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AGRO-ECOLOGICAL ZONING FOR YIELD PREDICTION FROM RUBBER PLANTATIONS IN INDIA

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Explanatory crop growth simulation models, constructed on the underlying physiological processes such as CO_2 assimilation and respiration as influenced by environmental factors, can be used to predict different levels of production classified on the basis of various stresses. Agro-ecological zoning of different parts of India for yield of rubber was carried out under rainfed conditions through simulation in different environments, without accounting for stresses due to nutrients, pests and diseases but taking into consideration standard loss of trees in the life cycle of the crop due to natural damage. Mean yield during the first 20 years of tapping has been simulated under specific assumptions for 27 locations, spread all over the traditional/non-traditional rubber cultivating regions of India. The commercial yield data of the clone RRIM 600 was used for the validation of the simulated yield. The yield per hectare ranged from 500 kg at Nellore in Andhra Pradesh to 1427 kg at Trivandrum in Kerala. Wide variations have been observed in the simulated yield among locations in non-traditional areas. On the basis of the predicted yield, the non-traditional areas were classified into high, medium and low productivity zones. The Andaman-Minicoy islands and locations in North East India are under the high productivity zone. The medium zone consists of locations in Karnataka, Goa, Maharashtra, Orissa and West Bengal. Nellore, Kakinada and Visakhapatnam are grouped under the low productivity zone. The rainfed rubber yield decreased with increase in latitude in the West Coast and its reverse is observed in the East Coast and North East India.

Key words: Agro-ecological zoning, Crop simulation model, *Hevea*, Yield prediction.

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INTRODUCTION

Plant growth and productivity are determined by a complex interaction of different genetic and environmental factors. The interrelationships among the biological and non-biological variables can be analysed through descriptive and explanatory crop models. Descriptive models are simple representations of the crop system in the form of mathematical regression equations based on empirical data. However, explanatory models, also known as mechanistic models, analyse crop growth on the basis of the underlying processes such as CO_2 assimilation and respiration as influenced by environmental factors. Growth and yield can be predicted for different production levels classified on a physiological basis as limited by weather, water, nutrients and pests and diseases (de Wit and Penning de Vries, 1982; Penning de Vries and van Laar, 1982). Along with the limiting factors, crop models include variables related to dry matter production, leaf area growth and phenological development. Crop growth simulation models are increasingly being used to support research and extension in agriculture (Penning de Vries *et al.*, 1989). The dynamism of crop simulation models in terms of predicting responses to different environments, situations and limiting factors led to their wider application in agroclimatic zonation and in studies related to the impact of infestation of pests and diseases, water and nutrient shortages, natural damage and various agronomic practices on crop yield. Kropff *et al.* (1994) used crop modelling to predict the impact of the incidence of blast epidemic in Thailand. Prediction of yield loss in rice due to expected intensity of drought using crop modeling has been reported (Wopereis *et al.*, 1993). Aggarwal *et al.* (1994) used crop modelling for agroclimatic zonation for wheat production in India. Crop modelling has been used in Brazil to study the impact of different planting densities and tapping systems in rubber (Brummer, 1992).

Earlier, rubber had been cultivated only in the southern-most part of India, mainly in the state of Kerala and the Kanyakumari district of the neighbouring state of Tamil Nadu. Non-availability of agronomically suitable land, the cropping pattern and other socio-economic factors limited further expansion of rubber cultivation in the traditional belt. From the early 1980s attempts have been made to extend rubber cultivation to non-traditional areas. The share of the non-traditional region in rubber planted area has increased from 5 per cent in 1980-81 to 12 per cent in 1999-00 (Rubber Board, 2000). The main objective of this study was to carry out agro-ecological zoning of different parts of India for rubber yield prediction under rainfed conditions through simulation in different environments.

