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Forecasting Economic Life of Rubber Plantation using Markov Model

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ABTRACT

The economic life of a rubber plantation is fundamentally dependent on the tapped trees per hectare which is proximate of yield per hectare. The study determines the transition probability and the incremental utility of a plantation rubber tree population as it transits from the initial density of over 500 trees per hectare to an arbitrary uneconomical threshold of less than 200 trees per hectare that necessitates a replanting programme. It involves Markovian analysis of the evolution of rubber tree density through three definable Markov states- untapped, tapped and dead states. Six-year documentary data obtained from permanent experimental plots is used to carry out the stationary and 50-year cohort simulation of the transition probabilities of eight rubber clones through the three states. The fundamental matrix solution is computed for each clone to determine the mean passage time and time to absorption. The 50- year simulation of the rubber tree cohort using TreeAge Pro decision software, forecasts only three out of the eight clones to be above the 40% economic threshold tapped density after 30 years. These include IRCA 18 (58%), RRIC 100 (46%) and IRCA 109 (44%). Mean passage time in tapping averaged 35 years while mean passage time in untapped state is 7 years. The data is subjected to the nonparametric Chi square statistics to ascertain significance difference between clones in mean time to absorption, mean passage time and mean time to replanting. The result shows that significant difference exists between rubber clones in all these plantation economic indices. The Markov model therefore provides a convenient analytical framework for forecasting the dynamics of rubber tree density to determine the economic life of rubber plantation.

Keywords: Markovian; clones; mean passage time; time to absorption; replanting; rubber

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INTRODUCTION

The role of the natural rubber in the Nigerian economy cannot be overemphasized. Firstly, is employment generation: natural rubber provides employment opportunities for residents in the rubber belt areas and therefore contributes to livelihoods and sustains rural communities? Secondly it provides raw material for industries: natural rubber serves as a vital raw material for various agro-based industries. These industries rely on rubber for manufacturing products such as tires, footwear, and industrial goods. Finally, it earns foreign exchange: Nigeria's natural rubber exports contribute to foreign exchange earnings. By exporting rubber, Nigeria participates in the global market and earns revenue that supports economic growth and development. In 2022, Nigeria exported $84.5M in Rubber, making it the 18th largest exporter of Rubber in the world. In the same year, Rubber was the 22nd most exported product in Nigeria (Organization for Economic Co-operation and Development (OECD) 2022).

Rubber varieties are budded clone, planted at a density of 400 to 550 trees per hectare either by seed or polybag budded stumps (Figure 1). The gestation period is seven years during which no income is earned from the rubber trees rather money is spent on maintenance of the field. The trees are opened for tapping when they attain a girth of 50cm at 100 cm height from ground level and have achieved 40% mature trees per hectare of initial planting density (Webster and Baulkwill, 1989). Tapping is carried out 5 to 10 times a month for 20 to 30 years by tappers working in gangs of 15 to 20 men (Jacob, 1995). The element of the exploitation standards that are of interest includes tapping depth, bark consumption, and general defect.

Major rubber plantation problem is the multiple transitions between tapping states which requires that the probabilities of the transitions between states, together with the related utility, vary over time with concomitant economic implication (Priyadarshan et al., 2005). Tree density deteriorates due to root disease and wind damage during the mature or tapping phase thereby increasing the entry of light which induces increase weed growth and field maintenance cost. Tapping density depends on initial planting density, extent of wind damage, disease and tapping panel dryness or brown bast - cessation of latex production due to alteration in the latex bearing cells (Cavaloc et al., 2005). Hence as time goes on during the production years the rubber trees transit from the states of UNTAPPED - TAPPED - STOPPED (due to brown bast/wind damage) and finally to the DEAD state (fomes/wind damage). The plantation is felled and may be renewed when the number of trees being tapped has dropped too far for them to be profitable. There is therefore a utility associated with a cycle in a particular state because profit per hectare is the product of yield per hectare (stand per ha) and profit per kg. It is this product which should be maximized (Lim, (1974). Economic life of rubber plantation therefore depends on the evolution of the tapped tree density. While experiments can show the relation between planting density and yield, they cannot fully achieve the practical objective of estimating the number of tappable trees per hectare that will maximize profit over the productive life of rubber plantation. Neither decision trees nor influence diagrams offer a practical approach to this problem. In contrast Markov models are designed to efficiently represent evolutionary, cyclical, recursive events, whether short term or long-term process (Charitos and Linda, 2004). A Markov model is a mathematical framework that represents a system with a finite set of states and transition probabilities between those states. It assumes that the future state of the system depends only on its current state (i.e., it has no memory of previous states). In the context of this study, the Markov model is used to predict tapping density changes over time because it provides a means of modelling ecosystems problems in which risk is continuous over time, in which event may occur more than once and when the utility of an outcome depends on when it occurs. Representing such ecosystem problems with conventional decision trees is difficult (Garcia, 2004). With Markovian analysis of forest dynamics, it is possible to establish the following:

(1) The existence of transient set of states and closed sets or absorbing state.
(2) Basic transitions can be partitioned, and several components investigated separately.
(3) Analysis of transition matrix leads to calculation of the mean time to move from one state to another and the mean length of stay in a particular state once it is entered.
(4) Where closed or absorbing states exist, the probability of absorption and the mean time for absorption can be calculated (Nelson, 1988).

