2.4 : Refining regional level prediction of cotton production

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Target & Achievements

Targets	Achievements	Centers involved
Field experimentation to determine genetic coefficients	Field experiments were conducted with a hybrid and variety at 2 dates of sowing under rainfed as well as irrigated condition. Phenology, growth and yield observations were recorded in addition to data on shed leaves and fruiting parts.	CICR (N), CICR(C), NBSS&LUP, UAS (D), NAU (S)
Collection of soil and weather data	The weather data, soil properties of the experimental station and rainfall data of all the rainguage sites of Nagpur, Dharwad and Baruch districts were collected.	CICR (N), CICR(C), NBSS&LUP, UAS (D), NAU (S)
Model calibration	INFOCROP – model has been calibrated to simulate the growth and yield under both dry land and irrigated condition. Data collected from the current year experiment was utilized to fine tune and account the model to leaf and fruiting form losses. Work is in progress to accurately simulate boll weight and boll number	CICR (N).
Model validation	Model was validated using data from different locations, years, hybrid, varieties, dates of sowing, levels of fertilizer, rainfed and irrigated conditions. Model validation was also done using on farm field trial experiments.	CICR (N), CICR(C), NBSS&LUP, UAS (D), NAU (S)
Integration of INFOCROP with GIS	The soil map digitization of Nagpur, Dharwad and Baruch districts were completed based on soil properties and rainfall pattern. An interface between the model and GIS was developed. Yield prediction of Nagpur and Dharwad districts has been done for year 2004-05.	CRIDA, NBSS & LUP.
Measurement of Spectral reflectance	Spectral reflectance data from the control experiment and reference plots of Nagpur, Dharwad and Bharuch districts were measured. Vegetative index (VI field) of reference plots was correlated with satellite data	CICR (N), UAS (D), NAU (S).

Delineation of total cotton area of Nagpur, Dharwad and Baruch district	Using spectral signatures at red and green region obtained from satellite, the total cotton area of Nagpur Dharwad and Baruch districts was estimated. Cotton area in these districts has been classified based on soil depth and soil texture. In Baruch, cloud free satellite data was available for only part of the district hence, area estimation was not accurate.	NRSA, NBSS &LUP, UAS (D), CRIDA.
Integration of soils and weather component with RS data using GIS (Arcview) technique.	The total cotton area derived from the satellite has been divided into 9 thesian polygons for Nagpur districts based on the soil texture, depth and rainfall information. Similarly, for Dharwad district 23 polythesian triangles were generated.	CRIDA, NRSA.
Prediction of cotton production using the integrated approach	Model was run to each of the polygons identified based on soil depth and soil texture properties of Nagpur and Dharwad districts. Yield of each polygon was summed up to get total production. Infocrop model was calibrated to simulate the actual yield observed under field condition accounting for the losses due to insect pests. Hence, in a insect free situation like the current year, where there was no insect attack the model had under predicated. Further work is on to account for the losses due to pest.	CICR (N), CICR(C), NBSS&LUP, UAS (D), NAU (S), CRIDA, NRSA.

Model Calibration and Validation

The field experiment data comprising date of sowing and N levels was used for model validation. Crop parameters such as phenological development, leaf area index, biomass accumulation and their partitioning into leaf, stem and fruiting parts, nitrogen accumulation and yield were estimated. Rest of the coefficients such as radiation use efficiency, light extinction coefficient, root extension growth, potential boll weight etc was collected from the literature. The genetic coefficients of different varieties used in the analysis of the model were estimated by repeated iterations until a close match between simulated and observed phenology and yield was obtained in these treatments (Table 2.4.1).

Table 2.4.1: Genetic coefficients set after the model calibration for a Hybrid and a variety

Genotypic constants	**Units**	**Hybrid**	**Variety**
Base temperature	oC	12.8	12.8
Thermal time for-	degree-		
Germination	days	70	70
Germination to anthesis (range)	degree-	1000 -1100	900 – 1000
Anthesis to maturity (range)	days	1600 - 1900	1500 - 1700
Relative growth rate of leaves during	degree-		
early stage (RGRPOT)	days	0.0095	0.009
Specific leaf area (SLA)	oC/ d	0.0022	0.0020
Radiation use efficiency (RUE) (range)	dm2/mg	1.8 – 2.0	1.6 – 1.8
Extinction coefficient of leaf at	g/MJ/day		
flowering		0.80	0.70
Potential boll weight	ha leaf/ha	5000	4500
Root extension growth rate	soil	12	12
Sensitivity to flooding (between 1.0 –	mg/boll	1.0	1.0
1.2)	mm day-1	1.0	1.0
Index of greenness of leaves (between			
0.8-1.2)	Scale		
	Scale		

