**3. MATERIAL AND METHODS**

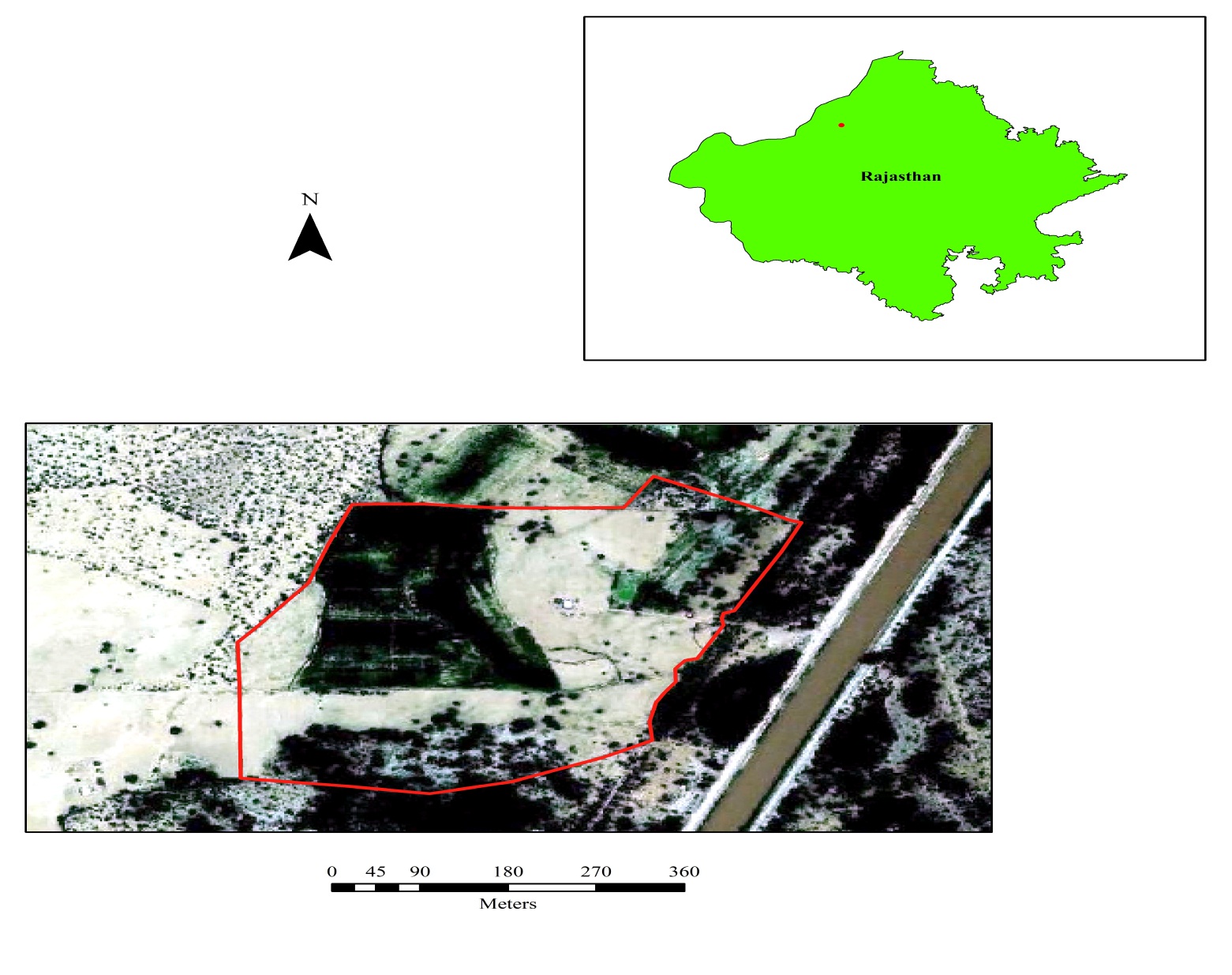
The study entitled **“Modelling the Soil-Water-Crop-Atmosphere System to Improve Land and Water Productivity in Stage II of IGNP”** was carried out during *kharif* and *rabi* season of 2012-13 and 2013-14. The details of experimental techniques adopted, criteria used for treatment, evaluation and methods followed during the course of investigation are described in this chapter.

