Improving water use for dry season agriculture by marginal and tenant farmers in the Eastern Gangetic Plains

Utilisation of residual soil moisture through relay cropping

Working Paper

Author: **Bibek Bahadur Shrestha, Prithwish Roy**

Date: June 2016

Australian Government
Australian Centre for International Agricultural Research

UTILISATION OF RESIDUAL SOIL MOISTURE THROUGH RELAY CROPPING

A Project Report

Submitted to the
Faculty of Technology
Uttar Banga Krishi Viswavidyalaya
in partial fulfillment of the requirements for the award of the degree of

Bachelor of Technology
In
Agricultural Engineering

By

Bibek Bahadur Shrestha & Prithwish Roy

Faculty of Technology
Uttar Banga Krishi Viswavidyalaya, Pundibari,
Cooch Behar, West Bengal- 736165, INDIA

JUNE 2016

UTTAR BANGA KRISHI VISWAVIDYALAYA

Faculty of Technology
Pundibari, Cooch Behar, West Bengal- 736165, INDIA

June, 2016

CERTIFICATE

This is to certify that the project report entitled **"Utilisation of Residual Soil Moisture through Relay Cropping"** submitted by Bibek Bahadur Shrestha (Reg. no. AE-2012-04B) & Prithwish Roy (Reg. no. AE-2012-10B) to the Faculty of Technology, Uttar Banga Krishi Viswavidyalaya, in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Agricultural Engineering, is a record of bonafide work carried out by them under my supervision and guidance. The project work, in my opinion, has reached the requisite standard fulfilling the requirement for the degree.

The results contained in this report have not been submitted in part or full to any other University or Institute for award of any degree or diploma.

(Dr. Rupak Sarkar)
Assistant Professor
Faculty of Technology
Uttar Banga Krishi Viswavidyalaya
Pundibari, Coochbehar- 736165
West Bengal, INDIA

APPROVED

(Dr. Rupak Sarkar)
DEAN (Acting), Faculty of Technology

ACKNOWLEDGEMENTS

We express our deep sense of gratitude and regards to our project guide ***Dr. Rupak Sarkar, Assistant Professor & Dean (Acting), Faculty of Technology, U.B.K.V,*** *for his constant inspiration, motivation, encouragement, guidance, and valuable criticism throughout the progress of this project.*

We are extremely thankful to the ***Australian Centre for International Agricultural Research (ACIAR)*** *for providing the funds towards the completion of this project.*

Last but not least, we express our profound and deep sense of indebtedness to our parents, friends and juniors without whose cooperation and guidance it would not have been possible to complete this project.

Pundibari (Bibek Bahadur Shrestha)

June, 2016

(Prithwish Roy)

TABLE OF CONTENTS

CHAPTER		Page No.

LIST OF FIGURES

LIST OF TABLES

TABLES	PAGE No.

ABSTRACT

Relay cropping is a very useful cropping system compared to the conventional cropping system. In the investigation of relay cropping of monsoon paddy and lentil, trials were conducted. The trials were taken up in two villages of North Bengal viz. Dhalaguri (Cooch Behar) having four plots (3.5 bigha) and Uttar Chakwakheti (Alipurduar) having four plots (1.5 bigha). The plots were located in low land areas with clay loam soil. The variety of paddy was MTU 7029 (Sarna) and the variety of lentil was B 77 (Asha). The lentil seeds were inoculated with rhizobium and azotobactor bacteria. The lentil seeds were broadcasted in the field before harvesting the paddy. The soil samples were collected from two depths viz. topsoil and 30 cm depth soil at weekly intervals from each of the plots. Gravimetric method was used to find out the moisture content of those collected soil samples. The first sampling was done only on topsoil on the date of sowing of lentil seeds. The soil moisture profiles in the plots for the first eight weeks of the lentil crop were monitored. In this period the water requirement of lentil was fulfilled by the residual moisture content as the soil moisture level was above wilting point. Only in one plot the soil moisture level of the topsoil dropped below the wilting point. Therefore, the residual moisture content was sufficient for the healthy growth of lentil without any supplemental irrigation till the eighth week of the crop. In the remaining crop duration, one supplemental irrigation (if required) should be sufficient to raise the crop. Thus the present study demonstrated the prospect of relay cropping with significant savings of agricultural inputs like water, fertilizer, and labour.

CHAPTER 1 INTRODUCTION

1.1.1 Overview

1.1.1 Definition

Relay cropping is a type of cropping system in which two or more crops are simultaneously grown during certain part of the growing seasons of the crops. The second crop is sown before harvesting of the first crop in the same field. In other words the second crop is planted in the same area as the first crop after the first has achieved reproductive maturity but before it has reached physiological maturity. For this cropping pattern the farmers can grow two different crops in one/two season(s) in same area where the growing season is not long enough to accommodate two crops separately (Guldan *et al*., 2008).

Relay cropping combinations include brassicas with sweet corn and chilli; soybean and wheat; strawberries with squash, muskmelons, pickles, or peppers; and sorghum with winter wheat, alfalfa, or cotton. A grower must be careful about the spatial arrangement, planting rates, maturity dates, and nutrient needs of both crops (Sullivan, 2003).

1.1.2 Advantages of relay cropping

There are many advantages of relay cropping over conventional cropping. These are listed below:

I. Residual moisture content can be utilized by relay cropping. This means the amount of moisture which is left at the root zone depth by the first crop is utilized by the second crop.
II. Less time is required for cultivation of two or more crops because growing season of each crop is overlapped with one another.
III. Leguminous crops involve in relay cropping add some nitrogen in the soil which is taken as the nutrient by the next crop.
IV. Better erosion control of soil because the ground cover is more compared to the conventional cropping.
V. Labour requirement is less.

VI. Overall cost of cultivation is less as irrigation water requirement, labour and power requirement for land preparation are significantly reduced.

1.1.3 Disadvantages of relay cropping:

There are some disadvantages in relay cropping too. These are listed below:

I. Mechanization in sowing and harvesting is difficult.
II. Crop management requirements are higher.
III. Overall costs per unit of production may be higher due to reduced efficiency in planting, weeding and harvesting.

1.1.4 Application of relay cropping:

To meet the high demand of food against the increasing population highest emphasis has been given to cereal production. Relay cropping is generally performed in loamy soil because it has the best moisture retaining capacity. Sandy soil has very low moisture retaining capacity. Therefore, sandy soil is not preferred for relay cropping. Moisture content in monsoon season is generally near to the field capacity of soil. But in winter season or dry season the moisture content goes down due to evaporation and transpiration. The rate of evaporation is higher in dry season because the humidity of air is less compared in monsoon season. Growing of legumes by relay cropping improves the soil condition and lentil (*Lens culinaris*) as a food legume has a role in growing protein rich food for human and for sustainable agriculture. Legumes fix nitrogen through their relationship with soil microbes called rhizobia. Lentil cultivation after the monsoon-rice harvesting in winter season (October-April) is affected by higher infestation of diseases and insect pests, resulting in lower yields. So in this respect, lentil relay in rice field has a greater opportunity which ensures timely sowing and best use of residual soil moisture. Various combinations of seed rate, fertilizer application, rice straw height along with different lentil varieties are attempted to elaborate the field of application of relay cropping system.

1.2 Objective:

In relay cropping the residual soil moisture which is left by the first crop is properly utilized by the second crop. Loam soil is preferred here for its good water holding capacity. The soil samples of two villages Dhalaguri in Coochbehar district and Uttar Chakawakheti in

Alipurduar district were tested for this project work. And the trial for relay cropping of *kharif* paddy and lentil was taken in this project. The objectives of this project work were:

I. To measure the moisture content at the surface soil and the soil at 30 cm depth at each week successively from the sowing of the second crop (lentil) in the *kharif* paddy field.
II. To plot curves between the residual soil moisture content versus time to monitor how the residual moisture content changes with time or how efficiently residual moisture content is utilized by lentil.
III. To observe any rainfall contributions to increase the moisture content of soil.
IV. To study if the residual soil moisture is sufficient for supporting the growth of the second crop (lentil) without any supplemental irrigation.

At different time many research scientists have done many research works on the relay cropping. Most of the works emphasized on how the residual moisture content is utilized by the second crop based on the time of sowing, period of overlapping of the crop periods of two different crops, type of soil, relative humidity and absolute humidity of air etc. This chapter covers the research works which are in some way related to the present study. A brief description of such relevant works has been presented below.

Martens *et al*. (2001) conducted the experiment at two sites in Manitoba in 1998 and 1999 to (i) assess establishment and dry matter (DM) production of legume cover crops that were relay-cropped [alfalfa *(Medicago sativa L.*) and red clover (*Trifolium pratense L*.)] or double-cropped [chickling vetch (*Lathyrus sativus L*.) and black lentil (*Lens culinaris Medik*. Sub sp. culinaris)] with winter cereals [winter wheat (*Triticum aestivum L*.) and fallrye (*Secalecereale L*.)], (ii) assess the effect of relay cover crops on cereal grain yield, and (iii) characterize the effects of a red clover cover crop on the microclimate after winter wheat harvest. Establishment and midseason DM of the relay crops were not affected consistently by cereal crop type. Legume DM at freeze-up was similar in winter wheat and fall rye systems and ranged from 190 to 1800 kg/ha, with moisture availability being the critical factor. Across all site-years, final DM for red clover, alfalfa, chickling vetch, and lentil averaged 1157, 690, 746, and 634 kg/ha.

Mahmood *et al.* (2003) investigated about the planting geometry of rice relay cropping at zero tillage. They considered different planting geometries of 20 x 20 cm hills, 30 cm apart single rows (30 x 15 cm), 45 cm apart double row strips (15 x 45 cm), 60 cm apart triple row strips (15 x 60 cm) and 75 cm apart four row strips (15 x 75 cm). The varieties of rice included were Basmati – 385 and Basmati – 370. It was recorded that Basmati – 385 matured and yielded higher than Basmati – 370. The pattern 20 cm x 20 cm yielded (34.42 q/ha) more than 75 cm apart four row strip pattern (30.66 q/ha).

Worku (2004) discussed the planting patterns and leaf stripping by farmers is not yet understood. The planting pattern included broadcasting, 60 cm/37.5 cm, 75 cm/30 cm, 100 cm/22.5 cm, while leaf removal consisted of no leaf removal, leaf removal below the ear, and the leaf removal below the ear plus two leaf removal at 10 days interval. Tef was sown by broadcasting under the standing maize crop about 35 days from maize silking. Broadcasting and narrow inter row maize spacing significantly reduced grain yield. Maize leaf removal below the ear improved tef grain yield without reducing maize yield. Addition leaf removal above the ear improved tef straw yield. Leaf removal was accompanied by shortening of days to maturity of maize and tef. Land equivalent ratio values ranged upto 1.3, which indicated an acceptable level of the efficiency for the cropping system.