Garcia (2004) used a state space approach to model plantations, representing the stand with three state variables, stand basal area, stocking and height which summarizes the historical events affecting stand development and allowed prediction from current state and future actions. Vanclay (1995), used the Markov chains to provide a concise summary of the behaviour of forest stands which started in state S_i, then in a single interval grow in height (function of cover, species and age), until recruited at breast height. If not recruited within a specified time (e.g., 25 years for spruce), trees die. Baker (1989) observed that the basic component of the model for plantation modelling using the whole stand model include an initial configuration, birth, death and

Figure 1: Rubber Plantation

change function and finally an output configuration. The initial configuration is simply a starting value in the whole stand models or starting distribution of the stands among the states in distribution stand model. Birth and death functions are important functions which add or remove while the change function modifies the output. By understanding how tapping density changes over time, plantation owners can make informed decisions about resource allocation, replanting, or rejuvenation. The Markov model helps estimate the economic life of the plantation by considering factors like yield, labor availability, and disease control. The aim of this study is therefore to determine the transition probability and possibly the incremental utility of rubber tree population as it transits from the initial density of over 500 trees per hectare to an arbitrary uneconomical threshold of less than 200 trees per hectare that necessitates a replanting programme. The specific objectives therefore include:

(i) To establish the conceptual framework for the selected model.

(ii) To analyze the documentary data of a representative permanent experimental sample plots of common clones in the plantation, from which data on annual untapped, tapped and dead trees counts are generated.

(iii) To establish that the evolution of the tapping density is a Markovian process with Markovian properties, robust enough to forecast the mean passage time and the mean time to absorption of the clones.

(iv) To determine the time dependent transition probability matrix that forecasts the mean time to replanting of each clone using Markov cohort simulation.

(v) To establish significant difference in mean passage time and the mean time to absorption of the clones using contingency table and Chi square.

METHODS AND MATERIALS

The dynamic of rubber tree density is studied through permanent experimental plots. The plots are fairly large

