and 12.76 t/ha during 1995 and 5.36 and 16.93 t/ha during 1996, respectively. The grain and straw yields were however, significantly higher where maize was grown alongwith ginger during both the years (data not given in the table). The average yields of maize grain and straw in this intercrop were 5.82 and 18.3 t/ha during 1995 and 6.4 and 19.5 t/ha during 1996, respectively.

4.9.1 Grain and straw yields of wheat

The influence of different irrigation treatments on the grain and straw yields of wheat during 1995-96 and 1996-97 is presented in Table 4.9.

The data indicate that during 1995-96, the grain and straw yields of W (PSI), W (PSI+CRI) and M+G-W (PSI) treatments were significantly higher than W (RF) treatment and significantly lower than W (PSI+CRI+F) and W (PEI) treatments. The grain yields were 2.60, 3.62, 3.00, 3.05, 3.70 and 3.08 t/ha and straw yields were 3.01, 5.16, 4.50, 4.64, 5.69 and 4.40 t/ha, respectively for W (RF), W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments. The empirical equation for Y= a+bx for grain yield was found to be 2.29+0.24x (r=0.66) for wheat 1995-96.

During 1996-97, the grain and straw yields of W (PSI) and W (PEI) treatments were significantly higher than W (RF) treatment but significantly lower than W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI), treatments. The later three treatments showed nonsignificant differences among themselves. For W (RF), W (PEI), W (PSI), W (PSI+CRI), W (PSI+CRI+F) and M+G-W (PSI) treatments, the grain yields were 1.40, 2.23, 2.21, 2.65, 2.73 and 2.75 t/ha and straw yields were 2.73, 4.08, 4.25, 5.71, 5.77 and 5.73 t/ha, respectively. The empirical equation for Y= a+bx for grain yield of wheat was 2.01+0.25x (r=0.55) during 1996-97.

4.9.2 Yield of vegetable crops

The data regarding rhizome yields of ginger, root yields of radish green onion yields and green pod yields of frenchbean are presented in Table 4.10.

4.9.2.1 Ginger yield

The rhizome yields of ginger were 1.46 and 4.69 t/ha during 1995 and 1996, respectively.

Table 4.9 Effect of different treatments on grain and straw yields of wheat (t/ha)

Treatment	1995-96		1996-97	
	Grain	Straw	Grain	Straw
M-W (RF)	2.60	3.01	1.40	2.73
M-W (PEI)	3.62	5.16	2.23	4.08
M-W (PSI)	3.00	4.50	2.21	4.25
M-W (PSI+CRI)	3.05	4.64	2.65	5.71
M-W (PSI+CRI+F)	3.70	5.69	2.73	5.77
M+G-W (PSI)	3.08	4.40	2.75	5.73
CD(0.05)	0.30	0.31	0.39	1.13

Table 4.10 Yield of vegetable crops (t/ha)

Crop	1995-96	1996-97
Ginger	1.46	4.69
Radish	14.17	21.46
Onion	20.60	33.96
Frenchbean	10.63	12.29

4.9.2.2 Radish yield

The root yields of radish were 14.17 and 21.46 t/ha during 1995 and 1996, respectively.

4.9.2.3 Onion yield

The green onion yields were 20.60 and 33.96 t/ha during 1995-96 and 1996-97, respectively.

4.9.2.4 Frenchbean yield

The green pod yields of frenchbean were 10.63 and 12.29 t/ha during 1996 and 1997, respectively.

4.10 Water use efficiency

The water use efficiency (WUE) for wheat under various irrigation treatments and radish, onion and frenchbean are presented in Table 4.11.

4.10.1 Water use efficiency under wheat

Data in Table 4.11a reveal that WUE of wheat was higher during 1995-96 than 1996-97. During 1995-96, it was highest under W (PEI) treatment (17.7 kg/ha/mm) followed by W (PSI+CRI+F) treatment (15.1 kg/ha/mm). WUE was lowest under W (RF) treatment (7.5 kg/ha/mm). WUE values for W (PSI), W (PSI+CRI) and M+G-W (PSI) treatments were 13.0, 12.7 and 13.2 kg/ha/mm, respectively.

During 1996-97, WUE was highest under M+G-W (PSI) treatment (10.0 kg/ha/mm) followed by W (PSI+CRI) treatment (9.6 kg/ha/mm) and lowest under W (RF) treatment (5.9 kg/ha/mm). WUE values for W (PEI), W (PSI) and W (PSI+CRI+F) treatments were 9.0, 8.3 and 9.2 kg/ha/mm, respectively.

4.10.2 Water use efficiency under vegetables

The WUE under radish, onion and frenchbean is given in Table 4.11b. The values were higher under all vegetable crops than wheat. WUE was higher during the second year of cropping than the first year. WUE values for radish, onion and frenchbean were 89.1, 54.5 and 31.8 kg/ha/mm during 1995-96 and 95.7, 91.4 and 32.3 kg/ha/mm during 1996-97, respectively.

Table 4.11 Effect of different treatments on water use efficiency (kg/ha/mm) of wheat and vegetable crops

(a) Wheat

Treatment	1995-96	1996-97
M-W (RF)	7.5	5.9
M-W (PEI)	17.7	9.0
M-W (PSI)	13.0	8.3
M-W (PSI+CRI)	12.7	9.6
M-W (PSI+CRI+F)	15.1	9.2
M+G-W (PSI)	13.2	10.0

(b) Vegetable crops

Crop	1995-96	1996-97
Radish	89.1	95.7
Onion	54.5	91.4
Frenchbean	31.8	32.3

4.11 Economic studies

The data on gross expenditure, gross returns and net profit (average of 1995-96 and 1996-97 cropping sequence) are presented in Table 4.12. The highest expenditure was observed for M+G-W (PSI) treatment (Rs. one lakh nine thousand four hundred fifty seven per hectare) followed by M-R-O-FB treatment. The minimum expenditure occurred on M-W (RF) treatment costing Rs. Twenty four thousand one hundred nine. Among remaining maize-wheat sequence, highest money was expended on M-W (PSI+CRI+F) treatment. The highest gross returns and highest net profit was recorded for M-R-O-FB treatment whose values were Rs. Three lakh seventeen thousand eight hundred and five for gross expenditure and Rs. Two lakh twelve thousand two hundred and sixty six per hectare for net profit. Among other maize-wheat sequences M-W (RF) treatment gave minimum gross and net returns whereas, M-W (PSI+CRI+F) treatment gave highest gross and net returns (Table 4.12).

Table 4.12 Gross expenditure, gross returns and net profit (Rs./ha/year) under different treatments (average of two years)

Treatment	Gross expenditure	Gross returns	Net profit
M-W (RF)	24,109	43,754	19,645
M-W (PEI)	24,408	51,754	27,346
M-W (PSI)	24,368	49,491	25,123
M-W (PSI+CRI)	24,592	52,065	27,484
M-W (PSI+CRI+F)	24,810	55,048	30,238
M+G-W (PSI)	1,09,457	1,21,556	12,099
M-R-O-FB	1,05,539	3,17,805	2,12,266

4.12 Post harvest studies at the end of experimentation

4.12.1 Bulk density

The effect of different treatments on bulk density of soil at the end of experimentation for 0-0.075, 0.075-0.15 and 0.15-0.30 m depths is given in Table 4.13. The bulk density reduced from the initial value under M+G-W (PSI) and M-R-O-FB treatments, but remained unaffected under the remaining treatments from its initial value at all the depths. Among different treatments the bulk density under M-W (RF) treatment was statistically at par with M-W (PEI), M-W (PSI), M-W (PSI+CRI) and M-W (PSI+CRI+F) treatments at all the depths. M+G-W (PSI) was statistically at par with M-R-O-FB treatment at all the depths. These two treatments showed significantly lower bulk density than all other treatments at all depths. The bulk density values for M-W (RF), M-W (PEI), M-W (PSI+CRI+F), M+G-W (PSI) and M-R-O-FB treatments were 1.19, 1.16, 1.16, 1.11 and 1.10 Mg/m^3 for 0-0.075m depth, 1.22, 1.20, 1.20, 1.14 and 1.12 Mg/m^3 for 0.075-0.15m depth and 1.23, 1.24, 1.24, 1.19 and 1.17 Mg/m^3 for 0.15-0.30m depth, respectively.

