# PROJECT REPORT

# Improving Crop and Water Productivity in Indira Gandhi Canal Command Area

# PHASE-I
# (2012-2015)

- **Stage-I (Mainawali,Hanumangarh)**
- **Stage-II (Baju)**

# PROJECT REPROT PHASE –I

**Introduction**

The Indira Gandhi *Nahar Pariyojana* (IGNP) is an enormous multi-purpose irrigation and settlement project, implementation of which started in the late 1960s. The goal was to transport and use over $l0^6$ billion cubic meter of water annually withdrawn from the Ravi-Beas River in the north of India for large-scale irrigation in Rajasthan. The aim of project stage I(Hanumangarh), commenced in 1974, was to pro- vide water for irrigation of about 553,000 ha in the north of Rajasthan. This had been achieved in 2000. Therefore, water of the Ravi-Beas river system has been diverted from Harike barrage in Punjab through a 204 km long Indira Gandhi Feeder Canal (no off-takes) into the 445 km long Indira Gandhi Main Canal (IGMC) at Masitawali head works (Figure 1). The water allowance is 0.0371 $m^3$/sec, which is equal to 3.2 mm $day^{-1}$. The intensity of irrigation was envisaged at 110% with 60% in the winter season (November-April) and 50% in the summer, monsoon season (July-October). At farm level, the water is distributed through a *warabandi* system. The mean annual rainfall is 297 mm and the potential evaporation 1,500-1600 mm, suggesting water deficits during the whole year including the monsoon months.

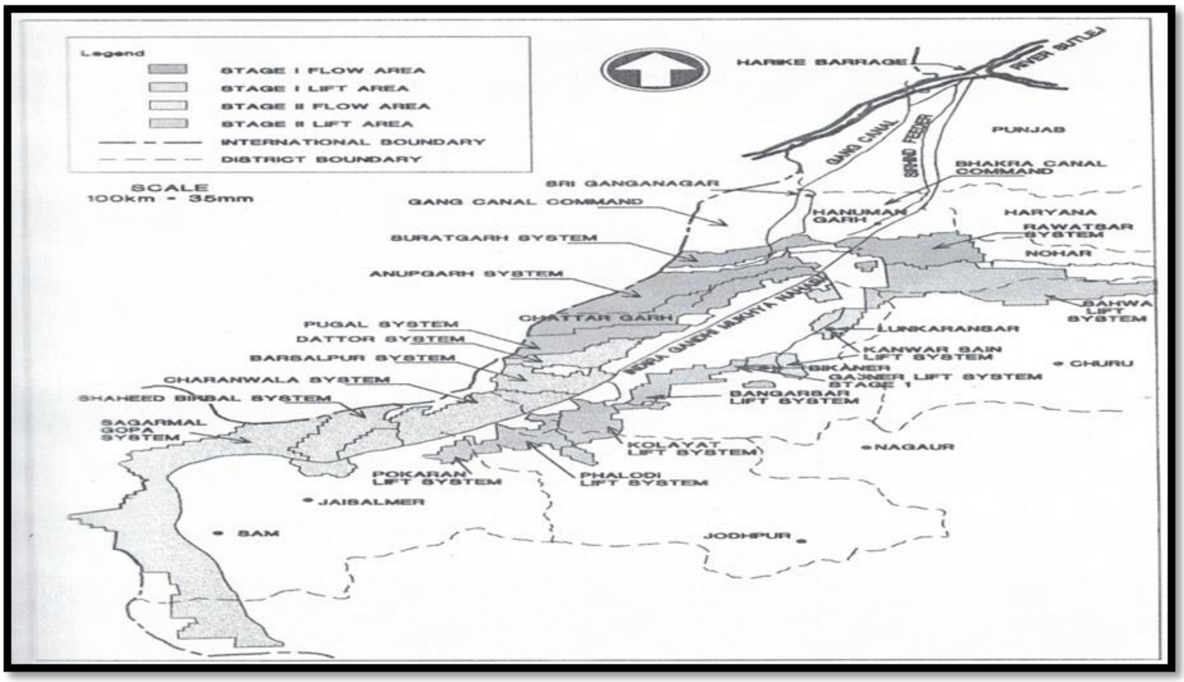



**Figure 1:** Layout of Indira Gandhi *Nahar Pariyojana* (IGNP)

**Nature of the Problem**

Implementation and management of the IGNP had been largely successful. Over the years several million people migrated into the region and were able not only to maintain their own livelihoods but also to produce food surpluses. However, ever since the inception of the IGNP, challenges – partly natural, partly anthropogenic – arose.

The problems can broadly be divided according to the two stages of the IGNP project:

| Stage I | Stage II |
|---|---|
| Low water productivity | Low land as well as water productivity |
| Water logging and salinity | Unreliable water supply |
| Low irrigation efficiency | Yield variability from year-to-year |
| Low nutrient-use efficiency | Low water and nutrient holding capacity of sandy soils |
| Wind erosion | Wind erosion |
| | Lack of crop diversification |

Partly due to edaphic conditions (sandy-loams or loamy sands in the north and sandy soils the south of Rajasthan), partly because of major differences in irrigation water availability (abundant in the north, scarce in the south), the cropping systems of stage I and stage II command area are quite different. Stage I is characterized by flood- or furrow-irrigated cropping systems with rotations such as wheat-cotton-wheat or mustard/chickpea-cluster bean-mustard/chickpea. Part of the croplands has been created by leveling the sand dunes; sand is sometimes spread over the land that get more and more enriched with lighter textured soil due to siltation from sediment-rich irrigation waters, to improve soil physical properties (infiltration, aeration). The stage I area nowadays is intensively cropped. Problems farmers encounter are low water productivity due to poor management of irrigation water, and, in depression areas, water logging and secondary soil salinization. Subsequently, also irrigation and nutrient-use efficiency is low.

Stage II, on the other hand, is characterized by sand dunes which have been stabilized with shrubs and trees (rather than levelling them), and interdunal plains where agriculture is practiced. Given the fact that water is scarce in this area – partly because of the overuse in the stage I area upstream – and prevailing soils are sandy (with infiltration rates too high for rational irrigation by furrows), the government started subsidizing modern irrigation techniques such as (micro-) sprinklers and drip irrigation systems. The idea is to promote efficient management of water by large-scale adoption of pressurized irrigation systems. This, however, requires water storage structures and access to at least moderately reliable source of water, and energy; which may cause problems in areas where these conditions are absent. Moreover, the sandy soils have a low water and nutrient holding/retention capacity. Wind erosion during summertime also at times covers the croplands with sand from neighbouring dunes if only poorly stabilized, damaging or burying crops and severely affecting harvest.

***Overarching Objectives***

1. Improved water and land productivity through better water management, appropriate cropping patterns and optimal cultural practices
2. Higher control of salinity and water-logging through new options for drainage and improved water management

3. Increased surface irrigation efficiency through better land preparation and improved system parameters and design
4. Improved human capacity of local researchers and technicians

**Methodology**

The project targets stage I and II command area of IGNP. Some of the outlined problems require field-level interventions and others are irrigation scheme problems and need to be addressed using interventions at that very scale. Therefore, we apply biophysical simulation models to understand the existing soil-water balance, movement of salts, fluctuations of groundwater, crop growth characteristics etc. On the one hand, this is a cropping system model for field-level modelling, and in parallel a scheme-scale model for the assessment of the irrigation and drainage system.

Following this, these models are applied to study the effectiveness of various intervention measures such as supplemental irrigation, land management, optimization of irrigation scheduling, subsurface drainage and others for solving problems such as low irrigation efficiency, low nutrient-use efficiency, water logging, low land and water productivity etc.

**Expected Outputs**

1. Crop models selected, calibrated, verified and used to understand, analyse and quantify the dynamics of soil-water crop relations and develop options for improved water and crops management
2. Scheme models selected, verified and used to understand water-salts and nutrient processes and quantify salts and water balances including after delivery application and drainage.
3. A set of recommendations on suitable water and crop management including rotations and their nutrient for stages I and II of the command area to improve field scale water productivity (kg/$m^3$ as well as Rupees/$m^3$)
4. A set of recommendations for alternative delivery and drainage options to improve irrigation scheme-scale water productivity (kg/$m^3$ released from the source), reduce groundwater rise and salinity build-up
5. Number of researchers able of conducting analysis of soil-water-crop using modelling approaches and system water and salt balance.

**Work Plan**

**Component 1: Understanding and managing water productivity at the field scale**

– Activity 1.1: Collect or measure data on cropping pattern, plant physiology, irrigation water management, weather, soil physical characteristics

– Activity 1.2: Crop modelling of typical existing crops, rotations and irrigation schedule in stage II of the canal command area

– Activity 1.3: Scenario simulation for recommending alternative crops and irrigation schedules for improved water productivity (kg/$m^3$ as well as Rupees/$m^3$)

– Activity 1.4: Report writing, dissertation writing and dissemination of research results

**Component 2: Understanding and managing water productivity at the scheme scale**

– Activity 2.1: Identification and delineation of a representative tertiary irrigation canal area. Collect data on weather, scheme inflows and outflow, and GIS data on land use, soil types, canal layout, topography

– Activity 2.2: Modelling of the area to understand the soil-water balance and water delivery efficiency

– Activity 2.3: Modelling of area under alternative delivery methods to improve irrigation scheme-scale water productivity (kg/$m^3$ released from the source), reduce groundwater rise

– Activity 2.4: Report writing, dissertation writing and dissemination of research results

**Component 3: Training and capacity building**

• Activity 3.1: Train national partners and students working on the project on hydrological modelling and crop modelling

• Activity 3.2: Two visits (one week duration each visit) of CAZRI-Bikaner scientists to ICARDA headquarters/regional office to see research experiments and exchange ideas

**Detailed Work plan for reporting period**

**Stage I**

**January 2013 to December 2013**

- Crop-wise, collection of data on soil moisture before application of irrigation – TDR reading up to 1m before irrigation.
- Analysis of harvested rabi crop for biomass, yield, harvest index etc.
- Planting of kharif season crops and phenological data collection
- Every 20 days recording of all piezometer levels as well as before irrigation; literature review
- Setting up of a basic functional crop model
- Calibration of model
- Dissertation writing and submission

**Stage II**

**January 2013 to June 2013**

- Weather data collection from nearby weather stations, and rainfall data from rain gauge
- Crop-wise, collect data at 20-day interval on soil moisture before application of irrigation – TDR reading up to 1m before irrigation, LAI, canopy height, leaf water potential, tensiometer reading
- Collect data on dates of start of different stages of plant growth (germination, flowering, maturity etc., depending on the crop)
- Fertilizer application rates and timings for each field and rabi crop
- Pesticide application rates and timings for each field and rabi crop
- Tillage and other agronomic management operations – date, equipment, depth etc
- Analysis of collected data, quality check
- Analysis of harvested crop (Rabi season) for biomass, yield, harvest index etc.
- Setting up of a basic functional crop model
- Calibration of model

**July 2013 (planting) - December 2013 (Harvest)**

- Planting of kharif season 2013 crops and phenological data collection

- Crop-wise, collect data at 20-day interval on soil moisture before application of irrigation – TDR reading up to 1m before irrigation, LAI, canopy height, leaf water potential, tensiometer reading
- Collect data on dates of start of different stages of plant growth (germination, flowering, maturity etc., depending on the crop)
- Fertilizer application rates and timings for each field and rabi crop
- Pesticide application rates and timings for each field and rabi crop
- Tillage and other agronomic management operations – date, equipment, depth etc
- Analysis of collected data, quality check
- Analysis of harvested crop (kharif season) for biomass, yield, harvest index etc.
- Setting up of a basic functional crop model
- Planting of Rabi season 2014 crops and phenological data collection
- Calibration of model
- Annual report writing

**Specific Objectives**

**Stage I (Menawali, Hanumangarh)**

a. To calibrate the crop model performance for an irrigation scheme
b. To simulate land and water productivity of the irrigation system using the calibrated crop model
c. To quantify water balance of the scheme
d. To calculate water productivity and economics of different crops in the study area
e. To assess irrigation performance

**Stage II (Bajju, Bikaner)**

a. To calibrate and test the crop model performance for conventional and progressive farming practices
b. To quantify water balance of the study area to estimate beneficial and non- beneficial depletions
c. To assess current land and water productivity
d. To improve land and water productivity through better water management, appropriate cropping patterns and optimum cultural practices.

**CropSyst Model**

CropSyst model has been chosen for this project. It is a multi-year, multi-crop, daily time step cropping systems simulation model developed to serve as an analytical tool to study the effect of climate, soils, and management on cropping systems productivity and the environment. Emphasis has been placed on developing a user-friendly interface, providing links to GIS software, a weather generator, and other utility programs. CropSyst simulates the soil water budget, soil plant nitrogen budget, crop phenology, canopy and root growth, biomass production, crop yield, residue production and decomposition, soil erosion by water, and salinity. These processes are affected by weather, soil characteristics, crop characteristics, and cropping system management options including crop rotation, cultivar selection, irrigation, nitrogen fertilization, soil and irrigation water salinity, tillage operations, and residue management. The development of CropSyst started in the early 1990s. The motivation for its development was based on the observation that there was a niche in the demand for cropping systems models, particularly those featuring crop rotation capabilities, which was not properly served. Efficient cooperation among researchers from several world locations, a free distribution policy, active cooperation of model developers and users in specific projects, and careful attention to software design from the onset allowed for rapid and cost-effective progress. Another important factor was the advantage of learning from a rich history of crop modelling efforts. CropSyst was designed to draw from the conceptual strengths of EPIC, but including a more process-oriented approach to the simulation of crop growth and its interaction with management and the surrounding environment. In addition, a stronger emphasis on software design was a clear departure from the EPIC and DSSAT approaches. Attention to a balance between the incorporation of sound science in the models and the utilization of adequate software design practices has been a trait of CropSyst since the beginning of its development. In this regard, it shares somewhat common objectives with APSIM (McCown et al., 1996; Keating et al., 2003), a modelling approach that has evolved to place substantial resources in the development of quality software engineering practices.

**Progress**

**Recruitment and progress of students**

Mr. Deepak Kumar Jat, M. Sc. (Agronomy) from College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner Campus, was selected under the project for his thesis/ research work.

Mr. Ramesh Kumar, M. Sc. (Agronomy) from College of Agriculture, Swami Keshwan and Rajasthan Agricultural University, Bikaner Campus, has submitted his M.Sc. dissertation.

Mr. Sita Ram Jat, Ph. D (Soil Science) from College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner Campus, is doing his thesis work under the project.

The students are paid monthly assistantships of Rs.15,000 for Ph.D. and Rs.10,000 for M.Sc.

**Consultant**

In the project one consultant Dr. Amit Kumawat, Ph. D. (agronomy) is working for different activities of the project and also to help the students along with making coordination between staff under the project.

**Meeting**

A meeting was organized by Dr. Ashutosh Sarkar, with CAZRI scientists, university professors on April 10, 2013 and progress of the project was presented.

**Visits:**

Dr. Mariya Glazirina visited CAZRI, RRS, Bikaner from 1-14 July, 2013 for guiding in CropSyst model calibration and during recruitment of M.Sc Student

Dr. Vinay Nangia visited CAZRI, RRS, Bikaner from 22-24 July, 2013 and Jodhpur from 26-28, November,2013 for monitoring the progress of the project.

**Training :**

Dr. N.D. Yadava , Principal Scientist and Head, CAZRI, RRs, Bikaner and Dr. Bundela , CSSRI, Karnal visited Amman (Jordan) from 27 October- 14 November, 2013 and attended the training course on Increasing water productivity in agricultural systems

**Purchase**
All equipment namely tensiometer, piezometer, rain gauge, water meters, computers, GPS etc. required and approved in the project were purchased by ICARDA, New Delhi office and sent to CAZRI-RRS, Bikaner for use in the project.

**Brainstorming Session:**

A brainstorming session entitled "**Improving Crop Water Productivity in Indira Gandhi Canal Command Area**" was organized as an event of the project at Central Arid Zone Research Institute, Regional Research Station, Bikaner. About 40 participants from different ICAR institutes (viz. CAZRI Jodhpur , CAZRI RRS Bikaner, CAZRI RRS Jaisalmer, CIAH Bikaner, NRCC Bikaner, CSWRI Bikaner , NRCE Bikaner), Swami Keshwanand Rajasthan Agricultural University, IGNP and NGO from Bikaner actively participated. Dr. M.M. Roy, the chairman of the session summed up the views and flashed the following issues which came out of the deliberations in the brainstorming session:

1. Agriculture in irrigated areas will continue with different shapes. So our efforts should be to minimize the losses of irrigation water by adopting suitable technologies of water saving.
2. There is a need to develop suitable integrated farming system models with adequate ratio of livestock and tree/woody components to improve water productivity.
3. The water allowance at the origin of canal has reduced due to lack of sufficient budgetary allocation for the maintenance of canal. Hence there is a need for sufficient budgetary allocation for maintenance of the canal to improve water storage capacity of IGNP and increase water productivity.
4. There is a need for checking conveyance losses by suitable lining material.
5. There is a need for providing incentives to the farmers growing low water requiring crops and adopting water saving technologies.
6. The support price for the low water requiring crops needs to be enhanced to discourage the high water requiring crops.
7. Community based linked research programme may be developed with proper linkage with line departments.







Photo 1: Brain storming session at CAZRI-RRS, Bikaner

# Stage- I

## (Mainawali,Hanumangarh)

# Part A:

## Calibration of CropSyst model

# (2012-13)

## PHASE-I

## Part A: Calibration of cropsyst model (2012-13)

## Improving Crop and Water Productivity in Indira Gandhi Canal Command Area-stage- I (Mainawali,Hanumangarh)

**Site**

The experiment was conducted at village Menawali, in Hanumangarh district of Rajasthan during *kharif* and *rabi* season of 2012-13 and 2013-14. Village Menawali is located between 074$^{o}$ 20’34”E to 074$^{o}$ 20’60” longitude and 28$^{o}$ 37’62” N to 29$^{o}$ 21’39” N latitude (Fig 2 and 3). The elevation is approximately 235 m above mean sea level. As per NARP classification of agro-climatic zones, Hanumangarh falls in Agro-climatic zone Ib (Irrigated North Western Plain Zone). The general topography of area is almost plain with some isolated steep contours. The soil texture varies from silt loam to silty clay loam. Invariably, all the soils have low organic carbon content.

**Climate**

The climate of the area is arid. The mean daily maximum temperature during May and June, which is the hottest period, varies from 41 to 46 °C. On individual days, during the hot period, it may rise up to about 49 °C. Hot winds, with low relative humidity, often cause dust storms during the hot season. January is generally the coldest month with a mean daily maximum temperature of 21°C and a minimum 5°C. The average annual rainfall of the tract is about 287.6 mm which is mostly received during the rainy season from July to September. During the months of December and January, occasional fogs reside in the area. An agricultural year may be divided into four distinct seasons: the hot dry season from March to June, hot rainy (monsoon) season from July to September, post-monsoon season from October to November and cold season from December to February.

The weather conditions prevailed during the period of experimentation (2012-13) were recorded at meteorological observatory of Agricultural Research Sub-station, Sriganganagar, Swami Keshwanand Rajasthan Agricultural University, Bikaner have been given in table 1 and graphically depicted in fig 4.

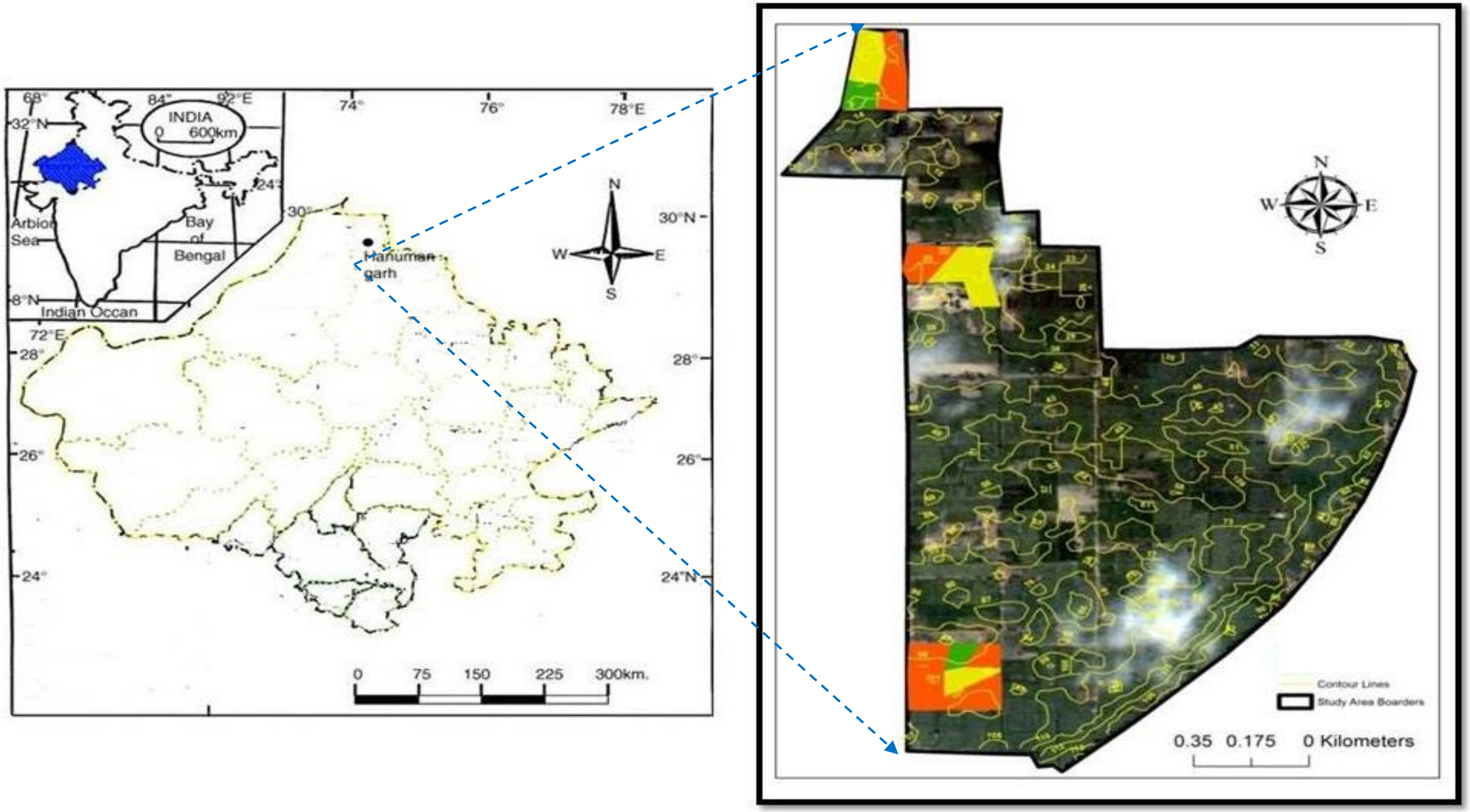



**Fig 2 (a) Geographical location of Hanumangarh (b) Study area**

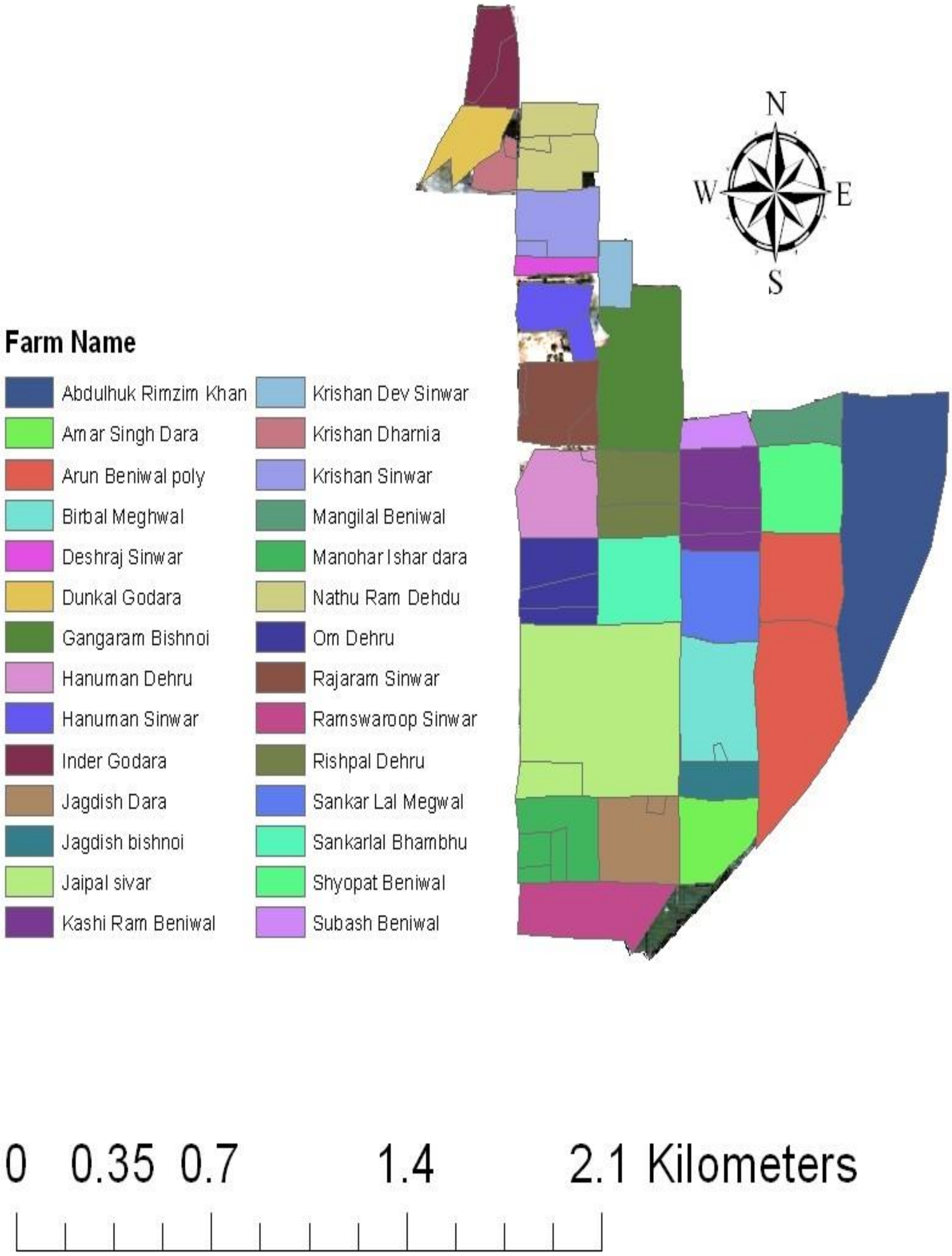



**Figure 3 Demarcation of the field at Menawali, Hanumangarh.**

**Soil characteristics and methods of their analysis**

The soils of the experimental area were alluvial and calcareous in nature, fairly deep and have low permeability, brown to greyish brown, dark grey in colour formed under arid and semi arid climate. Depth wise soil samples were collected (0-15, 15-25, 25-50, 50-75 and 75-100 cm) from cropped area of selected farmers fields in one scheme with the help of soil auger and analysed for physio-chemical properties. These soil samples were collected in clean polythene bags individually with proper labelling indicating their respective depths along with farmer name and crop details. All the collected soil samples were air dried and ground to pass through 2 mm mess sieve and labelled properly. A complete description of the various soil parameters viz. texture, hydraulic conductivity, field capacity, maximum water holding capacity, *pH*, electrical conductivity (*EC*), organic carbon, mineral nitrogen (N), available phosphorous and potash have been presented in table 2a and 2b.

**Particle size distribution analysis of soil:**

The analysis of particle size distribution (sand, silt and clay fractions) was carried out by Boyoucos hydrometer per procedure given by Kilmer and Alexander (1949).

**pH measurements:**

Hydrogen ion activity of all selected soil samples was determined by using pH meter in 1:2 soil-water suspensions at $25^0$ C.

**Electrical conductivity:**

Electrical conductivity was determined in 1:2 soil-water suspensions with the help of conductivity meter at $25^0$ C.

**Soil organic carbon**

Soil organic carbon was determined by the modified Walkley and Black's rapid titration method (1934).

**Bulk density**

The bulk density of soil was determined in the field with the help of core sampler having 7.5 cm diameter and 15 cm height. The bulk density is calculated as the dry weight of the soil per unit volume.

**Table: 1 Monthly meteorological data during crop season 2012-13**

| Month | Temperature (°C) | | Relative humidity (%) | | Total Rainfall (mm) | Pan Evaporation (mm) | Sunshine hours (h/day) |
|---|---|---|---|---|---|---|---|
| | Max | Min | RH Max | RH Min | | | |
| May-12 | 42.80 | 24.14 | 40.90 | 19.94 | 1.00 | 235.80 | 8.22 |
| June-12 | 43.24 | 28.81 | 49.73 | 26.30 | 14.30 | 270.30 | 5.70 |
| July-12 | 40.97 | 29.07 | 65.45 | 46.90 | 74.70 | 224.00 | 7.26 |
| August-12 | 37.41 | 27.69 | 78.35 | 59.32 | 33.80 | 163.30 | 5.83 |
| September-12 | 35.31 | 24.36 | 85.17 | 65.30 | 185.20 | 90.00 | 6.88 |
| October-12 | 33.78 | 16.89 | 81.23 | 53.10 | 0.00 | 91.70 | 8.33 |
| November-12 | 28.31 | 10.95 | 90.00 | 57.63 | 0.00 | 56.20 | 6.38 |
| December-12 | 21.45 | 6.89 | 94.13 | 63.81 | 4.80 | 43.20 | 5.82 |
| January-13 | 19.38 | 7.28 | 95.94 | 62.10 | 6 | 43.00 | 5.18 |
| February-13 | 22.83 | 9.34 | 95.04 | 63.89 | 58.80 | 52.40 | 6.03 |
| March-13 | 31.09 | 13.71 | 84.84 | 44.26 | 4.40 | 118.50 | 8.02 |
| April-13 | 36.57 | 18.30 | 58.53 | 31.57 | 32.10 | 165.60 | 7.86 |
| May-13 | 43.54 | 23.93 | 40.84 | 19.97 | 0.00 | 250.20 | 10.32 |

# data taken from Agro-meteorological Observatory, A.R.S. (Sriganganagar), SKRAU, Bikaner

**Fig. 4 Monthly meteorological data recorded during crop growing 2012-13**

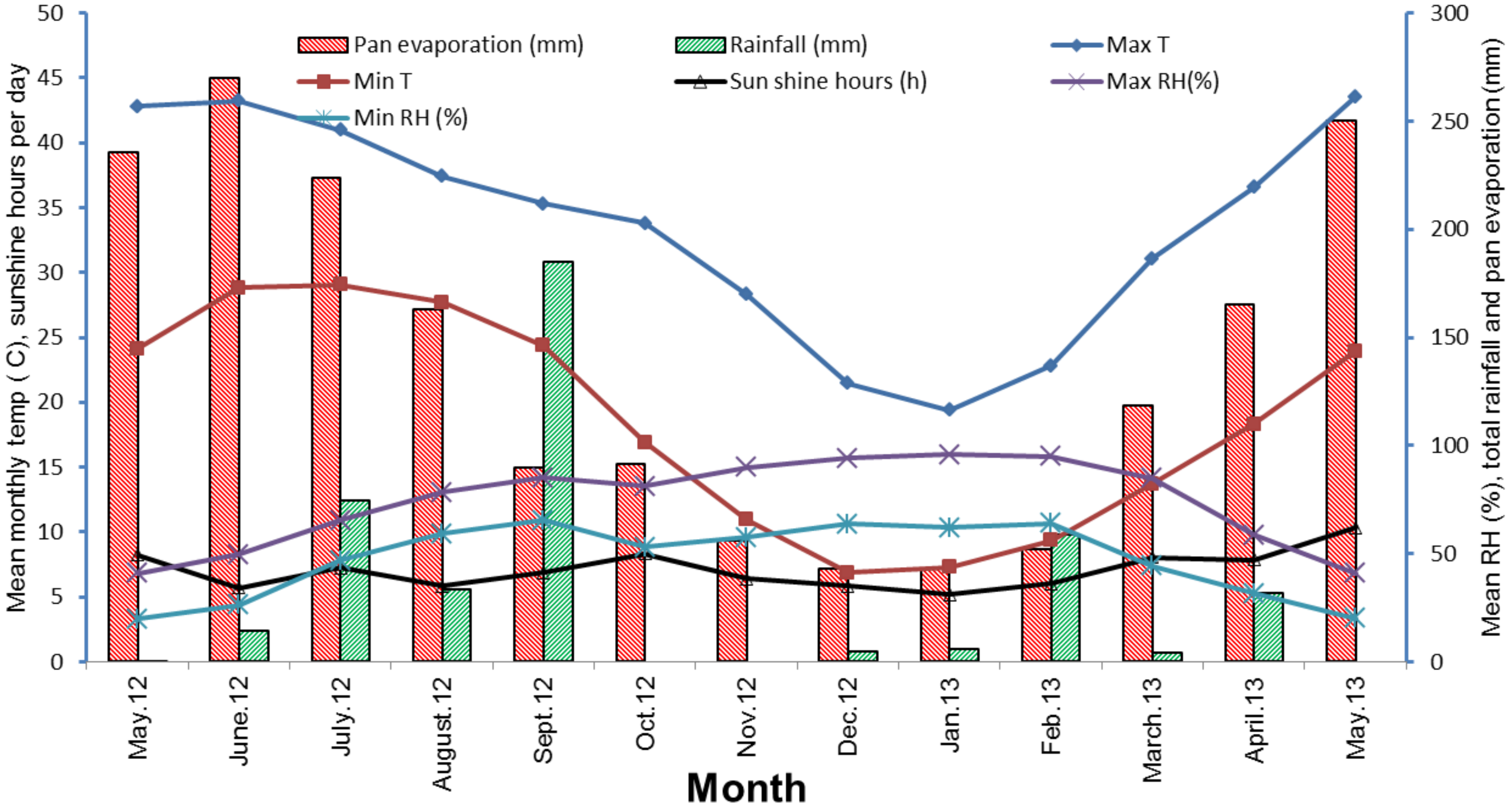


**Table 2 (A) Soil physical properties of experimental site (2012-13)**

| Layer | Thickness (m) | Sand (%) | Clay (%) | Silt (%) | Bulk density (g $cm^{-3}$) | CEC (cmol $kg^{-1}$) | pH | PWP ($m^3$ $m^{-3}$) | FC ($m^3$ $m^{-3}$) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Mean±SD | | | | |
| 1 | 0.15 | 67.75±6.30 | 11.14±1.73 | 21.01±4.60 | 1.44±0.06 | 5.39±0.56 | 8.09±0.15 | 0.085±0.01 | 0.186±0.01 |
| 2 | 0.10 | 67.61±6.32 | 11.21±1.75 | 21.17±4.63 | 1.45±0.06 | 5.53±0.55 | 8.04±0.18 | 0.086±0.01 | 0.187±0.01 |
| 3 | 0.25 | 67.45±6.31 | 11.27±1.76 | 21.25±4.67 | 1.46±0.07 | 5.61±0.54 | 7.95±0.20 | 0.088±0.01 | 0.189±0.01 |
| 4 | 0.25 | 67.23±6.26 | 11.41±1.74 | 21.36±4.61 | 1.47±0.07 | 5.77±0.52 | 7.89±0.21 | 0.089±0.01 | 0.191±0.01 |
| 5 | 0.25 | 66.95±6.23 | 11.51±1.72 | 21.58±4.66 | 1.48±0.07 | 5.91±0.58 | 7.86±0.21 | 0.092±0.01 | 0.195±0.01 |

**Table 2 (B) Initial soil conditions of experimental site (2012-13)**

| Layer | Thickness (m) | Water content ($m^3$ $m^{-3}$) | NO3 (kg N $ha^{-1}$) | NH4 (kg N $ha^{-1}$) | SOM (%) | Electrical Conductivity (dS $m^{-1}$) |
|---|---|---|---|---|---|---|
| | | | | Mean±SD | | |
| 1 | 0.15 | 0.173±0.015 | 20.18±1.60 | 55.65±4.24 | 0.295±0.074 | 0.175±0.073 |
| 2 | 0.10 | 0.177±0.401 | 18.28±1.51 | 49.98±4.17 | 0.312±0.079 | 0.173±0.067 |
| 3 | 0.25 | 0.181±0.016 | 16.24±1.54 | 49.20±4.50 | 0.290±0.072 | 0.173±0.063 |
| 4 | 0.25 | 0.186±0.015 | 14.20±1.57 | 49.05±5.18 | 0.272±0.073 | 0.164±0.066 |
| 5 | 0.25 | 0.193±0.015 | 14.02±1.46 | 47.37±4.90 | 0.261±0.074 | 0.165±0.063 |

**Hydraulic conductivity**

The saturated hydraulic conductivity (*K*sat) of the core soil samples was determined in the laboratory with the Constant Water Head Method (Klute and Dirksen, 1986).

**Infiltration rate**

The basic infiltration rate was determined with a closed top infiltrometer according to Malik *et al.* (1990).

**Soil moisture content**

Volumetric soil moisture content upto one meter soil depth (at an interval of 10 cm each) was determined with a TDR-meter before and after each irrigation, and at harvest .The TDR probe was calibrated for moisture content following the gravimetric method.

**Saturation percentage**

The saturation percentage of the disturbed soil samples at sowing was determined with the saturation paste method.

**Field capacity**

The field capacity was determined in the field by covering the fully saturated soil surface with a polythene sheet and measuring the moisture content after 24-72 hours depending on soil type.

In order to ascertain the physico-chemical characteristics, soil samples were collected from different spots of the experimental field in both the season. Representative composite samples obtained from samples of each season, were subjected to physical and chemical analysis separately. The physico-chemical characteristics of the soil of experimental field along with the methods followed for analysis are given in table 3.

**Selection of farmers**

Selection of farmers was done on the basis of major cropping sequence grown in the study area. A general survey of 28 farmers' fields was done out of which 15 farmers were selected keeping in view the irrigation facilities from the IGNP canal. The fields of farmers are depicted in Fig 5. The list of farmers along with their crop grown is presented in Table 4.

**Table 3 Overview of the soil properties data collected for calibration of CropSyst model at farmer fields in Hanumangarh district**

| Data | Method / source | Frequency | Purpose |
|---|---|---|---|
| Texture | Hygrometer method | Once | Input derivation |
| Bulk density | Core Method | Once | Input derivation |
| Saturated hydraulic conductivity | Constant Water Head Method (Klute and Dirksen, 1986) | Once | Input derivation |
| Saturation percentage / moisture | Saturation Paste Method | Once | Input derivation |
| Soil moisture | TDR | Before and after irrigation | Calibration and validation |
| pH | In soil-water suspension of 1:2 by pH meter | Before and after irrigation | General |
| Electrical Conductivity | In soil-water suspension of 1:2 by Conductivity Meter | Before and after irrigation | Calibration and validation |
| Organic Carbon | Wet digestion method (Walkley and Black, 1947) | Before sowing | Input derivation |

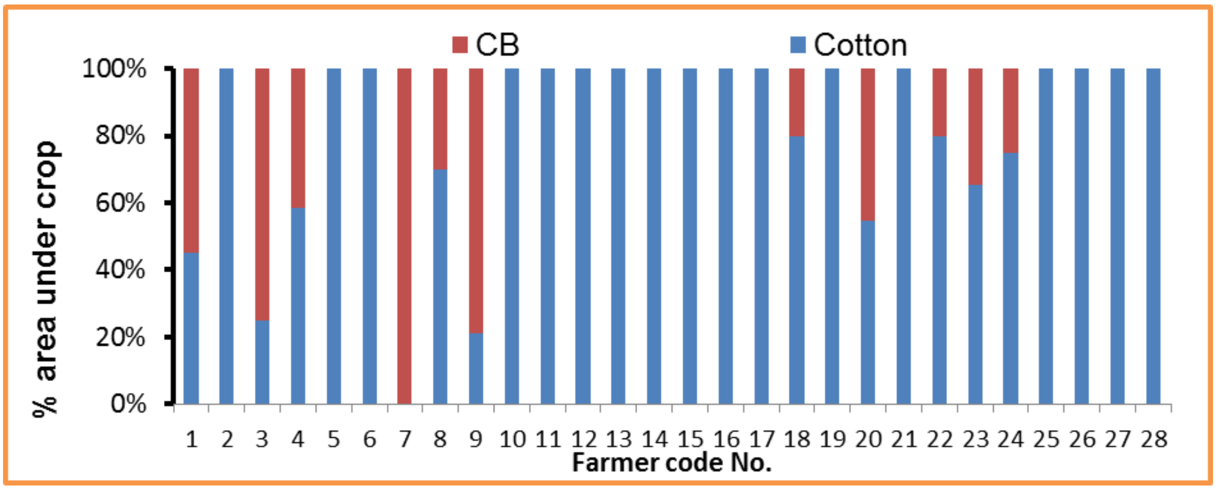
**Area under cultivation**

Total area of the experimental site was 187 ha out of which net cropped area were 170 ha Average land holding of 6.1 ha. Major crops of the area were cotton and clusterbean during *kharif* and wheat and mustard in *rabi*. Majority of farmers (about 80%) grow cotton and wheat in *kharif* and *rabi* season, respectively. About 18-20 % cropped area was under cluster bean and mustard during *kharif* and *rabi* season, respectively**.**

**Table 4 List of selected farmers along with their crop grown (2012-13)**

| Farmer No. | Crop | |
|---|---|---|
| | ***Kharif* (% Area)** | ***Rabi* (% Area)** |
| 1 | Cotton (54.8)<br>Cluster bean (45.2) | Wheat (46.2)<br>Mustard (53.8) |
| 2 | Cotton (100) | Wheat (80)Mustard (20) |
| 3 | Cotton (24.9)Cluster bean (75.1) | Mustard (100) |
| 4 | Cotton (58.3) | Wheat (58.3) |

| | | |
|---|---|---|
| | Cluster bean (41.7) | Mustard (41.7) |
| 5 | Cotton (100) | Wheat (80)<br>Mustard (20) |
| 6 | Cotton (100) | Wheat (100) |
| 7 | Cluster bean (100) | Mustard (100) |
| 8 | Cotton(70)<br>Cluster bean (30) | Wheat (96)<br>Chickpea (2)<br>Barley (2) |
| 9 | Cotton (78.9)<br>Cluster bean (21.1) | Mustard (100) |
| 10 | Cotton (100) | Wheat (79.7),Mustard (20.3) |
| 12 | Cotton (100) | Wheat (100) |
| 13 | Cotton (100) | Wheat (100) |
| 18 | Cotton (80)<br>Cluster bean (20) | Wheat (80)<br>Mustard (20) |
| 19 | Cotton (100) | Wheat (100) |
| 20 | Cotton (54.5)<br>Cluster bean (45.5) | Wheat (100) |



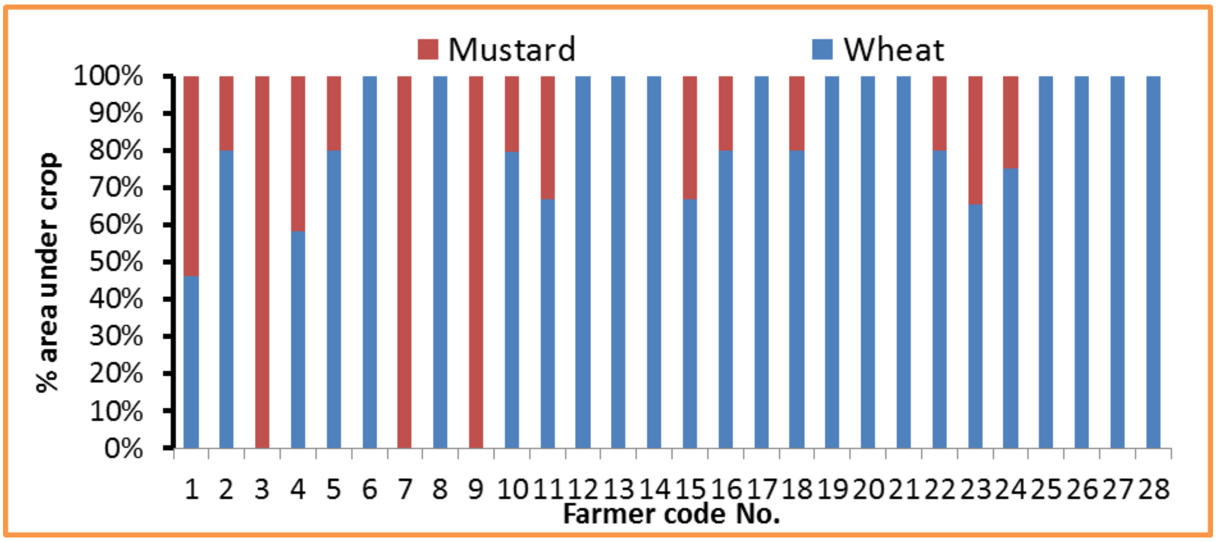




**Fig. 5 Area under cultivation during *kharif* and *rabi***

### Sampling, measurement and analysis

Most of the input parameters of CropSyst are site specific, and obtained by field measurements. Some of the input parameters such as soil hydraulic parameters are difficult to measure directly under field conditions, and hence determined through the calibration of the model. The calibration of CropSyst requires detailed crop measurements under field conditions.

The various observations required for model calibration were collected from farmer's field crop wise. The required input parameters can be categorized into meteorological, soil, water and crop parameters. These measurements were used to calibrate of CropSyst model.

### Crop and cropping sequences

In experimental area, more than 6 different types of crops are being grown by the farmers viz. *Gossypium hirsutum, Cymopsis tetragonaloba, Pennisetum glaucum, Triticum aestivum, Brassica Juncia, Cicer aeritinum* and *Hordium vulgares.* Cotton in Kharif and wheat in rabi season occupy the maximum area. The major crop sequences/rotations followed in Menawali region of Hanumangarh district is cotton-wheat for one year rotation. The major fruit crops of the district are *Citrus sinensis, Citrus reticulate* and grapes.

### Crop management practices (2012-13)

The details of crop management practices adopted for various crops at study site are as under:

### Cotton

The management practices of cotton adopted by the farmers in the study area during 2012-13 are presented in Annexure I. The tillage operation were ploughing, harrowing followed by cultivator and planking. Sowing was done between first week to last week of May. Seed rate used by the farmer range between 2.2 to 2.8 kg/ha with a spacing 60 cm x 45 cm by hand plough. Half dose of Nitrogen (N) and full Phosphorus (P) was applied as basal and remaining 1/2 dose of Nitrogen (N) was top dressed at 30 DAS

### Clusterbean

Annexure II shows the management practices of clusterbean adopted by the farmers in the study area during 2012-13. The tillage operation was ploughed, harrowing followed by cultivator and planking. Sowing was done between second week May to middle of June. Seed rate used by the farmers range between 14 to18 kg/ha with a spacing of 30 x 10 cm by seed drill. Full dose of nitrogen (N) and phosphorus (P) was applied as basal

**Wheat**

Annexure III shows the management practices of wheat adopted by the farmers in the study area during 2012-13 .The tillage operation were ploughing, harrowing followed by cultivator and planking. Sowing was done between first week November to last week of December. Seed rate used by the farmer range between 80 to 120 kg/ha with a spacing of 20 cm x 5 cm by seed drill. Half dose of nitrogen (N) and full phosphorus (P) was applied as basal and remaining 1/2 dose of nitrogen (N) was top dressed at 30 DAS

**Mustard**

Annexure IV shows the management practices of mustard adopted by the farmers in the study area during 2012-13. The tillage operation were ploughing, harrowing followed by cultivator and planking. Sowing was done between last week of October to second week of November. Seed rate used by the farmer range between 3 to 6 kg/ha with a spacing of 30 x 10 cm by seed drill. Half dose of nitrogen (N) and full phosphorus (P) was applied as basal and remaining 1/2 dose of nitrogen (N) was top dressed at 30 DAS.

**Barley**

Annexure V shows the management practices of barley adopted by the farmers in the study area during 2012-13. The tillage operation were ploughing, harrowing followed by cultivator and planking. Sowing was done on 15 December. Seed rate used by the farmer was 100 kg/ha with a spacing of 20 x 5 cm by seed drill. Half dose of nitrogen (N) and full phosphorus (P) was applied as basal and remaining 1/2 nitrogen (N) was top dressed at 30 DAS

**Chickpea**

The management practices of chickpea adopted by the farmers in the study area during 2012-13 are presented in Annexure VI. The tillage operation were ploughing, harrowing followed by cultivator and planking. Sowing was done on 25 December, 2012 using seed rate of 80 kg/ha with a spacing of 30 x 10 cm by Seed drill. Full dose of nitrogen (N) and phosphorus (P) was applied as basal

**Plant studies**

For measuring physiological parameters three sampling area in each crop of each farmers were selected during 2012-13. For cotton the area of each sampling area was 1m x 1 m, whereas in other crops an area of 0.50 m x 0.50 m were selected for measuring GAI and AGY. For measuring yields an area, quadrate sampling of 1 x 1m area were taken. In case of the crops which are grown by more than one farmers, individual farmers were considered as replication. In case of *Cicer aertinium* and *Hordeum vulgare* (the crop is grown by only one farmer) the individual sampling area (*i.e.* 3) were considered as replications. For measuring rooting depth, the five plants of each crop from ten farmers were used (Table 5).

**Table 5 Overview of the plant growth data collected for calibration of CropSyst model at farmer fields in Menawali, Hanumangarh district (2012-13)**

| Data | Method / source | Frequency | Purpose |
|---|---|---|---|
| Crop development stage (in days after sowing) *i.e*. emergence, panicle initiation, anthesis, maturity and harvest | Field observation | 4-5 times | Input derivation |
| Plant density | Field observation | 4-5 times | Input derivation |
| Leaf area | Field observation | 4-5 times | Calibration |
| Rooting depth | Field observation | 2-3 times | Input derivation |
| Crop yields | Field observation | at Harvest | Calibration |

**Leaf area ($cm^2$ $cm^{-2}$)**

The leaves from plants selected for growth analysis from each field were used for the estimation of leaf area. Leaf area was computed by leaf area meter and expressed as $cm^2$ per square meter.