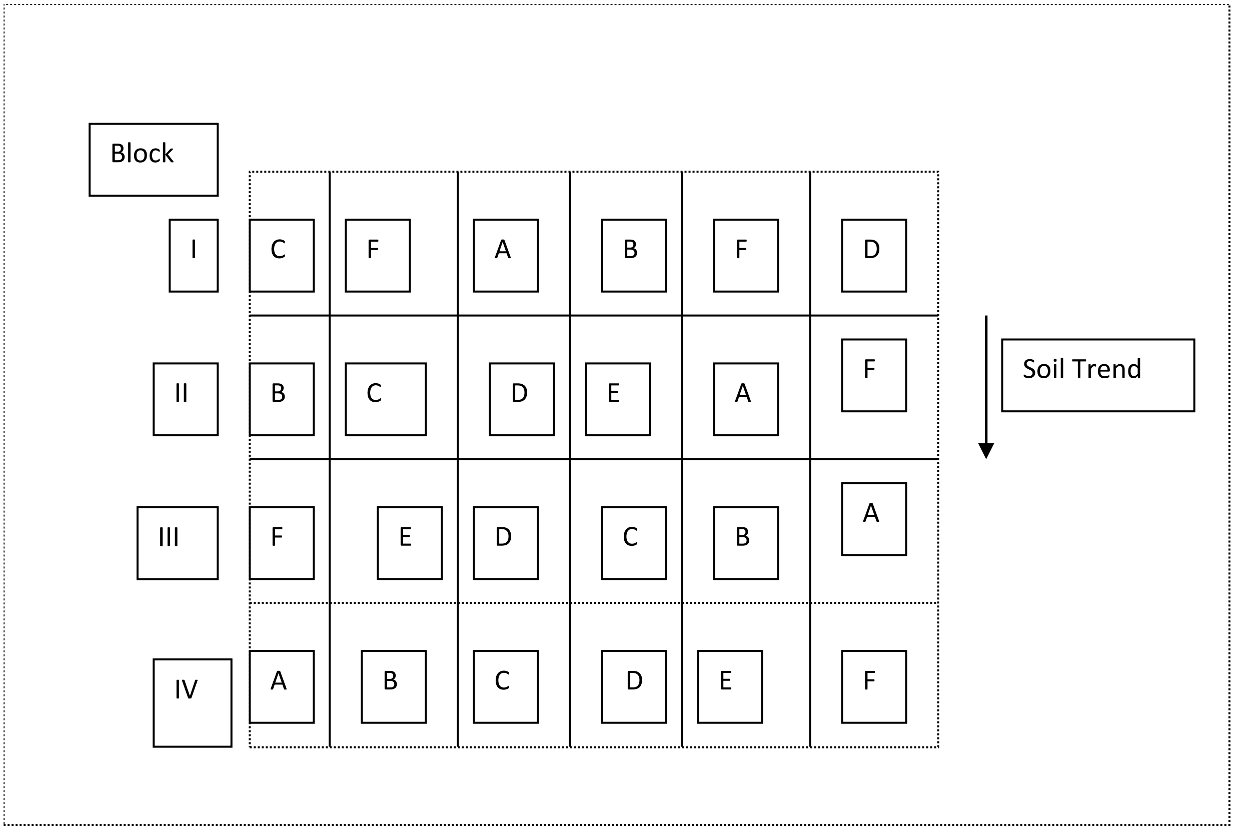

Figure 2: Randomized block experimental sampling design.

of about 1 to 1.2 hectare per clone replicated in four fisher blocks with finite number of stands ranging from 480 to 600 trees per clone. Data collected from the replicated fisher plots span a period of 12 years. The data were subjected to Markovian analysis, first to establish that the evolution of the tree's tapping density is a Markovian process with Markovian properties, robust enough to forecast the mean passage time and the mean time to absorption of the clones and secondly to determine the time dependent transition probability matrix that forecasts the mean time to replanting of each clone using Markov cohort simulation. The randomized block design permits the isolation of smaller areas, each homogenous within itself which are known as blocks as shown in (Figure 2). Every block contains one complete set of treatments. Each plot of the experiment studied is formed by a finite number of stands (120 to 150 trees) and composed of the same aged trees and clones. The trial is planted with eight rubber clones for long term periodic observation on budding and planting success, girth gains and resistance to disease, evolution of tapping density and yield per clone. The stimulation programme is different for each clone but tapping frequency D4 (4-day tapping interval) is the same for all treatments. Annual pest and disease inspection reveals the level of untapped, tapped, stopped and dead trees. Tapping may or may not induce dry bark (Stopped). The state of the tree population is therefore characterized into UNTAPPED, TAPPED, STOPPED and DEAD at any point in time. The utility of rubber tree exploitation depends on the state of the trees. The rate of change from one state to another is modelled on the state space approach while the whole stand transition matrix characterizes the state of the stands by number of trees in each state. One year cycle time is employed because it is the inspection interval for pest and disease control in this rubber plantation.

The interest of the study is the evolution of tapping density of the following rubber clones in the trial: IRCA 109, RRIC 100, PB 260, IRCA 111, PB 235, IRCA 18, GT 1, and PB 217 which are planted on industrial scale in the estates. Markov model is chosen for the analysis because the model allows the study of events that recur over time (Gupta, 2015). The state of trees is finite, mutually exclusive and exhaustive- a prerequisite for Markovian analysis. The process is completely defined by the probability distribution among the stated states and the probabilities for the individual allowed transitions. The annual pest and disease tree census record for the state of the rubber trees of each clone is used (Appendix I).

A Markov process is completely defined once its transition probability matrix and initial state are specified. Hence to construct Markov type models for the trial the following main items of information are needed:

(1) Some classification- that to a reasonable degree separates successive states into definable categories- Untapped, Tapped and Dead states.

(2) Data describing the initial conditions at some particular time-probability of a tree being in a given state just before block maturity (opening) i.e., when a plot of same aged rubber tree has 40% of its tree population at 50cm girth, 1 metre above ground.

(3) Data to determine the transfer probabilities or rates at which states change from one category of this classification to another through time-probabilities of average annual movement to and from different tapping states. This transition is expressed in the form of transition matrix P (equation 1) where P is given by:

$$P = \begin{array}{cccc} P_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & P_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ p_{n1} & p_{n2} & \cdots & p_{nn} \end{array} \qquad (1)$$

Where

P_{11} = the probability of remaining in state 1
P_{12} = the probability of going from state 1 to state 2
P_{21} = the probability of going from state 2 to state 1
P_{22} = the probability of remaining in state 2
P_{1n} = the probability of going from state 1 to state n

The transition probability matrix (TPM) loop diagram (Figure 3) presents all the data required for a Markov analysis of the transition from one state i in each period to another j in the next period, where P is the probability of making or not making the transition. Each circle represents a Markov state, and the arrows are in direction of transition whether possible or not possible. From the TPM loop diagram (Figure 3), the state Dead (1) is an absorbing state. The transition matrix for each clone is as shown in (Table 1). The transition probability matrix (Table 1) shows the existence of three states- Dead, Untapped and Tapped. The first row is the absorbing state of Dead with zero probability of leaving the state ($P_{12} = P_{13} = 0$), while the bottom two rows and columns are the transition states of Untapped and Tapped with their respective transition probabilities. The Markov process terminates in the absorbing state of DEAD in which after sufficient number of cycles the entire cohort will be absorbed.

