**6. SUMMARY AND CONCLUSION**

The study entitled **“Modelling the Soil-Water-Crop-Atmosphere System to Improve Land and Water Productivity in Stage II of IGNP”** was carried out at village Amarpura (Bajju), Bikaner during *kharif* and *rabi* seasons of 2012-13 and 2013-14. The results presented and discussed in the preceding chapters are summarized and concluded in this chapter:

**6.1 Current land and water productivity of different crops and cropping systems**

6.1.1 In the area of study groundnut and clusterbean with average areas of 61.4 percent and 36.7 percent, respectively were recognized as important crops. While in *rabi* season, wheat with an average area of 59.8 percent was observed as the most prominent crop followed by chickpea and mustard with average areas of 26.9 percent and 17.4 percent, respectively. Crops like cumin and isabgol were registered with negligible coverage area.

6.1.2 Highest average seed yield of 2852.7 kg ha-1 was recorded with groundnut whereas lowest average seed yield of 438 kg ha-1 was registered with cumin crop. Among the two *kharif* season crops, groundnut had higher water productivity of the order of 0.45 kg m-3 as compared to 0.39 kg m-3 registered with clusterbean. While amongst *rabi* season crops, chickpea had highest water productivity in terms of water applied of 0.58 kg m-3.

6.1.3 Highest seed yields were observed with groundnut-wheat cropping system followed by groundnut-mustard and lowest yields were recorded with clusterbean-chickpea cropping system. Highest water productivity was recorded with clusterbean-chickpea cropping system (0.49 kg m-3) followed by groundnut-wheat (0.47 kg m-3) and groundnut-mustard (0.46 kg m-3). Lowest water productivity of 0.33 kg m-3 was recorded with groundnut-cumin cropping system.

**6.2 Soil physical and chemical properties and quality of irrigation water**

6.2.1 Values CEC, pH, FC, PWP and soil-water content increased with increase in soil depth whereas values bulk density, NO3-N, NH4-N, soil organic matter and electrical conductivity decreased with increase in soil depth.

6.2.2 The quality of water used for irrigation was good. pH and EC of water ranged between 6.9 and 7.5 and 0.23 and 0.27 dS m-1, respectively.

**6.3 Productivity**

6.3.1 In terms of seed and biomass productivity, groundnut produced higher biomass than clusterbean among *kharif* seasons crops whereas wheat produced higher biomass than mustard, chickpea, cumin and isabgol among *rabi* season crops.

6.3.2 The average seed and biomass productivity was highest for groundnut-wheat cropping system followed by groundnut-mustard, groundnut-cumin, groundnut-isabgol and clusterbean-chickpea cropping systems during both years of study.

**6.4 Economics**

6.4.1 Higher cost of cultivation was recorded with groundnut as compare to clusterbean during *kharif* season of 2012 and 2013. While among *rabi* season crops, the highest cost of cultivation was recorded with wheat followed by chickpea, mustard, isabgol and cumin during 2012-13 and 2013-14 growing seasons.

6.4.2 In terms of monetary return, groundnut recorded higher gross return and net return over clusterbean during *kharif* seasons of 2012 and 2013. Among *rabi* season crops, chickpea registered with maximum gross return and net return. While, isabgol recorded lowest gross return and net return during 2012-13 and 2013-14.

6.4.3 Groundnut-wheat cropping system recorded highest cost of cultivation followed by groundnut-mustard, groundnut-isabgol, groundnut-cumin and clusterbean-chickpea cropping systems. Groundnut-mustard cropping system gave maximum gross return of Description: 120px-Indian_Rupee_symbol217296 ha-1 during 2012-13. While, during 2013-14 groundnut-wheat cropping system gave maximum gross return of the order of Description: 120px-Indian_Rupee_symbol210997 ha-1. But groundnut-cumin cropping system recorded highest net return of Description: 120px-Indian_Rupee_symbol168511 and 149824 ha-1 during both the year of study. Clusterbean-chickpea cropping system recorded lowest cost of cultivation as well as gross and net return.