**Specific leaf area (SLA)**

The Specific Leaf Area was calculated as follows:

$$SLA = \frac{\text{Leaf area (cm}^2\text{)}}{\text{Leaf dry weight (g)}}$$

**Leaf biomass (g)**

The leaves from plants for analysis were put in butter paper and kept in hot air over at 85 ± $1^0$ C for 24 hours. The dry weight of the leaves was recorded and expressed in grams

**Days to emergence**

The day on which 50 per cent of plants showed emergence in the fields was considered as emergence. The number of days taken from the date of sowing to emergence was calculated and expressed in number as days taken for emergence.

**Days to 50 per cent flowering**

The day on which 50 per cent of plants showed flowers in the fields was considered as 50 per cent flowing. The number of day taken from the date of sowing to flowering was calculated and expressed in number as days taken for 50 per cent flowering.

**Days to 50 per cent grain filling**

The day on which 50 per cent of grains filled in the fields was considered as 50 per cent grain filling. The number of day taken from the date of sowing to grain filling was calculated and expressed in number as days taken for 50 per cent grain filling.

**Days to maturity**

The day on which 50 per cent of plants showed maturity in the fields was considered as maturity of plants. The number of days taken from the date of sowing to maturity was calculated and expressed in number as days taken for maturity.

**1000 - seed weight**

A small seed sample was taken from the produce of each of the net plot harvested and 1000-seeds were counted and their weight was recorded as test weight (g).

**Seed yield**

The seed yield of each net plot was recorded in kg/plot after cleaning the threshed produce and was converted as kg/ha.

**Straw yield**

Straw yield was obtained by subtracting the seed yield (kg/ha) from biological yield (kg/ha). In case of cotton, seed + cotton were taken as economic yield.

**Biological yield**

The harvested material from net area of each plot was thoroughly sun dried. After drying, the produce of individual net plot was weighed with the help of a spring balance and recorded in kg/ plot. Later this was converted into kg/ha.

**Harvest index**

The harvest index was calculated by using following formula and expressed as percentage (Singh and Stoskopf, 1971).

$$\text{Harvest index (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} X100$$

**Nutrient content and uptake**

The representative samples of seed and straw drawn at the time of threshing and winnowing were ground and analyzed for nitrogen (Snell and Snell, 1949), phosphorus (Jackson, 1973) and potassium (Jackson, 1973) concentration. The uptake of nitrogen, phosphorus and potassium after harvest in seed and stover was estimated by using the following relationship:

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Nutrient content in seed (\%)} \times \text{Seed yield (kg/ha)} + \text{Nutrient content in stover (\%)} \times \text{Stover yield (kg/ha)}}{100}$$

**Statistical analysis**

**Water balance**

The field water balance can be written as

$$P = E + T + R + D + S - I$$

Where, P is precipitation, E is soil evaporation, T is crop transpiration, R is surface runoff, D is drainage, S is change in soil water storage and I is irrigation.

**Water use efficiency**

Water use efficiency (WUE) was computed by the following equation

$$WUE = \frac{\mathrm{Y}}{\mathrm{ET}}$$

Where, WUE represents water use efficiency for the grain yield (kg/ha), Y is the grain yield and ET is the evapo-transpiration during the growth period.

**Root Mean Square Error**

Root mean square error is used to test the error between simulated and observed values. The expression of RMSE is

$$RMSE = \sqrt{\frac{\sum_{i=0}^{n}(Observed\ i - Simulated\ i)^2}{n}}$$

**Correlation coefficient**

It is a measure that determines the degree to which two variable's movements are associated. The correlation coefficient was calculated by the following equation:

$$R = \frac{\sum(o_i - \bar{o})(p_i - \bar{p})}{\sqrt{\sum(o_i - \bar{o})^2 \sum(p_i - \bar{p})^2}}$$

**Index of agreement**

The index of agreement is used to pondered percentage of the criteria to which the alternative is preferred to alternative and is calculated by

$$I = 1 - \frac{\sum(p_i - o_i)^2}{\sum(|p_i - \bar{o}| + |o_i - \bar{o}|)^2}$$

**Irrigation**

In the study area, the source of irrigation is the IGNP canal. The method used for discharge, duration and depth of irrigation and frequency are presented in Table 6.

**Table 6 Overview of the irrigation data collected for calibration of CropSyst model at farmer fields in Menawali, Hanumangarh district (2012-13)**

| Data | Method / source | Frequency | Purpose |
|---|---|---|---|
| Discharge of Irrigation source i.e. canal water | V notch | 3 - 4 times | Input derivation |
| Duration of irrigation | Field observation | Each irrigation | Input derivation |
| Irrigation depth | Calculated by multiplying the discharge and duration of irrigation and divided by field area. | Each irrigation | Input derivation |

## Experimental Results (2012-13)

### Field data

Four *rabi* season crops (wheat, barley, mustard and chickpea) and two *kharif* season crops (cotton, clusterbean) were grown at study site (Menawali) in Hanumangarh district during 2012-13. Data pertaining to growth, biomass, phenology, LAI etc. of various crops which are required for calibration of CropSyst model-Version 4.15.24 (Stockle *et al.* 2003) were collected. Major biophysical model parameters were calibrated to the available data sets. Most of CropSyst model parameters were kept at the recommended default values.

### Seed, Straw and biomass yield of crops

### KHARIF CROPS

#### Cotton

The seed, straw and biomass yield of cotton varied between 1594 to 2354, 4726 to 6769 and 6320 to 9216 kg/ha, respectively (Table 7) during 2012. The average seed cotton, straw and biomass yield of cotton was 1946, 5413and 7359 kg/ha, respectively.

#### Clusterbean

Clusterbean produced 1214 to 1784, 3579 to 5164 and 4825 to 6948 kg/ha seed, straw and biomass yield, respectively (Table 7) during 2012. The average seed, straw and biomass yield of clusterbean was 1530, 4314 and 5844 kg/ha, respectively.

### RABI CROPS

#### Wheat

The seed, straw and biomass yield of wheat varied from 3893 to 4477, 5367 to 5879 and 9439 to 10218 kg/ha, respectively (Table 7) during 2012-13. The average seed, straw and biomass yield of wheat was 4275, 5809 and 10084 kg/ha, respectively.

#### Mustard

The seed, straw and biomass yield of mustard varied from 1621 to 2543, 3419 to 5331 and 5058 to 7874 kg/ha, respectively (Table 7) during 2012-13. The average seed, straw and biomass yield of mustard was recorded 1940, 4012 and 5952 kg/ha, respectively.

**Chickpea**

The chickpea crop was grown by only one farmer during 2012-13. The seed, straw and biomass yield of chickpea was 2292, 4290 and 6582 kg/ha, respectively (Table 7).

**Barley**

The barley crop was grown by only one farmer during 2012-13. The seed, straw and biomass yield of barley was 4051, 5743 and 9794 kg/ha, respectively (Table 7).

Between *kharif* season crops, cotton generated higher seed and biomass yield compared to clusterbean (Table 7). Amongst the *rabi* season crops, wheat out yielded other crops and produced 120.3, 86.5 and 5.5 % higher seed yields than mustard, chickpea and barley respectively. With respect to total biomass productivity, wheat gave highest biomass yield followed by barley, chickpea and mustard.

**Table 7 Observed Economic and straw yield and aboveground biomass of different crops grown at Menawali, Hanumangarh District (2012-13)**

| Crops | Seed yield (kg/ha) | | Straw yield (kg/ha) | | AGB (kg/ha) | |
|---|---|---|---|---|---|---|
| | Range | Mean± SD | Range | Mean± SD | Range | Mean± SD |
| Cotton | 1594 - 2354 | 1946 ± 228 | 4726 - 6769 | 5413 ± 637 | 6320 - 9123 | 7359 ± 846 |
| Clusterbean | 1214 - 1784 | 1530 ± 231 | 3579 - 5164 | 4314 ± 727 | 4825 - 6948 | 5844 ± 951 |
| Wheat | 3893 - 4477 | 4182 ± 180 | 5367 - 5879 | 5651 ± 162 | 9439 - 10218 | 9833 ± 286 |
| Mustard | 1621 - 2543 | 1940 ± 309 | 3419 - 5331 | 4012 ± 600 | 5058 - 7874 | 5952 ± 901 |
| Chickpea | 2045 - 2537 | 2292 ± 218 | 3856 - 4658 | 4290 ± 238 | 5975 - 7224 | 6582 ± 563 |
| Barley | 3871 - 4231 | 4051 ± 152 | 5624 - 5861 | 5743 ± 203 | 9495 - 10092 | 9794 ± 411 |

**Economic analysis**

**Kharif crops**

**Cotton**

The cost of cultivation of cotton varied from Rs. 40395 to 46080/ha with an average of Rs. 43530/ha during 2012. Cotton earned Rs. 96698/ha as gross return and Rs. 53580/ha as net return. The cultivation of cotton has 2.2 B:C ratio (Table 8).

**Clusterbean**

The cost of cultivation of clusterbean varied from Rs. 22764 to 28665/ha with an average of Rs. 24386/ha during 2012. Clusterbean earned Rs. 238065/ha as gross return and Rs. 213680/ha as net return with 9.8 B:C ratio(Table 8).

**Rabi Crops**

**Wheat**

The cost of cultivation of wheat ranged between Rs. 24541 - 30793/ha with an average of Rs. 27630/ha during 2012-13. The gross return of wheat observed Rs. 77521/ha. On an average wheat gave Rs. 50058/ha net return with B:C ratio of 2.8 (Table 8).

**Mustard**

The cost of cultivation of mustard varied from Rs. 15609 to 23432/ha with an average of Rs. 21524/ha during 2012-13. Mustard earned Rs. 52945/ha gross return and Rs. 31421/ha net return with average 2.4 B:C ratio (Table 8).

**Barley**

The average cost of cultivation of barley was Rs. 29600/ha. Barley earned Rs. 80020/ha gross and Rs. 50420/ha net return with B:C ratio of 2.7(Table 8) during 2012-13.

**Chickpea**

The cost of cultivation of chickpea was Rs. 26025/ha during 2012-13. Growing chickpea earned Rs. 77340/ha gross and Rs. 51315/ha net return with B:C ratio of 2.9(Table 8).

Highest cost of cultivation was observed in cotton in *kharif* and barley in *rabi* season. However, clusterbean recorded highest net return of Rs 213680/ha with B:C ratio of 9.8 followed by barley.

**Table 8 Economics of different crops grown at Menawali, Hanumangarh (2012-13)**

| Crops | Cost of cultivation (Mean± SD) | Gross return (Mean± SD) | Net return (Mean± SD) | B:C ratio |
|---|---|---|---|---|
| Cotton | 43118±2386 | 96698±11448 | 53580±11348 | 2.2 |
| Clusterbean | 24386±2175 | 238065±34858 | 213680±35659 | 9.8 |
| Wheat | 27630±2152 | 77521±4470 | 50058±3577 | 2.8 |
| Mustard | 21524±1729 | 52945±6855 | 31421±6606 | 2.4 |
| Barley | 29600±2124 | 80020±4543 | 50420±3671 | 2.7 |

| | | | | |
|---|---|---|---|---|
| Chickpea | 26025±1254 | 77340±2162 | 51315±785 | 2.9 |

**N-uptake**

Total N-uptake of cotton, clusterbean, wheat, mustard, chickpea and barley range from 56.9 to 94.1, 56.9 to 94.6, 94.2 to 114.8, 65.0 to 101.4, 106.4 to 117.3 and 108.6 to 119.8 kg/ha respectively with the average N-uptake of 78, 76, 103 and 79 kg/ha for cotton, clusterbean, wheat and mustard, respectively (Table 9) during 2012-13. The standard deviation (SD) of cotton, clusterbean, wheat and mustard were 11, 13, 5 and 18, respectively. N-uptake of chickpea and barley was recorded as 110.8 and 112.3kg/ha, respectively.

Data presented in Table 9 indicate that cotton and clusterbean gave relatively similar N-uptake in *kharif* season crops. Among the *rabi* season crops barley recorded higher N-uptake than other crops with a tune of 9.0, 42.1 and 1.3 % higher N-uptake than wheat, mustard and chickpea, respectively.

**Table 9 Nitrogen uptake of different crops grown at Menawali, Hanumangarh (2012-13)**

| **Crops** | **N-uptake (kg/ha)** | |
|---|---|---|
| | **Range** | **Mean± SD** |
| Cotton | 56.9 to 94.1 | 78±11 |
| Clusterbean | 56.9 to 94.6 | 79± 13 |
| Wheat | 94.2 to 114.5 | 103±5 |
| Mustard | 65.0 to 101.3 | 79±18 |
| Chickpea | 106.4 to 117.3 | 110.8±7 |
| Barley | 108.6 to 119.8 | 112.3±6 |

**Water balance**

Water used in different crops varied from 352.8 to 726.7 mm (Table 10). The highest water was used by cotton (726.7mm) followed by wheat (555.5mm), chickpea (415.0mm), barley (406.0mm), clusterbean (405.8mm) whereas lowest water was used by mustard (352.8mm) during 2012-13. Average ET losses in different crops ranged from 308.5 to 558.6 mm in which highest ET loss was observed in cotton and lowest in mustard. The deep drainage varied from 21.6 mm to 146.1 mm, being highest in cotton followed by clusterbean, chickpea, mustard, wheat and barley. The share of ET in total water applied was 77.9 to 93.4 % (Fig 4.1). The relative share of ET were highest for barley

(93.4 %) followed by wheat (88.5 %), mustard (87.4 %), chickpea (85.9 %), clusterbean (80.5 %) and cotton (76.9 %). The deep drainage constituted 5 % to 20 % of total water applied, and its value was highest for cotton (20.1 %) followed by clusterbean (13.1 %), chickpea (11.7 %), mustard (10.3 %), wheat (7.4 %) and barley (5.3 %).

**Table 10 Average Soil water balance components (mm) for different crops grown at Menawali, Hanumangarh (2012-13)**

| Component | Cotton | Clusterbean | Wheat | Mustard | Barley | Chickpea |
|---|---|---|---|---|---|---|
| **Inputs** | | | | | | |
| Irrigation (I) | 408.2 | 91.6 | 451.2 | 270.8 | 300 | 309 |
| Rainfall (R) | 318.5 | 314.1 | 104.3 | 82 | 106 | 106 |
| Total (I+R) | 726.7 | 405.8 | 555.5 | 352.8 | 406 | 415 |
| **Losses** | | | | | | |
| ET | 558.6 | 326.7 | 412.4 | 308.5 | 379.4 | 356.5 |
| Drainage | 146.1 | 53.2 | 93.8 | 36.2 | 21.6 | 48.5 |
| Stored soil moisture | 22 | 25.9 | 59.3 | 8.1 | 5 | 10 |

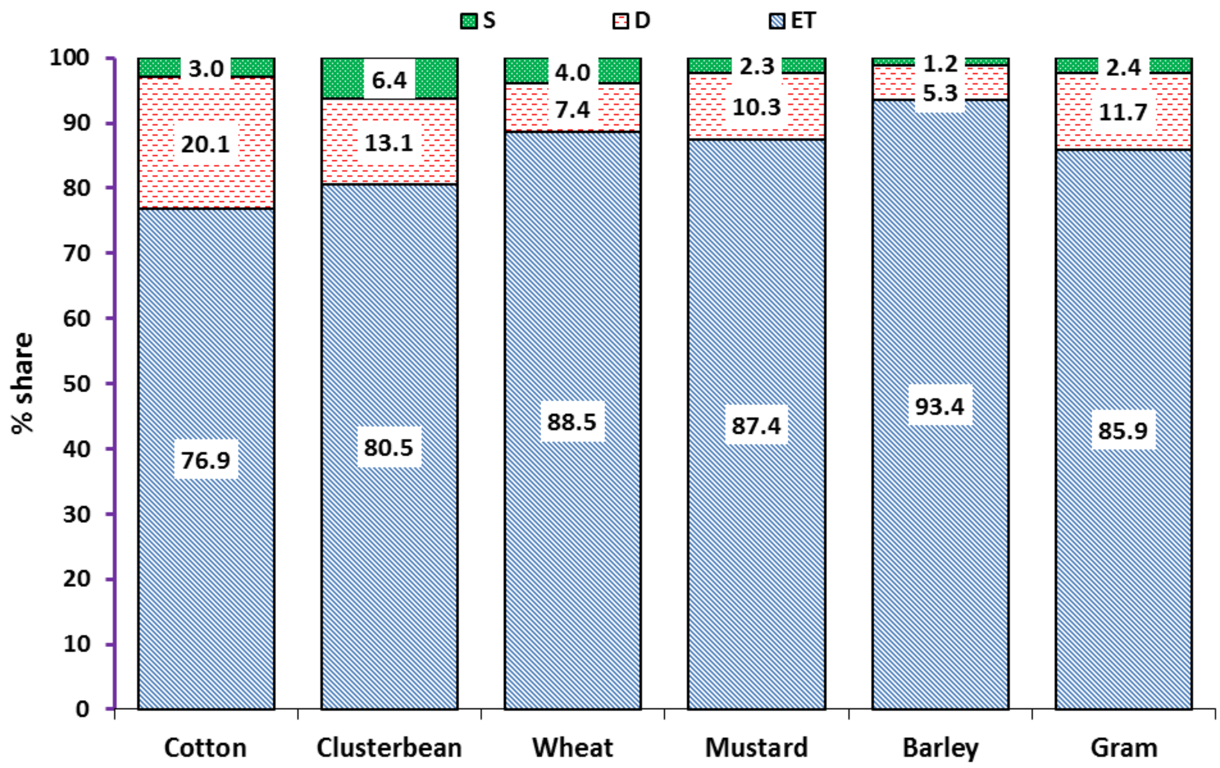


**Fig 6 Soil water balance components for different crops (2012-13)**

## Model Calibration

CropSyst model was calibrated for four *rabi* season crops (wheat, barley, mustard and chickpea) and two *kharif* season crops (cotton, cluster bean) during 2012-13. Various model parameters, related to crop transpiration, canopy growth, were kept at model default. Other model parameters were modified during the calibration process to improve the model prediction accuracy. For the parameters that could be fixed, a range of realistic values was determined, based on experimental data and literature. During calibration, latter parameters were adjusted by running the model with various combinations of values within these realistic ranges. The measured aboveground biomass (AGB), grain yield, N-uptake and soil moisture were compared with the simulated values. Taking into account difference in some physiological characteristics of crop varieties, calibration for each crop was carried out variety wise. However here we give generalized statistical measures for separate crops. As chickpea and barley were planted by only one farmer each, statistical measures for these were calculated only for soil moisture.

## Model Calibration for cotton

For calibration of CropSyst model for cotton, data of grain yield, above ground biomass (AGB) and N-uptake were used to determine the best crop model parameters.

### Seed yield

The seed cotton yield of *Bt* hybrids were simulated with CropSyst model by inputting the observed data on duration of different phenol-phases during the experiment under field conditions. Table 11 shows that the simulate yield (1891 kg/ha) of cotton were closer to the observed seed cotton yield of 1946 kg/ha as it is evident from the 7 % RRMSE during 2012-13. The correlation coefficient of 0.89 and Index of agreement of 0.92 calculated for yield of cotton (Table 11).

**Table 11 Quantitative measures of model performance for yield, AGB and N-uptake of cotton (2012-13)**

| Particular | Observed | Simulated | RMSE | RRMSE | Correlation coefficient | Index of agreement |
|---|---|---|---|---|---|---|
| **Seed yield** | 1946 | 1891 | 130 | 7 | 0.89 | 0.92 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **AGB** | 7359 | 7274 | 366 | 5 | 0.94 | 0.96 |
| **N-uptake** | 78 | 80 | 5 | 6 | 0.84 | 0.89 |

**Above ground biomass**

Simulations of cotton aboveground biomass matched with the field data reasonably well. Final aboveground biomass, however, was overestimated by the model. The simulated aboveground biomass (7274 kg/ha) was lower than observed aboveground biomass (7359 kg/ha) as shown in table 13 with 5 % RRMSE during 2012-13. Correlation coefficient of 0.94 and Index of agreement of 0.96 observed for AGB of cotton.

**N-uptake**

Simulations of N-uptake slightly matched with the field data. The simulated N-uptake (80 kg/ha) was closer to observed N-uptake (78 kg/ha) as shown in table 11 with 6 % RRMSE during 2012-13. Correlation coefficient of 0.84 and Index of agreement of 0.89 observed for N-uptake of cotton (Table 11).

**Model Calibration for clusterbean**

Calibration of clusterbean was based on the data from the grain yield, above ground biomass (AGB) and N-uptake used to determine the best crop parameters.

**Seed yield**

Seed yield was simulated with CropSyst model by inputting the observed data on duration of different phenol-phases during the experiment under field conditions. Table 12 showed that the simulate yield (1532 kg/ha) of clusterbean were closer to the observed yield of 1530 kg/ha as it is evident from the 7.8 % RRMSE. Correlation coefficient of 0.85 and Index of agreement of 0.92 observed for yield of clusterbean (Table 12) during 2012-13.

**Above ground biomass**

Simulations results of clusterbean aboveground biomass matched well with the field data. The simulated aboveground biomass (5913 kg/ha) was higher than observed aboveground biomass (5844 kg/ha) as shown in Table 12 with 6.3 % RRMSE. Correlation coefficient of 0.91 and Index of agreement of 0.95 observed for AGB of clusterbean (Table 12) during 2012-13.

**Table 12 Quantitative measures of model performance for yield, AGB and N-uptake of clusterbean (2012-13)**

| Particular | Observed | Simulated | RMSE | RRMSE | Correlation coefficient | Index of agreement |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| **Seed yield** | 1530 | 1532 | 119 | 7.8 | 0.85 | 0.92 |
| **AGB** | 5844 | 5913 | 369 | 6.3 | 0.91 | 0.95 |
| **N-uptake** | 74 | 75 | 8 | 11.0 | 0.79 | 0.81 |

**N-uptake**

Simulated data of N-uptake slightly matched with the field data. The simulated N-uptake (75 kg/ha) was closer to observed N-uptake (74 kg/ha) with 11 % RMSE (Table 16) during 2012-13. Correlation coefficient of 0.79 and Index of agreement of 0.81 observed for N-uptake of clusterbean (Table 12).

**Model Calibration for wheat**

For calibration of wheat data from the grain yield, above ground biomass (AGB), N-uptake and moisture content were used to determine the best crop parameters.

**Seed yield**

The seed yield was simulated with CropSyst model by inputting the observed data on duration of different phenol-phases during the experiment under field conditions. Table 13 showed that the simulate yield (4140 kg/ha) of wheat were closer to the observed yield of 4182 as it is evident from the 3 % RRMSE. Correlation coefficient of 0.87 and Index of agreement of 0.90 observed for yield of wheat (Table 13) during 2012-13.

**Table 13 Quantitative measures of model performance for yield, AGB and N-uptake of wheat (2012-13)**

| Particular | Observed | Simulated | RMSE | RRMSE | Correlation coefficient | Index of agreement |
|---|---|---|---|---|---|---|
| **Seed yield** | 4182 | 4140 | 124 | 3.0 | 0.87 | 0.90 |
| **AGB** | 9833 | 9956 | 553 | 5.6 | 0.76 | 0.67 |
| **N-uptake** | 104 | 100 | 7 | 6.5 | 0.64 | 0.74 |

**Above ground biomass**

Simulations of aboveground biomass development of wheat matched well with the field data. The simulated aboveground biomass (9956 kg/ha) was higher than observed aboveground biomass (9833 kg/ha) as shown in Table 13 with 5.6 % RRMSE during 2012-13. Correlation coefficient of 0.76 and Index of agreement of 0.67 observed for AGB of wheat (Table 13).

**N-uptake**

Simulations of N-uptake moderately matched with the field data. The simulated N-uptake 100 kg/ha) was closer to observed N-uptake (104 kg/ha) as shown in table 19 with 6.5 % RMSE. Correlation coefficient of 0.64 and Index of agreement of 0.74 observed for N-uptake of wheat (Table 13) during 2012-13.

**Moisture content**

Data presented in table 14 shows the RMSE, correlation and index of agreement values of moisture content at different fields during 2012-13. The RMSE of moisture content ranged from 0.0272 to 0.0424. These small values reveal that soil water flow was well simulated by CropSyst at different fields. As no systematic under or over estimation of moisture content was observed, the differences between the observed and simulated moisture content are contributed to the spatial heterogeneity and observation errors, which are inevitable under field conditions. Simulated value of moisture content predict well with observed values in the upper layers. The index of agreement was 0.91 in top soil layer of 0-10 cm (Fig 7).

**Table 14 Quantitative measures of model performance for soil moisture under wheat (2012-13)**

| Soil layer, cm | RMSE | RRMSE | Correlation | Index of agreement |
|---|---|---|---|---|
| 0-100 | 0.0355 | 18 | 0.956 | 0.85 |
| 0-10 | 0.0325 | 17 | 0.963 | 0.91 |
| 10-20 | 0.0327 | 17 | 0.981 | 0.87 |
| 20-30 | 0.0330 | 17 | 0.975 | 0.87 |
| 30-40 | 0.0307 | 15 | 0.985 | 0.87 |
| 40-50 | 0.0280 | 14 | 0.988 | 0.87 |
| 50-60 | 0.0272 | 14 | 0.987 | 0.88 |
| 60-70 | 0.0391 | 20 | 0.964 | 0.80 |
| 70-80 | 0.0400 | 21 | 0.969 | 0.78 |
| 80-90 | 0.0387 | 20 | 0.960 | 0.78 |
| 90-100 | 0.0424 | 22 | 0.985 | 0.75 |

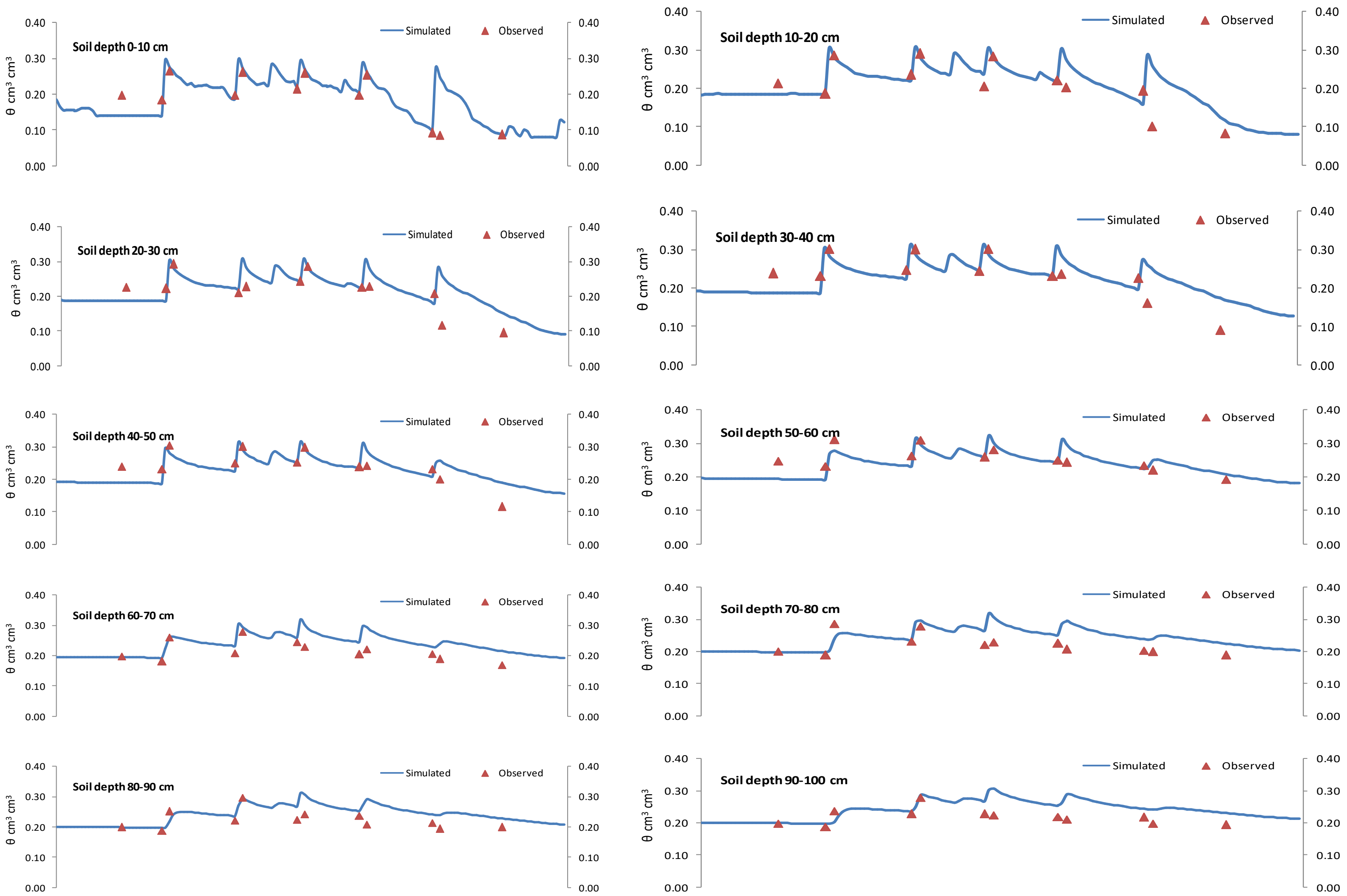



**Figure 7 Observed and simulated soil water content under wheat (2012-13)**

**Model Calibration for mustard**

For calibration of mustard data from the grain yield, above ground biomass (AGB), N-uptake and moisture content were used to determine the best crop parameters.

**Seed yield**

The seed yield was simulated with CropSyst model by inputting the observed data on duration of different phenol-phases during the experiment under field conditions. The simulate yield (1858 kg/ha) of mustard were closer to the observed yield of 1978 kg/ha (Table 15) as it is evident from the 10.3 % RRMSE during 2012-13. Correlation coefficient of 0.82and Index of agreement of 0.85 observed for yield of mustard (Table 15).

**Table 15 Quantitative measures of model performance for yield, AGB and N-uptake of mustard (20120-13)**

| Particular | Observed | Simulated | RMSE | RRMSE | Correlation coefficient | Index of agreement |
|---|---|---|---|---|---|---|
| **Seed yield** | 1940 | 1858 | 203 | 10.3 | 0.82 | 0.85 |
| **AGB** | 5952 | 5670 | 623 | 10.3 | 0.82 | 0.84 |
| **N-uptake** | 79.2 | 87.5 | 18 | 23.0 | 0.75 | 0.69 |

**Above ground biomass**

Simulations of aboveground biomass development of mustard matched with the field data. The observed aboveground biomass (5952 kg/ha) was higher than simulated aboveground biomass (5670 kg/ha) as shown in Table 15 with 10.3 % RRMSE during 2012-13. Correlation coefficient of 0.82 and Index of agreement of 0.84 observed for AGB of mustard Table 15).

**N-uptake**

Simulations of N-uptake moderately matched with the field data. The simulated N-uptake 87.5 kg/ha) was higher than observed N-uptake (79.2 kg/ha) as shown in Table 23 with 23% RMSE. The Correlation coefficient of 0.75 and Index of agreement of 0.69 observed for N-uptake of mustard (Table15) during 2012-13.

**Moisture content**

The RMSE of moisture content ranged from 0.0423 to 0.0562 during 2012-13. These values reveal that soil water flow was well simulated by CropSyst model. Simulated value of moisture content predict well with observed values in 0-100 cm with 0.0505, 0.956, 0.78 and 0.983 of RMSE, correlation and index of agreement, respectively (Table 16 and Fig 8).

**Table 16 Quantitative measures of model performance for soil moisture under mustard (2012-13)**

| Soil layer, cm | RMSE | RRMSE | Correlation | Index of agreement |
|---|---|---|---|---|
| 0-100 | 0.0505 | 28 | 0.956 | 0.78 |
| 0-10 | 0.0423 | 25 | 0.982 | 0.87 |
| 10-20 | 0.0513 | 29 | 0.972 | 0.78 |
| 20-30 | 0.0495 | 27 | 0.960 | 0.79 |
| 30-40 | 0.0510 | 27 | 0.956 | 0.78 |
| 40-50 | 0.0508 | 27 | 0.954 | 0.77 |
| 50-60 | 0.0484 | 26 | 0.970 | 0.80 |
| 60-70 | 0.0530 | 29 | 0.962 | 0.72 |
| 70-80 | 0.0562 | 32 | 0.952 | 0.70 |
| 80-90 | 0.0495 | 27 | 0.953 | 0.73 |
| 90-100 | 0.0496 | 28 | 0.952 | 0.70 |

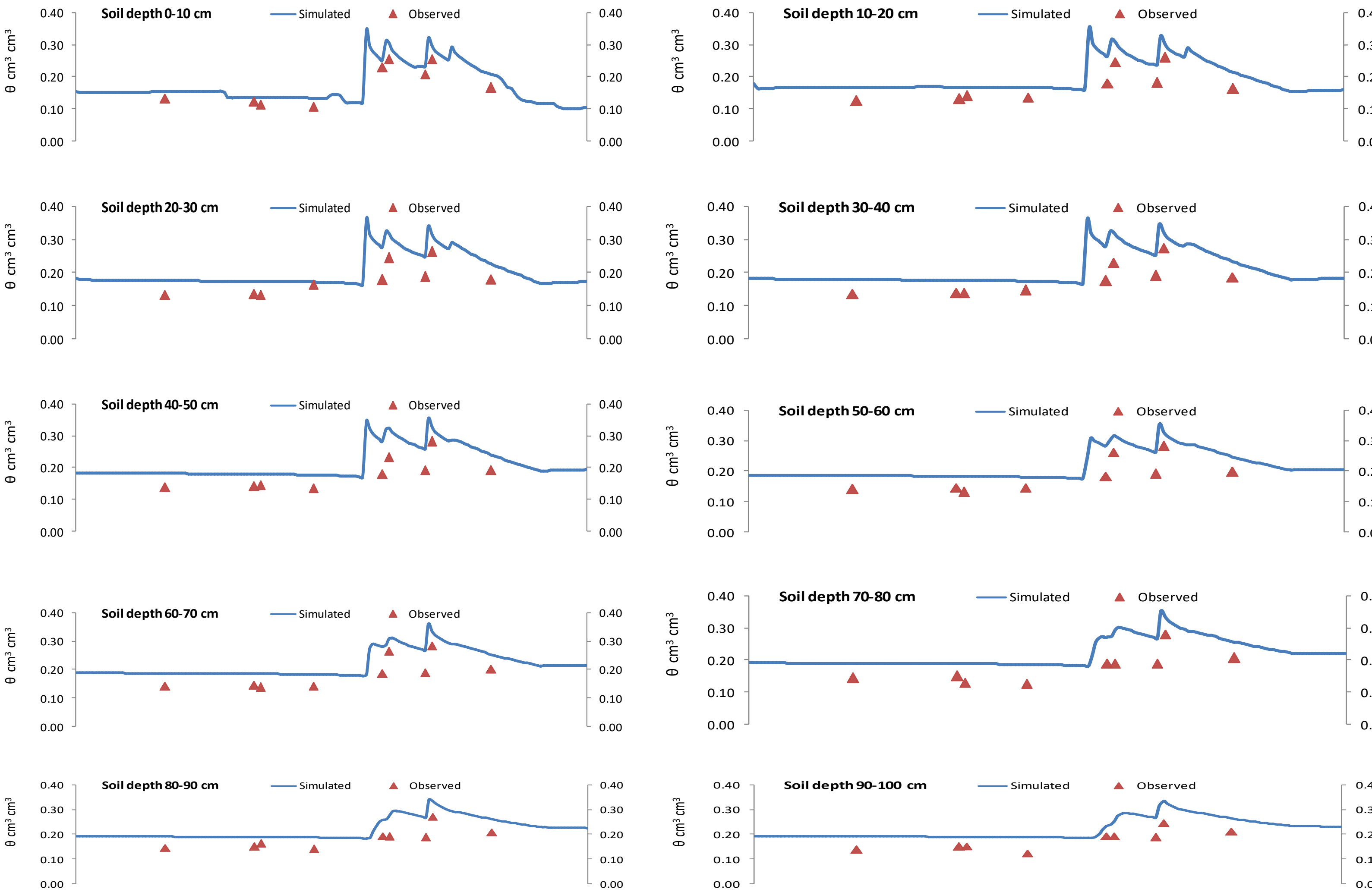



**Figure 8 Observed and simulated soil water content under mustard (2012-13)**

**Calibration for barley**

For calibration of barley data from the grain yield, above ground biomass (AGB), N-uptake and moisture content were used to determine the best crop parameters.

**Seed yield**

The seed yield was simulated with CropSyst model by inputting the observed data on duration of different phenol-phases during the experiment under field conditions. Table 17 showed that the simulate yield (4080 kg/ha) of barley were closer to the observed yield of 4051 kg/ha. The absolute and relative error was 29 and 0.70, respectively during 2012-13.

**Table 17 Quantitative measures of model performance for yield, AGB and N-uptake of barley (2012-13)**

| Particular | Observed | Simulated | Absolute error | Relative error |
|---|---|---|---|---|
| **Seed yield** | 4051 | 4080 | 29 | 0.70 |
| **AGB** | 9794 | 9487 | 307 | 3.13 |
| **N-uptake** | 94.31 | 81.8 | 13 | 13.29 |

**Above ground biomass**

Simulations of aboveground biomass development of mustard differ with the field data. The observed aboveground biomass (9794 kg/ha) was higher than simulated aboveground biomass (9487 kg/ha) (Table 17). The absolute and relative error was 307 and 3.13, respectively during 2012-13.

**N-uptake**

Simulations of N-uptake slightly matched with the field data. The simulated N-uptake 81.8 kg/ha) was lower than observed N-uptake (94.3 kg/ha) during 2012-13. The absolute and relative error was 13 and 13.2, respectively (Table 17).

**Moisture content**

Data presented in table 18 shows the RMSE, correlation and index of agreement values of moisture content during 2012-13. The RMSE of moisture content ranged from 0.0104 to 0.0599. These small values reveal that soil water flow was well simulated by CropSyst at different fields. As no systematic under or over estimation of moisture content was observed, the differences between the observed and simulated moisture content are contributed to the spatial heterogeneity and observation errors, which are inevitable under field conditions.

Simulated value of moisture content predict well with observed values in the upper layers up to 60 cm. The index of agreement was 0.99 in top soil layer of 50 cm (Fig 9).

**Table 18 Quantitative measures of model performance for soil moisture under barley (2012-13)**

| Soil layer, cm | RMSE | RRMSE | Correlation coefficient | Index of agreement |
|---|---|---|---|---|
| 0-100 | 0.0387 | 17 | 0.888 | 0.87 |
| 0-10 | 0.0112 | 6 | 0.999 | 0.99 |
| 10-20 | 0.0104 | 5 | 0.999 | 0.99 |
| 20-30 | 0.0104 | 5 | 0.999 | 0.99 |
| 30-40 | 0.0104 | 4 | 0.999 | 0.99 |
| 40-50 | 0.0104 | 4 | 0.999 | 0.99 |
| 50-60 | 0.0104 | 4 | 0.998 | 0.98 |
| 60-70 | 0.0599 | 28 | 0.997 | 0.59 |
| 70-80 | 0.0599 | 28 | 0.996 | 0.56 |
| 80-90 | 0.0599 | 28 | 0.995 | 0.54 |
| 90-100 | 0.0599 | 28 | 0.994 | 0.50 |

**Calibration for chickpea**

For calibration of chickpea data from grain yield, above ground biomass (AGB), N-uptake and moisture content were used to determine the best crop parameters.

**Seed yield**

The seed yield was simulated with CropSyst model by inputting the observed data on duration of different phenol-phases during the experiment under field conditions. Table 19 showed that the simulate yield (2281 kg/ha) of chickpea were agreed to the observed yield of 2292 kg/ha. The absolute and relative error was 11 and 0.48 during 2012-13.

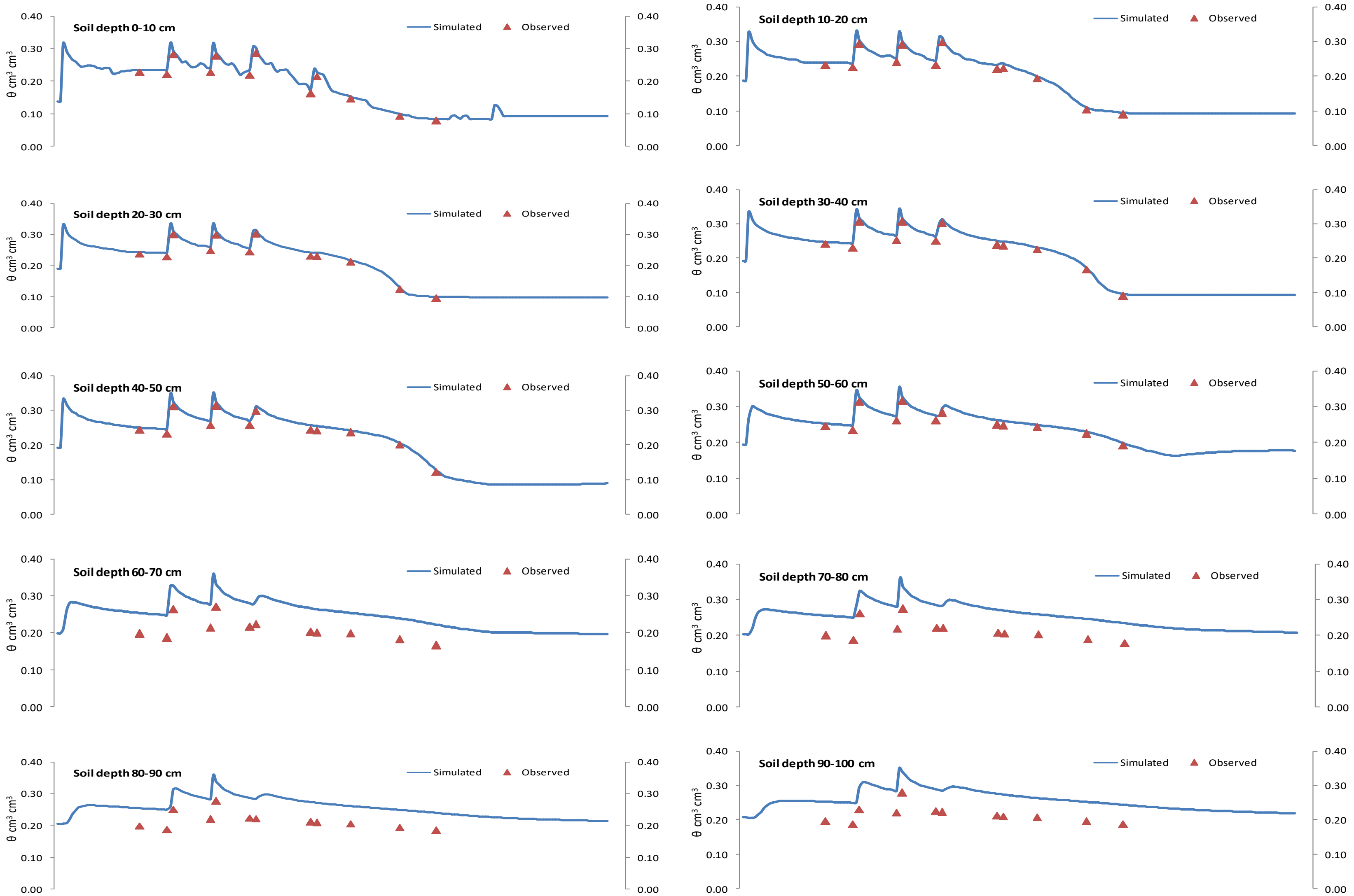



**Figure 9 Observed and simulated soil water content under barley (2012-13)**

**Table 19 Quantitative measures of model performance for yield, AGB and N-uptake of chickpea (2012-13)**

| Particular | Observed | Simulated | Absolute error | Relative error |
|---|---|---|---|---|
| **Seed yield** | 2292 | 2281 | 11 | 0.48 |
| **AGB** | 6582 | 7359 | 777 | 12 |
| **N-uptake** | 110 | 140 | 29 | 27 |

**Above ground biomass**

Simulations of aboveground biomass development of mustard differ with the field data. The observed aboveground biomass (6582 kg/ha) was lower than simulated aboveground biomass (7359 kg/ha) as shown in Table 19. The absolute and relative error was 777 and 12, respectively during 2012-13.

**N-uptake**

Simulations of N-uptake slightly matched with the field data. The simulated N-uptake 140 kg/ha) was higher than observed N-uptake (110 kg/ha) as shown in Table 19. The absolute and relative error was 29 and 27, respectively during 2012-13.

**Moisture content**

Data in table 20 shows the value of RMSE of moisture content ranged from 0.0423 to 0.0562 during 2012-13. These values reveal that soil water flow was well simulated by CropSyst model. Simulated value of moisture content predict well with observed values in 0-100 cm with 0.0359, 0.97, 0.89 and 0.99 of RMSE, correlation and index of agreement, respectively (Fig 10).

**Table 20 Quantitative measures of model performance for soil moisture under chickpea (2012-13)**

| Soil layer, cm | RMSE | RRMSE | Correlation coefficient | Index of agreement |
|---|---|---|---|---|
| 0-100 | 0.0359 | 17 | 0.97 | 0.89 |
| 0-10 | 0.0333 | 19 | 0.99 | 0.93 |
| 10-20 | 0.0386 | 20 | 0.98 | 0.88 |
| 20-30 | 0.0380 | 19 | 0.97 | 0.88 |
| 30-40 | 0.0376 | 18 | 0.98 | 0.88 |
| 40-50 | 0.0366 | 17 | 0.98 | 0.89 |
| 50-60 | 0.0404 | 19 | 0.95 | 0.86 |
| 60-70 | 0.0400 | 19 | 0.94 | 0.84 |
| 70-80 | 0.0309 | 14 | 0.98 | 0.90 |
| 80-90 | 0.0321 | 15 | 0.98 | 0.89 |
| 90-100 | 0.0291 | 13 | 0.97 | 0.89 |

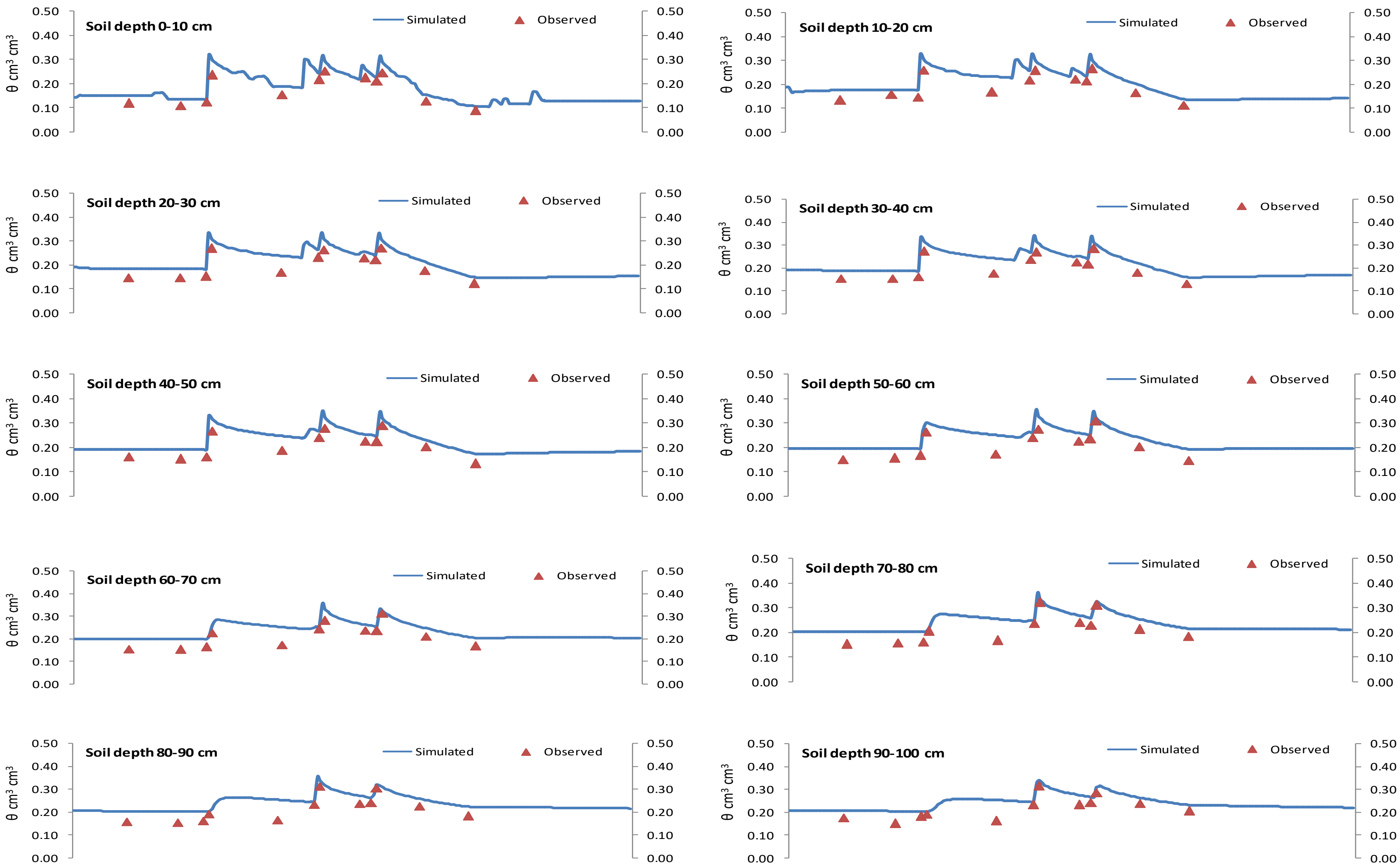



**Figure 10 Observed and simulated soil water content under chickpea (2012-13)**

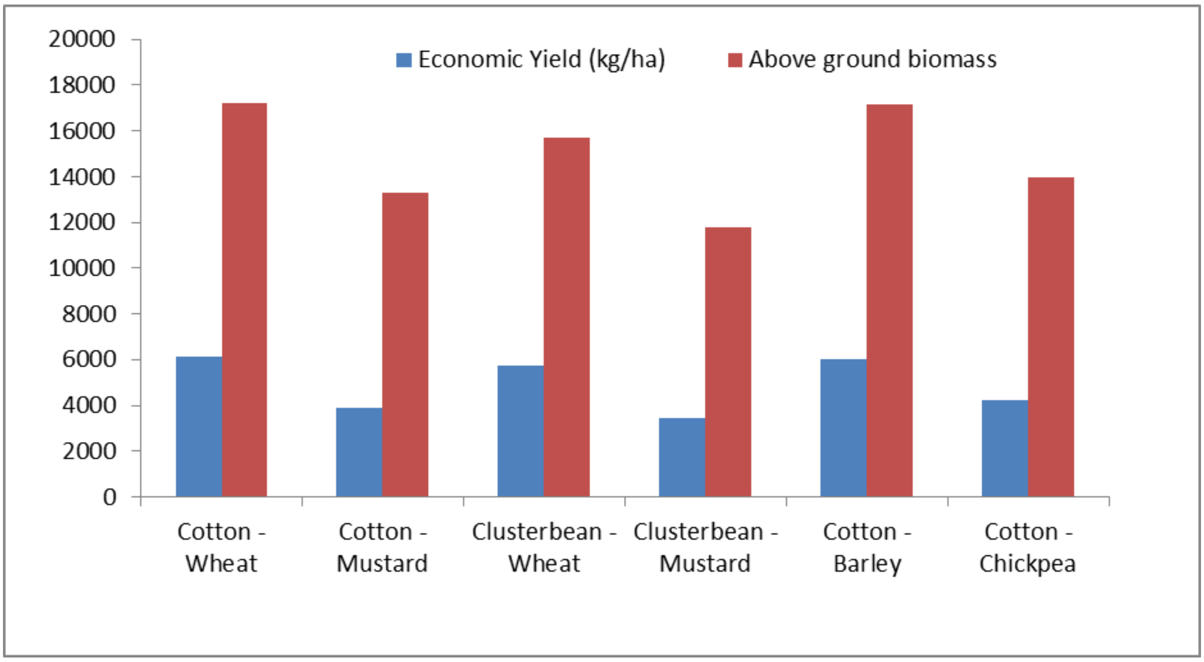
**Yield and economics of cropping system**

Cotton-barley and cotton-chickpea cropping system were negligible as they have less than 1% area in the study site. Seed and biomass yield of different cropping system varied from 3470 to 6128 and 11796 to 17192 kg/ha, respectively (Table 21 and Fig 11) during 2012-13. Cotton-wheat cropping system recorded highest seed (6128 kg/ha) and biomass yield (17192 kg/ha) over rest of the systems followed by clusterbean-wheat whereas clusterbean–mustard recorded lowest seed (3470 kg/ha) and biomass yield (11796 kg/ha). Cotton-wheat cropping system had 76.5, 57.6 and 7.2 percent higher seed and 45.7, 29.1 and 9.6 percent higher biomass yield over clusterbean – mustard, cotton–mustard and clusterbean-wheat, respectively. Data further revealed that cost of cultivation, gross and net return ranged from Rs. 45910 to 72423, 148873 to 314428 and 84526 to 262622/ha, respectively. Cotton-wheat recorded highest cost of cultivation (Rs.70466/ha) whereas clusterbean-wheat cropping system had highest gross return (Rs.314428/ha) and net return (Rs.262622/ha) followed by clusterbean–mustard (Rs.291010, 245101/ha). Clusterbean-wheat cropping system had 67.8, 61.1 and 6.6 percent higher net returns over cotton–mustard, cotton–wheat and clusterbean–mustard, respectively.

