Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 8 (5): 866-870, 2008
ISSN 1812-5654

Improving the Precision of Forestry Experimentation with Covariance Analysis

[1]I.C. Zobi, [2]J.P. Pascal, [3]P. Couteron and [1]K.B. Kouadio
[1]Laboratoire de Génie Forestier, Département Eaux, Forêts et Environnement,
Institut National Polytechnique Houphouët-Boigny, BP 2661 Yamoussoukro, Côte d'Ivoire
[2]Laboratoire de Biométrie et Biologie Evolutive, UMR CNRS 5558, Université Claude Bernard Lyon 1,
43 Bd du 11 Novembre 1918, 69622 Villeurbanne, Cedex France
[3]Department of Ecology, French Institute of Pondicherry, 605001 Pondicherry, India

Abstract: This study aims to provide a tool of study to forester and forest survey researchers. It deals with the effect of a method of thinning on tropical forest dynamic. In this method, elimination of trees species of no commercial value was done in order to increase the growth rate of the whole group of commercial ones. Specifically, this study shows how a statistical method which is covariance analysis can be used to solve an inadequacy of experimental design. This inadequacy results from a difference between the initial total basal area of the treated quadrants and that of the untreated (standard) quadrants. The gain of precision is 1.054. It provided the following estimates of the increase rate in basal area of the commercial species: 0.73 m^2 ha^{-1} $year^{-1}$ for the treated quadrants and 0.92 m^2 ha^{-1} $year^{-1}$ for the untreated ones. When the initial total basal area of the quadrants is not considered like an auxiliary variable, the values of the basal area of the commercial species are: 0.53 m^2 ha^{-1} $year^{-1}$ for the treated quadrants and 1.05 m^2 ha^{-1} $year^{-1}$ for the untreated ones.

Key words: Covariance analysis, thinning, commercial species, basal area, growth rate

INTRODUCTION

Since sustainable management of tropical forest ecosystem has become internationally an important issue and the environmental certification concept has been created, new silvicultural techniques have earlier been tested by Ivorian researchers in order to satisfy industrial product demands without damaging the environment (Zobi, 2002). One of those silvicultural techniques experimented by researchers is the method of thinning (Balboa-Murias *et al*., 2006; Utsugi *et al*., 2006). Closed to forest economy, this method consists of eliminating trees of no commercial species in order to increase the increment rate of the whole group of the commercial ones.

Thus, the statement saying that the method of thinning stimulates the dynamic of trees growth was proved by researchers through inventories in time and space (Chave, 1999; Blanco *et al*., 2006; Jaakkola *et al*., 2006; Kanninen *et al*., 2004). Since 1978, Sodefor (Société de Dévelopement des Forêts) has decided to confirm this statement by experimentation. For this raison, it created three permanent experimental designs. The main purpose of this experimentation is to check up whether the elimination of no commercial species (secondary species) can have a positive effect on commercial species (principal species) growth.

This study also aims at examining whether a statistical method (covariance analysis) (Dahdouh-Guebas and Koedam, 2006; Headley *et al*., 2005), can be used to solve the inadequacy of the experimental design which results from a skewness on the assessment of a silvicultural treatment effect.

MATERIALS AND METHODS

Experimental material and data-gathering: This study has been conducted from 1978 to 1998 on the experimental design installed in the classified forest of Mopri. This forest which covers an area of 33000 ha is located between 5° 40' and 5° 55' of Northern-latitude and 4° 52' and 5° 02' of Western-longitude (Vennetier and Laclavere, 1983). It is a semi-deciduous rainforest with an average annual rainfall of 1138 mm. The soils are ferralitic and the relief presents a weak slope, going from West to East (Roose, 1981).