6.4.4 Highest pooled cost of cultivation was registered with groundnut during *kharif* season. Groundnut earned highest gross return and net return. However, clusterbean has lowest cost of cultivation, gross return and net return, respectively. Among *rabi* season crops, highest cost of cultivation was recorded with wheat followed by chickpea, mustard, isabgol and cumin. Cumin registered lowest cost of cultivation. Chickpea gave maximum gross and net return. Isabgol registered lowest gross and net return.

6.4.5 Highest pooled cost of cultivation was recorded with groundnut-wheat cropping system followed by groundnut-mustard, groundnut-isabgol, groundnut-cumin and clusterbean-chickpea cropping system. Clusterbean-chickpea cropping system had lowest cost of cultivation. Groundnut-wheat cropping system gave maximum gross return. In terms of net return, groundnut-cumin cropping system recorded highest amount. Clusterbean-chickpea cropping system gave lowest gross and net return.

**6.5 Water use and water use efficiency**

6.5.1 The total water applied to different crops ranged from 289.2 to 728.9 mm and 188.0 to 619.6 mm during 2012-13 and 2013-14 growing seasons, respectively. Among *kharif* season crops higher total water was applied to groundnut (728.9 and 619.6 mm) as compared to clusterbean (349.2 and 264.8 mm) during both the years while among *rabi* season crops, maximum water was applied to wheat (498.6 and 547.2 mm) followed by isabgol (353.0 and 313.0 mm), cumin (353.0 and 250.6 mm), mustard (350.5 and 250.6 mm) and chickpea (289.2 and 188.0 mm).

6.5.2 The total water used in terms of ET by different crops ranged from 84.5 to 664.9 mm and 90.5 to 530.5 mm during 2012-13 and 2013-14, respectively. The highest water was used by groundnut (664.9 and 530.5 mm) followed by wheat (264.1 and 330.6 mm), clusterbean (205.6 and 183.7 mm), mustard (168.5 and 174.7 mm), chickpea (154.4 and 121.8 mm), cumin (92.6 and 92.4 mm) and isabgol (84.5 and 90.5 mm).

6.5.3 Clusterbean-chickpea cropping system recorded highest WP of 1.22 and 1.71 kg m-3 and 0.42 and 0.63 kg m-3, respectively for biological and seed yield during 2012-13 and 2013-14, followed by groundnut-mustard cropping system.

6.5.4 Clusterbean-chickpea cropping system recorded highest WPET of 2.17 and 2.54 kg m-3 for biological yield and 0.74 and 0.93 kg m-3 for seed yield whereas groundnut-cumin recorded lowest WPET 1.10 and 1.41 kg m-3 and 0.43 and 0.55 kg m-3 of biological and seed yield respectively, during 2012-13 and 2013-14.

6.5.5 Highest WP (in terms of water applied) and WPET (in terms of water used) for gross and net return was registered with clusterbean-chickpea cropping system and lowest with groundnut-wheat cropping system.

**6.6 N-uptake and N-balance**

6.6.1 Groundnut and chickpea recorded highest N-uptake among *kharif* and *rabi* season crops during both years. Clusterbean in *kharif* and isabgol in *rabi* season recorded lowest N-uptake during both years.

6.6.2 Among the different crops, wheat had highest total N followed by mustard and groundnut. Highest residual N in soil of the order of 105.2 and 96.6 kg ha-1 was recorded with wheat crop, whereas lowest residual soil N of 19.2 and 14.0 kg ha-1 was registered with groundnut crop.

**6.7 Model calibration**

6.7.1 Simulated values for GAI of clusterbean at different growth stages matched well with observed GAI with RMSE of 0.2810.

6.7.2 Simulated seed yield (1148 kg ha-1) of clusterbean was very closer to the observed seed yield of 1145 kg ha-1 with absolute and relative errors of 3.0 and 0.3 per cent, respectively. Similarly, the observed AGB (4202 kg ha-1) of clusterbean was slightly lower than simulated AGB (4273 kg ha-1) with absolute and relative errors of 71.0 and 1.7 percent, respectively.

6.7.3 The simulated N-uptake (40.2 kg ha-1) of clusterbean was slightly lower than observed N-uptake (47.3 kg ha-1) with absolute and relative errors of 7.1 and 15.0 percent.

