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Effect of the Tree Cutting Session on the Tea Leaves Yield in Burundi

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Abstract

Background: Tea crop provides a source of income for rural households and plays a prominent role in the Burundian economy. **Objective**: This paper aims to examine the effect of cutting session and tea complex on tea leaves yield in Burundi. **Methodology**: Data were gathered from Burundi Tea Board (OTB) and cover the period from 1995 to 2022. Dependent variable was the yield of green leaves (in tons) in the industrial block and explanatory variables were cutting session and tea complex. A Bayesian two-way analysis of variance was performed as an alternative to traditional approach. The process used 400,000 Markov chain Monte Carlo (MCMC) iterations and Gibbs sampling algorithm. Data processing and analysis were performed using R software, version 4.4.0. **Results**: The higher mean tea yield was observed in Rwegura complex and the seventh cutting session. Based on credible intervals, there was however a significant effect of cutting session and tea complex on the tea yield. **Conclusion**: Cutting session and tea complex influence significantly the tea yield. This study could serve as a baseline for researchers, tea growers themselves and decision-makers who are responsible for agriculture to know the periods of

breakage in tea yield and identify other factors that could explain tea yield. This study shows that the tea plant does not age and that cutting session can even go on for more than 4 years, as the overall trend has shown that yield continues to increase from the first year of cutting session to the fourth year. This recommendation is addressed to Burundi Agronomic Sciences Institute (ISABU) which is responsible for crop research.

Keywords: tea yield, cutting session, Bayesian two-way ANOVA, Burundi

1. Introduction

Worldwide, tea (*Camellia sinensis L.*) is a cash crop from the Theaceae family that contributes to country-specific economic development. Grown in Africa, Asia and Latin America and used as an energetic drinking that helps diminish the cholesterol concentration in the blood, tea crop contributes hence to achieve the first and the third Sustainable Development Goals [16,20,21]. As for other food crops and industrial crops, tea crop plays an important role in food security of both smallholder tea farmers and non-tea farmers and national economy, especially in East African countries including Burundi [8,18].

Tea is the second industrial crop grown in Burundi after coffee. The tea plant gets mature in at least three years and starts to produce green leaves. Exported essentially to China ($8.53 million), Pakistan ($2.97 million), Kenya ($0.0695 million), United Arab Emirates ($0.0545 million) and Japan ($0.0491 million), Burundi tea exports were estimated at $11.7 million in 2023 [19]. Tea was the third most exported product after coffee and gold. Tea income provides farmers livelihood, support them in case of food or money shortage and save them from issues when they retire [4]. Tea production and tea sale are controlled by Burundi Tea Board (OTB, Office du Thé du Burundi). Tea crop is grown in five tea complexes namely Rwegura, Teza, Tora, Ijenda and Buhoro. These tea complexes are themselves located in Kayanza, Muramvya, Bururi, Bujumbura and Cibitoke provinces respectively. Tea crop faces several challenges including price volatility, climate variability, scarcity of land for sustainable production, labour shortage, high production costs, high transaction costs and aging tea bushes [3].

Several studies focused on tea yield modelling. As a matter of fact, a study conducted in South Indian, which used multiple linear regression (MLR), seasonal autoregressive integrated moving average with exogenous variables model (SARIMAX), artificial neural network (ANN) and vector autoregressive model (VAR), showed among other findings that climate variability (temperature and rainfall) influenced significantly the tea yield [17]. Besides, a study carried out in both Tanzania and Kenya used the CUPPA-Tea, a simulation model of tea production and seasonal variation of tea yield, to show that tea yield is likely to be high for sites with a high level of organic content when nitrogen is not applied and a strong relationship between observed tea yield and CUPPA-Tea predicted yield [7]. A study conducted in Bangladesh in 2022 used several techniques such as Markov-switching, standard and exponential generalized autoregressive conditional heteroskedastic (MS-GARCH, GARCH, EGARCH, Bayesian MS-GARCH) models to estimate volatility and forecast tea crop price returns [10].

