Decision Support System for Climate Smartening of Tea Landscapes for Future Sustainability in North East India

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Abstract

Objectives: To develop a Decision Support System (DSS) for climate smartening tea production system in North East India.

Methods/Statistical analysis: A database, model base, knowledge base and user interface are used as components. Database consists of historical and future climate data which are future climate projections, model base includes research findings to be used in DSS and knowledge base includes expert knowledge. The user interfaces interact with the database, model base, and knowledge base to generate an effectual environment to make quality decisions towards a resilient tea production system.

Findings: The study brings out better understanding about the impact of the climatic parameters on tea yielding over the past years and also the future projections of their impact in spatio-temporal manner. The DSS also provides the user friendly tools to make decisions on adaptable measures (e.g. irrigation) that need to be adopted by the stakeholders, decision-makers and policy-makers so as to sustain tea production in the wake of climate change. Further, the DSS Framework developed in the study has multiple usages and provides instant decisions based on real-time data for tea plantations management with an insight into future. Since a web–based approach has been taken up, it provides an insightful and user-friendly appearance of data that can be accessed by an ample range of users at diverse geographical locations. Visual representations of the data facilitate communication of climate information among stakeholders and decision-makers in a much easier and comprehensible manner. Application/Improvements: The DSS has the scope to add further modules/ interfaces to further refine the DSS as and when additional information/data becomes available in future.

Keywords: Climate Change, Decision Support System, North East India, Resilient Tea Production, Tea Plantation

1. Introduction

North East India is typified by a monsoonal climate, coupled with high humidity and warm temperatures in most parts of the year. Traditionally, tea grows well in the hot-humid region of North East India due to plentiful rainfall and sunshine. However, marked changes in climate (poorly distributed and low rainfall with high temperature, fall in relative humidity) has impacted tea production adversely, putting millions of tea based livelihoods at risk in the region, besides tea growers facing increased pressure on available resources. The problem is becoming more complex due to poor decision making at both the policy making and the stakeholders (growers) level. Climate change is assumed to impact largely on two key sectors viz. agricultural and food systems and thus
to sustain the agricultural production, adequate adap-
tation measures based on quality decision is a prerequisite.
In spite of the fact that there are numerous technologi-
cal advances in terms of enhanced varieties, genetically
tailed organisms and irrigation schemes, weather and
climate still remains to be the key factors in agricul-
tural productivity and tea is no exception. Lately, there
is increasing evidence that climate change has disturbed
the hydrological cycle i.e. precipitation, as well as the pre-
vailing temperature, which are the most important factors
for local climate change. Consequently, any assessment
or decision making has to be specific for each local area
or landscape and should be based on verifiable data. In
this study, downscaled regional climate models from
global climate models have been used to predict future
scenarios. These scenarios were used in the region/land-
scape specific yield prediction equations developed under
study to predict the future yield in the major tea growing
regions of Assam. Further the effect of these scenarios on
performance of different cultivars of tea, released by Tea
Research Association, India for growing in North East
India were also studied in open top chambers to bring
out sustainability of the released clones that will survive
in future climate scenarios and consequently tea planters
will be advised to plant only those clones which will be
suitable for future climate scenarios.

Traditionally, tea is a rain fed crop and due to pro-
longed rainless periods, irrigation has become vital
during droughty periods. It is already observed that
rainfall pattern in North-eastern India has undergone
noticeable changes. Furthermore, distribution of rain-
fall too has become exceedingly irregular in North East
India. During the periods of low rainfall which is usually
from October to February, evaporation greatly exceeds
precipitation and therefore, supplementation of soil mois-
ture by irrigation becomes a requisite during this period
of moisture stress. Decision making for future irrigation
requirement is also a pertinent issue. Thus irrigation
requirement of the tea bushes under future climate con-
dition was also calculated using conventional methods
and expert domain knowledge available at Tea Research
Association, India archives. All these information are
then integrated together with an aim to develop an appro-
piate Decision Support System (DSS) for managing large
tea production system with climate as a main driver for
making this production system more climates resilient.