The experimental design is a square of 3000 m sidelong or a total area of 900 ha. But the test is carried out in the central square of the design and its area is

Corresponding Author: I.C. Zobi, Laboratoire de Génie Forestier, Département Eaux, Forêts et Environnement, Institut National Polytechnique Houphouët-Boigny, BP 2661 Yamoussoukro, Côte d'Ivoire
Tel: +225-05-05-26-42 Fax: +225-30-64-6691

400 ha. This one was subdivided into 25 parcels of 16 ha each. Each parcel comprises of two distinct parts which are the buffer zone and the central zone. The central zone of 4 ha is composed of 4 quadrants of 1 ha each. Among the 25 parcels of the experimental design, 15 were chosen randomly, thinned out and constitute the treated quadrants. The 10 others parcels which have not been treated constitute the untreated quadrants. Only the biggest trees among the secondary species were eliminated.

The observations and measurements were made in the quadrants. Only trees which diameter at 1.30 m above ground is superior or equal to 10 cm were considered. They were classified according to their economical importance: principal species and secondary species. The diameter of trees of principal species was measured. Their coordinates (x, y), their scientific and commercial names were determined. Contrary to the principal trees, the precision on the diameter of the secondary trees was approximate: they were merely gathered by range of diameter.

Measurements were done every 2 years. The proportion of basal area eliminated corresponds to the rate of thinning. This rate expresses the thinning intensity and represents the degree of stress undergone by the forest stand. They distinguish two types of thinning which are T_1 and T_2. T_1 stands for the average thinning (rate from 25-35%) and T_2 stands for the highest thinning (rate from 36- 50%). For the untreated quadrants, the total basal area before thinning (G_i) is equal to the total basal area after thinning (G_r).

Principle of covariance analysis: The principle of covariance analysis is based on the comparison of several regression models (Aznar and Guijarro, 2007; Inglot and Ledwina, 2006; Pines *et al.*, 1992; Dagnélie, 1998; Mead, 1988). The goal of a regression model is to explain a quantitative variable (increase rate in basal area of principal species-R) by the means of qualitative variables (thinning and site) and quantitative variable (initial total basal area-G_i). The models that covariance analysis compares are of three types:

Model 1 explains the R by the means of qualitative variables treatment and site. It is a model of two-ways analysis of variance. Mathematically, it is formulated as follows:

$$a_{ij} = m + t_i + b_j + e_{ij} \tag{1}$$

Where:

a_{ij} = R of the quadrants j, having received treatment i
m = Mean R of all the quadrants
t_i = Effect of treatment i (treated and untreated)
b_j = Effect of the quadrant j
e_{ij} = Experimental error

Model 2 explains R by the means of two qualitative variables treatment and site and a quantitative variable G_i. It is a model of covariance analysis with only one covariable. It is formulated as follows:

$$a_{ij} = m + t_i + b_j + \alpha\,(u_i - \bar{u}) + e_{ij} \tag{2}$$

Where:

u_i = G_i of the quadrants having received treatment i
$\bar{u}$ = Mean G_i of all the quadrants
α = Linear coefficient of regression of R (a_i) in G_i (u_i)

Model 3 explains R by the means of the qualitative variable site and the quantitative variable G_i. Mathematically, it is formulated as follows:

$$a_{ij} = m + b_j + \alpha\,(u_i - \bar{u}) + e_{ij} \tag{3}$$

RESULTS

A classical analysis of variance of data concerning increase in basal area in the treated and untreated quadrants was done.

The F test points out a highly significant effect of the site and a very highly significant effect of the silvicultural treatment on the increase rate (R) (Table 1). The intensity of the treatments (T_1 and T_2) allows two independent comparisons (treated versus untreated and T_1 versus T_2) and to use the method of contrasts.

It was noticed that the difference observed between the silvicultural treatments is mainly due to the difference between the mean value of R ($\bar{a}_i$) in the treated quadrants (1.05 m^2 ha^{-1} $year^{-1}$) and that of the untreated ones (0.53 m^2 ha^{-1} $year^{-1}$). It was also observed that the T_2 is lightly superior to the T_1.