4.12.2 Mean-weight diameter

The effect of different treatments on mean-weight diameter (MWD) of soil (0-0.15m) is given in Table 4.13. MWD increased from its initial value under M+G-W (PSI) and M-R-O-FB treatments whereas, it remained unaffected under remaining treatments. Among different treatments the MWD of M-R-O-FB treatment was statistically at par with M+G-W (PSI) treatment and significantly higher than remaining treatments. The remaining treatments were statistically at par with each other. The values of MWD for different treatments were 2.238, 2.255, 2.295, 2.246, 2.284, 2.732 and 2.753 mm under M-W (RF), M-W (PEI), M-W (PSI), M-W (PSI+CRI), M-W (PSI+CRI+F), M+G-W (PSI) and M-R-O-FB treatments, respectively (Table 4.13).

Table 4.13 Bulk density (Mg/m³) and mean weight diameter (mm) of soil under different treatments at the end of experimentation

Treatment	Bulk density			Mean weight diameter
	0-0.075m	0.075-0.15m	0.15-0.30m	(0-0.15m)
M-W (RF)	1.19	1.22	1.23	2.238
M-W (PEI)	1.16	1.20	1.24	2.255
M-W (PSI)	1.18	1.21	1.23	2.295
M-W (PSI+CRI)	1.17	1.22	1.21	2.246
M-W (PSI+CRI+F)	1.16	1.20	1.24	2.284
M+G-W (PSI)	1.11	1.14	1.19	2.732
M-R-O-FB	1.10	1.12	1.17	2.753
CD (0.05)	0.04	0.05	0.03	0.110

4.12.3 Soil moisture retention characteristics

The effect of various treatments on soil moisture retention characteristics for 0-0.15m depth is given in Fig. 21. With respect to the initial value of 'θ' at different corresponding suctions (ψ), only M+G-W (PSI) and M-R-O-FB treatments exhibited higher 'θ' at all the 'ψ' values except at saturation (0 kPa suction). At saturation 'θ' values were 62.4, 64.0, 60.9, 61.9, 65.4, 64.3 and 65.4 m³/100m³ for M-W (RF), M-W (PEI), M-W (PSI), M-W (PSI+CRI), M-W (PSI+CRI+F), M+G-W (PSI) and M-R-O-FB treatments, respectively. At 33 kPa suction 'θ' values for the same treatments were 27.3, 28.7, 30.8, 29.8, 30.6, 32.3 and 32.4 m³/100m³ and at 1500 kPa suction, these were 13.2, 13.4, 13.3, 13.6, 13.9, 14.1 and 14.4 m³/100m³, respectively.

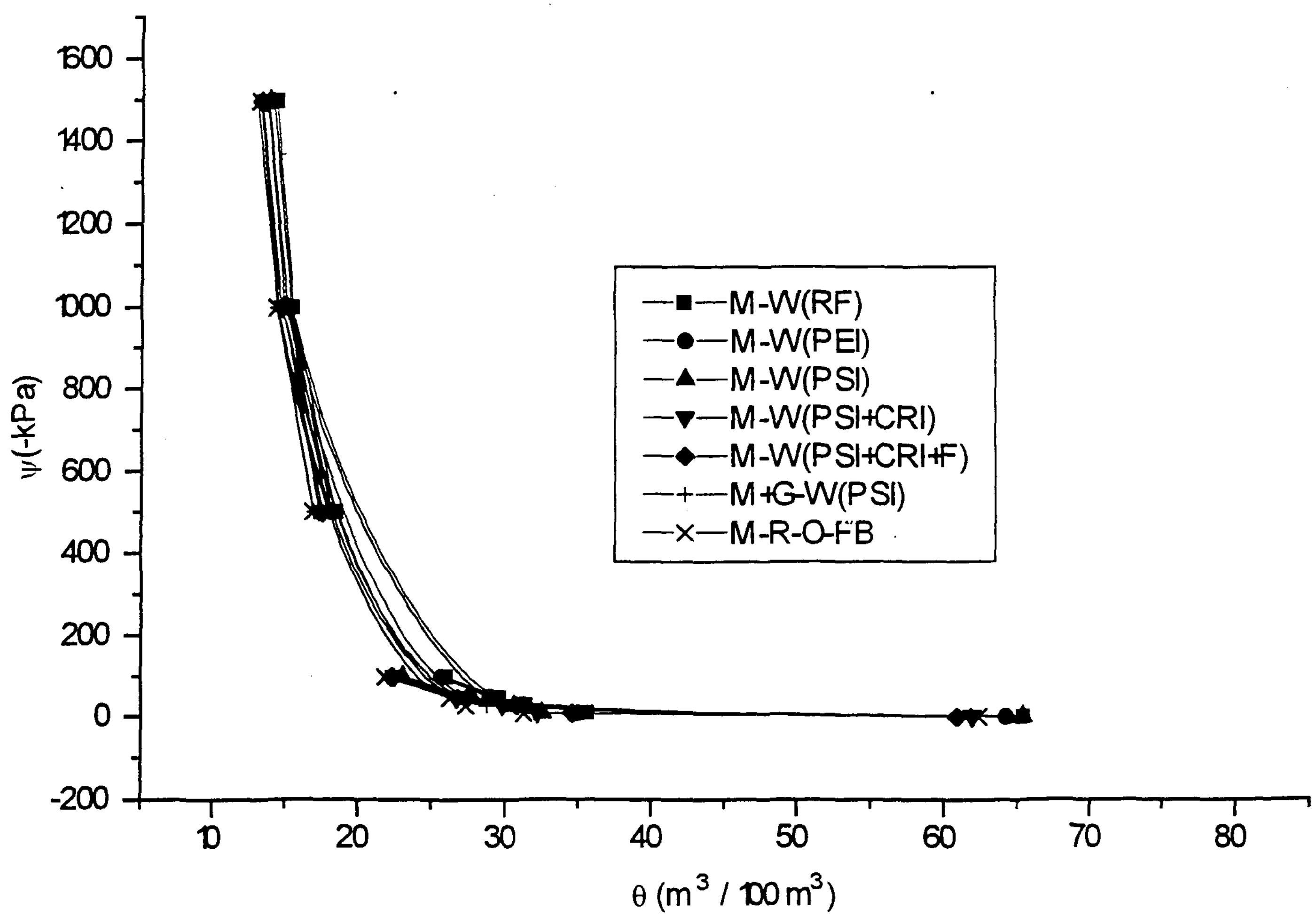


Fig. 21. Soil moisture retention characteristics (0-0.15m) under different treatments at the end of experimentation

4.12.4 Infiltration

The effect of different treatments on infiltration rate (i) and accumulated infiltration (I) is depicted in Fig. 22 and empirical relationships are presented in Table 4.14. The final infiltration rate and accumulated infilteration were higher under M+G-W (PSI) and M-R-O-FB treatments, but almost similar under the remaining treatments with respect to the initial 'i'. At the end of the experimentation, the values of 'i' (mm/h) and 'I' (mm) were higher under M+G-W (PSI) and M-R-O-FB treatments than all other treatments. After one hour values of 'i' under M-W (RF), M-W (PEI), M-W (PSI), M-W (PSI+CRI), M-W (PSI+CRI+F), M+G-W (PSI) and M-R-O-FB treatments were 65, 64, 73, 65, 85 and 100 mm/h, respectively and corresponding values of 'I' were 127, 132, 151, 153, 136, 185 and 200 mm, respectively. After 3 hours the corresponding values of 'i' were 30, 35, 29, 34, 37, 38 and 42 mm/h and that of 'I' were 201, 215, 221, 235, 221, 277 and 307 mm, respectively. Finally after seven hours, 'i' values were 18, 20, 22, 22, 23, 30 and 35 mm/h and 'I' values were 283, 306, 312, 330, 329, 404 and 448 mm, respectively.