Application of DSS in tea plantation management is
extremely rare. Few studies have conceptualized the DSS
framework for application in tea plantation manage-
ment, with no actual development or implementation.
As climate change indicators are already visible in the tea
landscapes North East India, more effective tea plantation
management is required using real-time data. The ratio-
nale of this DSS is to advise the tea growing communities
and stakeholders in North East India for making effective
quality decisions. The final DSS has been customised
in a user friendly format so that the end users with a
preliminary knowledge of computers will be able to use
it effectively and efficiently. It will be dynamic and any
amount of information can be integrated in future to fur-
ther fine tune for local conditions at micro level.

2. Decision Support System

A typical DSS includes five components: database, model
base, knowledge base, Graphic User Interface (GUI),
and user. The database holds the data to be used in the
process of decision making, model base consists of the
collection of models developed or used which aids the
analysis capabilities of the DSS, knowledge bases contains
the knowledge gathered from the domain experts on the
subject matter, the GUI supports in all sorts of communi-
cation between the user and the DSS, and finally the user
is the person who uses the DSS to support the decision
making process.

3. Design and Development of
Proposed DSS

The proposed DSS is designed by following the conven-
tional three step process which includes the pre-design
phase; followed by a design phase and then the imple-
mentation and adaptation phase.

During the pre-design phase three major tasks viz.
planning, research and analysis of the conceptual design
are accomplished. The initial planning stage includes the
requirements of the user (obtained from a typical tea gar-
den management system) in terms of decision-making in
the tea plantation management. In the second task, the
critical review of the available resources is carried out to
collect relevant research findings which aided in selection
of resources for designing the DSS. Finally, in the third
task extraction of domain knowledge from tea experts
and other published materials on issues on decision mak-
ing is accomplished.
Subsequently a web-based approach is taken up, as it provides an insightful and user-friendly appearance of data that can be accessed by a wide range of users with varying computational skills (sometimes even elementary) placed at different geographical locations. Visual representations of the data facilitate communication of climate information among stakeholders and decision-makers in a much easier and comprehensible manner. This was done with an intention to have a forum for discussion and decision-making (by tea planters and stakeholders) by presenting the relevant information via a web-based user interface so that this information can be made widely accessible, even at remote places. The softwares used for developing this system are PHP 5.5.12 for server side scripting, My SQL 5.5.17 in back end, web server Apache 2.4.9, Wamp server 2.5 tools, Adobe Photoshop, Dreamweaver, HTML, Javascript, Css, AJAX, JQuery and JSON. This environment gives an efficient GUI which is platform independent. Data needed for DSS are characteristically historical data collected from the major tea growing regions (South bank, Upper Assam, North bank and Cachar) of Assam, India and then combined together in the database subsystem. As shown in figure. 1, the major data requirements are categorized as weather data, crop data, clonal data, carbon dioxide concentration data and water requirement conditions. The knowledge base subsystem consists of the domain knowledge gathered from tea experts. The model base subsystem consists of all the models which are created or used to generate future scenarios along with their consequent adaptive strategies that needs to be adopted if required. Its working and interpretation are based on the sequence of choices and inputs by the user, which are linked by IF-THEN logic.

The implementation and adaptation phase handles real time testing, documentation, evaluation and improvements to the DSS. This phase is an unremittent process where there is provision for inclusion of new modules to the DSS for further improvements in the system.

3.1 Components of Tea Production Specific DSS

In a DSS, the major task is to generate decisions from the processed data. Data processing is the initial stage where the generated results are incorporated to the DSS as readily available decisions or the relationships among data as mathematical tools in the model base, which generate decisions or knowledge for different alternative scenarios. Figure 1 shows, the conventional framework of DSS modified to tea specific requirements with components.

3.1.1 Database Management Subsystem

The weather data contains measured average, maximum and minimum temperatures, total rainfall and average actual sunshine hours on monthly and yearly basis. These data are stored in the form of tables as well as maps. Crop data includes data on the yearly production and yield of tea data needed for estimation of tea production under future scenarios. The clonal data comprises of the database of clones which are experimentally derived to be suitable under different scenarios in future. The carbon dioxide concentration data includes the measure of CO$_2$ in Parts per Million (ppm) over the years needed for clonal suitability assessment in the future. The water requirement conditions are the rainfall data derived from the weather database for the specific months which will specify whether irrigation will be required or not during those months.