MATERIALS AND METHODS

For simulation of growth and productivity of rubber, FORTRAN Simulation Translator (FST) version of EMB-RUBBER model was used. This model was originally built to simulate rubber growth and production, to assess the relative importance of alternative research priorities and generate hypotheses in theoretical studies (Castro, 1988; Brummer, 1992). Later, this model was refined by Bernardes and Goudriaan (1994) and written to FST (Rappoldt and Kraalingen, 1996). The model consists of carbon and water balance and simulates dry matter accumulation, girth of tree, leaf area index (LAI), rubber yield and other variables with one day time intervals. It was adapted from the level II basic crop growth simulator (MACROS), developed by Penning de Vries *et al.* (1989) and originally written in the Continuous System Modelling Program (CSMP), with some subroutines and functions written in FORTRAN 77. Some of the abbreviations used in this model were taken from simple and universal crop growth simulator termed as SUCROS2 (Keulen *et al.*, 1992).

The weather data for 25 locations in India were collected from AB-DLO meteorological data base documented by the Department of Agrobiology and Soil Fertility (AB-DLO) at Wageningen, The Netherlands. Weather data recorded at two research stations of Rubber Research Institute of India (RRII) were also included. One of the stations is located in the traditional rubber growing region of Kerala (RRII Central Experimental Station, Chethackal, 9° 22′ N 76° 50′ E, 50 m MSL humid climate) and the other is in the non-traditional region of Maharashtra (RRII Regional Research Station, Dapchari, 20° 04′N, 72° 04′ E, 50 m MSL dry sub-humid climate). The data files for short period were expanded into time-series weather data files for 20 years using the weather generator model (Richardson and Wright, 1984; Stol, 1994) for the 27 stations from real data inputs of the same locations. The daily values were obtained by linear interpolation. The weather variables used were total global radiation ($J/m^2/d$), maximum and minimum air temperature (°C), vapour pressure (K Pa), wind speed (m/s) and rainfall (mm/d). The yield data of the clone RRIM 600 for 20 years were used for the validation of the simulated yield. The data were obtained from a continuous commercial yield evaluation scheme initiated by Rubber Research Institute of India in 1974 (Joseph *et al.*, 1999a).

Key assumptions

Rubber yield under rainfed conditions for different locations in India were simulated on the basis of the assumptions that (1) soil types were suitable for rubber cultivation (2) trees were rainguarded during rainy months (3) trees were taped in 1/2S d/2 system in both traditional and non-traditional areas (4) yielding period was 20 years (5) initial stand per ha was 420 trees and subsequently the stand was reduced annually by one per cent to account for natural damage (6) percentages of tappable trees estimated in a linear manner were 70, 95 and 100 per cent of the respective stand at 7 (years of opening), 11 (established phase) and 33 (terminal years), (7) trees attained tappable girth (50 cm) by seventh year in traditional and non-traditional areas (8) the plants were not affected by serious diseases and pests and (9) the cultural practices followed were as per the recommendations of Rubber Board.

The clone RRIM 600, which has been popularly planted in both traditional and non-traditional regions, was taken for the validation of the simulated yield.

Validation of EMB-Rubber model under Indian climatic conditions

Several modifications have been made to the original model to simulate the yield of rubber under Indian climatic conditions. The modifications were as follows.

1. Life of rubber leaf is nearly 300 days and for such a long period, the average potential CO_2 assimilation rate can be taken as AMX = 20.2 (Dey and Vijayakumar, 2002). Phenology of leaf duration and defoliation were included.
   PARAM AMX =20.2
   FUNCTION AMTMPT = 25., 1.0, 33., 1.0
   FUNCTION LAIMTB = 6.0, 5.3, 33.0, 5.3

   FUNCTION FLVTDT = 0.0, 0.0, 15.0, 0.0, 45.0, 1.0, 115.0, 0.05, 350.0, 0.05, ...
   359.0, 0.0, 366.0, 0.0
   FUNCTION LLVDTB = 0.0, 0.0, 0.091, 7.0, 0.092, 10.0, 0.99, 16.0, 0.0, 136.0, 0.0, ...
   350.0, 0.001, 361.0, 0.09, 366.0, 0.091