A multilevel Bayesian model was applied to assess factors (presence of pesticides, coloring agents, additives, label issues) influencing nonconformity of tea products in terms of quality and safety in China market [24]. Bayesian ANOVA has been developed elsewhere and was based on the Bayes factor or the Markov chain Monte Carlo (MCMC) algorithms like Gibbs sampling and Metropolis Hastings [11,12,6]. To our best knowledge, there is no study which focused on Bayesian modelling of tea leaves yield in Burundi. The aim of this article was to examine the effect of cutting session and tea complex on the tea leaves yield using a Bayesian analysis of variance (ANOVA) as an alternative to traditional ANOVA when conditions are not met. This study could help decision-makers with agriculture in their responsibilities, researchers and tea growers themselves to know the periods of breakage in tea yield and identify other factors that could explain tea leaves yield.

2. Materials and methods

Available data were gathered from Burundi Tea Board (OTB) and cover the period from 1995 to 2022. Dependent variable was the yield of green leaves (in tons) in the industrial block. This annual tea yield was calculated by dividing tea production and planted area in each tea complex. The first explanatory variable was tea complex with four categories (1=Buhoro, 2=Rwegura, 3=Teza, 4=Tora). Ijenda tea complex was excluded because it does not possess the industrial block. The tea cutting session is done once a 4-year period. There were then seven cutting session categories (S1=1995-1998, S2=1999-2002, S3=2003-2006, S4=2007-2010, S5=2011-2014, S6=2015-2018, S7=2019-2022). The zero value for tea yield in the first cutting session (Buhoro tea complex) was imputed by the mean value (4.15) of yield of green leaves for the remaining observations in the same cutting session.

The F-test in a traditional one-way and two-way analysis of variance (ANOVA) model was performed. The equation of a two-way ANOVA model with two main fixed effects and an interaction term is [15]:

$$y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk} \tag{1}$$

where y_{ijk} stands for the k^{th} ($k = 1,...,n_{ij}$) observation for the i^{th} ($i = 1,...,I$) level of cutting session (first factor) and the j^{th} ($j = 1,...,J$) level of tea complex (second factor), n_{ij} the number of observations in the cell *(i,j)*, μ the overall mean, α_i the effect of the i^{th} level of cutting session, β_j the effect of the j^{th} level of tea complex, $(\alpha\beta)_{ij}$ the interaction effect between cutting session and tea complex and $\varepsilon_{ijk} \sim N\left(0,\sigma_\varepsilon^2\right)$ a random error of the observation y_{ijk}. The sum of squares total (*SST*), also called the total variability, was broken down into the sum of the sum of squares due to the cutting session (SSCS), the sum of squares due to the tea complex (SSTC), the sum of squares due to the interaction (SS_CS_TC) and the sum of squares due to the residuals (SSR):

$$\underbrace{\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{n}\left(y_{ijk}-\bar{y}_{\bullet\bullet}\right)^2}_{SST} = \underbrace{nJ\sum_{i=1}^{I}\left(\bar{y}_{i\bullet}-\bar{y}_{\bullet\bullet}\right)^2}_{SSCS} + \underbrace{nI\sum_{j=1}^{J}\left(\bar{y}_{\bullet j}-\bar{y}_{\bullet\bullet}\right)^2}_{SSTC} + \underbrace{\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{n}\left(y_{ijk}-\bar{y}_{i\bullet}-\bar{y}_{\bullet j}+\bar{y}_{\bullet\bullet}\right)^2}_{SS\_CS\_TC} \quad (2)$$

The F-statistic compares within groups and between groups variances. The probability of obtaining the observed F greater than or equal to the theoretical F value, also called p-value, was determined. A significance threshold of 5% was used. Results of the F-test were valid if the residuals of the model were independent, drawn from a normal distribution and homogeneous. Those conditions were checked using the Box-Pierce test, the Shapiro-Wilk normality test in each level of the explanatory variable and the Hartley test of homogeneity of variances respectively [5,13,2]. In a traditional ANOVA, it is rare that the validity conditions are simultaneously met. In such case, a nonparametric approach (Kruskal-Wallis test in one-way ANOVA or Friedman test in two-way ANOVA) based on robust parameter such the median or the rank of the observations can be used. Even though validity conditions are met, one might be interested in data source aspects and taking account the information available in the data. Specifically, tea yield at time *t* depends on tea yield at time *t-1* because of a residual effect of fertilizer, indicating the absence of independence. A Bayesian ANOVA provides a good alternative approach.