Table 4.14 Empirical equations of infiltration under different treatments at the end of experimentation

Treatment	$I = a\,t^b$	'r' value
M-W (RF)	$I = 2.08\ t^{0.47}$	0.997
M-W (PEI)	$I = 2.09\ t^{0.49}$	0.998
M-W (PSI)	$I = 2.13\ t^{0.45}$	0.991
M-W (PSI+CRI)	$I = 2.14\ t^{0.48}$	0.992
M-W (PSI+CRI+F)	$I = 2.12\ t^{0.48}$	0.998
M+G-W (PSI)	$I = 2.21\ t^{0.50}$	0.992
M-R-O-FB	$I = 2.24\ t^{0.52}$	0.992

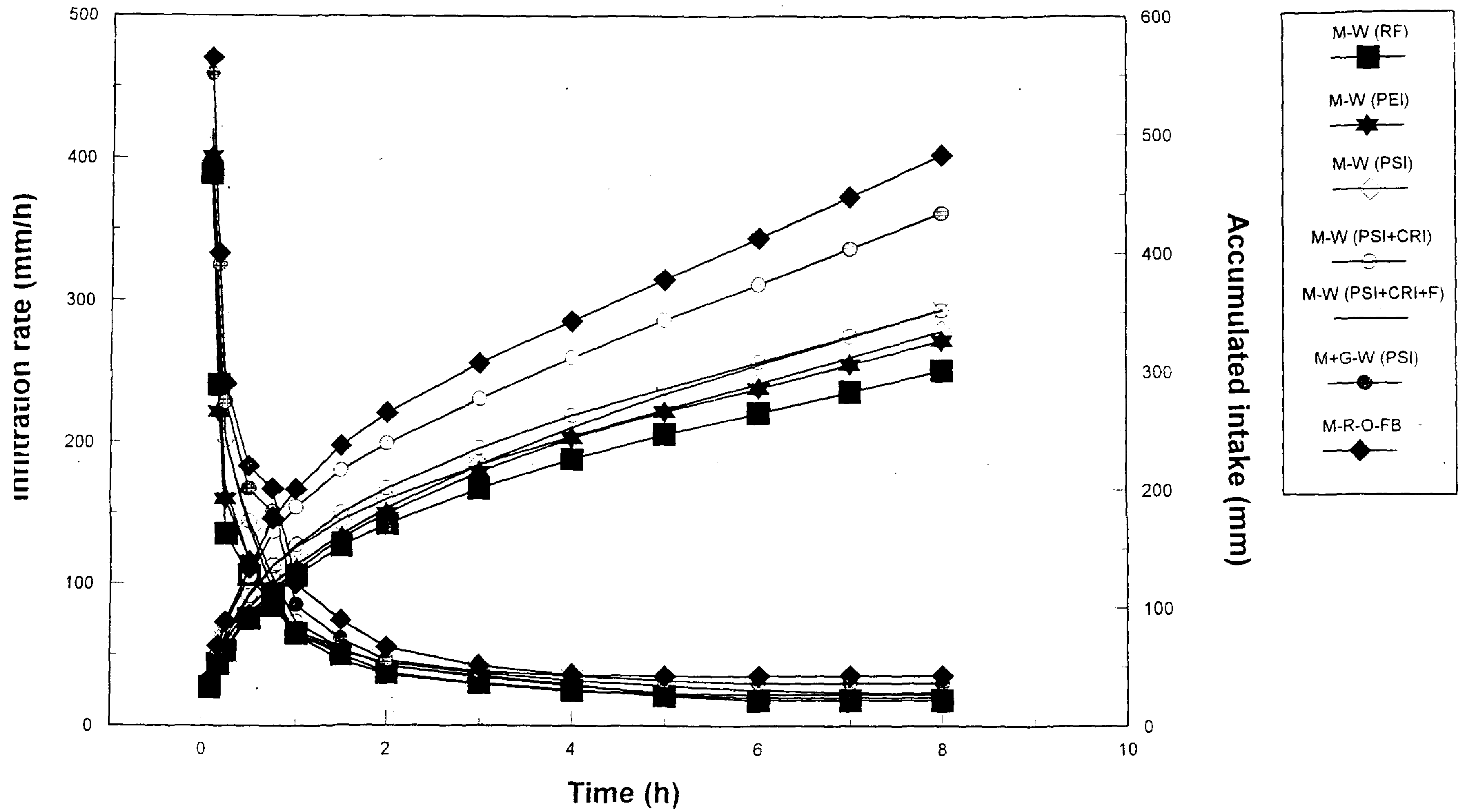


Fig. 22. Infiltration studies of soil under different treatments at the end of experimentation.

The 'a' value of equation $I = at^b$ was higher under M+G-W (PSI) (2.21) and M-R-O-FB (2.24) treatments than other treatments under maize-wheat sequence (Table 4.14).

4.12.5 Soil organic carbon

The effect of various treatment on per cent organic carbon content (OC) of soil for 0-0.075, 0.075-0.15 and 0.15-0.30 m depth is given in Table. 4.15. From the initial value OC content increased under M+G-W (PSI) and M-R-O-FB treatments, but remained almost similar under the remaining treatments at all the depths. Among various treatments OC content was significantly higher under M+G-W (PSI) and M-R-O-FB treatments than the remaining treatments which were statistically at par with each other at all the depths. The values of OC for 0-0.075 m depth were 1.02, 1.03, 1.04, 1.01, 1.02, 1.18 and 1.22 per cent for M-W (RF), M-W (PEI), M-W (PSI), M-W (PSI+CRI), M-W (PSI+CRI+F), M+G-W (PSI) and M-R-O-FB treatments, respectively. The corresponding values of the same treatments for 0.075-0.15m depth were 0.87, 0.92, 0.90, 0.90, 0.91, 1.12 and 1.15 per cent and for 0.15-0.30m depth the values were 0.78, 0.81, 0.80, 0.79, 0.81, 0.89 and 0.92 per cent, respectively.

Table 4.15 Organic carbon content (%) of soil under different treatments at the end of experimentation

Treatment	0 - 0.075m	0.075 - 0.015m	0.15 - 0.30m
M-W (RF)	1.02	0.87	0.78
M-W (PEI)	1.03	0.98	0.81
M-W (PSI)	1.04	0.90	0.80
M-W (PSI+CRI)	1.01	0.90	0.79
M-W (PSI+CRI+F)	1.02	0.91	0.81
M+G-W (PSI)	1.18	1.12	0.89
M-R-O-FB	1.22	1.15	0.92
CD (0.05)	0.08	0.07	0.05

4.12.6 Available soil nutrients

The effect of various treatments on available soil nutrients viz. available nitrogen (N) phosphorus (P) and potassium (K) contents for 0-0.15m depth is presented in Table 4.16.

Available NPK at the end of experimentation decreased slightly from their initial values under all maize-wheat treatments except under M+G-W (PSI) treatment. Their values increased under M-R-O-FB treatment. A study of Table 4.16 indicates that available NPK were significantly higher under M+G-W (PSI) and M-R-O-FB treatments than all other treatments which were statistically at par with one another. The values of available N, P and K were 300.6, 16.4 and 203.4 kg/ha for M+G-W (PSI) and 307.3, 17.3 and 209.0 kg/ha for M-R-O-FB treatments.

Table 4.16 Available NPK (kg/ha) and pH of soil (0-0.15m) under different treatments at the end of experimentation

Treatment	N	P	K	pH
M-W (RF)	264.1	13.1	190.0	5.6
M-W (PEI)	258.8	13.4	185.8	5.5
M-W (PSI)	257.0	12.3	184.7	5.5
M-W (PSI+CRI)	260.7	12.4	183.1	5.6
M-W (PSI+CRI+F)	254.9	12.9	186.7	5.5
M+G-W (PSI)	300.6	16.4	203.4	5.5
M-R-O-FB	307.3	17.3	209.0	5.6
CD (0.05)	10.4	2.1	7.3	NS

4.12.7 Soil reaction

The effect of various treatments on soil reaction (pH) is presented in Table 4.16. There was no difference in soil pH before and after studies under all the treatments. Among different treatments the results were found to be nonsignificant for soil reaction. The values of pH were 5.5 for M-W (PEI), M-W (PSI), M-W (PSI+CRI+F) and 5.6 for M-W (RF), M-W (PSI+CRI) and M-R-O-FB treatments.