**3.1 Site**

The study area is located at village Amarpura (RD 771 of Bajju), in Bikaner District of Rajasthan between 072o47’79”E longitude and 28o14’23”N latitude (fig 3.1). The elevation is approximately 234.7m above mean sea level. As per NARP classification of agro-climatic zones, Bikaner falls in Agro-climatic zone I-C (Hyper arid partially irrigated western plain zone). The general topography of area is undulating with some isolated steep contours. The soil texture is loamy sand. Invariably, the soil has low organic carbon content.

**3.2 Climate**

The study area features arid climatic conditions with an average annual rainfall of 250 mm, about 75% of which is received from the southwest monsoon during July–September. Rainfall conditions in the region are variable both in time and space. During the hottest period from May to June, mean daily maximum temperature rises up to 42°C. On individual days during the hottest period, it may rise up to 48°C. Hot winds with low relative humidity often cause dust storms during this season.



**Fig 3.1 Geographical location of Bajju, Bikaner**

In the winter season from December to January during both years, the daily mean temperature varied from 7.1 to 24.1°C. The winter 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.

After the withdrawal of monsoon at the end of September, temperature begins to decrease and leads to the winter season. November is distinguished as the post-monsoon season. During the months of December and January, occasional fog resides in the area.

In brief, the climate of Bikaner District is characterized by its dryness, extremes of temperature and scanty rainfall. The weather conditions prevailed during the period of experimentation (2012-2014) have been given in Table 3.1 and graphically depicted in figures 3.2 and 3.3.

**3.3 Soil**

The soils of the area are loamy sand in texture and slightly alkaline in reaction. The soil is 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 and poor fertility status are main features of soils of Bikaner District.

**3.4 Selection of farmer**

Selection of farmer was done on the basis of major cropping sequence grown in the study area and the willingness to participate. A general survey of farmers’ fields was carried out and representative farmer was selected keeping in view the responsiveness and irrigation facilities from the IGNP canal. A three dimensional view of the experimental field is depicted in fig 3.1.

**Table: 3.1 Monthly meteorological data during crop season 2012-13 (Y1) and 2013-14 (Y2) measured at meteorological observatory of Regional Research station, Central Arid Zone Research Institute, Bikaner.**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Month** | **Temperature (°C)** | | | | **Relative humidity (%)** | | | | **Total rainfall (mm)** | | **Evaporation**  **(mm)** | | **Solar Radiation (MJ m-2 d-1)** | |
| **Maximum** | | **Minimum** | | **Maximum** | | **Minimum** | |
| **Y1** | **Y2** | **Y1** | **Y2** | **Y1** | **Y2** | **Y1** | **Y2** | **Y1** | **Y2** | **Y1** | **Y2** | **Y1** | **Y2** |
| 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 |

**Fig. 3.2 Monthly meteorological data recorded during crop growing 2012-13 measured at meteorological observatory of Regional Research station, Central Arid Zone Research Institute, Bikaner.**

**Fig. 3.3 Monthly meteorological data recorded during crop growing 2013-14 measured at meteorological observatory of Regional Research station, Central Arid Zone Research Institute, Bikaner.**

### 3.5 Detailed plan of work

The experiment was conducted for two years (2012-13 and 2013-14) by growing two *kharif* season crops (Groundnut, clusterbean) and five *rabi* season crops (wheat, mustard, chickpea, isabgol and cumin) with different rotations. Total area of the experimental site was 17.5 ha out of which net cropped area was 13 ha. The study was carried out in the following four phases:

1. Selection of representative farmer’s field in Stage II of IGNP canal command area on the basis of pre survey of area
2. Observation on weather parameters, soil properties especially on physical characteristics, cropping pattern, plant physiology, and irrigation water management during cropping season of experimental period
3. Use of CropSyst model for crop modelling using experimental data of different crops/crop rotations and irrigation schedules
4. Scenario simulation for recommending alternative crops against traditional cropping and irrigation schedules for improved land and water productivity (kg m-3 water applied as well as rupees m-3 water applied)