Ghosh and Dayal (2005) conducted research on a vertisol in a new system of summer groundnut-relay cropping (SGRC) to find out the optimum date of sowing of groundnut in a relay cropping system with wheat and to assess the productivity and profitability of the system. In SGRC wheat was sown at 30 cm and 45 cm row spacing. Groundnut was sown in furrows between 45 cm wheat rows and hand dibbled between 30 cm wheat rows at 3 growth stages of wheat (heading-19th January, grain filling-31st January and 15 days before harvest-10th February). The results revealed that biomass production, crop growth rate (CGR), leaf area index (LAI), pod yield and haulm yield of relay groundnut were much lower than sole groundnut particularly when relay groundnut was sown at heading stage of wheat (19th January). However, total system productivity and net returns in the relay cropping system were higher than sole cropping groundnut and these were maximum when relay groundnut was sown at grain filling stage of wheat (25 days before harvest of wheat). This is a promising system for the semi-arid tropics of India.

Reda *et al.* (2005) conducted a test in northern Ethiopia to improve the cropping system by relay cropping system. Low soil fertility and environmental degradation develops weed infestation in agricultural lands. The relay cropping of sorghum and legume shrub was investigated at two locations. Legume shrubs resulted in lowering the yield of sorghum in a dry location (Adibakel). But the weed infestation reduced significantly. *Sesbania sesban* was the better adapted legume in dry land areas.

Kataria and Chandel (2007) conducted an experiment for 2 years during spring season at the research farm of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur to study the influence of different moisture regimes on growth and yield of potato and explore the possibility of growing relay crops in spring potato (*Solanum tuberosum L.*) Mulching with pine needles significantly increased tuber yield, growth and yield attributes. Optimum moisture regime (irrigation at IW / CPE ratio of 1.0) resulted in significantly higher tuber yield, growth and yield attributes. Rajmash was grown successfully as relay crop in spring potato resulting in significantly higher potato equivalent yield and net returns.

Ali *et al.* (2012) discussed that lentil relay in paddy field has greater opportunity to use the residual moisture. Different combinations of seed rate, fertilizer application and paddy straw height with different lentil verities were attempted by them. Lentil verities such as BARI Musur-4, BARI Musur-5,BARI Musur-7 with rice straw height under 30 cm, at the seed rate of 50 kg/ha and with a fertilizer level of 30-60-30 kg/ha of N-P_2O_5-K_2O produced a lentil seed yield of 2070 kg/ha. Relay of lentil in the monsoon rice field provided better yield of lentil, providing better nutrition to the population and quality improvement of soil for sustainable production system.

Buttar *et al.* (2013) described that sowing of wheat is delayed due to picking operation of cotton and time needed to prepare seedbed, resulting low yield of wheat. Lack of suitable machinery is also another major problem. To overcome this problem the '2-wheel tractor-based self-propelled relay seeder' with seed cum fertilizer attachment was developed. Four locations during 2009 – 2010 and ten locations during 2010 – 2011 were selected to evaluate the performance of that machine in relay cropping of cotton and wheat in the areas of south western Punjab. They developed four wheat sowing techniques. These are (1) zero till seeding in standing cotton using a self-propelled relay seeder, (2) relay seeding in standing cotton with a manual drill without prior tillage (2010 only), (3) relay broadcast seeding in standing cotton following light manual tillage and (4) conventional sowing of wheat after cotton harvest by conventional tillage and sowing by a seed – fertilizer drill. Planting of wheat under conventional practice was delayed by 20 to 44 days compared with relay seeding. Yield of wheat sown with the self-propelled relay seeder was 41.2% and 11.8% higher than with conventional practice in 2009–2010 and 2010–2011 respectively.

Yirzagla *et al.* (2013) investigated about the production efficiency of millet and legume by relay cropping in Upper East Region (UER) of Ghana. Three types of millets (Bongo Shorthead, Arrow Millet and Bristled Millet) were relayed with three legumes namely cowpea, groundnut and soyabean. Bongo Shorthead followed by cowpea relay cropping had the maximum prospect of yield of grain. But Bongo Shorthead followed by groundnut relay cropping is the least suitable combination of relay cropping within the Upper East Region of Ghana.

Aslam *et al*. (2014) conducted an experiment during winter seasons 2011-12 and 2012-13. The effect of different dates of removal of cotton sticks on the yield of wheat as relay crop sown in standing cotton was evaluated at Adaptive Research Farm. Four different dates (removal of cotton sticks 40 days after sowing wheat i.e. 20th December, after 50 days i.e 30th December, after 60 days i.e. 10th January and after 70 days i.e. 20th January of wheat sown in standing cotton were evaluated in a three replicated RCBD method. Results revealed that all the yield and yield parameters were significantly affected by the removal of cotton sticks of wheat in standing cotton. The average of two years result revealed that significant maximum plant germination i.e. 156.70 m^{-2}, fertile tillers i.e. 321.43 m^{-2}, height 105.15 cm, 1000 grain weight i.e. 39 g and grain yield of 4240 kg ha^{-1} was obtained when dry wheat seed was broadcasted immediately after irrigation.

Malik *et al.* (2014) discussed the relay cropping system in Eastern Gangetic Plains of Bangladesh, India and Nepal based on rice. Two strategies ware used by them to fit lentil as relay crop with monsoonal paddy (*aman*) and pre-monsoonal paddy (*aus*) or irrigated paddy (*boro*) crop. Tests were conducted at Ishurdi in Bangladesh and in Western Bangladesh. These tests were conducted over three years between sole cropped lentil and relay cropped lentil. Flowering of sole cropped lentil was 9 – 17 days earlier than relay cropped lentil but relay cropped lentil produced more economic yield compared to sole cropped lentil.

Bitew and Asargew (2015) conducted the experiment on rice as a main crop and chickpea as a companion crop relay intercropping. Five seed rates of chick pea relayed intercropped in between rows of transplanted rice and one sole rice were tested i.e. full recommended seed rate of chick pea relay intercropped in between rows of transplanted rice, two-third of the recommended seed rate of chick pea relay intercropped in between rows of transplanted rice, two-third of the recommended seed rate of chick pea relay intercropped in between alternate rows of transplanted rice, half of the recommended seed rate of chick pea relay intercropped in between rows of transplanted rice, half of the recommended seed rate of chick pea relay intercropped in between alternate rows of transplanted rice and the sole transplanted rice used as comparison. The study conducted for two consecutive years at all test sits confirmed that chick pea after twenty to thirty days from the planting time was completely dried and unable to gave seed yield from rice-chickpea relay intercropping experiment. Hence, under current crop management practice of rice at Fogera vertisol areas, chickpea cannot replace the grass pea in rice-grass pea relay intercropping system (farmers practice); and relay intercropping of chickpea with rice is not economically important for farmers to increase the yield potential and land use efficiency. It needs intensive Agronomy research on rice-chickpea intercropping systems and breeding on both component crops.

Mandal *et al*. (2015) conducted an experiment at a village Bodikona under Sylhet district in Bangladesh during November 2012 to March 2013 to know the performance of lentil varieties such as BARI mausur-3, BARI mausur-4, BARI mausur-6 and BARI mausur-7 under traditional and relay sowing with *Aman* rice. This experiment was conducted on the basis of days of 50% flowering, days of maturity, plant population per unit area, number of branches per plant, seed yield and straw yield. Significantly lower seed yield was obtained from relay cropping field compared to traditional cropping field because of lower plant population per unit area, number of branches per plant. The variety BARI masur-7 produced the highest seed yield (541.6 kg/ha) followed by BARI masur-4 (575.2 kg/ha).

Punyalue *et al.* (2015) conducted a test to reduce burning of residues of maize crop in highlands of Thailand. The residues are burned to prepare land for new crop. Three maize-legume relay cropping (maize + lablab, maize + ricebean and maize + cowpea) and maize monoculture was done in the wet season of 2012 and 2013. The yield of maize is 5.19 Mg/ha in maize mono cropping but in relay cropping the yield is increased by 24 to 53 percent. The legume grain yield was of 0.13 Mg/ha for maize and lablab, 0.3 Mg/ha for maize and ricebean and 0.73 Mg/ha for maize and cowpea. The nitrogen retained in the residue for maize and lablab was of 136 kg/ha, for maize and ricebean was of 68 kg/ha and for maize and cowpea 36 kg/ha. This maize and legume relay cropping system benefits the high lands of Thailand by reducing burning and increasing maize yield.

Sandler *et al.* (2015) researched about the relay intercropping of wheat (*Triticum aestivum* L.) followed by legume crop in Missouri as well as much of the Midwest of USA. Row spacing is the very important criteria to increase the crop productivity. They conducted two different aspects to evaluate the production yield. These were (1) winter wheat relay inter cropping using different legume crops and (2) relay inter cropping based on different row spacing. Normal wheat cultivation yields wheat by 150 kg/ha. For narrow spacing and relay intercropping with soybean, the total grain yield increased to 575 kg/ha. Land equivalent ratio (LER) values for determining the productivity of relay intercrop system of 19 and 38 cm row spacing showed an advantage in better production of legume crops in 2013.

The study of the available literature clearly showed relay cropping as a very useful method of crop cultivation. Different crop combinations can be effectively selected for relay cropping. The prospect of lentil as a relay crop with monsoon paddy was also evident from the present literature survey. Therefore, in the present investigation emphasis has been given to evaluate the capacity of residual moisture content of soil to support the optimum growth of lentil in a paddy-lentil relay cropping system.

CHAPTER 3 MATERIALS AND METHODS

3.1 Selection of crop field for relay cropping

The selection of suitable crop field for relay cropping is very important in relay cropping of paddy and lentil. This type of relay cropping cannot be performed in any type of soil. The characteristics of the field chosen are given below.

I. Ideally clay loam soil with significant water holding capacity should be selected. Therefore, in the present study the plots with medium textured soil have been selected for trial.
II. The plots were situated in low land areas. Therefore, higher available moisture was present in the plots at the end of monsoon season.
III. After withdrawal of monsoon there should be sufficient residual moisture in the soil to support the second crop during the majority of its growth period.