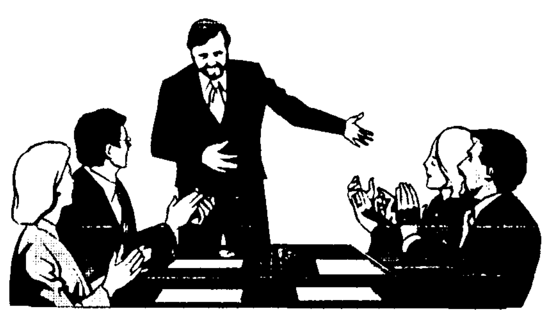
4.13 Input and output data on fish culture

Data regarding input and output of fish in presented in Appendix-IV. During 1995, 50 grass carp and 50 common carp fingerlings were obtained @ Re. 1 and Re. 0.50 per piece, respectively, from Department of Fisheries, HPKV, Palampur. The total cost of 100 fignerlings was Rs. 87.50. The cost of 5 kg of feed was Rs. 25. Thus, total input cost was Rs. 112.50. 37 pieces of fish were harvested out of which 35 pieces were of common carp only, weighed 4.550 kg with a selling price of Rs 40 per kg. Thus, the total output was Rs 182.00 and net profit was approximately Rs 70.00.

During 1996 the input number and input costs were same i.e. Rs. 112.50. 31 pieces of fish were harvested out of which 27 pieces were of common carp only, weighing 5.030 kg with a selling price of Rs. 40.00/kg. The total output was Rs. 201.00 with a net profit of Rs. 89.00.

CHAPTER - 5

DISCUSSION



Chapter-5

Discussion

The present study entitled "Evaluating Intra-terrace Water Harvesting in Poly-lined Tank and its Productivity" was conducted from *Kharif* 1995 under maize-wheat, maize+ginger-wheat and maize-radish-onion (green) -frenchbean (green pods) sequences at the experimental farm of H.P. Krishi Vishvavidyalaya, Palampur (Kangra). The study reports data for two years (1995-96 and 1996-97). A poly-lined tank with a water storage capacity of 70.11m^3 was constructed at the end of a terrace to provide minimal irrigation through gravity to wheat and vegetable crops. Maize was grown as a general crop and hence only average grain and straw yields are presented. Ginger, wheat, radish, onion and frenchbean were grown as test crops.

Since non-availability of enough water for irrigation, in the absence of timely rains, is one of the major problems in the area and of the state, this study aimed at monitoring periodical changes in water storage in poly-lined tank, determining water use under limited irrigation to wheat and vegetable crops and evaluating the possibility of introducing pisciculture in the poly-lined tank. Seven treatments viz. maize-rainfed wheat [M-W (RF)], maize-wheat with one pre-emergence irrigation in the absence of rain ([M-W (PEI)], maize-wheat with pre-sowing irrigation [M-W (PSI)], maize-wheat with irrigation at PSI and crown root initiation stages [M-W (PSI+CRI)] maize-wheat with irrigation at PSI, CRI and flowering stages [M-W (PSI+CRI+F)], maize+ginger-wheat with PSI [M+G-W (PSI)] and maize-radish-onion (green)-frenchbean (green pods) [M-R-O-FB] were imposed. Wheat was grown with 50 per cent of recommended NPK dose with 10 t/ha FYM and the remaining crops were grown under recommended practices (Table 3.2).

Mechanical composition of the experimental site indicates that soil texture is silty clay loam (Table 4.1). Silt was present to the maximum content (49.7%) followed by clay (30.2%) and sand (20.1%) in the surface 0-0.15m depth. Bulk density increased with depth from 1.17 Mg/m^3 for 0-0.075m to 1.29 Mg/m^3 for 0.45-0.60m depth. The soil dominates in oxides of Fe, Al and Mn (Bishnoi *et al.*, 1987) and is one of the reasons for higher value of mean weight diameter (MWD). The water retention at or around field capacity in the surface 0-0.15m depth was poor due to higher value of MWD and lower bulk density in surface layers. The decrease in water content for 0-10 kPa suction was quite rapid and became gradual beyond 10 kPa suction.

The soil was acidic in reaction with a pH of 5.6. The organic carbon content decreased with increase in depth from 1 per cent for 0-0.075m depth to 0.78 per cent for 0.15-0.30m depth. The soil was medium in available N, P and K with values of 279, 13 and 203 kg/ha, respectively.

The continuous occurrence of rainfall yielded more amount of water per unit time in the tank as compared to erratic rains. Higher volumes of water were collected in the month of August than in June and July 1996 due to higher rainfall receipt as well as more flow of water at the soil surface because of saturated soil conditions during this month. Heavy showers during summer monsoon periods resulted in higher percentage of water collected than low intensity winter rains. The data regarding the periodical changes in water storage (Fig.4) revealed that the loss in water level during the course of study was either due to evaporation or due to application of irrigation to different crops. This indicated that there was no percolation loss from the tank. Srivastava and Tandon (1984), Kumar (1992) and Acharya and Kapur (1997) also found no percolation loss of water from the poly-lined tank.

Wheat was irrigated with minimal water to wet the lines of seed zone upto around field capacity under irrigation treatments. Vegetable crops were given light and frequent irrigations to increase the productivity of stored water.

The moisture content (θ) matric potential (ψ) and hydraulic gradients under minimal irrigated wheat plots were favourable for wheat growth than under rainfed conditions. Minimal irrigation applied to wheat at different growth stages also favourably modified conditions suitable for crop growth.

During 1995-96 a light rain of 6.8mm 2DAS followed by 7.5mm irrigation under W (PEI) treatment not only initiated better germination under this treatment but also supplied moisture for a long time, which ultimately benefited the crop. Due to this rain the emergence also got initiated under W(RF) treatment.

During 1996-97 because of non-receipt of timely rains, the germination occurred very late under W (RF) treatment and early under all PSI related treatments. The constant emergence of wheat (Table 4.4) under M+G-W (PSI) treatment compared with W (RF) was significantly higher due to higher moisture retention characteristics of soil under this treatment as a result of higher quantity of added FYM . The days taken for constant emergence were 15.3 and 67.5 for W (RF), 20.5 and 32.5 for M+G-W (PSI) and 19.8 and 30.8 for W (PSI+CRI+F) treatments during 1995-96 and 1996-97, respectively. Acharya *et al.,* (1988) and Rajput and Sastry (1988) also reported favourable effects of FYM on crop growth.

The xylem water potential (XWP) on 104 DAS (Table 4.6) during 1995-96 was significantly higher under W (PEI) treatment due to better growth than W (RF) treatment at all the 3 times of observations. On 144 DAS it was significantly higher under W (PSI+CRI+F) treatment due to application of 20 mm irrigation.

During 1996-97 XWP (Table 4.6) was significantly higher under M+G-W (PSI) treatment than all other treatments on 122 DAS due to higher 'θ' and matric potential than all other treatments. Due to poor plant growth under W (RF) treatment it was lower under this treatment. Ma *et al.* (1995) and Singh (1995) also reported higher XWP of wheat under non-stressed conditions. The XWP (Table 4.5) was higher under W (PSI+CRI+F) treatment on 158 DAS because this treatment received 20mm irrigation on 157 DAS.

A better plant growth under W (PEI) and W (PSI+CRI+F) treatments during 1995-96 resulted in significantly higher root mass density (RMD) (Table 4.6) and root volume (RV) (Tabie 4.7) than the other treatments upto 0.30m soil depth. Prihar *et al.* (1989) and Verma and Acharya (1996b) also reported higher RMD and RV when crop was growing under normal non-stressed conditions in relation to water availability.

During 1996-97, RMD and RV of wheat were significantly higher under irrigated than under rainfed conditions. However, these were still higher under M+G-W (PSI) than W (PSI) and W (PEI) treatments. This effect could be attributed to better plant growth under M+G-W (PSI) treatment as a result of higher 'θ' at different stages of crop growth because of higher amount of FYM added and deep ploughing at sowing of ginger. Sharma and Acharya (1993) reported that for the same soil deep ploughing (0-0.30m) encouraged greater root growth of wheat and resulted in water extraction from subsurface depths.

The water use, in general, was higher during 1996-97 as compared to the year 1995-96 for all the crops. It's values for both the years were higher under onion (378 mm/ha during 1995-96 and 371.7 mm/ha during 1996-97) and frenchbean (334.8 mm/ha during 1996 and 380.5 mm/ha during 1997) than wheat but lower under radish crop, as the duration of radish for growing was smaller than other crops. The yield of wheat in general under different treatments was low during both the years because it was applied 50 per cent of recommended NPK with 10 t/ha FYM (Table 4.9).