Leaf area index, biomass accumulation and yield

Fig. 1, 2, 3 presented the time course increment in LAI, biomass accumulation, stem weight, leaf weight and yield of cotton with two dates of planting and two nitrogen levels under rainfed condition of Nagpur. It is clear that in cotton at early growth stages both leaf area expansion and biomass accumulations were sluggish, picked up at squaring (approx. 45 DAS) and peaked at flowering and early boll development stages (90 to 120 DAS). Up to flowering much of the biomass was partitioned towards the leaf, while at later stages most of the biomass was accumulated in the stem and fruiting parts (Fig. 2.4.2).

Effect of date of sowing

LAI, biomass production and yield declined in late sown crop. LAI reduced from 1.6 to 0.9 while the biomass and yield were reduced from 4800 kg ha^{-1} to 4000 kg ha^{-1} and 852 kg ha^{-1} to 526 kg ha^{-1} respectively. Model captured the decline in both LAI and biomass of late sown crop and the pattern was on par with the field measurements (Fig. 2.4.1,2,3).

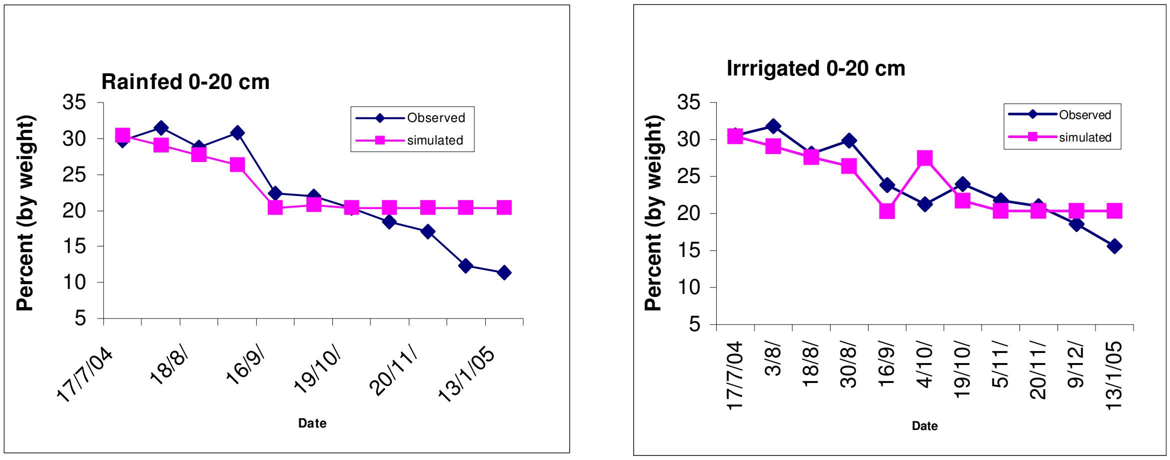
Low Nitrogen effect

Under rainfed condition significant differences were not seen in growth and yield of cotton at different N levels. Hence, to determine the sensitivity of the model to 'N' a treatment without 'N' fertilizer (0 kg N ha^{-1}) was compared with recommended dose of 'N' (90 kg ha^{-1}). LAI, biomass and seed cotton yield increased with increase in N level. Model simulated values showed a marginal increase in LAI, biomass and yield in good agreement with observed values (Fig. 2.4.1,2,3).

Effect of water stress

Water deficit is an important constraint to cotton production under dryland condition, and Fig. 2.4.5 gives an example of the capability of the model to simulate the water deficit effects of a crop (cv. NHH 44) sown in the rainy season of 2004 at CICR farm, Nagpur without irrigation. Cotton crop in general, experiences intermittent drought because of uneven distribution of rainfall or terminal drought because of early cessation of rains. In this Experiment, crop experienced a terminal drought and the application of single irrigation at boll development significantly increased the LAI, biomass and seed cotton yield. Fig. 2.4.6 shows that the model was sensitive to simulate the increased growth and yield with irrigation. The observed and simulated soil moisture status of rainfed and irrigated condition is presented in Fig. 2.4.4. The crop duration was extended with the application of irrigation, which was precisely simulated by the model. This resulted in higher boll number which, led to increased yield under irrigated condition.