**Table 21 Yield and economics of different cropping system grown at Menawali, Hanumangarh (2012-13)**

| Cropping system | Seed Yield (kg/ha) | Biomass yield (kg/ha) | Cost of cultivation (₹/ha) | Gross return (₹/ha) | Net return (₹/ha) |
|---|---|---|---|---|---|
| Cotton – Wheat | 6128 | 17192 | 70466 | 172291 | 102047 |
| Cotton – Mustard | 3886 | 13311 | 64347 | 148873 | 84526 |
| Clusterbean – Wheat | 5712 | 15677 | 52029 | 314428 | 262622 |
| Clusterbean – Mustard | 3470 | 11796 | 45910 | 291010 | 245101 |
| Cotton – Barley* | 5997 | 17153 | 72423 | 175948 | 103525 |
| Cotton – Chickpea* | 4238 | 13941 | 68848 | 173268 | 104420 |

***** Cotton-barley and cotton-chickpea cropping system were negligible as they have less than 1% area in the study site



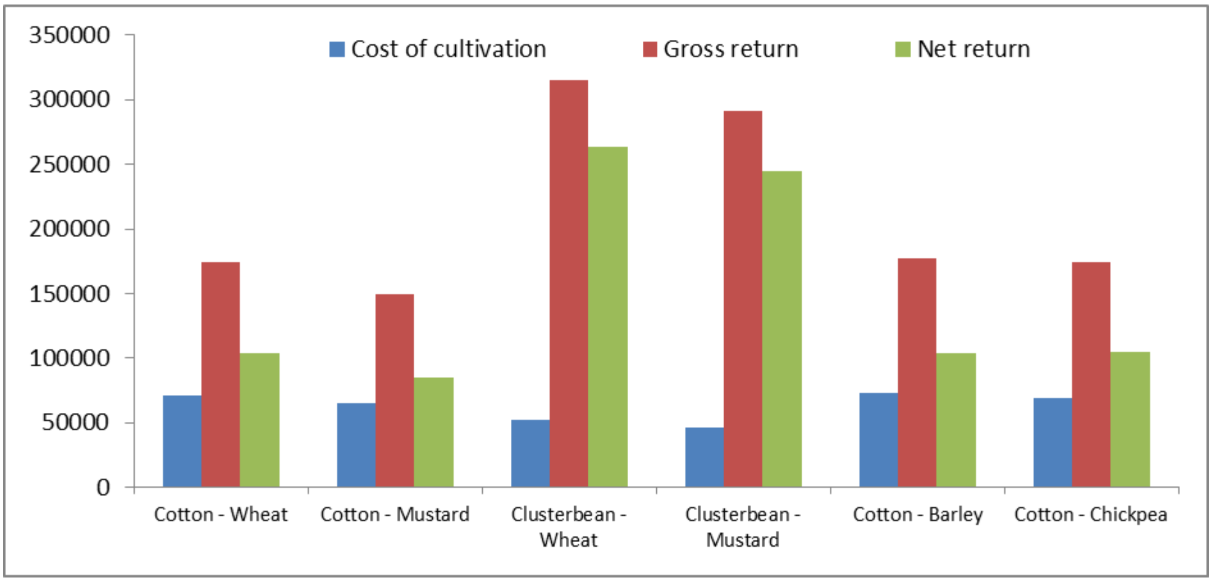




**Fig 11 Yield and economics of different cropping system (2012-13)**

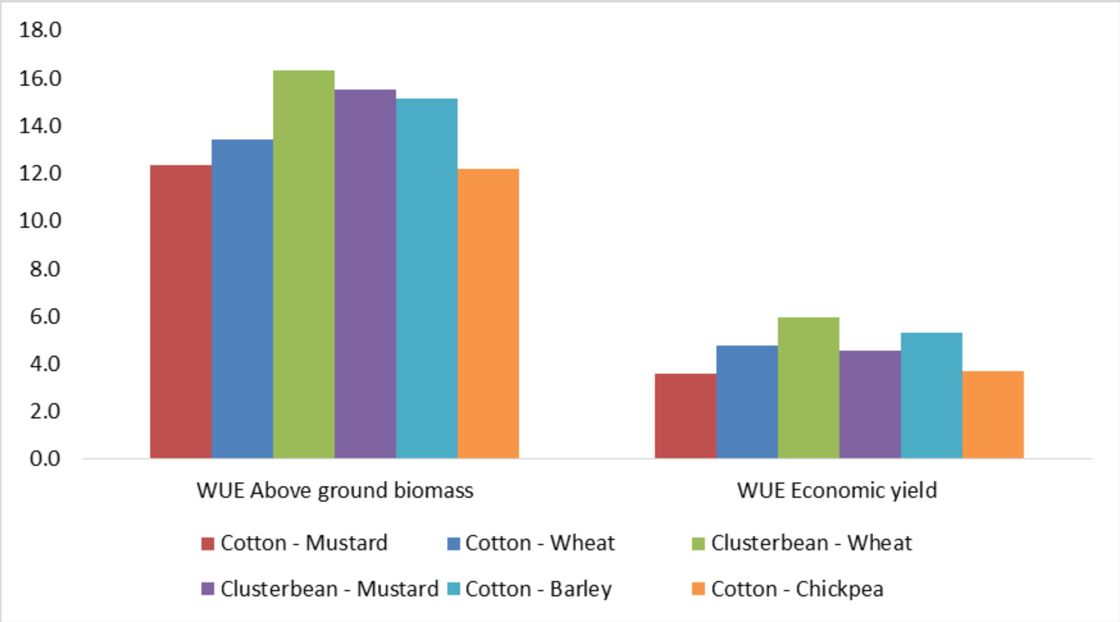
**Water use efficiency of cropping system**

The WUE varied from 12.3 to 16.3 and 3.6 to 5.9 kg/ha mm of biological and seed yield and 134.4 to 383.6 and 78.3 to 323.1 of monetary returns in terms of water applied in different cropping system (Table 22 and Fig 12a and 12b) during 2012-13. Clusterbean-wheat cropping system recorded highest WUE both in biological (16.3 kg/ha-mm) and seed yield (5.9 kg/ha-mm) followed by clusterbean-mustard whereas cotton-mustard recorded lowest WUE both in yield and monetary returns. However, clusterbean-mustard cropping system produces highest WUE in monetary returns both in gross and net returns. Data further revealed that WUE varied from 15.4 to 21.2 and 4.5 to 7.7 kg/ha mm of biological and seed yield and 171.7 to 458.1 and 97.5 to 385.9 of monetary returns in terms of water applied $WUE_{ET}$ in different cropping system. Clusterbean-wheat cropping system recorded highest $WUE_{ET}$ both in biological (21.2 kg/ha m) and seed yield (7.7 kg/ha mm) whereas cotton-mustard recorded lowest $WUE_{ET}$ both in yield and monetary returns. However, clusterbean-mustard cropping system produces highest $WUE_{ET}$ in monetary returns both in gross and net returns.

**Table 22 Water use efficiency of different cropping system grown at Menawali, Hanumangarh (2012-13)**

| Cropping system | Yield (kg/ha mm) | | Return (₹/ha mm) | |
|---|---|---|---|---|
| | Biological Yield | Seed Yield | Gross Return | Net Return |
| | **Water Use Efficiency (in terms of water applied)** | | | |
| Cotton - Wheat | 13.4 | 4.8 | 134.4 | 79.6 |
| Cotton - Mustard | 12.3 | 3.6 | 137.9 | 78.3 |
| Clusterbean - Wheat | 16.3 | 5.9 | 327.1 | 273.2 |
| Clusterbean - mustard | 15.5 | 4.6 | 383.6 | 323.1 |
| Cotton – Barley* | 15.1 | 5.3 | 155.3 | 91.4 |
| Cotton – Chickpea* | 12.2 | 3.7 | 151.8 | 91.5 |
| | **Water Use Efficiency (In terms of water used) $WUE_{ET}$** | | | |
| Cotton - Wheat | 17.7 | 6.3 | 177.4 | 105.1 |
| Cotton - Mustard | 15.4 | 4.5 | 171.7 | 97.5 |
| Clusterbean - Wheat | 21.2 | 7.7 | 425.4 | 355.3 |
| Clusterbean - Mustard | 18.6 | 5.5 | 458.1 | 385.9 |
| Cotton – Barley* | 18.3 | 6.4 | 187.6 | 110.4 |
| Cotton – Chickpea* | 15.2 | 4.6 | 189.3 | 114.1 |

***** Cotton-barley and cotton-chickpea cropping system were negligible as they have less than 1% area in the study site



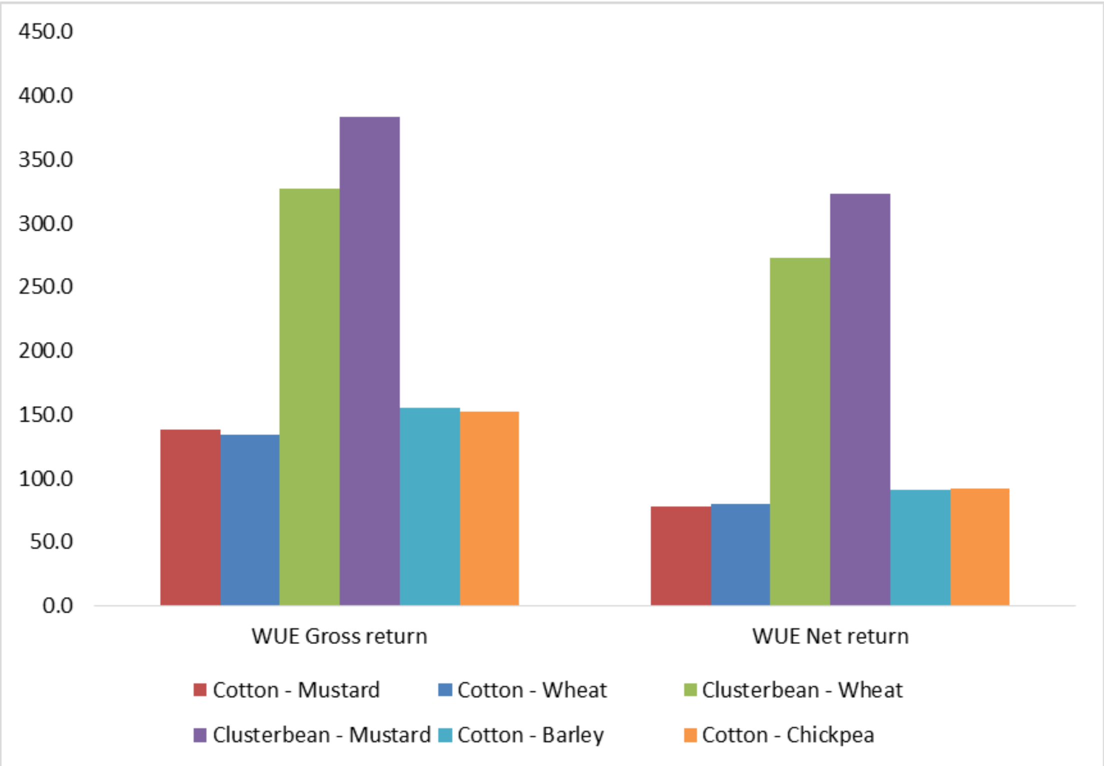
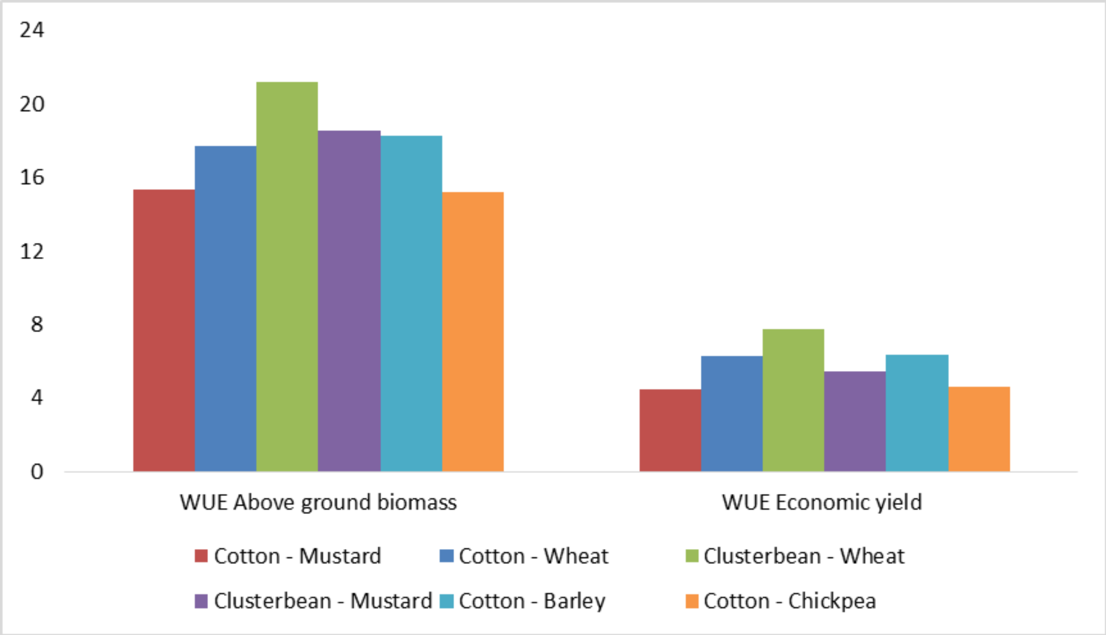




**Figure 12 (a) Water Use Efficiency (in terms of water applied) (2012-13)**



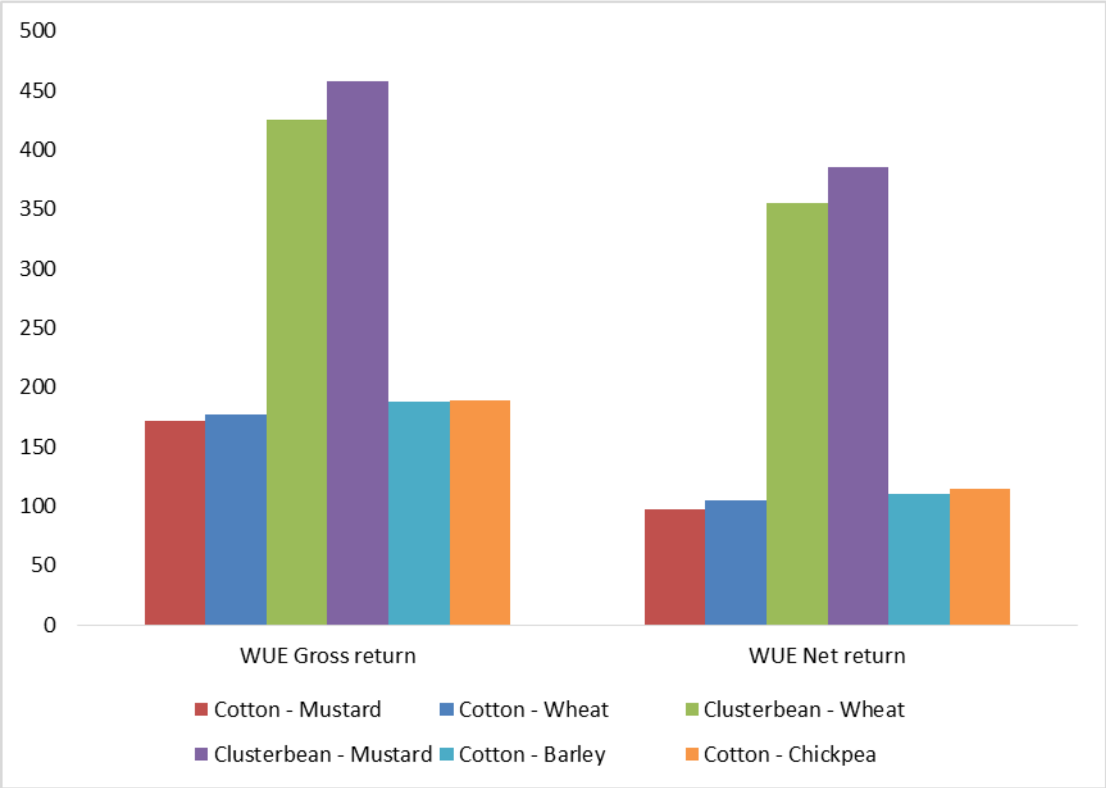




**Figure 12(b) Water Use Efficiency (In terms of water used) WUE $_{ET}$ (2012-13)**

**Relationship between observed and simulated values in different crops at Hanumangarh(2012-13)**

**Fig 1:Economic yield ,Above ground biomass and N uptake of clusterbean in stage-I (2012)**

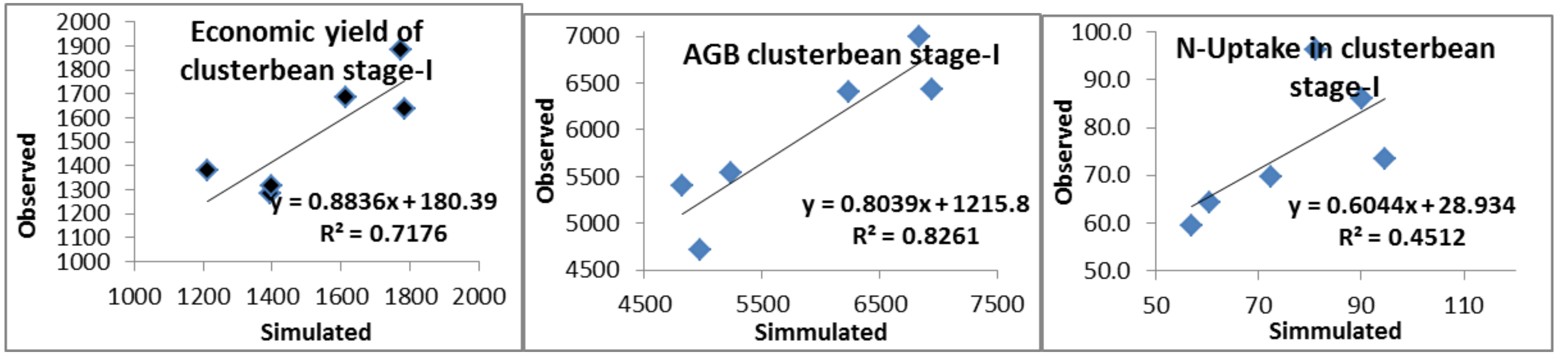



**Fig 2 :Economic yield ,Above ground biomass and N uptake of cotton in stage-I (2012)**

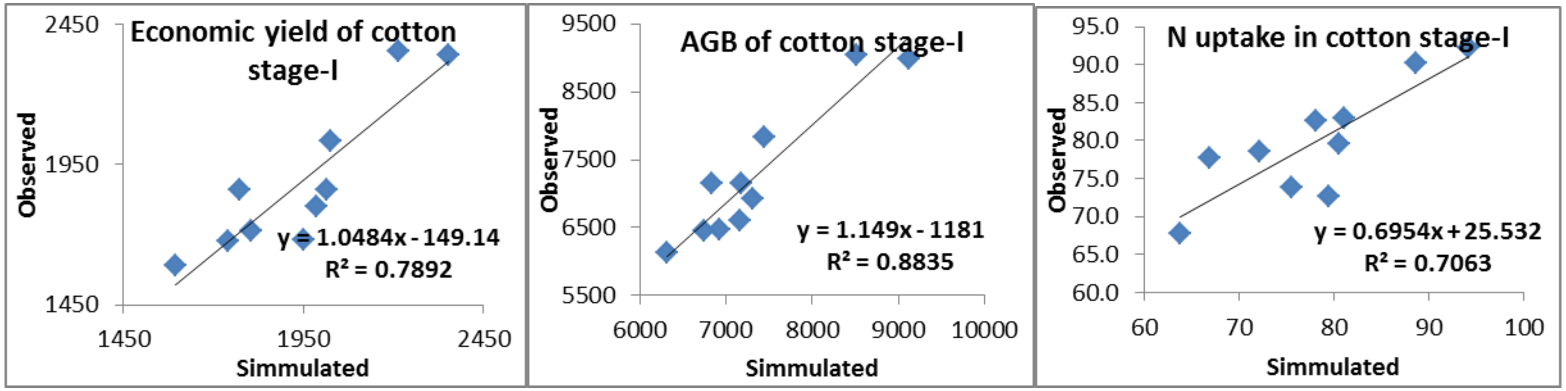


**Fig 3 : Economic yield ,Above ground biomass and N uptake of mustard in stage-I**

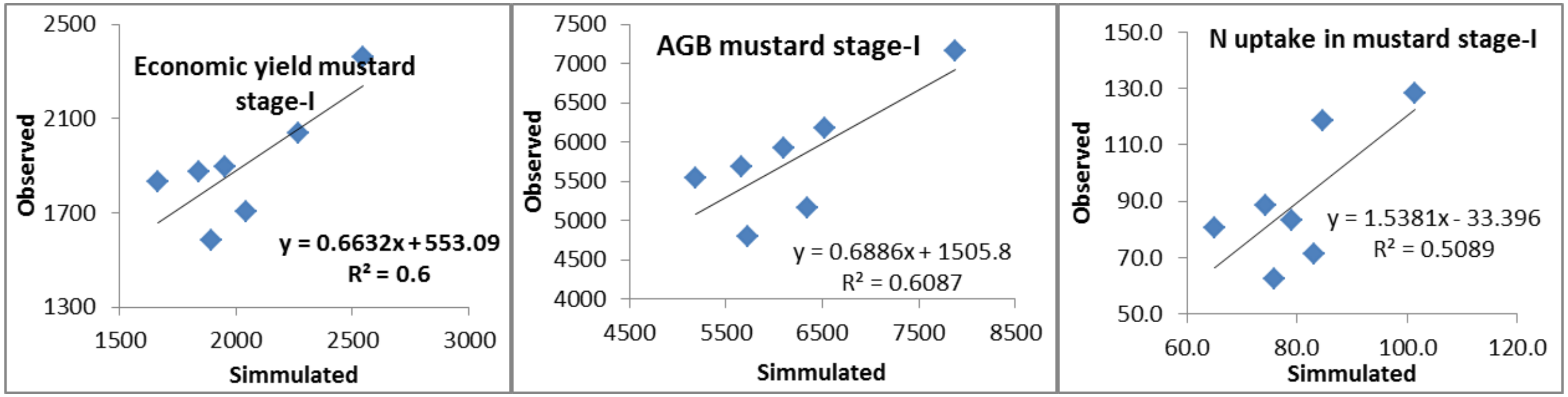
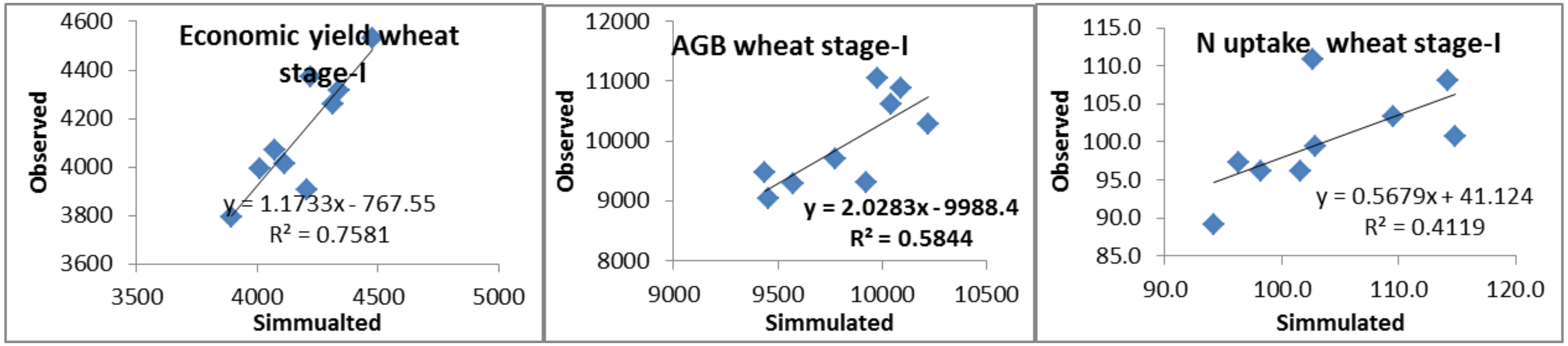



**Fig4: Economic yield ,Above ground biomass and N uptake of wheat in stage-I 2012-13**



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# Stage-I

## (Mainawali,Hanumangarh

# Part –B:

# Validation of cropsyst model

# Part –B: Validation of cropsyst model

**Climate**

The climate of the area is arid. The mean daily maximum temperature during May and June, which is the hottest period, varies from 41 to 46 °C. On individual days, during the hot period, it may rise up to about 49 °C. Hot winds, with low relative humidity, often cause dust storms during the hot season. January is generally the coldest month with a mean daily maximum temperature of 21°C and a minimum 5°C. The average annual rainfall of the tract is about 281.4 mm which is mostly received during the rainy season from July to September. During the months of December and January, occasional fogs reside in the area. An agricultural year may be divided into four distinct seasons: the hot dry season from March to June, hot rainy (monsoon) season from July to September, post-monsoon season from October to November and cold season from December to February.

The weather conditions prevailed during the period of experimentation (2013-14) were recorded at meteorological observatory of Agricultural Research Sub-station, Sriganganagar, Swami Keshwanand Rajasthan Agricultural University, Bikaner have been given in table 1 and graphically depicted in fig 1.

**Table: 1 Monthly meteorological data during crop season 2013-14**

| Month | Temperature (°C) | | Relative humidity (%) | | Total Rainfall (mm) | Pan Evaporation (mm) | Solar Radiation (MJ $m^{-2}$ $d^{-1}$) |
|---|---|---|---|---|---|---|---|
| | Max | Min | RHMax | RHMin | | | |
| May | 43.5 | 23.9 | 40.8 | 20.0 | 0.0 | 250.2 | 25.4 |
| June | 42.2 | 29.0 | 56.4 | 34.5 | 27.8 | 254.9 | 23.2 |
| July | 40.2 | 28.9 | 70.4 | 55.2 | 80.6 | 207.3 | 21.4 |
| August | 36.7 | 27.4 | 82.1 | 68.8 | 113.7 | 136.9 | 19.6 |
| September | 38.0 | 25.1 | 75.5 | 48.4 | 6.0 | 172.6 | 20.1 |
| October | 35.3 | 20.5 | 81.4 | 50.1 | 0.0 | 105.8 | 15.9 |
| November | 28.5 | 11.0 | 87.5 | 55.0 | 4.5 | 60.9 | 13.2 |
| December | 23.5 | 7.1 | 91.6 | 60.0 | 0.0 | 51.2 | 11.4 |
| January | 20.2 | 5.6 | 94.0 | 60.5 | 0.2 | 38.0 | 11.0 |
| February | 21.9 | 8.0 | 91.3 | 56.4 | 17.1 | 40.0 | 13.9 |
| March | 28.1 | 12.9 | 85.6 | 49.7 | 68.1 | 80.9 | 17.7 |
| April | 35.7 | 18.0 | 65.0 | 32.5 | 8.0 | 149.3 | 21.8 |

# data taken from Agro-meteorological Observatory, A.R.S. (Sriganganagar), SKRAU, Bikaner

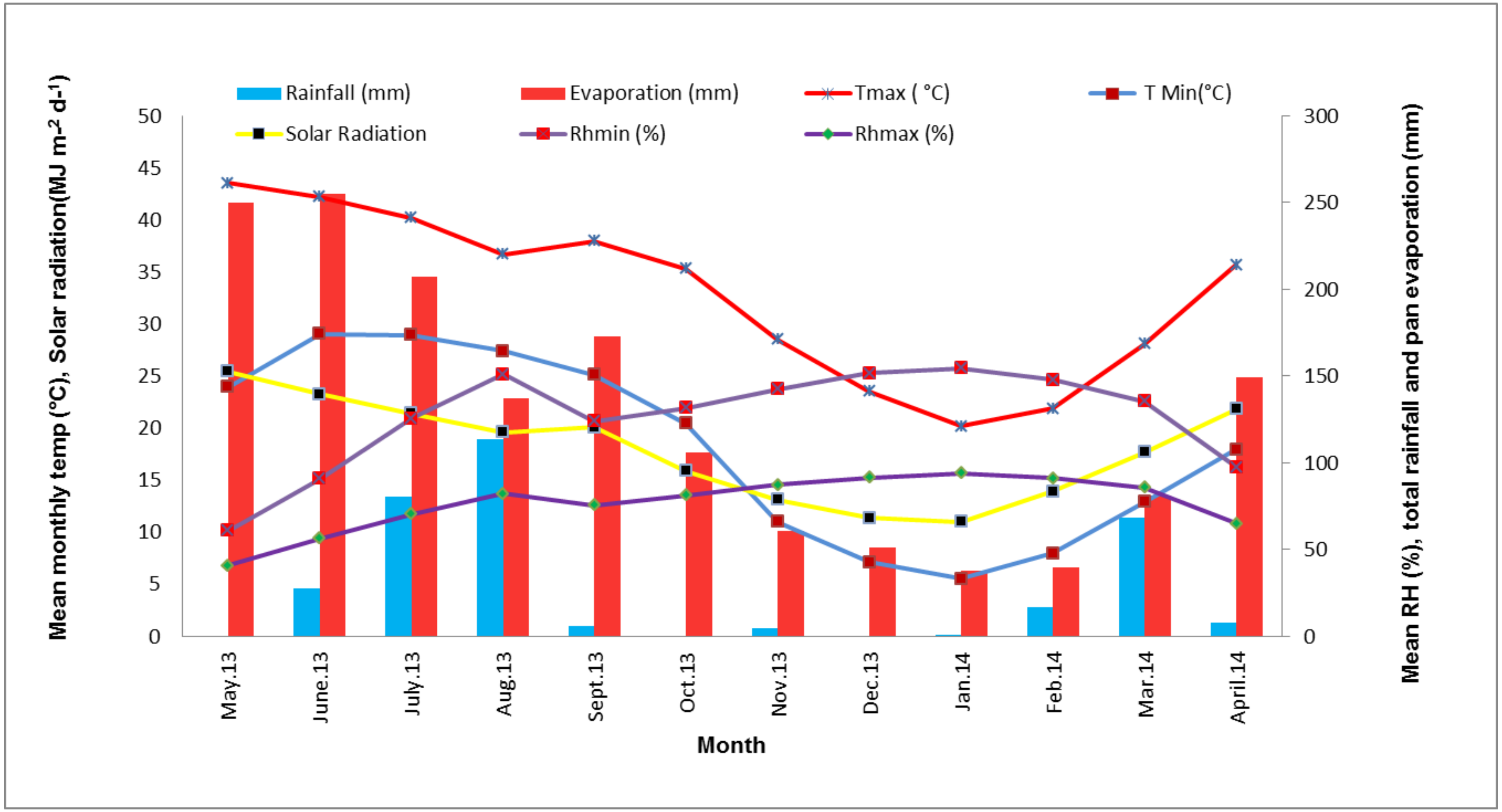



**Fig. 1 Monthly meteorological data recorded during crop growing 2013-14**

**Table 2 (A) Soil physical properties of experimental site (2013-14)**

| Layer | Thickness (m) | Sand (%) | Clay (%) | Silt (%) | Bulk density (g cm$^{-3}$) | CEC (cmol kg$^{-1}$) | pH | PWP (m$^3$ m$^{-3}$) | FC (m$^3$ m$^{-3}$) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.15 | 67.75±6.30* | 11.14±1.73 | 21.01±4.60 | 1.44±0.06 | 5.39±0.56 | 8.02±0.16 | 0.088±0.01 | 0.189±0.01 |
| 2 | 0.10 | 67.61±6.32 | 11.21±1.75 | 21.17±4.63 | 1.45±0.06 | 5.53±0.55 | 7.94±0.18 | 0.086±0.01 | 0.184±0.01 |
| 3 | 0.25 | 67.45±6.31 | 11.27±1.76 | 21.25±4.67 | 1.46±0.07 | 5.61±0.54 | 8.05±0.21 | 0.085±0.01 | 0.192±0.01 |
| 4 | 0.25 | 67.23±6.26 | 11.41±1.74 | 21.36±4.61 | 1.47±0.07 | 5.77±0.52 | 7.92±0.20 | 0.091±0.01 | 0.188±0.01 |
| 5 | 0.25 | 66.95±6.23 | 11.51±1.72 | 21.58±4.66 | 1.48±0.07 | 5.91±0.58 | 7.88±0.21 | 0.090±0.01 | 0.193±0.01 |

*Mean±SD.

**Table 2 (B) Initial soil conditions of experimental site (2013-14)**

| Layer | Thickness (m) | Water content (m$^3$ m$^{-3}$) | NO3 (kg N ha$^{-1}$) | NH4 (kg N ha$^{-1}$) | SOM (%) | Salinity (dS m$^{-1}$) |
|---|---|---|---|---|---|---|
| 1 | 0.15 | 0.126±0.028* | 13.63±1.66 | 23.84±3.66 | 0.290±0.069 | 0.183±0.079 |
| 2 | 0.10 | 0.131±0.028 | 11.57±1.77 | 19.46±3.99 | 0.307±0.075 | 0.183±0.071 |
| 3 | 0.25 | 0.135±0.028 | 9.73±1.88 | 17.64±4.09 | 0.284±0.068 | 0.182±0.067 |
| 4 | 0.25 | 0.139±0.028 | 8.01±1.82 | 16.58±3.94 | 0.265±0.069 | 0.172±0.070 |
| 5 | 0.25 | 0.145±0.029 | 7.45±1.89 | 15.03±4.05 | 0.258±0.069 | 0.174±0.067 |

*Mean±SD.

**Area under cultivation**

Total area of the experimental site was 187 ha out of which net cropped area were 170 ha Average land holding of 6.1 ha. Major crops of the area were cotton and clusterbean during *kharif* and wheat and mustard in *rabi*. Majority of farmers (about 80%) grow cotton and wheat in *kharif* and *rabi* season, respectively. About 18-20 % cropped area was under cluster bean and mustard during *kharif* and *rabi* season, respectively

**Table 3 List of selected farmers along with their crop grown (2013-14)**

| Farmer No. | Farmer Name | *Kharif Crop* (% Area) | *Rabi Crop* (% Area) |
|---|---|---|---|
| 1 | Indra Godara | Cotton (44.2)<br>Cluster bean (55.1)<br>Fodder Bajra (0.7) | Wheat (44.4)<br>Barley (55.0)<br>Fodder Barseem (0.6) |
| 2 | Dhunkal Godara | Cotton (99.2)<br>Fallow (0.8) | Wheat (79.2)<br>Mustard (20.0) Fallow (0.8) |
| 3 | Krishan Dharnia | Cluster bean (99.3)<br>Fodder Bajra (0.7) | Wheat (74.5)<br>Mustard (24.6) Fodder Barseem (0.9) |
| 4 | Nathu Ram Dehru | Cotton (58.2)<br>Cluster bean (41.4) Fodder Bajra (0.4) | Wheat (58.2)<br>Barley (41.4) Fodder Barseem (0.6) |
| 5 | Krishan Sinwar | Cluster bean(99.5) Fallow (0.5) | Wheat (80.4)<br>Mustard (19.1) Fallow (0.5) |
| 6 | Deshraj Sinwar | Cluster bean (99.4) Fodder Bajra (0.6) | Mustard (100) Fodder Barseem (0.6) |
| 7 | Krishan Dev Sinwer | Cluster bean (99.7) Fallow (0.3) | Mustard (99.7) Fallow (0.3) |
| 8 | Gangaram Bishnoi | Cotton (70.1)<br>Cluster bean (29.3) Fodder Bajra (0.6) Fallow (0.3) | Wheat (68.2)<br>Mustard(30.9) Fodder Barseem (0.6) , Fallow (0.3) |
| 9 | Hanuman Sinwer | Cluster bean (99.6)<br>Fodder Bajra (0.4) | Barley (99.5) Fodder Barseem (0.5) |
| 10 | Rajaram Sinwer | Cotton (55.4)<br>Cluster bean (44.3) Fallow (0.3) | Wheat (99.7)<br>Fallow (0.3) |
| 12 | Subash Beniwal | Cotton (99.6) Fallow (0.4) | Wheat (66.5)<br>Barley (33.1) Fallow (0.4) |
| 13 | Mangilal Beniwal | Cotton (99.5) Fodder Bajra (0.5) | Wheat (99.5) Fodder Barseem (0.5) |
| 18 | Richhpal Dehru | Cotton (79.2)<br>Cluster bean (20.1) Fallow (0.7) | Wheat (80.0)<br>Mustard (19.3) Fallow (0.7) |
| 19 | Hanuman Dehru | Cotton (58.3)<br>Cluster bean (41.1) Fallow (0.6) | Wheat (99.4) Fallow (0.6) |
| 20 | Om Dehru | Cluster bean (99.7) Fallow (0.3) | Wheat (99.6) Fallow (0.4) |

## EXPERIMENTAL RESULTS (2013-14)

### Productivity

Three *rabi* season crops (wheat, barley and mustard) and two *kharif* season crops (cotton and clusterbean) were grown at study site (Menawali) in Hanumangarh district. The seed, straw and biomass yield of these crops are described as below.

### KHARIF CROPS

Data presented in Table 5 shows that the seed cotton, straw and biomass yield of cotton varied From 2035 to 2349, 5571 to 6207 and 7653 to 8534 kg $ha^{-1}$, respectively with average seed cotton, straw and biomass yield of 2212, 5865 and 8077 kg $ha^{-1}$, respectively. Similarly, clusterbean produced 1356 to 1754, 3891 to 4876 and 5247 to 6630 kg $ha^{-1}$ seed, straw and biomass yield, respectively with average values of 1612, 4477 and 6089 kg $ha^{-1}$, respectively. The observed increase in seed cotton, straw and biomass yield of cotton was to the tune of 37.2, 31.0 and 32.6 per cent over clusterbean during 2013-14.

### RABI CROPS

A perusal of data in Table 4 shows that the grain, straw and biomass yield of wheat varied from 3872 to 4487, 5010 to 7850 and 9334 to 11975 kg $ha^{-1}$, respectively during 2013-14. The average grain, straw and biomass yield of wheat was 4178, 5950 and 10128 kg $ha^{-1}$, respectively whereas, the grain, straw and biomass yield of mustard varied from 1753 to 2142, 3462 to 4382 and 5234 to 6524 kg $ha^{-1}$, respectively with average grain, straw and biomass yield of 1936, 3908 and 5844 kg $ha^{-1}$, respectively. However, seed, straw and biomass yield of barley varied from 3834 to 4147, 5742 to 6310 and 9754 to 10144 kg $ha^{-1}$, respectively. The average grain, straw and biomass yield of barley was recorded 3991, 5937 and 9928 kg $ha^{-1}$, respectively. Amongst the *rabi* season crops wheat out yielded other crops and produced 115.8 and 4.68 per cent higher seed yields than mustard and barley respectively. With respect to total biomass productivity, wheat gave highest biomass yield followed by barley and mustard.

**Table 4 Observed Economic and straw yield and aboveground biomass of different crops grown at Menawali, Hanumangarh District (2013-14)**

| Crops | Seed yield (kg ha$^{-1}$) | | Straw yield (kg ha$^{-1}$) | | AGB (kg ha$^{-1}$) | |
|---|---|---|---|---|---|---|
| | Range | Mean± SD | Range | Mean± SD | Range | Mean± SD |
| Cotton | 2035 - 2349 | 2212±111 | 5571 - 6207 | 5865±216 | 7653 - 8534 | 8077±294 |
| Clusterbean | 1356 -1754 | 1612±109 | 3891 - 4876 | 4477±312 | 5247 - 6630 | 6089±398 |
| Wheat | 3872 - 4487 | 4178±201 | 5010 - 7850 | 5950±865 | 9334 - 11975 | 10128±800 |
| Mustard | 1753 - 2142 | 1936±143 | 3462 - 4382 | 3908±280 | 5234 - 6524 | 5844±378 |
| Barley | 3834 - 4147 | 3991±138 | 5742 - 6310 | 5937±294 | 9754 - 10144 | 9928±162 |

**N-uptake**

There were three *rabi* season (wheat, barley and mustard) and two *kharif* season crops (cotton and clusterbean) grown at the experimental site of Menawali in Hanumangarh district. Data presented in Table 5 shows that the N-uptake of cotton, clusterbean, wheat, mustard and barley range from 72.0 to 82.0, 61.1 to 73.7, 86.0 to 105.9, 70.0 to 82.0 and 92.0 to 103.0 kg ha$^{-1}$ respectively with the average N-uptake of 77.3, 69.8, 96.1, 74.8 and 98.0 kg ha$^{-1}$ for cotton, clusterbean, wheat, mustard and barley, respectively during 2013-14. The observed increase in N-uptake of cotton was 10.7 per cent over clusterbean in *kharif* season crops. Among the *rabi* season crops barley recorded higher N-uptake than other crops. The magnitude was of 1.9 and 31.0 % higher N-uptake than wheat and mustard, respectively.

**Table 5 Nutrient uptake of different crops grown at Menawali, Hanumangarh (2013-14)**

| Crops | N-uptake (kg ha$^{-1}$) | |
|---|---|---|
| | Range | Mean± SD |
| Cotton | 72.0 to 82.0 | 77.0±3 |
| Clusterbean | 61.1 to 73.7 | 69.8± 3 |
| Wheat | 86.0 to 105.9 | 96.1±4 |
| Mustard | 70.0 to 82.0 | 74.8±5 |
| Barley | 92.0 to 103.0 | 98.0±4 |

**Economic analysis**

**Kharif crops**

A perusal of data in Table 6 shows that the average cost of cultivation of cotton was ₹40479 $ha^{-1}$ during 2013-14. Cotton earned ₹130903 $ha^{-1}$ as gross return and ₹90423 $ha^{-1}$ as net return. with B:C ratio of 3.2. However, the average cost of cultivation of clusterbean was ₹23824 $ha^{-1}$ and it earned ₹87276 $ha^{-1}$ as gross return and ₹63452 $ha^{-1}$ as net return with 3.7 B:C ratio. The observed increase in net return of cotton was 42.5 per cent over clusterbean during *kharif* season crops.

**Rabi Crops**

A critical examination of data in Table 6 shows that the average cost of cultivation of wheat, mustard and barley was ₹32042, 25019 and 28524 $ha^{-1}$ respectively during 2013-14. On an average wheat, mustard and barley gave gross return of ₹88193, 67004 and 62417 $ha^{-1}$ and ₹56152, 41985 and 33893 $ha^{-1}$ as net return and corresponding B:C ratio are 2.75, 2.68 and 2.19, respectively. The observed increase in cost of cultivation, gross return and net return of wheat over mustard and barley was in the tune of 28.0 and 12.3, 31.6 and 41.2 and 33.7 and 65.6 respectively during *rabi* season.

**Table 6 Economics of different crops grown at Menawali, Hanumangarh (2013-14)**

| Crops | Cost of cultivation (Mean± SD) | Gross return (Mean± SD) | Net return (Mean± SD) | B:C ratio |
|---|---|---|---|---|
| Cotton | 40479±1174 | 130903±5108 | 90423±5023 | 3.23 |
| Clusterbean | 23824±482 | 87276±4441 | 63452±4391 | 3.66 |
| Wheat | 32042±1214 | 88193±4124 | 56152±4082 | 2.75 |
| Mustard | 25019±1032 | 67004±4621 | 41985±4607 | 2.68 |
| Barley | 28524±664 | 62417±1171 | 33893±814 | 2.19 |

**Water balance**

Soil water balance components for different crops are presented in Table 7 Water used in different crops varied from 277.0 to 624.5 mm. The highest water was used by cotton (624.5 mm) followed by wheat (559.2 mm), barley (415.0 mm), clusterbean (313.9 mm) during 2013-14. Whereas, lowest water was used by mustard (277.0 mm). Average ET loss in different crops range from 211.8 to 456.1 mm out of which highest ET loss observed in cotton and lowest was observed in mustard. The deep drainage varied from 35.1 mm to 106.4 mm, being highest in cotton followed by wheat, barley, clusterbean and mustard. The ET consisted 73.0 to 80.8 % share in total water applied (Fig 4.1), the relative share of ET was highest for barley (80.8 %), wheat (79.1 %), mustard (76.4 %), clusterbean (75.0 %) and cotton (73.0 %). The deep drainage constituted 9.4 % to 17 % of total water applied, and its value was highest for cotton (17.0 %) followed by clusterbean (14.9 %), wheat (12.8 %), mustard (12.6 %) and barley (9.4 %).

**Table 7 Soil water balance components for different crops grown at Menawali, Hanumangarh (2013-14)**

| Component | Cotton | Clusterbean | Wheat | Mustard | Barley |
|---|---|---|---|---|---|
| | | | (mm) | | |
| **Inputs** | | | | | |
| Irrigation (I) | 396.4 | 91.8 | 470.4 | 234.1 | 315.8 |
| Rainfall (R) | 228.1 | 222.1 | 88.8 | 42.8 | 99.2 |
| Total (I+R) | 624.5 | 313.9 | 559.2 | 277.0 | 415.0 |
| **Losses** | | | | | |
| ET | 456.1 | 235.7 | 442.5 | 211.8 | 335.5 |
| Drainage | 106.4 | 46.8 | 71.8 | 35.1 | 39.2 |
| Stored soil moisture | 62.0 | 31.4 | 44.9 | 30.0 | 40.3 |

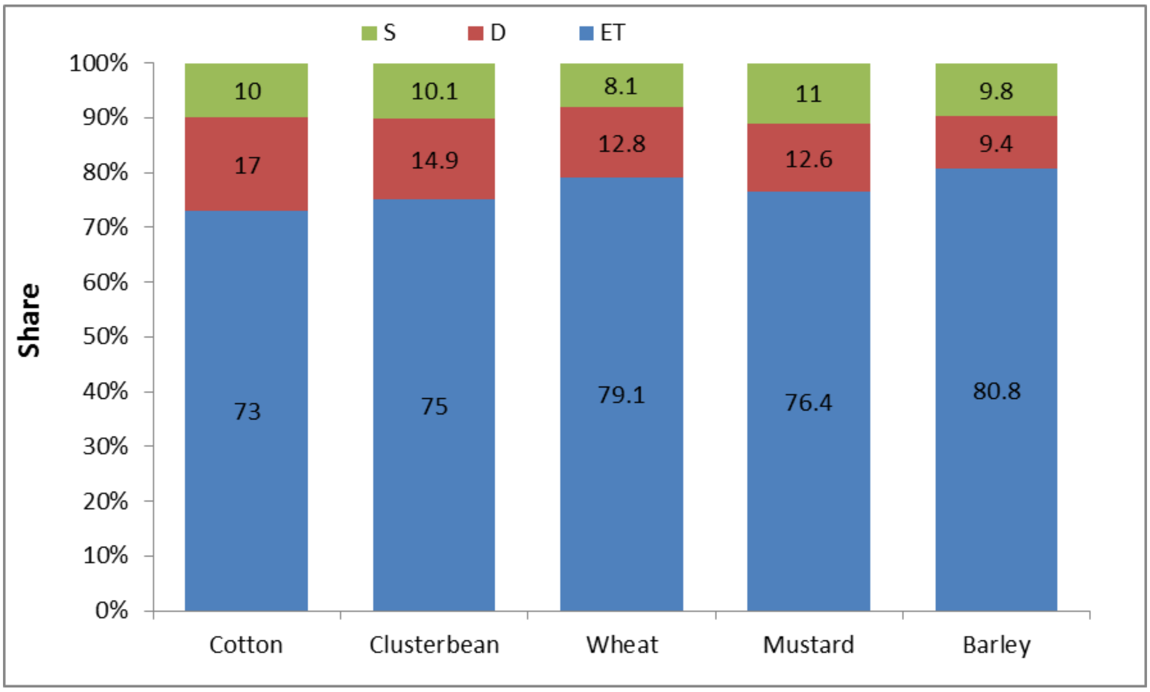



**Fig 2 Soil water balance components for different crops (2013-14)**

### Yield and economics of cropping system

A perusal of data in Table 8 and Fig 3 revealed that seed/grain and biomass yield of different cropping system varied from 3548 to 6390 and 11933 to 18205 kg ha$^{-1}$, respectively during 2013-14. Cotton-wheat cropping system recorded highest economic (6390 kg ha$^{-1}$) and biomass yield (18205 kg ha$^{-1}$) over rest of the systems followed by cotton-barley. Whereas, clusterbean–mustard recorded lowest economic (3548 kg ha$^{-1}$) and biomass yield (11933 kg ha$^{-1}$). Cotton-wheat cropping system had 80.1, 54.0, 10.3 and 3.0 percent higher seed and 52.5, 30.7, 12.2 and 1.1 percent higher biomass yield over clusterbean–mustard, cotton–mustard, clusterbean-wheat and cotton-barley, respectively. Data further revealed that cost of cultivation, gross and net return ranged from ₹48842 to 72521, 154279 to 219096 and 105437 to 146575 ha$^{-1}$, respectively. Cotton-wheat recorded highest cost of cultivation (₹72521 ha$^{-1}$), gross return (₹219096 ha$^{-1}$) and net return (₹146575 ha$^{-1}$) followed by cotton–mustard (₹197906, 132408 ha$^{-1}$). Cotton-wheat cropping system had 39.0, 22.5, 17.9 and 10.7 percent higher net returns over clusterbean–mustard, clusterbean–wheat, cotton–barley and cotton–mustard, respectively.