3.2 Crops selected for relay cropping

The two crops selected for relay cropping were monsoon paddy and lentil. Paddy is the first crop and lentil is the second crop. Some specific information about the two crops has been given below.

3.2.1 Monsoon Paddy (*Kharif*)

In the present study *kharif* paddy was chosen as the first crop. The basic information about this *kharif* paddy is given in Table 3.1.

Table 3.1 Crop related data of *kharif* paddy

Date of sowing	30th June, 2015
Date of harvesting	25th November, 2015
Water requirement	120 cm (Approx)
Variety	MTU 7029 (Sarna)

3.2.2 Lentil

Lentil was selected as the second or relay crop which was planted before the harvesting of paddy. Some basic agronomic information of the crop is given in Table 3.2..

Table 3.2 Crop related data of lentil

Date of sowing	18th November, 2015
Date of harvesting	25th March, 2016
Water requirement	20 to 25 cm
Varity	B 77 (Asha)
Germination	80% (minimum)
Purity	98% (minimum)

3.3 Seed Inoculation

3.3.1 Definition

Seed inoculation is defined as the process of mixing of effective nitrogenous bacteria such as rhizobium, azotobactor to the seeds of leguminous crops such as lentil, peas, beans, vetches, alfalfa, clovers etc. The main objective of seed inoculation is to help the legume crop to fix gaseous nitrogen into a plant-usable from, which allows better growth for both the legumes and the subsequent crops. Some legumes are capable of fixing up to 300 lb of nitrogen/acre, other fix between 50 – 200 lb of nitrogen/acre. Species and variety selection, plant population, soil type and fertility, water availability and growing periods all affect nitrogen fixation ability of legumes. In order to insure good nitrogen fixation by legume it is necessary to inoculate the legume with proper kind of bacteria. This simple, low cost process returns benefits many times higher than the costs. Seed inoculation rate for each of azotobactor and rhizobium is 10 gm/kg of seed.

3.3.2 Method to inoculate legume seeds

I. Fresh inoculants have to be used. All inoculants have a shelf life and are dated on the package to ensure high populations of active bacteria in the package.

II. It has to be ensured that proper inoculants are being used with the proper seed. Each species of legume requires a specific type of rhizobacteria for nitrogen fixation. For an example, vetch inoculant will not work on clovers. The package is labelled with the plant species for which the package is intended.

III. One can use too much inoculant but cannot use too little. It is all right to use two or three times of the recommended rate on the package. This is especially useful if planting into a soil which has never had this type of legume before or if planting into soils which are not going to be irrigated, as some of the rhizobium will die if rains are not in time.

IV. The bacteria are sensitive to heat and sunlight. It is not recommended to leave these packages in open sun. These have to be stored in a cool location, a refrigerator is the best.

V. Most growers inoculate as they want to ensure high populations of the bacteria on the seed. Inoculated seeds can be stored for up to 4-8 hours; after that they should be re-inoculated. Inoculated seeds should be kept out of the sun as much as possible.

VI. At first peat and moss are mixed with seeds. The mixture has to stick with the seeds. The best way to stick the mixture with seed is to wet the seed. Non-chlorinated water can be used but to obtain much better result a combination of whole milk and molasses is used. One quart of whole milk is mixed with two table spoon of molasses. One quart of this mixture can be mixed with 1500lb of seed. In the present study rice drain was used to wet the seeds of lentil (Fig. 3.1).

VII. The seeds are put on a plastic sheet. Then the mixture of whole milk and molasses is sprayed on the seeds. Then the seeds are turned and the processed is repeated. Then the mixture of inoculant, pit and moss is mixed with the seeds. This process has to be conducted under a shaded place. The seed will blacken after it comes in contact with inoculant.

VIII. Then the seeds have to be planted immediately. The longer the seeds stay exposed to sunlight, the less effective the inoculation will be.

IX. Irrigation has to apply as soon as possible after plantation. This will increase the survival and germination of the seed and inoculant.

3.4 Broadcasting of lentil seed

3.4.1 Definition

Broadcasting is the process of random scattering of seed, by hand or mechanically, over a relatively large area. When broadcasting is done manually, uniformity of seed depends upon the skill of the labour. After broadcasting seeds are covered by devices. Mechanical broadcasters are used for large scale work. This machine scatters the seeds uniformly on the land surface at a controlled rate. Fig. 3.2 shows manual broadcasting of lentil on standing paddy crop.

(a) Lentil seeds

(b) Seed wetting by rice drain

(c) Mixing of seed inoculants

(d) Drying of inoculated seeds in shade

Fig. 3.1(a-d). Seed inoculation process of lentil seed before broadcasting as relay crop

Fig. 3.2 Manual broadcasting of lentil seeds on standing paddy crop

3.4.2 Harvesting of paddy after broadcasting

Ideally the paddy should be harvested two weeks after broadcasting of lentil seeds. From Tables 3.1 and 3.2 it is evident that the paddy was harvested 17 days after sowing of lentil. The reasons of the minimum crop overlap period are as follows:

I. The critical stage of paddy growth is over after around two weeks of sowing of lentil.
II. The germination time of lentil is 4 to5 days after sowing. Around 5 cm height of lentil is achieved in these two weeks. Therefore, the extent of damage of lentil seedlings by manual interventions during harvesting of paddy should be minimum. Fig. 3.3 shows the germinated lentil plants after harvesting of paddy.

Fig 3.3 Germinated lentil seeds after harvesting of paddy

3.5 Application of foliar nutrition

A dose of foliar nutrition [urea (CH_4N_2O)] was applied to the lentil after one month of sowing. A 2% (20 gm/per liter of water) solution of urea was prepared and applied to the lentil foliage using a knapsack sprayer. It is generally applied to promote branching of lentil crops.

3.6 Soil sampling and moisture content analysis

The soil samples were taken from the relay cropped lentil plots located in the two villages of Coochbehar and Alipurduar districts. The village in Coochbehar was Dhalaguri and the village in Alipurduar was Uttar Chakawakheti. Soil samples were taken from two depths, one from surface (top 15 cm) and other from 30 cm depth. A soil auger was used to collect the soil of 30 cm depth. There were four plots in each of the two villages from where the soil samples were collected. The area of Dhalaguri where this relay cropping was performed was 3.25 bigha and the cropped area of Uttar Chakawakheti was 1.5 bigha. The first soil sample was taken on the date of sowing i.e. from Dhalaguri on 13th November, 2015 and from Uttar Chakawakheti on 14th November, 2015. First soil sample was taken just from surface soil, because lentil roots were not developed on that particular date. After that seven samples from surface soil and 30 cm depth were taken from each plot of Dhalaguri and Uttar Chakawakheti. The last soil samples were collected on 6th January from Dhalaguri and on 7th January from Uttar Chakawakheti.

Fig 3.4 Collection of soil samples using soil auger

3.7 Determination of moisture content of soil samples

Soil samples were collected from the relay cropped fields at weekly interval to monitor how the residual soil moisture left by paddy is utilized by lentil. The collected soil samples were analysed in the laboratory using gravimetric method to estimate the moisture contents. The instruments required for estimating the moisture content of the soil samples are given below.

1. Hot air oven.
2. Soil moisture box.
3. Electronic weighing balance.

3.7.1 Hot air oven

Hot air oven (Fig. 3.5) was used to dry the collected soil samples. It can be operated in the temperature range from 50 to 300°C. Using a thermostat we can control the temperature. Double walled insulation keeps the heat in and conserves energy. The inner layer is a poor conductor and the outer layer is metallic. There is also an air filled space in between to aid insulation. Air circulating fan helps in uniform distribution of heat. The interior of the oven is filled with the adjustable wire mesh plated trays.

3.7.1.1 Advantages of hot air dryer

The advantages of hot air dryer are given below.

I. There is not much pressure build up within the oven.
II. It is suitable for use in laboratory environment.
III. It is very efficient in removing moisture from soil sample.

3.7.1.2 Disadvantage of hot air dryer

The disadvantages of hot air dryer are given below.

I. It is a high time consuming process.
II. It is not efficient to dry a large amount of soil at a time.

The specifications of the hot air oven used are given in Table 3.3.

Fig 3.5 Hot air oven dryer (SONAR+)

Table 3.3: Specification of hot oven dryer

Temperature	250°C
Size	24 inch x 36 inch x 18 inch
Load	0.5 kW
Input voltage	220 – 230 V
Number of trays in the dryer	3
ISO code	ISO 9001-2000

3.7.2 Moisture Box

These are circular shaped box made of aluminum (Fig. 3.6). It is used to take weight and dry the soil sample in the oven for moisture content determination of soil samples. Eight numbers of moisture boxes were used in this project to dry the collected topsoil and soil at 30 cm depth of four plots of each location (Dhalaguri and Uttar Chakawakheti).

3.1.2.1 Features of Moisture Box

I. It eliminates change in weight of container due to rusting.
II. It is lightweight and not damaged by prolonged heating in the oven.

Fig 3.6 Moisture box

Table 3.4: Specifications of the soil moisture box

Diameter	11.1 cm
Height	4.2 cm
Weight	32 – 34 gm

3.7.3 Electronic Weighing Balance

An electronic weighing balance (Fig. 3.7) was used to measure the mass of the dry and wet soil samples. It is a very precise and sensitive instrument to accurately measure the mass of a sample. It is very compact in design and handy for quick reference of weight of the samples. The specifications of the electronic balance used are given in Table 3.5.

Fig 3.7 Electronic weighing machine (METTLER TOLEDO PB 153-S)

Table 3.5 Specifications of the electronic weighing balance

Make	METTLER TOLEDO
Mass capacity (gm)	151 ± 0.02
Voltage (V)	14.5 – 8
Load (W)	6

3.8 Experimental Procedure

The determination of moisture content by oven drying method is termed as gravimetric method. In this method the soil sample is dried for 24 hours at 105°C temperature. After that the soil sample becomes bone dried. Then the dry moisture content is measured by the moisture evaporated with respected to the bone dry mass of the soil sample. The procedure of determination of dry basis moisture content of soil samples is given below.

I. At first the eight moisture boxes were cleaned and dried. Their empty masses were recorded by the electronic weighing balance.
II. The wet soil samples were put in sealed polythene pouches immediately after collection from the field. Each sample weighed approximately 100 g or more. These samples were marked for identification of the samples. These samples were taken to the laboratory for further analysis.
III. The wet soil samples were put in the moisture box and their weights were noted. The weight of the empty moisture box was subtracted to obtain the weight of the wet soil mass.
IV. Then the soil samples were put into the oven with the lid of the moisture boxes open.
V. The hot oven dryer was set at 105°C and the samples were kept for 24 hours.
VI. After 24 hours the soil samples were bone dried and they were taken off from the hot oven dryer.
VII. The weight of the moisture box containing dry soil mass (with top lids) was recorded. Subtracting the weight of the empty moisture box the weight of the dry soil was estimated.
VIII. Subtracting the weight of the dry soil mass from the wet soil mass, the weight of moisture was estimated.
IX. The moisture content of each soil sample was expresses in dry basis.