Fig. 2.4.4 Observed and simulated soil moisture under rainfed and irrigated



conditions (0-20 cm depth).

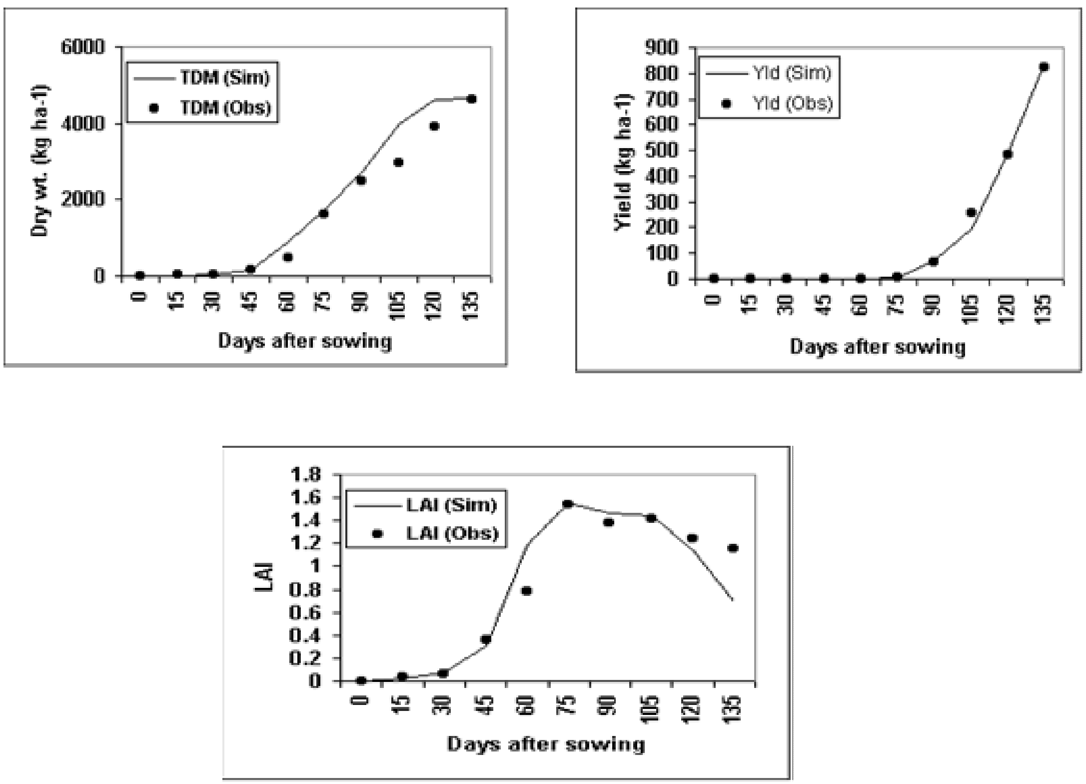


Fig. 2.4.5 Observed (Symbols) and simulated (Line)) (a) LAI, (b) biomass and (c) seed cotton yield in a dry land experiment with intra-hirsutum hybrid NHH 44 sown on 22nd June, 2004 on vertisol at CICR