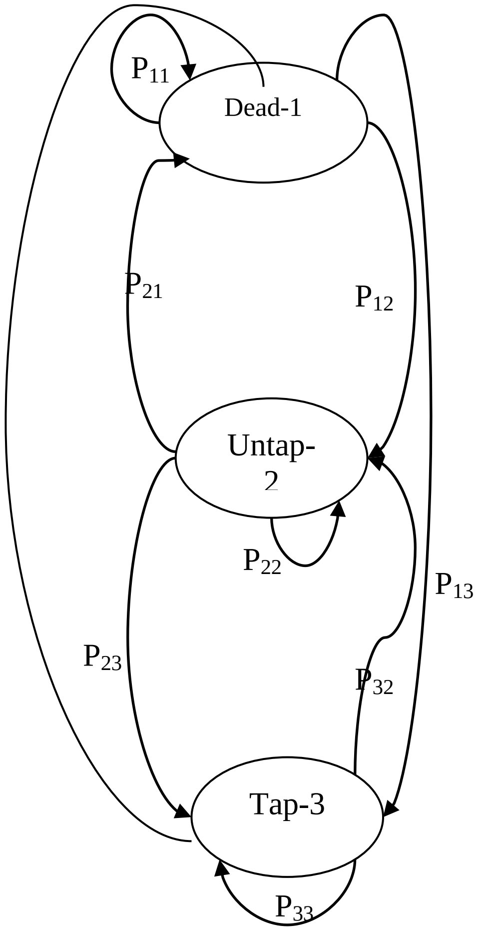

Figure 3: Transition Probability Matrix (TPM) Loop

When the transition matrix is expressed in the canonical form the absorbing states is followed by the non-absorbing states as in equation 2:

$$P = \begin{bmatrix} I & 0 \\ R & Q \end{bmatrix} \qquad (2)$$

Then the fundamental matrix solution is computed from the observed transition probabilities inverse:

$$N = (I-Q)^{-1} \qquad (3)$$

where:

I, = the identity matrix (The identity matrix I is unit matrix with nonzero elements 1 (one) only on the main

Table 1: Transition probability matrix

From/To	Dead	Untapped	Tapped
Dead	1	0	0
Untapped	P_{21}	P_{22}	P_{23}
Tapped	P_{31}	P_{32}	P_{33}

Table 2: Clone's transfer probabilities.

		Transition	Probability	Matrices
Clone	**State**	**Dead**	**Untapped**	**Tap**
GT 1	Dead	1.000	0.000	0.000
	Untapped	0.026	0.312	0.662
	Tap	0.033	0.113	0.854
IRCA 109	Dead	1.000	0.000	0.000
	Untapped	0.021	0.296	0.683
	Tap	0.022	0.112	0.866
IRCA 111	Dead	1.000	0.000	0.000
	Untapped	0.024	0.304	0.672
	Tap	0.029	0.126	0.844
IRCA 18	Dead	1.000	0.000	0.000
	Untapped	0.007	0.285	0.707
	Tap	0.015	0.098	0.887
PB 217	Dead	1.000	0.000	0.000
	Untapped	0.021	0.387	0.592
	Tap	0.040	0.139	0.821
PB 235	Dead	1.000	0.000	0.000
	Untapped	0.022	0.275	0.703
	Tap	0.030	0.156	0.814
PB 260	Dead	1.000	0.000	0.000
	Untapped	0.017	0.277	0.706
	Tap	0.029	0.106	0.865
RRIC 100	Dead	1.000	0.000	0.000
	Untapped	0.014	0.282	0.704
	Tap	0.022	0.150	0.829

diagonal).

Q = the Q-matrix.

The fundamental matrix is used to determine the average number of transitions of the trees through each state (until absorption takes place) and the time to absorption-the row total for each non absorbing state in the fundamental matrix or by the M-matrix calculation. The Scientific WorkPlace 5.5 software (Relex Software Corporation, 2007) is employed in calculating this invertible matrix. To provide further insight into the rubber plantation dynamics, a cohort consisting of all the tree of each treatment starting from the UNTAPPED to the DEAD state is modelled. The time dependent transition probabilities are obtained using TreeAge Pro Software (TreeAge Software INC, 2007) to simulate the cohort rather than the stabilized matrix for stationary Markov process as done earlier. A tree in the UNTAPPED state may make a transition to the DEAD state if attacked by root disease- fomes or wind damage. It may transit to a TAPPED state by achieving a girth of 50cm at 100cm above ground level (mature) or remain UNTAPPED if otherwise (immature).

