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Clonal Propagation Index for cutting production in forestry

Índice de Propagación Clonal para la producción de estaquillas en forestería

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Abstract

With the development of clonal production systems in forestry, there is a need for efficient indicators to determine the production capacity of the system. The Clonal Propagation Productivity Index (CPI) is recommended to determine the effect of possible technical improvement on the production capacity. CPI allows assessing productivity differences according to the month of year, between years, between species, between nutrition programs, irrigation programs, or other changes in the clonal production system. It is based on several efficiency criteria for each of the universal components in a clonal production system: a) Mother stock garden, b) Rooting area, c) Acclimatization area. In mother stock garden were considered as parameters 1) planting density; 2) mortality; 3) harvest frequency; 4) shoot production rate per mother plant. Meanwhile, for the rooting area the parameters were, 1) first quality control (previous cutting preparation); 2) rooting rate; 3) rooting duration. In the acclimatization area, survival rate and final quality control were included. Finally, a unit of time in weeks is required to produce an effective cutting. The CPI value for teak (*Tectona grandis* L.) was 130 and for melina (*Gmelina arborea* Roxb.) 279 effective cuttings/m²/month. The minimum value that the index has registered was for *Dipteryx oleifera* with 18 cuttings per month per m², while the maximum value can reach 330 cuttings in the index with an optimal *Gmelina arborea* production system. It is concluded that CPI is an easy and accurate indicator to estimate production capacity in a clonal system, sensitive enough to determine the effect of any improvement in the technological package. The proposed index includes all the factors affecting mass clonal production in forestry systems.

Key words: tree improvement, clonal forestry, silviculture, nursery, greenhouse.

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Resumen

Con el desarrollo de sistemas de producción clonal en silvicultura, existe la necesidad de indicadores de eficiencia para determinar la capacidad de producción del sistema. Se propone el Índice de Propagación Clonal (IPC) para determinar el efecto de cualquier mejora técnica sobre la capacidad de producción. El IPC permite evaluar diferencias de productividad según mes del año, entre años, entre especies, entre programas de nutrición, programas de riego o cualquier otro cambio en el sistema de producción clonal. Se basa en una serie de criterios de eficiencia para cada uno de los componentes universales en un sistema de producción clonal: a) Minijardín clonal, b) Área de enraizamiento, c) Área de aclimatación. En el minijardín clonal se consideraron como parámetros 1) la densidad de siembra; 2) la mortalidad; 3) la frecuencia de cosecha; 4) la tasa de producción de brotes por planta madre. Mientras que en el área de enraizamiento los parámetros fueron, 1) primer control de calidad (preparación previa del esqueje); 2) tasa de enraizamiento; 3) tiempo de enraizamiento. En el área de aclimatación se incluyó la tasa de supervivencia y el control de calidad final. Finalmente, se requiere una unidad de tiempo en semanas para todo el ciclo de producción clonal. El valor del IPC para la teca (*Tectona grandis* L.) fue de 130 y para la melina (*Gmelina arborea* Roxb.) de 279 estacas efectivas/m²/mes. El valor mínimo que el índice puede alcanzar es el registrado para *Dipteryx oleifera* con 18 estaquillas/m²/mes. Mientras que el valor máximo podría alcanzar las 330 estaquillas/m²/mes en un sistema de producción clonal óptimo con la especie *Gmelina arborea*. Se concluye que el IPC es un indicador fácil y preciso para estimar la capacidad de producción en un sistema clonal, lo suficientemente sensible como para determinar el efecto de cualquier mejora en el paquete tecnológico. El índice propuesto comprende todos los factores que afectan la productividad de estaquillas a escala masiva comercial en sistemas forestales.

Palabras clave: Mejoramiento genético, silvicultura clonal, silvicultura, viveros, ambiente protegido.

Introduction

Modern clonal forestry is becoming more and more the usual reforestation system being practiced for companies everywhere [1]. Propagation by cuttings has become popularized due to the uniform development of trees, lower management costs, higher stand productivity and maintenance of the genetic background from the original superior genotypes [2], [3], [4], [5]. It consists of the development of clonal mini-gardens, known as mother stock and based on elite-donor-trees, from which mini-cuttings are frequently excised through the tips of the new sprouts (usually every one or two weeks). The cuttings are then rooted in shaded greenhouse and finally acclimated before being send to the field [6].

New techniques and production increments in mini clonal gardens are frequently reported in literature [2], [7], [8], [9], [10], [11], [12], [13]. However, there are no methods or parameters that can be utilized for comparisons nor measuring increments in productivity. There is a lack of an easy procedure that expresses the state of cutting production capacity, clonal system efficiency, fulfillment of production goals to accomplish annual planting among others. Clonal production planning at any scale in environmentally controlled systems (greenhouse), is based on the productivity rate of the system. Therefore, efficiency parameters must be rigorously monitored. Often and almost always there are new reagents and products available, like growth regulators, etc., which may increase productivity [14], [15], [16],[5], so there is a need to test and estimate any improvement effect on the system. Thus, a Clonal Productivity Index (CPI) such as the one proposed here, needs to be sensitive enough to determine the effect of any technical improvement. For instance, it is important to determine if there is a productivity variation within a year, between chambers/units, between greenhouses, among organizations, etc. [17], [16],[13], [18]. Finally, an organization may be interested in following its historical progress in clonal productivity as well, which becomes into the real usage of the CPI for self-monitoring.