Contrary to the traditional approach which focusses on the p-values, the Bayesian approach takes into account not only the information available in the data but also sources of variability and uncertainty. Besides, it helps determine how much the model is supported by the data [22]. The information contained in the data, also called prior knowledge about the parameters, is updated through the likelihood (data distribution) and yields to the posterior distribution as follows:

$$p(\theta \mid y) \propto p(\theta) \times p(y \mid \theta) \tag{3}$$

where $p(\theta \mid y)$ is the posterior distribution of the parameter θ given the data, $p(\theta)$ the prior distribution of the parameter θ and $p(y \mid \theta)$ the likelihood.

Specifically, the tea yield was modeled as a Gaussian linear function of cutting session, tea complex and their interaction throughout Markov chain Monte Carlo (MCMC):

$$y_i = X\beta + \varepsilon_i \tag{4}$$

where y_i is the i^{th} observation of tea yield of tea green leaves, X the design matrix, β the vector of parameters and $\varepsilon_i \sim N(0, \sigma^2)$ a random error considered as a prior Gaussian distribution with zero mean and constant variance σ^2. The Bayesian model's parameters were estimated using a MCMC Bayesian approach instead of the ordinary least squares (OLS) used in the traditional linear regression method. This approach was used because it is an alternative for estimating complicated models [1]. In order to complete the Bayesian model, we need to specify prior distributions for the parameters:

$$\begin{aligned} & y \mid \beta, \sigma^2 \sim N(X\beta, \sigma^2) \\ & \beta \mid \sigma^2, y \sim N(b_0, B_0^{-1}) \\ & \sigma^2 \mid y \sim IG(a, b) \end{aligned} \tag{5}$$

where $a = \frac{n-1}{2}$ and $b = \frac{(n-1)s^2}{2}$ are the shape and the scale parameters of the inverse-Gamma distribution of σ^2 (the conditional error variance structure), s^2 the variance of y ($s^2 = 0.04$), *n-1* the number of pseudo-observations (*n-1=55*), $b_0 = 0$ and $B_0 = 0$ (improper uniform prior on beta). These two last parameters are the prior mean and the prior precision of β. The starting value for the β was the estimate of the ordinary least squares (OLS) of β. No starting value was given for σ^2. The scale parameter b was considered as the sum of squares of residuals. The MCMCregress function helped obtain the posterior distribution of the independent hyper-parameters (β, σ^2) using Gibbs sampling algorithm. The coda and *MCMCpack* packages, 400,000 MCMC iterations and 2 long Markov chains were used [14]. Those chains were combined and helped check convergence. The posterior distribution was given by the MCMC algorithm and then summarized by computing the mean, the standard deviation and the 95% credible intervals for the beta's. The convergence of the algorithm and the speed of convergence of a chain were investigated. To achieve this, statistical tools and methods such as trace plots, the Effective Sample Size (ESS), the Heidelberger and Welch Diagnostic and the Geweke diagnostic were used [6].

Trace plots, which should be with random waves and without trend to insure convergence, show the sample values of the parameters against the number of iterations. The effective sample size should be as large as possible, an indication of a good mixing of the chain. Besides, the test for the Heidelberger and Welch diagnostic should pass for all parameters, indicating the stationarity and the convergence of the chain. Not significant p-values for the Geweke diagnostic show no differences between mean values of the earliest and the latest samples in the chain. For this criterion, parameters with a z-score within the interval [-1.96, 1.96] were considered as indicative of convergence at 95% credible interval.

3. Results

3.1. Descriptives statistics

Median tea yield of green leaves was higher in the seventh cutting session (5.88 tons) and Rwegura tea complex (6.39 tons) (**Figure 1**, **Figure 2**).