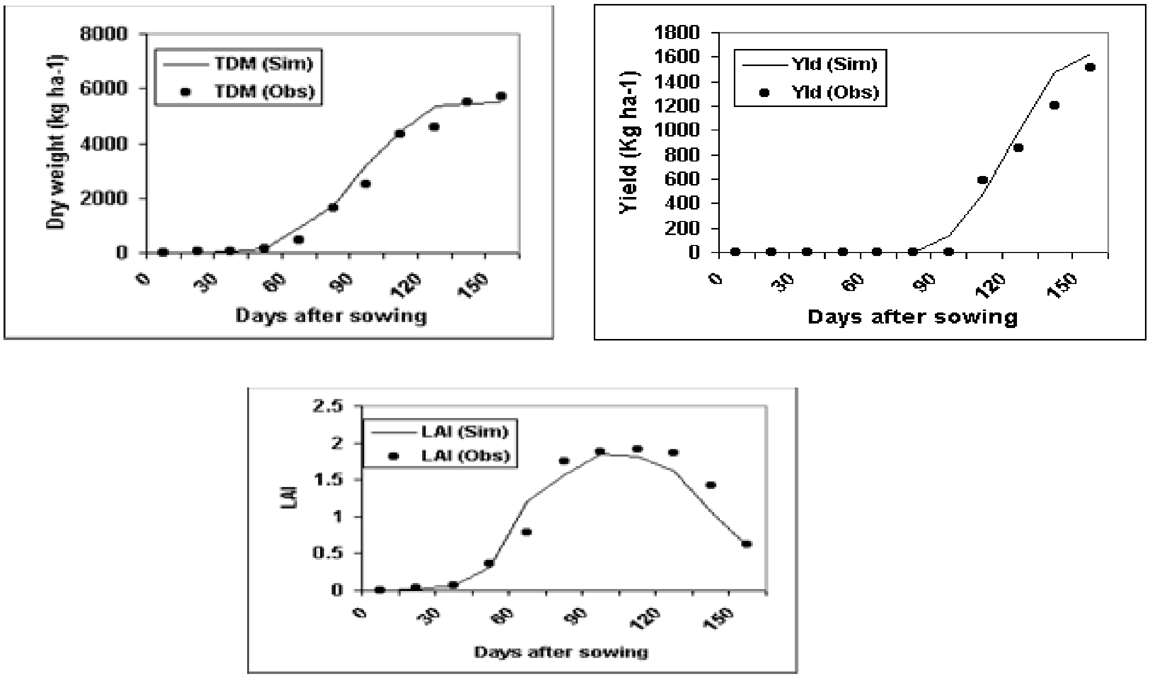


Fig 2.4.6 : Observed (Symbols) and simulated (Line) (a) LAI, (b) biomass and (c) seed cotton yield in an irrigated experiment with intra-hirsutum hybrid (NHH 44) sown on 22nd June, 2004 on vertisol at CICR Farm, Nagpur

Sensitivity analysis

The sensitivity of the model was tested for input parameters such as change in ambient temperature and levels of N application. These studies were done for irrigated conditions because significant responses to N fertilizer were not seen under rainfed condition. Analysis was done using weather and soils data of Coimbatore. In all cases, optimal sowing dates and recommended fertilizer management was used. Simulation was done using 10 years of weather data.

The effect of change in temperature was studied for every 2°C change in maximum as well as minimum temperatures during the entire life cycle. The range of such evaluation was from –8 to +8 °C. The sensitivity of the model to N levels was analyzed for every 15 kg increment in N fertilizer from 0 kg to 120 kg N ha^{-1}.

It was very sensitive to decrease in temperature compared to increased temperature. A temperature increase by 8 °C reduced the yield by 40 % while, 8 °C reduced temperature decreased the yield by 86 %. On the other hand, low temperature extends the crop duration and exposes the reproductive phase to very low temperature (December to February). Low temperature reduces the overall growth rate and leads to sterility. A decrease in temperature beyond –2 ^{o}C resulted in a linear decrease in yield of about 250 kg $^{o}C^{-1}$.

Yield increased by 18 % from 0 kg to 15 kg N ha^{-1} . It continued to increase up to 60 kg N ha^{-1} beyond which plants did not show significant response to N. This is the recommended dose of N for varieties. At higher N levels plants develop large canopy, which leads to mutual shading and attracts large numbers of disease and pest attacks.

Model validation

Field experiment for evaluation of model performance

Data sets generated from the field experiments conducted during 2000-01, 2001-02, 2002-03 and 2003-04 crop seasons in major cotton producing states of India across locations spreading from Hisar in North to Coimbatore in South were used for model validation. Cotton cultivation in North and partly in South India is irrigated while; in Central India it is mostly rainfed. Hybrids are more predominant in Central and southern zones. The treatments included varied in locations, weather, soil characters, hybrids/varieties, sowing dates, fertilizer and seasons. Before sowing the soil profile was examined and horizon wise soil samples were analysed for texture, soil reaction, EC, bulk density, water holding capacity, hydraulic conductivity, organic carbon, $CaCO_3$, exchangeable cations, CEC, initial ammonical N, nitrate N, soil available N, available P and available K.

Subsequently, soil moisture was recorded at 15 days interval from 3 layers - 0-20, 20-40 and 40-60 cm. Crop parameters such as phenological development, leaf area index, biomass accumulation and their partitioning into leaf, stem and fruiting parts, nitrogen accumulation and yield were compared with model-simulated values.

