Abstract

Soybean (*Glycine max(l) Merill*) is a short season leguminous crop that grows well under diverse thermal and moisture regimes. It is an excellent source of protein and edible oil and its potential in meeting the demand for the same in India is well recognized. Soybean cultivation is mainly concentrated in the states of Madhya Pradesh (M. P.), Maharashtra and Rajasthan accounting for approximately 97% of the area. Maharashtra has witnessed phenomenal growth in area under soybean in the last decade (0.2 to 2.1 mha) and reports higher mean yield of 1.25 t/ha as compared to 1.02 t/ha in M.P. Kolhapur district in Maharashtra reports record yields (1.56 t/ha) with contribution of more than 35% area coming from Shirol *taluka.*

In the country, the growth in area under soybean is not in tune with growth in productivity; the latter has remained abysmally low (0.96 t/ha) as compared to world average (1.8 t/ha). Thus the production growth pattern is dominantly area-led. Yield led pattern in the years to come should primarily emerge from applying integrated technologies to support crop, water and land management decisions. In view of this, the present study has attempted development of Spatial Decision Support System (SDSS) for soybean agriculture at farm level in Shirol *taluka* with respect to crop, water and land management. The decision support is generated at a spatial unit (soil depth polygon per village) derived from integration of village map with soil depth map. Visual Basic for Applications programming language is used for linking and embedding the three management modules in GIS.

Crop management

The crop management module deals with modeling of soybean (JS-335 variety) phenology and yield using artificial neural network (ANN) trained with data generated from agronomic experiments. During the years 2003 and 2004, soybean crop was subjected to treatments of soil depth (shallow, medium and deep), sowing date (early, mid and late-May) and plant population (16, 32 and 48 plants/m^2) at different locations in the study area. Temperature data at 5 experimental sites and soil physical and chemical characteristics at 27 sample points distributed in the study area were measured. Phenology was modeled as a function of

temperature by computing accumulated growing degree days (GDDs) over 11 ten-day periods during the soybean growing season using an artificial neural network with 12 input neurons (12^{th} being julian day of sowing). Four output neurons accounted for dates of achievement of phenological stages viz., flowering, pod formation, pod filling and pod maturity.

Yield was modeled using datasets of weather, soil and management parameters generated during the agronomic experiments of 2003 and 2004. 11 input neurons constituting accumulated GDDs computed for four growth stages listed above (dates for which are obtained from phenology model) representing weather, pH, EC, OC, P and K as soil chemical and fertility characteristics, and sowing date and plant population (plants/m^2) as management parameters are used for training ANN with one output neuron i.e. soybean yield. Training was done using bootstrapping and crossvalidation employing Quickprop algorithm as learning rule for both phenology and yield models with an RMSE of 1 day and 176 kg/ha respectively.

Variability in soybean yield is found decreasing with i) early planting, ii) increasing soil depth and iii) increasing plant density. Delayed planting reduced GDD requirement resulting in early achievement of growth stages and reduced soybean yield due to inadequate establishment of soybean crop stand as compared to early planting. Availability of irrigation and rain water during early and later growth phases determine stability of soybean growth and yield; this moisture regime gets balanced in the deeper soil profiles having high moisture holding capacity. Yield increasingly stabilizes with increasing plant density as productivity per plant gets compensated.

In the SDSS, phenology dates and potential yield in the given agro-environment are reported using normal daily temperature and spatially interpolated soil chemical and fertility characteristics averaged for each spatial unit (stored in the DBMS). Fertilizer prescriptions are given based on available soil nutrients and the targeted yield. Field management recommendations are given with respect to plant and row spacing and protection measures along with schedule of thinning and weeding based on standard literature and our experiences during the experimental period.

Water management

Decision support for water management is provided using a soil water balance approach by quantification of available and required water in the root zone over the growing period of soybean under conditions of unlimited and limited water supply. The Versatile Soil Moisture Budget model (VB) (Baier and Robertson, 1966) used in the study works on a daily time step with inputs of daily values of normal ET_0, precipitation, layer-wise available water capacity (AWC) for soils, root distribution and crop coefficients of soybean. Two output reports are obtained; i) the irrigation schedule comprising dates and amount of irrigation under unlimited water supply, and ii) reduction in yield with user defined irrigation dates under limited water supply. The latter termed as stress model computes water stress index and outputs number of stress days and resultant reduction in yield according to growth stages and season with reference to potential (obtained from crop management module). VB model was validated by comparing estimated and observed soil moisture data in the field according to growth stages, soil depth and soil layers. Observed soil moisture agreed satisfactorily with the model estimates for all growth stages with best agreement at pod formation stage. The agreement between observed and estimated soil moisture improved with soil depth (as a profile) and layer-wise from top to bottom. Sensitivity analysis carried out under diverse managerial scenarios for geographically distributed spatial units proved the robust performance of the model.

The SDSS reports in the form of graphs and tables. The graphical report of this module allows evaluation of daily march of any 2 output variables of water balance model while tabular report offers spreadsheet display of the entire computations. The soil water balance is primarily driven by spatial layer-wise AWC maps. The other aspatial model inputs like normal ET_0, normal precipitation, root and crop coefficients are used from the inbuilt DBMS.

Land management

Land suitability for soybean was evaluated using multicriteria decision making approach following FAO framework of land evaluation. The criteria used were soil and land qualities viz., soil texture, drainage, depth, slope, erosion hazard, coarse fragments, and risk of flooding, obtained from the physiographic soil map and pH, EC and organic carbon (OC) obtained by interpolating the soil samples layer. Pairwise comparisons were made between the criteria to generate the weights using Analytic Hierarchy Process (AHP) and a satisfactory consistency was achieved for the judgements in pairwise comparisons.

The criteria obtained from soil map ranked on an ordinal scale (1 to 9) and cardinal values of pH, EC and OC were fuzzified using the Semantic Import (SI) model. The fuzzified layers were then combined using linear weighted combination of fuzzy membership values. The land suitability map for soybean was obtained with four classes of suitability viz., highly, moderately, marginally and not suitable lands. The distribution of land in Shirol taluka was found 36%, 43%, 17% and 4% respectively.

The suitability map was overlaid with village map to generate village-wise inventory of suitable areas. Soybean area was estimated using digital satellite data for year 2003 and compared with village-wise reported soybean area. The soybean area map (2003) was overlaid with village-wise suitability inventory map to get soybean inventory according to village-wise suitability classes.

The limiting factors for soybean cultivation in moderately suitable lands were found to be pH, risk of flooding and OC while in marginally suitable lands, erosion hazard, coarse fragments and organic carbon constrain the suitability for soybean.

The principles considered for the recommending strategies for improving land quality are, increasing soil cover, organic matter content, infiltration and water retention and reducing the runoff, improving rooting conditions, chemical fertility and productivity. Such recommendations are kept resident in the knowledgebase for each spatial unit and for each limitation which the user retrieves as decision support under land management module of the SDSS.

Decision support to soybean cultivator through comprehensive and integrated agro-environmental investigation is satisfactorily accomplished by development of user friendly VB application at GIS platform.