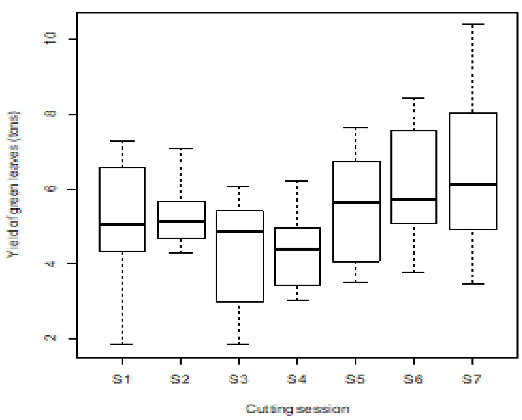

Figure 1: Yield over cutting session

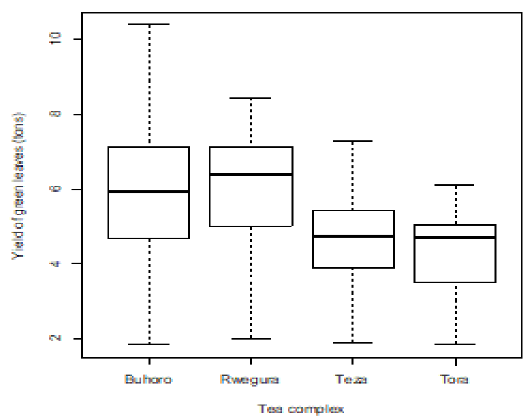

Figure 2: Yield over tea complex

The overall mean yield of green leaves was 5.33 tons per hectare with a standard deviation of 1.61. The higher mean tea yield (mean±standard deviation (SD): 6.57±2.10) was found at the seventh cutting session and the lower mean tea yield (4.29±1.03) at the fourth cutting session (**Table 1**). The higher mean tea yield was observed in Rwegura tea complex (6.14±1.39) and the lower mean yield (4.38±0.96) was found in Tora tea complex (**Table 2**).

Table 1: Descriptive statistics of tea yield over cutting session

Cutting session	Frequency	Minimum	Mean	Standard deviation	Maximum
S1	16	1.83	5.23	1.52	7.27
S2	16	4.28	5.31	0.78	7.10
S3	16	1.85	4.34	1.50	6.06
S4	16	3.01	4.29	1.03	6.23
S5	16	3.50	5.50	1.46	7.64
S6	16	3.77	6.08	1.38	8.43
S7	16	3.48	6.57	2.10	10.39
Overall	112	1.83	5.33	1.61	10.39

Table 2: Descriptive statistics of tea yield over tea complex

Tea complex	Frequency	Minimum	Mean	Standard deviation	Maximum
Buhoro	28	1.83	6.08	1.96	10.39
Rwegura	28	2.01	6.14	1.39	8.43
Teza	28	1.88	4.73	1.17	7.27
Tora	28	1.85	4.38	0.96	6.10
Overall	112	1.83	5.33	1.61	10.39

3.2. Traditional one-way and two-way ANOVA

The Bartlett test of homogeneity of variances did not reject the null hypothesis of equal variances across cutting session, except Teza tea complex (**Table 3**).

Table 3: Checking traditional one-way ANOVA assumptions

Tea complex	Bartlett	Shapiro-Wilk	Durbin-Watson
Rwegura	B^2=8.70, df=6, p=0.19	W=0.90, p=0.01	DW=2.33, p=0.38
Teza	B^2=16.80, df=6, p=0.01	W=0.87, p=0.002	DW=2.36, p=0.42
Tora	B^2=11.43, df=6, p=0.08	W=0.96, p=0.37	DW=2.94, p=0.94
Buhoro	B^2=7.50, df=6, p=0.28	W=0.92, p=0.03	DW=2.63, p=0.72

The Shapiro-Wilk normality test did not reject the null hypothesis of normal residuals only in Tora tea complex and the Durbin-Watson test did not reject the null hypothesis of independence of residuals respectively across cutting session in all tea complexes. **Table 4** shows that the effect of cutting session on tea yield was significant in all tea complexes. In this table, SS denotes the sum squares, df the number of degrees of freedom and MS the mean squares.

Table 4: Traditional one-way ANOVA of yield accros tea complexes

Tea complex		SS	Df	MS	F	P-value
Buhoro	Cutting session	71.52	6	11.92	7.88	0.0002
	Residuals	31.78	21	1.51		
Rwegura	Cutting session	29.82	6	4.97	4.63	0.0038
	Residuals	22.54	21	1.07		
Teza	Cutting session	18.55	6	3.09	3.50	0.0148
	Residuals	18.57	21	0.88		
Tora	Cutting session	11.02	6	1.84	2.82	0.0360
	Residuals	13.70	21	0.65		

From cutting session S1 to cutting session S7, mean tea yield presented an increasing trend for Buhoro, Rwegura and Tora tea complexes (**Figure 3**).