Phenology

In the data sets used for model validation large variation was seen for time to flowering and maturity. Time to flowering ranged from 56 to 84 days while time to maturity ranged from 150 to 204 days. Year to year fluctuation was more under rainfed condition compared to irrigated condition. Model simulated the time for flowering more accurately compared to time to maturity. The simulated time to flowering ranged between 54 to 80 days with an RMSE value of 3 days, while time to maturity ranged between 136 to 193 days with an RMSE of 8.5 days . In most part of India, cotton at early growth stages suffers from intermittent drought, water logging and insect attack and at later stages owing to its indeterminate growth habit produces multiple flushes of square and bolls, which complicated the determination of physiological maturity of the crop. This led to poor relations between phenology and heat unit in cotton under adverse condition that, might explain the discrepancies seen between observed and simulated phenology.

Biomass and yield

A close relation was obtained between simulated and observed biomass and seed cotton yields across all treatments of locations, seasons, genotypes, sowing dates and N levels. Measured biomass and seed cotton yield ranged from 3096 to 8319 kg ha^{-1} and 590 to 2466 kg ha^{-1} respectively. Though, strong correlations were seen between the total biomass and yield, but under rainfed condition the relation does not hold good for cotton. A lot of fruiting forms are lost both by biotic (insect damage) and abiotic factors such as drought, water logging, temperature, cloudiness and nutrient limitation. Thus, the final yield depends on the amount of fruit loss and the plants ability to compensate for the loss. Even with the above limitation model simulated yield showed an accuracy of 94% with and RMSE of 200 kg ha^{-1}. Simulated biomass on the other hand showed 89% accuracy with an RMSE value of 608 kg ha^{-1}. The difficulty in recording of lost leaves, squares and bolls in between observations could be partially responsible for not getting good agreement between simulated and observed biomass.

Boll number and boll weight

Yield-attributing characters such as the boll number and boll weight were simulated well by the model. Boll number was relatively more accurate compared to boll weight. The r^2 value for boll number and boll weight of observed and simulated regression was 89% and 83% respectively. Simulated boll number tended to overestimate under irrigated condition compared to dry land condition. On the contrary the boll weight was underestimated in irrigated condition compared to dry land condition. This suggests that plant response to water balance at boll development phase requires further calibrations in the model. This is too complicated in cotton because there is loss of boll by both abiotic and biotic factors. Depending upon the genotype, soil moisture status and stage at which loss occurs, plant tries to compensate by producing new flushes. Thus, uncertainties in the measured data exist. Moreover, insect populations in cotton are known to fluctuate widely during the growing season, and the number and size of fruit attacked by insects may also vary.

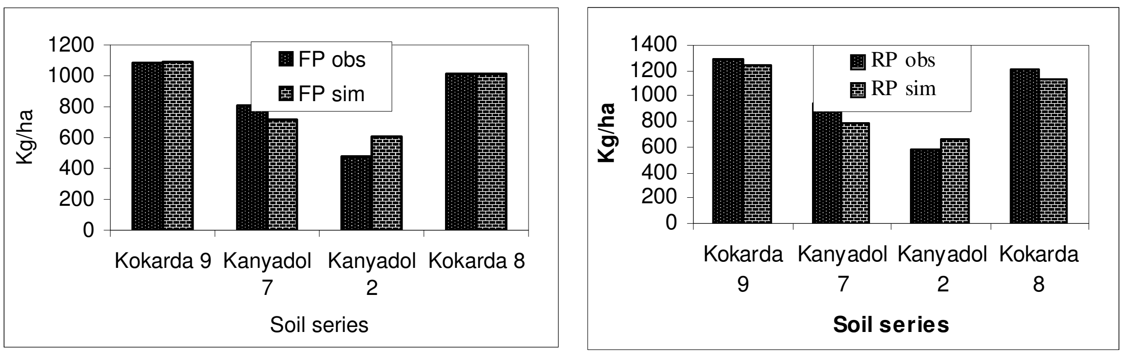
Model performance with on farm experimental data:

The performance of INFOCROP was validated through a series of on farm experiments (Fig. 2.4.7) conducted on farmers' field from 2001-2002 through 2003-04 in Kokarda –Kaniyadol watershed, Nagpur (under AESR 10.2) characterized by a dry, hot sub humid climate. Field experiments were conducted using hybrid cotton (NHH-44) under rainfed condition on four identified soil series, namely Kaniyadol 2 (Vertic Haplusteps with 45 cm depth), Kaniyadol 7 (Typic Haplustepts with 66 cm. Depth) Kokarda 8 (Vertic Haplusteps with 97 cm depth) and Kokarda 9 (Typic Haplustepts with 150 cm depth). Recommended package of practices (100: 50: 50 and 60x60 cm spacing) was compared with a farmer practice (65:30:30 and 90x90 cm spacing). Both the observed and simulated results indicated that the soil belonging to Kokarda 8 and Kokarda 9 series supported better plant growth and produced higher seed cotton yield than the soil of Kaniyadol 2 and Kaniyadol 7 series .