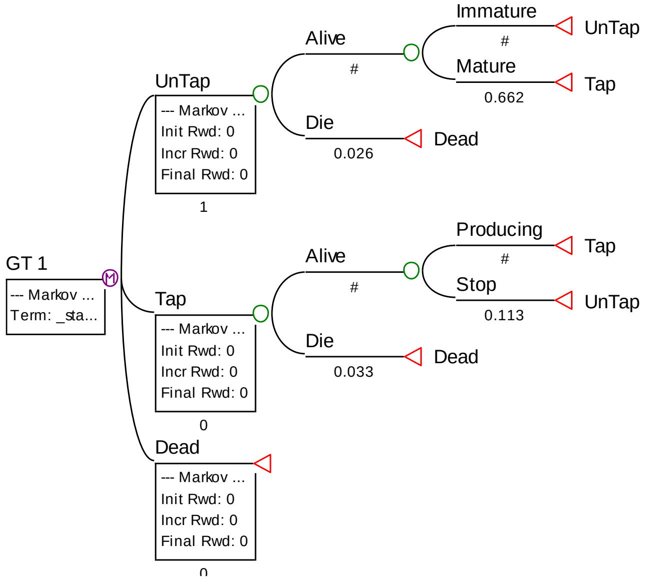

Figure 4: Markov Cycle Cohort Simulation of GT 1 Rubber Tree (TreeAge Pro 2007)

A tree in the TAPPED state may stop production due to bark dryness to become STOPPED or may die from disease or mechanical damage to become DEAD. A tree in the STOPPED state may remain stopped or dies to become DEAD.

The Markov 50-year cohort simulation provides estimates of time for each clone to transit to less than 40% economic tapping density that activates the replanting programme. The probability of a tree being in a given state just before maturity and the observed transfer probabilities or rates at which trees change from one Markov state to another through time are the input data to create the Markov cycle tree that initiates the simulation process.

The simulation is as follows. For each cycle the fraction of the cohort initially in each state is partitioned among all the states according to the transition probabilities specified by the P matrix. This results in a new distribution of the cohort among the various states for the subsequent cycle.

The simulation is run for enough cycle so that the entire cohort is in the dead state. Figure 4 is a typical Markov Cycle Tree created using the TreeAge Pro 2007 for a 50-year cohort simulation of GT 1 transition probability (Table 2).

As an absorbing Markov process, the untapped and tapped non-absorbing states will ultimately be absorbed by the dead state. Hence the notion of long run distribution (stationarity) amongst the non-absorbing states is not relevant rather the proportion of the trees which begin in each of the non-absorbing states that is ultimately absorbed by the absorbing state is determined.

RESULTS AND DISCUSSION

Transfer probabilities

Presented in Table 2 are clone by clone rate of transfer probabilities into tapped state in the opening year obtained from analysis of 6-year documentary data of tree annual pest and disease census (appendix I). All the clones have about 70% transition from untapped to tap except PB 217 which has 59%. PB 217 has the highest transition from tap to dead of 4% followed by GT1, IRCA 111, PB 235, and PB 260 with 3% apiece. IRCA 18 transition probability from tap to dead is the least (1.5%) followed by RRIC 100 and IRCA 109 (2.2% each). IRCA 18 has the highest probability of tree in tapping of 89%, followed by IRCA 109 and PB 260- 84% each. The least in P (tap) is PB 235 (81%). The probability of transiting to dead state from untapped state is lowest for IRCA 18 with only 0.7% as against the 3% for GT 1 and about 2% for the other clones.

Fundamental matrix

Scientific WorkPlace 5.5 software was used for the invertible (I-Q) matrix to obtain the fundamental matrix as shown: GT 1 Canonized Transition Probability Matrix & Fundamental Matrix Calculation is as follows:

Provide the title to table xxxxxx

From/To	Dead	Untapped	Tapped
Dead	1	0	0
Untapped	0.026	0.312	0.662
Tapped	0.033	0.113	0.854

$$(I-Q)=\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix}-\begin{bmatrix}0.312 & 0.662\\ 0.113 & 0.854\end{bmatrix}=\begin{bmatrix}0.688 & -0.662\\ -0.113 & 0.146\end{bmatrix}$$

Determinant $D=$

$$|I-Q|=\begin{bmatrix}0.688 & -0.662\\ -0.113 & 0.146\end{bmatrix}=+0.688(0.146)-(-0.113)(-0.662)=0.025642$$

Co-Factor $C=\begin{bmatrix}0.146 & 0.113\\ 0.662 & 0.688\end{bmatrix}$

Co-Factor Transposed $C^{T}=\begin{bmatrix}0.146 & 0.662\\ 0.113 & 0.688\end{bmatrix}$

Summary of result from the analysis for all 8 rubber clones is presented in (Table 3). From the (Table 3), average tapped mean passage time is 35 years while the average untapped mean passage time is 7 years with 13- and 2-year standard deviation respectively. Replanting of low tree density blocks in plantations commences at about 40% tapped tree density. It is also worthy of note that IRCA 18 consistently maintain high performance rating on all transition probability matrix parameters. These include over 50 years 40% tapping density, 58% tapping density after 30 years and the highest tapping density of 84% in the 3rd year of tapping.