6.7.4 The RMSE values of soil moisture content for clusterbean field ranged from 0.0183 to 0.0445. Simulated values of moisture content matched well with observed values in most of the layers up to 100 cm with index of agreement of 0.87 for soil depth of 0-100 cm.

6.7.5 Simulated values of GAI for groundnut at different growth stages matched well with the observed GAI with RMSE of 0.2410.

6.7.6 Simulated seed yield (2942 kg ha-1) of groundnut was in good agreement to the observed yield of 2856 kg ha-1 with absolute and relative errors of 86.0 and 3.0 percent, respectively. Similarly, the observed AGB of groundnut (7197 kg ha-1) was slightly lower than simulated (7356 kg ha-1) with absolute and relative errors of 159.0 and 2.2 percent, respectively.

6.7.7 Simulated N-uptake (108.3 kg ha-1) of groundnut was slightly lower than observed N-uptake (122.3 kg ha-1) with absolute and relative errors of 14.0 and 11.4 percent, respectively.

6.7.8 The RMSE values of soil moisture content for groundnut field ranged from 0.0062 to 0.0115. Simulated values of moisture content matched well with observed values in the soil layers up to 100 cm with the index of agreement of 0.82 for soil depth of 0-100 cm.

6.7.9 Simulated values of GAI for wheat at different growth stages were in good agreement with observed GAI as indicated by low order RMSE of 0.1980.

6.7.10 Simulated seed yield (2047 kg ha-1) of wheat was slightly lower than the observed yield of 2470 kg ha-1, with the absolute and relative errors of 423.0 and 17.1 percent, respectively. Similarly, the observed AGB of wheat (5871 kg ha-1) was slightly higher than simulated AGB (5111 kg ha-1) with absolute and relative errors of 760.0 and 12.9 percent, respectively.

6.7.11 Simulated N-uptake (61.1 kg ha-1) was very close to observed N-uptake (62.0 kg ha-1) in wheat with absolute and relative errors of 0.9 and 1.5 percent, respectively.

6.7.12 The RMSE values of soil moisture content for wheat ranged from 0.0301 to 0.0436. Simulated values of moisture content matched well with observed values in most of the layers up to 100 cm, with index of agreement of 0.84 in soil depth for 0-100 cm.

6.7.13 Simulated GAI at different growth stages of mustard matched well with the observed GAI with RMSE of 0.2350.

6.7.14 Simulated seed yield (1385 kg ha-1) of mustard was in good agreement to the observed yield of 1458 kg ha-1 with absolute and relative errors of 73.0 and 5.0 percent, respectively. Similarly, the observed AGB of mustard (4435 kg ha-1) was slightly higher than simulated AGB (4198 kg ha-1) with absolute and relative errors of 237.0 and 5.3 percent, respectively.

6.7.15 Simulated N-uptake (48.2 kg ha-1) of mustard was lower than observed N-uptake (57.2 kg ha-1) with absolute and relative errors of 9.0 and 15.7 percent, respectively.

6.7.16 The RMSE values of moisture content for mustard ranged from 0.0384 to 0.0501. Simulated values of moisture content matched well with observed values in the soil layers up to 100 cm, with index of agreement of 0.81 in soil depth for 0-100 cm.

6.7.17 Simulated values for GAI for chickpea at different growth stages were in good agreement with observed GAI with RMSE of 0.2810.

6.7.18 Simulated seed yield of 1473 kg ha-1 of chickpea was in good agreement to the observed yield of 1515 kg ha-1 with absolute and relative errors of 42.0 and 2.8 percent, respectively. Similarly, the observed AGB (3604 kg ha-1) of chickpea was slightly lower than simulated AGB (3690 kg ha-1) with absolute and relative errors of 86 and 2.4 percent, respectively.

6.7.19 Simulated N-uptake (62.0 kg ha-1) of chickpea was slightly lower than observed N-uptake (66.8 kg ha-1) with absolute and relative errors of 4.8 and 7.2 percent, respectively.

6.7.20 The RMSE values of soil moisture content for chickpea ranged from 0.0117 to 0.0216. Simulated values of moisture content matched well with observed values in most of the layers up to 100 cm with index of agreement of 0.95 for soil depth of 0 to 100 cm.

6.7.21 Simulated GAI of cumin for different growth stages were in good agreement with the observed GAI with RMSE of 0.0910.