2. Phenology of fruit set and fall (Sudhasowmyalatha *et al.*, 1997; Veeraputhran and Joseph, 2000) were included.
   FSO = FSOTS * FSOTD
   FSPTS = AFGEN (FSOTSF, STAGE)
   FSOTD = AFGEN (FSOTDT, DOY)
   FUNCTION FSOTST = 0.0, 0.0, 6.0, 0.35, 11.0, 1.0, 33.0, 1.0
   FUNCTION FSOTDT = 0.0, 0.0, 16.0, 0.0, 175.0, 0.025, 176.0, 0.0, 366.0, 0.0
   FUNCTION LSODTB = 0.0, 0.0, 176.0, 0.0, 177.0, 0.6, 197.0, 0.99, 198.0, 1.0, 366.0, 0.0

3. Standard loss of root was included
   LRT = WRT *AFGEN (LRTST, STAGE)
   FUNCTION LRTST = 0.0, 0.0, 6.0, 0.0015, 33.0, 0.002

4. The yield components were a function of climatic parameters (Dey *et al.*, 1999)

   For traditional areas
   FLOW = 0.172- (0.005*TMMX) – (0.001*TMMN) + (0.01*VP)
   DRCL = 4.84 + (0.825*TMMX)
   PLIN = (0.59*TMMX) – (0.135*TMMN) – 11.9

   For non-traditional areas
   FLOW = 0.006- (0.001*TMMX) – (0.033*TMMN) + (0.03*VP)
   DRCL = 15.27 + (0.386*TMMX)
   PLIN = (0.22*TMMX) + (0.142 TMMN) – 6.48

MFRT = AFGEN (MFRTST, STAGE)
FUNCTION MFRTST = 0.0, 0.0, 5.999, 0.0, 6.0, 0.44, 12.0, 0.233, 33.0, 0.08

5. The tapping days were restricted to 150 days in the traditional area and 120 days in the non-traditional area. The trees were given rest during summer months in the non-traditional area (Dey *et al.*, 1999).

IMP = PUSH* RESTS
RESTS = AFGEN (RESTTB, DOY)

For traditional areas
FUNCTION RERSTTB = 0.0, 1.0, 31.0, 32.0, 0.0, 90.0, 91.0, 1.0, 366.0, 1.0

For non-traditional areas
FUNCTION RERSTTB = 0.0, 1.0, 31.0, 32.0, 0.0, 150.0, 151.0, 1.0, 366.0, 1.0

6. Standard loss of trees (Joseph *et al.*, 1999) were included.

NTREE = AFTEN (NTRETB, STAGE)

FUNCTION NTRETB = 0.0, 420.0, 7.0, 400.0, 12.0, 380.0, 33.0, 220.0

RESULTS AND DISCUSSION

The simulated average yield for 20 years in the traditional area was 1356 kg/ha/year for 150 tapping days or 9 kg/ha/tap. The average commercial yield for 20 years for clone RRIM 600 was 1349 kg/ha/year for comparable tapping intensity in the traditional area (Joseph *et al.*, 1999). Simulated average yield (four locations) of the traditional area and observed yield are presented in Figure 1. Simulated yield was 570 kg/ha for the first year of tapping in the non-traditional area (Dapchari), which was close to the observed data of 622 kg/ha and 549 kg/ha including and excluding summer yield respectively (Chandrashekar *et al.*, 1990). Thus the simulated yield estimates are reasonably reliable and comparable with observed commercial yield.