3.1.2 Model Management Subsystem

Model management subsystem includes the models used in this study, which use data and management scenarios to predict solutions or alternative management options for prevailing and most possible cases. The management subsystem of the models select the appropriate alternative decision from a large number of alternatives, based on the tea garden management’s
requirement and experience, which is also coded into the model as basic guiding principles. The details of the models are given in the following sections.

3.1.2.1 Future Scenario Development Model

The future scenario development model is incorporated in the model base subsystem which includes the database of future climate scenarios developed using the recent regional climate change scenarios derived from the downscaling of the Hadley Centre Global Environmental Model 2-Earth System (HadGEM2-ES) model of the United Kingdom Meteorological Office, Hadley Centre. These data are the most recent GCM climate projections that are used in Fifth Assessment Report (AR5) of the United Nations Intergovernmental Panel on Climate Change (IPCC), and are freely available from www.worldclim.org. GCM models include four scenarios which are called Representative Concentration Pathways (RCPs) based on greenhouse gas concentration trajectories adopted by the IPCC. These RCPs consists of four possible climate futures, all of which are considered possible depending on how much greenhouse gases will be emitted in the years to come. The four RCPs viz. RCP2.6, RCP4.5, RCP6.0, and RCP8.5, are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m², respectively).

The IPCC AR5 is based on 21 global climate models with a resolution of 30 arc sec (1 km), hence require no downscaling. Moreover, the data are available on a monthly scale thus enabling the present study to be carried out in tea growing season and dormant season scale for tea plantations. In the Indian context for the temperature variable, the models used are NorESM1-M, CCSM4, MIROC5 and HadGEM2-ES while for the precipitation variable GFDL-CM3, CCSM4 and HadGEM2-ES are used. These models individually simulate results which are close to observations either for temperature or precipitation for the India region.

In the present study, all the four RCPs of the 5 models were analysed both individually and as an average. Hence, the results of the average of the 5 models are included for all the RCPs. The GCM output is downscaled and calibrated (bias corrected) using WorldClim1.4 as baseline 'current' climate and eventually tested for preparing maps as shown in Figure 2.

3.1.2.2 Crop Production Empirical Relationship Model

It is very important to know how tea will perform in a changing climate so as suitable adaptive measures can be taken. Thus, tea production empirical relation model is developed to foresee the production trends in future. Data mining techniques are used for estimating the future yield prediction in tea cultivation with climatic change trends observed in last 30 years (1977-2006). The patterns of crop production in response to the climatic (rainfall, temperature, relative humidity, evaporation and sunshine) effect across the four tea growing regions (South Bank, North Bank, Upper Assam and Cachar) of Assam were developed using Multiple Linear Regression (MLR) technique.

The four tea production estimation equations are derived for the four regions and the equations thus generated represent the relation between the meteorological parameters and yield specific to the particular region. The equations derived are given below as equation (1), (2), (3) and (4) for South bank, Upper Assam, North Bank and Cachar, respectively.

\[
P_{\text{SOUTH_BANK}} = 383773 - 16656.9*S - 5.5612*R - 17276.8*T_{\text{diff}}
\]

\[
P_{\text{UPPER_ASSAM}} = 235133.3 - 5790.38*S - 7.22811*R - 4772.87*T_{\text{diff}}
\]

\[
P_{\text{NORTH_BANK}} = 245962.8 - 23078.4*S - 19.5684*R + 1698.916*T_{\text{diff}}
\]

\[
P_{\text{CACHAR}} = 7126.21 - 6493.54*S - 2.90149*R + 1475.789*T_{\text{diff}}
\]

Where \(P_{\text{SOUTH_BANK}}\), \(P_{\text{UPPER_ASSAM}}\), \(P_{\text{NORTH_BANK}}\), \(P_{\text{CACHAR}}\) represents the predicted production for South bank, Upper Assam, North Bank and Cachar respectively, S, R and \(T_{\text{diff}}\) are average sunshine hours (April to November), total

![Predicted distribution of rainfall, minimum temperature and maximum temperature in Assam, India in 2050 and 2070 (GCM output downscaled and calibrated (bias corrected) using WorldClim1.4 as baseline 'current' climate).](image)

Figure 2. Predicted distribution of rainfall, minimum temperature and maximum temperature in Assam, India in 2050 and 2070 (GCM output downscaled and calibrated (bias corrected) using WorldClim1.4 as baseline ‘current’ climate).
rainfall (April to November) and difference of average maximum and minimum temperature (April to November).