6.7.22 Simulated seed yield (426 kg ha-1) of cumin well-matched to the observed yield of 438 kg ha-1 with absolute and relative errors of 12.0 and 2.7 percent, respectively. Similarly, the observed AGB (1123 kg ha-1) of cumin was slightly lower than simulated AGB (1237 kg ha-1) with absolute and relative errors of 114.0 and 10.2 percent, respectively.

6.7.23 Simulated N-uptake (27.4 kg ha-1) of cumin was higher than observed N-uptake (17.3 kg ha-1) with absolute and relative errors of 10.1 and 58.4 percent, respectively.

6.7.24 The RMSE values of moisture content ranged from 0.0081 to 0.0123 in cumin field. Simulated values of moisture content matched well with observed values in the soil layers up to 100 cm with index of agreement of 0.96 for soil depth of 0-100 cm.

6.7.25 Simulated values for GAI for isabgol at different growth stages were in good agreement with observed GAI with RMSE of 0.1690.

6.7.26 Simulated seed yield (429 kg ha-1) of isabgol well matched to the observed yield of 462 kg ha-1 with the absolute and relative errors of 33.0 and 7.1 percent, respectively. Similarly, the observed AGB (1085 kg ha-1) was slightly higher than simulated AGB (997 kg ha-1) with absolute and relative errors of 88.0 and 8.1 percent, respectively.

6.7.27 Simulated N-uptake (20.0 kg ha-1) of isabgol was lower than observed N-uptake (28.0 kg ha-1) with the absolute and relative errors of 8.0 and 28.6 percent, respectively.

6.7.28 The RMSE values of soil moisture content for isabgol ranged from 0.0139 to 0.0785. Simulated values of moisture content matched well with observed values in most of the layers up to 100 cm with index of agreement of 0.44 for soil depth of 0-100 cm.

**6.8 Model validation**

6.8.1 Validated values of GAI for clusterbean at different growth stages found in good agreement with observed GAI (RMSE of 0.2790).

6.8.2 Validated seed yield 1094 kg ha-1 of clusterbean matched well with observed seed yield of 1047 kg ha-1 with absolute and relative errors of 47.0 and 4.5 percent, respectively. Similarly, the observed AGB of clusterbean (3828 kg ha-1) was slightly lower than simulated AGB (4055 kg ha-1) with absolute and relative errors of 227.0 and 5.9 percent, respectively.

6.8.3 Simulated N-uptake (42.7 kg ha-1) of clusterbean was slightly lower than observed N-uptake (46.2 kg ha-1) with absolute and relative errors of 3.5 and 7.6 percent, respectively.

6.8.4 RMSE values of soil moisture content for clusterbean ranged from 0.0182 to 0.0443. Simulated values of soil moisture content matched well with observed values in most of the upper layers up to 100 cm with index of agreement of 0.87 for soil depth of 0-100 cm.

6.8.5 Simulated values of GAI for groundnut at different growth stages were in good agreement with observed GAI with RMSE of 0.3050.

6.8.6 Simulated seed yield (3023 kg ha-1) of groundnut was in good agreement to the observed seed yield of 2926 kg ha-1 with absolute and relative errors were 97.0 and 3.3 percent, respectively. Similarly, the observed AGB (7399 kg ha-1) was slightly lower than simulated AGB (7559 kg ha-1) with absolute and relative errors of 160.0 and 2.2 percent, respectively.

6.8.7 Simulated N-uptake of groundnut (145.5 kg ha-1) was slightly higher than observed N-uptake (134.2 kg ha-1) with the absolute and relative errors of 11.3 and 8.4 percent, respectively.

6.8.8 RMSE values of soil moisture content for groundnut field ranged from 0.0050 to 0.0118. Simulated value of soil moisture content matched well with observed values in the soil layers up to 100 cm with index of agreement of 0.83 for soil depth of 0-100 cm.

6.8.9 Simulated values of GAI for wheat at different growth stages matched well with observed GAI with RMSE of 0.2850.

6.8.10 Simulated seed yield (2532 kg ha-1) of wheat was slightly lower to the observed seed yield of 2772 kg ha-1 with absolute and relative errors of 240.0 and 8.7 percent, respectively. Similarly, the observed AGB (6599 kg ha-1) was slightly higher than simulated AGB (6143 kg ha-1) with absolute and relative errors of 456.0 and 6.9 percent, respectively.