The refined model was used to estimate the climatically determined rubber yield for different locations in India under rainfed condition. The yield was deter-

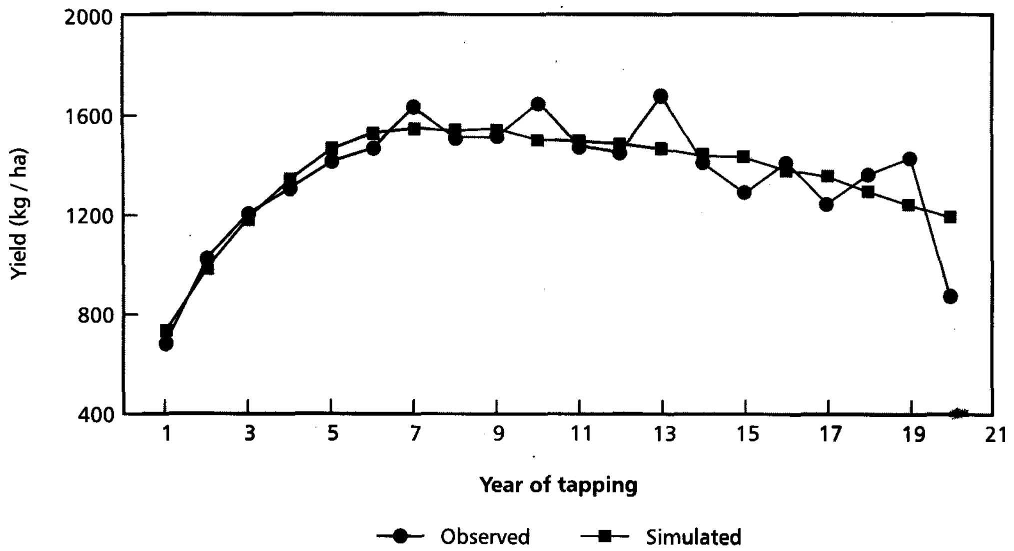

Fig. 1. Observed and simulated mean yield for clone RRIM 600 over 20 years of tapping in traditional rubber growing area

mined for 27 locations, spread all over the rubber producing regions of India under rainfed conditions (Fig. 2). The daily climatic data were used as the driving variables in the model. The yield for clone RRIM 600 was estimated for each location, based on the laid out assumptions.

Simulated average rubber yield (over 20 years) varied from 500 to 1193 kg/ha depending upon the location in the non-traditional area (Table 1). Based on the simulated results under rainfed condition, the non-traditional area can be classified into three major zones, *viz.*, high, medium and low productivity zones. In the high productivity zone, locations with yield potential above 1000 kg/ha with 20 per cent reduction of tapping days as compared to the traditional area were included. In the medium productivity zone, yield varied from771 to 983 kg/ha whereas in the low productivity zone the yield potential was below 700 kg/ha.