3.9 Calculation dry moisture content of soil samples

Dry basis moisture content of soil is the ratio of the mass of total moisture in the soil sample to the mass of the solid material of the dry soil. Therefore, the equation for expressing dry basis moisture content of soil can be given as:

$$M_d = (W_w / W_s) \times 100\% \qquad \ldots (3.1)$$

where,

M_d = dry basis moisture content of soil sample (%)

W_w = weight of the water removed from soil sample by oven drying (g)

W_s = weight of the soil solids in the soil sample (g)

In this chapter the detailed description about the results of the tests conducted to determine the moisture contents and to the variation of soil moisture contents in a plot with time are presented. The first sampling was done on the date of sowing of the lentil seed and the last sampling was done before the onset of pre-monsoon showers. In the first sampling only topsoil samples were collected as the roots of the second crop was not developed at that time. However, in all the subsequent samplings the soil samples were collected randomly from the plots with one topsoil sample and one sample from 30 cm depth for each location.

4.1 Experimental results of Plot 1 (E_1) at Dhalaguri

Table 4.1 and Figs. 4.1 and 4.2 show the variations of the topsoil (15 cm) and subsoil (30 cm) moisture contents in percent dry basis (db) for the relay cropped Plot 1 (E_1) in Dhalaguri. The total sampling period was 8 weeks starting from the date of sowing.

Table 4.1 Variations of surface soil moisture contents and 30 cm depth soil moisture contents in the plot E_1

Weeks	Moisture contents at surface soil (% db)	Moisture content at 30 cm depth soil (% db)
1st	41.38	-
2nd	33.60	35.87
3rd	29.40	31.74
4th	22.70	26.86
5th	25.43	29.90
6th	28.40	33.97
7th	25.25	32.49
8th	27.42	38.45

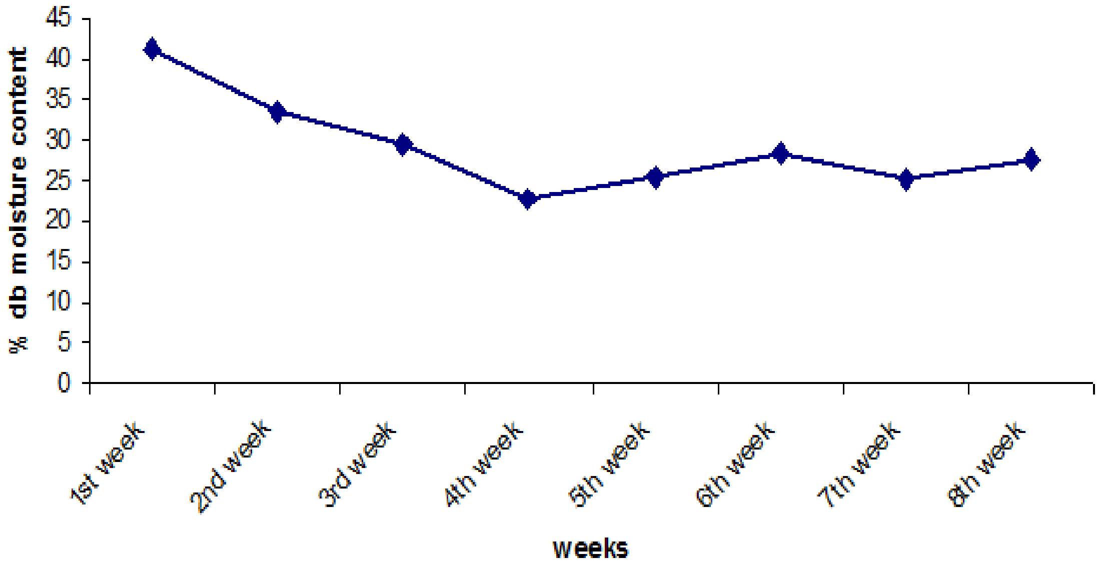

Fig. 4.1 Weekly **v**ariations of moisture content (% db) of topsoil in the plot E_1

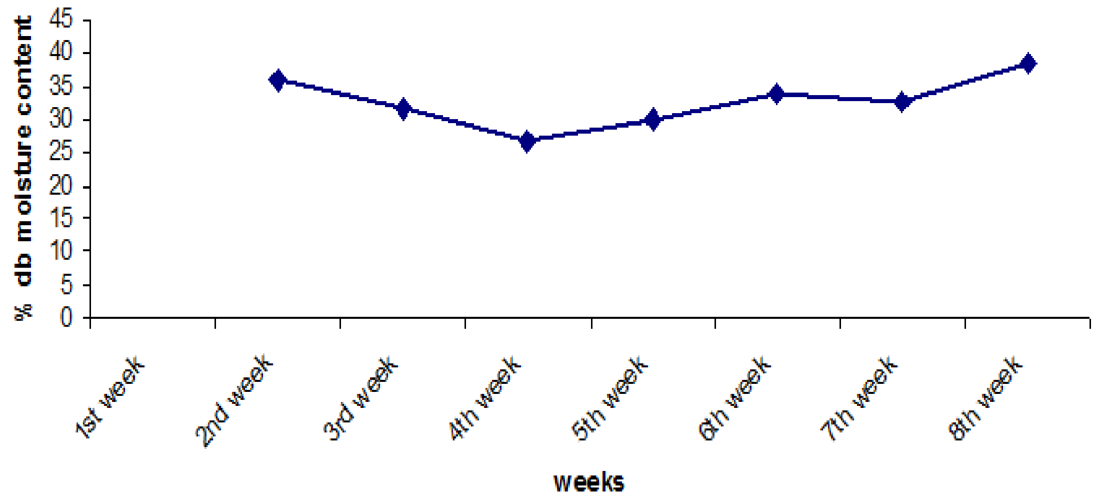

Fig. 4.2 Weekly **v**ariations of moisture content (% db) at 30 cm depth in the plot E_1

4.2 Experimental results of Plot 2 at Dhalaguri (E_2)

Table 4.2 and Figs. 4.3 and 4.4 show the variations of the topsoil (15 cm) and subsoil (30 cm) moisture contents in percent dry basis (db) for the relay cropped Plot 2 (E_2) in Dhalaguri. The total sampling period was 8 weeks starting from the date of sowing.

Table 4.2 Variations of surface soil moisture contents and 30 cm depth soil moisture contents in the plot E_2

Weeks	Moisture contents at surface soil (% db)	Moisture content at 30 cm depth soil (% db)
1st	48.44	-
2nd	42.50	21.34
3rd	29.17	31.16
4th	11.26	28.74
5th	23.92	25.70
6th	28.52	29.14
7th	19.20	24.62
8th	30.23	31.12

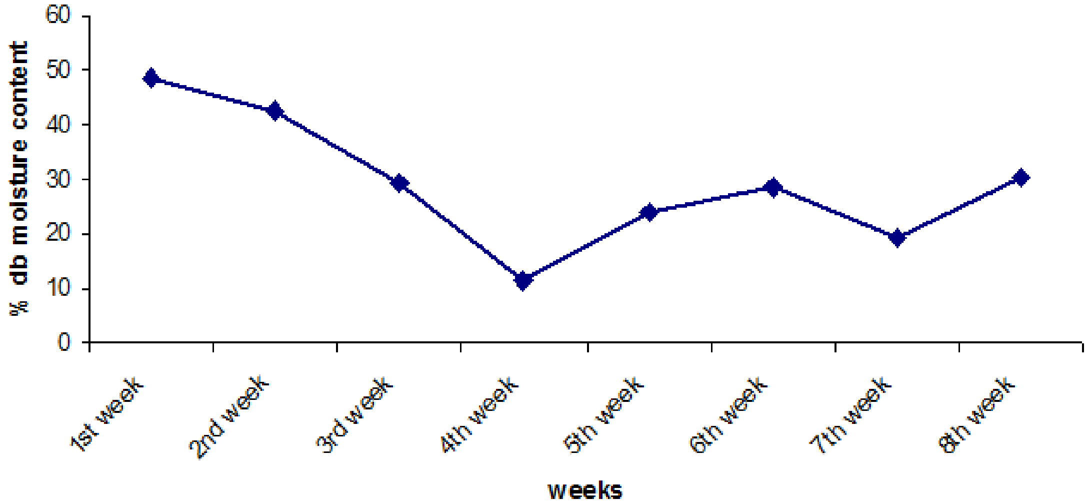

Fig. 4.3 Weekly **v**ariations of moisture content (% db) of topsoil in the plot E_2

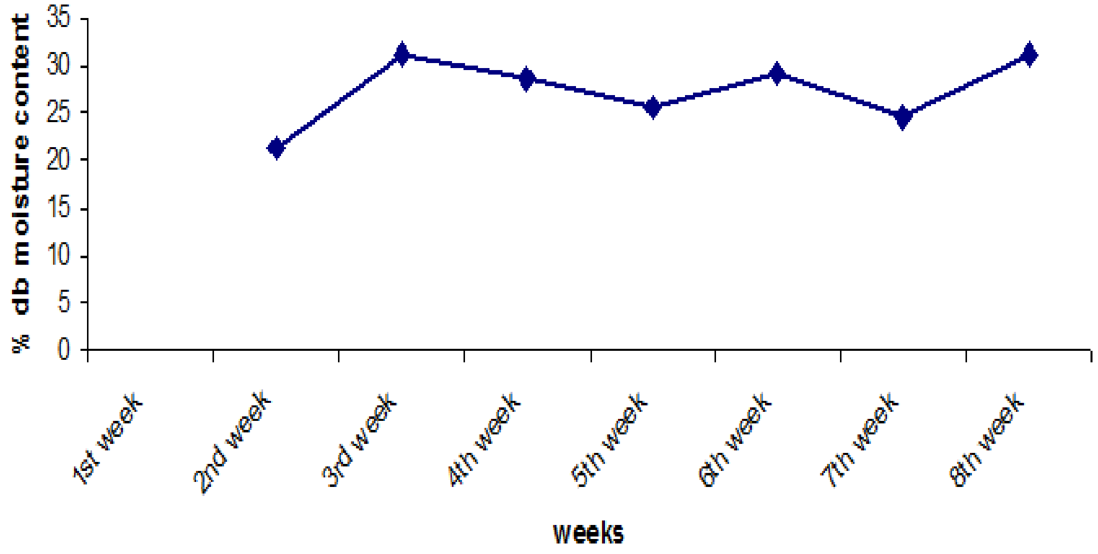

Fig. 4.4 Weekly **v**ariations of moisture content (% db) at 30 cm depth in the plot E_2

4.3 Experimental results of Plot 3 at Dhalaguri (E_3)

Table 4.3 and Figs. 4.5 and 4.6 show the variations of the topsoil (15 cm) and subsoil (30 cm) moisture contents in percent dry basis (db) for the relay cropped Plot 3 (E_3) in Dhalaguri. The total sampling period was 8 weeks starting from the date of sowing.