These four tea production estimation equations are also validated for the regions with the help of the actual production data collected from the Tea Board of India database for the years 2007, 2009 and 2010 and the results are found to be significant. Thus, this model is incorporated in the model base subsystem which will enable the user to know what exactly will be the production of tea in any particular year in future.

3.1.2.3 Clonal Suitability Assessment Model

The clonal suitability assessment model is incorporated in the model base subsystem which includes the database of those clones which are suitable under different future climate scenarios. The clonal suitability database is obtained from the simulation experiments conducted at TRA, Climate Research Centre at Jorhat, Assam, India where studies are executed in Open Top Chambers (OTCs). An OTC facility is capable of providing a mean by which the environment (E) around growing plants (G) can be modified to different climatic conditions particularly of temperature and carbon dioxide concentration and management (M) practices. The response of these tea clones to elevated temperature and CO\textsubscript{2} on morphological, physiological and biochemical characters has been done. The screened out clones based on their performance to future climate scenarios are fed into the DSS under clonal suitability model. This model will respond to the queries of the users in the way that when a user enters a particular future temperature and CO\textsubscript{2} concentration level, the DSS will suggest what are the clones which will behave positively in that situation or are best suited for such conditions in future years.

3.1.2.4 Irrigation Water Need Model

Precipitation and temperature are two climate factors among others which highly influence tea productivity. Tea being a rain fed crop is assumed to suffer considerably due to the uncertainties in rainfall occurring due to climate change. Therefore, water availability plays a critical role in sustaining future tea production in Assam. Rainfall is decreasing in the major tea growing regions of Assam with a decrease of over 220 mm of rainfall over a period of 97 years (1919-2016) in the South Bank region of Assam as shown in Figure 3. Similar trend of decrease was observed for others tea growing regions.

Figure 3. Yearly total rainfall (mm) in south bank region, Assam, India (1919-2016).

If these trends of rainfall continue then the crop water requirement has to be compensated by irrigation. This model uses the well established method of irrigation for tea developed at Tocklai Tea Research Institute, Assam India\textsuperscript{24}. It shows that the irrigation water need (IN) is the difference between the crop water need (ET\textsubscript{crop}) and the amount of rainfall which is effectively used by the plants (Pe).

\begin{align*}
\text{Therefore, } IN &= \text{ET crop} \cdot Pe. \\
Pe &= 0.8 P-25 \text{ if } P > 75 \text{ mm/month} \\
Pe &= 0.6 P-10 \text{ if } P < 75 \text{ mm/month}
\end{align*}

Where 

- \(P\) = rainfall or precipitation (mm/month)
- \(Pe\) = effective rainfall or effective precipitation (mm/month)
- \(ET\) = evapotranspiration (i.e. sum of evaporation and plant transpiration)

Hence, future rainfall data are extracted from IPCC AR5 scenarios freely available from www.worldclim.org and then fed into the model for the sake of calculation of irrigation need for the region.

3.1.3 Knowledge Base Subsystem

The knowledge base includes number of IF-THEN statements. These IF-THEN rules are developed from knowledge gathered through discussion with domain experts on the subject matter and also integrating the knowledge generated through mathematical models, which represent the problem domain. The knowledge base also incorporates the whole set of alternative
management options to be undertaken if any unfavourable situation arises in existing or future years to come.

The general format of an IF-THEN rule is,

\[
\text{IF (Condition 1) AND/OR (Condition 2) AND/OR... (Condition n) THEN (Action 1) (Action 2) \ldots \ldots (Action n) ELSE (Action x) (Action y) \ldots \ldots (Action z),}
\]

3.1.4 Dialog Subsystem

As DSS starts, it displays the main window of the system having pull down menus and submenus to open edit and simulate the input parameters to get the results. Any information entered or modified in the system gets saved in the database. User friendliness makes the DSS operable to wide range of users as person with preliminary knowledge of computers will be able to use it effectively and efficiently. Built-in help facilities and menu-driven command options are the essential features of the DSS. The output can be generated in both tabular and graphical forms. The required inputs are selected by the user through the graphical user interface and input dialog boxes. The data input by the user could be used by the model in predictions based on the relationships developed through modelling approach. The graphical user interface acts as the bridge among the user, the knowledge base, information stored, mathematical relationships and inference engine.