**Table 8 Yield and economics of different cropping system followed at Menawali, Hanumangarh**

| Cropping system | Seed Yield (kg ha$^{-1}$) | Biomass yield (kg ha$^{-1}$) | Cost of cultivation (₹ ha$^{-1}$) | Gross return (₹ ha$^{-1}$) | Net return (₹ ha$^{-1}$) |
|---|---|---|---|---|---|
| Cotton - Wheat | 6390 | 18205 | 72521 | 219096 | 146575 |
| Cotton - Mustard | 4148 | 13921 | 65498 | 197906 | 132408 |
| Clusterbean - Wheat | 5790 | 16217 | 55865 | 175469 | 119604 |
| Clusterbean - Mustard | 3548 | 11933 | 48842 | 154279 | 105437 |
| Cotton – Barley | 6203 | 18005 | 69003 | 193319 | 124316 |

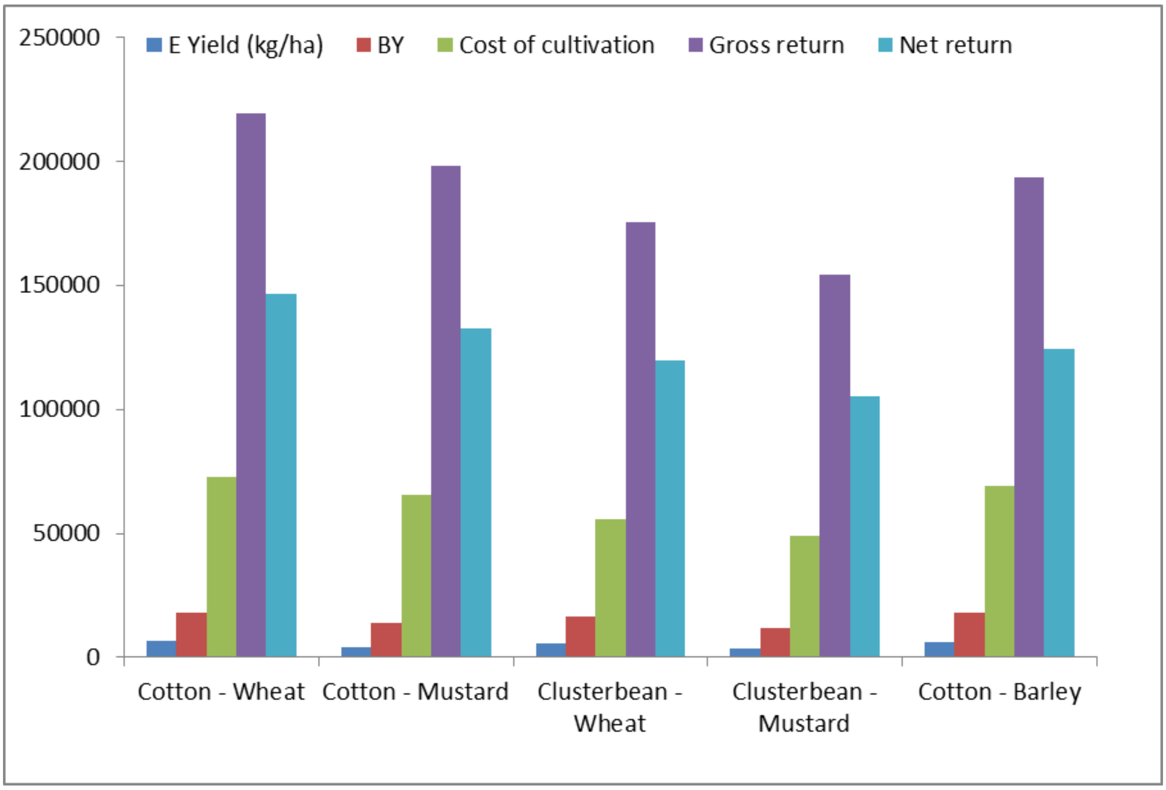


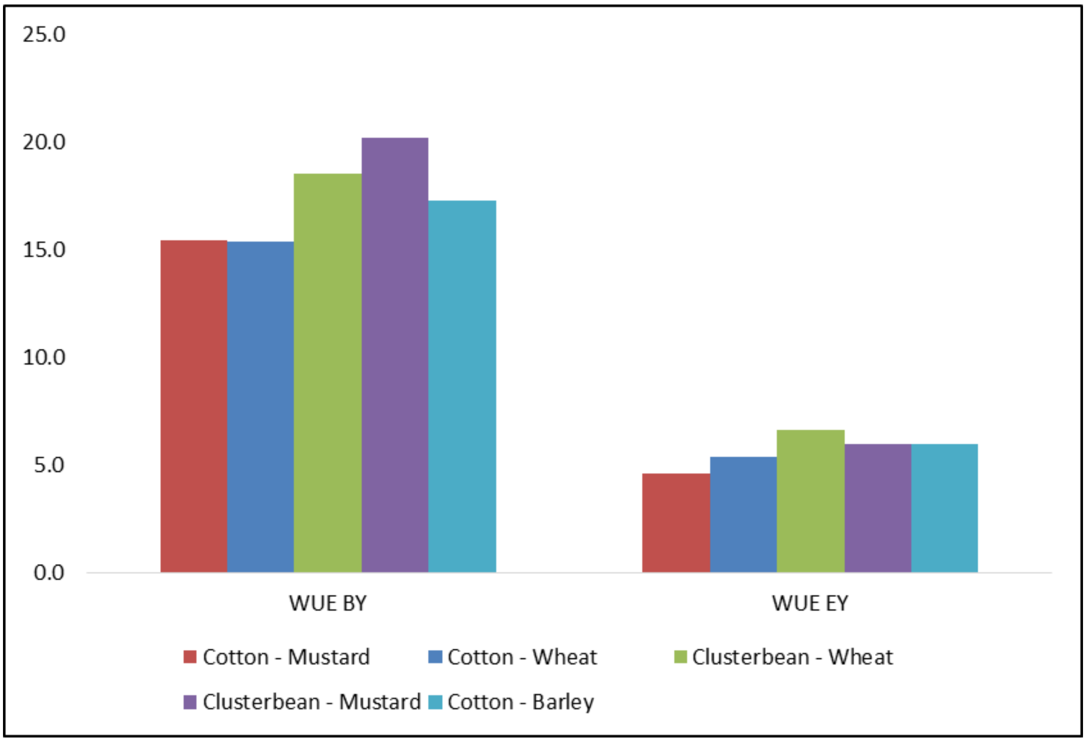

**Fig 3 Yield and economics of different cropping system**

**Water use efficiency of cropping system**

It is evident from the data in Table 9 and Fig 4 and 5 that WUE varied from 15.38 to 20.20 and 4.60 to 5.97 kg $ha^{-1}$ mm of biological and seed yield and 185.0 to 261.1 and 119.6 to 178.5 of monetary returns in terms of water applied in different cropping system during 2013-14. Clusterbean-mustard cropping system recorded highest WUE in biological yield (20.20 kg $ha^{-1}$ mm) followed by Clusterbean-wheat, however, clusterbean-wheat cropping system recorded highest WUE in seed yield (6.63 kg $ha^{-1}$ mm) followed by clusterbean-mustard whereas cotton-wheat and cotton-mustard recorded lowest WUE in yield. However, clusterbean-mustard cropping system produces highest WUE in monetary returns both in gross and net returns. Data further revealed that WUE varied from 20.26 to 26.67 and 6.2 to 8.5 kg $ha^{-1}$ mm of biological and seed yield and 243.8 to 344.8 and 157.0 to 235.6 of monetary returns in terms of water used $WUE_{ET}$ in different cropping system. Clusterbean-mustard cropping system recorded highest WUE in biological yield (26.67 $kgha^{-1}$ mm) and clusterbean-wheat cropping system recorded highest $WUE_{ET}$ in seed yield (8.5 $kgha^{-1}$ mm). Whereas, cotton-mustard recorded lowest $WUE_{ET}$ in seed yield whereas cotton-wheat recorded lowest $WUE_{ET}$ in biological yield and in gross returns and cotton-barley recorded lowest $WUE_{ET}$ in net returns. However, clusterbean-mustard cropping system produces highest $WUE_{ET}$ in terms of monetary returns both in gross and net returns.

**Table 9 Water use efficiency of different cropping system followed at Menawali, Hanumangarh (2013-14)**

| Cropping system | Yield (kg ha$^{-1}$ mm) | | Return (₹ ha$^{-1}$ mm) | |
|---|---|---|---|---|
| | Biological Yield | Economic Yield | Gross Return | Net Return |
| | **Water Use Efficiency (in terms of water applied)** | | | |
| Cotton - Wheat | 15.38 | 5.40 | 185.0 | 123.8 |
| Cotton - Mustard | 15.44 | 4.60 | 219.5 | 146.9 |
| Clusterbean – Wheat | 18.57 | 6.63 | 200.9 | 137.0 |
| Clusterbean - Mustard | 20.20 | 6.01 | 261.1 | 178.5 |
| Cotton – Barley | 17.32 | 5.97 | 186.0 | 119.6 |
| | **Water Use Efficiency (In terms of water used) $WUE_{ET}$** | | | |
| Cotton - Wheat | 20.26 | 7.11 | 243.8 | 163.1 |
| Cotton - Mustard | 20.84 | 6.21 | 296.3 | 198.2 |
| Clusterbean – Wheat | 23.91 | 8.54 | 258.7 | 176.4 |
| Clusterbean - Mustard | 26.67 | 7.93 | 344.8 | 235.6 |
| Cotton – Barley | 22.75 | 7.84 | 244.2 | 157.0 |



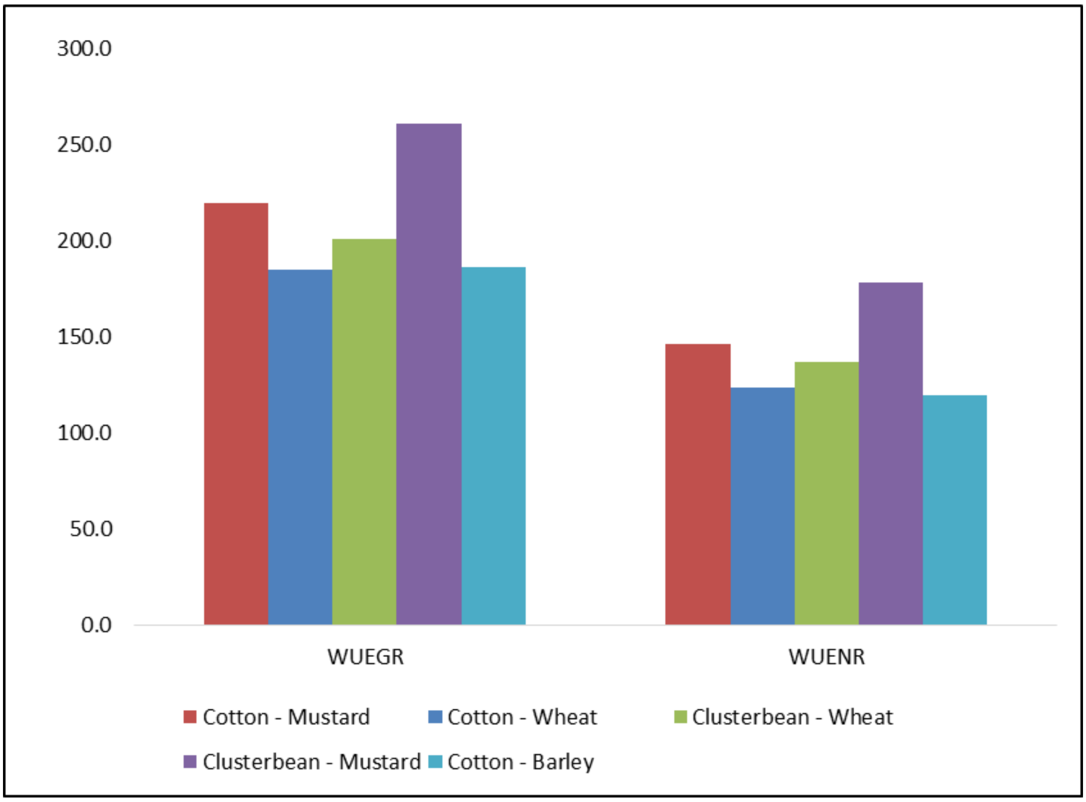
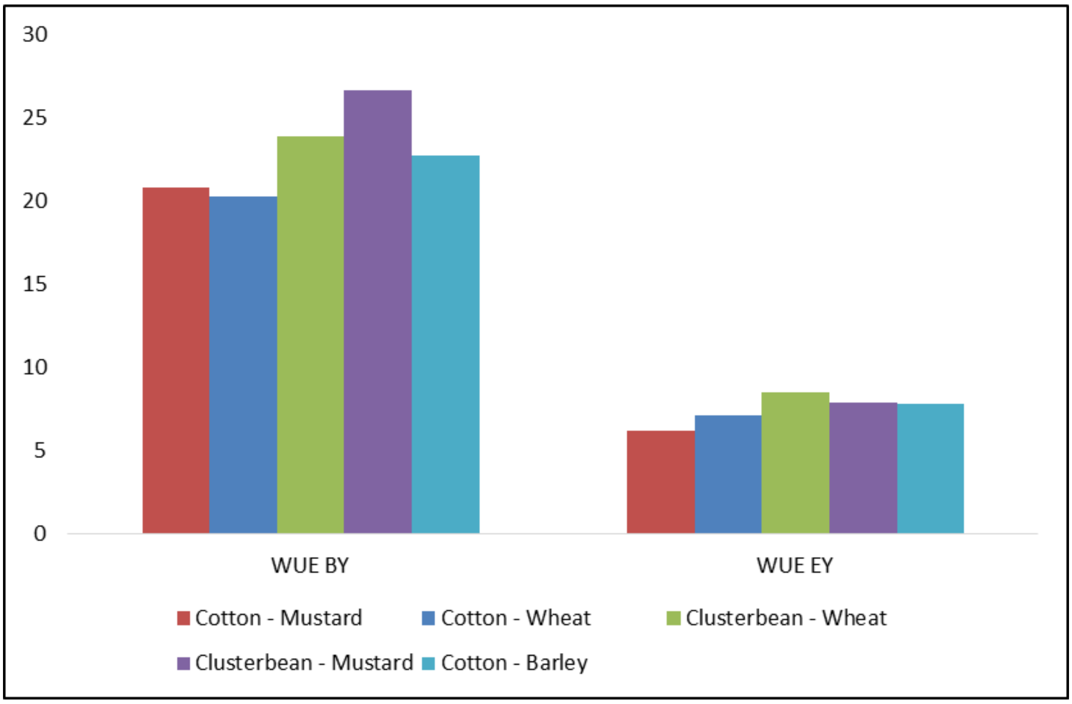




**Figure 4 Water Use Efficiency (in terms of water applied) (2013-14)**



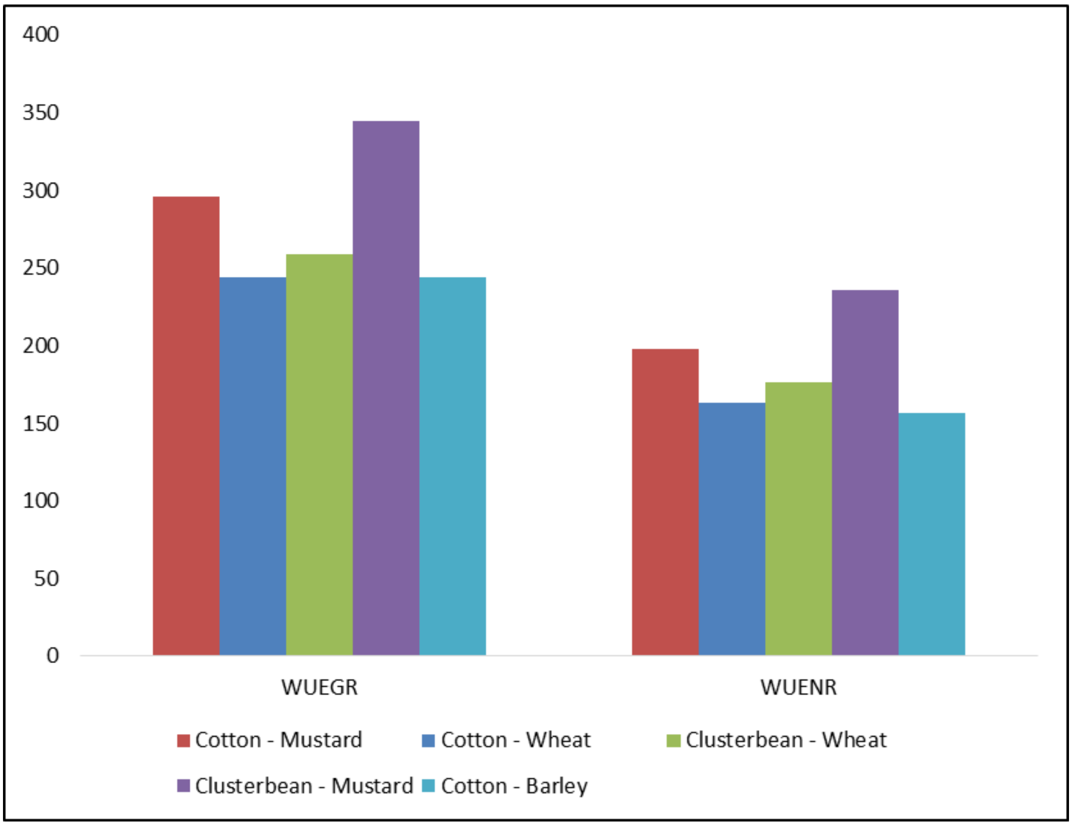




**Figure 5 Water Use Efficiency (In terms of water used) WUE $_{ET}$ (2013-14)**

**CropSyst Validation**

CropSyst model was calibrated for kharif and rabi season crops (cotton, clusterbean,wheat, barley and mustard) in 2012-13. The calibrated model was validated during 2013-14 for the site conditions using the crop model parameter values calibrated as mentioned years with associated water management. Soil characteristics, initial conditions of available soil water, nitrogen and organic matter and daily weather data were model input data for CropSyst as observed in the experiment. Model evaluation and validation was conventionally made by comparing simulation outputs with observed and simulated data. The CropSyst model was validated using the field experiment data conducted in 2013-14 growing season. It was validated for aboveground biomass (AGB), grain yield and N-uptake. The difference measures include the root mean square error (RMSE) and index of agreement (IoA). Taking into account difference in some physiological characteristics of crop varieties, validation for each crop was carried out variety wise. However here we give generalized statistical measures for separate crops.

**Validation for cotton**

For validation of cotton, data of grain yield, above ground biomass (AGB) and N-uptake were used to determine the best crop model parameters.

**Seed yield**

Validation of CropSyst model for seed yield showed good agreement between measured and predicted seed yield. Table 10 shows that the validated yield (2275 kg ha$^{-1}$) of cotton were closer to the observed seed cotton yield of 2212 kgha$^{-1}$ as it is evident from the 3.81% RRMSE during 2013-14. The correlation coefficient of 0.86 and Index of agreement of 0.84 calculated for yield of cotton (Table 11)

**Table 10 Quantitative measures of model performance for yield, AGB and N-uptake of cotton (2013-14)**

| Particular | Observed | Validated | RMSE | RRMSE | Correlation coefficient | Index of agreement |
|---|---|---|---|---|---|---|
| **Seed yield** | 2212 | 2275 | 84.3 | 3.81 | 0.86 | 0.84 |
| **AGB** | 8077 | 8750 | 700.2 | 8.67 | 0.88 | 0.51 |
| **N-uptake** | 77.0 | 86.0 | 11.3 | 14.62 | 0.87 | 0.45 |

**Above ground biomass**

Validation results of cotton aboveground biomass matched with the field data reasonably well. Final aboveground biomass, however, was overestimated by the model. The validated aboveground biomass (8750 $kgha^{-1}$) was higher than observed aboveground biomass (8077 $kgha^{-1}$) as shown in table 10 with 8.67 % RRMSE. Correlation coefficient of 0.88 and Index of agreement of 0.51 observed for AGB of cotton during 2013-14.

**N-uptake**

Validation for N-uptake of cotton slightly matched with the field data. The validated N-uptake (86 $kgha^{-1}$) was higher than observed N-uptake (77 $kgha^{-1}$) as shown in table 10 with 14.6 % RMSE. Correlation coefficient of 0.87 and Index of agreement of 0.45 observed for N-uptake of cotton during 2013-14.

**Moisture content**

Data in table 11 lists the RMSE, correlation and index of agreement values of moisture content at different fields. The RMSE of moisture content ranged from 0.0205 to 0.0260 during 2013-14. These small values reveal that soil water flow was well validated by CropSyst at different fields. As no systematic under or over estimation of moisture content was observed, the differences between the observed and validated moisture content are contributed to the spatial heterogeneity and observation errors, which are inevitable under field conditions. Validated value of moisture content predict well with observed values in the upper layers. The index of agreement was 0.90 in top soil layer of 0-10 cm (Fig 6).

**Table 11 Quantitative measures of model performance for soil moisture under cotton**

| Soil layer (cm) | RMSE | RRMSE | Correlation coefficient | Index of agreement |
|---|---|---|---|---|
| 0-100 | 0.0224 | 18 | 0.956 | 0.87 |
| 0-10 | 0.0205 | 18 | 0.961 | 0.90 |
| 10-20 | 0.0211 | 18 | 0.984 | 0.89 |
| 20-30 | 0.0223 | 19 | 0.981 | 0.88 |
| 30-40 | 0.0216 | 18 | 0.970 | 0.88 |
| 40-50 | 0.0210 | 17 | 0.964 | 0.87 |
| 50-60 | 0.0235 | 19 | 0.962 | 0.84 |
| 60-70 | 0.0232 | 18 | 0.952 | 0.83 |
| 70-80 | 0.0260 | 20 | 0.935 | 0.79 |
| 80-90 | 0.0217 | 16 | 0.937 | 0.84 |
| 90-100 | 0.0230 | 17 | 0.879 | 0.82 |

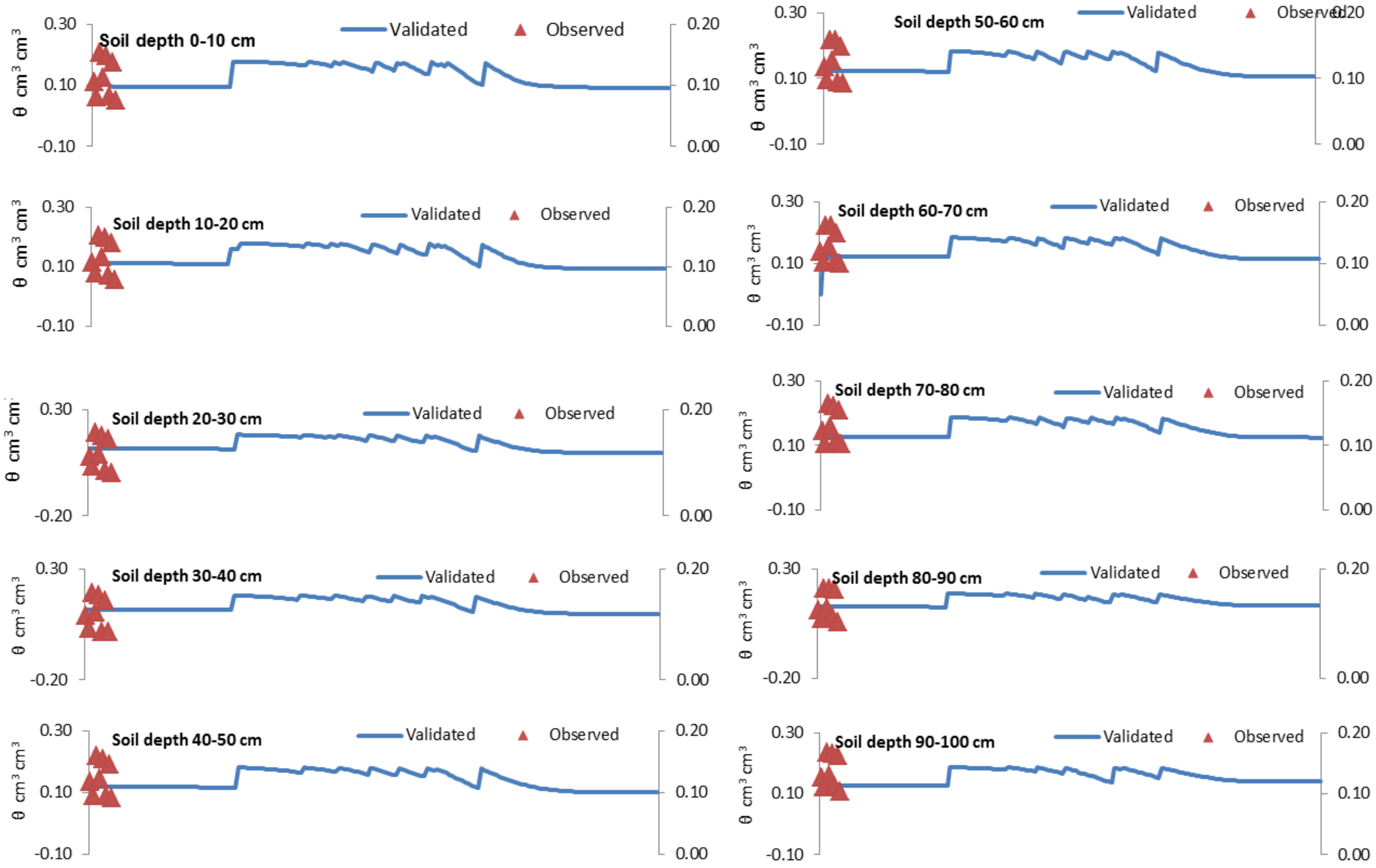



**Figure 6 Observed and validated soil water content under cotton (2013-14)**

**Validation for clusterbean**

Validation of clusterbean was based on the data from the green area index (GAI), grain yield, above ground biomass (AGB) and N-uptake used to determine the best crop parameters.

**Seed yield**

Validation results showed that predictions using CropSyst were satisfactory for seed yield (Table 12). Validated seed yield (1558 $kgha^{-1}$) of clusterbean were closer to the observed yield of 1612 $kgha^{-1}$ as it is evident from the 5.93 % RRMSE. Correlation coefficient of 0.74 and Index of agreement of 0.81 observed for yield of clusterbean during 2013-14.

**Table 12 Quantitative measures of model performance for yield, AGB and N-uptake of clusterbean (2013-14)**

| Particular | Observed | Validated | RMSE | RRMSE | Correlation coefficient | Index of agreement |
|---|---|---|---|---|---|---|
| **Seed yield** | 1612 | 1558 | 95.5 | 5.93 | 0.74 | 0.81 |
| **AGB** | 6089 | 5927 | 388.3 | 6.38 | 0.73 | 0.81 |
| **N-uptake** | 70 | 75 | 6.2 | 8.90 | 0.75 | 0.60 |

**Above ground biomass**

Validation results of clusterbean aboveground biomass matched well with the field data. The validated aboveground biomass (5927 kg $ha^{-1}$) was lower than observed aboveground biomass (6089 kg $ha^{-1}$) as shown in Table 12 with 6.38 % RRMSE. Correlation coefficient of 0.73 and Index of agreement of 0.81 observed for AGB of clusterbean during 2013-14.

**N-uptake**

Validation of N-uptake slightly matched with the field data. The validated N-uptake (75.0 kg $ha^{-1}$) was higher than observed N-uptake (70.0 kg $ha^{-1}$) as shown in table 12 with 8.9 % RMSE during 2013-14. Correlation coefficient of 0.75 and Index of agreement of 0.60 observed for N-uptake of clusterbean.

**Moisture content**

Data in table 13 lists the RMSE, correlation and index of agreement values of moisture content at different fields. The RMSE of moisture content ranged from 0.0204 to 0.0298 during 2013-14. These small values reveal that soil water flow was well validated by CropSyst at different fields. As no systematic under or over estimation of moisture content was observed, the differences between the observed and validated moisture content are contributed to the spatial heterogeneity and observation errors, which are inevitable under field conditions. Validated value of moisture content predict well with observed values in the upper layers. The index of agreement was 0.90 in bottom soil layer of 60-90 cm.

**Table 13 Quantitative measures of model performance for soil moisture under clusterbean (2013-14)**

| Soil layer, cm | RMSE | RRMSE | Correlation coefficient | Index of agreement |
|---|---|---|---|---|
| 0-100 | 0.0250 | 19 | 0.906 | 0.88 |
| 0-10 | 0.0219 | 19 | 0.833 | 0.85 |
| 10-20 | 0.0298 | 25 | 0.838 | 0.81 |
| 20-30 | 0.0282 | 23 | 0.872 | 0.83 |
| 30-40 | 0.0288 | 23 | 0.867 | 0.83 |
| 40-50 | 0.0246 | 19 | 0.917 | 0.88 |
| 50-60 | 0.0248 | 19 | 0.927 | 0.89 |
| 60-70 | 0.0236 | 18 | 0.942 | 0.90 |
| 70-80 | 0.0241 | 18 | 0.941 | 0.90 |
| 80-90 | 0.0224 | 16 | 0.948 | 0.90 |
| 90-100 | 0.0204 | 14 | 0.925 | 0.89 |

**Validation for wheat**

For validation of wheat data from the grain yield, above ground biomass (AGB), N-uptake and moisture content were used to determine the best crop parameters.

**Seed yield**

The results demonstrated that model responded well to the measured seed yield of wheat. Table 14 showed that the validated yield (4090 kg ha$^{-1}$) of wheat were closer to the observed yield of 4178 as it is evident from the 3.7 % RRMSE. Correlation coefficient of 0.74andIndex of agreement of 0.81 observed for yield of wheat during 2013-14.

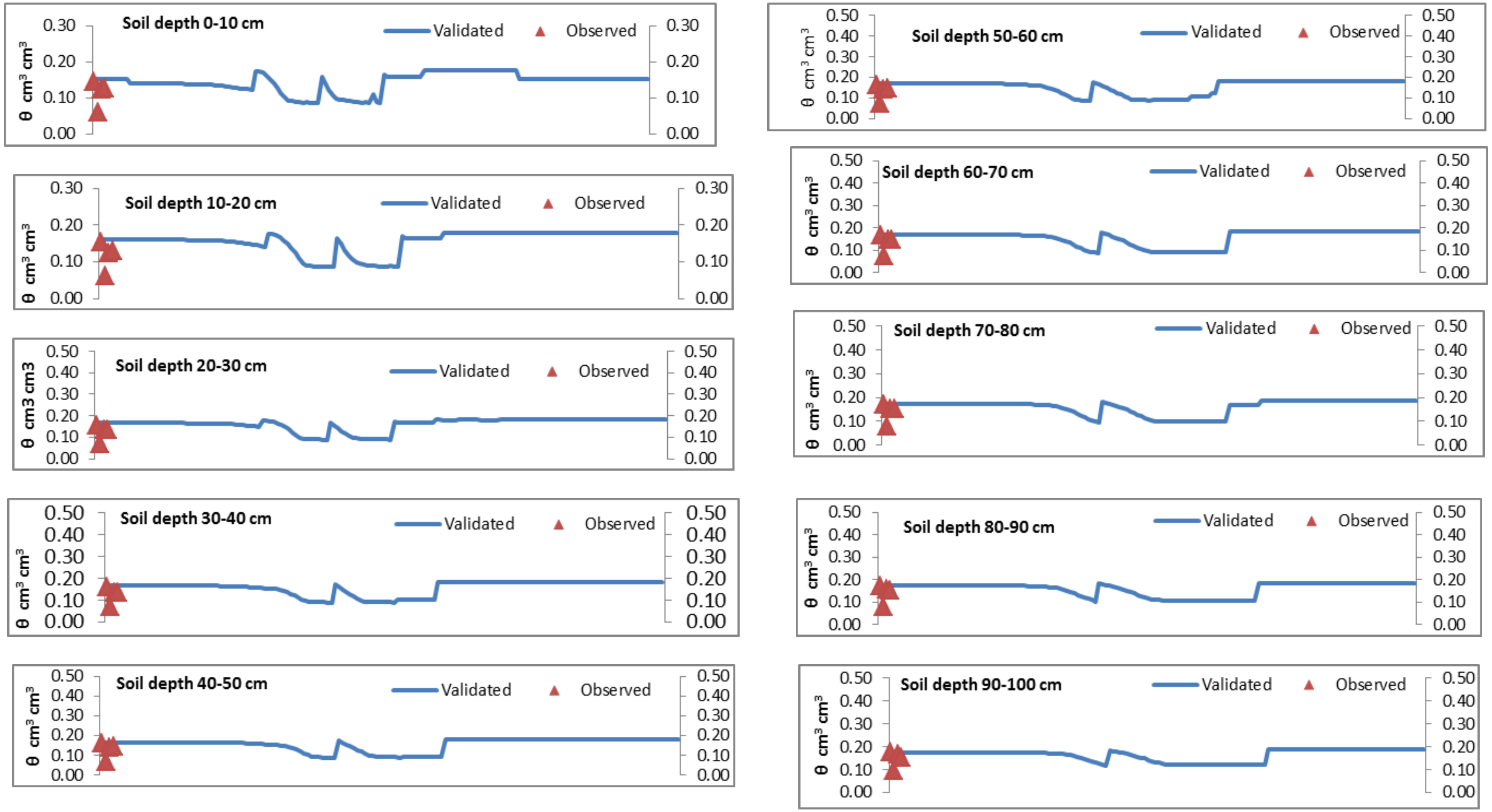



**Figure 7 Observed and validated soil water content under clusterbean (2013-14)**

**Table 14 Quantitative measures of model performance for yield, AGB and N-uptake of wheat (2013-14)**

| Particular | Observed | Validated | RMSE | RRMSE | Correlation coefficient | Index of agreement |
|---|---|---|---|---|---|---|
| **Seed yield** | 4178 | 4090 | 157.8 | 3.78 | 0.74 | 0.81 |
| **AGB** | 10128 | 10260 | 546.3 | 5.39 | 0.83 | 0.90 |
| **N-uptake** | 96.1 | 88.3 | 13.4 | 14.0 | 0.82 | 0.54 |

**Above ground biomass**

Validation of aboveground biomass development of wheat matched well with the field data. The validated aboveground biomass (10260 kg $ha^{-1}$) was higher than observed aboveground biomass (10128 kg $ha^{-1}$) as shown in Table 14 with 5.3 % RRMSE. Correlation coefficient of 0.83andIndex of agreement of 0.90 observed for AGB of wheat during 2013-14.

**N-uptake**

Validated N-uptake of wheat moderately matched with the field data. The validated N-uptake (88.3 kg $ha^{-1}$) was lower than observed N-uptake (96.1 kg $ha^{-1}$) as shown in table 14 with 14% RRMSE. Correlation coefficient of 0.82 and Index of agreement of 0.54 observed for N-uptake of wheat during 2013-14.

Among the various parameters, CropSyst predict GAI better than economic yield AGB and N-uptake. The index of agreement was 0.85 for GAI.

**Moisture content**

Data in table 15 lists the RMSE, correlation and index of agreement values of moisture content at different fields. The RMSE of moisture content ranged from 0.0211 to 0.0243 during 2013-14. These small values reveal that soil water flow was well validated by CropSyst at different fields. As no systematic under or over estimation of moisture content was observed, the differences between the observed and validated moisture content are contributed to the spatial heterogeneity and observation errors, which are inevitable under field conditions. Validated value of moisture content predict well with observed values in the upper layers. The index of agreement was 0.90 in top soil layers.

**Table 15 Quantitative measures of model performance for soil moisture under wheat (2013-14)**

| Soil layer, cm | RMSE | RRMSE | Correlation coefficient | Index of agreement |
|---|---|---|---|---|
| 0-100 | 0.0227 | 17 | 0.916 | 0.90 |
| 0-10 | 0.0243 | 20 | 0.900 | 0.90 |
| 10-20 | 0.0241 | 20 | 0.907 | 0.90 |
| 20-30 | 0.0240 | 19 | 0.916 | 0.88 |
| 30-40 | 0.0235 | 18 | 0.914 | 0.88 |
| 40-50 | 0.0213 | 16 | 0.931 | 0.90 |
| 50-60 | 0.0223 | 16 | 0.934 | 0.88 |
| 60-70 | 0.0215 | 15 | 0.939 | 0.89 |
| 70-80 | 0.0226 | 16 | 0.933 | 0.87 |
| 80-90 | 0.0211 | 14 | 0.913 | 0.88 |
| 90-100 | 0.0217 | 14 | 0.838 | 0.86 |

**Validation for mustard**

For validation of mustard data from the grain yield, above ground biomass (AGB), N-uptake and moisture content were used to determine the best crop parameters.

**Seed yield**

The results demonstrated that model responded well to the measured seed yield of mustard. Table 16 showed that the validated yield (1866 kg $ha^{-1}$) of mustard were closer to the observed yield of 1936 kg $ha^{-1}$ as it is evident from the 6.36 % RRMSE during 2013-14. Correlation coefficient of 0.83 and Index of agreement of 0.85 observed for yield of mustard.

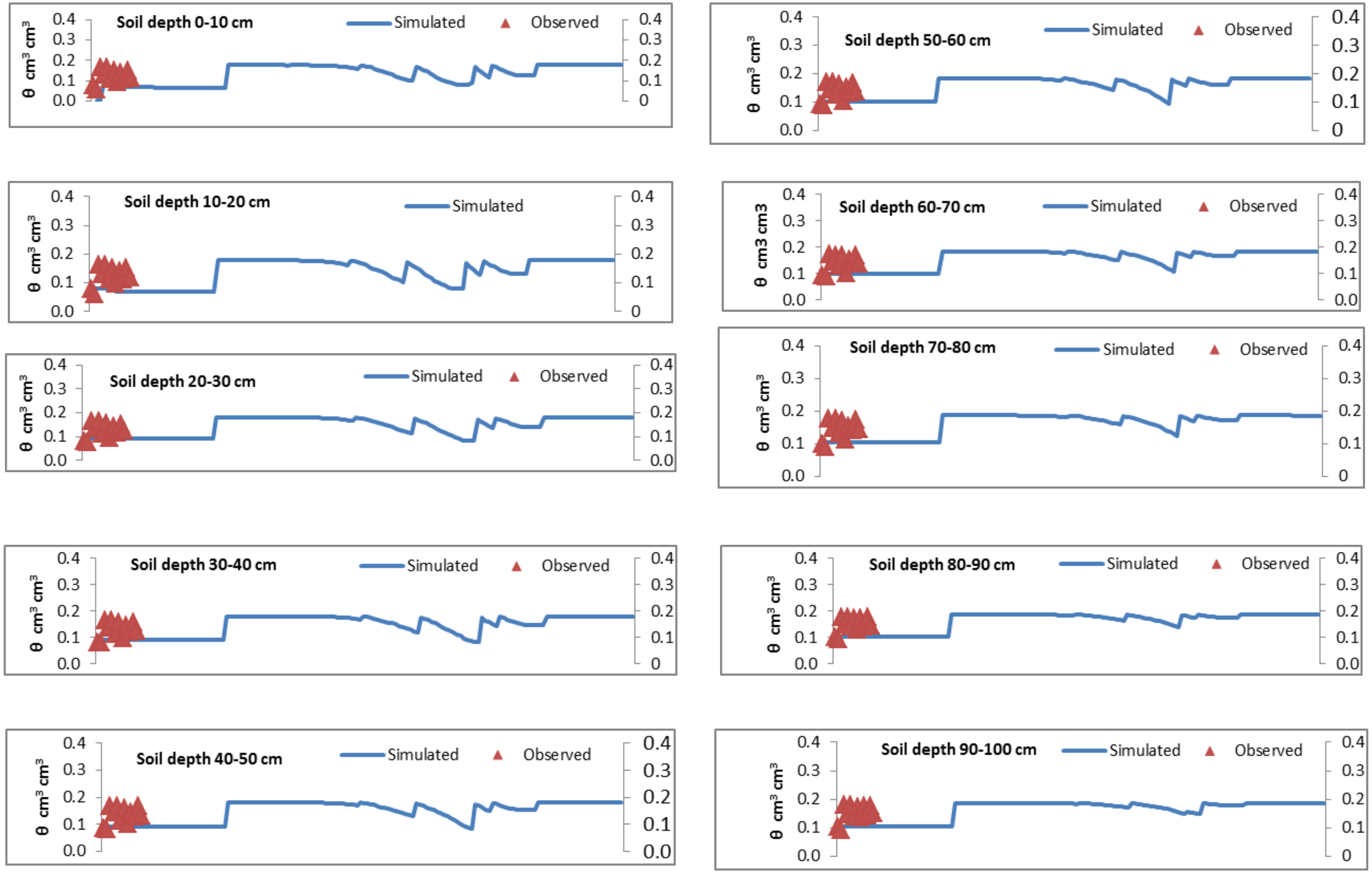



**Figure 8 Observed and validated soil water content under wheat (2013-14)**

**Table 16 Quantitative measures of model performance for yield, AGB and N-uptake of mustard (2013-14)**

| Particular | Observed | Validated | RMSE | RRMSE | Correlation coefficient | Index of agreement |
|---|---|---|---|---|---|---|
| **Seed yield** | 1936 | 1866 | 123.0 | 6.36 | 0.83 | 0.85 |
| **AGB** | 5915 | 5764 | 215.3 | 4.68 | 0.87 | 0.89 |
| **N-uptake** | 74.8 | 82.2 | 14.31 | 19.14 | 0.90 | 0.59 |

**Above ground biomass**

Validation of aboveground biomass development of mustard matched with the field data. The observed aboveground biomass (5915 kg $ha^{-1}$) was higher than validated above ground biomass (5764 kg $ha^{-1}$) as shown in Table 16 with 4.68 % RRMSE. Correlation coefficient of 0.87 and Index of agreement of 0.89 observed for AGB of mustard during 2013-14.

**N-uptake**

Validated N-uptake of mustard moderately matched with the field data. The validated N-uptake (82.2 kg $ha^{-1}$) was higher than observed N-uptake (74.8 kg $ha^{-1}$) as shown in Table 16 with 19.1 % RMSE. The Correlation coefficient of 0.90andIndex of agreement of 0.59 observed for N-uptake of mustard during 2013-14

**Moisture content**

Data presented in table 17 shows the RMSE, correlation and index of agreement values of moisture content. The RMSE of moisture content ranged from 0.0208 to 0.0257 during 2013-14. These small values reveal that soil water flow was well validated by CropSyst at different fields. As no systematic under or over estimation of moisture content was observed, the differences between the observed and validated moisture content are contributed to the spatial heterogeneity and observation errors, which are inevitable under field conditions. Validated value of moisture content predict well with observed values in the upper layers. The index of agreement was 0.90 in top soil layer of 0-10 cm.

**Table 17 Quantitative measures of model performance for soil moisture under mustard (2013-14)**

| Soil layer, cm | RMSE | RRMSE | Correlation coefficient | Index of agreement |
|---|---|---|---|---|
| 0-100 | 0.0230 | 17 | 0.939 | 0.85 |
| 0-10 | 0.0224 | 18 | 0.916 | 0.90 |
| 10-20 | 0.0229 | 18 | 0.932 | 0.89 |
| 20-30 | 0.0257 | 20 | 0.955 | 0.86 |
| 30-40 | 0.0229 | 17 | 0.952 | 0.88 |
| 40-50 | 0.0234 | 18 | 0.949 | 0.87 |
| 50-60 | 0.0221 | 16 | 0.947 | 0.88 |
| 60-70 | 0.0208 | 15 | 0.949 | 0.89 |
| 70-80 | 0.0239 | 17 | 0.941 | 0.51 |
| 80-90 | 0.0224 | 15 | 0.932 | 0.84 |
| 90-100 | 0.0232 | 16 | 0.904 | 0.84 |

**Validation for barley**

For validation of barley data from grain yield, above ground biomass (AGB), N-uptake and moisture content were used to determine the best crop parameters.

**Seed yield**

Validation of CropSyst model for seed yield of barley showed good agreement between measured and validated seed yield. Table 18 showed that the validated yield (4128 kg $ha^{-1}$) of barley were closer to the observed yield of 3991 kg $ha^{-1}$ with RRMSE of 3.79.The correlation coefficient and index of agreement were0.85 and 0.72, respectively during 2013-14.

**Table 18 Quantitative measures of model performance for yield, AGB and N-uptake of barley (2013-14)**

| Particular | Observed | Validated | RMSE | RRMSE | Correlation coefficient | Index of agreement |
|---|---|---|---|---|---|---|
| **Seed yield** | 3991 | 4128 | 151.5 | 3.79 | 0.85 | 0.72 |
| **AGB** | 9927 | 10129 | 374.9 | 3.78 | 0.78 | 0.58 |
| **N-uptake** | 98 | 94 | 4.71 | 4.81 | 0.86 | 0.76 |

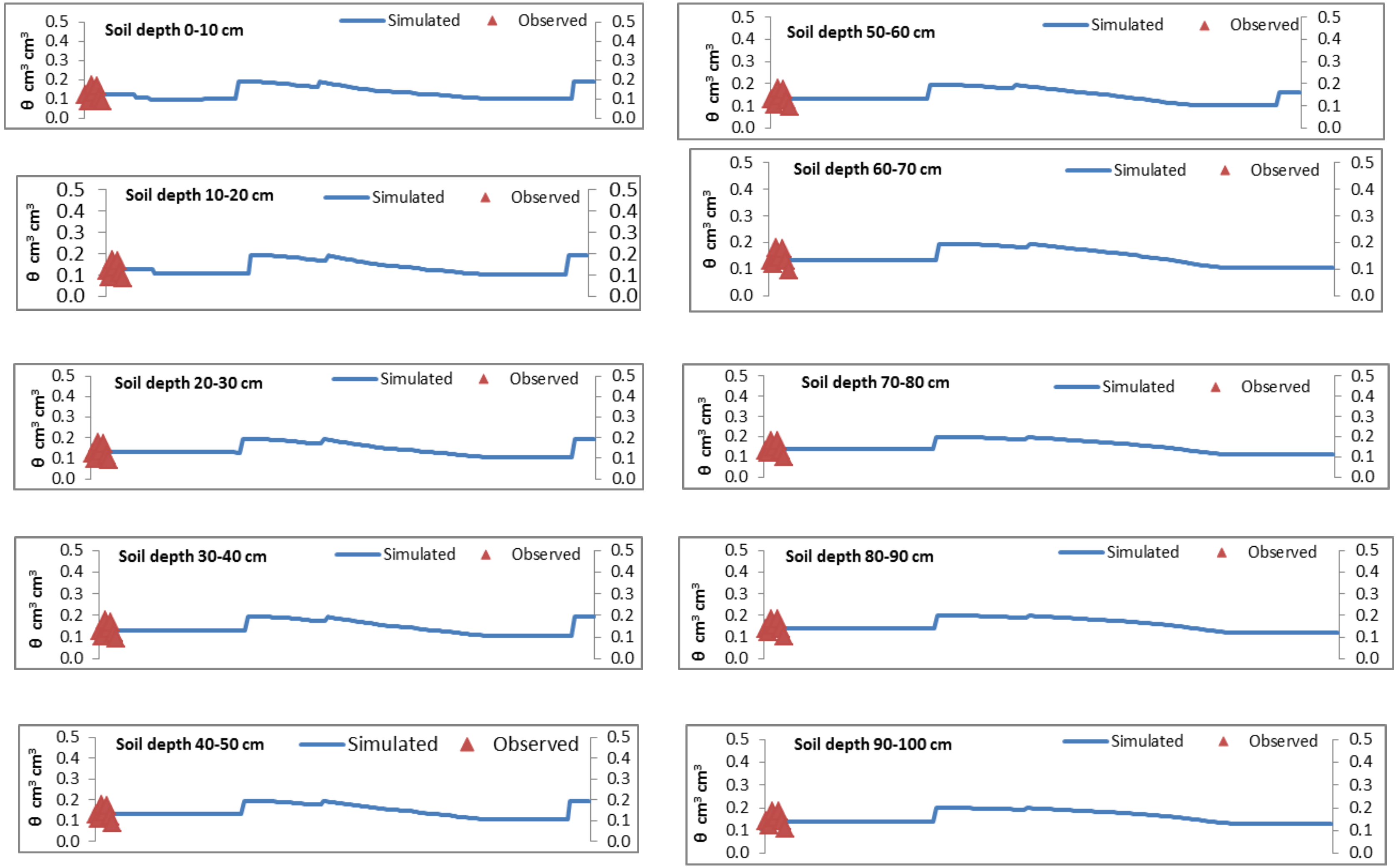



**Figure 9 Observed and validated soil water content under mustard (2013-14)**

**Above ground biomass**

The results demonstrated that model responded well to the measured seed yield of barley. The observed aboveground biomass (10129 kg $ha^{-1}$) was higher than validated aboveground biomass (9927 kg $ha^{-1}$) as shown in Table 18 with RRMSE of 3.78.Correlation coefficient of 0.78 and Index of agreement of 0.58 observed for AGB of barley during 2013-14.