However, the high value of the coefficient of variation ($100\times\sqrt{0.16} \div 0.84 = 47.6\%$) leads to some doubt about the validity of these results. Indeed, this high value of the coefficient of variation shows that some significant sources of variation between both groups of quadrants were not taken into account during the experimentation.

Therefore, it is interesting to take into consideration the characteristics of the site. The effect of those characteristics remains very significant, even though the site effect is evaluated basing on the treatment effect. For that, the mean value of G_i ($\bar{u}_i$) was considered because it is directly accessible. Treated quadrants $\bar{u}_i$ (31.77 m^2 ha^{-1}) is significantly different from that of the untreated one (21.60 m^2 ha^{-1}).

Table 1: Analysis of variance result for sites and treatments effect on the increase rate (R)

Sources of variation	df	Sum of squares	Mean of squares	F-calculated	p-value
Treatments	1	6.60	6.60	42.40	$7.0e^{-9}$***
Sites	23	7.61	0.33	2.12	$7.8e^{-3}$**
Residual	75	11.68	0.16		
Total	99	25.89	0.26		

df = degree of freedom, *** = Very highly significant ($p\leq 0.001$), ** = Highly significant ($p\leq 0.01$)

Table 2: Decomposition of the sum of squares for the 3 models of regression

	Model 1		Model 2		Model 3	
	df	Sum of squares	df	Sum of squares	df	Sum of squares
Regression	24	14.21	25	14.94	25	14.94
Residual	75	11.68	74	10.94	74	10.94
Total	99	25.89	99	25.89	99	25.89

df = degree of freedom

Table 3: Correction of R values using covariance analysis

Treatments	Mean value of R observed ($\bar{a}_i$) (m^2 ha^{-1} $year^{-1}$)	Mean value of G_i ($\bar{u}_i$) (m^2 ha^{-1})	Corrected mean [$\bar{a}_i$ - α (u_i-$\bar{u}$)] (m^2 ha^{-1} $year^{-1}$)
Untreated	0.53	21.60	0.73
treated	1.05	31.77	0.92

The $\bar{u}_i$ value was taken into consideration through covariance analysis. The purpose of this statistical method is to eliminate the influence of $\bar{u}_i$ value from the mean value of R (α_i). It allows the comparison of both groups of quadrants regarding that $\bar{u}_i$ value is identical. The obtained result shows that models (2) and (3) are equivalent because $SS_{(2)} = SS_{(3)}$ and $df_{(2)} = df_{(3)}$. However, in addition to all the sources of variation considered in model (3), the model (2) expressed the effect of the silvicultural treatment (t_i) which is consequently null. Thus, the effect of the silvicultural treatment is not significant (5%) when $\bar{u}_i$ value is regarded as identical in both types of quadrants (i.e., treated and untreated) (Table 2).

Regarding $\bar{u}_i$ value, $\bar{a}_i$ values were revaluated by using the technique of mean correction that is associated to covariance analysis method. This correction or adjustment of $\bar{a}_i$ values aims at determining values that probably would be observed if both types of quadrants had the same $\bar{u}_i$ value. That explains the introduction of the quantity α (u_i -$\bar{u}$) in the mathematical expression of models (2) and (3). For any quadrant j, this quantity represents the presumably linear relationship between G_i ($\bar{u}_i$) and R ($\bar{a}_i$). We suppose that $\bar{u}_i$ is the mean G_i of all the quadrants that have received treatment i. For this treatment i, the R value is corrected by subtracting the quantity α (u_i -$\bar{u}$) from $\bar{a}_i$. The value of the coefficient of regression α is 0.032 and the mean value of G_i for all the quadrants ($\bar{u}$) is 27.68 m^2 ha^{-1}.

The positive value of the coefficient of regression α indicates that G_i trends to increase R values in the quadrants. When G_i value decreases, R value increases. The difference between the corrected mean (0.73 and 0.92 m^2 ha^{-1} $year^{-1}$) is not significant, but R value of untreated quadrants remains lower than that of the treated quadrants (Table 3).