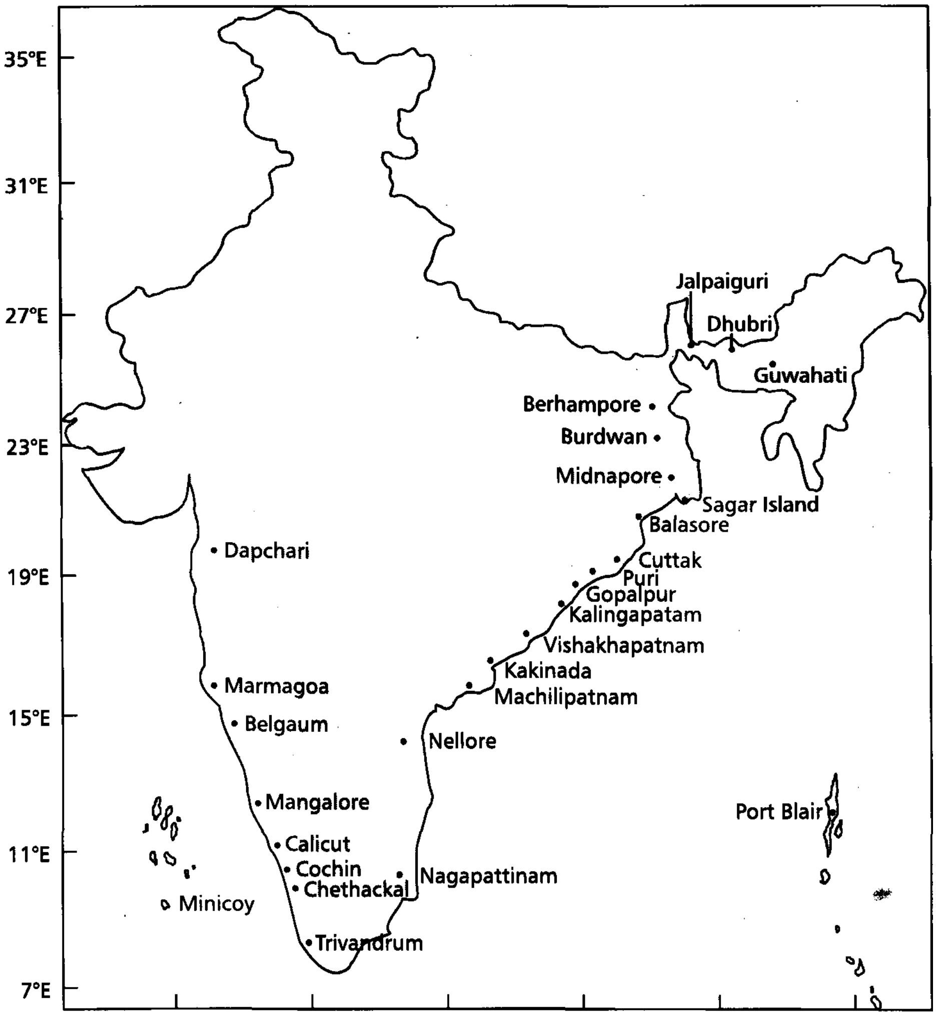

Fig. 2. The different locations in India (•) for which productivity of rubber was simulated

Table 1. **Simulated yield of rubber under rainfed conditions at different locations in India**

Location	Mean yield over 20 years (kg/ha/year)
Traditional area	
Trivandrum	1427
Chethackal	1402
Cochin	1396
Calicut	1200
Non-traditional area	
High productivity zone	
Port Blair	11093
Minicoy	1193
Jalpaiguri	1116
Guwahati	1085
Dhubri	1163
Low productivity zone (South East Coast)	
Nagapattinam	512
Nellore	500
Machilipatnam	578
Kakinada	643
Visakhapatnam	577
Kalingapatam	631
Medium productivity zone (West Coast)	
Mangalore	894
Marmagoa	783
Bulgaum	848
Dapchari	771
Medium productivity zone (East Coast and Bengal)	
Gopalpur	826
Puri	827
Cuttack	805
Balasore	903
Sagar Island	983
Midnapore	887
Burdwan	927
Berhampore	905

The Andamans, Minicoy islands and north eastern locations were under the high productivity zone. Locations in the West (Karnataka, Goa and Maharashtra) and East Coast (Orissa and Bengal) were under medium productivity zone and South East India (Nellore, Kakinada and Visakhapatnam) came under the low productivity zone. The yield reduction was in the order of 16, 36 and 57 per cent in high, medium and low productivity zones respectively, compared to the traditional zone.

The present study was to establish the trends of climatically determined yield across locations for the clone RRIM 600. These results are based on mean climatic conditions and for the specific locations described in Table 1. The yield may also vary with clone, soil factors and effects of disease and pest incidence. The yield is expected to vary with change in climate and tapping days also. These simulated results can give a broad understanding of clone specific yield in the non-traditional area compared to that in the traditional area.

Considering the simulated results, it can be concluded that the rainfed rubber yield decreases with increase in latitude in the West Coast, while it is the opposite in the East Coast or North East India. Such simulation studies have the advantage of identifying areas suitable for rubber cultivation. These results can be taken as guidelines for further field trials and for designing crop expansion strategies.

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