6.8.11 Simulated N-uptake (61.6 kg ha-1) of wheat was slightly lower than observed N-uptake (69.7 kg ha-1) with absolute and relative error of 8.1 and 11.6 percent, respectively.

6.8.12 RMSE values of soil moisture content for wheat ranged from 0.0069 to 0.0234. Simulated value of soil moisture content matched well with observed values in most of the layers up to 100 cm with index of agreement of 0.96 for soil depth of 0-100 cm.

6.8.13 Simulated values of GAI for mustard at different growth stages were in poor agreement with observed GAI (RMSE of 0.2910)

6.8.14 Simulated seed yield (1534 kg ha-1) of mustard was in good agreement to the observed yield of 1692 kg ha-1 with relative errors of 9.3 per cent, respectively. Similarly, the observed AGB (4996 kg ha-1) was slightly higher than simulated AGB (4653 kg ha-1) with absolute and relative errors of 343.0 and 6.9 percent, respectively.

6.8.15 Simulated N-uptake (58.3 kg ha-1) of mustard was slightly lower than observed N-uptake (63.9 kg ha-1) with absolute and relative errors of 5.6 and 8.8 percent, respectively.

6.8.16 RMSE values of moisture content for mustard ranged from 0.0117 to 0.0224. Simulated value of soil moisture content matched well with observed values in the soil layers 0-100 cm with index of agreement of 0.96 for soil depth of 0-100 cm.

6.8.17 Simulated values of GAI for chickpea at different growth stages were in poor agreement with observed GAI with RMSE of 0.2700.

6.8.18 Simulated seed yield (1661 kg ha-1) of chickpea was in good agreement to the observed seed yield of 1791 kg ha-1 with absolute and relative errors of 130.0 and 7.3 per cent, respectively. Similarly, the observed AGB (3928 kg ha-1) of chickpea was slightly lower than simulated AGB (4355 kg ha-1) with absolute and relative errors of 427.0 and 10.9 percent, respectively.

6.8.19 Simulated N-uptake (79.0 kg ha-1) of chickpea was slightly higher than observed N-uptake (71.0 kg ha-1) with absolute and relative errors of 8.0 and 11.3 percent, respectively.

6.8.20 RMSE values of soil moisture content for chickpea ranged from 0.0089 to 0.0223. Simulated soil moisture content matched well with observed values in most of the layers up to 100 cm with index of agreement of 0.95 for soil depth of 0-100 cm.

6.8.21 Simulated values of GAI for cumin at different growth stages were in poor agreement with observed GAI with RMSE of 0.1140.

6.8.22 Simulated seed yield (410 kg ha-1) of cumin moderately matched to the observed yield of 502 kg ha-1 with absolute and relative errors of 92.0 and 18.3 per cent, respectively. Similarly, the observed AGB (1403 kg ha-1) of cumin was higher than simulated AGB (1195 kg ha-1) with absolute and relative errors of 208.0 and 14.8 percent, respectively.

6.8.23 Simulated N-uptake (26.5 kg ha-1) of cumin was slightly higher than observed N-uptake (22.0 kg ha-1) with absolute and relative errors of 4.5 and 20.5 percent, respectively.

6.8.24 The RMSE values of soil moisture content for cumin ranged from 0.0049 to 0.0138. Simulated value of soil moisture content matched well with observed values in the soil layers up to 100 cm with index of agreement of 0.90 for soil depth of 0-100 cm.

6.8.25 Simulated values for GAI of isabgol at different growth stages were in poor agreement with observed GAI with RMSE of 0.2150.

6.8.26 Simulated seed yield (597 kg ha-1) of isabgol was well matched with the observed yield of 557 kg ha-1 with absolute and relative errors of 40.5 and 7.3 percent, respectively. Similarly, the observed AGB (1395 kg ha-1) was lower than simulated AGB (1894 kg ha-1) with absolute and relative errors of 499.0 and 35.8 percent, respectively.