4.4 Experimental results of Plot 4 at Dhalaguri (E_4)

Table 4.4 and Figs. 4.7 and 4.8 show the variations of the topsoil (15 cm) and subsoil (30 cm) moisture contents in percent dry basis (db) for the relay cropped Plot 4 (E_4) in Dhalaguri. The total sampling period was 8 weeks starting from the date of sowing.

4.5 Experimental results of Plot 1 at Uttar Chakawakheti (E_5)

Table 4.5 and Figs. 4.9 and 4.10 show the variations of the topsoil (15 cm) and subsoil (30 cm) moisture contents in percent dry basis (db) for the relay cropped Plot 1 (E_5) in Uttar Chakawakheti. The total sampling period was 8 weeks starting from the date of sowing.

4.6 Experimental results of Plot 2 at Uttar Chakawakheti (E_6)

Table 4.6 and Figs. 4.11 and 4.12 show the variations of the topsoil (15 cm) and subsoil (30 cm) moisture contents in percent dry basis (db) for the relay cropped Plot 2 (E_6)

in Uttar Chakawakheti. The total sampling period was 8 weeks starting from the date of sowing.

Table 4.3 Variations of surface soil moisture contents and 30 cm depth soil moisture contents in the plot E_3

Weeks	Moisture contents at surface soil (% db)	Moisture content at 30 cm depth soil (% db)
1^{st}	45.12	-
2^{nd}	46.28	26.40
3^{rd}	43.40	31.72
4^{th}	25.90	28.49
5^{th}	29.10	27.30
6^{th}	33.40	35.17
7^{th}	31.47	32.70
8^{th}	36.20	28.52

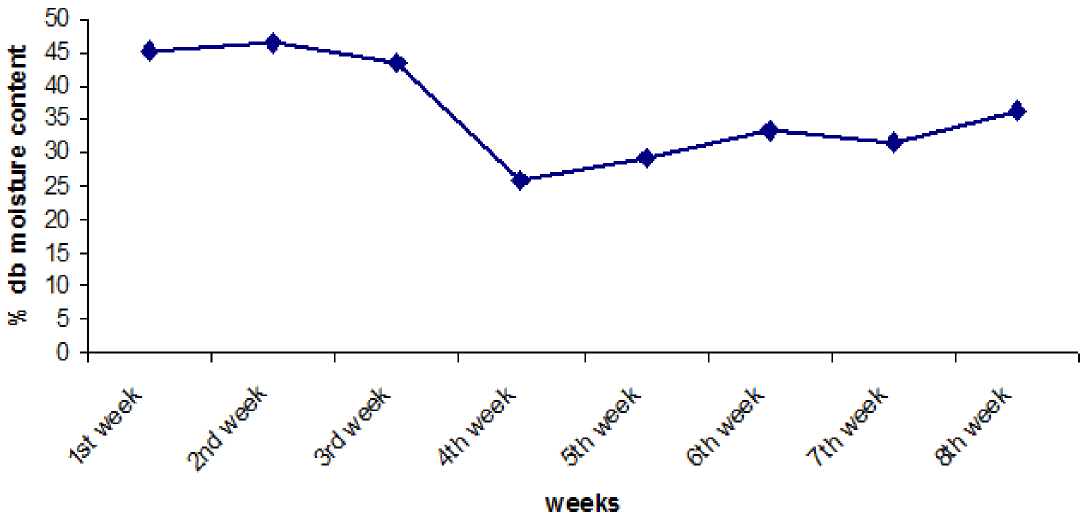

Fig. 4.5 Weekly **v**ariations of moisture content (% db) of topsoil in the plot E_3

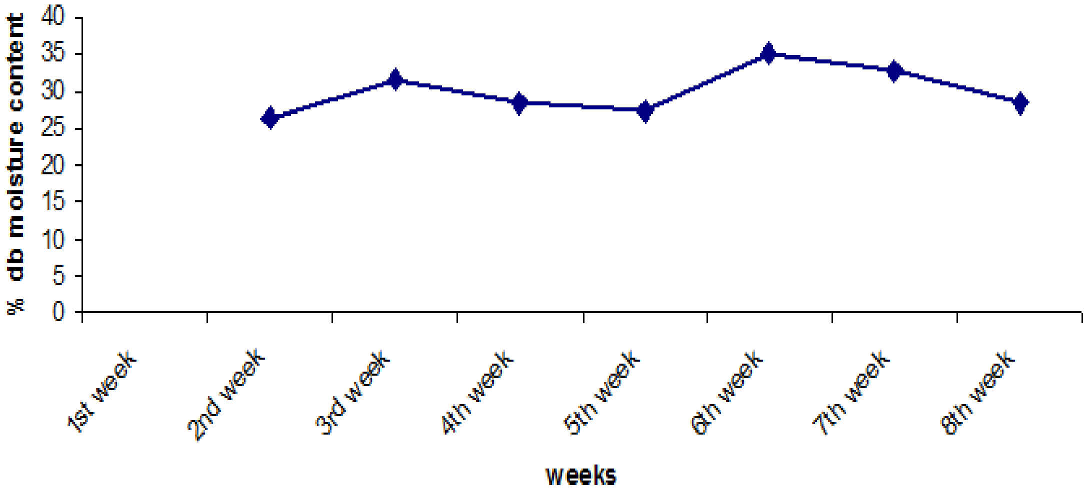

Fig. 4.6 Weekly **v**ariations of moisture content (% db) at 30 cm depth in the plot E_3

Table 4.4 Variations of surface soil moisture contents and 30 cm depth soil moisture contents in the plot E_4

Weeks	Moisture contents at surface soil (% db)	Moisture content at 30 cm depth soil (% db)
1^{st}	47.12	-
2^{nd}	46.40	30.70
3^{rd}	41.20	31.30
4^{th}	34.60	27.70
5^{th}	20.13	25.60
6^{th}	39.20	33.78
7^{th}	35.13	33.12
8^{th}	32.55	32.84

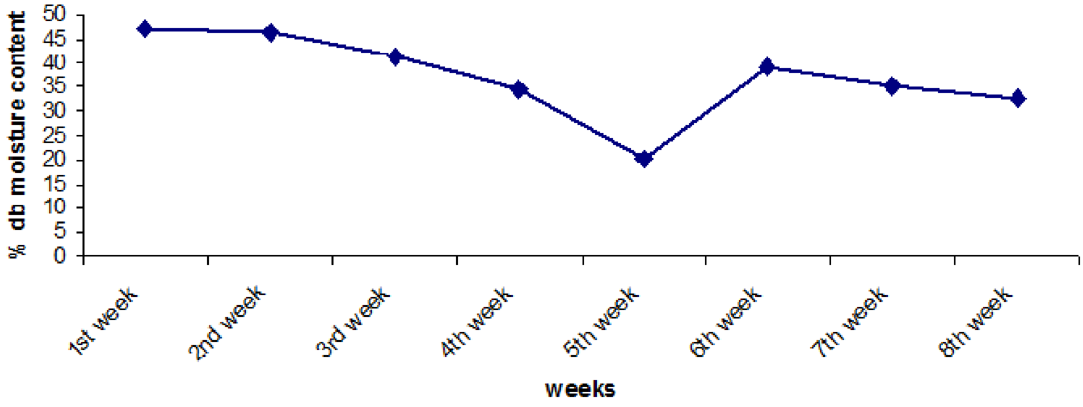

Fig. 4.7 Weekly **v**ariations of moisture content (% db) of topsoil in the plot E_4

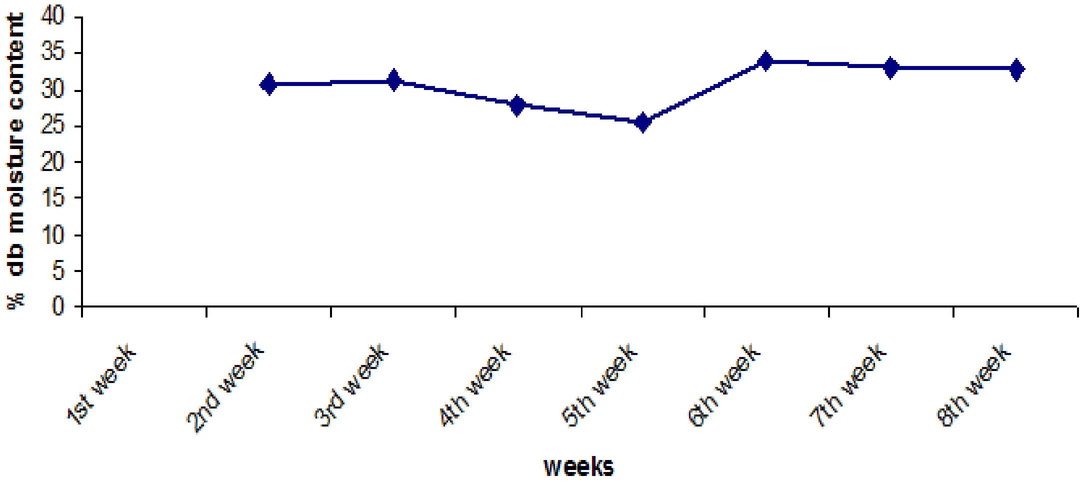

Fig. 4.8 Weekly **v**ariations of moisture content (% db) at 30 cm depth in the plot E_4