The effect of PSI to wheat was well marked as the grain and straw yields under W (PSI) treatment were significantly higher than that under W (RF) treatment during both the years. A better growth under W (PEI) treatment during 1995-96 at early stages of crop growth resulted in higher yield. Favourable moisture regime reflected through 'θ' and matric potential provided better environment for emergence, root growth (RMD and RV values) and finally produced higher yields. The yield was 15.38 per cent higher under W (PSI), 39.2 per cent higher under W (PEI) and 42.3 per cent higher under W (PSI+CRI+F) treatments than W (RF) treatment during 195-96. During 1996-97 it was 57.9 per cent higher under W (PSI), 95 per cent higher under W (PSI+CRI+F) and 46.4 per cent higher under M+G-W (PSI) treatments than W (RF) treatment.

The beneficial effects of pre-sowing irrigation over rainfed treatment are also reported by several workers (Zaman and Mallick, 1987; Grewal *et al.* 1989; Gupta *et al.* 1990 and Acharya, 1992). A higher yield by applying pre-emergence irrigation (PEI) over PSI has also been reported by Mittal *et al.* (1987).

The yield of wheat was significantly higher with one minimal irrigation, each applied at PSI, CRI and flowering stages as compared to yield obtained by applying minimal irrigation at PSI or PSI+CRI stages indicating that irrigation at flowering stage was also crucial as for as the yield is concerned. A minimal irrigation of 20mm at flowering stage resulted in higher 'θ', matric potential, xylem water potential and higher RMD and RV than irrigation at other stages. Raghu *et al.* (1984) and Malik *et al.* (1985) also reported higher yield of wheat when it was irrigated at flowering stage.

In 1996-97 again the yield of W (RF) treatment was significantly lower compared to other treatments due to non-receipt of rains during early stages of crop growth which resulted in delayed germination under W (RF) treatments (Table 4.9). The yield of W (PSI) was statistically at par with that of W (PEI) treatment and the yield of W (PSI+CRI) was at par with W (PSI+CRI+F) treatment. The reason for obtaining no response of irrigation at flowering stage could be due to the occurrence of differential rains after the flowering stage (Appendix-I). Better hydro-thermal regimes coupled with higher availability of plant nutrients for higher growth and development of wheat resulted in higher yield under M+G-W (PSI) treatment. These findings are in lines with those obtained by Acharya *et al.* (1988) and Rajput and Sastry (1988).

The yield of ginger was very low (1.458 t/ha) during 1995-96 as it was severely hit by a fungal disease (rhizome rot), whereas during 1996 its yield was 4.69 t/ha. The yields of radish were 14.17 t/ha and 21.46 t/ha during 1995 and 1996, respectively. Green onion yields during 1995-96 and 1996-97 were 20.60 and 33.96 t/ha, respectively. Green pod yields of frenchbean during 1996 and 1997 were 10.63 and 12.29 t/ha. Several workers (Chung, 1989; Patel *et al.*, 1992a; Rana and Sharma, 1994; Hegde, 1987a,b and Hegde and Srinivas, 1987) have reported higher yields of vegetable crops when irrigated frequently with light irrigations.

Water use efficiency (WUE) under different treatments in maize-wheat, maize+ginger-wheat and maize-radish-onion-frenchbean sequences (Table 4.11) shows that it was higher under radish, onion and frenchbean crops as compared to WUE under wheat. This is because of the reason that WUE values for these vegetable crops were calculated on fresh weight basis at the time of harvest.

Under different wheat treatments WUE during 1995-96 and 1996-97 was 136 and 52.5 per cent higher under W (PEI), 73.3 and 40.7 per cent higher under W (PSI) and 101.3 and 55.9 per cent higher under W (PSI+CRI+F) treatments, respectively, than W (RF) treatment. During 1995-96 WUE was highest (17.7 kg/ha/mm) under W (PEI) treatment due to its

At 33 kPa suction, 'θ' increased by 11.38 and 11.72 per cent from its initial value, respectively under the same treatments. Infiltration rate increased under the same treatments by 66.7 and 94.4 per cent and MWD increased by 19.82 and 20.75 per cent, respectively from their initial values.

Organic carbon contents (0-0.075m) increased by 18.00 and 22.00 per cent, respectively, for the same treatments from their initial values.

The improvement in these soil properties could be attributed to addition of higher quantity of FYM under M+G-W (PSI) treatment (50 t/ha/ year) as well as under M-R-O-FB treatment (65 t/ha/year) compared to other treatments in which only 20 t/ha/year FYM was added under M-W sequence.

Biswas *et al.* (1971) reported significant increase in organic matter content of soil, improvement in structure and bulk density with application of organic manures over no organic matter in alluvial sandy loam soil. Acharya *et al.* (1988) also showed that FYM application improved structural index, infiltration rate, water retention characteristics over the treatment without FYM. Bhagat and Verma (1991) observed higher percentage of water stable aggregates >0.25 mm diameter, larger mean weight diameter, higher porosity and lower bulk density by application of FYM over no FYM.

Available N, P and K contents (0-0.15m depth) increased under the same two M+G-W (PSI) and M-R-O-FB treatments and slightly decreased under the remaining treatments from their initial values. Under the two former treatments the increase in available N was 7.74 and 10.14 per cent, available P 26.15 and 33.08 per cent and available K 0.2 and 2.96 per cent, respectively from their initial values. Gattani *et al.* (1976), Mathan *et al.* (1978a,b) also reported an increase in available N on application of FYM. Many investigators (Khanna and Roy, 1956; Vyas, 1964; Singh and Srivastava, 1971 and Minhas and Tripathi, 1986) observed an increase in available P on application of organic matter. Organic matter has also been found to increase available K status by Sanyasi Razu (1952), Kanwar and Prihar (1962) and Stevenson (1968). A number of workers (Mandal and Pain, 1965; Acharya and Rajagopalan, 1956 and Sinha, 1957) observed an increase in available NPK by application of bulky organic manures.

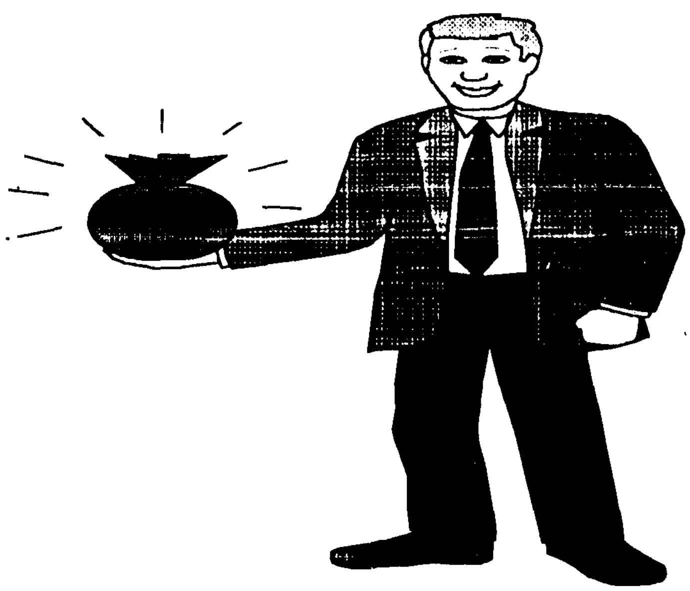
The treatments showed nonsignificant differences in soil pH and its value remained the same as at the beginning of the experimentation.

Appendix-IV reveals that for increasing the productivity of stored water common carp (mirror carp) rather than grass carp fish can be raised as the latter requires regular supply of fresh water. Hence, maximum number (35 out of 37 during 1995 and 27 out of 31 during 1996) was obtained of the common carp fish only.