**3.5.1 Survey of the area to assess current land and water productivity**

To assess the current land and water productivity, 20 farmers having average land holding (15-25 ha) were selected randomly from IGNP irrigated area near Bajju (Bikaner). Data on crops grown, cropping pattern, fertilizer use, number of irrigation, depth of irrigation, crop yield etc. were collected using personnel interview method by employing pre-tested schedule during year 2012-13. Water productivity was computed by the formula:

Water productivity = Yield (kg)/water applied (m3)

**3.5.2 Field experiment**

To improve the water productivity at field scale a field experiment was conducted in *kharif* and *rabi* season of 2012-13 and 2013-14 with the following cropping systems replicated four times at the farmer’s field. The selection of farmer was done on the basis of major cropping sequence representing the study area, water availability and responsiveness. The crops were selected on the basis of their higher economic value, more profit and low water requirement.

|  |  |
| --- | --- |
| **S. No.** | **Cropping system** |
| **1** | Groundnut - Wheat |
| **2** | Groundnut - Cumin |
| **3** | Groundnut - Isabgol |
| **4** | Groundnut - Mustard |
| **5** | Clusterbean – Chickpea |

### 3.6 Agronomical operation

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

**3.6.1 Groundnut (Var. TG-1)**

The management practices of groundnut adopted by the farmer in the study area are presented in Annexure-I. The tillage operations were ploughing, harrowing followed by cultivator and planking. Sowing was done on May 25, 2012 in first year and on June 23, 2013 in second year. Seed rate used during the experiment was 100 kg ha-1with a spacing 0.30 x 0.10 m by seed-drill. Full dose of nitrogen (N) and phosphorus (P) was applied as basal.

**3.6.2 Clusterbean (RGC- 936)**

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 August 13, 2012 in first year and on July 28, 2013 in second year with seed rate of 16 kg ha-1with a spacing of 0.30 x 0.10 m by seed drill. Full dose of nitrogen (N) and phosphorus (P) was applied as basal.

**3.6.3 Wheat (Raj. 3765)**

The tillage operation were ploughing, harrowing followed by cultivator and planking (Annexure- I). Sowing was done on December 13, 2012 in Ist year and on December 9, 2013 in IInd year. Seed rate used by the farmer ranged between 100 kg ha-1with a spacing of 0.20 x 0.05 m by seed drill. Half dose of nitrogen (N) and full phosphorus (P) was applied as basal and remaining half dose of nitrogen (N) was top dressed at 30 DAS.

**3.6.4 Mustard (Pusa bold)**

Annexure I shows the management practices of mustard adopted by the farmer in the study area. The tillage operations were ploughing, harrowing followed by cultivator and planking. Sowing was done on November 25, 2012 during first year and on December 8, 2013 during the second year with seeding rate of 6 kg ha-1 with a spacing of 0.30 x 0.10 m by seed drill. Half dose of nitrogen (N) and full phosphorus (P) was applied as basal and remaining half dose of nitrogen (N) was top dressed at 30 DAS.

**3.6.5 Chickpea (RSG-963)**

The management practices of chickpea adopted by the farmer in the study area are presented in Annexure I. The tillage operations were ploughing, harrowing followed by cultivator and planking. Sowing was done on December 13, 2012 during the Ist year and on December 9, 2013 during the IInd year using seed rate of 80 kg ha-1with a spacing of 30 x 10 cm by Seed drill. Full dose of N and P was applied as basal.

**3.6.6Cumin (GC-4)**

Annexure-I shows the management practices of cumin adopted by the farmer in the study area. The tillage operations were ploughing, harrowing followed by cultivator and planking. Sowing was done on December 13, 2012 during the first year and on December 9, 2013 during the second year. Seed rate used by the farmer was 8 kg ha-1with a spacing of 0.30 x 0.10 m by seed drill. Half dose of N and full P was applied as basal and remaining half N was top dressed at 30 DAS

**3.6.7 Isabgol (GI-2)**

Annexure-I shows the management practices of isabgol adopted by the farmer in the study area. The tillage operations were ploughing, harrowing followed by cultivator and planking. Sowing was done on December 13, 2012 during the Ist year and on December 9, 2013 during the IInd year. Seed rate used by the farmer was 8 kg ha-1 with a spacing of 0.30 x 0.10 m by seed drill. Half dose of N and full P was applied as basal and remaining half N was top dressed at 30 DAS.