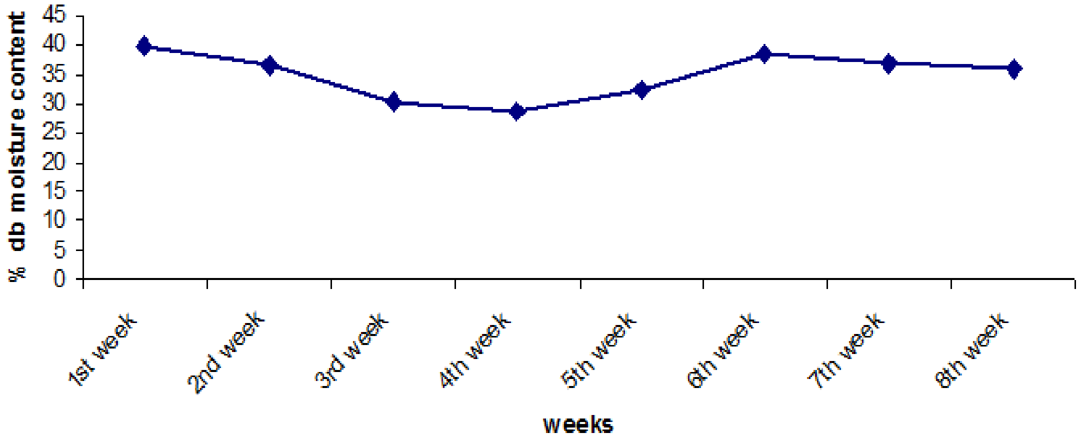

Fig. 4.9 Weekly **v**ariations of moisture content (% db) of topsoil in the plot E_5

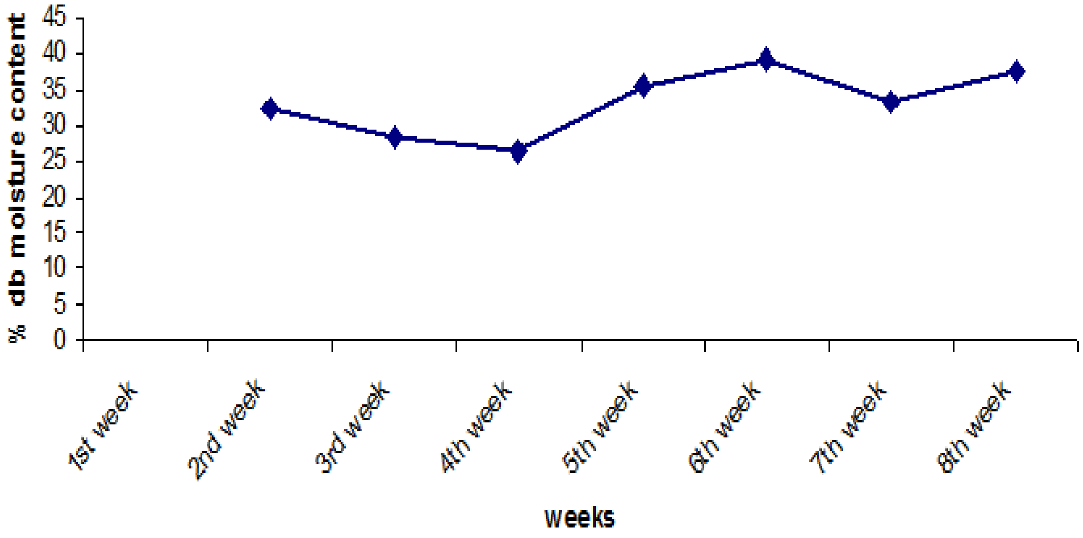

Fig. 4.10 Weekly **v**ariations of moisture content (% db) at 30 cm depth in the plot E_5

Table 4.5 Variations of surface soil moisture contents and 30 cm depth soil moisture contents in the plot E_5

Weeks	Moisture contents at surface soil (% db)	Moisture content at 30 cm depth soil (% db)
1st	39.85	-
2nd	36.43	32.30
3rd	30.27	28.41
4th	28.80	26.54
5th	32.14	35.60
6th	38.54	39.20
7th	36.81	33.15
8th	42.43	37.42

Table 4.6 Variations of surface soil moisture contents and 30 cm depth soil moisture contents in the plot E_6

Weeks	Moisture contents at surface soil (% db)	Moisture content at 30 cm depth soil (% db)
1st	40.90	-
2nd	35.23	30.70
3rd	31.53	28.32
4th	29.40	28.83
5th	31.90	29.43
6th	36.21	39.44
7th	32.19	36.46
8th	36.14	38.19

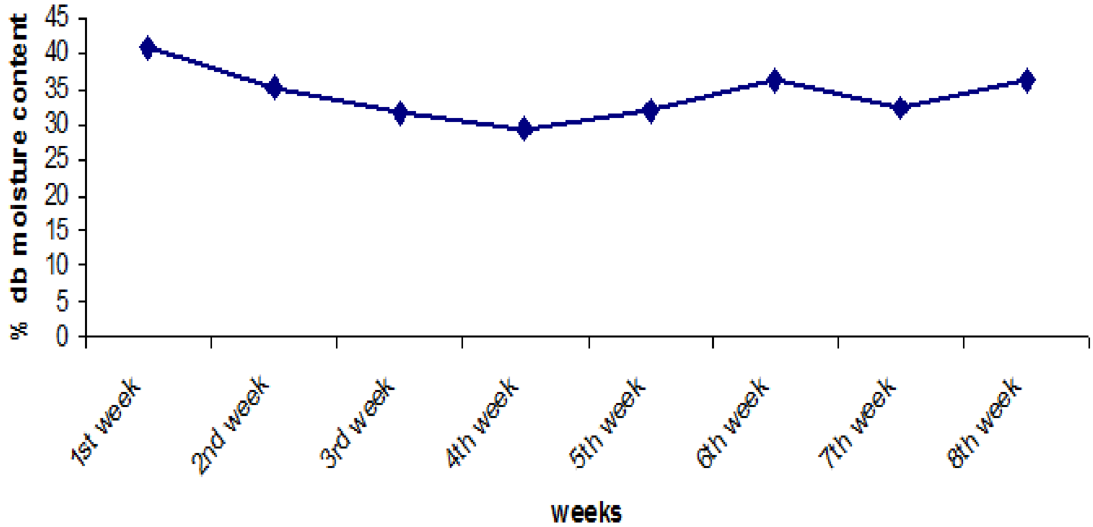

Fig. 4.11 Weekly **v**ariations of moisture content (% db) of topsoil in the plot E_6

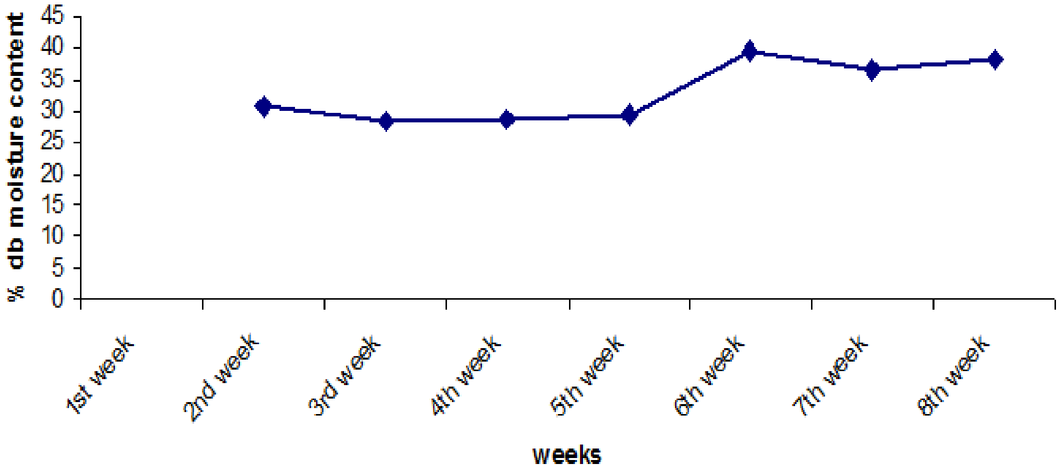

Fig. 4.12 Weekly **v**ariations of moisture content (% db) at 30 cm depth in the plot E_6

4.7 Experimental results of Plot 3 at Uttar Chakawakheti (E_7)

Table 4.7 and Figs. 4.13 and 4.14 show the variations of the topsoil (15 cm) and subsoil (30 cm) moisture contents in percent dry basis (db) for the relay cropped Plot 3 (E_7) in Uttar Chakawakheti. The total sampling period was 8 weeks starting from the date of sowing.

Table 4.7 Variations of surface soil moisture contents and 30 cm depth soil moisture contents in the plot E_7

Weeks	Moisture contents at surface soil (% db)	Moisture content at 30 cm depth soil (% db)
1st	42.89	-
2nd	40.40	32.10
3rd	43.67	32.90
4th	19.35	29.20
5th	25.60	24.10
6th	35.50	27.37
7th	28.56	20.50
8th	42.45	34.60

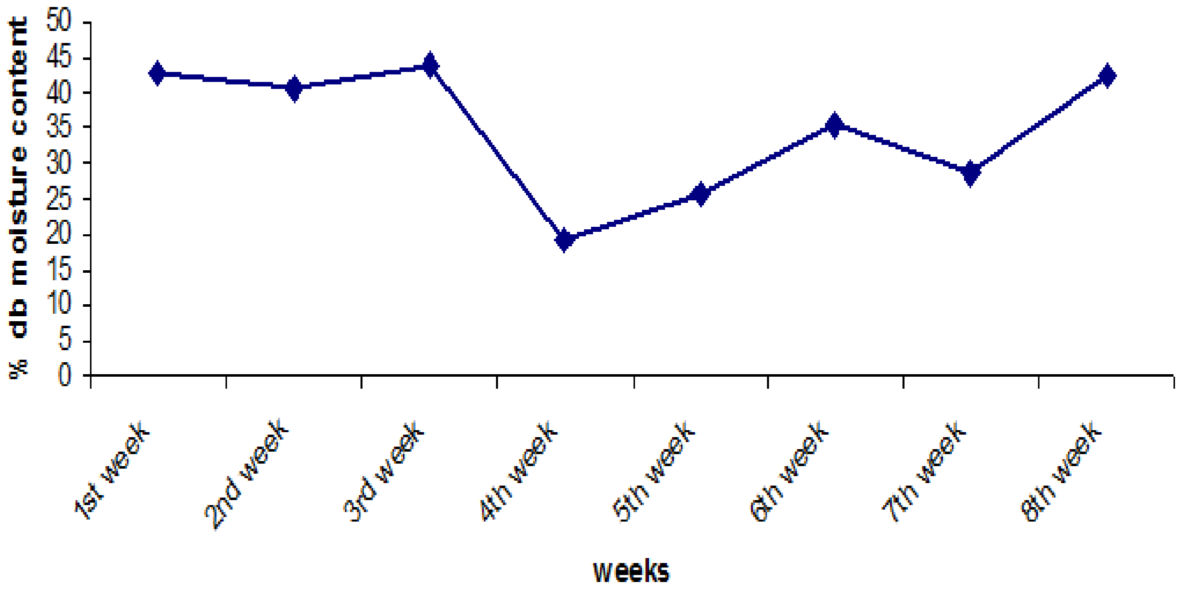

Fig. 4.13 Weekly **v**ariations of moisture content (% db) of topsoil in the plot E_7