Under the recommended practice, across the soil types and years the mean observed seed cotton yield ranged from 470-1520 kg/ha and the simulated yield ranged from 566-1402 kg/ha. Under farmers practice, across the soil types and years the mean observed seed cotton yield ranged from 430 –1320kg/ha. And the simulated yield ranged from 531-1234 kg/ha. The observed yields fitted fairly well with the simulated yields under both the conditions with and RMSE of 143.9 kg/ha (14.3% of mean observed yield) under recommended practices and 134.5 kg/ha (15.9% of mean observed yield) under farmers practice.

The correlation coefficient between observed and simulated yields was highly significant (r=0.91 with an SE of 125.8 kg/ha under recommended practice and r=0.86 with an SE of 126.4 kg/ha under farmers practice). The fit was better in deeper soil than shallow or medium soils, possibly due to the presence of weathered basalt layer which would have altered the soil moisture relations and root penetration. The model is currently not able to account for these variations. The differences in observed yield owing to variations in soil properties and rainfall patterns were consistently reflected in the simulated results.

The simulated crop duration, phenology, growth parameters (Leaf Area Index and total dry matter), root extension and soil moisture varied across the soil types and years. The values of these parameters were similar to those reported from the controlled field experiments in rainfed cotton conducted else where in this region and other published literature.



(a) **(b)**

Fig 2.4.7 : INFOCROP validation- mean (3 years) seed cotton yield under (a) farmers management and (b) recommended management

Model performance for current year (2004-05)

In general the LAI under irrigated condition was marginally higer than rainfed condition and showed a decline with with late planting both under rainfed and irrigated conditions across the genotypes. Model simulated LAI was slighltly higher than the observed values necessiating further refinement of the model either at partioning of biomass towards leaf or the senescence rate inresponse to temperature or soil moiture deficit. The simulated biomass was 96 % in agreement with the observed biomass. Hybrid NHH 44 produced more biomass compared to variety LRA 5166. Similarly, under irrigated condition both the genotypes produced 10 q/ha more biomass than under dry land condition. These differences were well captured by the model.

Model simulated seed cotton yield was less accurate (91 %) as compared to biomass. In general across the genotypes both under rainfed and irrigated condition the model under predicted the yield. The INFOCROP model was calibrated to predict the actual yield harvested in the field without accounting for the loss of insects which could be responsible for under estimation of yield in an insect free year like the last year. Thus, the model needs calibration to account for the losses due to insect pests.

- **Spatial distribution of cotton crop**

During the 2004-05, analysis of satellite data to derive the information of the spatial distribution of cotton crop overlay, analysis of the soil and crop maps of Nagpur, Dharwad and Bharuch districts were carried out. In addition, trend fitted yield was also derived for these districts. Meteorological yield was also computed for Nagpur district. The details are presented hereunder.

Analysis of satellite data

LISS-III data of IRS-P6 corresponding to October 11 & 16, 2004 covering Nagpur district was classified using total enumeration approach and spatial distribution of cotton crop was derived. Administrative boundary of Nagpur district was overlaid and the acreage of cotton crop of Nagpur district was found to be 76047 ha. In comparison to the previous year, a marginal reduction of about 3% of cotton cropped area in this year was observed.

Satellite data covering Dharwad district of Karnataka state and Bharuch district of Gujarat state were also classified and the spatial distribution of cotton crop was derived. In case of Dharwad district, the total cotton cropped area was 159018 ha. In case of Bharuch district, the entire district was not covered in the selected satellite dataset and the area of cotton crop in the satellite data used in the analysis was 52523 ha.

Integration of soils and weather component

In order to integrate the information of spatial distribution of cotton crop as derived from the satellite data with the soil and weather parameters, GIS techniques were employed. Soil map prepared on 1: 2500000 scale by NBSS & LUP alongwith the polythesian triangles based on the location of the station for weather parameters were provided in the form of a shape file by the Central Research Institute for Dryland Agriculture (CRIDA). This shape file was converted into polygons in Arc GIS. The raster data of the classified cotton map was also vectorized.