The introduction of variable G_i allows to estimate the gain of precision by comparing model (1) and model (2). Table 1 gives an estimate value of the error variance that is $11.68 \div 75 = 0.156$ for model (1) and $10.94 \div 75 = 0.148$ for model (2). The relationship ($0.156 \div 0.148 = 1.054$) between these two estimates shows that using covariance analysis have the same effect on the experimentation precision like the multiplication of the replicates number by 1.054.

DISCUSSION

In tropical forests, biological material precedes most of the time the experimental plan and the installation of experimental design. It is therefore difficult, even impossible, for the experimenter to constitute homogeneous blocks in a strict sense of the experimental statistics. The permanent design of Mopri is a good example that illustrates that reality.

Although silvicultural treatments were attributed randomly, both groups of quadrants (treated and untreated) differ from their initial total basal area. This is due to the diversity of environmental factors which effects are not sometimes considered by the experimenter. In the case of Mopri, with covariance analysis, it was discovered that the variable initial basal area that was neglected at the beginning of the experimentation appeared very important. Although the precision increase is low (1.054), there are a significant difference between the observed R values (0.53 and 1.05 m^2 ha^{-1} $year^{-1}$) and the corrected R values (0.73 and 0.92 m^2 ha^{-1} $year^{-1}$). As a result, the productivity increases of 0.2 m^2 ha^{-1} $year^{-1}$ in the untreated quadrants while it depletes of 0.13 m^2 ha^{-1} $year^{-1}$ in the treated quadrants.

These corrections are particularly significant on the scale of tropical forests which areas represent generally several thousands of hectares.

This example shows that in forestry, with the method of covariance analysis, it is possible to take into consideration some important variables omitted during a study. This statistical technique should however not be used abusively, because significance tests issues are lightly important than those of experimental organization and control (Atkinson and Donev, 1992). The best solution for the forest experimenter should be always consulting a biometrician. In that case, the biometrician could advise the experimenter to give up the test if its implementation is not going to be successful. Indeed, what is the importance of performing an experiment which has only few chances to highlight interesting differences? The biometrician should indicate the way in which the experimentation must be performed in order to obtain the most effective control of the environmental heterogeneity. According to the number of replicates, he should calculate the expected precision (Foster, 2001; Guimarães and Guimarães, 2006; Snedecor and Cochran, 1989).

CONCLUSION

Covariance analysis constitutes a set of methods which are all together related to the analysis of variance and the regression. Its use is justified in this study where the influence of two classification factors (treatment and site) on a quantitative variable (rate of increase) is studied.

We proceed like in a traditional analysis of variance, eliminating by regression the effect of the auxiliary variable observed in the same quadrant. In contrast to analysis of variance, covariance analysis can be used only under relatively strict conditions such as the distributions normality, the variances equality, etc. These application conditions must always be confirmed. This statistical technique should not be used systematically and it is always preferable to consult a biometrician during the experimental plan development.

ACKNOWLEDGMENTS

We thank SODEFOR and CIRAD-FORET for the installation of permanent experimental design in Côte d'Ivoire and data-gathering. We also thank Drs. Kadio A., J.P. Pascal, J.G. Bertault, J.F. Dhôte, P. Couteron and D. Chessel for their effective contribution and their advices in data analysis. We are very grateful with the French Mission of Cooperation and Cultural Action (MCAC) in Abidjan and with FORAFRI project which financed this study.

REFERENCES

Atkinson, A.C. and A.N. Donev, 1992. Optimum Experimental Designs. Oxford, Clarendon, pp: 18-29.

Aznar, J. and F. Guijarro, 2007. Estimating regression parameters with imprecise input data in an appraisal context. Eur. J. Operat. Res., 176 (3): 1896-1907.