Simulation of rubber tree tapping density

Maximum tapping density forecasted using TreeAge Pro 2007 simulation software for each clone is summarized in (Table 4). It shows a variation in tapping density by clones that range from 72 % for PB 217 to 84 % for IRCA 18. Expected percentage tappable density at 50 years has only IRCA 18 to be above 40%. RRIC 100 is at 30% and IRCA 109, 28%. The rest are about and below 20% tappable density from 50 years. Maximum tapping density is achieved in the second year of tapping by 5 clones (PB 260, PB 235, RRIC 100, GT 1 and 111) and the other 3 clones in the third year (PB 217, IRCA 18 and IRCA 109).

Mean time to replanting

Using TreeAge Pro software, forecasted average number of years it takes each clone to be at or below 40% tapped trees per hectare is shown in (Table 5). Table 5 shows that IRCA 18 has the longest expected year before replanting (>50 years) while PB 217 has the least mean time to replanting of 20 years. The earliest replanting period of 20 years associated with PB 217 is predicated on its lowest transition probability to “tap” from “untapped” state of only 59% (Table.2), highest dead rate from “tapped” and “untapped” of 4% and 2% respectively. Its predicted maximum tap density P (tap) is the lowest- 72% (4).

Significant test of difference and independence

The observed transition data and the generated fundamental matrix information are statistically tested to determine significant difference between clones in Transition, Meantime to Absorption, and Mean Time to Replanting. Chi square and contingency table of test of independence are used to treat the nominal scale data collected by counting. The data size per clone is greater than 5-a prerequisite for deployment of chi square test statistics.

H_0: Null Hypothesis: There is no relationship between clone and its transition to/from the Markov states-test of independence

The computation of the contingency table test of the

Table 3: Mean passage time, time to absorption and probability of absorption.

Clones	State	Mean Passage time Tapped (yr)	Mean Passage time Untapped (yr)	Absorption Time (yr)	Probability of Abs.
GT 1	Tapped	27	4	31	1.000
	Untapped	26	6	32	1.000
IRCA 109	Tapped	39	6	45	1.000
	Untapped	38	8	46	1.000
IRCA 111	Tapped	29	5	34	0.971
	Untapped	28	7	35	0.972
IRCA 18	Tapped	62	9	71	0.991
	Untapped	61	10	71	0.990
PB 217	Tapped	22	5	27	1.000
	Untapped	22	7	29	1.000
PB 235	Tapped	29	6	35	1.000
	Untapped	28	7	35	1.000
PB 260	Tapped	32	5	37	1.000
	Untapped	31	6	37	1.000
RRIC 100	Tapped	42	9	51	1.042
	Untapped	41	10	51	1.041
Mean	Tapped	35	6	41	1.000
	Untapped	34	7	42	1.000
Std. Deviation	Tapped	13	2	14	0.000
	Untapped	13	2	14	0.000

Table 4: Markov Cohort Simulation Information.

Clones	P(tap) At 50-Year	P(Tap) At 30-yr	Max Tap Density (%)	Year of Max Tapped Density
GT 1	0.17	0.32	77	2
IRCA 109	0.28	0.44	80	3
IRCA 111	0.20	0.36	77	2
IRCA 18	0.44	0.58	84	3
PB 217	0.13	0.27	72	3
PB 235	0.19	0.35	76	2
PB 260	0.18	0.34	80	2
RRIC 100	0.30	0.46	80	2

Table 5: Mean time to replanting.

Clones	Years P(tap)>=40%
GT 1	24
IRCA 109	36
IRCA 111	26
IRCA 18	>50
PB 217	20
PB 235	25
PB 260	25
RRIC 100	36

Table 6: Contingency table test of independence: clone to transition.

Actual Table

	GT 1	**IRCA 109**	**IRCA 111**	**IRCA 18**	**PB 217**	**PB 235**	**PB 260**	**RRIC 100**	**Total**
Dead	22	15	19	9	26	20	20	14	145
Untapped	76	73	84	62	89	101	71	97	651
Tap	577	567	558	557	529	526	576	535	4424
Total	675	655	661	628	644	646	666	645	5220

Expected Table

	GT 1	IRCA 109	IRCA 111	IRCA 18	PB 217	PB 235	PB 260	RRIC 100	Total
Dead	19	18	18	17	18	18	18	18	145
Untapped	84	82	82	78	80	81	83	80	651
Tap	572	555	560	532	546	548	565	547	4424
Total	675	655	661	628	644	646	666	645	5220

Table 6: Contd.

Computation of Chi Square									
	GT 1	IRCA 109	IRCA 111	IRCA 18	PB 217	PB 235	PB 260	RRIC 100	Total
Dead	0.643	0.666	0.056	3.740	3.718	0.174	0.058	0.840	9.895
Untapped	0.788	0.916	0.013	3.605	1.007	4.932	1.861	3.205	16.327
Tap	0.038	0.265	0.008	1.162	0.538	0.860	0.230	0.271	3.372
Total	1.469	1.847	0.076	8.507	5.263	5.965	2.149	4.317	29.5947

Table 7: Chi square test of time to absorption.