CPI can be useful for controlling if there is occurring an increase in production costs [19]. A decrease in system productivity will immediately be reflected in higher costs of production. Variables such as quality control, shoot production rate per mother plant, are clear indicators of possible improvements in nutrition, irrigation, etc. Although there are specific production conditions in each organization, some universal principles can be used in the construction of a general CPI model. Almost all clonal production systems are constituted by a) a mother stock clonal garden, where the collection of genetic material remains, b) a rooting area, and c) an acclimatization area and final plants dispatch [20], [3]. The objective of the study was to build up a productivity measurement index as a tool, for usage in clonal forestry plant production systems.

Methodology

A clonal production system is organized in three major components as mentioned: mother stock clonal garden, rooting area and acclimatization area. Therefore, a clonal productivity index most incorporate all of them into a comprehensive unit of measurement, that may account for any factor affecting productivity.

Mother stock or clonal garden. In the mother stock or clonal garden, the following criteria were considered: A) planting density or number of mother plants per square meter. This is a crucial element since there are several options of spacing and spatial arrangements, which can largely affect the production of new shoots per area [21], [22], [18]. The usual pattern observed is that the higher the density of plants per square meter, the higher the collective production of shoots per unit area. Consequently, there will also be a decrease in the rate of new shoots per individual mother plant [4]. B) Clonal garden mortality, which accounts for the variation in the real number of effective mother plants producing shoots. Survival and health of the mother stock clonal garden is probably the most important factor of the whole production system. Its nutritional status, irrigation programming, weed maintenance, pests and diseases prevention and control, among other issues explain the new shoots production capacity per mother plant. The healthy and vigor of the mother plants is the true heart of the system. Conversely, mortality reflects the opposite to good silvicultural practices, and it need to be accounted, since it will affect the rate of shoot production per mother plant, therefore, the final productivity accounting. C) Harvest frequency per month, as one of the most important elements of productivity. The ability of the system to allow several harvests per month will depend mainly on factors such as nutrition/irrigation, which have an impact on the health and vigor of the mother plants [7], [10], [11]. But it will also depend on the size of cuttings to be harvested. Studies on cuttings size mention at least three options, mini cuttings (less than 3-4 cm in height), medium cuttings (4 to 6 cm) and large cuttings. Generally, medium size cuttings are preferred for factors such as ease of handling and rooting vigor. The most productive species (*Gmelina arborea*) can be harvested 3 to 4 times per month or every week, while *Tectona grandis* should be harvested every 14 days [13]. Finally, D) shoot production ratio per mother plant at harvest. This is the parameter most used by organizations and is clearly a response to good management practices and, of course, to the species. The obvious general trend is how to achieve the highest shoot rate per mother plant. In this regard, numerous efforts have been made to try to modify the mother plant "crown" to generate more stems and shoots. Planting density plays an important role in this respect, together with fertigation, harvest frequency, as well as the species.

Rooting area. Here the criteria were E) Shoot quality control previous preparation for rooting. During this process, many shoots are not suitable and must be eliminated at this stage. These materials need to be removed at this point and prevented from continue further into the rooting area. An adequate shoot rejection rate should be lower than 10 to 15 %. Higher values may be associated to poor management practices, harvest technique failures, poor sprout selection or problems with harvesting frequency. F) Rooting rate is a critical factor, which depends mostly on the cutting physiological conditions like juvenility in the clonal garden area, and all elements around mother plant vigor and healthy. Environmental conditions are also critical, usually it is required a properly conditioned humidity chamber, able to control high humidity (> 80 to 90 %) and temperature levels. In the case of warm tropical zones, radiation control is also required using 60 % shading. Rooting rates above 60-70 % can be considered as minimal in several tree species [4], however in teak and melina it is usually observed rooting rates above 90 to 95 %. Rooting rate can be also considered as critical economically speaking. A low rooting rate implies the need for a larger greenhouse surface and a greater use of resources, such as trays, pots, substrate, among others.

Acclimatization area. At this final stage G) survival rate is one of the important criteria which should be usually very high (> 95 %), otherwise it has important implications on overall production costs. Finally, as the last criteria H) Final plant quality control. Final quality control aims to deploy cuttings of highest possible quality. The elimination of less than 10 % of the plants is generally expected, a higher rejection rate has implications on the overall production costs. However, there may be external elements, like weather or planting site preparation, that condition the type of plant that should be delivered, which may produce an increment in rejection rate.