It is evident from Fig. 1 and Appendix-I that summer monsoons are heavy resulting in an increase in water volume due to higher run-off. Further, as most of the farmers (82%) of the state fall in the category of small and marginal with average holdings of less than 0.5 ha and about 62 per cent of them having holdings of less than 0.3 hectare, a model for a small farmer having 10 *kanals* (4000 m^2) area in terms of growing wheat, vegetable crops and fodder, can be suggested. A small farmer with very limited input of fertilizer gets about 1 t/ha average yield of wheat under rainfed conditions which can be increased to 1.5 t/ha with only 10mm irrigation as PSI. Thus from 10 *kanals* a farmer obtains 400 kg of wheat grains which can be obtained from 6.7 *kanals* area with only 10mm of irrigation as PSI. This will require $27m^3$ irrigation water. From a $700m^2$ catchment area a tank of $70m^3$ capacity can get filled in September end. Evaporation in dry months of October, November and December under Palampur conditions will reduce volume by $16m^3$ and hence $27m^3$ of water will remain available on January 1. Due to winter rains the volume in the tank (after considering evaporation losses) on 1 April is likely to be approximately $50m^3$. Radish, onion, frenchbean and ginger require $31.5m^3$ water/$100m^2$ area. Therefore, a farmer can put approximately $150m^2$ area for growing vegetables throughout the year for diversifying his farming. Increasing wheat production from whole of 10 *kanals* by enhancing wheat productivity through PSI will not help him as he is not going to sell the small quantity of surplus wheat in the market. Best course for him would be that the land thus saved (1170 m^2) may be put under nutritious grasses as there is always an acute shortage of fodder in the hilly areas. For increasing productivity of stored water a farmer can also raise common carp fish @ 1/m^2. This is how small and marginal farmers can get benefited through water harvesting based on labour and cost effective technology on the principles of low external input and sustainable agriculture.

CHAPTER - 6

SUMMARY AND CONCLUSIONS



Chapter-6

Summary and Conclusions

Present study entitled "Evaluating Intra-terrace Water Harvesting in Poly-lined Tank and its Productivity" was conducted at the experimental farm of H.P. Krishi Vishvavidyalaya, Palampur (Kangra) for two years (1995-96 and 1996-97) under maize-wheat, maize+ginger-wheat and maize-radish-onion-frenchbean sequences. The study aimed at monitoring periodical changes in water storage in poly-lined tank, to determine water use under limited irrigation to wheat and to evaluate the possibility of growing vegetables and introducing pisciculture in the poly-lined tank for increasing water productivity and its economic viability. The experiment included seven treatments viz. maize-wheat grown as rainfed crop [M-W (RF)], maize-wheat with pre-emergence irrigation in the absence of rain [M-W (PEI)], maize-wheat with one pre-sowing irrigation [M-W (PSI)], maize-wheat with irrigation at PSI and crown root initiation stages [M-W (PSI+CRI)], maize-wheat with irrigation at PSI, CRI and flowering stages [M-W (PSI+CRI+F)], maize+ginger-wheat with PSI [M+G-W (PSI)] and maize-radish-onion (green)-frenchbean (green pods) (M-R-O-FB). Wheat was grown under 50% of recommended NPK with 10 t/ha FYM, whereas, other crops were grown under recommended practices.

The experiment was conducted in randomised block design, replicated four times, with a plot size of $12m^2$. Mechanical composition of the soil of the experimental site showed that the soil was silty clay loam. The bulk density increased with depth from 0-0.60m. The mean weight diameter of surface soil was high. The water retention at or around field capacity was 29%. Steady state infiltration was high. The soil was acidic in reaction (pH 5.6). Organic carbon content of 1.0 per cent at 0.075m depth decreased with depth. Soil was medium in available N, P and K.

A polyethylene lined tank of 70.11m^3 capacity was constructed at the end of a terrace which was situated three terraces above the area where the crops were grown. Wheat and vegetable crops were irrigated through gravitational flow with minimal irrigation. Pisciculture was introduced in the tank to increase the productivity of the stored water.

The rate of entry and per cent rain water harvested in the tank increased with increase in amount and intensity of rainfall. Both of these characteristics were higher in the month of August, 1995. Summer monsoons yielded higher amount of water harvested than the winter one.

No percolation loss in the water harvesting tank was recorded during the course of study. The fall in water level, was either due to evaporation or due to irrigation of crops. Higher amount of water was required for irrigation from April to May and October to December than other months.

Higher soil moisture (θ) and matric potential (ψ) were observed under irrigated conditions during growth of wheat. During 1995-96 a light rain of 6.8 mm 2 days after sowing (DAS) followed by minimal irrigation of 7.5 mm 7 DAS under W (PEI) treatment boosted the growth in this treatment. 'θ' at different stages was also higher under other irrigated conditions than under rainfed. During 1996-97, 'θ' and 'ψ' were higher under M+G-W (PSI) treatment due to its better moisture retention characteristics as a result of addition of higher quantity of organic matter.

The seedling emergence parameters viz. seedling emergence count/m^2, days taken for initiation of emergence and for attaining constant emergence were favourably improved by application of irrigation as compared to rainfed conditions during both the years.

The xylem water potential (XWP) recorded at maximum tillering and flowering stages showed higher values under irrigated conditions. XWP during 1995-96 was higher under W (PEI) treatment due to its better early growth. During 1996-97 it was higher under M+G-W (PSI) treatment.

Higher values of root mass density (RMD) and root volume (RV) were obtained under irrigated conditions than under rainfed conditions. W (PEI), W (PSI+CRI+F) treatments during 1995-96 and M+G-W (PSI) treatment during 1996-97 recorded higher values of RMD and RV than W (RF) treatment. Water use, in general, was higher under vegetable crops than under wheat. Among different wheat treatments water use was higher under irrigated conditions than under rainfed conditions. It was highest under W (PSI+CRI+F) treatment during both the years.

During 1995-96, grain and straw yields of wheat were significantly higher under irrigated than under rainfed conditions. These yields were however, still higher under W (PEI) and W (PSI+CRI+F) treatments.

During 1996-97, the yields were again lower under rainfed conditions, and higher under W (PSI+CRI+F) and M+G-W (PSI) treatments than under other treatments. The yields of vegetable crops were higher during the second year of study than the Ist year. Yield of ginger during 1995 was low due to attack of rhizome rot.

Water use efficiency was higher under vegetable crops than under wheat. It was, however, lowest under W (RF) treatment. During 1995-96, under wheat treatments, it was highest under W (PEI) and during 1996-97 it was highest under M+G-W (PSI) treatment.

Highest gross expenditure was observed under M+G-W (PSI) treatment followed by M-R-O-FB treatment, whereas highest gross return and highest net profit were obtained under M-R-O-FB treatment. Among wheat treatments highest gross expenditure, gross returns and net profit were obtained under M-W (PSI+CRI+F) treatment.

The bulk density upto 0.30m depth, decreased whereas, mean weight diameter, infiltration rate, soil organic carbon (upto 0.30m depth) increased and soil moisture retention characteristics were favourably improved under M+G-W (PSI) and M-R-O-FB treatments at the end of the experimentation. These soil properties remained unaffected under remaining treatments.

Available NPK increased under M+G-W (PSI) and M-R-O-FB treatments and decreased slightly under the remaining treatments from their initial values.

The growth of common carp fish (Mirror carp) was found better than grass carp during both the years.

Conclusions

Study brought out the following:

1. In hilly areas where land holdings are small, soil is shallow in depth and of boulder-ridden nature, water losses through percolation very high, land undulating, rains erratic in behaviour and irrigation facility non-existent, it is advisable to construct a small poly-lined tank for intra-terrace water harvesting, so as to irrigate crops through gravity without any external input of energy for lifting irrigation water.
2. It is beneficial to apply irrigation as pre-sowing/pre-emergence to wheat when only one irrigation is available.
3. To increase the productivity of stored water inclusion of vegetables in maize based cropping sequence gives higher returns per unit of water consumed.
4. Application of minimal irrigation to wheat ensures timely germination and establishment of the crop which enhances the use efficiency of nutrients applied through costly fertilizers.
5. Application of 50 per cent of the recommended dose of NPK to wheat along with 10 t/ha FYM produced respectable average yield of 2.6 t/ha when the germination of wheat was ensured even with 4.1mm of irrigation as pre-sowing. This yield was significantly higher over the rainfed yield (2.0 t/ha).
6. The soil-water-plant relationships in wheat were favourably improved with application of minimal irrigation from the water harvested in the poly-lined tank.
7. A poly-lined tank with 70 m^3 storage capacity is sufficient to provide pre-sowing irrigation of 10 mm to wheat in 6.7 *Kanal* (2680 m^2) and to raise radish-onion-frenchbean in 150 m^2 area with maize based cropping sequence.
8. The water productivity can further be enhanced by raising mirror carp fish in the tank.