Balboa-Murias, M.A., R. Rodríguez-Soalleiro, A. Merino and J.G. Alvarez-González, 2006. Temporal variations and distribution of carbon stocks in aboveground biomass of radiata pine and maritime pine pure stands under different silvicultural alternatives. For. Ecol. Manage., 237 (1-3): 29-38.

Blanco, J.A., B.J. Imbert and F.J. Castillo, 2006. Influence of site characteristics and thinning intensity on litterfall production in two *Pinus sylvestris* L. forests in the Western Pyrenees. For. Ecol. Manage., 237 (1-3): 342-352.

Chave, J., 1999. Dynamique spatio-temporelle de la forêt tropicale: Influence des perturbations climatiques et étude de la phytodiversité. Thèse de l'Université Paris-Sud, Orsay, France.

Dagnélie, P., 1998. Statistiques théorie et appliquée-Tome 2: Inférence statistique à une et à deux dimensions. Paris et Bruxelles, De Boeck et Larcier, pp: 78-99.

Dahdouh-Guebas, F. and N. Koedam, 2006. Empirical estimate of the reliability of the use of the Point-Centred Quarter Method (PCQM): Solutions to ambiguous field situations and description of the PCQM+ protocol. For. Ecol. Manage., 228 (1-3): 1-18.

Foster, J.R., 2001. Statistical power in forest monitoring. For. Ecol. Manage., 151 (1-3): 211-222.

Guimarães, P.R. Jr. and P. Guimarães, 2006. Improving the analyses of nestedness for large sets of matrices. Environ. Modell. Software, 21 (10): 1512-1513.

Headley, T.R., E. Herity and L. Davison, 2005. Treatment at different depths and vertical mixing within a 1-m deep horizontal subsurface-flow wetland. Ecol. Eng., 25 (5): 567-582.

Inglot, T. and T. Ledwina, 2006. Asymptotic optimality of new adaptive test in regression model. Annales de l'Institut Henri Poincare (B). Prob. Stat., 42 (5): 579-590.

Jaakkola, T., H. Mäkinen and P. Saranpää, 2006. Wood density of Norway spruce: Responses to timing and intensity of first commercial thinning and fertilisation. For. Ecol. Manage., 37 (1-3): 513-521.

Kanninen, M., D. Pérez, M. Montero and E. Víquez, 2004. Intensity and timing of the first thinning of *Tectona grandis* plantations in Costa Rica: Results of a thinning trial. For. Ecol. Manage., 203 (1-3): 89-99.

Mead, R., 1988. The Design of Experiments: Statistical Principles for Practical Applications. Cambridge, University Press, pp: 9-22.

Pines, A., C. Lemesch and O. Grafstein, 1992. Regression analysis of time trends in occupational accidents (Israel, 1970-1980). Safety Sci., 15 (2): 77-95.

Roose, E., 1981. Dynamique actuelle des sols ferralitiques et ferrugineux tropicaux d'Afrique occidentale. Travaux et Documents ORSTOM., Abidjan, Côte d'Ivoire, pp: 14-19.

Snedecor, G.W. and W.G. Cochran, 1989. Statistical Methods. 8th Edn. Ames, Iowa: Iowa State University Press, pp: 22-35.

Utsugi, E., H. Kanno, N. Ueno, M. Tomita, T. Saitoh, M. Kimura, K. Kanou and K. Seiwa, 2006. Hardwood recruitment into conifer plantations in Japan: Effects of thinning and distance from neighbouring hardwood forests. For. Ecol. Manage., 237 (1-3): 15-28.

Vennetier, P. and G. Laclavere, 1983. Atlas de Côte d'Ivoire. Paris, France, (ED) Jeune Afrique.

Zobi, I.C., 2002. Contribution à la gestion sylvicole des forêts humides ivoiriennes à travers l'analyse des dispositifs permanents de Mopri et d'Irobo. Thèse de l'Université Claude Bernard Lyon 1, France.