**N-uptake**

Validation for N-uptake of barley matched with the field data. The validated N-uptake (94 kg $ha^{-1}$) was lower than observed N-uptake (98 kg $ha^{-1}$) with RRMSE of 4.81 during 2013-14. Correlation coefficient of 0.86 and Index of agreement of 0.76 observed for N-uptake of barley (Table 18).

**Moisture content**

Data presented in table 19 shows the RMSE, correlation and index of agreement values of moisture content. The RMSE of moisture content ranged from 0.0138 to 0.0230 during 2013-14. These small values reveal that soil water flow was well validated by CropSyst at different fields. As no systematic under or over estimation of moisture content was observed, the differences between the observed and validated moisture content are contributed to the spatial heterogeneity and observation errors, which are inevitable under field conditions. Validated value of moisture content predict well with observed values in the upper layers up to 60 cm. The index of agreement was 0.96 in top soil layer of 0-10 cm.

**Table 19 Quantitative measures of model performance for soil moisture under barley (2013-14)**

| Soil layer (cm) | RMSE | RRMSE | Correlation coefficient | Index of agreement |
|---|---|---|---|---|
| 0-100 | 0.0169 | 12 | 0.929 | 0.93 |
| 0-10 | 0.0138 | 11 | 0.965 | 0.96 |
| 10-20 | 0.0144 | 11 | 0.958 | 0.95 |
| 20-30 | 0.0160 | 12 | 0.964 | 0.93 |
| 30-40 | 0.0150 | 11 | 0.962 | 0.94 |
| 40-50 | 0.0146 | 11 | 0.966 | 0.95 |
| 50-60 | 0.0163 | 12 | 0.950 | 0.94 |
| 60-70 | 0.0161 | 11 | 0.942 | 0.94 |
| 70-80 | 0.0187 | 13 | 0.910 | 0.91 |
| 80-90 | 0.0194 | 13 | 0.889 | 0.89 |
| 90-100 | 0.0230 | 16 | 0.751 | 0.83 |

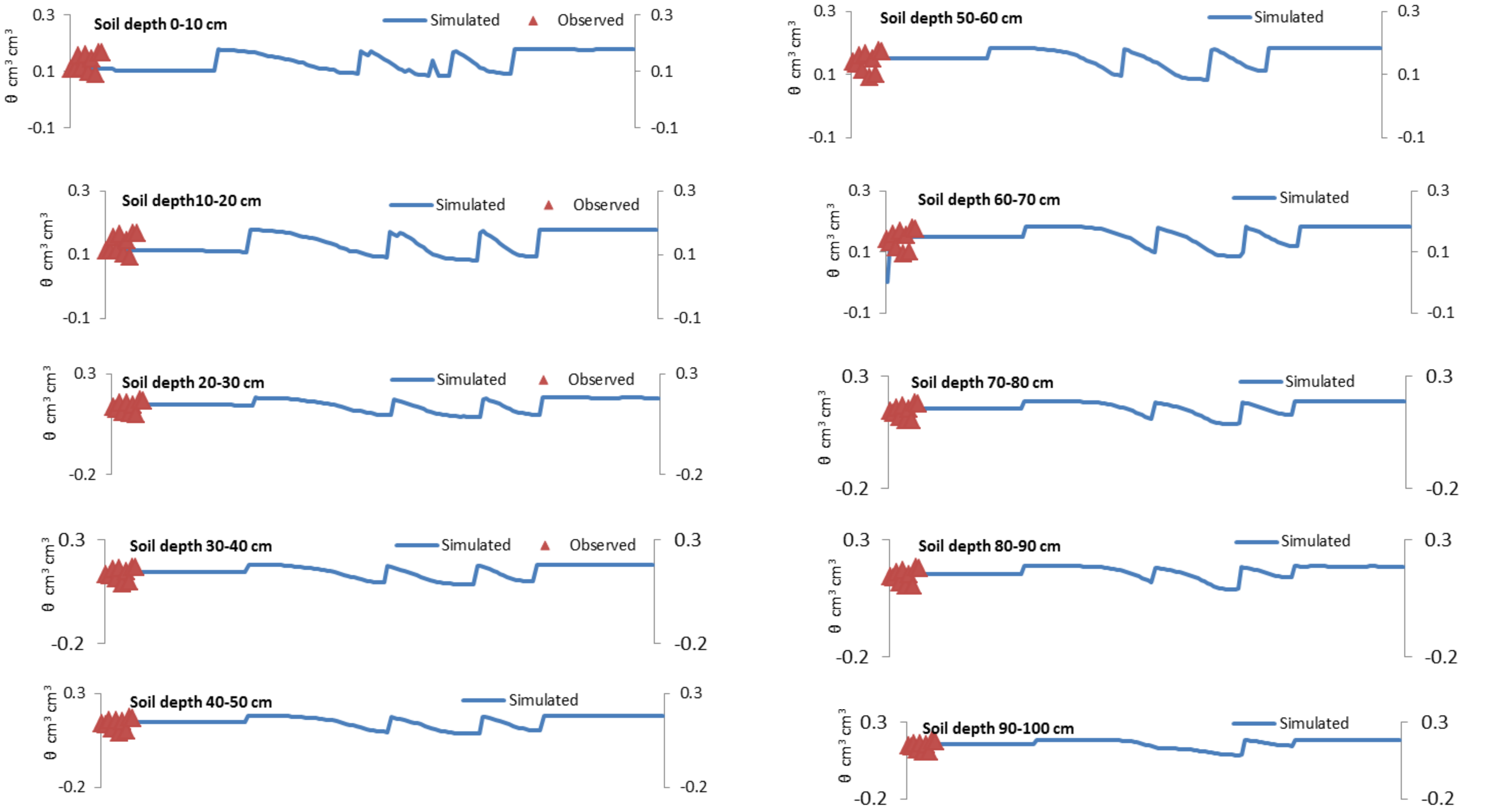



**Figure 10 Observed and validated soil water content under barley (2013-14)**

**Relationship of Observed and simulated values in different crops**

Fig1: Observed and simulated values for barley at Hanumangarh(2013-14)

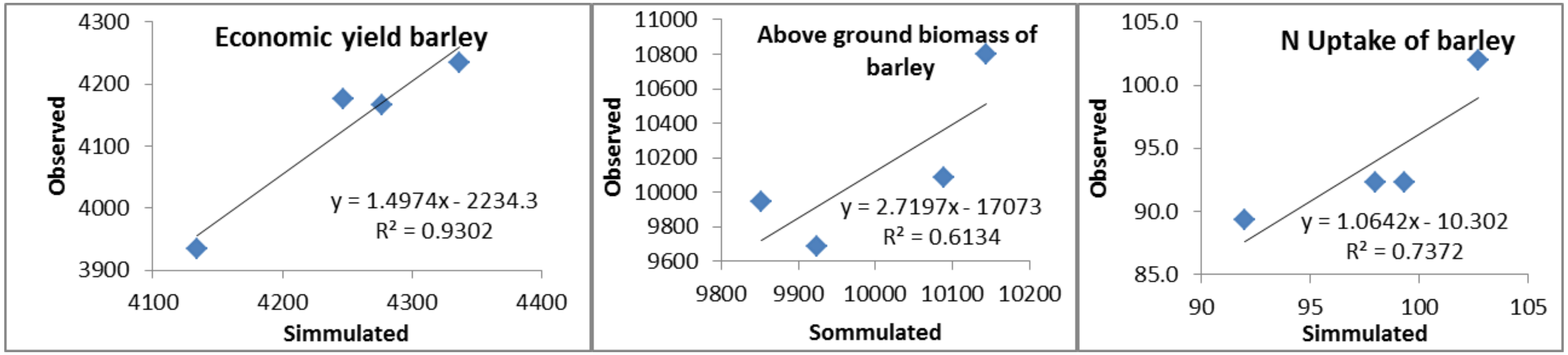



Fig2: Observed and simulated values for clusterbean at Hanumangarh(2013)

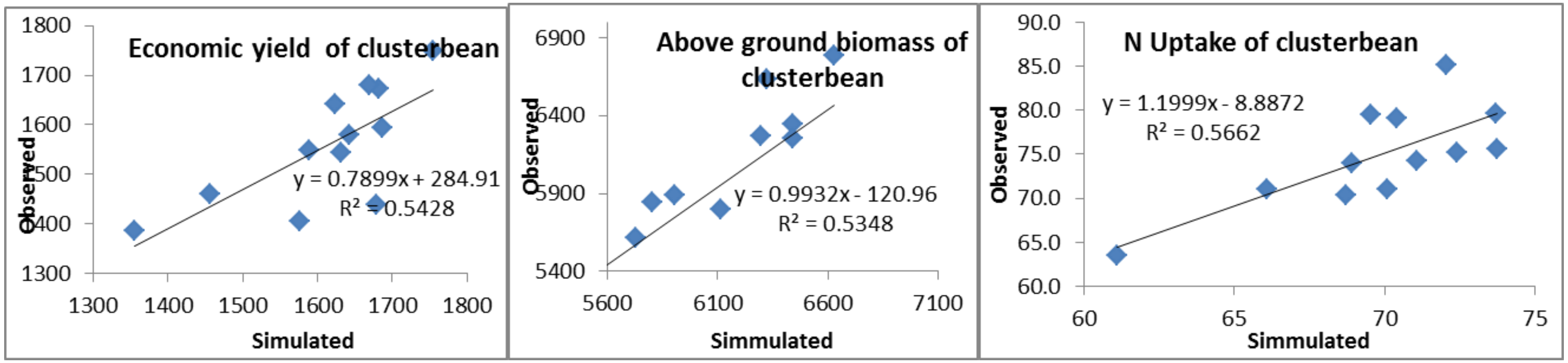


Fig3: Observed and simulated values for cotton at Hanumangarh(2013)

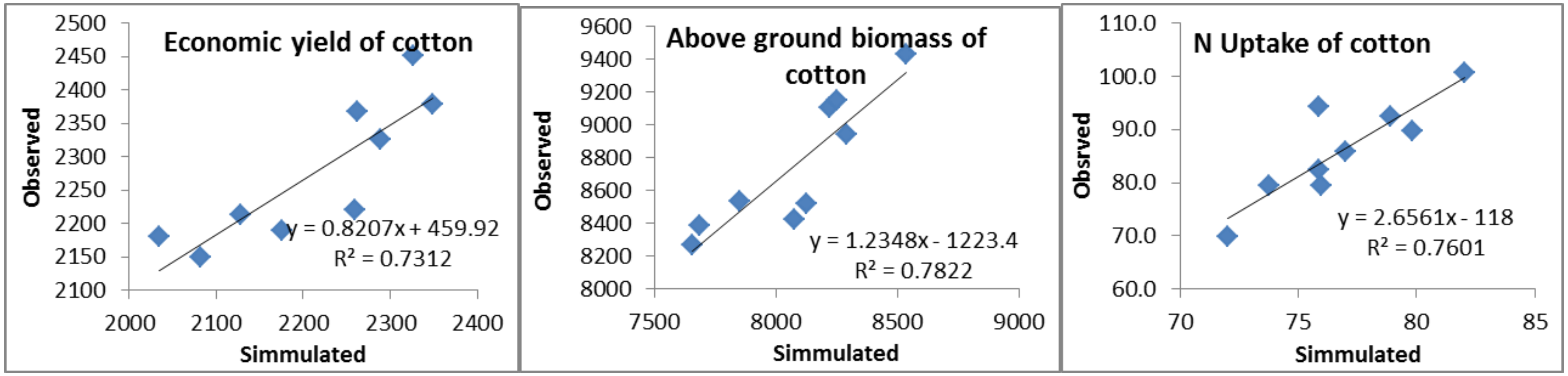



Fig1: Observed and simulated values for mustard at Hanumangarh (2013-14)

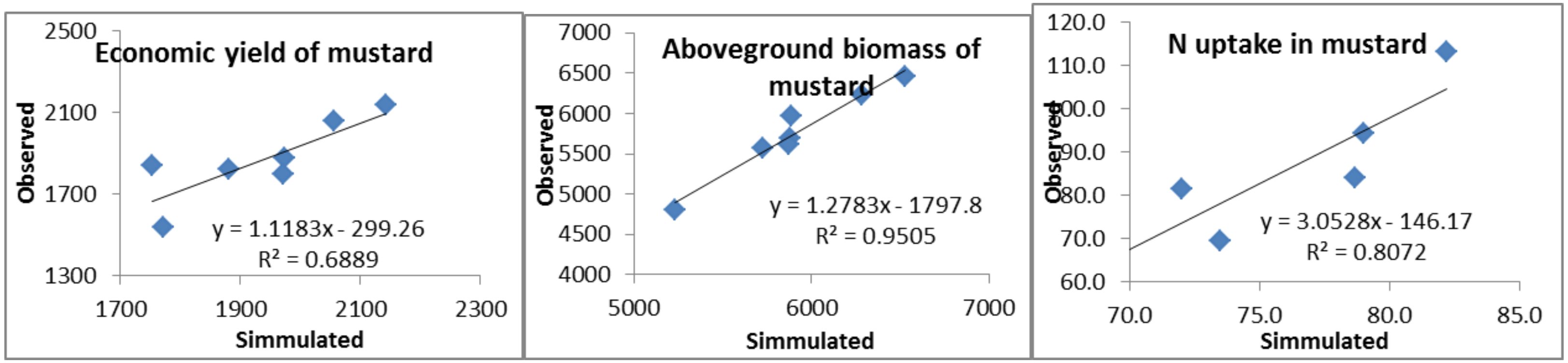
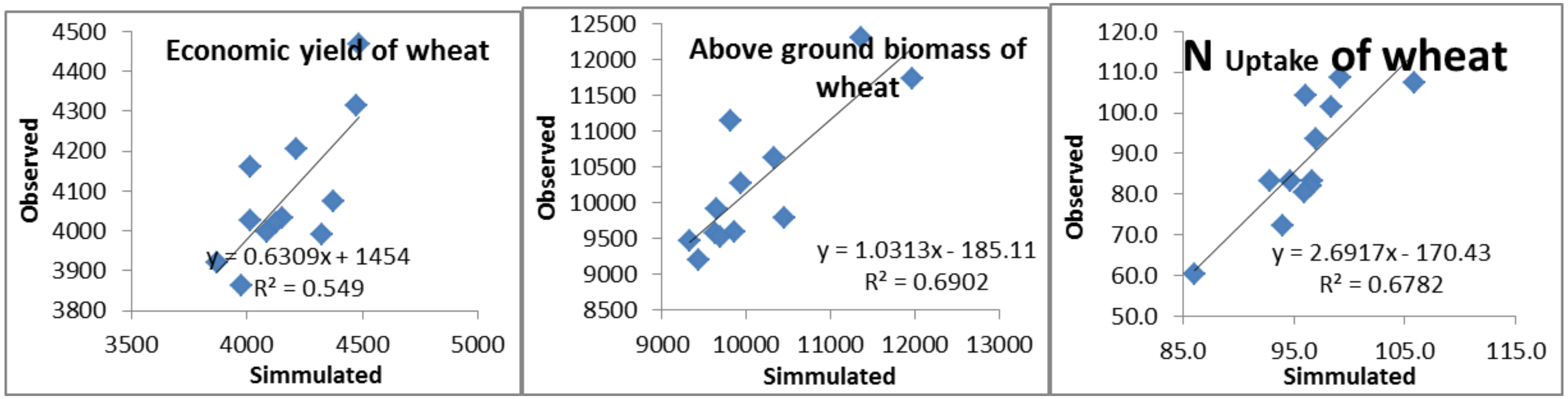


Fig1: Observed and simulated values for wheat at Hanumangarh (2013-14)



# PROJECT REPORT

# Improving Crop and Water Productivity in Indira Gandhi Canal Command Area

## PHASE-I
## (2012-2015)

## Stage-II (Baju)

**Central Arid Zone Research Institute**
**Regional Research Station**
**Bikaner-334004**

**Project Report –Phase-I**

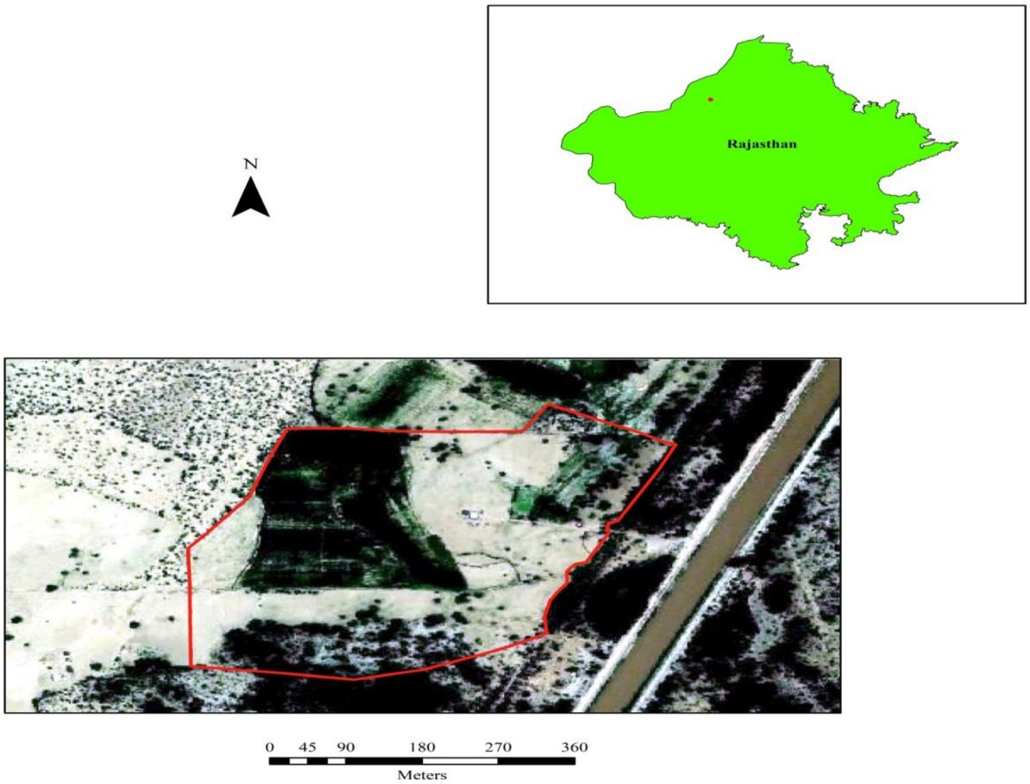
**Modelling the Soil-Water-Crop-Atmosphere System to improve land and water productivity in stage II of IGNP (2012-13)**

**Description of site:**

Stage II followed in 1980 and was completed only in the last decade, with the aim to add another 1.41 M ha of semi-arid and range-land/desert area in north-west Rajasthan, south of the stage I of canal area. The experiment was conducted at village Amarpura (Bajju), in Bikaner district of Rajasthan during *kharif* and *rabi* season of 2012-13 and 2013-14. Village Amarpura is located between 072°47’79”E longitude and 28°14’23”N latitude (Fig 1). The elevation is approximately 234.7m above mean sea level. As per NARP classification of agro-climatic zones, Bikaner falls in Agro-climatic zone IC (Hyper arid partially irrigated Western Plain Zone).The general topography of area is undulating, almost plain with some isolated steep contours. The soil texture is loamy sand. Invariably, the soil has low organic carbon content.

**Climate**

The climate of the area is arid. During the hottest period from May to June, mean daily maximum temperature rises up to 39.2-42.4°C. On individual days during the hottest period, it may rise up to about 48°C. Hot winds with low relative humidity often cause dust storms during this season. In the cold season from December to January in both year, the daily mean temperature varies from 7.1 to 24.1°C. The cold season is followed by a dry hot season, which lasts till the end of June. The period from July to September constitutes the southwest monsoon (rainy) season. About 80% of the annual rainfall occurs during this season. The rainfall in Bikaner district can be characterized as low and spatial distribution. The average annual rainfall of the tract is about 282.4 mm which is mostly received during the rainy season from July to September. After the withdrawal of monsoon in the end of September, temperature begins to decrease and leads to the cold season.




November is distinguished as the post-monsoon season. During the months of December and January, occasional fogs reside in the area. An agricultural year may be divided into four distinct seasons: the hot dry season from March to June, hot rainy (monsoon) season from July to September, post-monsoon season from October to November and cold season from December to February.

In summary, the climate of Bikaner district is characterized by its dryness, extremes of temperature and scanty rainfall. Crop production is very limited without irrigation, even in the monsoon (rainy) season. The weather conditions prevailed during the period of experimentation (2012-13) were recorded at meteorological observatory of Regional Research station, Central Arid Zone Research Institute, Bikaner have been given in table 1 and graphically depicted in fig 2 and 3.

**Soil**

The soils of the area are loamy sand in texture and slightly alkaline in reaction. The status of soil was poor in available nitrogen and medium in phosphorus but high in available potassium. Most of the soils in the Bikaner district can be characterized as well drained, single grained structure. The low water holding capacity, high infiltration rate, low organic matter, poor fertility status and salinity are main issues related to the soils in Bikaner district. Soil sampling with an interval of 0-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90 and 90-100 cm soil depths, respectively were taken with the help of soil auger crop wise from the fields and were analyzed for physiochemical properties. These soil samples were collected in clean polythene bags individually with proper labeling indicating their respective depths along with farmer name and crop details. All the collected soil samples were spread over papers for air and sun drying. After sun drying these soil samples were sieved through 2 mm sieve for preparing soil samples with proper labeling. The important soil parameters (Table 2 ,3), which were taken into consideration for this purpose, were texture, hydraulic conductivity, field capacity, maximum water holding capacity, pH, electrical conductivity (EC), organic carbon, mineral nitrogen (N), available phosphorous and potash. Water analysis will be done for pH, EC, $CO_3^{2-}$, $HCO_3^-$, $Na^+$, $K^+$, $Ca^{2+}$+$Mg^{2+}$,$Cl^-$, $SO_4^{2-}$, and $NO_3^-$-N (Table 4)

**Table: 1 Monthly meteorological data during crop season 2012-13 ($Y_1$) and 2013-14 ($Y_2$)**

| Month | Temperature (°C) | | | | Relative humidity (%) | | | | Total rainfall (mm) | | Evaporation (mm) | | Solar Radiation (MJ $m^{-2}$ $d^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Maximum | | Minimum | | Maximum | | Minimum | | | | | | | |
| | $Y_1$ | $Y_2$ | $Y_1$ | $Y_2$ | $Y_1$ | $Y_2$ | $Y_1$ | $Y_2$ | $Y_1$ | $Y_2$ | $Y_1$ | $Y_2$ | $Y_1$ | $Y_2$ |
| May | 40.3 | 42.9 | 25.8 | 23.8 | 60.8 | 41.1 | 25.8 | 19.8 | 53.2 | 0.0 | 324.6 | 339.0 | 21.0 | 24.6 |
| June | 38.2 | 41.8 | 28.7 | 27.2 | 65.9 | 59.1 | 39.1 | 31.8 | 4.8 | 14.0 | 327.0 | 333.0 | 22.4 | 22.5 |
| July | 39.7 | 38.2 | 29.7 | 24.5 | 63.6 | 74.7 | 37.8 | 49.0 | 0.0 | 78.9 | 260.9 | 298.0 | 23.0 | 19.5 |
| August | 38.1 | 35.6 | 26.9 | 22.7 | 73.8 | 82.9 | 47.4 | 53.0 | 158.9 | 117.7 | 244.4 | 227.0 | 20.7 | 19.8 |
| September | 37.1 | 36.4 | 24.9 | 24.0 | 73.1 | 72.0 | 38.6 | 38.4 | 45.2 | 6.0 | 224.2 | 288.0 | 20.0 | 20.3 |
| October | 38.0 | 35.1 | 21.6 | 18.9 | 68.2 | 68.3 | 27.0 | 34.3 | 0.0 | 1.0 | 227.9 | 264.0 | 18.3 | 17.9 |
| November | 31.5 | 28.9 | 13.0 | 10.6 | 64.9 | 62.0 | 29.8 | 24.3 | 0.0 | 0.0 | 170.6 | 170.0 | 14.9 | 14.9 |
| December | 26.0 | 24.4 | 8.8 | 10.7 | 81.7 | 65.0 | 56.8 | 30.5 | 0.0 | 0.0 | 120.3 | 77.5 | 13.0 | 13.8 |
| January | 22.1 | 20.3 | 5.4 | 4.9 | 72.6 | 70.2 | 25.5 | 37.9 | 1.0 | 0.0 | 72.5 | 43.5 | 13.9 | 13.9 |
| February | 24.1 | 24.6 | 9.4 | 9.1 | 78.9 | 66.6 | 33.4 | 32.3 | 12.4 | 1.0 | 86.5 | 116.0 | 15.9 | 16.1 |
| March | 32.1 | 29.9 | 13.1 | 14.6 | 66.2 | 68.0 | 18.9 | 37.7 | 5.4 | 0.0 | 165.5 | 203.0 | 19.2 | 19.6 |
| April | 37.5 | 37.6 | 18.1 | 19.9 | 57.9 | 58.3 | 31.5 | 29.1 | 1.4 | 14.9 | 233.0 | 291.8 | 21.2 | 23.8 |

# data taken from meteorological observatory of Regional Research station, Central Arid  Zone Research Institute, Bikaner

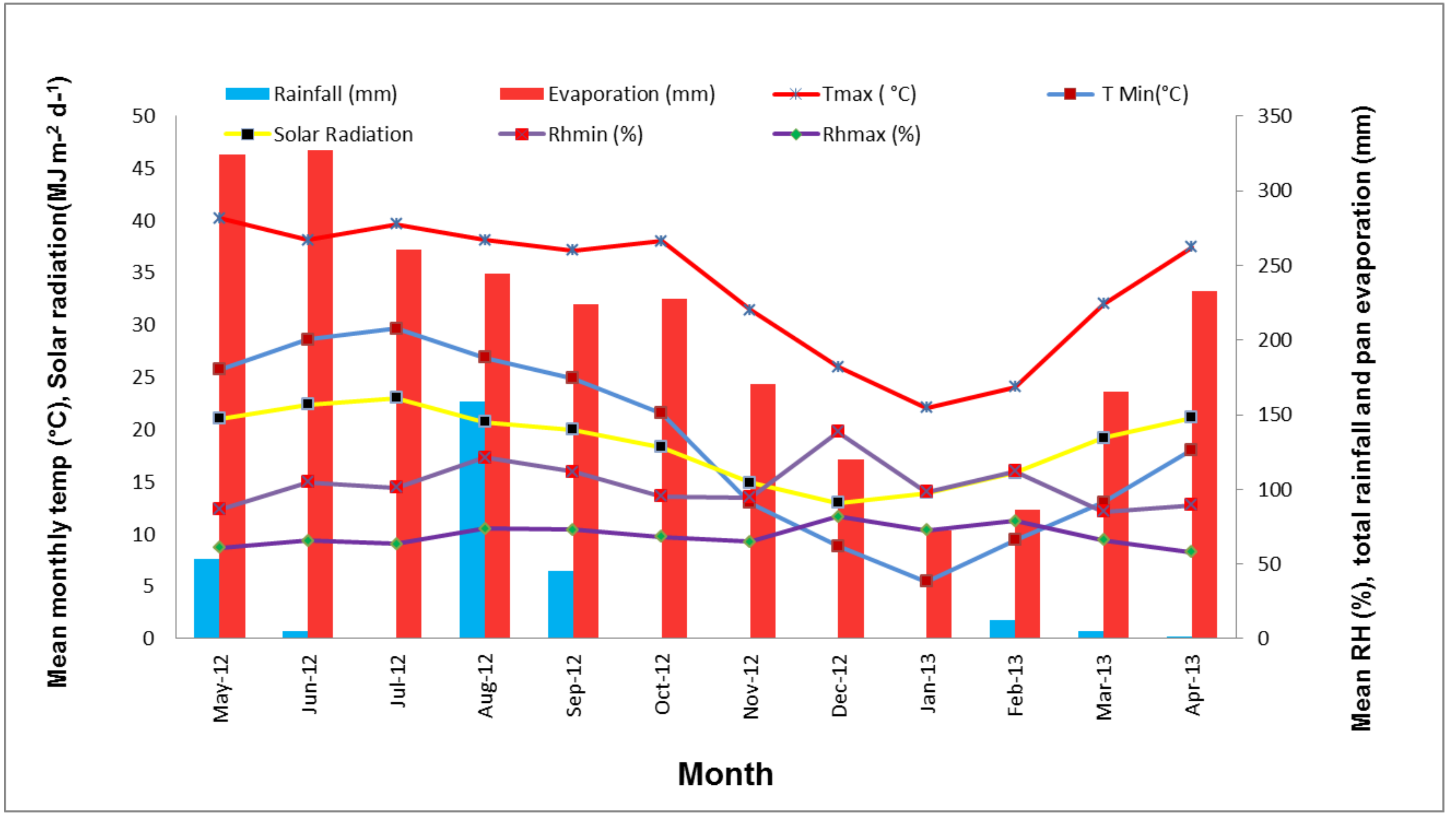



**Fig. 2 Monthly meteorological data recorded during crop growing 2012-13**

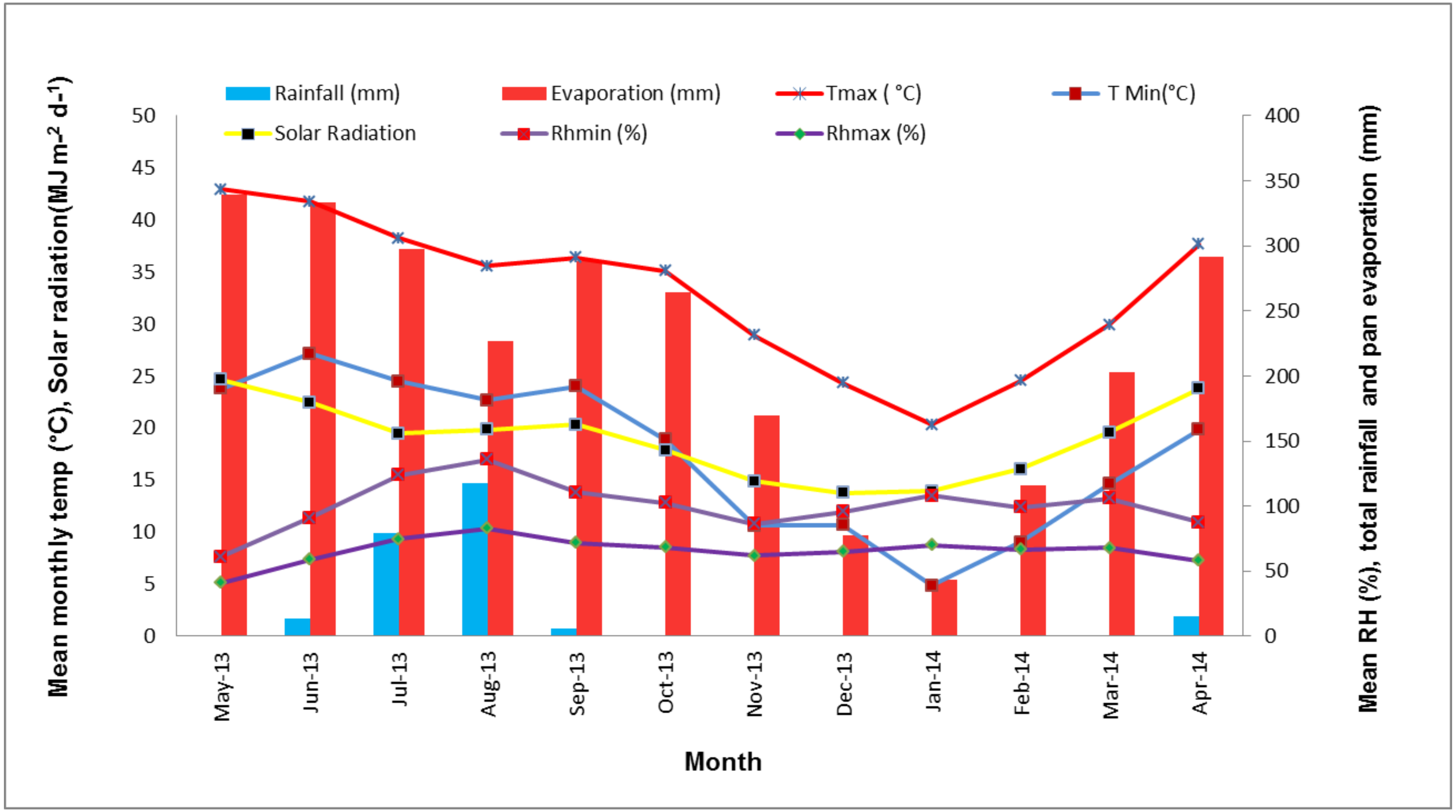



**Fig. 3 Monthly meteorological data recorded during crop growing 2013-14**

**Table 2 Soil physical properties of experimental site 2012-13 and 2013-14**

| Thick ness (m) | Sand (%) | | Clay (%) | | Silt (%) | | Bulk density (g $cm^{-3}$) | | CEC (cmol $kg^{-1}$) | | pH | | PWP ($m^3$ $m^{-3}$) | | FC ($m^3$ $m^{-3}$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $Y_1$ | $Y_2$ | $Y_1$ | $Y_2$ | $Y_1$ | $Y_2$ | $Y_1$ | $Y_2$ | $Y_1$ | $Y_2$ | $Y_1$ | $Y_2$ | $Y_1$ | $Y_2$ | $Y_1$ | $Y_2$ |
| 0.15 | 86.5 | 86.4 | 5.5 | 5.8 | 7.7 | 7.8 | 1.55 | 1.54 | 4.1 | 4.3 | 7.5 | 7.6 | 0.077 | 0.076 | 0.154 | 0.152 |
| 0.10 | 85.8 | 84.9 | 5.9 | 6.4 | 8.0 | 8.7 | 1.52 | 1.53 | 4.4 | 4.6 | 7.8 | 7.7 | 0.079 | 0.078 | 0.158 | 0.155 |
| 0.25 | 84.8 | 85.7 | 6.2 | 5.8 | 8.7 | 8.5 | 1.52 | 1.54 | 4.5 | 4.4 | 7.9 | 7.8 | 0.081 | 0.082 | 0.165 | 0.162 |
| 0.25 | 84.2 | 84.6 | 6.6 | 6.3 | 8.9 | 9.1 | 1.53 | 1.54 | 4.9 | 4.7 | 7.9 | 7.8 | 0.083 | 0.083 | 0.168 | 0.167 |
| 0.25 | 83.7 | 84.5 | 6.8 | 6.2 | 9.2 | 9.3 | 1.52 | 1.51 | 5.1 | 4.8 | 8.0 | 7.9 | 0.086 | 0.085 | 0.167 | 0.167 |

**Table 3 Initial soil conditions of experimental site 2012-13 and 2013-14**

| Layer | Thickness (m) | Water content ($m^3$ $m^{-3}$) | | NO3 (kg N $ha^{-1}$) | | NH4 (kg N $ha^{-1}$) | | SOM (%) | | Salinity (dS $m^{-1}$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $Y_1$ | $Y_2$ | $Y_1$ | $Y_2$ | $Y_1$ | $Y_2$ | $Y_1$ | $Y_2$ | $Y_1$ | $Y_2$ |
| 1 | 0.15 | 0.061 | 0.073 | 14.37 | 11.92 | 37.28 | 29.57 | 0.13 | 0.12 | 0.17 | 0.18 |
| 2 | 0.10 | 0.063 | 0.074 | 12.37 | 9.80 | 32.25 | 25.99 | 0.06 | 0.07 | 0.11 | 0.11 |
| 3 | 0.25 | 0.065 | 0.072 | 11.59 | 11.39 | 30.24 | 26.66 | 0.08 | 0.07 | 0.12 | 0.12 |
| 4 | 0.25 | 0.073 | 0.079 | 10.29 | 11.72 | 28.54 | 25.39 | 0.11 | 0.12 | 0.15 | 0.14 |
| 5 | 0.25 | 0.073 | 0.075 | 9.12 | 9.13 | 25.09 | 19.92 | 0.11 | 0.11 | 0.09 | 0.11 |

**Table 4 Chemical properties of the canal Water (IGNP)**

| Sample No. | pH | EC ($dSm^{-1}$) | $CO_3^{2-}$ ($meL^{-1}$) | $HCO_3^-$ ($meL^{-1}$) | $Na^+$ ($meL^{-1}$) | $K^+$ ($meL^{-1}$) | $Ca^{2+} + Mg^{2+}$ ($meL^{-1}$) | $Cl^-$ ($meL^{-1}$) | $SO_4^{2-}$ ($meL^{-1}$) | $NO^{3-} – N$ ($meL^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 7.5 | 0.25 | 0.12 | 1.23 | 0.81 | 0.044 | 1.72 | 0.45 | 0.73 | 0.25 |
| 2 | 6.9 | 0.27 | 0.14 | 1.27 | 0.78 | 0.048 | 1.75 | 0.51 | 0.76 | 0.26 |
| 3 | 7.3 | 0.23 | 0.15 | 1.28 | 0.74 | 0.037 | 1.68 | 0.50 | 0.74 | 0.24 |

**Table 5 Overview of the soil properties data collected for calibration of CropSyst model at farmer fields in Bikaner district (2012-13 and 2013-14)**

| Data | Method / source | Frequency | Purpose |
|---|---|---|---|
| Texture | Hygrometer method | Once | Input derivation |
| Bulk density | Core Method | Once | Input derivation |
| Saturated hydraulic conductivity | Laboratory measurement of hydraulic conductivity of saturated soil(Klute,1965) | Once | Input derivation |
| Saturation percentage / moisture | Saturation Paste Method | Once | Input derivation |
| Soil moisture | TDR | Before and after irrigation | Calibration and validation |
| pH | In soil-water suspension of 1:2 by pH meter | Before and after irrigation | General |
| Electrical Conductivity | In soil-water suspension of 1:2 by Conductivity Meter | Before and after irrigation | Calibration and validation |
| Organic Carbon | Wet digestion method (Walkley and Black, 1947) | Before sowing | Input derivation |

**Selection of farmer**

Selection of farmer was done for tow year experiment on the basis of major cropping sequence grown in the study area during 2012-13. A general survey of different farmers' fields was done out of which one farmer was selected keeping in view the irrigation facilities from the IGNP canal. The field of farmer is depicted in Fig 1.

**Area under cultivation**

Total area of the experimental site was 17.5 ha out of which net cropped area were 13ha Average land holding of 6.1 ha. Major crops of the area were groundnut and Clusterbean during *kharif* (2012 and 2013) and wheat, mustard, chick pea, cumin and Isabgol in *rabi* 2012-13 and 2013-14.

**Sampling, measurement and analysis**

Most of the input parameters of CropSyst are site specific, and obtained by field measurements. Some of the input parameters such as soil hydraulic parameters are difficult to measure directly under field conditions, and hence determined through the calibration of the model. The calibration of CropSyst requires detailed crop measurements under field conditions.

The various observations required for model calibration were collected from farmer's field crop wise. The required input parameters can be categorized into meteorological, soil, water and crop parameters. These measurements were used to calibrate of CropSyst model.

**Crop and cropping sequences**

In this region there are more than 6 different types of crops grown like*: Arachis hypogea, Cymopsis tetragonaloba, Triticum aestivum, Brassica Juncia, Cicer aeritinum, Cuminum cyminum* and *Plantego oveta* out of which maximum area is under Groundnut. Wheat is next most popular crop among farmers living in the region. It was observed that 75% of the population was engaged in agriculture. The major crop sequences/rotations followed in Bajju region of Bikaner district are Groundnut-wheat for one year rotation. The major fruit crops of the district are *Citrus sinensis, Citrus* reticulate, *Phoenix dactylifera* and *Zyzipus morisiyana*.

**Crop management practices (2012-13 and 2013-14)**

The details of crop management practices adopted for various crops at study site areas under:

**1 Groundnut**

The management practices of groundnut adopted by the farmer in the study area are presented in Annexure I. The tillage operation were ploughing, harrowing followed by cultivator and planking. Sowing was done on 25-05-2012 in first year and on 23-06-2013 in second year. Seed rate used by the farmer range between 100 to120 kg $ha^{-1}$ with a spacing 30 x 10 cm by seed-drill. Full dose of Nitrogen (N) and Phosphorus (P) was applied as basal.

**2 Clusterbean**

Annexure I shows the management practices of clusterbean adopted by the farmer in the study area. The tillage operation was ploughed, harrowing followed by cultivator and planking. Sowing was done on 13-08-2012 in first year and on 28-07-2013 in second year. Seed rate used by the farmers range between 16 to18 kg $ha^{-1}$ with a spacing of 30x10 cm by seed drill. Full dose of nitrogen (N) and phosphorus (P) was applied as basal.

**3 Wheat**

Annexure I shows the management practices of wheat adopted by the farmer in the study area .The tillage operation were ploughing, harrowing followed by cultivator and planking. Sowing was done on13-12-2012 in $I^{st}$ year and on 09-12-2013 in $II^{nd}$ year. Seed rate used by the farmer range between 100 to120 kg $ha^{-1}$ with a spacing of 20 x 5 cm by seed drill. Half dose of nitrogen (N) and full phosphorus (P) was applied as basal and remaining 1/2 dose of nitrogen (N) was top dressed at 30 DAS

**4 Mustard**

Annexure I shows the management practices of mustard adopted by the farmer in the study area.The tillage operation were ploughing, harrowing followed by cultivator and planking. Sowing was done on 25-11-2012in first year and on 08-12-2013 in second year. Seed rate used by the farmer range between 3 to 6 kg $ha^{-1}$ with a spacing of 30x10 cm by seed drill. Half dose of nitrogen (N) and full phosphorus (P) was applied as basal and remaining 1/2 dose of nitrogen (N) was top dressed at 30 DAS.

**5 Chickpea**

The management practices of chickpea adopted by the farmer in the study area are presented in Annexure I. The tillage operation were ploughing, harrowing followed by cultivator and planking. Sowing was done on 13-12-2012in $I^{st}$ year and on 09-12-2013 in $II^{nd}$year using seed rate of 80 kg $ha^{-1}$ with a spacing of 30 x 10 cm by Seed drill. Full dose of nitrogen (N) and phosphorus (P) was applied as basal.

**6 Cumin**

Annexure I shows the management practices of cumin adopted by the farmer in the study area.The tillage operation were ploughing, harrowing followed by cultivator and planking.Sowing was done on 13-12- 2012 in first year and on 09-12-2013 in second year. Seed rate used by the farmer was 8 kg $ha^{-1}$ with a spacing of 30 x 10 cm by seed drill. Half dose of nitrogen (N) and full phosphorus (P) was applied as basal and remaining 1/2 nitrogen (N) was top dressed at 30 DAS

**7 Isabgol**

Annexure I shows the management practices of isabgol adopted by the farmer in the study area. The tillage operation were ploughing, harrowing followed by cultivator and planking. Sowing was done on 13-12- 2012 in I[st] year and on 09-12-2013 in II[nd] year. Seed rate used by the farmer was 8 kg $ha^{-1}$ with a spacing of 30 x 10 cm by seed drill. Half dose of nitrogen (N) and full phosphorus (P) was applied as basal and remaining 1/2 nitrogen (N) was top dressed at 30 DAS

**Plant studies (2012-13 and 2013-14)**

For measuring physiological parameters three sampling area in each crop farmer were selected. For all crops the area of each sampling was 0.50 m x 0.50 m were selected for measuring GAI and AGY. For measuring yields an area of 1x1m area were selected for each crop. For measuring rooting depth, the five plants were used (Table 6).

**Table 6 Overview of the plant growth data collected for calibration of CropSyst model at farmer fields in Bikaner district (2012-13 and 2013-14)**

| Data | Method / source | Frequency | Purpose |
|---|---|---|---|
| Crop development stage (in days after sowing) *i.e.* emergence, panicle initiation, anthesis, maturity and harvest | Field observation | 4-5 times | Input derivation |
| Plant density | Field observation | 4-5 times | Input derivation |
| Leaf area | Field observation | 4-5 times | Calibration |
| Rooting depth | Field observation | 2-3 times | Input derivation |
| Crop yields | Field observation | at Harvest | Calibration |

**Leaf area ($cm^2cm^{-2}$)**

The leaves from plants selected for growth analysis from field were used for the estimation of leaf area. Leaf area was computed by leaf area meter and expressed as $cm^2$per square meter.

**Specific leaf area (SLA)**

The Specific Leaf Area was calculated as follows:

$$SLA = \frac{\text{Leaf area (cm}^2\text{)}}{\text{Leaf dry weight (g)}}$$

**Leaf biomass (g)**

The leaves from plants for analysis were put in butter paper and kept in hot air over at 85 ± $1^0$ C for 24 hours. The dry weight of the leaves was recorded and expressed in grams

**Days to emergence**

Plants were observed for emergence. The day on which 50 percent of plants showed emergence in the fields was considered as emergence. The number of days taken from the date of sowing to emergence was calculated and expressed in number as days taken for emergence.

**Days to 50 per cent flowering**

The day on which 50 per cent of plants showed flowers in the fields was considered as 50 percent flowing. The number of day taken from the date of sowing to flowering was calculated and expressed in number as days taken for 50 per cent flowering.

**Days to 50 per cent grain filling**

The day on which 50 per cent of grains filled in the fields was considered as 50 per cent grain filling. The number of day taken from the date of sowing to grain filling was calculated and expressed in number as days taken for 50 per cent grain filling.

**Days to maturity**

The day on which 50 per cent of plants showed maturity in the fields was considered as maturity of plants. The number of days taken from the date of sowing to maturity was calculated and expressed in number as days taken for maturity.

**1000 - seed weight**

A small seed sample was taken from the produce of each of the net plot harvested and 1000-seeds were counted and their weight was recorded as test weight (g).

**Seed yield**

The seed yield of each net plot was recorded in kg/plot after cleaning the threshed produce and was converted as kg/ha.

**Straw yield**

Straw yield was obtained by subtracting the seed yield (kg/ha) from biological yield (kg/ha).

**Biological yield**

The harvested material from net area of each plot was thoroughly sun dried. After drying, the produce of individual net plot was weighed with the help of a spring balance and recorded in kg/plot. Later this was converted into kg/ha.

**Harvest index**

The harvest index was calculated by using following formula and expressed as percentage (Singh and Stoskopf, 1971).

$$\text{Harvest index (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

**Nutrient content and uptake**

The representative samples of seed and straw drawn at the time of threshing and winnowing were ground and analyzed for nitrogen(Snell and Snell, 1949), phosphorus(Jackson, 1973) and potassium(Jackson,1973) concentration. The uptake of nitrogen, phosphorus and potassium after harvest in seed and stover was estimated by using the following relationship:

$$\text{Nutrient uptake (kg/ha)} = \frac{\text{Nutrient content in seed (\%)} \times \text{Seed yield (kg/ha)} + \text{Nutrient content in stover (\%)} \times \text{Stover yield (kg/ha)}}{100}$$

**Irrigation**

In the study area, the source of irrigation is the IGNP canal. The method used for discharge, duration and depth of irrigation and frequency are presented in Table 7

**Table 7 Overview of the irrigation data collected for calibration of CropSyst model at farmer fields in Bikaner district**

| Data | Method / source | Frequency | Purpose |
|---|---|---|---|
| Discharge of Irrigation source i.e.canal water | Sprinkler | 3 - 4 times | Input derivation |
| Duration of irrigation | Field observation | Each irrigation | Input derivation |
| Irrigation depth | Calculated by multiplying the discharge and duration of irrigation and divided by field area. | Each irrigation | Input derivation |

**Model description**

CropSyst model has been chosen for this project. It is a multi-year, multi-crop, daily time step cropping systems simulation model developed to serve as an analytical tool to study the effect of climate, soils, and management on cropping systems productivity and the environment. Emphasis has been placed on developing a user-friendly interface, providing links to GIS software, a weather generator, and other utility programs. CropSyst simulates the soil water budget, soil plant nitrogen budget, crop phenology, canopy and root growth, biomass production, crop yield, residue production and decomposition, soil erosion by water, and salinity. These processes are affected by weather, soil characteristics, crop characteristics, and cropping system management options including crop rotation, cultivar selection, irrigation, nitrogen fertilization, soil and irrigation water salinity, tillage operations, and residue management. The development of CropSyst started in the early 1990s. The motivation for its development was based on the observation that there was a niche in the demand for cropping systems models, particularly those featuring crop rotation capabilities, which was not properly served. Efficient cooperation among researchers from several world locations, a free distribution policy, active cooperation of model developers and users in specific projects, and careful attention to software design from the onset allowed for rapid and cost-effective progress. Another important factor was the advantage of learning from a rich history of crop modeling efforts. CropSyst was designed to draw from the conceptual strengths of EPIC, but including a more process-oriented approach to the simulation of crop growth and its interaction with management and the surrounding environment. In addition, a stronger emphasis on software design was a clear departure from the EPIC and DSSAT approaches. Attention to a balance between the incorporation of sound science in the models and the utilization of adequate software design practices has been a trait of CropSyst since the beginning of its development. In this regard, it shares somewhat common objectives with APSIM (McCown*et al*., 1996; Keating *et al*., 2003), a modeling approach that has evolved to place substantial resources in the development of quality software engineering practices. CropSyst model will be applied to carry out the research study. The model has been developed to serve as an analytic tool to study the effect of cropping systems management on productivity and the environment. The model simulates the soil water budget, soil-plant nitrogen budget, crop canopy, root growth, dry matter production, yield, erosion, residue production and decomposition. Management options include: cultivar selection, crop rotation (including fallow years), irrigation, nitrogen fertilization, tillage operations (over 80 options) and residue management.