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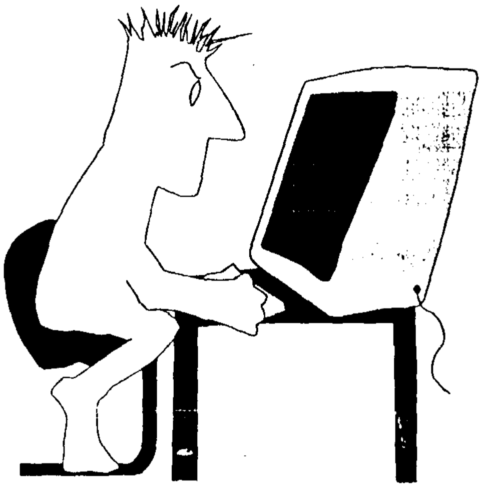

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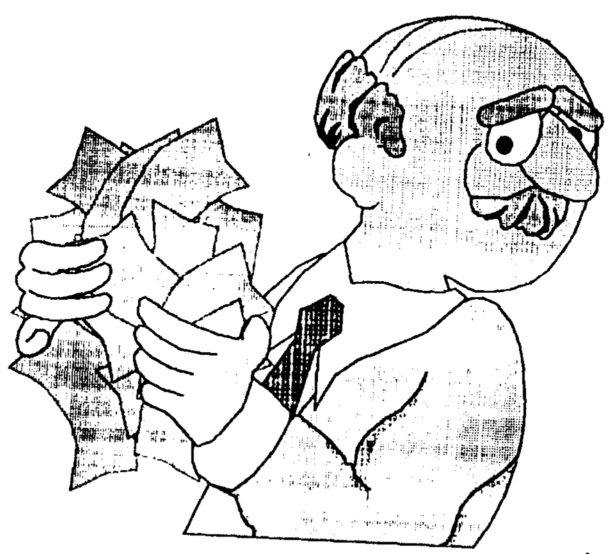
APPENDICES



Appendix-I

Mean weekly weather data of Palampur during the course of study (July 1995 to June 1997)

*SW No.	Week	Max. °C	Min. °C	RH (%)	BSSH	WV (km/h)	Rainfall (mm)	Evaporation (mm)
1995								
26	25June-1 July	29.5	18.3	64	8.7	5.8	11.8(2)	4.2
27	2-8	27.1	20.9	79	4.7	4.9	38.5(5)	2.2
28	9-15	26.6	19.9	82	3.1	3.8	152.6(7)	1.2
29	16-22	26.8	20.9	81	2.9	4.3	116.3(7)	1.2
30	23-29	25.3	19.8	80	2.6	4.2	192.3(6)	0.9
31	30-5 Aug.	25.7	20.2	86	3.5	3.3	293.1(6)	1.2
32	6-12	24.7	20.3	85	1.7	2.8	80.7(6)	1.2
33	13-19	25.0	20.5	85	1.6	3.3	115.8(6)	1.3
34	20-26	26.2	19.9	81	4.3	3.4	97.9(5)	1.3
35	27-2 Sept.	26.3	18.9	83	4.6	4.1	142.2(7)	1.4
36	3-9	24.1	17.9	84	3.2	4.0	211.0(6)	1.1
37	10-16	25.6	17.6	70	6.3	4.5	24.9(4)	1.8
38	17-23	27.0	17.9	66	9.5	4.3	0.0	3.0
39	24-30	25.8	17.6	67	7.2	4.7	36.8(4)	2.4
40	1-7 Oct.	26.4	16.8	55	9.1	4.9	10.0(2)	3.1
41	8-14	26.0	16.2	60	9.3	4.7	0.0	2.6
42	15-21	24.3	14.3	46	6.6	5.3	2.0(1)	2.5
43	22-28	23.9	12.1	40	9.2	4.8	0.0	2.8
44	29-4 Nov.	23.2	11.5	39	9.1	5.2	4.8(1)	2.9
45	5-11	22.9	11.1	36	9.5	4.8	0.0	2.8
46	12-18	22.3	10.4	43	8.9	4.7	0.0	2.4
47	19-25	20.6	8.3	34	9.4	4.9	0.0	2.2
48	26-2 Dec.	17.8	5.2	42	7.0	5.7	6.8(1)	1.8

Contd...........

49	3-9	17.5	7.9	45	6.1	4.5	0.9(1)	1.5
50	10-16	16.8	7.2	51	4.4	4.6	0.6(1)	1.5
51	17-23	16.2	6.7	54	4.0	4.0	1.4(1)	1.3
52	24-31	16.6	5.7	46	7.0	4.5	0.0	1.7

1996

1	Jan.1-7	17.1	5.1	44	7.8	4.7	0.0	2.1
2	8-14	16.1	6.1	52	5.4	4.6	1.0(1)	1.5
3	15-21	12.7	3.8	67	4.5	6.4	32.7(2)	1.0
4	22-28	14.6	4.4	58	6.0	5.5	7.0(2)	1.4
5	29-4 Feb.	18.3	6.2	37	8.4	4.6	0.0	2.5
6	5-11	18.0	7.8	49	4.9	5.1	3.8(3)	2.2
7	12-18	17.5	6.5	53	7.6	5.8	21.0(1)	1.7
8	19-25	17.8	8.1	55	6.0	6.7	34.6(3)	2.1
9	26-4 Mar.	18.6	10.4	52	5.7	6.1	15.4(2)	2.4
10	5-11	22.1	11.2	51	7.6	5.2	0.3(1)	3.0
11	12-18	19.9	11.6	65	3.8	7.3	28.4(4)	2.6
12	19-25	18.9	9.1	60	5.7	6.1	28.5(4)	1.6
13	26-1 Apr.	23.1	11.1	51	7.8	6.2	7.5(3)	2.9
14	2-8	24.3	12.9	35	7.8	6.7	6.7(2)	4.8
15	9-15	25.8	14.1	38	9.3	5.7	0.0	5.1
16	16-22	27.9	16.7	46	7.3	5.4	7.8(2)	5.8
17	23-29	27.2	16.6	56	7.9	5.4	7.5(1)	4.5
18	30-6 May	29.9	18.3	39	8.6	7.5	7.5(2)	6.8
19	7-13	30.9	17.5	33	8.7	6.6	12.5(1)	8.1
20	14-20	27.3	16.2	45	7.4	5.7	7.2(3)	5.9
21	21-27	32.0	17.6	50	6.3	5.3	1.6(2)	5.0
22	28-3 June	32.9	19.8	30	11.1	6.8	4.8(1)	8.5
23	4-10	30.6	19.2	50	8.9	6.1	6.0(3)	6.1
24	11-17	29.3	20.0	63	5.8	5.0	53.9(2)	3.9
25	18-24	28.2	20.5	76	4.2	5.2	71.5(5)	3.2
26	25-1 July	26.2	19.1	80	4.0	4.3	128.4(6)	1.4

Contd...........

27	2-8	26.5	18.9	73	6.1	4.4	26.9(2)	2.2
28	9-15	26.3	20.7	82	2.9	3.8	38.1(6)	1.7
29	16-22	27.5	20.7	75	4.6	4.3	16.1(3)	2.2
30	23-29	27.3	20.3	81	3.3	3.4	88.5(5)	1.7
31	30-5 Aug.	26.1	20.7	83	1.7	3.2	70.6(6)	1.3
32	6-12	25.9	20.3	88	2.6	2.8	131.5(7)	0.8
33	13-19	24.0	19.5	89	1.2	3.2	152.3(7)	1.3
34	20-26	23.7	18.0	82	3.8	3.7	66.7(5)	1.3
35	27-2 Sept.	27.1	19.6	83	4.9	3.7	169.9(5)	1.8
36	3-9	26.3	18.0	78	6.6	4.3	54.3(5)	2.0
37	10-16	25.7	18.1	79	3.0	3.8	32.0(3)	2.1
38	17-23	26.5	16.9	65	7.9	4.2	2.0(1)	2.6
39	24-30	27.8	17.7	66	8.6	5.0	9.0(3)	3.2
40	1-7 Oct.	26.0	14.9	63	7.6	4.8	14.6(2)	3.0
41	8-14	25.4	13.9	53	10.1	5.0	0.0	2.9
42	15-21	25.2	13.8	57	9.1	5.6	2.3(1)	3.2
43	22-28	24.5	12.3	44	9.8	5.2	0.0	3.2
44	29-4 Nov.	24.9	12.2	49	9.9	4.4	0.0	2.8
45	5-11	26.1	11.2	43	9.0	4.7	0.0	2.7
46	12-18	22.3	9.3	38	4.7	4.9	0.0	2.4
47	19-25	19.9	8.7	47	8.5	3.7	0.0	1.8
48	26-2 Dec.	19.8	7.3	34	9.1	4.3	0.0	2.0
49	3-9	18.5	6.0	41	9.3	4.4	0.0	2.0
50	10-16	20.5	6.6	30	9.3	4.5	9.4(1)	2.2
51	17-23	19.9	5.9	36	9.1	4.3	0.0	2.1
52	24-31	18.7	7.3	48	8.2	4.2	5.8(1)	2.1