6.8.27 Simulated N-uptake (34.0 kg ha-1) was higher than observed N-uptake (26.0 kg ha-1) with absolute and relative errors of 8.0 and 30.8 percent, respectively.

6.8.28 RMSE values of soil moisture content ranged from 0.0143 to 0.0280 in isabgol field. Simulated value of moisture content matched well with observed values in most of the layers up to 100 cm with index of agreement of 0.95 for soil depth of 0-100 cm.

**6.9 Model simulation scenarios**

6.9.1 Clusterbean yield increased with the subsequent increase in the levels of addition of water and nitrogen fertilizer. In contrast, water productivity decreased with the subsequent increase in the levels of addition of water but increased with increasing levels of fertilizer. Yield was higher with 150 mm applied water and 40 kg ha-1 nitrogen application. Water productivity, however was maximum with 100 mm applied water and 40 kg ha-1 nitrogen application.

6.9.2 Groundnut yield increased with the subsequent increase in the levels of addition of water and nitrogen fertilizers. In contrast, water productivity decreased with the subsequent increase in the levels of addition of water except with 400 mm and increased with increasing levels of fertilizer. Yield and water productivity of groundnut were maximum with 450 mm applied water and 40 kg ha-1 nitrogen application.

6.9.3 Subsequent increase in the levels of addition of water with 50 kg ha-1 N decreased to wheat yield and in case of 200 kg N ha-1 yield increased with the subsequent increase in the levels of addition of water. In contrast, water productivity decreased with the subsequent increase in the levels of addition of water and increased with increasing levels of fertilizer. Wheat yield and water productivity were higher with 200 mm applied water and 100 kg ha-1 nitrogen application.

6.9.4 Mustard yield was higher with 150 mm applied water and 80 kg ha-1 nitrogen application. In contrast, water productivity decreased with the subsequent increase in the levels of addition of water and increased with increasing levels of fertilizer. Water productivity was higher with 100 mm applied water and 80 kg ha-1 nitrogen application.

6.9.5 Chickpea yield increased with the subsequent increase in the level of addition of water and nitrogen fertilizers. In contrast, water productivity decreased with the subsequent increase in the levels of addition of water and increased with increasing levels of fertilizer. Yield was higher with 150 mm applied water and 60 kg ha-1 nitrogen application. Water productivity was maximum with 100 mm applied water and 40 kg ha-1 nitrogen application.

**CONCLUSION**

The present study showed that water deficit is an important constraint in limiting the yields of crop under arid environment. Further, nitrogen availability can also limit yield in a more important way than poor water condition. Groundnut produced higher biomass and seed yield than clusterbean during *kharif* season and among *rabi* season wheat produced higher biomass and seed yield than other crops. The seed yields were higher for groundnut-wheat, intermediate for groundnut-mustard and lower for groundnut-isabgol, groundnut-cumin and clusterbean-chickpea cropping system. Cost of cultivation and returns of crops varied considerably and highest cost of cultivation was observed for groundnut than clusterbean during *kharif* season and among *rabi* season crops, wheat incurred highest cost of cultivation than other crops. Groundnut crop had highest net return followed by clusterbean, chickpea, cumin, mustard, wheat and isabgol. Among the tested cropping systems, groundnut-cumin, groundnut-mustard and groundnut-wheat were more profitable than other cropping systems.

ET loss by crops varied from 300-560 mm and constituted 77-93% of total water applied. Clusterbean–chickpea had highest water productivity in physical terms.

In the present study the CropSyst (Cropping System) model was calibrated, validated and used as a tool to predict the yield and water balance of crops in IGNP Stage-II. Predictions of GAI, AGB, seed yield and water balance tended to be quite accurate in general but for N-uptake prediction accuracy was comparatively lower. Among the tested crops, it was better suited for groundnut, clusterbean, wheat, mustard and chickpea relative to other crops. Simulation demonstrated that the current productivity of various crops grown in the area can be achieved with less fertilizer (nitrogen) and deficit irrigation regime. It can only be concluded that with fewer input parameters and less complete calibration procedures, CropSyst can be applied for simulating the effect of N and water management on yield and water productivity of crops under arid condition of IGNP. It was also demonstrated that the model can be use to derive best management options in term of nitrogen fertilizer and irrigation application.