### 3.6.8 Source of Irrigation

In the study area, the source of irrigation is the IGNP canal water. The method used for discharge, duration and depth of irrigation and frequency are presented in Table 3.2.

**Table 3.2 Overview of the irrigation data collected for calibration of CropSyst model at farmer fields in Bikaner District.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Data** | **Method / source** | **Frequency** | **Purpose** |
| Discharge from 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 |

**3.7 Plant studies**

**3.7.1 Yield attributes and yield**

For measuring physiological parameters three sampling areas for each crop farmer were selected. For all crops, the area of each sampling of 0.50 m x 0.50 m was selected for measuring GAI and AGY. For measuring yields, an area of 1 m x 1m area was selected for each crop. For measuring rooting depth, five plant samples were used (Table 3.3).

**Table 3.3 Overview of the plant growth data collected for calibration of CropSyst model at farmer fields in Bikaner District**

|  |  |  |  |
| --- | --- | --- | --- |
| **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 | Input derivation |
| Rooting depth | Field observation | 2-3 times | Input derivation |
| Crop yields | Field observation | at Harvest | Calibration and Validation |

**3.7.1.1 Leaf area (cm2 cm-2)**

The leaves from plants selected for growth analysis from field were used for the estimation of leaf area. Leaf area was measured by leaf area meter and expressed as cm2 per square meter.

**3.7.1.2 Specific Leaf Area (SLA)**

The Specific Leaf Area was calculated as follows:

Leaf area (cm2)

SLA = ------------------------------

Leaf dry weight (g)

**3.7.1.3 Leaf biomass (g)**

The leaves from plants for analysis were put between butter paper sheets and kept in hot air over at 85 ± 10 C for 24 hours. The dry weight of the leaves was recorded and expressed in grams.

**3.7.1.4 Days to emergence**

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

**3.7.1.5 Days to 50 percent flowering**

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

**3.7.1.6 Days to 50 percent grain filling**

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

**3.7.1.7 Days to maturity**

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

**3.7.1.8 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).

**3.7.1.9 Seed yield**

The seed yield of each net plot was recorded in kg plot-1 after cleaning the threshed produce and was converted to kg ha-1.

**3.7.1.10 Straw yield**

Straw yield was obtained by subtracting the seed yield (kg ha-1) from biological yield (kg ha-1).

**3.7.1.11 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-1. Later this was converted to kg ha-1.

**3.7.1.12 Harvest index**

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

|  |  |  |
| --- | --- | --- |
| Harvest index (%) = | Economic yield | x 100 |
| Biological yield |

**3.7.2 Chemical analysis**

**3.7.2.2.1 Nitrogen 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, after harvest in seed and stover was estimated by using the following relationship:

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Nitrogen uptake =  (kg/ha) | Nitrogen content in  seed (%) | x | Seed  yield (kg/ha) | **+** | Nitrogen content in stover (%) | x | Stover yield (kg/ha) |
| 100 | | | | | | |

**3.8 Soil studies**

The soil of each plot was analysed for physical and chemical properties of soil as per method listed in Table 3.5.

**3.9 Collection of soil sample**

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 depth, respectively was 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’s farm 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 with proper labeling.

**Table 3.4 Overview of the soil properties data collected for calibration of CropSyst model at farmer fields in Bikaner District.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Data** | **Method / source** | **Frequency** | **Purpose** |
| Texture | Hydrometer method | Once | Input derivation |
| Bulk density | Core Sampler 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 sowing | General |
| Electrical Conductivity | In soil-water suspension of 1:2 by Conductivity  Meter | Before sowing | Input derivation |
| Organic Carbon | Wet digestion method (Walkley and Black, 1947) | Before sowing | Input derivation |