As per the NBSS & LUP soil map, six categories each of soil type and depth are represented. The soil maps are decomposed to generate soil depth and type maps separately and after overlaying the cotton vector, the area statistics of cotton in each of the attributes was derived.

Soil Depth

Six categories of soil depth were used in the generation of the soil map. The area statistics of cotton in each of the six soil depth categories were computed. It is revealed that about two-thirds of cotton crop of Nagpur district is grown on deep soils. Though very shallow soils are not congenial for cotton cultivation, yet about 22% of cotton is being cultivated on very shallow soils.

Soil Type

The area statistics of cotton in each of the soil type categories were computed and are presented in the Table-2.4.4. From the table it is revealed that Distribution of cotton crop was found to be about two-thirds on fine textured soils. About 22% is distributed on coarse textured soils.

These vectors were integrated to generate area statistics of cotton crop cultivated under different soil depth, soil type regimes individually and across all combinations for each of the 9 polythesian triangles of Nagpur district. Yield computed for these different spatial domains of soil, varying in soil texture and type for a given polythesian triangle alongwith the cropped area statistics would provide the production at disaggregated level.

A combined analysis of the cultivation of cotton crop on different soil types and depths across the district was carried out. In this analysis, the per centage of association of a given soil depth with soil type were worked out. Further, proportion of the cotton area in each of these combined units was also worked out.

Table 2.4.4 : Cotton cropped area in different soil types of Nagpur district

Texture	Area (ha)	Proportion of cotton area (%)
Clayey	11244.3	15.5
Fine	33193.8	45.7
Fine-Loamy	3728.5	5.1
Loamy	8013.8	11.0
Coarse-Loamy	16220.2	22.3
Loamy-Skeletal	188.4	0.3
Total	72589.0	100.0

Dharwad district:

The soil map of Dharwad district prepared by NBSS & LUP on 1: 250000 scale has 6 categories each of soil texture and depth. Cotton cropped area statistics for all the categories independently and in association was generated after overlaying the cotton cropped area for each weather station.

Soil Depth

Six categories viz., very deep, deep, moderately deep, shallow, moderately shallow and very shallow are represented in the soil map. About 80% of the cotton is distributed on very deep to moderately deep categories.

Soil Texture

Five categories viz., calcareous clay, clayey, cracking clayey, gravelly clayey and gravelly loam soil textures are represented in the soil map. About 90% of the cotton is distributed on fine textured classes that are more suited for cotton cultivation - Table-2.4.5:

Table 2.4.5 : Cotton cropped area in different soil types of Dharwad district

Soil type	Area (ha)	Proportion (%) of cotton cropped area
Calcareous, Clayey	71276	44.8
Clayey	32535	20.5

Cracking Clay	41645	26.2
Gravelly Clay	11249	7.1
Gravelly Loam	2297	1.4
Total	159018	100.0

These vectors were integrated to generate area statistics of cotton crop cultivated under different soil depth, soil type regimes individually and across all combinations for each of the 23 polythesian triangles of Dharwad district. Yield computed for these different spatial domains of soil, varying in soil texture and type for a given ploythesian triangle alongwith the cropped area statistics would provide the production at disaggregated level.

Bharuch district:

In the soil map provided by the NBSS & LUP, the soil polygons are classified into 3 soil types and 4 depths, leading to 6 out of 12 possible combinations. Cotton area in these individual soil
types and depth classes and in combination were also extracted and the results are presented in the Table 2.4.6.

Table 2.4.6 : Cotton cropped area (ha) in different textures and types in combination

Soil Texture	Depth	Cotton cropped area (ha)
Clayey	Shallow	3350
	Moderate	68
	Deep	1569
	Very deep	39793
Loamy	Very deep	7394
Sandy	Very deep	349

Production Estimationn - Integrated approach

Nagpur district

The vectors were integrated to generate area, production and productivity statistics of cotton crop cultivated under different soil depth, soil type regimes individually and across all combinations for each of the 9 polythesian triangles of Nagpur district.. Yield computed for these different spatial domains of soil, varying in soil texture and type for a given polythesian triangle revealed that the productivity levels are high at Ramtek. Narkhed, and Kuhi whereas it was lowest at Katol, Kalmeshwar and Nagpur. The average productivity of Nagpur district was 462 kg/ha which was relatively low mainly because of low yields obtained at Katol and Kalmeshwar.