Clones	Absorption Time	Expected Abs. Time	χ2 value
GT 1	31	41	2.502
IRCA 109	46	41	0.451
IRCA 111	34	41	1.193
IRCA 18	71	41	20.619
PB 217	27	41	4.740
PB 235	35	41	0.999
PB 260	36	41	0.605
RRIC 100	51	41	2.005
Total	331	331	**33.115**

Table 8: Chi square test of significance difference: time to replanting P (Tap<0.4).

Clones	Forecasted Yr. to Replanting	Expected Yr. to Replanting	χ2 value
GT 1	24	31	1.581
IRCA 109	35	31	0.516
IRCA 111	26	31	0.806
IRCA 18	57	31	21.806
PB 217	20	31	3.903
PB 235	25	31	1.161
PB 260	25	31	1.161
RRIC 100	36	31	0.806
Total	248	248	31.742

above hypothesis is presented in (Table 6). The computed value of the contingency table of 29.6 is greater than the critical value of 23.6 at 5% confidence level (14 DF).

$$\chi^2 = 29.6 > \chi^2_{table} = 23.6$$

Thus, the null hypothesis of no relationship between clone and its transition is rejected. Therefore, the rate of transfer from one Markov state to the other is not independent of the clone. The alternative hypothesis that the transition probability is a function of the clone is accepted.

H_0: null hypothesis: There is no difference in the meantime to absorption between clones

The above null hypothesis is tested against the alternative hypothesis that significant difference exists in mean time to absorption between the clones using chi-square test statistics as shown in (Table 7). From the table, Chi Square computed is 33 while the Chi Square critical table value at 5% level and 7 degree of freedom is 14.06. Chi Square computed is larger than the critical value. Hence the difference in time to absorption between the clones is significant and the null hypothesis is therefore rejected for the alternative hypothesis of significant difference in time to absorption.

H_0: null hypothesis: There is no difference in mean time to replanting between clones

Replanting of low tree density blocks commences at about 40% of tapped tree density. The Markov 50-year cohort simulation provides estimates of time for each clone to transit to less than 40% tapping density. Chi square is employed to test the above hypothesis against the alternative hypothesis of significant difference between clones in replanting time (Table 8). From Chi square table the critical value of 14.06 at 5% level (7 DF) is less than the computed Chi square value of 32 (Table 8). Hence there is significant difference in time to replanting between clones. The null hypothesis of no difference is therefore rejected. Contingency test of independence of the rubber clones to tree count of its Markov states and Chi square test of significant difference in mean time to absorption; mean passage time and mean time to replanting between clones were significant at 5% level of confidence. Thus, the transition probability matrices are significantly different and depend on the clone. The 50- year cohort simulations of the observed transition probability estimated only three out of the eight clones studied to be above 40% tapped density after 30 years. These include IRCA 109 (44%), IRCA 18 (58%) and RRIC 100 (46%). Further GT 1, IRCA 111, PB 235, and PB 260 were below 40% P(tap) economic threshold after 24, 26, 25, and 25 years respectively. The high P (tap) forecasted for IRCA 18 (84%) is likely due to its high industrial budding success-initial survival rate, low bark necrosis and its sturdy architecture that reduces susceptibility to wind damage and hence transition to dead state. PB 217 has the shortest mean time to replanting of only 20 years. This poor performance is probably related to its known initial low budding success/survival rate in addition to susceptibility to leaf disease at immature.

Conclusion

Specific objectives of study include establishing the probability of a tree moving from non-absorbing state of Untapped to another non-absorbing state of Tapped and vice versa –mean passage time, the average number of time a tree stays in non-absorbing state before being absorbed- time to absorption and the average number of years each clones tapping density P (tap) can be above 40% of initial planting density – mean time to replanting. State of the art software was employed including TreeAge Pro 2007 for the cohort simulation (Markov cycle trees) and Scientific WorkPlace 5.5 Mackichan software for algebraic calculation of the invertible matrices. Markov 50-year cohort simulation provides estimates of time for each rubber clone to transit to less than 40% tapping density to establish the economic life for each of the eight rubber clones studied. The result shows that significant difference exists between clones in mean passage time, mean time to replanting and mean time to absorption. Hence, the rate of transfer is a function of the clone. The Markov transition matrix and thus the fundamental Matrix information is clone dependent. It is also discernible from the study that given the standard practice of 200 trees per hectare (40%) economic threshold, for initial opening as well as felling/replanting programme in most industrial rubber plantations in Nigeria, that the mean time to replanting of 35 years forecasted by the study is in consonance with the nominal 30-40 year mean time to replanting of plantations in the country. The long run transition probability matrix of the tapping density is not stationary as it varied from year to year and from clone to clone. Over 77% tap density became 39% or less after 24 years in tapping for GT 1, after 27 years for IRCA 111 and after 26 years for PB 235 and PB 260. Task sizes, number of tappers and hence profit per hectare varies accordingly to determine the profitability of the plantation. The study offered insight into the dynamics of a rubber plantation transition process from one utility state to the other aimed at proffering strategy for incipient planting density, recruitment of tappers, task sizing, mature area upkeep and replanting programme. The Markov model therefore provides a convenient analytical framework for forecasting tapping density evolution in a given plantation based on documentary data of annual pest and disease control (PDC) census of rubber trees to forecast the economic life of a rubber plantation.