**Methods of analysis:**

**Table 3.5 Method of analysis**

|  |  |  |  |
| --- | --- | --- | --- |
| **S.NO.** | **Property** | **Procedure** | **Reference** |
| **Soil Analysis** | | | |
| 1 | pH | 1:2 soil water suspension (using pH meter) | Richards (1954) |
| 2 | EC | 1:2 soil water suspension  (using conductivity meter) | Richards (1954) |
| 3 | Organic carbon | Wet digestion method | Walkley and Black (1934) |
| 4 | Cation Exchange Capacity | Sodium Index method | Richards (1954) |
| 5 | Calcium carbonate | Rapid Titration method | Hutchinson and McLennan (1914) |
| 6 | Total-N | Modified kjeldahl method | Jackson (1973) |
| 7 | NH4-N | Nessler’s method | Peechet. al.(1947) |
| 8 | NO3-N | Phenoldisulphonic acid method | Harper(1924) and Prince (1945) |
| 9 | Exchangeable potassium | Available potassium - water soluble potassium | Pratt (1982) |
| 10 | Bulk density | Core sampler method | Blake and Hartge (1986a) |
| 11 | Particle density | Core sampler method | Blake and Hartge (1986b) |
| 12 | Mechanical analysis | Hydrometer method | Bouyoucos (1962) |
| 13 | Saturated hydraulic conductivity | Laboratory measurement of hydraulic conductivity of saturated soil | Klute (1965) |
| 14 | Soil water constants | Using pressure plate (Membrane) apparatus | Richards and firemen (1943) |
| 15 | Soil moisture | Using TDR | Ledieuet. al. (1986) |
| **Water analysis** | | | |
| 1 | Ca+ Mg | Titration for Ca+Mg with standard EDTA solution as per method No. 7 of USDA Hand Book No. 60. | Richards (1954) |
| 2 | Na and K | Sodium with the help of flame photometer as per method (10a) of USDA Hand Book No. 60 | Richards (1954) |
| 3 | Cl content | Titration for Cl- with standard AgNO3 solution as per method No.13 of USDA Hand Book No.60. | Richards (1954) |
| 4 | SO4content | Turbidimetric method | Chesnin and Yien (1951) |
| 5 | CO3and HCO3 | Titration with standard sulphuric acid using methyal red and phenolphthalein indicator | A.O.A.C. (1950) |
| 6 | NO3-N | Phenoldisulphonic acid method | Harper(1924) and Prince (1945) |
| **Plant analysis** | | | |
| 1 | Nitrogen | Modified macro kjeldahl method | Jackson (1958) |

**3.9 Model description**

CropSyst model was chosen for this study. 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 (Stockle *et al.,* 2003). The model is user-friendly, has capability to provide links to GIS software, a weather generator and other utility programs. It 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. 3.4). 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 3.6.



**Figure 3.4: Overview of components and modular structure of CropSyst model (Stockle *et al.* 2003)**

**Table 3.6: 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 |

**3.10 CropSyst Model Calibration and Validation**

CropSyst model was calibrated for two *kharif* season crops (clusterbean and groundnut) grown during 2012 and five *rabi* season crops (wheat, mustard, chickpea, cumin and isabgol) grown during 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 in 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 calibration and validation was conventionally made by comparing simulation outputs with observed data. The CropSyst model was validated using the field experiment data collected in 2012-13 growing season. It was validated for aboveground biomass (AGB), grain yield, N-uptake and green area index (GAI). The statistical analysis of difference between measured and simulated values included 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.

**3.11 Statistical analysis**

**3.11.1 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.

**3.11.2 Water use efficiency**

Water use efficiency (WUE) was defined as

|  |
| --- |
| Y |
| ET |

WUE=

where, WUE represents water use efficiency for the grain yield (kg/ha), Y is the grain yield and ET is the evapotranspiration during the growth period.

**3.11.3 Root Mean Square Error**

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

**3.11.4 Correlation coefficient**

A measure that determines the degree to which two variable's movements is associated. (Kwon and Torrie, 1964)  
  
The correlation coefficient is calculated as:

**3.11.5 Index of agreement**

The index of agreements used to pondered percentage of the criteria to which the alternative is preferred to alternative and is calculated by (Willmott, 1982)