The CropSyst model has a main driver program, a land unit module and modules for the primary components that make up a land unit in a cropping system (Fig. 4). The primary modules are for weather, soil, plant, soil-plant-atmosphere interface, and management components. Collectively, these components describe the time changes in the soil and plants that occur on a single unit in response to weather and management. Summary descriptions of management module are described in Table 8.

**Table 8 : Summary description of management module**

| | |
|---|---|
| Planting | Determines planting date based on read-in value or simulated using an input planting window and soil, weather conditions |
| Harvesting | Determines harvest date, based on maturity, read-in values or automatic applications based on soil water depletion |
| Irrigation | Determines daily irrigation, based on read-in values or automatic applications based on soil water depletion |
| Fertilizer | Determines fertilizer additions, based on read-in values or automatic conditions |
| Residue | Application of residue and other organic material as read-in or simulated in crop rotations |

**Model Calibration (2012-13) and Validation (2013-14)**

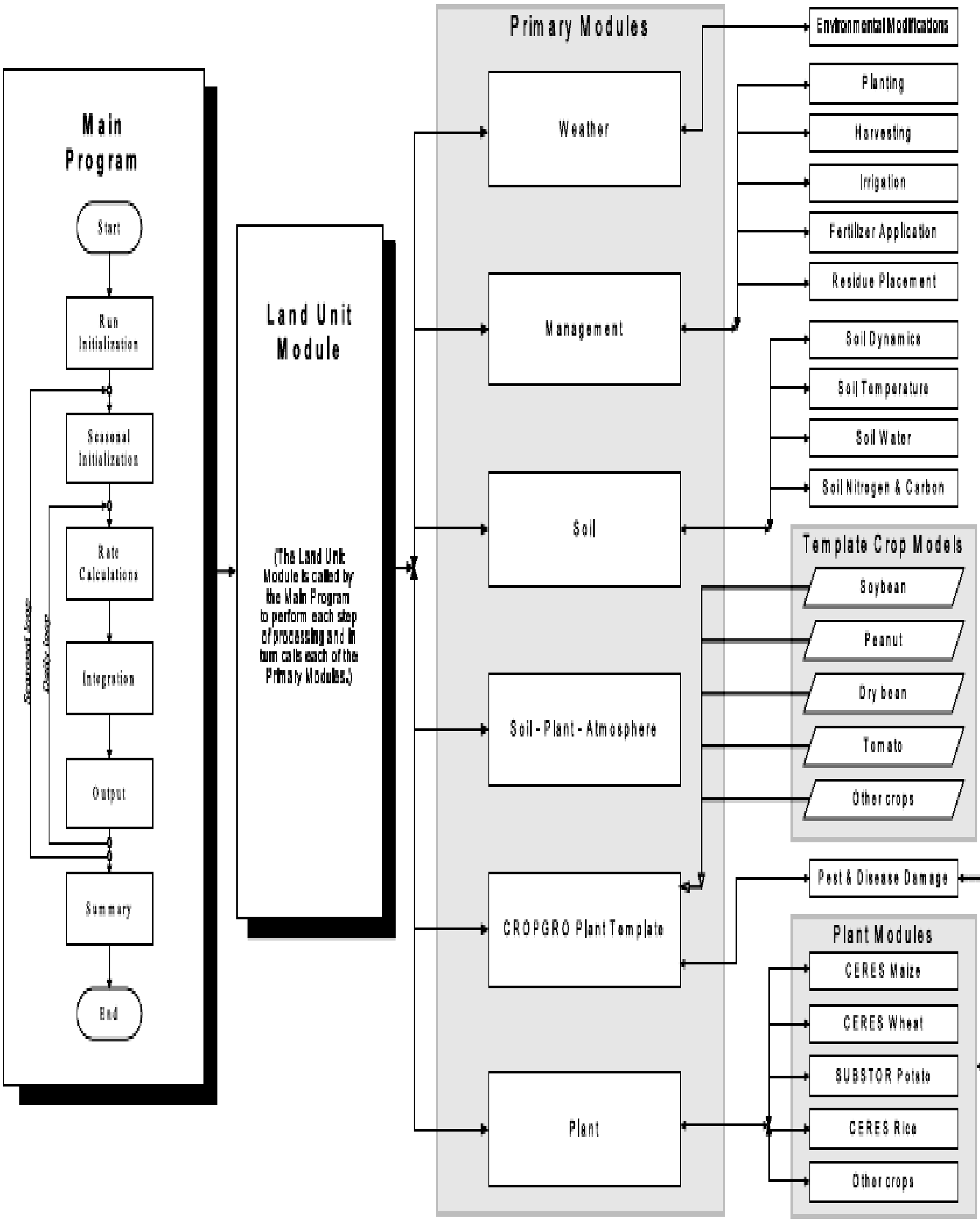



**Figure 4 : Overview of components and modular structure of CropSyst model (Stockle*et al.* 2003)**

CropSyst model was calibrated for two *kharif* season crops (clusterbean and groundnut) in 2012 and five *rabi* season crops (wheat, mustard, chickpea, cumin and isabgol) in 2012-13. After calibration of the model for 2012 and 2012-13, it was validated for the next year 2013 and 2013-14 for the site conditions using the crop model parameter values calibrated as mentioned years with associated water management. Soil characteristics, initial conditions of available soil water, nitrogen and organic matter and daily weather data were model input data for CropSyst as observed in the experiment. Model evaluation and validation was conventionally made by comparing simulation outputs with observed and simulated data. The CropSyst model was validated using the field experiment data conducted in 2012-13 growing season. It was validated for aboveground biomass (AGB), grain yield, N-uptake and green area index (GAI). The percent difference measures include the root mean square error (RMSE) and index of agreement (IoA). Taking into account difference in some physiological characteristics of crop varieties, validation for each crop was carried out variety wise. However here we give generalized statistical measures for separate crops.

**Statistical analysis (2012-13 and 2013-14)**

**Water balance**

The field water balance can be written as

$$P = E + T + R + D + S - I$$

Where, P is precipitation, E is soil evaporation, T is crop transpiration, R is surface runoff, D is drainage, S is change in soil water storage and I is irrigation.

**Water use efficiency**

Water use efficiency (WUE) was defined as

$$WUE = \frac{Y}{ET}$$

Where, WUE represents water use efficiency for the grain yield (kg/ha), Y is the grain yield and ET is the evapo-transpiration during the growth period.

**Root Mean Square Error**

Root mean square error is used to test the error between simulated and observed values. The expression of RMSE is

$$RMSE = \sqrt{\frac{\sum_{i=0}^{n}(Observedi - Simulatedi)^2}{n}}$$

**Correlation coefficient**

A measure that determines the degree to which two variable's movements are associated.

The correlation coefficient is calculated as:

$$R = \frac{\sum(o_i - \bar{o})(p_i - \bar{p})}{\sqrt{\sum(o_i - \bar{o})^2 \sum(p_i - \bar{p})^2}}$$

**Index of agreement**

The **index of agreement**s used to pondered percentage of the criteria to which the alternative is preferred to alternative and is calculated by

$$I = 1 - \frac{\sum(p_i - o_i)^2}{\sum(|p_i - \bar{o}| + |o_i - \bar{o}|)^2}$$

**Experimental results**

**Productivity**

Five *rabi* season crops (wheat, mustard, chickpea, Isabgol and Cumin) and two *kharif* season crops (Groundnut, clusterbean) were grown at study site (Bajju) in Bikaner district. The seed, straw and biomass yield of these crops are described as below

**Kharif crops**

Data presented in Table 9 shows that the seed, straw and biomass yield of groundnut was 2856, 4341 and 7197 and 2926, 4473 and 7399 kg ha$^{-1}$ during 2012 and 2013, respectively. Similarly clusterbean produced 1145, 3057 and 4202 kg ha$^{-1}$ seed, straw and biomass yield, respectively in 2012 and 1047, 2781 and 3828 kg ha$^{-1}$ respectively in 2013. The observed increase in seed, straw and biomass yield of groundnut to the tune of 149.4, 42.0 and 71.2 per cent in 2012 and in 2013 it was 179.4, 60.8 and 93.2 percent over clusterbean, respectively.

**Rabi crops**

A perusal of data in Table 9 shows that the seed, straw and biomass yield of wheat were higher amongst mustard, chickpea, cumin and Isabgol during 2012-13 and 2013-14. Amongst the *rabi* season crops wheat out yielded other crops and produced 69.4, 63.0, 463.9 and 434.6 per cent in 2012-13 and in 2013-14 63.8, 54.8, 452.2 and 398.1 per cent higher seed yields than mustard, chickpea, cumin and Isabgol respectively. With respect to total biomass productivity, wheat gave highest biomass yield followed by mustard, chick pea, cumin and isabgol.

**Table 9 Observed Economic and straw yield and aboveground biomass of different crops grown at Bajju, Bikaner**

| Crops | Seed yield (kg ha$^{-1}$) | | Straw yield (kg ha$^{-1}$) | | Aboveground biomass (kg ha$^{-1}$) | |
|---|---|---|---|---|---|---|
| | 2012-13 | 2013-14 | 2012-13 | 2013-14 | 2012-13 | 2013-14 |
| Clusterbean | 1145 | 1047 | 3057 | 2781 | 4202 | 3828 |
| Ground nut | 2856 | 2926 | 4341 | 4473 | 7197 | 7399 |
| Wheat | 2470 | 2772 | 3401 | 3827 | 5871 | 6599 |
| Mustard | 1458 | 1692 | 2977 | 3304 | 4435 | 4996 |
| Chick pea | 1515 | 1791 | 2089 | 2137 | 3604 | 3928 |
| Cumin | 438 | 502 | 685 | 901 | 1123 | 1403 |
| Isabgol | 462 | 556.5 | 623 | 838.5 | 1085 | 1395 |

**N-uptake**

There were five *rabi* season (wheat, mustard, chickpea, cumin and isabgol) and two *kharif* season crops (groundnut and clusterbean) grown at the experimental site of Bajju in Bikaner district. Data presented in Table 10 shows that groundnut and chickpea recorded highest N-uptake among *kharif* and *rabi* season crops during both the years. The observed increase in N-uptake of groundnut was 61.3 per cent and 65.1 per cent over clusterbean in *kharif* season crops of 2012 and 2013 respectively. Among the *rabi* season crops chickpea recorded higher N-uptake than other crops with a tune of 8.0, 17.5, 294.1 and 139.2 and 1.8, 11.1, 222.7 and 173.0 per cent higher N-uptake than wheat, mustard, cumin and isabgol respectively during 2012-13 and 2013-14. Cumin has lowest N- uptake 17 and 22 kg $ha^{-1}$.

**Table 10 Observed N-uptake of different crops grown at Bajju, Bikaner**

| Crops | N-uptake (kg $ha^{-1}$) | |
|---|---|---|
| | **2012-13** | **2013-14** |
| Clusterbean | 47.3 | 46.2 |
| Ground nut | 122.3 | 134.2 |
| Wheat | 62.0 | 69.7 |
| Mustard | 57.0 | 63.9 |
| Chick pea | 67.0 | 71.0 |
| Cumin | 17.0 | 22.0 |
| Isabgol | 28.0 | 26.0 |

**Economic analysis**

The economics of various crops including *kharif* and *rabi* are described below

**Kharif crops**

A perusal of data in Table 11 shows that the cost of cultivation of groundnut was ₹ 42523 and 39323 $ha^{-1}$, groundnut earned ₹ 165005 and 168665 $ha^{-1}$ as gross return and ₹ 122482 and 118842 $ha^{-1}$as net return respectively 2012 and 2013. The cultivation of groundnut has 3.9 and 4.3 B:C ratio in 2012 and 2013. However, the average cost of cultivation of clusterbean in 2012 and 2013 was ₹ 22233 and 21933 $ha^{-1}$ and earned ₹ 53443 and 48833 $ha^{-1}$ as gross return and ₹ 31210 and 26900 $ha^{-1}$ as net return with 2.4 and 2.2 B:C ratio respectively. The observed increase in net return of groundnut was 290.8 and 380.8 per cent over clusterbean during *kharif* season 2012 and 2013.

**Table 11 Economics of different crops grown at Bajju, Bikaner**

| Crops | Cost of cultivation (₹ ha$^{-1}$) | | Gross return (₹ ha$^{-1}$) | | Net return (₹ ha$^{-1}$) | | B:C ratio | |
|---|---|---|---|---|---|---|---|---|
| | **2012-13** | **2013-14** | **2012-13** | **2013-14** | **2012-13** | **2013-14** | **2012-13** | **2013-14** |
| Clusterbean | 22233 | 21933 | 53443 | 48833 | 31210 | 26900 | 2.4 | 2.2 |
| Ground nut | 42523 | 39323 | 165005 | 168665 | 121982 | 129342 | 3.9 | 4.3 |
| Wheat | 28076 | 26676 | 58995 | 66259 | 30920 | 39584 | 2.1 | 2.5 |
| Mustard | 19969 | 18569 | 58503 | 67440 | 38534 | 48871 | 2.9 | 3.6 |
| Chick pea | 22714 | 23460 | 80973 | 94893 | 58259 | 71433 | 3.6 | 4.0 |
| Cumin | 21597 | 19357 | 53930 | 62042 | 32333 | 42685 | 2.5 | 3.2 |
| Isabgol | 23053 | 21653 | 207760 | 267870 | 184707 | 246217 | 9.0 | 12.4 |

**Rabi crops**

A critical examination of data in Table 11 shows that the highest cost of cultivation (₹ 28076 and 26676 $ha^{-1}$) was recorded in wheat followed by isabgol and chickpea during both the years. Isabgol gave maximum gross return of ₹ 207760 and 267870 and net return of 184707 and 246217 $ha^{-1}$ with 9.0 and 12.4 B:C ratio, respectively in 2012-13 and 2013-14. However, cumin recorded lowest gross return (₹ 53930 and 62042 $ha^{-1}$) during both the years. The observed increase in net return of isabgol was 217.0, 379.3, 471.2 and 497.3 and 244.6, 403.8, 476.8 and 522.0 per cent over chickpea, mustard, cumin and wheat, respectively during both the years.

**Water balance**

Soil water balance components for different crops are presented in Table 12 Water used in different crops varied from 289.2 to 728.9 mm and 188.0 to 619.6 mm, respectively in 2012-13 and 2013-14. The highest water was used by groundnut (728.9 and 619.6 mm) and lowest water was used by chickpea (289.2 and 188.0 mm) in 2012-13 and 2013-14. ET losses in different crops range from 84.5 to 664.9 and 90.5 to 530.5 mm, respectively in 2012-13 and 2013-14. The highest ET loss observed in groundnut (664.9 and 530.5) followed by wheat (264.1and 330.6), clusterbean (205.6 and 183.7), mustard (168.5 and 174.7), chickpea (154.4 and 121.8), cumin (92.6 and 92.4) and isabgol (84.5 and 90.5), respectively in 2012-13 and 2013-14. The deep drainage varied from 13.7 mm to 189.4 mm in 2012-13 and 15.2 mm to 152.0 mm in 2013-14, being highest in Isabgol. The ET consisted 23.9 to 91.2 % and 28.9 to 85.6 % share in total water applied respectively in 2012-13 and 2013-14 (Fig 5 and 6).The deep drainage constituted 1.8 % to 53.5 % in 2012-13 and 5.7% to 48.5 % in 2013-14 of total water applied, and its value was highest for Isabgol.

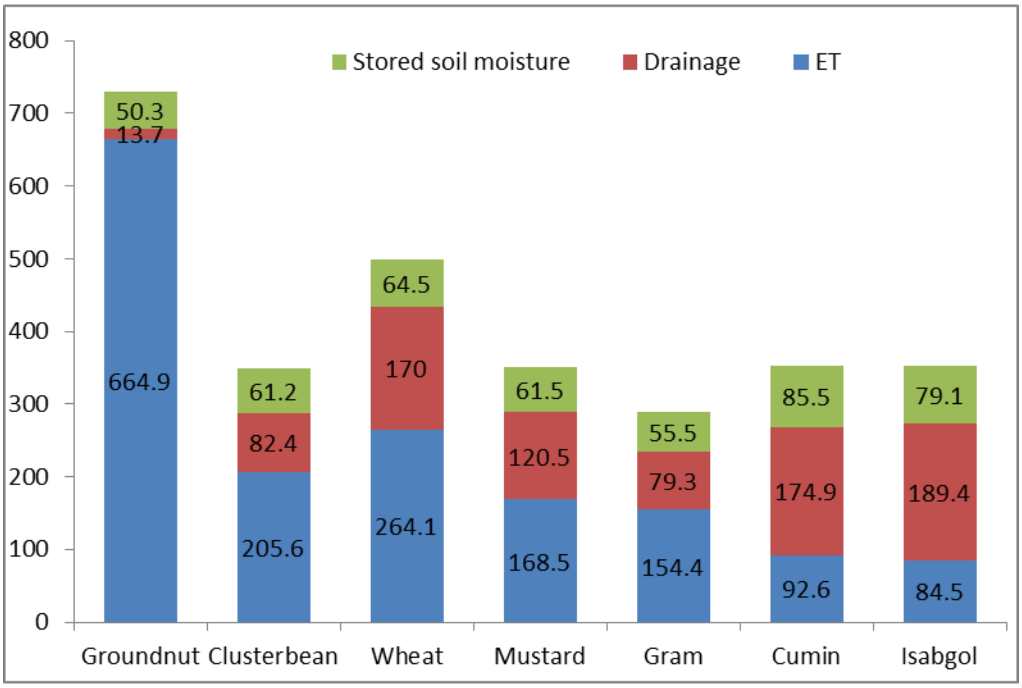



**Fig 5 Soil water balance components for different crops (2012-13)**

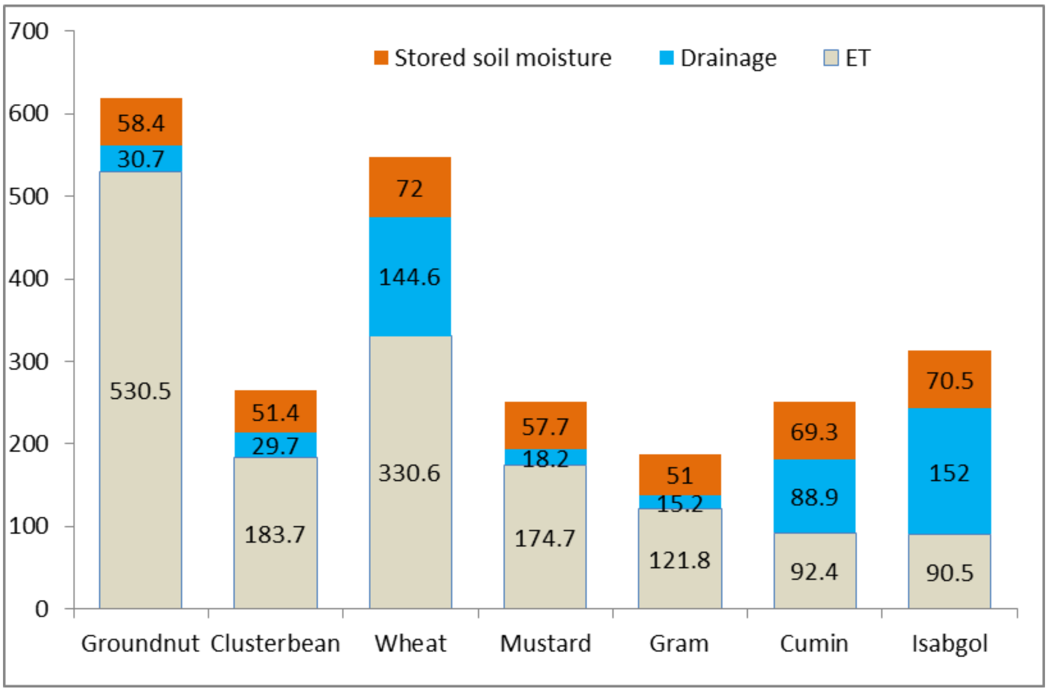



**Fig 6 Soil water balance components for different crops (2013-14)**

**Table 12 Soil water balance components for different crops grown at Bajju, Bikaner during 2012-13 and 2013-14**

| Component | Groundnut | | Clusterbean | | Wheat | | Mustard | | Gram | | Cumin | | Isabgol | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2012-13 | 2013-14 | 2012-13 | 2013-14 | 2012-13 | 2013-14 | 2012-13 | 2013-14 | 2012-13 | 2013-14 | 2012-13 | 2013-14 | 2012-13 | 2013-14 |
| **Inputs (mm)** | | | | | | | | | | | | | | |
| Irrigation (I) | 520.0 | 416 | 187.2 | 124.8 | 478.4 | 540.8 | 332.8 | 249.6 | 270.4 | 187 | 332.8 | 249.6 | 332.8 | 312 |
| Rainfall (R) | 208.9 | 203.6 | 162 | 140 | 20.2 | 6.4 | 17.7 | 1 | 18.8 | 1 | 20.2 | 1 | 20.2 | 1 |
| Total (I + R) | 728.9 | 619.6 | 349.2 | 264.8 | 498.6 | 547.2 | 350.5 | 250.6 | 289.2 | 188 | 353 | 250.6 | 353 | 313 |
| **Losses(mm)** | | | | | | | | | | | | | | |
| ET | 664.9 | 530.5 | 205.6 | 183.7 | 264.1 | 330.6 | 168.5 | 174.7 | 154.4 | 121.8 | 92.6 | 92.4 | 84.5 | 90.5 |
| Drainage (D) | 13.7 | 30.7 | 82.4 | 29.7 | 170 | 144.6 | 120.5 | 18.2 | 79.3 | 15.2 | 174.9 | 88.9 | 189.4 | 152 |
| Stored soil moisture (S) | 50.3 | 58.4 | 61.2 | 51.4 | 64.5 | 72 | 61.5 | 57.7 | 55.5 | 51 | 85.5 | 69.3 | 79.1 | 70.5 |

**Yield of cropping system**

A perusal of data in Table 13 and Fig 7 and 8 revealed that in different cropping system the seed and biomass yield varied from 2660 to 5326 and 7806 to 13168 during 2012-13 and 2838 to 5498 and 7756 to 13698 kg ha$^{-1}$ during 2013-14. Groundnut-wheat cropping system recorded highest seed (5326 and 5498 kgha$^{-1}$) and biomass yield (13168 and 13698 kg ha$^{-1}$) over rest of the systems followed by groundnut-mustard whereas clusterbean–chickpea recorded lowest seed (2660 and 2838 kg ha$^{-1}$) and biomass yield (7806 and 7756 kg ha$^{-1}$) respectively during 2012-13 and 2013-14. Groundnut-wheat cropping system had 61.7 and 66.2, 60.5 and 63.5, 23.5 and 23.3 and 100.2 and 100.7 percent higher seed and 57.1 and 59.0, 57.8 and 59.2, 12.3 and 12.9 and 67.4 and 80.4 percent higher biomass yield over groundnut–cumin, groundnut–isabgol, groundnut-mustard and clusterbean-chickpea respectively in 2012-13 and 2013-14.

**Table 13 Seed and Biomass yield of different cropping system grown at Bajju, Bikaner**

| Cropping system | Seed Yield (kg ha$^{-1}$) | | Biomass yield (kg ha$^{-1}$) | |
|---|---|---|---|---|
| | **2012-13** | **2013-14** | **2012-13** | **2013-14** |
| Groundnut – Wheat | 5326 | 5698 | 13068 | 13998 |
| Groundnut – Cumin | 3294 | 3428 | 8320 | 8802 |
| Groundnut - Isabgol | 3318 | 3483 | 8282 | 8794 |
| Groundnut - Mustard | 4314 | 4618 | 11632 | 12395 |
| Clusterbean – Chickpea | 2660 | 2838 | 7806 | 7756 |

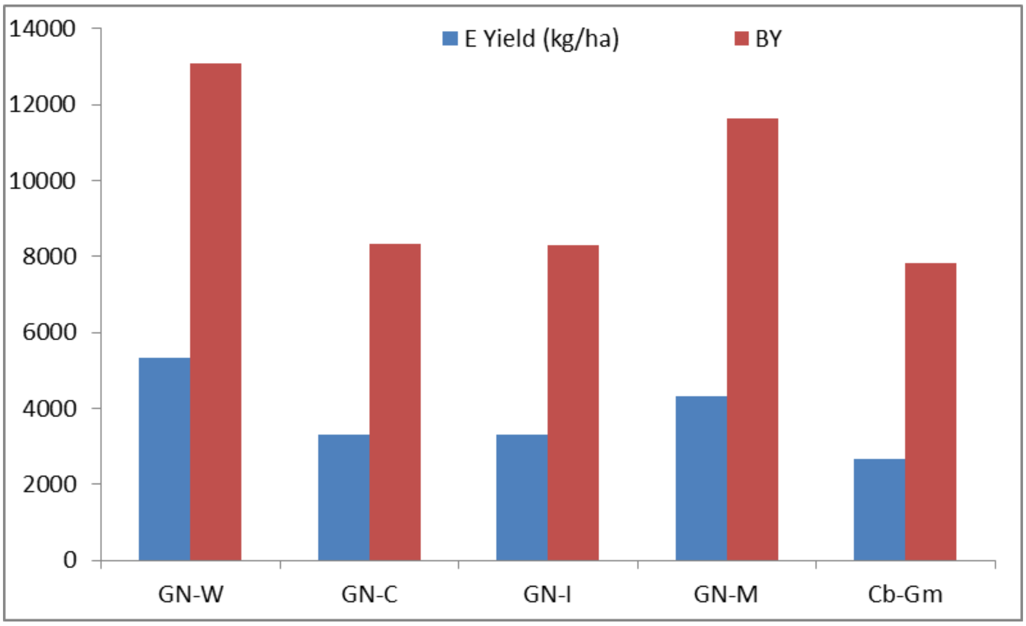



**Fig 7 Seed and Biomass yield of different cropping system grown at Bajju, Bikaner (2012-13)**

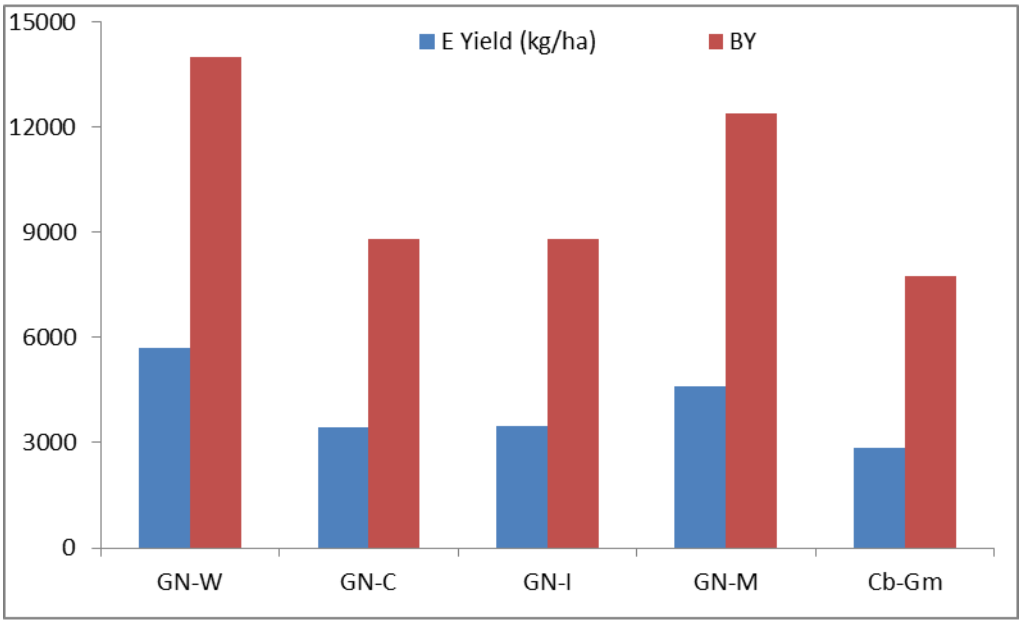



**Fig 8 Seed and Biomass yield of different cropping system grown at Bajju, Bikaner (2013-14)**

**Economics of cropping system**

Data presented in (table 14 and fig. 9 and 10) revealed that the cost of cultivation, gross and net return of different cropping system ranged from ₹44947 to 70599, 134415 to 372765 and 89468 to 307189 during 2012-13 while 45393 to 65999, 143725 to 462035 and 98332 to 365059, respectively in 2013-14. Groundnut-wheat cropping system recorded highest cost of cultivation (₹70599 and 65999 $ha^{-1}$) followed by groundnut-isabgol while groundnut-isabgol recorded maximum gross return (₹372765 and 436535 $ha^{-1}$), net return (₹306689 and 375559 $ha^{-1}$) with B:C ratio of 5.7 and 7.2, respectively during 2012-13 and 2013-14. Whereas clusterbean-chickpea cropping system recorded lowest cost of cultivation, gross and net return. Groundnut-isabgol cropping system had 100.6 and 122.3, 98.7 and 118.3, 91.0 and 110.7 and 242.7 and 281.9 percent higher net returns over groundnut-wheat, groundnut–cumin, groundnut-mustard and clusterbean-chickpea, respectively in 2012-13 and 2013-14.

**Water use efficiency of cropping system**

It is evident from the data in Table 15 and Fig 11 to 14 showed that water use efficiency varied from 7.7 to 12.2 and 9.4 to 17.1 kg $ha^{-1}$ mm of biological yield and 3.0 to 4.3 and 3.7 to 6.3 kg $ha^{-1}$ mm of seed yield during 2012-13 and 2013-14. while 182.5 to 344.5 and 201.3 to 468.1 ₹/ha mm of gross return and 117.0 to 263.7 and 135.8 to 391.4 ₹/ha mm of net return in terms of water applied in different cropping system, respectively in 2012-13 and 2013-14. Clusterbean-chickpea cropping system recorded highest WUE in biological yield (12.2 and 17.1 kg $ha^{-1}$mm) and seed yield (4.2 and 6.3 kg $ha^{-1}$ mm) followed by groundnut-mustard, respectively in 2012-13 and 2013-14. Data further revealed that WUE varied from 11.1 to 21.7 and 14.1 to 25.4 kg $ha^{-1n}$ mm of biological yield and 4.3 to 7.4 and 5.5 to 9.3 kg $ha^{-1}$ mm of seed yield and 241.1 to 497.4 and 272.8 to 703.0 and 164.6 to 409.2 and 196.2 **to**

**Table 14 Economics of different cropping system grown at Bajju, Bikaner**

| Cropping system | Cost of cultivation (₹ ha$^{-1}$) | | Gross return (₹ ha$^{-1}$) | | Net return (₹ ha$^{-1}$) | | B:C Ratio | |
|---|---|---|---|---|---|---|---|---|
| | 2012-13 | 2013-14 | 2012-13 | 2013-14 | 2012-13 | 2013-14 | 2012-13 | 2013-14 |
| Groundnut - Wheat | 70599 | 65999 | 224000 | 234924 | 152901 | 168925 | 3.2 | 3.6 |
| Groundnut - Cumin | 64120 | 58680 | 218935 | 230707 | 154315 | 172027 | 3.4 | 3.9 |
| Groundnut - Isabgol | 65576 | 60976 | 372765 | 436535 | 306689 | 375559 | 5.7 | 7.2 |
| Groundnut - Mustard | 62492 | 57892 | 223508 | 236105 | 160516 | 178213 | 3.6 | 4.1 |
| Clusterbean-Chickpea | 44947 | 45393 | 134415 | 143725 | 89468 | 98332 | 3.0 | 3.2 |

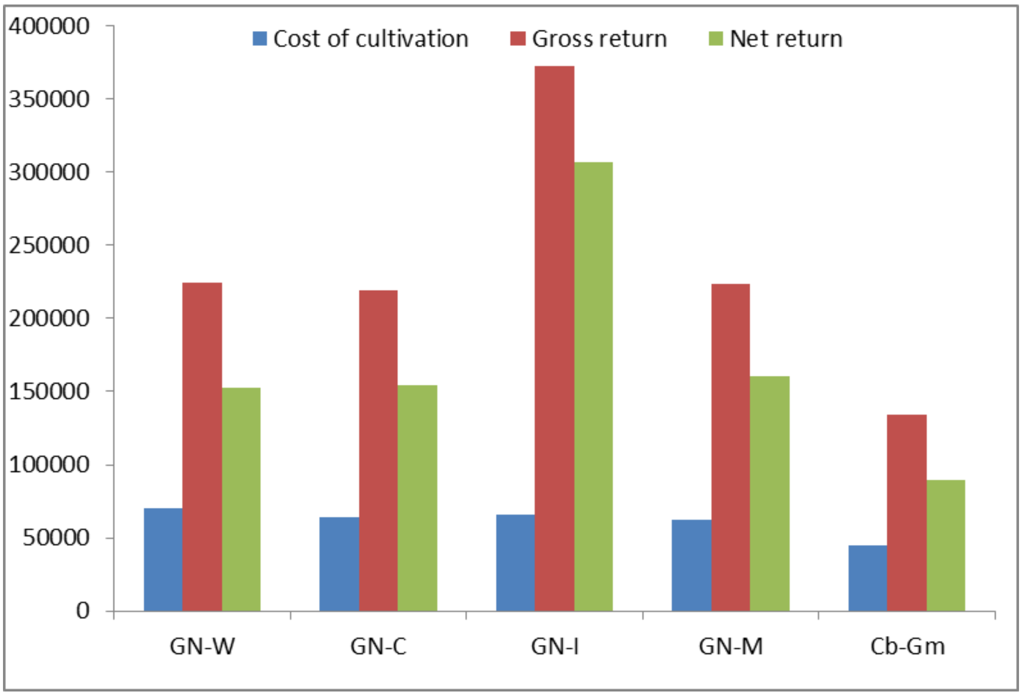



**Fig 9 Economics of different cropping system grown at Bajju, Bikaner (2012-13)**

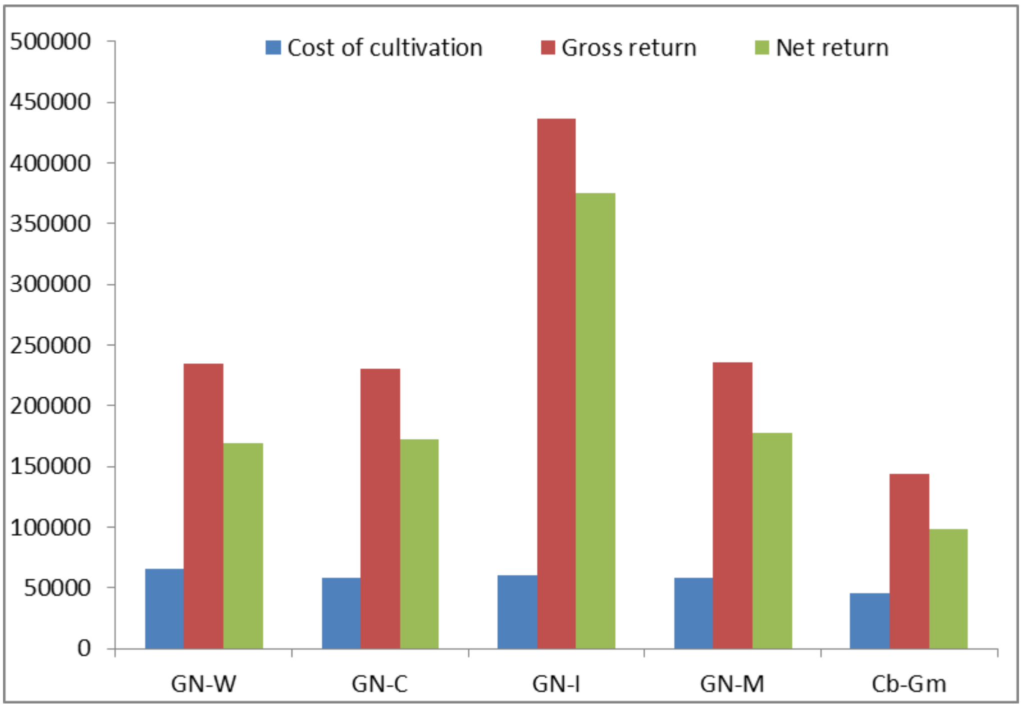
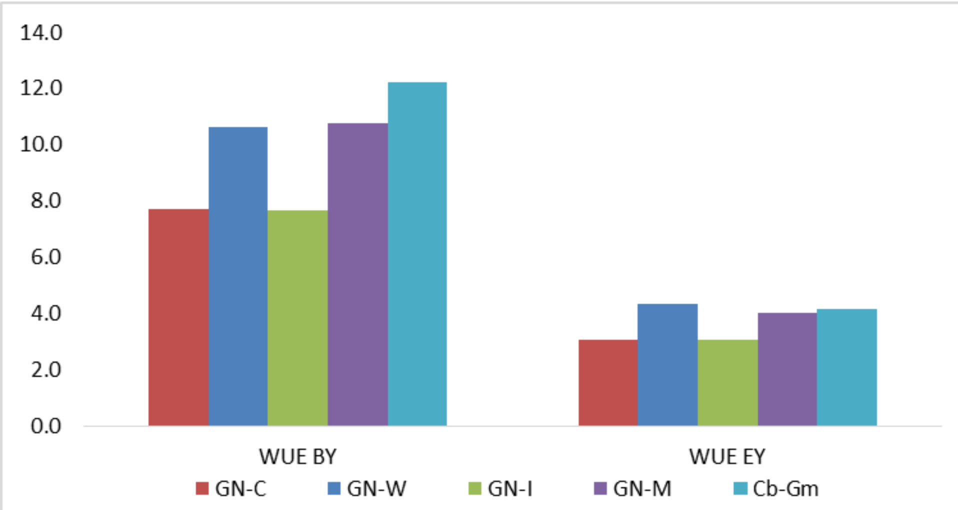



**Fig 10 Economics of different cropping system grown at Bajju, Bikaner (2013-14)**

604.8 of monetary returns in terms of water used ($WUE_{ET}$) in different cropping system, respectively in 2012- 13 and 2013-14. Clusterbean-chickpea cropping system recorded highest $WUE_{ET}$ in biological yield (21.7 and 25.4 kg $ha^{-1}$ mm) and in seed yield (7.4 and 9.3 kg $ha^{-1}$ mm) whereas groundnut-cumin recorded lowest $WUE_{ET}$ in biological and seed yield respectively in 2012-13 and 2013-14. However, during both years groundnut-isabgol cropping system produces highest WUE and $WUE_{ET}$ in terms of monetary returns both in gross and net returns while lowest was observed in groundnut-wheat cropping system.



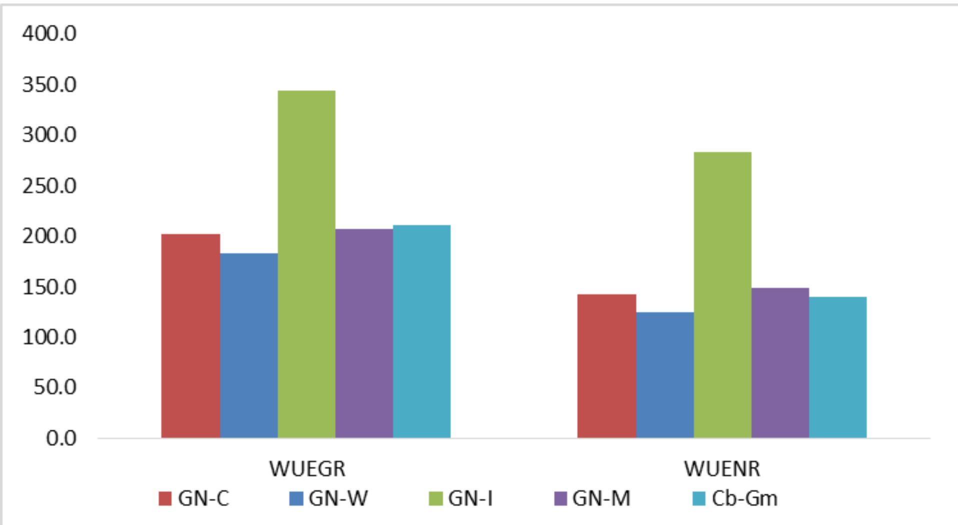
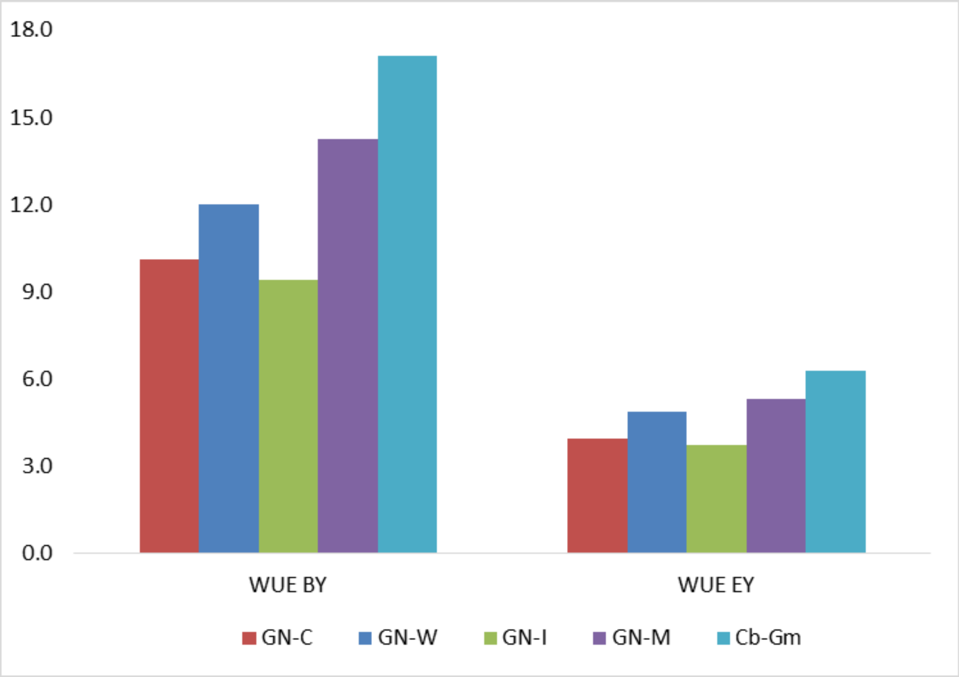




**Fig 11 Water use efficiency (in term of water applied) 2012-13**



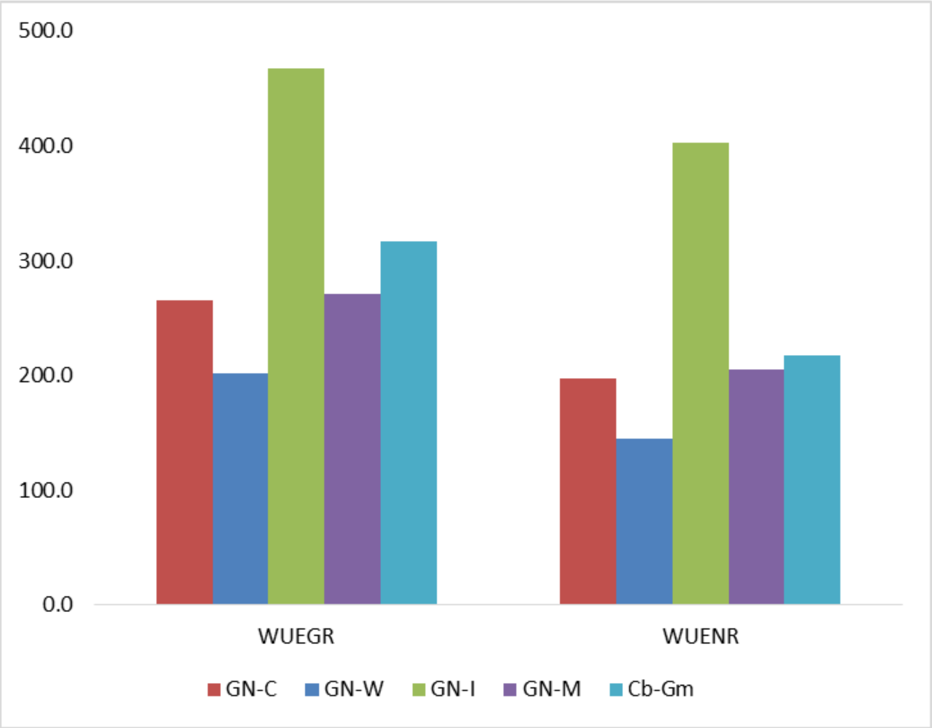
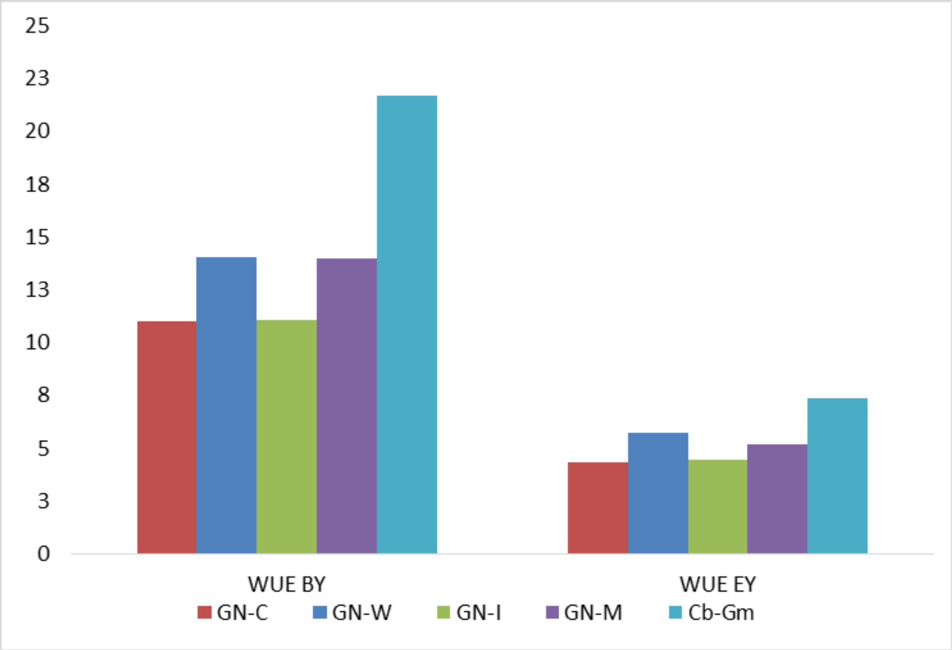




**Fig 12 Water use efficiency (in term of water applied) 2013-14**

**Table 15 Water use efficiency of different cropping system grown at Bajju, Bikaner during 2012-13 and 2013-14**

| Cropping system | Yield (kg ha-1 mm) | | | | Monetary return (₹ /ha mm) | | | |
|---|---|---|---|---|---|---|---|---|
| | Biological Yield | | Seed Yield | | Gross Return | | Net Return | |
| | 2012-13 | 2013-14 | 2012-13 | 2013-14 | 2012-13 | 2013-14 | 2012-13 | 2013-14 |
| **Water Use Efficiency (in terms of water applied)** | | | | | | | | |
| Groundnut - Wheat | 10.6 | 12.0 | 4.3 | 4.9 | 182.5 | 201.3 | 124.6 | 144.8 |
| Groundnut - Cumin | 7.7 | 10.1 | 3.0 | 3.9 | 202.4 | 265.1 | 142.6 | 197.7 |
| Groundnut - Isabgol | 7.7 | 9.4 | 3.1 | 3.7 | 344.5 | 468.1 | 283.5 | 402.7 |
| Groundnut - Mustard | 10.8 | 14.1 | 4.0 | 5.3 | 207.1 | 271.3 | 148.7 | 204.8 |
| Clusterbean – Chickpea | 12.2 | 17.1 | 4.2 | 6.3 | 210.5 | 317.4 | 140.1 | 217.2 |
| **Water Use Efficiency (In terms of water used) $WUE_{ET}$** | | | | | | | | |
| Groundnut - Wheat | 14.1 | 16.3 | 5.7 | 6.6 | 241.1 | 272.8 | 164.6 | 196.2 |
| Groundnut - Cumin | 11.0 | 14.1 | 4.3 | 5.5 | 289.0 | 370.4 | 203.7 | 276.2 |
| Groundnut - Isabgol | 11.1 | 14.2 | 4.4 | 5.6 | 497.4 | 703.0 | 409.2 | 604.8 |
| Groundnut - Mustard | 14.0 | 17.6 | 5.2 | 6.5 | 268.2 | 334.8 | 192.6 | 252.7 |
| Clusterbean – Chickpea | 21.7 | 25.4 | 7.4 | 9.3 | 373.4 | 470.5 | 248.5 | 321.9 |



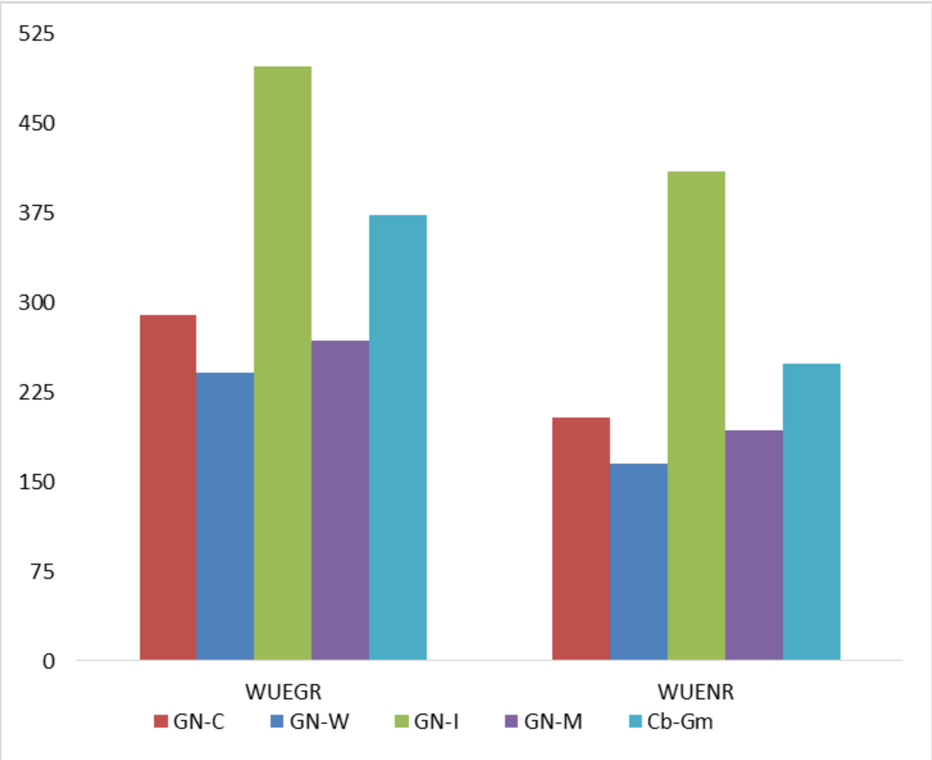
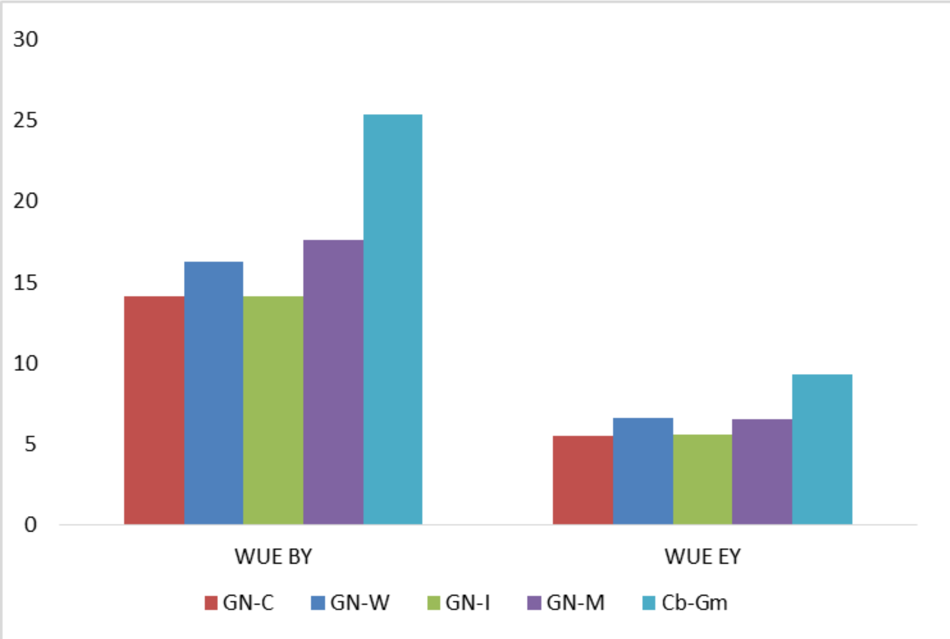




**Fig 13 Water use efficiency (in term of water used) $WUE_{ET}$ 2012-13**



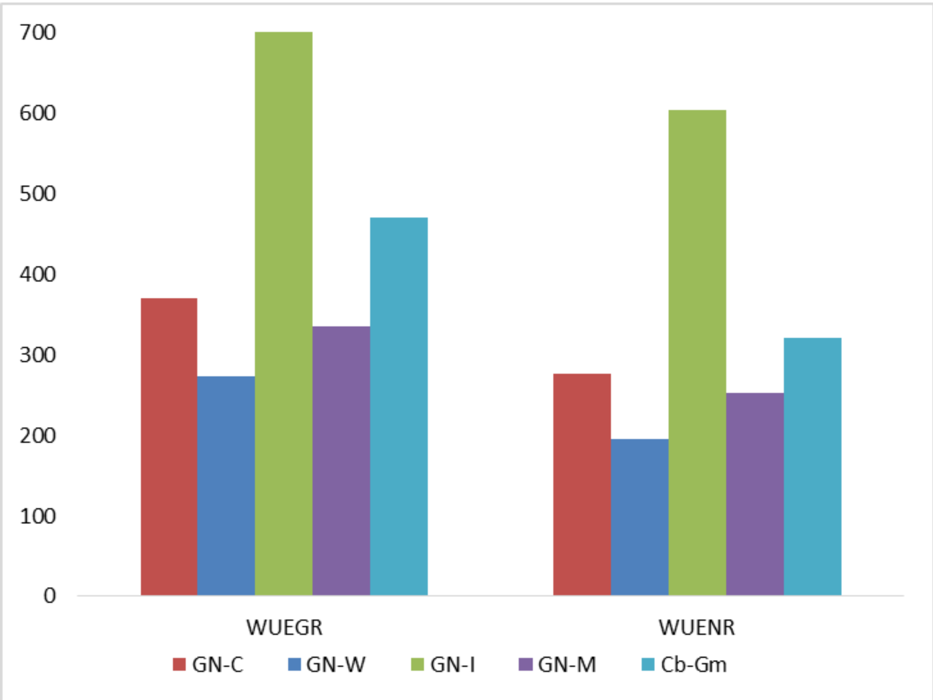




**Fig 14 Water use efficiency (in term of water used) WUE $_{ET}$**
**2013-14**

**Model Calibration (2012-13)**

CropSyst model was calibrated for five *rabi* season crops (wheat, mustard, chickpea, cumin and isabgol) and two *kharif* season crops (groundnut and cluster bean). Various model parameters related to crop transpiration, canopy growth were kept at model default values and other model parameters were modified during the calibration process to improve the model prediction accuracy. For the parameters that could be fixed, a range of realistic values was determined, based on experimental data and literature. During calibration, latter parameters were adjusted by running the model with various combinations of values within these realistic ranges. The measured aboveground biomass (AGB), grain yield, N-uptake, green area index (GAI) and soil moisture were compared with the simulated values.