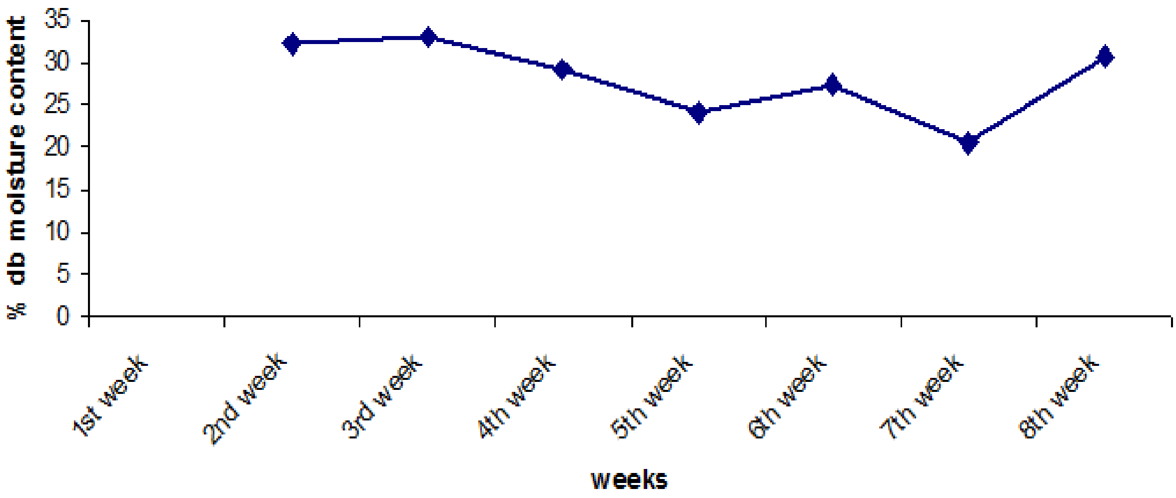

Fig. 4.14 Weekly **v**ariations of moisture content (% db) at 30 cm depth in the plot E_7

4.8 Experimental results of Plot 4 at Uttar Chakawakheti (E_8)

Table 4.8 and Figs. 4.15 and 4.16 show the variations of the topsoil (15 cm) and subsoil (30 cm) moisture contents in percent dry basis (db) for the relay cropped Plot 4 (E_8) in Uttar Chakawakheti. The total sampling period was 8 weeks starting from the date of sowing.

Table 4.8 Variations of surface soil moisture contents and 30 cm depth soil moisture contents in the plot E_8

Weeks	Moisture contents at surface soil (% db)	Moisture content at 30 cm depth soil (% db)
1st	41.78	-
2nd	43.45	32.10
3rd	31.60	32.90
4th	28.30	29.20
5th	22.60	24.10
6th	25.43	22.62
7th	21.90	19.50
8th	38.65	44.60

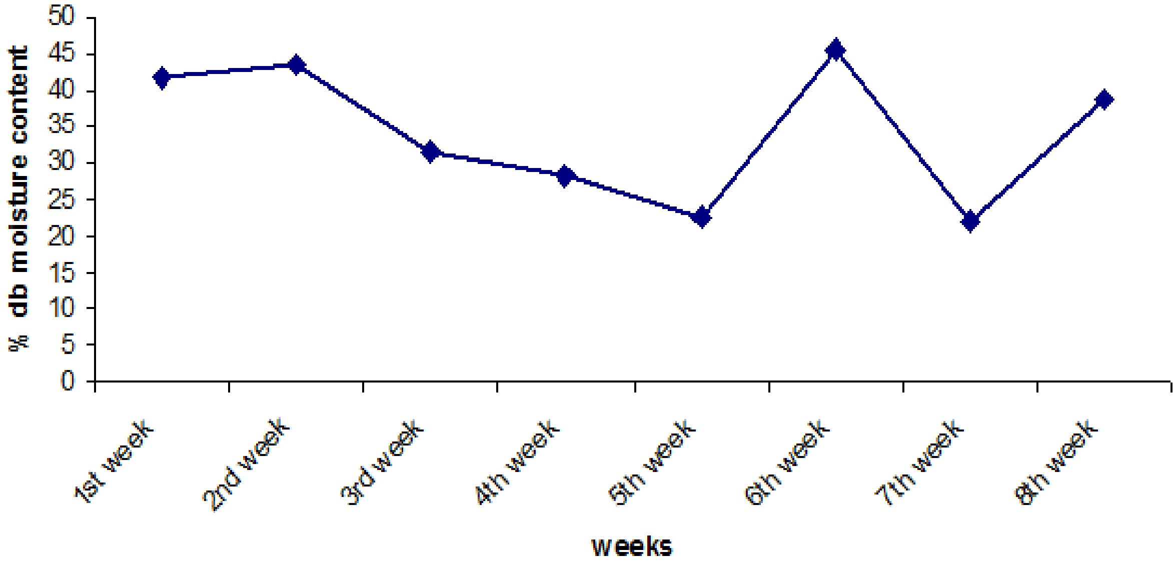

Fig. 4.15 Weekly **v**ariations of moisture content (% db) of topsoil in the plot E_8

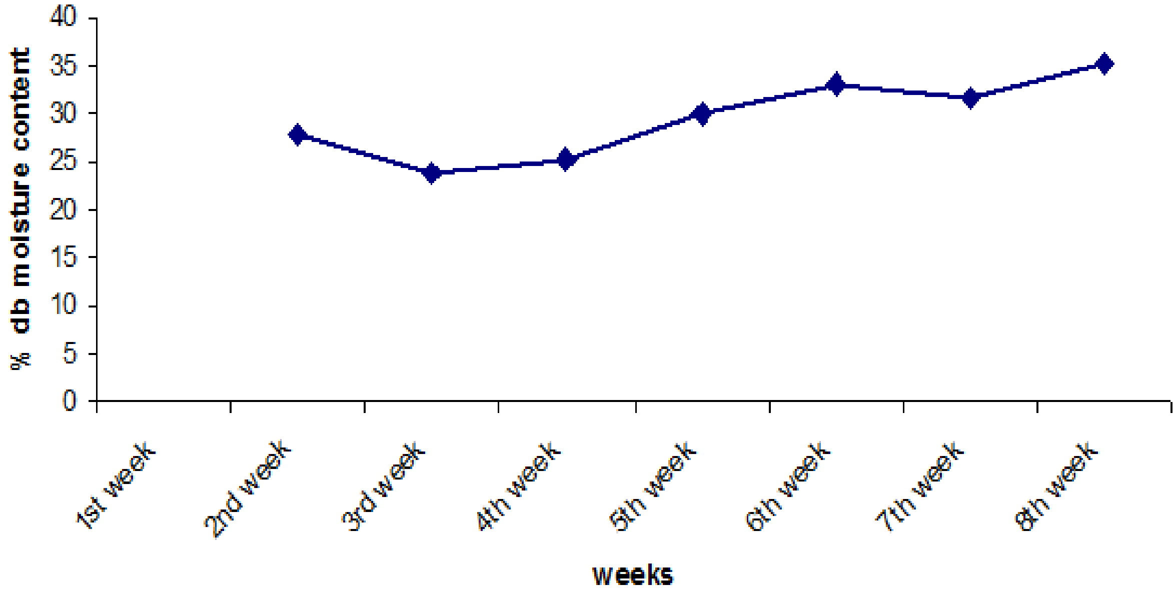

Fig. 4.16 Weekly **v**ariations of moisture content (% db) at 30 cm depth in the plot E_8

4.9 Discussions

4.9.1 Choice of fields for relay cropping

The fields chosen for relay cropping in Dhalaguri and Uttar Chakawakheti were of medium textured clay loam soil. Its average field capacity was 24% (db) and average permanent wilting point was 15% (db). As the plots were located in low land area, there was sufficient residual moisture content after harvesting of monsoon paddy. The initial topsoil moisture contents in the chosen crop fields were sufficient to help good germination of the lentil seeds. From the graphical plots of temporal variations of soil moisture contents (topsoil and subsoil at 30 cm depth) it is also clear that even after 8 weeks of the crop the residual moisture contents in the topsoil and subsoil were sufficient to support the healthy growth of the crop (Fig. 4.17) without any supplemental irrigation.

4.9.2 Choice of crops for relay cropping

In the present study the crops selected for relay cropping were monsoon paddy and lentil. Paddy was the first crop and lentil was the second crop. Monsoon paddy or *kharif* paddy was selected because after monsoon season when the paddy is harvested there was sufficient soil moisture to sustain the critical growth period of the second crop i.e. lentil. From Table 3.1 it can be seen that the average water requirement of paddy is about 120 cm. For monsoon paddy the bulk of this requirement is supplied by rainfall. Under favourable soil conditions, even after satisfying the crop water requirement of paddy, sufficient moisture might be available in soil for the cultivation of a low water requiring crop. Lentil was selected as the second crop because lentil has low water requirement, it improves soil health and nutrient profile, it reduces pest and diseases problems in the crop field. Being a legume crop lentil is known to fix the gaseous nitrogen in soil through many bacteria such as rhizobium, azotobactor etc. This nitrogen allows better growth of legumes and the other subsequent crops. Furthermore, the residual fertilizers in the paddy fields can also be utilized by the lentil crop.

(a) (b)

Fig. 4.17 Healthy growth of relay cropped lentil at (a) Uttar Chakwakheti and (b) Dhalaguri

4.9.3 Effect of seed inoculation

For inoculation of lentil seed 10 gram of rhizobium and 10 gram of azotobactor were mixed with one kg of lentil seed. This inoculation of the seeds helps in rapid growth of the nitrogen fixing bacteria in the plant. Therefore, supplemental fertilizer requirement of the crop is also significantly reduced. It is a very low cost technique to save the cost of fertilizers, improve soil health, and for the healthy growth of the crop.