4. Results and Discussion

The DSS starts with a title window having Home, Login and About buttons. Home button is present in all the pages of the DSS clicking on which the user will return to the main home page of the DSS. The Login button contains the user name and password options through which only registered users can enter into the main window and use the DSS. The main window displays the study area, location map along with pull down menus like Home, Tea growing regions, Results, and Logout button in the title bar. The Tea growing regions menu consists of the names of the four regions considered in this study namely South bank, Upper Assam, North bank and Cachar. On selecting any one of the regions, a screen pops up with the location map of that region in the background and containing different buttons from which all relevant information regarding the displayed region can be gathered. All the information are categorised under three sub headings namely, climate, area under production of tea and total production of tea in the region under different years. For the climate information the user has to choose year from the drop down menu and select the required climate variable using radio button. When this query is submitted, the DSS raises two issues: i) the basis on which data has to be retrieved i.e. monthly, yearly, dormant season or growing season and ii), the output type, whether the result needs to be presented in the form of data, graph or map. Based on all these inputs from the user, the DSS will generate the outputs and present it to the user. Similarly, information on area under tea production and total tea produced in that region for a particular year or number of years can also be retrieved from the DSS based on the selection criteria of the user.

The result options are available in the menu bar through which a user can have an insight to the future of tea production. The outputs under this section are categorised mainly into four divisions viz., future climate, irrigation water need, clonal suitability and future yield of tea. On clicking the future climate button, the screen that will come up will have options to select the region, year for which information is required and scenarios which include four RCPs viz. RCP2.6, RCP4.5, RCP6.0, and RCP8.5. After relevant selection, the DSS will ask the user for entering the basis of the output to be shown either in monthly or yearly basis along with the type of output to be shown, whether in data format or map view. On providing all these inputs by the user, the DSS will display the output.

After future climate sub menu the next option which comes under results section is the irrigation tab, which is intended to aid the users with decision making for the crop water requirement during different months of a year in future, precisely during the period of moisture stress. Also, the user will be able to decide whether to irrigate or not and if required what is irrigation water requirement that needs to be supplemented. On clicking the irrigation water need button, the DSS will navigate to the window where the user needs to provide the inputs and based on that the DSS generates the output as shown in Figure 4.
Firstly the user has to select the region and then the year and month in future for which the irrigation requirement needs to be determined. Once these inputs are provided the DSS will generate the results using the irrigation water need model from the model management subsystem and the domain knowledge incorporated in the knowledge base subsystem. Thus, the output generated will help the user to schedule irrigation based on the future rainfall data contained the weather database and thus saving input cost.

The next submenu under the results menu is the clonal suitability assessment tab which will recommend the tea clones that will survive in future climate scenarios based on controlled experiments conducted at Tocklai Tea Research Institute, Assam, India, inside OTCs to study the effect of elevated carbon dioxide and temperature. The concentrations of atmospheric carbon dioxide have been increased from approximately 315 ppm in 1959 to a current atmospheric average of approximately 398 ppm observed at the local tea landscapes and expected to rise in future. Therefore, screening of the clones which will be sustainable in future climate scenarios will be urgently required. The window of clonal suitability has options to select the year and option to select the level of carbon dioxide concentration in ppm based on which the DSS will generate the results of suitable tea clones in that particular year as shown in Figure 4.

This window consists of options for the user to enter the year and region for which yield needs to be determined and based on the inputs, the DSS will provide the predicted yield for that particular year in the region. The DSS predicts the yield with the help of the predicted future climate data and the crop production empirical relationship model developed in this study. This result will give the users (Tea Planters) an insight into the future climate and yield scenarios. The schematic flow of working of the DSS navigating from one screen to another is based on the selection criteria of the user and are ensemble together in one frame and presented in Figure 4.

5. Conclusion

The DSS Framework developed in the study has multiple usages and can develop instant decisions for tea plantations management with an insight into future using real time data. The main tea growing regions of Assam is significantly influenced by total rainfall, sunshine duration and difference between mean-maximum temperature and mean-minimum temperature. The DSS uses these parameters in real time to develop decisions. The DSS has the scope to add further modules/ interfaces to refine the DSS when additional information/data becomes available.

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