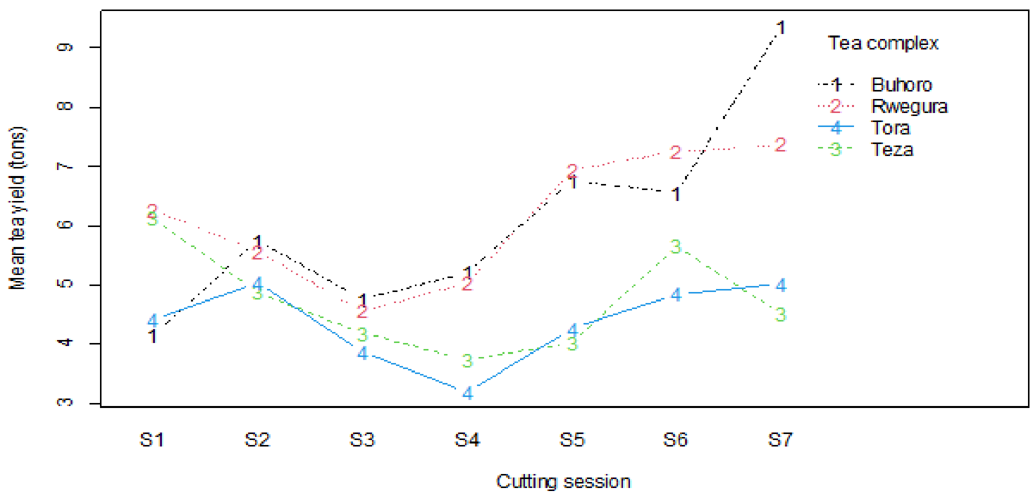

Figure 3: Trend of mean tea yield over cutting session by tea complex

Results of the traditional two-way ANOVA showed that the interaction effect between cutting session and tea complex was not significant (F=3.46, p-value= 5.93×10^{-5}) and was then removed from the model. The mean yield in Rwegura tea complex increased from 4.56 tons to 7.37 tons from S3 (2003-2006) to S7 (2019-2022). The mean yield in Tora tea complex increased from 4.27 tons to 5.02 tons from S4 (2007-2010) to S7 (2019-2022). It decreased in all tea complexes from S2 (1999-2002) to S3. There was a significant effect of cutting session (F=7.54, p-value=1.06×10^{-6}) and tea complex (F=15.74, p-value=1.75×10^{-8}) on tea yield (**Table 5**).

Table 5: Traditional two-way ANOVA

Variation source	Sum Square	Df	Mean Square	F^{obs}	F^{tab}	P-value
Cutting session	68.80	6	11.13	7.54	2.19	1.06×10^{-6}
Tea complex	69.75	3	23.25	15.74	2.69	1.75×10^{-8}
Residuals	150.70	102	1.48			
Total	289.25	111				

Checking assumptions, the Hartley test of homogeneity of variances rejected the null hypothesis of equal variances across cutting session (F=7.32, df=15, I=7, p-value=0.0 06) and tea complex (F=4.18, df=27, J=4, p-value=0.002), an sign that there is not a s ubstantial evidence to indicate that the observed differences in mean yield are due to t he disparate tea complexes or that the variance of residuals was homogeneous. The S hapiro-Wilk normality test did not reject the null hypothesis of residuals for all cuttin g sessions (p-value=0.07), suggesting that residuals were normally distributed in the t ea complex levels. Besides, residuals were normally distributed in all tea complexes (p-value=0.07). The time-series Box-Pierce test (K^2=32.43, df=1, p-value=1.24×10^{-8}) r ejected the nul hypothesis of independence of residuals. Residuals were then consider ed as dependent or auto-correlated.

3.3. Bayesian two-way ANOVA

The model with interaction showed that the credible interval (CrI) included zero in Rwegura and Tora tea complexes but somewhere in Teza, the CrI did not include zero. This suggested that the coefficients were not significant and then, the interaction effect was not significant.

In the model without interaction, the expected mean tea yield increased from the cutting session S1 to any other cutting session, except the cutting sessions S2 and S3 where it decreased, as shown in Table 6. Besides, the expected mean tea yield observed in cutting session S7was significantly different from the expected mean tea yield observed in the cutting session S1. The expected mean tea yield observed in Rwegura, Teza and Tora tea complexes were not significantly different from the expected mean tea yield observed in Buhoro tea complex, an indication of a significant effect of cutting session and tea complex on tea yield (**Table 6**). The first quartile (P25), median (P50) and the third quartile (P75) of the posterior distribution were also reported.