**Calibration for clusterbean**

For calibration of clusterbean, data from the seed yield, above ground biomass (AGB) and N-uptake were used to determine the best crop parameters.

**Seed yield**

The seed yield was simulated with CropSyst model by inputting the observed data on duration of different phenol-phases during the experiment under field conditions. Table 16 showed that the simulate yield (1148 kg $ha^{-1}$) of clusterbean were match well to the observed yield of 1145 kg $ha^{-1}$. The absolute and relative error was 3.0 and 0.3, respectively during 2012-13.

**Aboveground biomass**

Simulations of aboveground biomass development of clusterbean match with the field data. The observed aboveground biomass (4202 kg $ha^{-1}$) was lower than simulated aboveground biomass (4273 kg $ha^{-1}$) as shown in Table 16. The absolute and relative error was 71 and 1.7, respectively during 2012-13.

**Table 16 Quantitative measures of model performance for yield, AGB and N-uptake of clusterbean (2012-13)**

| Particular | Observed | Simulated | AE | RE |
|---|---|---|---|---|
| Seed yield | 1145 | 1148 | 3 | 0.3 |
| AGB | 4202 | 4273 | 71 | 1.7 |
| N-uptake | 47.3 | 40.2 | 7.1 | 15.0 |

**N-uptake**

Simulations of N-uptake of clusterbean slightly matched with the field data. The simulated N-uptake (40.2 kg $ha^{-1}$) was lower than observed N-uptake (47.3 kg $ha^{-1}$) with absolute and relative error of 7.1 and 15.0, respectively (Table 16) during 2012-13.

**Calibration for groundnut**

For calibration of groundnut data from the grain yield, above ground biomass (AGB) and N-uptake were used to determine the best crop parameters.

**Seed yield**

The seed yield was simulated with CropSyst model by inputting the observed data on duration of different phenol-phases during the experiment under field conditions. Table 17 showed that the simulate yield (2942 kg $ha^{-1}$) of groundnut were agreed to the observed yield of 2856 kg $ha^{-1}$ during 2012-13. The absolute and relative error was 86 and 3.0.

**Table 17 Quantitative measures of model performance for yield, AGB and N-uptake of groundnut (2012-13)**

| Particular | Observed | Simulated | AE | RE |
|---|---|---|---|---|
| Seed yield | 2856 | 2942 | 86 | 3.0 |
| AGB | 7197 | 7356 | 159 | 2.2 |
| N-uptake | 122.3 | 108.3 | 14 | 11.4 |

**Aboveground biomass**

Simulations of aboveground biomass of groundnut slightly match with the field data. The observed aboveground biomass (7187 kg $ha^{-1}$) was lower than simulated (7356 kg $ha^{-1}$) as shown in table 17. The absolute and relative error was 159 and 2.2, respectively during 2012-13.

**N-uptake**

Simulations of N-uptake slightly matched with the field data. The simulated N-uptake (108.3 kg $ha^{-1}$) was lower than observed N-uptake (122.3 kg $ha^{-1}$) as shown in table 17. The absolute and relative error was 14 and 11.4, respectively during 2012-13.

**Calibration for wheat**

For calibration of wheat data from the grain yield, above ground biomass (AGB), N-uptake and moisture content were used to determine the best crop parameters.

**Seed yield**

The seed yield was simulated with CropSyst model by inputting the observed data on duration of different phenol-phases during the experiment under field conditions. Table 18 showed that the simulate yield (2047 kg $ha^{-1}$) of wheat were differ to the observed yield of 2470 kg $ha^{-1}$. The absolute and relative error was 423 and 17.1, respectively during 2012-13.

**Table 18 Quantitative measures of model performance for yield, AGB and N-uptake of wheat (2012-13)**

| Particular | Observed | Simulated | AE | RE |
|---|---|---|---|---|
| Seed yield | 2470 | 2047 | 423 | 17.1 |
| AGB | 5871 | 5111 | 760 | 12.9 |
| N-uptake | 62.0 | 61.1 | 0.9 | 1.5 |

**Aboveground biomass**

Simulations of aboveground biomass development of wheat differ with the field data. The observed aboveground biomass (5871 kg $ha^{-1}$) was higher than simulated aboveground biomass (5111 kg $ha^{-1}$) as shown in table 18. The absolute and relative error was 760 and 1.5, respectively during 2012-13.

**N-uptake**

Simulations of N-uptake slightly matched with the field data. The simulated N-uptake (61.1 kg $ha^{-1}$) was lower than observed N-uptake (62.0 kg $ha^{-1}$). The absolute and relative error was 0.9 and 1.5, respectively (Table 18) during 2012-13.

**Moisture content**

Data presented in table 19 shows the RMSE, RRMSE, correlation coefficient and index of agreement values of moisture content of wheat during 2012-13. The RMSE of moisture content ranged from 0.0301 to 0.0436. These small values reveal that soil water flow was well simulated by CropSyst at different layers. As no systematic under or over estimation of moisture content was observed, the differences between the observed and simulated moisture content are contributed to the spatial heterogeneity and observation errors, which are inevitable under field conditions.Simulated value of moisture content predict well with observed values in the upper layers up to 80 cm. The index of agreement was 0.87 in top soil layer of 50 cm (Fig 15).

**Table 19 Quantitative measures of model performance for soil moisture under wheat (2012-13)**

| Soil layer, cm | RMSE | RRMSE | Correlation coefficient | Index of agreement |
|---|---|---|---|---|
| 0-100 | 0.0400 | 24 | 0.748 | 0.84 |
| 0-10 | 0.0301 | 28 | 0.836 | 0.91 |
| 10-20 | 0.0401 | 24 | 0.713 | 0.83 |
| 20-30 | 0.0425 | 25 | 0.696 | 0.82 |
| 30-40 | 0.0424 | 24 | 0.706 | 0.82 |
| 40-50 | 0.0423 | 24 | 0.712 | 0.82 |
| 50-60 | 0.0436 | 24 | 0.697 | 0.81 |
| 60-70 | 0.0403 | 23 | 0.740 | 0.82 |
| 70-80 | 0.0395 | 22 | 0.751 | 0.81 |
| 80-90 | 0.0390 | 23 | 0.681 | 0.75 |
| 90-100 | 0.0383 | 22 | 0.581 | 0.66 |

**Calibration for Mustard**

For calibration of mustard data from the grain yield, above ground biomass (AGB), N-uptake and moisture content were used to determine the best crop parameters.

**Seed yield**

The seed yield was simulated with CropSyst model by inputting the observed data on duration of different phenol-phases during the experiment under field conditions. Table 20 showed that the simulate yield (1385 kg $ha^{-1}$) of mustard were agreed to the observed yield of 1458 kg $ha^{-1}$. The absolute and relative error was 73 and 5.0 during 2012-13.

**Table 20 Quantitative measures of model performance for yield, AGB and N-uptake of mustard (2012-13)**

| Particular | Observed | Simulated | AE | RE |
|---|---|---|---|---|
| Seed yield | 1458 | 1385 | 73 | 5.0 |
| AGB | 4435 | 4198 | 237 | 5.3 |
| N-uptake | 57.2 | 48.2 | 9 | 15.7 |

**Aboveground biomass**

Simulations of aboveground biomass development of mustard differ with the field data. The observed aboveground biomass (4435 kg $ha^{-1}$) was higher than simulated aboveground biomass (4198 kg $ha^{-1}$) as shown in table 20. The absolute and relative error was 237 and 5.3, respectively during 2012-13.

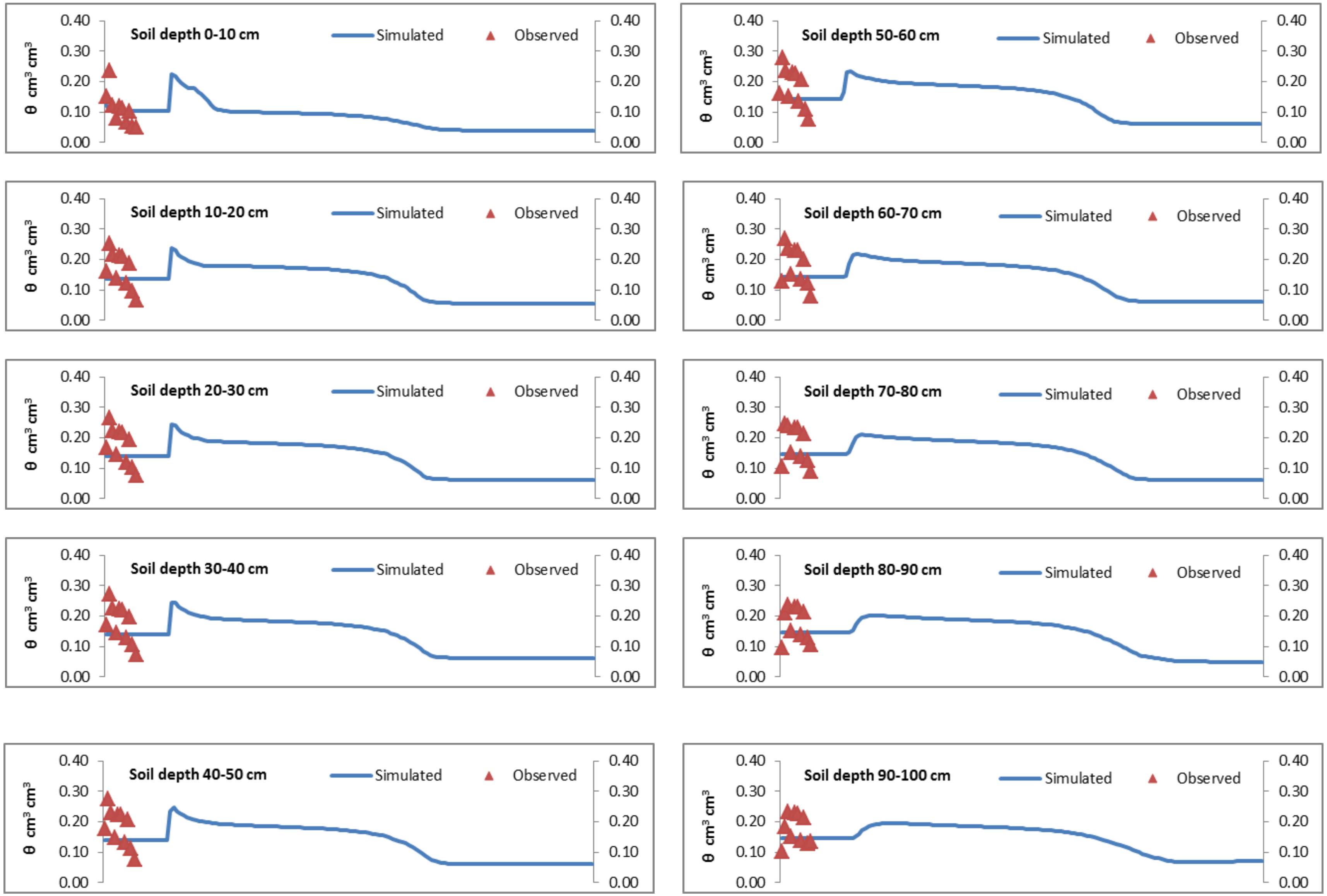



**Figure 15 Observed and simulated soil water content under wheat**

**N-uptake**

Simulations of N-uptake slightly matched with the field data. The simulated N-uptake (48.2 kg $ha^{-1}$) was lower than observed N-uptake (57.2 kg $ha^{-1}$) as shown in table 20. The absolute and relative error was 9 and 15.7, respectively during 2012-13.

**Moisture content**

Data in table 21 shows the value of RMSE of moisture content ranged from 0.0384 to 0.0501. These values reveal that soil water flow was well simulated by CropSyst model during 2012-13. Simulated value of moisture content predict well with observed values in 0-100 cm with 0.0454, 35, 0.96 and 0.81 of RMSE, RRMSE, correlation and index of agreement, respectively (Fig 16).

**Table 21 Quantitative measures of model performance for soil moisture under Mustard (2012-13)**

| Soil layer, cm | RMSE | RRMSE | Correlation coefficient | Index of agreement |
|---|---|---|---|---|
| 0-100 | 0.0454 | 35 | 0.965 | 0.81 |
| 0-10 | 0.0384 | 34 | 0.977 | 0.84 |
| 10-20 | 0.0402 | 34 | 0.974 | 0.85 |
| 20-30 | 0.0430 | 32 | 0.978 | 0.85 |
| 30-40 | 0.0432 | 34 | 0.978 | 0.85 |
| 40-50 | 0.0464 | 36 | 0.973 | 0.83 |
| 50-60 | 0.0482 | 36 | 0.977 | 0.82 |
| 60-70 | 0.0473 | 35 | 0.977 | 0.80 |
| 70-80 | 0.0468 | 34 | 0.959 | 0.76 |
| 80-90 | 0.0490 | 37 | 0.924 | 0.67 |
| 90-100 | 0.0501 | 38 | 0.911 | 0.63 |

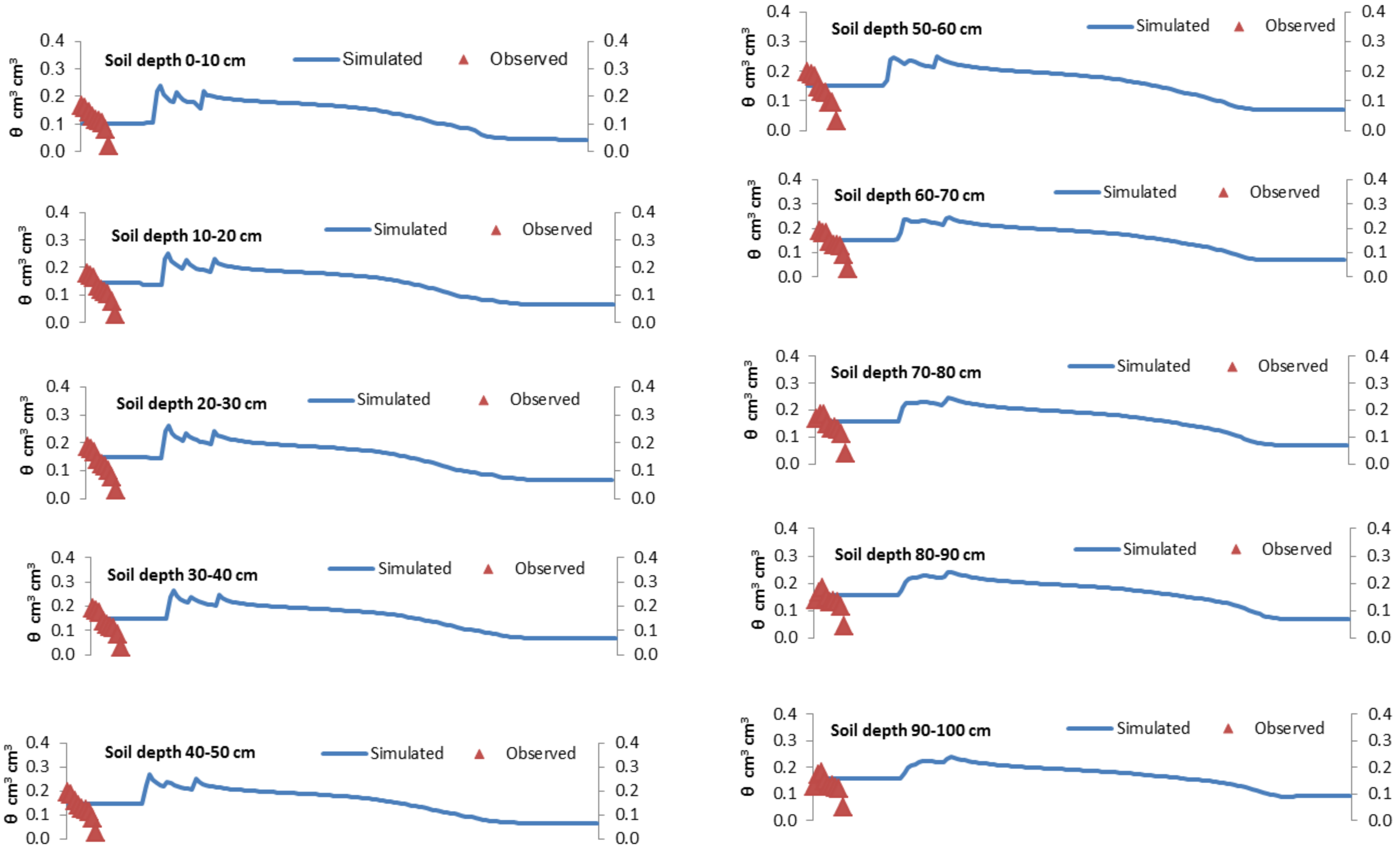



**Figure 16 Observed and simulated soil water content under mustard**

**Calibration for chickpea**

For calibration of chickpea data from the grain yield, above ground biomass (AGB), N-uptake and moisture content were used to determine the best crop parameters.

**Seed yield**

The seed yield was simulated with CropSyst model by inputting the observed data on duration of different phenol-phases during the experiment under field conditions. Table 22 showed that the simulate yield (1473 kg $ha^{-1}$) of chickpea were agreed to the observed yield of 1515 kg $ha^{-1}$ with absolute and relative error of 42 and 2.8 during 2012-13.

**Table 22 Quantitative measures of model performance for yield, AGB and N-uptake of chickpea (2012-13)**

| Particular | Observed | Simulated | AE | RE |
|---|---|---|---|---|
| Seed yield | 1515 | 1473 | 42 | 2.8 |
| AGB | 3604 | 3690 | 86 | 2.4 |
| N-uptake | 66.8 | 62.0 | 4.8 | 7.2 |

**Aboveground biomass**

Simulations of aboveground biomass development of chickpea well match with the field data. The observed aboveground biomass (3604 kg $ha^{-1}$) was slightly lower than simulated aboveground biomass (3690 kg $ha^{-1}$) as shown in table 22. The absolute and relative error was 86 and 2.4, respectively during 2012-13.

**N-uptake**

Simulations of N-uptake slightly matched with the field data. The simulated N-uptake (62.0 kg $ha^{-1}$) was lower than observed N-uptake (66.8 kg $ha^{-1}$) as shown in table 22. The absolute and relative error was 4.8 and 7.2, respectively during 2012-13.

**Moisture content**

Data in table 23 shows the value of RMSE of moisture content ranged from 0.0117 to 0.0216. These values reveal that soil water flow was well simulated by CropSyst model. Simulated value of moisture content predict well with observed values in 0-100 cm with 0.0184, 16, 0.96 and 0.95 of RMSE, RRMSE, correlation and index of agreement, respectively (Fig 17) during 2012-13.

**Table 23 Quantitative measures of model performance for soil moisture under chickpea (2012-13)**

| Soil layer, cm | RMSE | RRMSE | Correlation | Index of agreement |
|---|---|---|---|---|
| 0-100 | 0.0184 | 16 | 0.960 | 0.953 |
| 0-10 | 0.0117 | 14 | 0.936 | 0.920 |
| 10-20 | 0.0184 | 16 | 0.971 | 0.951 |
| 20-30 | 0.0189 | 16 | 0.969 | 0.953 |
| 30-40 | 0.0198 | 17 | 0.969 | 0.948 |
| 40-50 | 0.0200 | 17 | 0.972 | 0.948 |
| 50-60 | 0.0216 | 18 | 0.972 | 0.939 |
| 60-70 | 0.0189 | 15 | 0.969 | 0.946 |
| 70-80 | 0.0182 | 15 | 0.970 | 0.948 |
| 80-90 | 0.0172 | 14 | 0.963 | 0.953 |
| 90-100 | 0.0175 | 14 | 0.968 | 0.945 |

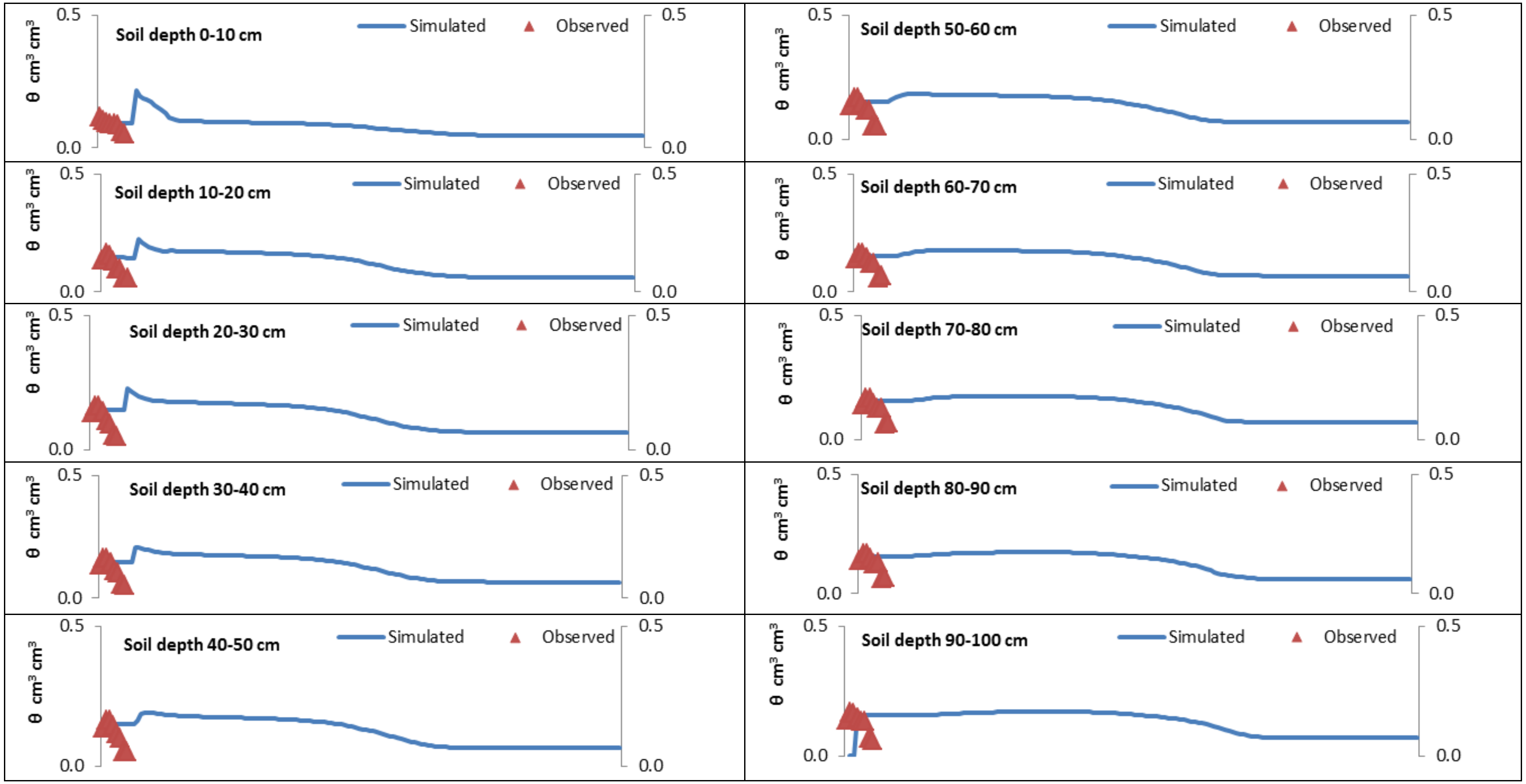



**Figure 17 Observed and simulated soil water content under chickpea**

**Calibration for cumin**

For calibration of cumin data from the grain yield, above ground biomass (AGB), N-uptake and moisture content were used to determine the best crop parameters.

**Seed yield**

The seed yield was simulated with CropSyst model by inputting the observed data on duration of different phenol-phases during the experiment under field conditions. Table 24 showed that the simulate yield (426 kg $ha^{-1}$) of cumin were well matched to the observed yield of 438 kg $ha^{-1}$. The absolute and relative error was 12 and 2.7, respectively during 2012-13.

**Table 24 Quantitative measures of model performance for yield, AGB and N-uptake of cumin (2012-13)**

| Particular | Observed | Simulated | AE | RE |
|---|---|---|---|---|
| Seed yield | 438 | 426 | 12 | 2.7 |
| AGB | 1123 | 1237 | 114 | 10.2 |
| N-uptake | 17.3 | 27.4 | 10.1 | 58.4 |

**Aboveground biomass**

Simulations of aboveground biomass development of cumin agreed with the field data. The observed aboveground biomass (1123 kg $ha^{-1}$) was slightly lower than simulated aboveground biomass (1237 kg $ha^{-1}$) as shown in table 24. The absolute and relative error was 114 and 10.2, respectively during 2012-13.

**N-uptake**

Simulations of N-uptake slightly moderately matched with the field data. The simulated N-uptake (27.4 kg $ha^{-1}$) was higher than observed N-uptake (17.3 kg $ha^{-1}$). The absolute and relative error was 10.1 and 58.4, respectively (Table 24) during 2012-13.

**Moisture content**

Data presented in Table 25 shows the RMSE, correlation and index of agreement values of moisture content. The RMSE of moisture content ranged from 0.0081 to 0.0123. These small values reveal that soil water flow was well simulated by

CropSyst at different fields during 2012-13. As no systematic under or over estimation of moisture content was observed, the differences between the observed and simulated moisture content are contributed to the spatial heterogeneity and observation errors, which are inevitable under field conditions.Simulated value of moisture content predict well with observed values in the upper layers up to 60 cm. The index of agreement was 0.83 in top soil layer of 50 cm (Fig 18).

**Table 25 Quantitative measures of model performance for soil moisture under Cumin (2012-13)**

| Soil layer | RMSE | RRMSE | Correlation | Index of agreement |
|---|---|---|---|---|
| 0-100 | 0.0099 | 7 | 0.972 | 0.96 |
| 0-10 | 0.0102 | 14 | 0.994 | 0.87 |
| 10-20 | 0.0095 | 7 | 0.951 | 0.95 |
| 20-30 | 0.0111 | 8 | 0.963 | 0.93 |
| 30-40 | 0.0098 | 7 | 0.965 | 0.94 |
| 40-50 | 0.0084 | 6 | 0.992 | 0.94 |
| 50-60 | 0.0123 | 9 | 0.880 | 0.83 |
| 60-70 | 0.0088 | 6 | 0.956 | 0.89 |
| 70-80 | 0.0092 | 6 | 0.954 | 0.83 |
| 80-90 | 0.0109 | 8 | 0.878 | 0.74 |
| 90-100 | 0.0081 | 5 | 0.441 | 0.61 |

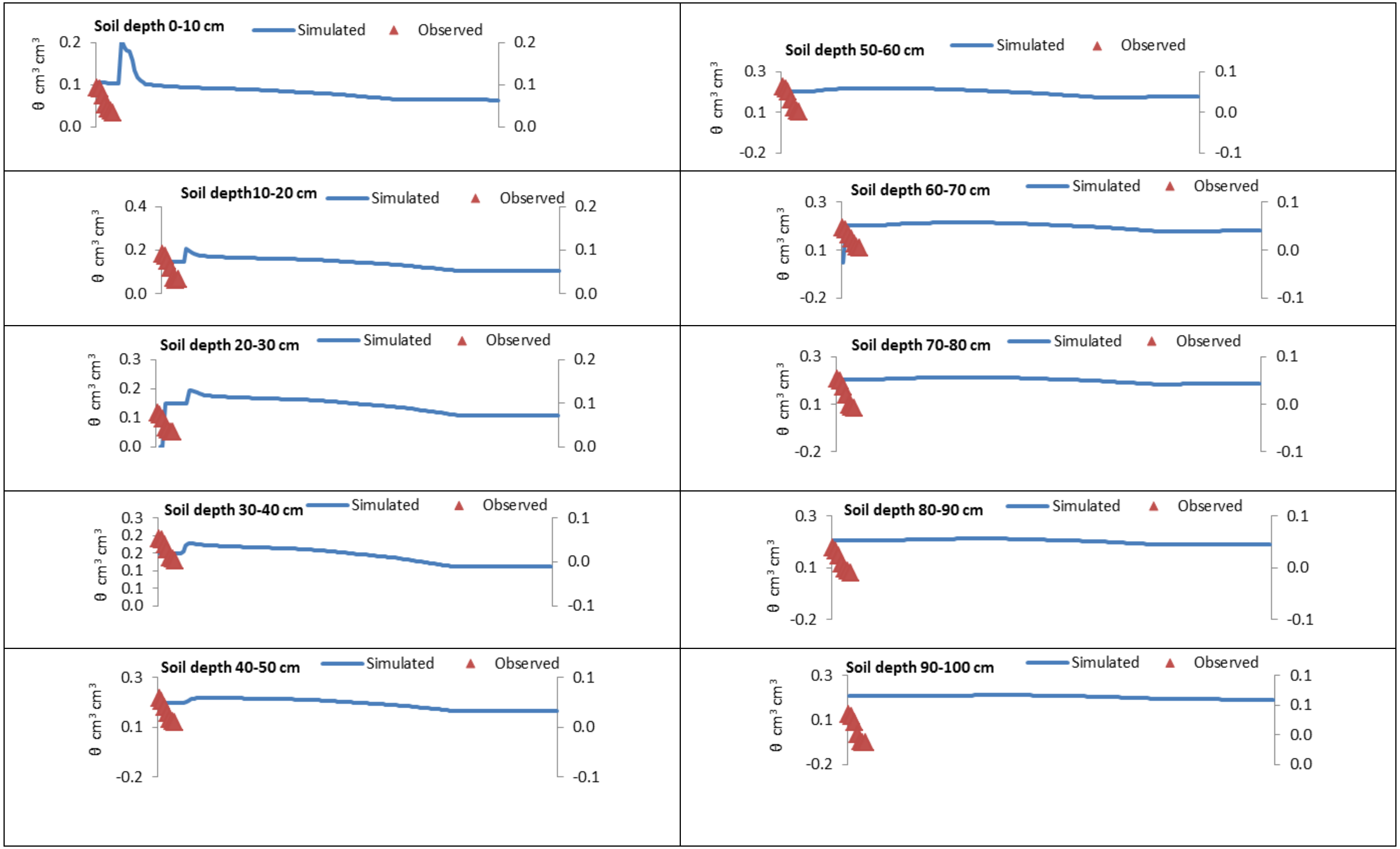



**Figure 18 Observed and simulated soil water content under cumin**

**Calibration for isabgol**

For calibration of isabgol data from the grain yield, above ground biomass (AGB), N-uptake and moisture content were used to determine the best crop parameters.

**Seed yield**

The seed yield was simulated with CropSyst model by inputting the observed data on duration of different phenol-phases during the experiment under field conditions. Table 26 showed that the simulate yield (429 kg $ha^{-1}$) of isabgol were well matched with the observed yield of 462 kg $ha^{-1}$. The absolute and relative error was 33 and 7.1, respectively during 2012-13.

**Table 26 Quantitative measures of model performance for yield, AGB and N-uptake of Isabgol (2012-13)**

| Particular | Observed | Simulated | AE | RE |
|---|---|---|---|---|
| Seed yield | 462 | 429 | 33 | 7.1 |
| AGB | 1085 | 997 | 88 | 8.1 |
| N-uptake | 28.0 | 20.0 | 8 | 28.6 |

**Aboveground biomass**

Simulations of aboveground biomass development of isabgol match with the field data. The observed aboveground biomass (1085 kg $ha^{-1}$) was higher than simulated aboveground biomass (997 kg $ha^{-1}$) as shown in Table 26. The absolute and relative error was 88 and 8.1, respectively during 2012-13.

**N-uptake**

Simulations of N-uptake slightly matched with the field data. The simulated N-uptake (20.0 kg $ha^{-1}$) was lower than observed N-uptake (28.0 kg $ha^{-1}$). The absolute and relative error was 8 and 28.6, respectively during 2012-13 (Table 26).

**Moisture content**

Data presented in table 27 shows the RMSE, correlation and index of agreement values of moisture content. The RMSE of moisture content ranged from 0.0139 to 0.0785. These small values reveal that soil water flow was well simulated by CropSyst at different fields during 2012-13. As no systematic under or over estimation of moisture content was observed, the differences between the observed and simulated moisture content are contributed to the spatial heterogeneity and observation errors, which are inevitable under field conditions.Simulated value of moisture content predict well with observed values in the upper layers up to 60 cm (Fig. 19).

**Table 27 Quantitative measures of model performance for soil moisture under Isabgol (2012-13)**

| Soil layer | RMSE | RRMSE | Correlation | Index of agreement |
|---|---|---|---|---|
| 0-100 | 0.0607 | 66 | 0.285 | 0.44 |
| 0-10 | 0.0139 | 15 | 0.979 | 0.65 |
| 10-20 | 0.0529 | 60 | 0.934 | 0.38 |
| 20-30 | 0.0420 | 40 | 0.847 | 0.66 |
| 30-40 | 0.0485 | 46 | 0.701 | 0.60 |
| 40-50 | 0.0575 | 60 | 0.829 | 0.52 |
| 50-60 | 0.0605 | 62 | 0.819 | 0.44 |
| 60-70 | 0.0717 | 82 | 0.574 | 0.39 |
| 70-80 | 0.0753 | 87 | 0.359 | 0.36 |
| 80-90 | 0.0785 | 95 | 0.061 | 0.29 |
| 90-100 | 0.0765 | 90 | 0.343 | 0.30 |

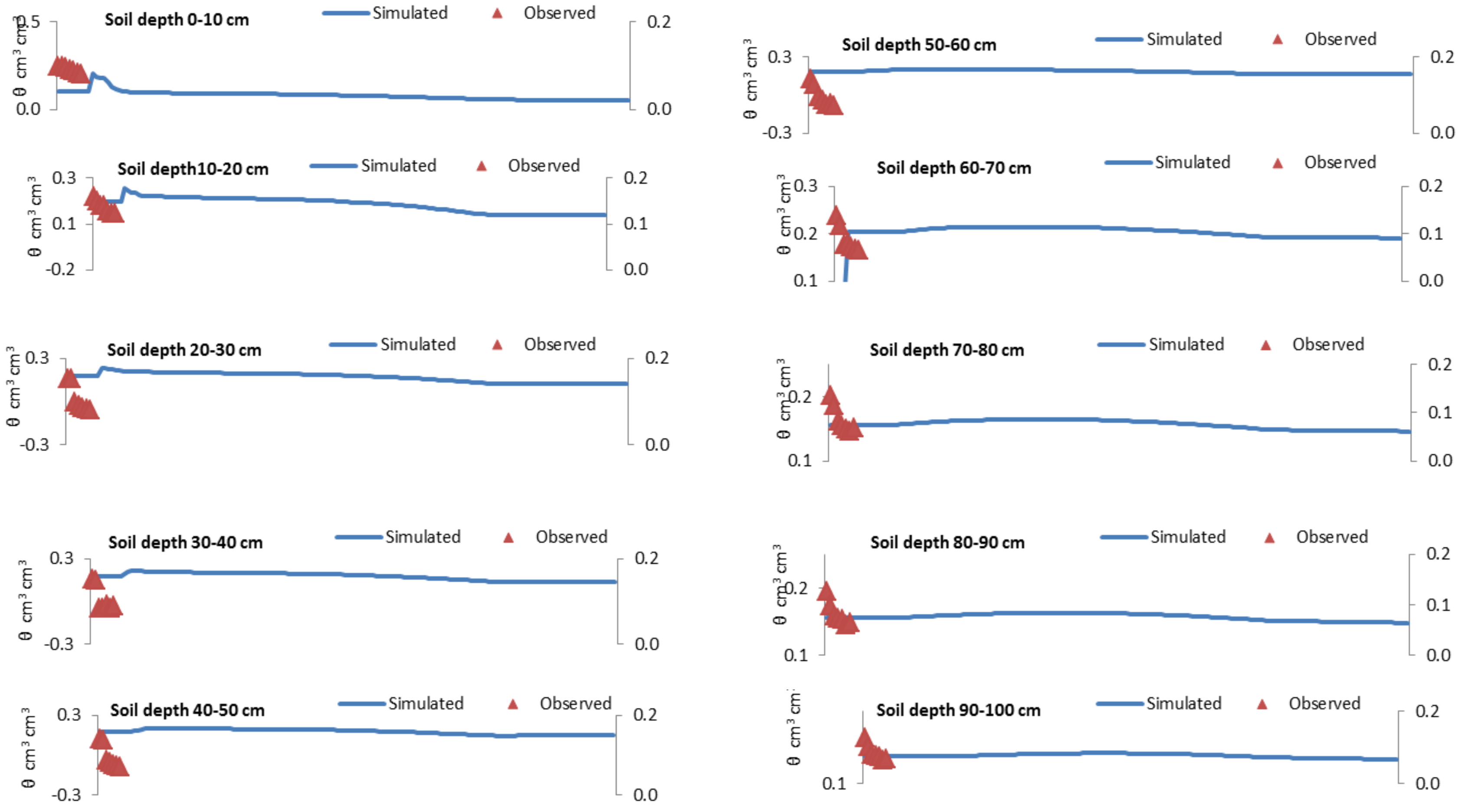



**Figure 19 Observed and simulated soil water content under Isabgol**

**Model Validation (2013-14)**

CropSyst model was calibrated for *kharif* and *rabi* season crops (groundnut, clusterbean, wheat, mustard, chickpea, cumin and isabgol) in 2012-13. The calibrated model was validated during 2013-14 for the site conditions using the crop model parameter values calibrated as mentioned years with associated water management. Soil characteristics, initial conditions of available soil water, nitrogen and organic matter and daily weather data were model input data for CropSyst as observed in the experiment. Model evaluation and validation was conventionally made by comparing simulation outputs with observed and simulated data. The CropSyst model was validated using the field experiment data conducted in 2013-14 growing season. It was validated for aboveground biomass (AGB), grain yield, N-uptake green area index (GAI) and moisture content. The difference measures include the root mean square error (RMSE) and index of agreement (IoA).

**Validation for clusterbean**

For validation of clusterbean, data from the grain yield, above ground biomass (AGB), N-uptake and moisture content were used to determine the best crop parameters.

**Seed yield**

The seed yield was validated with CropSyst model by inputting the observed data on duration of different phenol-phases during the experiment under field conditions. Table 28 showed that the simulate yield 1047 kg $ha^{-1}$ of clusterbean were match well to the observed yield of 1094 kg $ha^{-1}$. The absolute and relative error was 47 and 4.5, respectively during 2013-14.

**Aboveground biomass**

Validation of aboveground biomass development of clusterbean moderately match with the field data. The observed aboveground biomass (3828 kg $ha^{-1}$) was lower than validated aboveground biomass (4055 kg $ha^{-1}$) as shown in table 28. The absolute and relative error was 227 and 5.9, respectively during 2013-14.

**Table 28 Quantitative measures of model performance for yield, AGB and N-uptake of clusterbean (2013-14)**

| Particular | Observed | Validated | AE | RE |
|---|---|---|---|---|
| Seed yield | 1047 | 1094 | 47 | 4.5 |
| AGB | 3828 | 4055 | 227 | 5.9 |
| N-uptake | 46.2 | 42.7 | 3.5 | 7.6 |

**N-uptake**

Validation of N-uptake slightly matched with the field data. The validated N-uptake 42.7 kg $ha^{-1}$) was lower than observed N-uptake (46.2 kg $ha^{-1}$). The absolute and relative error was 3.5 and 7.6, respectively (Table 28) during 2013-14.

**Moisture content**

Data presented in table 29 shows the RMSE, RRMSE, correlation coefficient and index of agreement values of moisture content during 2013-14. The RMSE of moisture content ranged from 0.0182 to 0.0443. These small values reveal that soil water flow was well validated by CropSyst at different fields. As no systematic under or over estimation of moisture content was observed, the differences between the observed and simulated moisture content are contributed to the spatial heterogeneity and observation errors, which are inevitable under field conditions.Simulated value of moisture content predict well with observed values in the upper layers up to 100 cm. The index of agreement was 0.82 in top soil layer of 50 cm (Fig 20).

**Table 29 Quantitative measures of model performance for soil moisture under Clusterbean (2013-14)**

| Soil layer, cm | RMSE | RRMSE | Correlation coefficient | Index of agreement |
|---|---|---|---|---|
| 0-100 | 0.0250 | 20 | 0.869 | 0.87 |
| 0-10 | 0.0198 | 17 | 0.898 | 0.88 |
| 10-20 | 0.0182 | 14 | 0.941 | 0.91 |
| 20-30 | 0.0443 | 38 | 0.628 | 0.70 |
| 30-40 | 0.0208 | 16 | 0.930 | 0.90 |
| 40-50 | 0.0206 | 15 | 0.918 | 0.90 |
| 50-60 | 0.0223 | 17 | 0.921 | 0.89 |
| 60-70 | 0.0304 | 24 | 0.814 | 0.80 |
| 70-80 | 0.0230 | 18 | 0.925 | 0.89 |
| 80-90 | 0.0198 | 16 | 0.930 | 0.92 |
| 90-100 | 0.0189 | 15 | 0.941 | 0.93 |

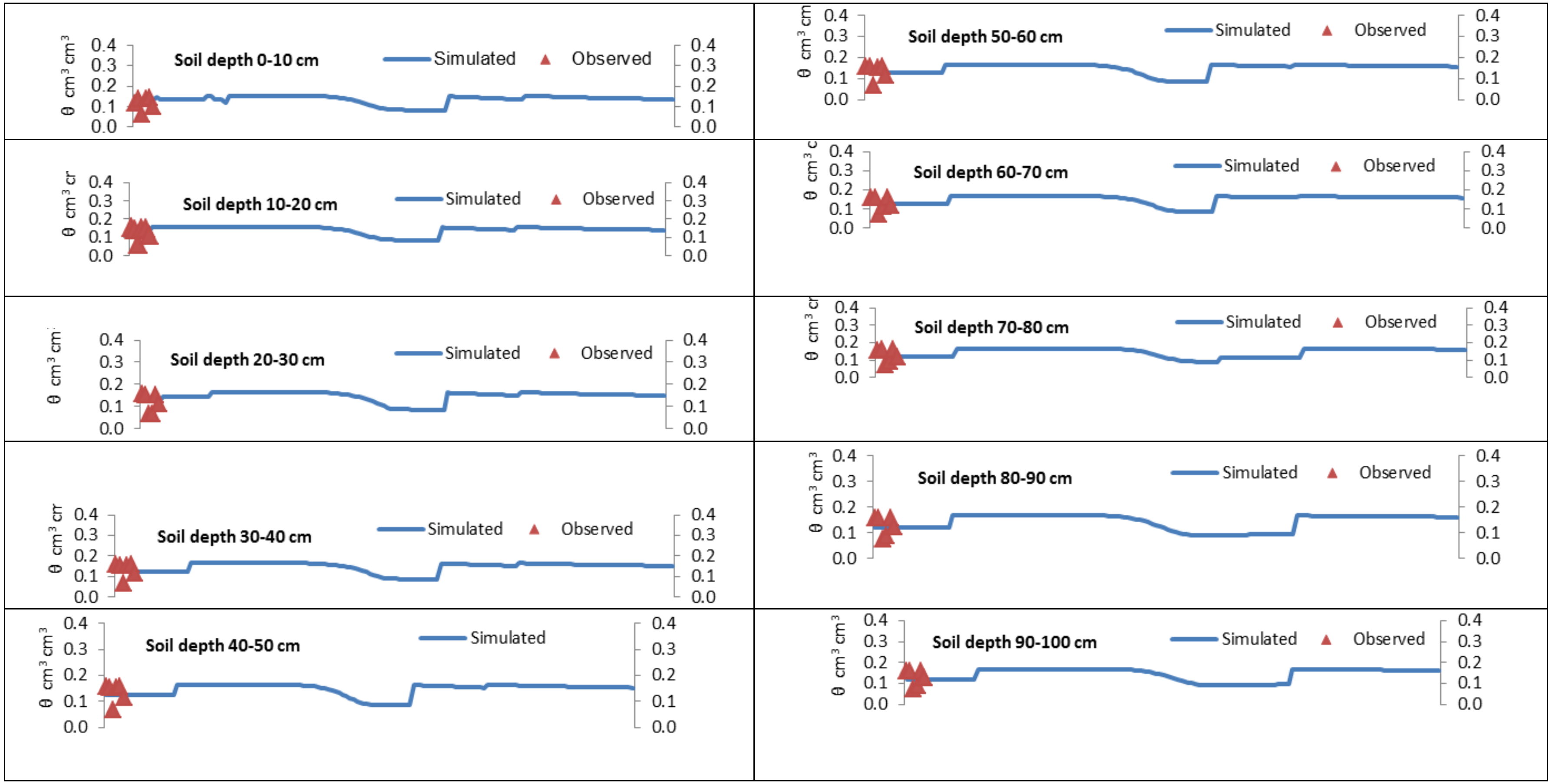



**Figure 20 Observed and simulated soil water content under Clusterbean**

**Validation for groundnut**

For validation of groundnut data from the grain yield, above ground biomass (AGB), N-uptake and moisture content were used to determine the best crop parameters.