1997

1	Jan.1-7	17.4	5.9	52	7.0	4.0	0.0	1.7
2	8-14	17.1	5.2	47	8.2	4.3	0.0	1.9
3	15-21	13.6	3.6	59	4.5	5.6	56.5(3)	1.5
4	22-28	12.1	2.9	50	6.6	4.5	12.4(2)	1.5

Contd............

5	29-4 Feb	13.5	5.0	63	5.8	4.3	11.4(3)	1.9
6	5-11	13.4	4.2	57	4.5	6.4	15.3(3)	1.7
7	12-18	17.0	5.5	46	8.9	5.1	0.0	1.9
8	19-25	18.6	6.9	55	8.1	5.4	2.0(1)	2.8
9	26-4 Mar	20.7	9.3	48	5.8	6.1	2.4(3)	2.9
10	5-11	22.9	12.1	44	7.4	4.9	0.0	3.4
11	12-18	21.0	10.3	57	4.5	5.0	27.4(3)	2.5
12	19-25	18.9	8.7	56	7.2	5.6	17.2(1)	2.4
13	26-1 Apr	20.8	10.8	62	6.1	5.6	23.9(3)	3.1
14	2-8	18.1	9.5	67	4.8	4.9	26.0(4)	2.4
15	9-15	23.2	12.6	60	6.4	6.1	22.6(4)	3.2
16	16-22	24.2	12.2	45	8.6	7.3	8.6(1)	4.2
17	23-29	28.0	17.1	49	9.4	6.6	6.8(3)	5.2
18	30-6 May	25.4	14.6	55	6.9	5.3	13.2(4)	3.4
19	7-13	25.6	14.6	45	9.9	6.8	23.2(1)	4.2
20	14-20	27.5	16.6	34	10.7	5.7	0.0	6.4
21	21-27	30.9	19.0	39	9.6	5.4	0.0	7.4
22	28-3 Jun	27.8	16.8	52	6.5	5.9	14.4(2)	4.6
23	4-10	27.9	18.2	55	5.1	4.9	9.4(4)	4.7
24	11-17	30.2	18.9	58	9.4	5.7	11.2(2)	4.2
25	18-24	29.2	19.1	69	9.2	4.8	84.6(4)	5.1
26	25-1 Jul	27.5	18.9	71	5.9	4.4	28.0(4)	3.0

* Standard week number

Figure in parentheses are number of rainy days

Soil moisture content ($m^3/100m^3$) under different treatments (0.30-0.45m and 0.45-0.60m) during growth of wheat (1995-96)

Treatments	Days after sowing								
	0	7	21	52	61	91	112	143	169
a. 0.30-0.45m									
W(RF)	17.9	20.6	14.6	27.1	24.1	35.0	31.4	26.5	26.0
W(PEI)	15.3	23.5	16.4	30.1	27.8	38.5	32.5	27.0	25.9
W(PSI)	19.2	22.3	14.1	27.9	24.3	35.9	33.4	24.3	24.5
W(PSI+CRI)	20.5	24.4	20.8	31.7	27.0	34.7	33.2	24.9	24.8
W(PSI+CRI+F)	19.7	20.9	15.3	29.0	25.3	36.8	33.8	27.5	28.0
M+G-W(PSI)	20.5	24.5	20.5	26.6	22.5	37.8	34.0	24.8	26.6
b. 0.45-0.60m									
W(RF)	19.7	20.4	15.7	26.2	20.6	26.3	31.4	22.5	27.7
W(PEI)	21.0	22.4	18.5	27.0	18.3	30.1	32.3	25.7	30.2
W(PSI)	22.5	20.8	17.8	25.1	19.1	27.4	33.4	23.8	27.7
W(PSI+CRI)	23.0	21.1	20.6	26.9	21.9	28.2	33.3	23.9	27.3
W(PSI+CRI+F)	23.5	20.9	19.9	26.1	18.7	26.9	31.8	26.2	30.3
M+G-W(PSI)	23.7	21.6	19.2	25.5	23.2	29.5	33.0	24.3	29.7

Soil moisture content ($m^3/100m^3$) under different treatments (0.30-0.45m and 0.45-0.60m) during growth of wheat (1996-97)

Treatments	Days after sowing										
	0	8	28	61	83	110	122	148	157	170	178
a. 0.30-0.45m											
W(RF)	15.9	13.1	24.9	34.8	24.8	19.9	32.5	28.8	26.4	36.1	29.5
W(PEI)	16.4	18.0	26.0	34.5	27.6	20.9	33.6	31.4	27.8	36.9	31.0
W(PSI)	20.1	15.9	24.2	35.4	26.8	21.7	34.6	30.5	28.3	36.5	30.1
W(PSI+CRI)	20.0	16.4	27.4	37.0	28.0	21.5	34.5	29.6	30.3	39.6	33.4
W(PSI+CRI+F)	17.8	17.3	26.6	36.9	26.8	21.7	33.6	28.9	31.1	39.8	34.6
M+G-W(PSI)	20.9	18.5	26.6	36.9	25.5	21.8	35.9	30.8	29.0	36.9	27.8
b. 0.45-0.60m											
W(RF)	16.6	14.0	25.1	33.5	25.8	17.1	28.2	29.1	22.1	34.7	28.0
W(PEI)	18.0	18.1	24.4	34.8	25.9	21.3	30.6	29.1	25.0	34.4	28.3
W(PSI)	21.1	17.3	23.4	33.3	24.7	21.5	31.0	30.7	24.5	37.6	30.6
W(PSI+CRI)	16.9	17.3	27.3	34.5	28.4	22.0	31.2	32.9	24.1	38.2	31.0
W(PSI+CRI+F)	21.1	18.1	24.8	33.5	28.4	21.5	29.4	30.7	26.0	39.0	32.1
M+G-W(PSI)	21.4	17.1	25.8	36.0	25.3	25.2	30.0	32.6	25.2	34.3	28.8

Input and output data on fish culture

Year : 1995 **[*from 18.7.95 to 17.11.95 (122 days)*]**

Inputs allocated

Fingerlings raised

a) Common carp (mirror carp) 50 @ Re 0.75/piece = Rs. 37.50

b) Grass carp 50 @ Re 1.00/piece = Rs. 50.00

Total Weight : 0.360 kg.

Cost of 100 fingerlings = Rs. 87.50

Cost of 5 kg feed @ Rs. 5.00/kg = Rs. 25.00

Total input cost = Rs.112.50

Outputs obtained

Fish harvested

a) Common carp (mirror carp) 35

b) Grass carp 2

Total weight : 4.550 kg.

Selling price @ Rs. 40/kg = Rs.182.00

Net profit = Rs. 69.50

Year : 1996 **[*from 16.7.96 to 14.11.96 (121 days)*]**

Inputs allocated

Fingerlings raised

a) Common carp (mirror carp) 50 @ Re 0.75/piece = Rs. 37.50

b) Grass carp 50 @ Re 1.00/piece = Rs. 50.00

Total Weight : 0.220 kg.

Cost of 100 fingerlings = Rs. 87.50

Cost of 5 kg feed @ Rs. 5.00/kg = Rs. 25.00

Total input cost = Rs. 112.50

Outputs obtained

Fish harvested

a) Common carp (mirror carp) 27

b) Grass carp 4

Total weight : 5.030 kg.

Selling price @ Rs. 40/kg = Rs. 201.20

Net profit = Rs. 88.70