4.9.4 Seed broadcasting and application of foliar nutrition

For broadcasting of lentil seed plant spacing often become dense or there are empty patches around the field. The distribution of the seeds largely depends on the efficiency of the labour performing the broadcasting. For rapid growth of the crop a dose of foliar nutrition in the form of urea (CH_4N_2O) was applied at one month after the date of sowing. Post application of foliar nutrition rapid vegetal growth of the crop was evident in the plots. The plots where foliar nutrition was not applied, the crop growth was poor.

4.9.5 Residual soil moisture and relay cropping

In the present study the temporal variations of the soil moisture profile (topsoil and at 30 cm depth) was monitored in eight plots of paddy-lentil relay cropping system over a period of eight weeks since the date of sowing of the second crop (lentil). The eight plots were located in two villages of North Bengal, viz. Cooch Behar and Uttar Chakwakheti, with four plots in each village. Some significant observations from the present investigation are given below:

I. It was seen from the weekly variations of soil moisture contents that the variations in surface soil moisture contents were more compared to the soil moisture level changes at 30 cm depth. This can be attributed to the fact that after the harvest of the first crop the evaporation losses from the topsoil were more than the loss from the subsoil. The percolation and seepage of soil water from the topsoil to the subsoil also has a tendency to maintain the subsoil moisture content at a near steady level.

II. It can be noted that in the experimental plots there was an increase in the moisture content at around sixth weeks from the date of sowing. This was because in the fifth week there was a rainfall which contributed to the increase of soil moisture content. Such pre-monsoon showers are quite common and these are extremely supportive for relay cropping. These pre-monsoon rainfall events often delay the need of supplemental irrigation for the second crop. In the present investigation the results of soil moisture profile clearly show that till 8^{th} week of the second crop (lentil) no supplemental irrigation was required.

III. In most of the plots throughout the period of soil moisture profile monitoring, the topsoil and subsurface moisture contents of the soils were well above the permanent wilting point for clay loam soil [15% (db)]. Only in Plot 2 of Dhalaguri (E_2) the moisture content of the surface soil in the fourth week dropped below 15% (db). Therefore, in general, even without any supplemental irrigation the lentil crop was not exposed to soil moisture stress during its early growth stage. This emphasizes the prospect of relay cropping in the area with minimum cost of agricultural inputs like irrigation, fertilizer, and labour.

IV. The present study clearly demonstrated that during the first eight weeks of the crop season of lentil there was no deficiency of soil moisture. During the rest of the cropping season single supplemental irrigation (if required) should be sufficient to mature the lentil crop. The study clearly demonstrated the prospect of paddy-lentil relay cropping in the area under favourable soil and climatic conditions.

CHAPTER 5 SUMMARY AND CONCLUSIONS

5.1 Summary

In the present investigation trials of relay cropping of monsoon paddy and lentil were conducted to study the utilization of residual soil moisture by the second crop (lentil). The trials were conducted in eight plots in two villages of North Bengal viz. Dhalaguri (Cooch Behar) and Uttar Chakwakheti (Alipurduar). There were four plots (3.5 bigha) in Dholaguri and four plots (1.5 bigha) in Uttar Chakwakheti. The selected plots were located in low land areas with clay loam soil. The variety of paddy was MTU 7029 (Sarna) and the variety of lentil was B 77 (Asha). The lentil seeds were inoculated with rhizobium (10 g) and azotobactor (10 g) per kg of seed. The inoculated seeds were sowed by hand broadcasting in the paddy fields well before harvesting. After harvesting of the paddy, the lentil crop was raised in the same field as a relay crop. The soil samples were collected at weekly interval from each plot by random sampling to monitor the soil moisture profile of the plots. At each location soil samples were collected from two depths viz. Topsoil and soil at 30 cm depth. The moisture contents of the collected soil samples were estimated by gravimetric method. The first sampling (only topsoil) was done on the date of sowing of the lentil seeds. A soil augar was used to collect the soil samples from 30 cm depth.

The soil moisture profile in the trial plots were monitored for a period of eight weeks starting from the date of sowing. This covered the critical growth period of the lentil crop which has tentative crop duration of 12 weeks. The study of temporal variations in soil moisture content in the trial plots in the sampling period showed that the surface moisture contents had greater variations than the subsoil moisture contents. This was due to the higher evaporation rates from the topsoil. Even without any supplemental irrigation, in most of the plots the soil moisture contents did not fall below the wilting point for clay loam soil. One event of pre-monsoon rainfall helped to maintain the soil moisture level well above the wilting point in most of the cases. Only in one plot, the soil moisture of the topsoil was found to drop below the wilting point. Therefore, in general the residual soil moisture was sufficient to support the growth of the lentil crop without any supplemental irrigation till the eighth week. In the remaining crop duration one supplemental irrigation (if required) should be sufficient to raise the crop. The relay cropping system demonstrated significant reduction in the cost of agricultural inputs like irrigation water, fertilizer, and labour.

5.2 Major Conclusions

The following major conclusions could be drawn from the present investigation:

- The present study demonstrated the salient advantages of relay cropping of kharif paddy and lentil over conventional cropping system.
- The clay loam soils in low land areas are suitable for relay cropping as they can hold sufficient soil moisture to support the second crop for a significant period.
- If the lentil seeds are broadcasted in paddy fields well before the harvesting of the paddy, the germination of lentil and its early growth can be satisfactory. The seeds rate of 30 kg per hectare was sufficient for lentil.
- Inoculation of the lentil seeds by nitrogen fixing bacteria before broadcasting reduced the fertilizer requirement of the lentil crop. Nitrogen fixation is also known to improve the soil health for the subsequent crops.
- Foliar nutrition application (urea) enhanced the growth of the lentil crop.
- During the majority of the growth period of lentil (first eight weeks) the soil moisture contents in the majority of the trial plots did not fall below the permanent wilting point of the soil.
- During the first eight weeks of growth the lentil, even without any supplemental irrigation, the crop was not exposed to water stress condition. It clearly demonstrates the suitability of paddy-lentil relay cropping system in the area under investigation.
- The choice of relay cropping of paddy-lentil under suitable soil and climatic conditions should greatly reduce the cost of cultivation by reducing the costs of agricultural inputs like water, fertilizer, and labour.
- Due to overlapping of the crop seasons in relay cropping the timeliness for the subsequent crops can be more efficiently managed.

Ali, M. O., Zuberi, M. I., and Sarkar, A. (2012). Lentil Relay Cropping in the Rice-Based Cropping System: An Innovative Technology for Lentil Production, Sustainability and Nutritional Security in Changing Climate of Bangladesh. *Journal of Food Science and Engineering*, 2(9), 528-532.

Aslam, M., Sanghi, A. H., and Khalid, L. (2014). Demonstration and evaluation of the effect of different seeding techniques on the yield of wheat in standing cotton. *International Journal of Advanced Research in Biological Sciences*, 1(5), 99-104.

Bitew, Y., and Asargew, F. (2015). Rice (*Oryza Sativa*) and chickpea (*Cicer Aritinum L*) relay intercropping systems in an additive series experiment in rain fed lowland ecosystem of fogera vertisols. *Scientific Journal of Review*, 4(1), 10-16.

Buttar, G. S., Sidhu, H. S., Singh, V., Jat, M. L., Gupta, R., Singh, Y., and Singh, B. (2013). Relay planting of wheat in cotton: an innovative technology for enhancing productivity and profitability of wheat in cotton–wheat production system of south Asia. *Experimental Agriculture*, 49(01), 19-30.

Ghosh, P. K., and Dayal, D., (2005). Optimization of date of sowing in a new Groundnut-Wheat relay cropping system in semi-arid tropics of India. *Journal of Sustainable Agriculture*, 26(3), 83-94.

Guldan, S.J., Ball, S.T. and Martin, C.A. (2008). Relay intercropping Brassicas into Chile and Sweet Corn. New Mexico State University Cooperative Extension Service. Guide A-609.

Kayaria, R. K., and Chandel, K. (2007). Moisture regimes and relay cropping studies in spring potato (Solanum tuberosum L.) under mid hill conditions of Himachal Pradesh. *International Journal of Agricultural Science*, 3(2), 18-21.

Mahmood, A., Anjum, F. H., and Ali, A. (2003). Rice planting geometry facilitating relay cropping at zero tillage. *International Journal of Agriculture And Biology*, 5(4), 435-437.

Malik, A. I., Ali, M. O., Zaman, M. S., Flower, K., Rahman, M. M., and Erskine, W. Relay sowing of lentil (Lens culinaris subsp. culinaris) to intensify rice-based cropping. *Journal of Agricultural Science*, 18(2), 601-608.

Mandal, P., Biswas, M., and Miah, M. N. H. (2015). Effect of Relay and Traditional Sowing Methods on Yield and Economic Performance of Lentil in Transplant Aman Rice Field. *International Journal of Research in Agriculture and Forestry*, 2(1), 21-32.

Martens, T., Joanne, R., Hoeppner, J. W., and Entz, H. (2001). Legume cover crops with winter cereals in southern Manitoba: establishment, productivity, and microclimate effects. *Agronomy Journal*, 93(5), 1086-1096.

Punyalue, A., Jongjaidee, J., Jamjod, S., & Rerkasem, B. (2015). Reduce Burning in Maize Production by Relay Cropping with Legume. *Agriculture and Agricultural Science Procedia*, *5*, 17-21.

Reda, F., Verkleij, J. A. C., and Ernst, W. H. O., (2005). Relay cropping of Sorghum and Legume Shrubs for crop yield improvement and *Striga* control in the subsistence agriculture region of Tigray (Northern Ethiopia). *Journal of Agronomy and Crop Science*, 191(1), 20-26.

Sandler, L., Nelson, K. A., and Dudenhoeffer, C., (2015). Winter Wheat Row Spacing and Alternative Crop Effects on Relay-Intercrop, Double-Crop, and Wheat Yields. *International Journal of Agronomy*, 1-8.

Sullivan, P. (2003). Intercropping principles and production practices. NCAT, Appropriate Technology Transfer for Rural Areas, Publication No. IP 135.

Worku, W., (2014). Maize-Tef relay intercropping as affected by Maize planting pattern and leaf removal in southern Ethiopia. *African Crop Science Journal*, 12(4), 359-367.

Yirzagla, J., Denwar, N. N., Dogbe, W., Kanton, R. A. L., Inusah, I. Y. B., Akakpo, D. B., and Mohammed, I., (2013). Compatibility of millet and legume under relay cropping condition. *Journal of Biology, Agriculture and Horticulture*, 3(15), 86-91.