**Seed yield**

The seed yield was validated with CropSyst model by inputting the observed data on duration of different phenol-phases during the experiment under field conditions. Table 30 showed that the validate yield (2926 kg $ha^{-1}$) of groundnut were agreed to the observed yield of 3023 kg $ha^{-1}$ during 2013-14. The absolute and relative error was 97 and 3.3.

**Table 30 Quantitative measures of model performance for yield, AGB and N-uptake of groundnut (2013-14)**

| Particular | Observed | Validated | AE | RE |
|---|---|---|---|---|
| Seed yield | 2926 | 3023 | 97 | 3.3 |
| AGB | 7399 | 7559 | 160 | 2.2 |
| N-uptake | 134.2 | 145.5 | 11.3 | 8.4 |

**Aboveground biomass**

Validations of aboveground biomass development of groundnut slightly match with the field data. The observed aboveground biomass (7399 kg $ha^{-1}$) was lower than validated aboveground biomass (7559 kg $ha^{-1}$) as shown in table 30. The absolute and relative error was 160 and 2.2, respectively during 2013-14.

**N-uptake**

Validations of N-uptake slightly matched with the field data. The validated N-uptake (145.5 kg $ha^{-1}$) was higher than observed N-uptake (134.2 kg $ha^{-1}$) as shown in table 30. The absolute and relative error was 38.1 and 20.5, respectively during 2013-14.

**Moisture content**

Data in table 31 shows the value of RMSE of moisture content ranged from 0.0050 to 0.0118.These values reveal that soil water flow was well validated by CropSyst model during 2013-14. Validated value of moisture content predict well with observed values in 0-100 cm with 0.0094, 0.89 and 0.83 of RMSE, correlation coefficient and index of agreement, respectively (Fig 21).

**Table 31 Quantitative measures of model performance for soil moisture under groundnut (2013-14)**

| Soil layer, cm | RMSE | RRMSE | Correlation coefficient | Index of agreement |
|---|---|---|---|---|
| 0-100 | 0.0094 | 6 | 0.892 | 0.83 |
| 0-10 | 0.0064 | 5 | 0.972 | 0.94 |
| 10-20 | 0.0050 | 3 | 0.965 | 0.95 |
| 20-30 | 0.0096 | 6 | 0.502 | 0.64 |
| 30-40 | 0.0072 | 5 | 0.964 | 0.89 |
| 40-50 | 0.0082 | 5 | 0.891 | 0.77 |
| 50-60 | 0.0115 | 7 | 0.797 | 0.59 |
| 60-70 | 0.0118 | 8 | 0.554 | 0.44 |
| 70-80 | 0.0118 | 8 | 0.328 | 0.37 |
| 80-90 | 0.0102 | 7 | 0.916 | 0.44 |
| 90-100 | 0.0095 | 6 | 0.884 | 0.61 |

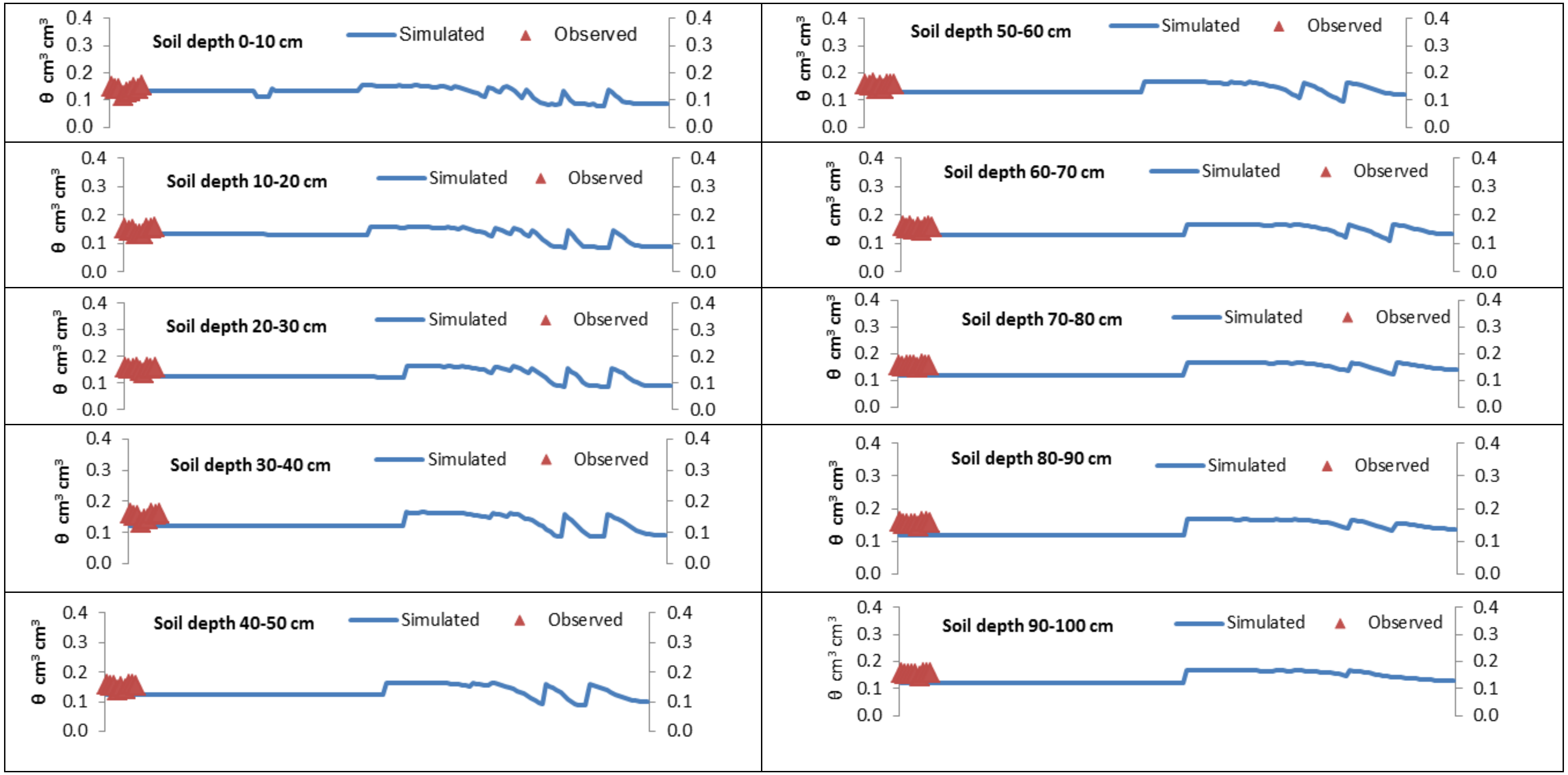



**Figure 21 Observed and validated soil water content under Groundnut**

**Validation for wheat**

For validation of wheat data from the green area index (GAI), grain yield, above ground biomass (AGB), N-uptake and moisture content were used to determine the best crop parameters.

**Seed yield**

The seed yield was validated with CropSyst model by inputting the observed data on duration of different phenol-phases during the experiment under field conditions. Table 32 showed that the validate yield (2532 kg ha$^{-1}$) of wheat were differ to the observed yield of 2772 kg ha$^{-1}$. The absolute and relative error was 240 and 8.7, respectively during 2013-14.

**Table 32 Quantitative measures of model performance for yield, AGB and N-uptake of wheat (2013-14)**

| Particular | Observed | Validated | AE | RE |
|---|---|---|---|---|
| Seed yield | 2772 | 2532 | 240 | 8.7 |
| AGB | 6599 | 6143 | 456 | 6.9 |
| N-uptake | 69.7 | 61.6 | 8.1 | 11.6 |

**Aboveground biomass**

Validations of aboveground biomass development of wheat differ with the field data. The observed aboveground biomass (6599 kg ha$^{-1}$) was higher than validated aboveground biomass (6143 kg ha$^{-1}$) as shown in table 32. The absolute and relative error was 456 and 6.9, respectively during 2013-14.

**N-uptake**

Validations of N-uptake slightly matched with the field data. The validated N-uptake (61.6 kg ha$^{-1}$) was lower than observed N-uptake (69.7 kg ha$^{-1}$). The absolute and relative error was 8.1 and 11.6, respectively (Table 32) during 2013-14.

**Moisture content**

Data presented in table 33 shows the RMSE, correlation and index of agreement values of moisture content. The RMSE of moisture content ranged from 0.0069 to 0.0234 during 2013-14. These small values reveal that soil water flow was well validated by CropSyst at different fields. As no systematic under or over estimation of moisture content was observed, the differences between the observed and validated moisture content are contributed to the spatial heterogeneity and observation errors, which are inevitable under field conditions.Validated value of moisture content predict well with observed values in the upper layers up to 60 cm. The index of agreement was 0.82 in top soil layer of 50 cm (Fig 22).

**Table 33 Quantitative measures of model performance for soil moisture under wheat (2013-14)**

| Soil layer, cm | RMSE | RRMSE | Correlation | Index of agreement |
|---|---|---|---|---|
| 0-100 | 0.0140 | 11 | 0.964 | 0.96 |
| 0-10 | 0.0069 | 5 | 0.931 | 0.96 |
| 10-20 | 0.0089 | 6 | 0.922 | 0.94 |
| 20-30 | 0.0100 | 7 | 0.949 | 0.88 |
| 30-40 | 0.0111 | 7 | 0.874 | 0.79 |
| 40-50 | 0.0099 | 7 | 0.901 | 0.80 |
| 50-60 | 0.0104 | 7 | 0.930 | 0.75 |
| 60-70 | 0.0185 | 16 | 0.987 | 0.96 |
| 70-80 | 0.0165 | 15 | 0.996 | 0.97 |
| 80-90 | 0.0148 | 13 | 0.997 | 0.98 |
| 90-100 | 0.0237 | 22 | 0.991 | 0.94 |

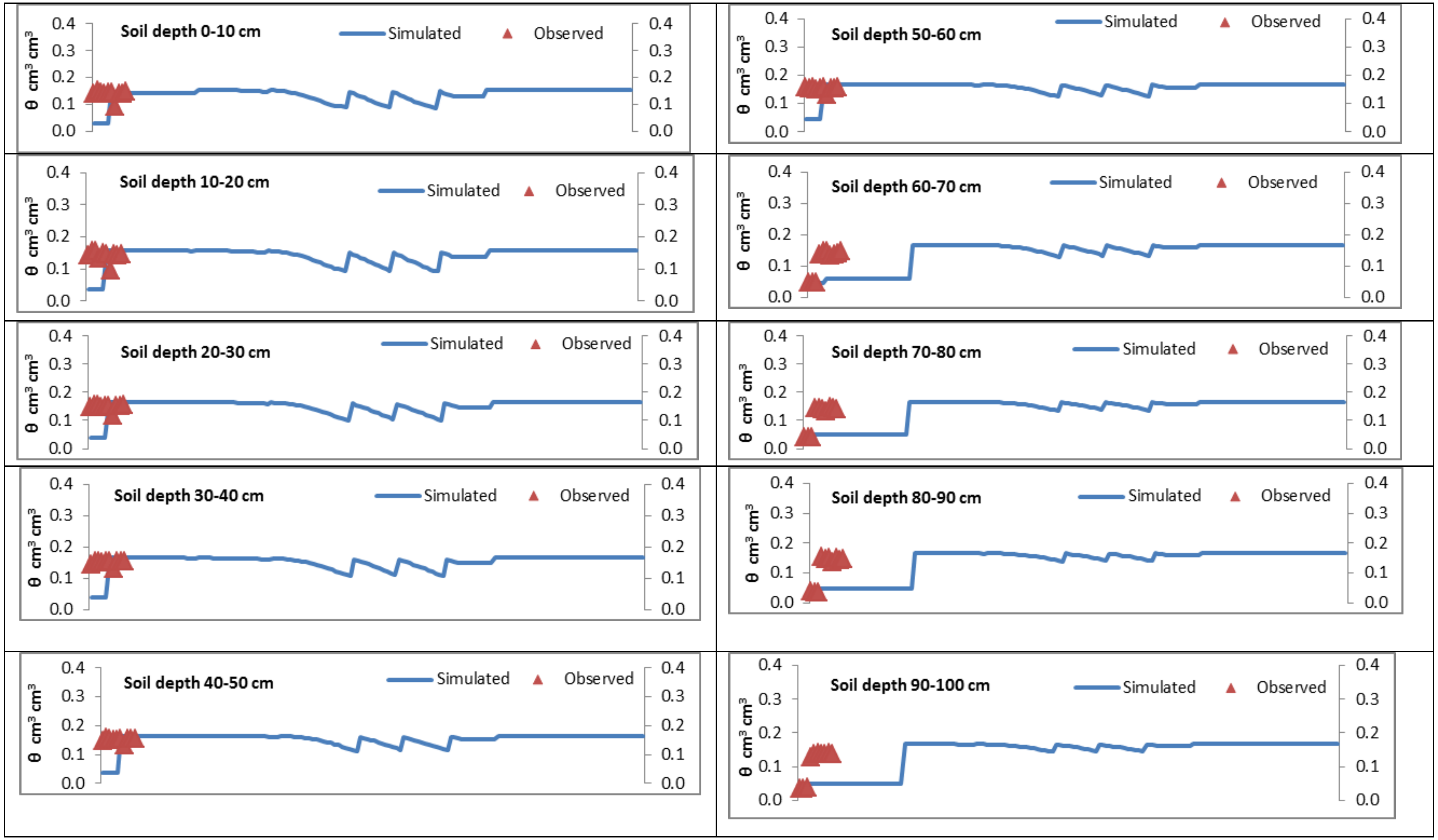



**Figure 22 Observed and validated soil water content under wheat**

**Validation for mustard**

For validation of mustard data from the grain yield, above ground biomass (AGB), N-uptake and moisture content were used to determine the best crop parameters.

**Seed yield**

The seed yield was validated with CropSyst model by inputting the observed data on duration of different phenol-phases during the experiment under field conditions. Table 34 showed that the validate yield (1534 kg ha$^{-1}$) of mustard were agreed to the observed yield of 1692 kg ha$^{-1}$ with relative error of 9.3 during 2013-14.

**Table 34 Quantitative measures of model performance for yield, AGB and N-uptake of mustard (2013-14)**

| Particular | Observed | Validated | AE | RE |
|---|---|---|---|---|
| Seed yield | 1692 | 1534 | 158 | 9.3 |
| AGB | 4996 | 4653 | 343 | 6.9 |
| N-uptake | 63.9 | 58.3 | 5.6 | 8.8 |

**Aboveground biomass**

Validations of aboveground biomass development of mustard differ with the field data. The observed aboveground biomass (4996 kg ha$^{-1}$) was higher than validated aboveground biomass (4653 kg ha$^{-1}$) as shown in table 34. The absolute and relative error was 343 and 6.9, respectively during 2013-14.

**N-uptake**

Validations of N-uptake slightly matched with the field data. The validated N-uptake (58.3 kg ha$^{-1}$) was lower than observed N-uptake (63.9 kg ha$^{-1}$) as shown in table 34. The absolute and relative error was 5.6 and 8.8, respectively during 2013-14.

**Moisture content**

Data in table 35 shows the value of RMSE of moisture content ranged from 0.0117 to 0.0224. These values reveal that soil water flow was well validated by CropSyst model during 2013-14. Validated value of moisture content predict well with observed values in 0-100 cm with 0.0359, 0.97, 0.89 and 0.99 of RMSE, correlation and index of agreement, respectively (Fig 23).

**Table 35 Quantitative measures of model performance for soil moisture under mustard (2013-14)**

| Soil layer, cm | RMSE | RRMSE | Correlation | Index of agreement |
|---|---|---|---|---|
| 0-100 | 0.0179 | 18 | 0.991 | 0.96 |
| 0-10 | 0.0195 | 17 | 0.988 | 0.89 |
| 10-20 | 0.0195 | 17 | 0.990 | 0.90 |
| 20-30 | 0.0224 | 19 | 0.986 | 0.88 |
| 30-40 | 0.0221 | 18 | 0.989 | 0.87 |
| 40-50 | 0.0182 | 15 | 0.979 | 0.90 |
| 50-60 | 0.0170 | 16 | 0.993 | 0.97 |
| 60-70 | 0.0176 | 16 | 0.995 | 0.96 |
| 70-80 | 0.0117 | 15 | 0.999 | 0.97 |
| 80-90 | 0.0135 | 21 | 0.995 | 0.97 |
| 90-100 | 0.0145 | 26 | 0.997 | 0.97 |

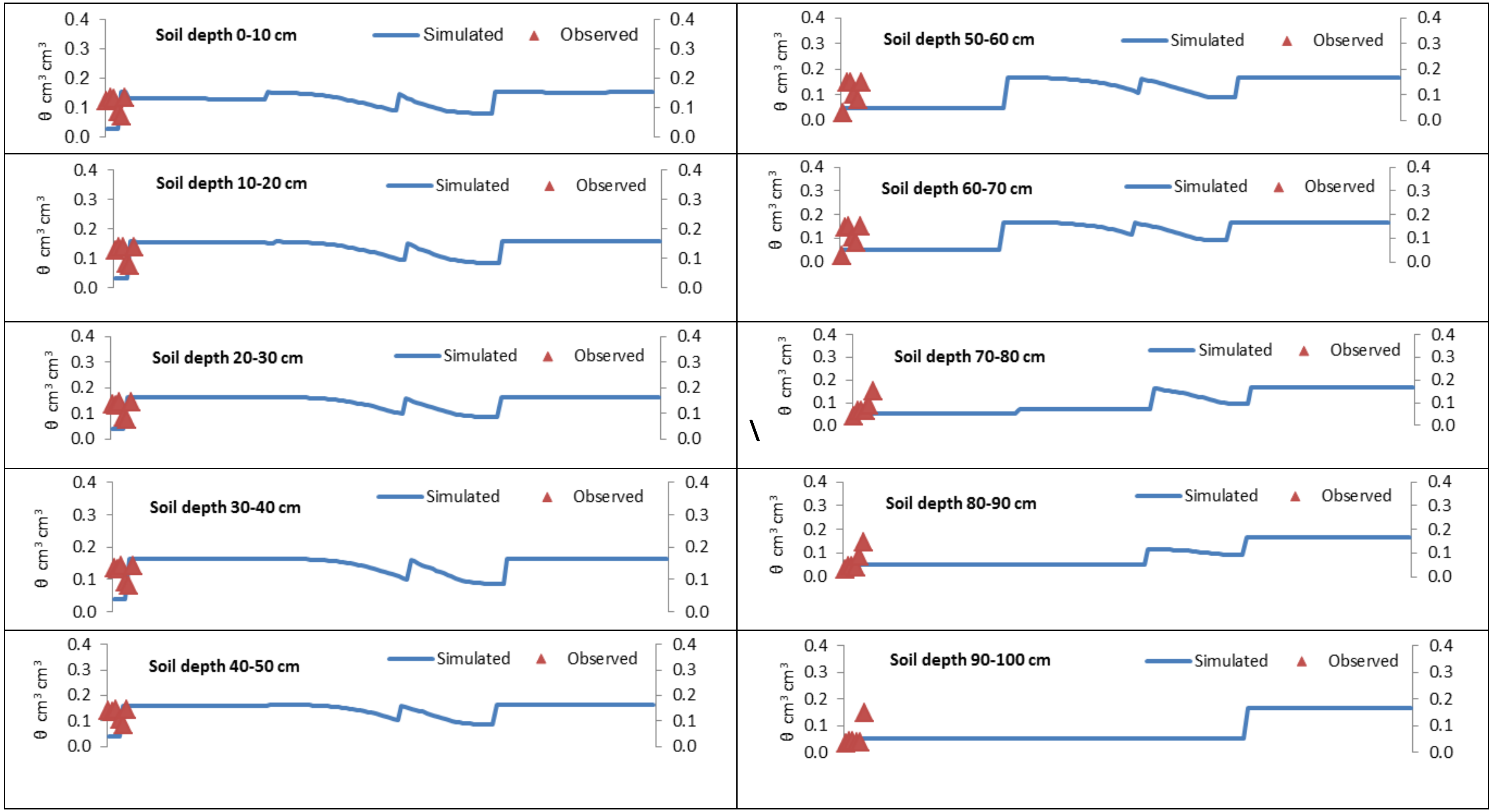



**Figure 23 Observed and validated soil water content under mustard**

**Validation for chickpea**

For validation of chickpea data from the grain yield, above ground biomass (AGB), N-uptake and moisture content were used to determine the best crop parameters.

**Seed yield**

The seed yield was validated with CropSyst model by inputting the observed data on duration of different phenol-phases during the experiment under field conditions during 2013-14. Table 36 showed that the validate yield (1661 kg $ha^{-1}$) of chickpea were agreed to the observed yield of 1791 kg $ha^{-1}$. The absolute and relative error was 130 and 7.3.

**Table 36 Quantitative measures of model performance for yield, AGB and N-uptake of chickpea (2013-14)**

| Particular | Observed | Validated | AE | RE |
|---|---|---|---|---|
| Seed yield | 1791 | 1661 | 130 | 7.3 |
| AGB | 3928 | 4355 | 427 | 10.9 |
| N-uptake | 71.0 | 79.0 | 8.0 | 11.3 |

**Aboveground biomass**

Validations of aboveground biomass development of chickpea slightly matched with the field data. The observed aboveground biomass (3928 kg $ha^{-1}$) was lower than validated aboveground biomass (4355 kg $ha^{-1}$) as shown in table 36. The absolute and relative error was 427 and 10.9, respectively during 2013-14.

**N-uptake**

Validations of N-uptake slightly matched with the field data. The validated N-uptake (79.0 kg $ha^{-1}$) was higher than observed N-uptake (71.0 kg $ha^{-1}$) as shown in Table 36. The absolute and relative error was 8.0 and 11.3, respectively during 2013-14.

**Moisture content**

Data in table 37 shows the value of RMSE of moisture content ranged from 0.0089 to 0.0223. These values reveal that soil water flow was well validated by CropSyst model.Validated value of moisture content predict well with observed values in 0-100 cm with 0.0359, 0.97, 0.89 and 0.99 of RMSE, correlation and index of agreement, respectively (Fig 24) during 2013-14.

**Table 37 Quantitative measures of model performance for soil moisture under chickpea (2013-14)**

| Soil layer, cm | RMSE | RRMSE | Correlation | Index of agreement |
|---|---|---|---|---|
| 0-100 | 0.0121 | 10 | 0.913 | 0.95 |
| 0-10 | 0.0089 | 8 | 0.955 | 0.97 |
| 10-20 | 0.0093 | 8 | 0.988 | 0.97 |
| 20-30 | 0.0096 | 7 | 0.958 | 0.97 |
| 30-40 | 0.0090 | 7 | 0.959 | 0.97 |
| 40-50 | 0.0090 | 7 | 0.955 | 0.97 |
| 50-60 | 0.0098 | 7 | 0.964 | 0.97 |
| 60-70 | 0.0123 | 9 | 0.931 | 0.95 |
| 70-80 | 0.0129 | 9 | 0.885 | 0.94 |
| 80-90 | 0.0223 | 17 | 0.686 | 0.82 |
| 90-100 | 0.0117 | 11 | 0.906 | 0.71 |

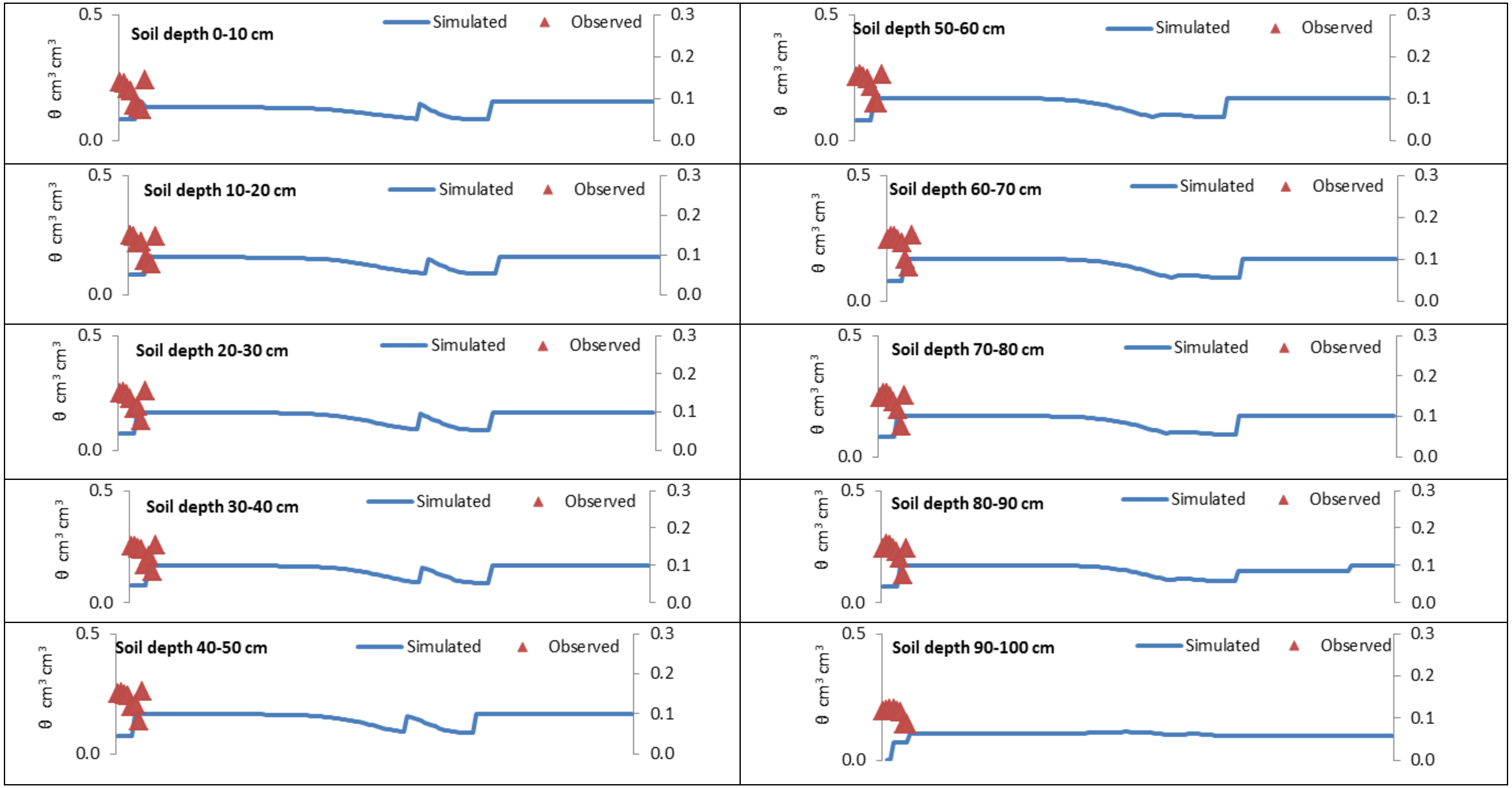



**Figure 24 Observed and validated soil water content under chickpea**

**Validation for Cumin**

For validation of cumin data from the grain yield, above ground biomass (AGB), N-uptake and moisture content were used to determine the best crop parameters.

**Seed yield**

The seed yield was validated with CropSyst model by inputting the observed data on duration of different phenol-phases during the experiment under field conditions. Table 38 showed that the validate yield (410 kg ha$^{-1}$) of cumin were moderately match to the observed yield of 502 kg ha$^{-1}$. The absolute and relative error was 92 and 18.3, respectively during 2013-14.

**Table 38 Quantitative measures of model performance for yield, AGB and N-uptake of cumin (2013-14)**

| Particular | Observed | Validated | AE | RE |
|---|---|---|---|---|
| Seed yield | 502 | 410 | 92 | 18.3 |
| AGB | 1403 | 1195 | 208 | 14.8 |
| N-uptake | 22.0 | 26.5 | 4.5 | 20.5 |

**Aboveground biomass**

Validations of aboveground biomass development of cumin moderately differ with the field data. The observed aboveground biomass (1403 kg ha$^{-1}$) was higher than validated aboveground biomass (1195 kg ha$^{-1}$) as shown in table 38. The absolute and relative error was 208 and 14.8, respectively during 2013-14.

**N-uptake**

Validations of N-uptake matched with the field data. The validated N-uptake (26.5 kg ha$^{-1}$) was higher than observed N-uptake (22.0 kg ha$^{-1}$). The absolute and relative error was 4.5 and 20.5, respectively (Table 38) during 2013-14.

**Moisture content**

Data presented in table 39 shows the RMSE, correlation and index of agreement values of moisture content during 2013-14. The RMSE of moisture content ranged from 0.0049 to 0.0138. These small values reveal that soil water flow was well validated by CropSyst at different fields. As no systematic under or over estimation of moisture content was observed, the differences between the observed and validated moisture content are contributed to the spatial heterogeneity and observation errors, which are inevitable under field conditions.Validated value of moisture content predict well with observed values in the upper layers up to 60 cm. The index of agreement was 0.90 in 0-100 cm soil layer (Fig 25).

**Table 39 Quantitative measures of model performance for soil moisture under cumin (2013-14)**

| Soil layer, cm | RMSE | RRMSE | Correlation coefficient | Index of agreement |
|---|---|---|---|---|
| 0-100 | 0.0117 | 7.9 | 0.964 | 0.90 |
| 0-10 | 0.0049 | 3.4 | 0.996 | 0.89 |
| 10-20 | 0.0082 | 5.6 | 0.879 | 0.51 |
| 20-30 | 0.0132 | 8.7 | 0.679 | 0.44 |
| 30-40 | 0.0128 | 8.5 | 0.661 | 0.46 |
| 40-50 | 0.0120 | 7.9 | 0.693 | 0.46 |
| 50-60 | 0.0138 | 9.0 | 0.672 | 0.42 |
| 60-70 | 0.0132 | 8.5 | 0.684 | 0.42 |
| 70-80 | 0.0125 | 8.1 | 0.812 | 0.39 |
| 80-90 | 0.0125 | 9.0 | 0.997 | 0.97 |
| 90-100 | 0.0114 | 8.1 | 0.997 | 0.98 |

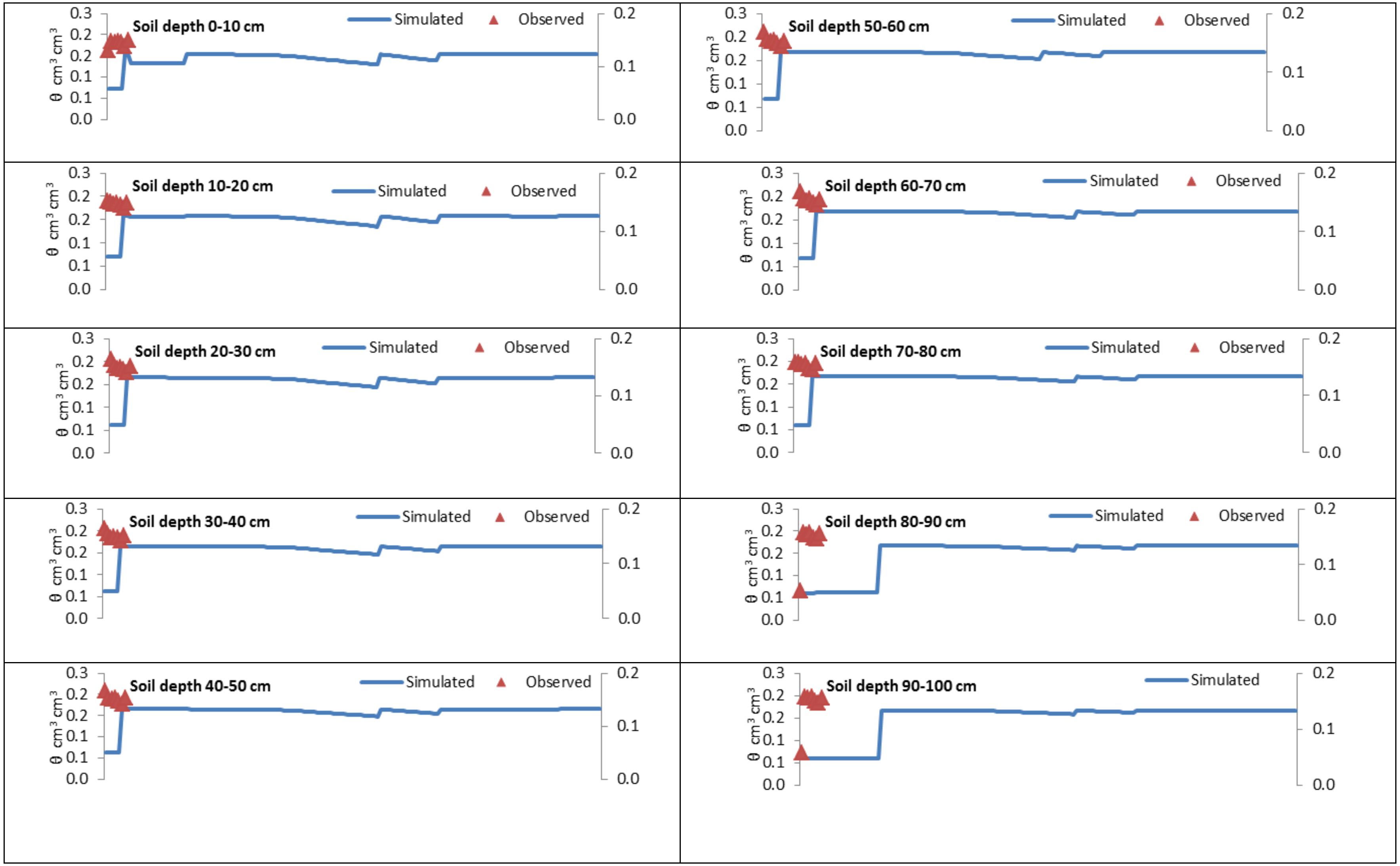



**Figure 25 Observed and validated soil water content under cumin**

**Validation for isabgol**

For validation of isabgol data from the grain yield, above ground biomass (AGB), N-uptake and moisture content were used to determine the best crop parameters.

**Seed yield**

The seed yield was validated with CropSyst model by inputting the observed data on duration of different phenol-phases during the experiment under field conditions. Table 40 showed that the validate yield (597 kg $ha^{-1}$) of isabgol were well matched with the observed yield of 557 kg $ha^{-1}$. The absolute and relative error was 40.5 and 7.3, respectively during 2013-14.

**Table 40 Quantitative measures of model performance for yield, AGB and N-uptake of isabgol (2013-14)**

| Particular | Observed | Validated | AE | RE |
|---|---|---|---|---|
| Seed yield | 557 | 597 | 40.5 | 7.3 |
| AGB | 1395 | 1894 | 499 | 35.8 |
| N-uptake | 26.0 | 34.0 | 8 | 30.8 |

**Aboveground biomass**

Validations of aboveground biomass development of isabgol moderately match with the field data. The observed aboveground biomass (1395 kg $ha^{-1}$) was lower than validated aboveground biomass (1894 kg $ha^{-1}$) as shown in table 40. The absolute and relative error was 499 and 35.8, respectively during 2013-14.

**N-uptake**

Validations of N-uptake moderately matched with the field data. The validated N-uptake (34.0 kg $ha^{-1}$) was higher than observed N-uptake (26.0 kg $ha^{-1}$). The absolute and relative error was 8 and 30.8, respectively (Table 40) during 2013-14.

**Moisture content**

Data presented in table 41 shows the RMSE, correlation and index of agreement values of moisture content during 2013-14. The RMSE of moisture content ranged from 0.0143 to 0.0280.These small values reveal that soil water flow was well validated by CropSyst at different fields. As no systematic under or over estimation of moisture content was observed, the differences between the observed and validated moisture content are contributed to the spatial heterogeneity and observation errors, which are inevitable under field conditions.Validated value of moisture content predict well with observed values in the upper layers up to 100 cm. The index of agreement was 0.95 in 0-100 cm soil layer (Fig 26).

**Table 41 Quantitative measures of model performance for soil moisture under isabgol (2013-14)**

| Soil layer | RMSE | RRMSE | Correlation | Index of agreement |
|---|---|---|---|---|
| 0-100 | 0.0222 | 22 | 0.988 | 0.95 |
| 0-10 | 0.0143 | 14 | 0.991 | 0.97 |
| 10-20 | 0.0192 | 18 | 0.999 | 0.95 |
| 20-30 | 0.0214 | 18 | 0.961 | 0.93 |
| 30-40 | 0.0183 | 15 | 0.997 | 0.95 |
| 40-50 | 0.0274 | 23 | 0.999 | 0.90 |
| 50-60 | 0.0280 | 23 | 0.996 | 0.88 |
| 60-70 | 0.0228 | 24 | 0.996 | 0.94 |
| 70-80 | 0.0274 | 36 | 0.990 | 0.94 |
| 80-90 | 0.0184 | 22 | 0.997 | 0.97 |
| 90-100 | 0.0206 | 25 | 0.996 | 0.96 |

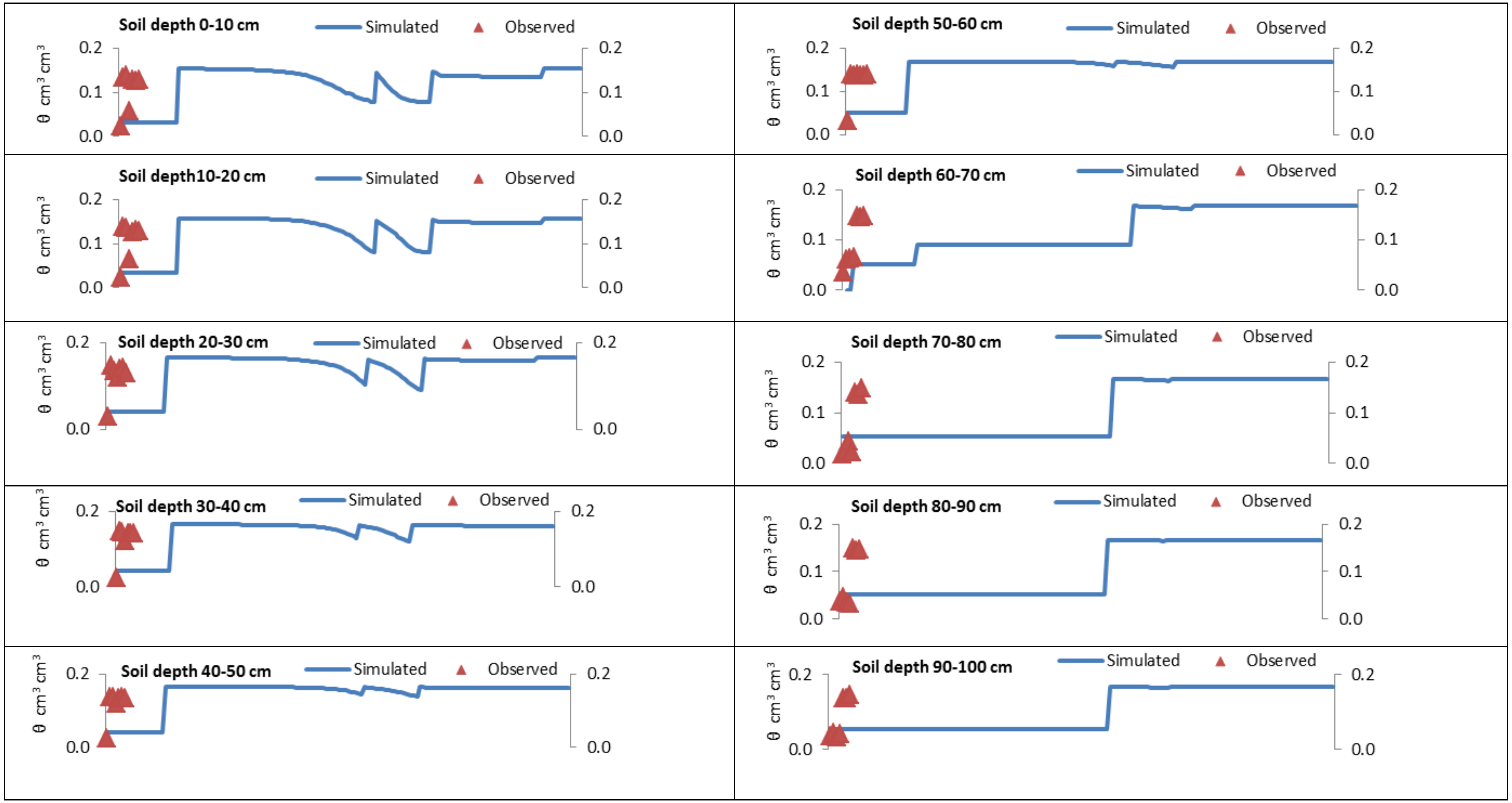



**Figure 26 Observed and validated soil water content under Isabgol**

# CropSyst Model Scenarios

# At

# Different levels of Nitrogen & Irrigation

# Hanumangarh

**Cotton**

| Irrigation level (mm) | Economic yield (kg/ha) | | | Water productivity (kg $m^{-3}$) | | |
|---|---|---|---|---|---|---|
| | Nitrogen level (kg/ha) | | | | | |
| | 100 | 120 | 150 | 100 | 120 | 150 |
| **300** | 2235 | 2235 | 2235 | 0.75 | 0.75 | 0.75 |
| **400** | 2876 | 2876 | 2876 | 0.72 | 0.72 | 0.72 |
| **500** | 3047 | 3047 | 3047 | 0.61 | 0.61 | 0.61 |
| **550** | 3047 | 3047 | 3047 | 0.55 | 0.55 | 0.55 |
| Farmers practice ( 396 mm+ 90 N kg/ha) EY = 2212 kg/ha WP= 0.55 kg/m3 | | | | | | |

**Clusterbean**

| Irrigation level (mm) | Economic yield (kg/ha) | | | Water productivity (kg $m^{-3}$) | | |
|---|---|---|---|---|---|---|
| | Nitrogen level (kg/ha) | | | | | |
| | 20 | 40 | 60 | 20 | 40 | 60 |
| **100** | 878 | 878 | 878 | 0.88 | 0.88 | 0.88 |
| **150** | 1406 | 1410 | 1416 | 0.94 | 0.94 | 0.94 |
| **200** | 1672 | 1701 | 1747 | 0.84 | 0.85 | 0.87 |
| **250** | 1898 | 1917 | 1920 | 0.76 | 0.77 | 0.77 |
| **300** | 1903 | 1925 | 1931 | 0.63 | 0.64 | 0.64 |
| Farmers practice ( 91 mm+ 20 N kg/ha) EY = 1612 kg/ha WP= 1.7 kg/m3 | | | | | | |

**Wheat**

| Irrigation level (mm) | Economic yield (kg/ha) | | | | Water productivity (kg $m^{-3}$) | | | |
|---|---|---|---|---|---|---|---|---|
| | Nitrogen level (kg/ha) | | | | | | | |
| | 100 | 120 | 140 | 160 | 100 | 120 | 140 | 160 |
| **350** | 3231 | 3373 | 3499 | 3608 | 0.92 | 0.96 | 1.00 | 1.03 |
| **400** | 3760 | 3893 | 4016 | 4140 | 0.94 | 0.97 | 1.00 | 1.04 |
| **450** | 3970 | 4161 | 4340 | 4506 | 0.88 | 0.92 | 0.96 | 1.00 |
| **500** | 4316 | 4449 | 4564 | 4675 | 0.86 | 0.89 | 0.91 | 0.94 |
| **550** | 4321 | 4453 | 4568 | 4678 | 0.79 | 0.81 | 0.83 | 0.85 |
| Farmers practice ( 470 mm+ 100 N kg/ha) EY = 4178 kg/ha WP= 0.88 kg/m3 | | | | | | | | |

**Mustard**

| Irrigation level (mm) | Economic yield (kg/ha) | | | Water productivity (kg $m^{-3}$) | | |
|---|---|---|---|---|---|---|
| | Nitrogen level (kg/ha) | | | | | |
| | 60 | 80 | 100 | 60 | 80 | 100 |
| **100** | 1537 | 1537 | 1537 | 1.54 | 1.54 | 1.54 |
| **150** | 2133 | 2133 | 2133 | 1.42 | 1.42 | 1.42 |
| **200** | 2337 | 2337 | 2337 | 1.17 | 1.17 | 1.17 |
| **250** | 2641 | 2734 | 2741 | 1.06 | 1.09 | 1.10 |
| **300** | 2663 | 2741 | 2741 | 0.89 | 0.91 | 0.91 |
| Farmers practice ( 234 mm+ 40 N kg/ha) EY = 1936 kg/ha WP= 0.82 kg/m3 | | | | | | |

**Barley**

| Irrigation level (mm) | Economic yield (kg/ha) | | | | Water productivity (kg $m^{-3}$) | | | |
|---|---|---|---|---|---|---|---|---|
| | Nitrogen level (kg/ha) | | | | | | | |
| | **100** | **120** | **140** | **160** | **100** | **120** | **140** | **160** |
| **250** | 3125 | 3125 | 3125 | 3125 | 1.25 | 1.25 | 1.25 | 1.25 |
| **300** | 3935 | 3935 | 3935 | 3935 | 1.31 | 1.31 | 1.31 | 1.31 |
| **350** | 4329 | 4329 | 4329 | 4329 | 1.24 | 1.24 | 1.24 | 1.24 |
| **400** | 4520 | 4520 | 4520 | 4520 | 1.13 | 1.13 | 1.13 | 1.13 |
| **450** | 4522 | 4522 | 4522 | 4522 | 1.00 | 1.00 | 1.00 | 1.00 |
| Farmers practice ( 315 mm+ 100 N kg/ha) EY = 3991 kg/ha WP= 1.26 kg/m3 | | | | | | | | |

# Bajju, Bikaner

**Clusterbean**

| Irrigation level (mm) | Economic yield (kg/ha) | | | Water productivity (kg $m^{-3}$) | | |
|---|---|---|---|---|---|---|
| | Nitrogen level (kg/ha) | | | | | |
| | 20 | 40 | 60 | 20 | 40 | 60 |
| **100** | 1199 | 1199 | 1199 | 1.20 | 1.20 | 1.20 |
| **150** | 1249 | 1249 | 1249 | 0.83 | 0.83 | 0.83 |
| **200** | 1586 | 1586 | 1586 | 0.79 | 0.79 | 0.79 |
| **250** | 1586 | 1586 | 1586 | 0.63 | 0.63 | 0.63 |
| Farmers practice ( 187 mm+ 20 N kg/ha) EY = 1145 kg/ha WP= 0.61 kg/m3 | | | | | | |

**Groundnut**

| Irrigation level (mm) | Economic yield (kg/ha) | | | Water productivity (kg $m^{-3}$) | | |
|---|---|---|---|---|---|---|
| | Nitrogen level (kg/ha) | | | | | |
| | 20 | 40 | 60 | 20 | 40 | 60 |
| **400** | 1160 | 1165 | 1165 | 0.29 | 0.29 | 0.29 |
| **450** | 2729 | 2818 | 2874 | 0.61 | 0.63 | 0.64 |
| **500** | 2924 | 2985 | 3042 | 0.58 | 0.60 | 0.61 |
| **550** | 3007 | 3040 | 3074 | 0.55 | 0.55 | 0.56 |
| Farmers practice ( 520 mm+ 30 N kg/ha) EY = 2856 kg/ha WP= 0.54 kg/m3 | | | | | | |

**Wheat**

| Irrigation level (mm) | Economic yield (kg/ha) | | | | Water productivity (kg $m^{-3}$) | | | |
|---|---|---|---|---|---|---|---|---|
| | Nitrogen level (kg/ha) | | | | | | | |
| | 100 | 120 | 140 | 160 | 100 | 120 | 140 | 160 |
| **350** | 1175 | 1175 | 1175 | 1175 | 0.34 | 0.34 | 0.34 | 0.34 |
| **400** | 2252 | 2252 | 2252 | 2252 | 0.56 | 0.56 | 0.56 | 0.56 |
| **450** | 2539 | 2539 | 2539 | 2539 | 0.56 | 0.56 | 0.56 | 0.56 |
| **500** | 2887 | 2887 | 2887 | 2887 | 0.58 | 0.58 | 0.58 | 0.58 |
| **550** | 2852 | 2887 | 2887 | 2887 | 0.52 | 0.52 | 0.52 | 0.52 |
| Farmers practice ( 478 mm+ 80 N kg/ha) EY = 2470 kg/ha WP= 0.51 kg/m3 | | | | | | | | |

**Mustard**

| Irrigation level (mm) | Economic yield (kg/ha) | | | | Water productivity (kg $m^{-3}$) | | | |
|---|---|---|---|---|---|---|---|---|
| | Nitrogen level (kg/ha) | | | | | | | |
| | 40 | 60 | 80 | 100 | 40 | 60 | 80 | 100 |
| **200** | 1102 | 1102 | 1102 | 1102 | 0.55 | 0.55 | 0.55 | 0.55 |
| **250** | 1322 | 1322 | 1322 | 1322 | 0.53 | 0.53 | 0.53 | 0.53 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **300** | 1432 | 1432 | 1432 | 1432 | 0.48 | 0.48 | 0.48 | 0.48 |
| **350** | 1514 | 1514 | 1514 | 1514 | 0.43 | 0.43 | 0.43 | 0.43 |
| **400** | 1512 | 1514 | 1514 | 1514 | 0.38 | 0.38 | 0.38 | 0.38 |
| Farmers practice ( 332 mm+ 40 N kg/ha) EY = 1458 kg/ha WP= 0.43 kg/m3 | | | | | | | | |

**Chickpea**

| **Irrigation level (mm)** | **Economic yield (kg/ha)** | | | **Water productivity (kg m$^{-3}$)** | | |
|---|---|---|---|---|---|---|
| | **Nitrogen level (kg/ha)** | | | | | |
| | **20** | **40** | **60** | **20** | **40** | **60** |
| **200** | 810 | 951 | 1110 | 0.41 | 0.48 | 0.56 |
| **250** | 1233 | 1234 | 1271 | 0.49 | 0.49 | 0.51 |
| **300** | 1464 | 1472 | 1503 | 0.49 | 0.49 | 0.50 |
| **350** | 1478 | 1562 | 1615 | 0.42 | 0.45 | 0.46 |
| Farmers practice ( 270 mm+ 20 N kg/ha) EY = 1515 kg/ha WP= 0.56 kg/m3 | | | | | | |