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Appendix 1: Annual census &transition probabilities.

			Data			Total	P31	P32	P33	Check
Non-Absorbing State	Clone	Year	Dead	UnTap1	Tap					
Tap	GT 1	1	24	68	590					
		2	19	80	573					
		3	19	91	566					
		4	19	91	566					
		5	20	62	597					
		6	32	64	567					
	GT 1 Total		22	76	577	675	0.033	0.113	0.854	1.000
	IRCA 109	1	10	57	582					
		2	11	79	566					
		3	9	103	548					
		4	9	101	548					
		5	12	62	592					
		6	37	36	566					
	IRCA 109 Total		15	73	567	655	0.022	0.112	0.866	1.000
	IRCA 111	1	11	72	575					
		2	13	89	557					
		3	13	108	547					
		4	13	108	547					
		5	16	67	581					
		6	50	57	543					
	IRCA 111 Total		19	84	558	661	0.029	0.126	0.844	1.000
	IRCA 18	1	7	55	566					
		2	7	70	549					
		3	6	59	556					
		4	6	59	556					
		5	10	64	572					
		6	20	62	543					
	IRCA 18 Total		9	62	557	628	0.015	0.098	0.887	1.000
	PB 217	1	26	77	535					
		2	22	94	527					
		3	25	89	527					
		4	25	89	527					
		5	24	84	544					
		6	34	103	513					
	PB 217 Total		26	89	529	644	0.040	0.139	0.821	1.000
	PB 235	1	16	89	542					
		2	17	121	510					
		3	17	98	521					
		4	17	98	521					
		5	23	96	557					
		6	28	101	504					
	PB 235 Total		20	101	526	646	0.030	0.156	0.814	1.000
	PB 260	1	15	55	590					
		2	16	71	575					
		3	17	84	570					
		4	17	84	570					
		5	19	65	595					
		6	33	65	557					
	PB 260 Total		20	71	576	666	0.029	0.106	0.865	1.000
	RRIC 100	1	10	91	549					
		2	10	98	531					
		3	15	107	519					
		4	15	105	519					
		5	10	82	561					
		6	24	96	528					
	RRIC 100 Total		14	97	535	645	0.022	0.150	0.829	1.000
Tap Total			18	81	553	652	0.028	0.125	0.848	1.000

UnTap	GT 1	1	18	634	0	Total	P21	P22	P23	Check
		2	15	333	304					
		3	15	122	515					
		4	20	49	583					
		5	20	49	583					
		6	14	35	603					
	GT 1 Total		17	204	431	652	0.026	0.312	0.662	1.000
	IRCA 109	1	16	616	0					
		2	15	256	361					
		3	15	117	500					
		4	10	48	574					
		5	10	48	574					
		6	13	37	582					
	IRCA 109 Total		13	187	432	632	0.021	0.296	0.683	1.000
	IRCA 111	1	22	612	0					
		2	12	229	393					
		3	12	136	486					
		4	16	68	550					
		5	16	68	550					
		6	12	45	577					
	IRCA 111 Total		15	193	426	634	0.024	0.304	0.672	1.000
	IRCA 18	1	4	605	0					
		2	4	210	395					
		3	4	98	507					
		4	6	47	556					
		5	6	47	556					
		6	3	36	570					
	IRCA 18 Total		5	174	431	609	0.007	0.285	0.707	1.000
	PB 217	1	14	615	0					
		2	16	380	233					
		3	16	184	429					
		4	16	101	512					
		5	16	109	504					
		6	0	72	557					
	PB 217 Total		13	244	373	629	0.021	0.387	0.592	1.000
	PB 235	1	7	606	0					
		2	16	167	430					
		3	16	85	512					
		4	16	55	542					
		5	16	55	542					
		6	10	44	559					
	PB 235 Total		14	169	431	613	0.022	0.275	0.703	1.000
	PB 260	1	13	622	0					
		2	11	262	362					
		3	11	93	531					
		4	10	29	596					
		5	10	29	596					
		6	10	19	606					
	PB 260 Total		11	176	449	635	0.017	0.277	0.706	1.000
	RRIC 100	1	8	605	0					
		2	9	175	429					
		3	9	97	507					
		4	7	57	549					
		5	7	57	549					
		6	11	48	554					
	RRIC 100 Total		9	173	431	613	0.014	0.282	0.704	1.000
UnTap Total			12	190	425	627	0.019	0.303	0.678	1.000