Table 6: Bayesian two-way ANOVA without interaction

	Categories	Mean	SD	P25	P50	P75	95% CrI
Intercept		5.98	0.43	5.69	5.98	6.27	[5.13, 6.83]
Cutting session	S2	0.08	0.51	-0.27	0.07	0.42	[-0.92, 1.09]
	S3	-0.89	0.51	-1.23	-0.89	-0.54	[-1.89, 0.11]
	S4	-0.94	0.51	-1.28	-0.93	-0.60	[-1.93, 0.06]
	S5	0.26	0.51	-0.08	0.26	0.61	[-0.73, 1.26]
	S6	0.85	0.51	0.50	0.85	1.19	[-0.14, 1.86]
	S7	1.33	0.51	0.99	1.33	1.68	[0.34, 2.32]
Tea complex	Rwegura	0.06	0.39	-0.20	0.06	0.32	[-0.70, 0.81]
	Teza	-1.35	0.39	-1.61	-1.35	-1.09	[-2.11, -0.60]
	Tora	-1.70	0.39	-1.96	-1.70	-1.44	[-2.46, -0.95]
σ^2	σ^2	2.07	0.20	1.93	2.06	2.20	[1.71, 2.51]

The Geweke diagnosis showed that all parameters converged (**Figure 4**). The z-score was -0.25 for intercept, -0.31 for session S2, 0.22 for session S3, 0.66 for session S4, 0.10 for session S5, 0.49 for session S6, -0.20 for session S7, -0.28 for Rwegura, 0.14 for Teza, 0.45 for Tora and -0.80 for σ^2. All these values lay in the interval [-1.96, 1.96], an indication of convergence of the chain. When using the Heidelberger and Welch diagnostic, all p-values were greater than 5%. This suggested that the chain used in MCMC converged well. This was graphically proved by trace plots for all parameters (**Figure 4**).