Soil Depth

The area, production and productivity statistics of cotton in each of the six soil depth categories were computed. It is revealed that medium deep to deep soils are congenial for cotton cultivation under rainfed conditions of Nagpur district. Productivity of medium deep soil is around 752 kg/ha while in deep soil it was around 608 kg/ha. In too deep soils plants get waterlogged at one or the other stage of the crop hence, yield declined. Similarly, in shallow soils plants are quite often subjected to intermittent drought and hence, yield showed proportionate decline in yield with reduction in depth of the soil.

Soil Type

The area, production and productivity statistics of cotton in each of the soil type categories were computed .It is revealed that productivity was highest in fine loamy soil, followed by fine and coarse textured loamy soils. However, productivity levels are too low in clayey and loamy soils suggesting the necessity for further refinement in the model to simulate the yield under heavy clayey conditions. A combined analysis of the cultivation of cotton crop on different soil types and depths across the district revealed that 55% of the production is from fine textured soils and nearly 88% of the production is from deep soils (Fig. 2.4.8 a & b).

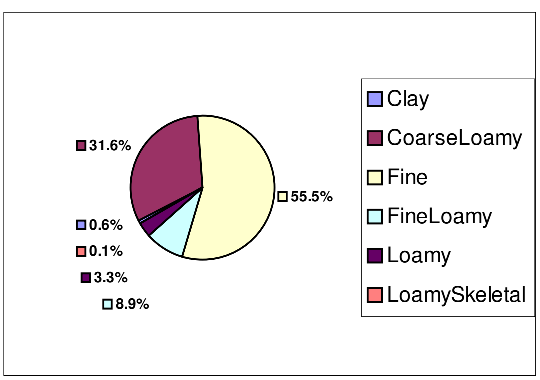


Fig. 2.4.8a

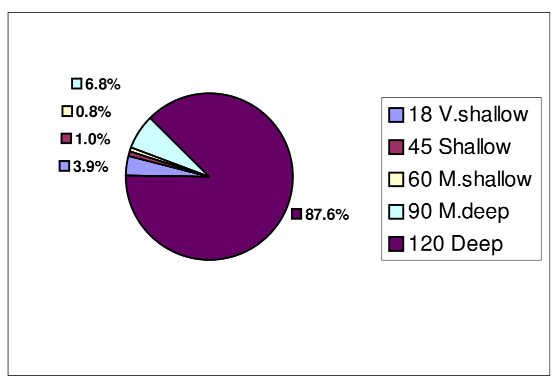


Fig. 2.4.8b

Fig.2.4.8 : Proportion (%) of the cotton production in (a) different soil types and (b) different depths in Nagpur district

Dharwad district:

The soil map of Dharwad district prepared by NBSS & LUP on 1: 250000 scale has 6 categories each of soil texture and depth. There are 20 polythesian triangles of Dharwar district . Yield computed for these different spatial domains of soil, varying in soil texture and type for a given polythesian triangle revealed that the productivity levels are high at Havanagi, Hattimattur, Gudgeri and Dharwad while it was low at Bellatti and Morab. The average productivity of the Dharwad district was 415 kg/ha and it was low mainly because of low yield at Morab. If Morab is excluded, the average yield of the district goes up to 587 kg/ha.

Soil Depth

Six categories viz., very deep, deep, moderately deep, shallow, moderately shallow and very shallow are represented in the soil map. Productivity is high at moderately shallow to medium deep soils where as it is low in shallow soils.

Soil Texture

Five categories viz., calcareous clay, clayey, cracking clayey, gravelly clayey and gravelly loam soil textures are represented in the soil map. Productivity levels are high in cracking clay and gravelly clay soils while it was low in calcareous clay type.

In Dharwad district maximum production comes from deep soil (73%) having either calcareous or cracking clayey

Time series yield:

A second order time series equation was fitted for the historical cotton yield of Nagpur district. The general expression of the equation is:

$$Y = a_0 + b_1 * T + b_2 T^2 + c\, C$$

where Y is cotton yield (kg/ha), T is time in years, C is scaled crop condition, as manifested by yield and a_0, b_1, b_2 and c are constants. The estimate for 2004 was calculated as 214 kg/ha, with an R-square of 0.868, standard error of 51.3. The production was estimated as 95.73 thousand bales of 170 kg. each. The estimate for Dharwad was found to be 247 kg/ha, with an R-square of 0.748, standard error of 28.31. The production was estimated as 231.04 thousand bales of 170 kg. each.