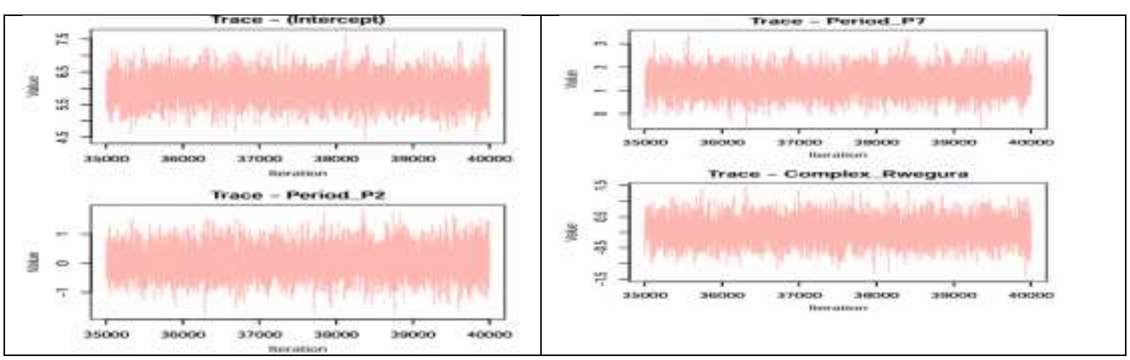

Figure 4: Trace plots for model parameters

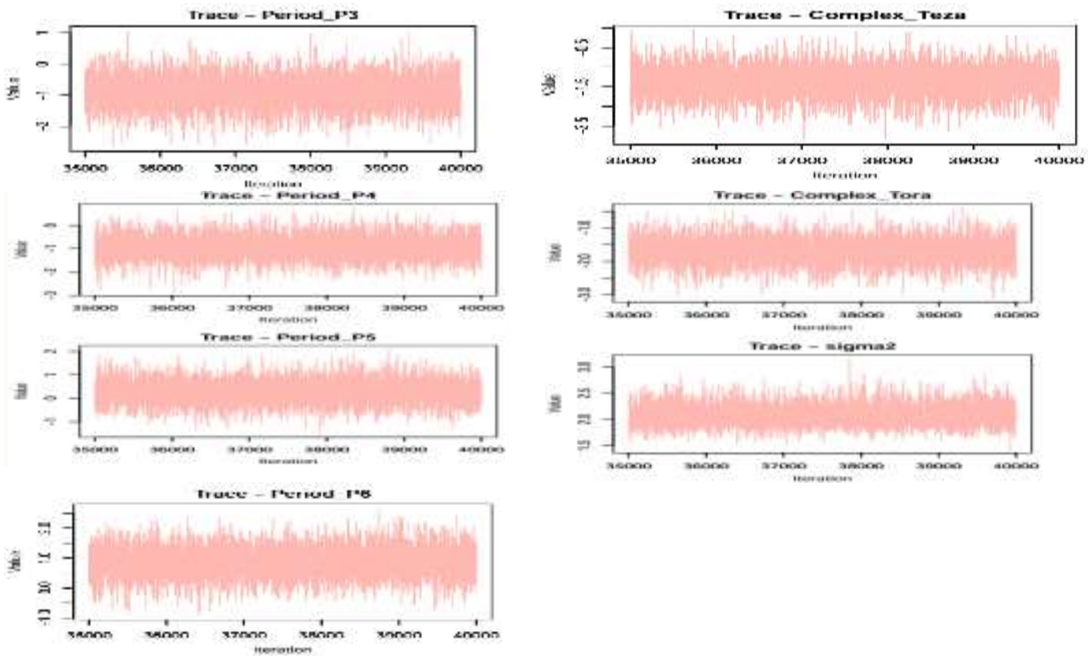

Figure 4: Trace plots for model parameters (continued)

The effective sample size (ESS) obtained for each coefficient was between 38235.35 for the session S4 and 42,060.29 for session S5. The ESS was greater than 1000, indicating that the MCMC samples were uncorrelated and then reflected a well-performing MCMC process. This provided a good estimate of the parameters.

4. Discussion

Tea crop is part of the economy in Burundi and other countries such as China [23]. The purpose of this study was to examine the effect of cutting session and tea complex on tea yield in Burundi using the Bayesian analysis of variance (ANOVA) as an alternative to the traditional ANOVA. In Burundi, tea crop is grown on reliefs which are generally the highest with an altitude of around 2000 m. The mountain peaks are conical and the rainfall is abundant and regular (at least 2000 mm per year) and the temperature is high (20°C most often during the year).

The overall mean tea yield of green leaves was 5.33 tons per hectare with a standard deviation of 1.61 tons per hectare. This mean tea yield is low and improvements are needed for the mechanization level of tea production as proposed by QiangXu et al. in China in 2021 [23]. The decreasing tea yield observed in all tea complexes from S2 (1999-2002) to S3 (2003-2006) was due to insecurity particularly in the Teza and Buhoro tea complexes and the embargo on the Burundian Government in 1996. The higher mean tea yield was observed in Rwegura tea complex because of the favorable climatic conditions for tea in Rwegura tea complex located itself in Buyenzi natural region. This result lines with the findings of a previous study carried out in Mugongomanga and Bukeye (Burundi) in 2020 [4].

Buyenzi natural region has an altitude varying from 2050 m to 2500 m and it is the wettest with a mean rainfall of over 1700 mm per year. In addition, rainfall is sufficient and almost regular. As for the temperature, it varies between 19°C and 21°C. These characteristics corroborate findings which showed that optimal conditions for tea crop are so that mean temperature lays between 18°C and 23°C, annual rainfall varies from 1500 mm to 2000 mm, annual relative humidity is comprise between 80% and 85%, and a soil pH between 4.5 and 5.5 (acid soil) [9]. Results of Bayesian two-way ANOVA showed a significant effect of cutting session and tea complex on tea yield. A further study should explore the link between the combination of climate variables, soil biological and chemical properties and tea yield as proved elsewhere [17].

5. Conclusion

This study showed that cutting session and tea complex have a significant effect on the tea yield. It could help researchers, tea growers themselves and decision-makers who are responsible for agriculture to know the periods of breakage in tea yield and identify other factors that could explain tea yield in order to improve the tea yield. Given the place of tea crop in Burundian economy, the Government should ensure that growers cut their tea crops once every 4-years period or more and encourage Burundi Tea Board (OTB) and farmers who possess acid land to extend area for tea cultivation.

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