Unit of time in a Productivity Index. Finally, any productivity index requires a relationship to some unit of time (I). Nowadays, clonal production systems are becoming more and more intensive in technology, require less production area and there, time variable is critical. The number of weeks it takes for a sprout, from its initial harvest in the clonal garden, to become an effective cutting to be shipped out to the field, is undoubtedly the proper time measurement unit. Number of weeks is easier to account and sensitive enough to discriminate between different tree species, or production technology changes in the whole system. However, in terms of comprehension, the time variable is simpler to express and relate when using the month as the unit final report.

Based on these principles in summary, the CPI provides an estimate of the production capacity of the system, expressed by the number of effective cuttings per greenhouse area (m^2) per month^{-1}.

$$\textbf{CPI} = \frac{A*B*C*D*E*F*G*H}{I} \quad (1)$$

Where: A = Original number of mother plants per square meter (n) in the clonal garden, or planting density (m²); B = Clonal garden mortality rate (%); C = Harvest frequency per month (n); D = Shoot production ratio per mother plant at harvest (n); E = Shoot quality control previous preparation for rooting (%); F = Rooting rate (%); G = Survival rate in acclimatization area (%); H = Final plant quality control (%); I = Time required to produce an effective plant or cutting (weeks).

Based on the studies of [23], [13] with *T. grandis*, the values for each of the criteria included in the proposed CPI were determined. With *G. arborea*, values were taken from the production and research greenhouses for clonal production of GENFORES Tree Improvement Cooperative, established at the regional campus of the Instituto Tecnológico de Costa Rica northern zone of Costa Rica.

Results y discusión

Table 1 shows the CPI values for teak and melina, based on the mass clonal propagation system, at Instituto Tecnológico de Costa Rica, regional campus (northern zone), which is based on an annual production of 300 to 500 thousand cuttings.

It can be observed that melina doubles the CPI value with respect to teak, explained by its greater vigor, high shoot production capacity per mother plant and speadness in general.

CPI values can then be utilized for estimating a differentiated cutting-production cost for teak and melina. Melina will require 1.5 less greenhouse area and 25 % less time for producing the same amount of cuttings.

In table 2 is shown another example of the usage of the CPI, as a comprehensive and easy measurement, that is sensitive enough to discriminate between new treatments or any innovation in mass clonal propagation systems [18].

CPI can be then taken as a continuous variable, which allows for any proper statistical analysis as desired. In this study, can be observed large differences in CPI values among treatments. There is a clear gradient of increasing productivity as long as more mother plants/m^2 are established, however, mortality rates tend to increase with higher stock density in the mini-clonal garden as expected. Shoot production rate per mother plant exhibited similar values in all treatments, which suggests that teak is a very tolerant plant to competition effect. It is also important to observe, that high planting density is dependent on a more demanding nutritional and irrigation protocols [10].

What is the lowest and highest possible CPI values that can be obtained? A native tree species like almendro (*Dipteryx oleifera*) has been the tree with the lowest clonal propagation values registered, which can be explained by its low sprouting rate per mother plant per month (0,8 tips per harvest once a month) or its low rooting rate per month (30-40 %), that accounts for a CPI of 18 cuttings per m² per month. Meanwhile, *Gmelina arborea* is probably one of the tree species with the highest productivity rates. Under optimal clonal production conditions, where mother plants can be excised every week, rooting can get as much as 95 %, then CPI values can reach as much as 330 cuttings per area (m²) per month. However, comparisons between CPI values make sense exclusively within the same tree species. Table 3 shows

Table 1. CPI values for mass clonal production of teak and melina in San Carlos, northern zone of Costa Rica

Cuadro 1. Valores de CIP para la producción clonal masiva de teca y melina en San Carlos, zona norte de Costa Rica

Criteria		*Tectona grandis*	*Gmelina arborea*
Mini clonal garden	Number of mother plants m²	145	145
	Clonal garden mortality (%)	92	95
	Harvests frequency per month	2	3.75
	Shoot production rate per mother plant at harvest	1.16	1.0
Rooting	Shoot quality control previous preparation for rooting (%)	15	15
	Rooting rate (%)	98	90
Acclimatization	Survival rate in acclimatization (%)	95	95
	Final cutting quality control (%)	10	10
Time	Time-span in weeks for producing a cutting	8	6
CPI = Cutting number m² month^{-1}		130	279

Table 2. Effect of five planting spatial patterns in the Clonal Productivity Index of *T. grandis* mass clonal propagation, San Carlos, northern zone of Costa Rica (adapted from Rodríguez [13]).

Cuadro 2. Efecto de cinco patrones espaciales de siembra en el Índice de Productividad Clonal de propagación clonal masiva de *T. grandis*, San Carlos, zona norte de Costa Rica (adaptado de Rodríguez [13]).

Planting spacement (cm) and spatial allocation	10x10 (control)	10x10*1/2 (one extra plant in between)	10x10*2 (2 plants per hole)	10x5	7x5
Number of mother plants m^2	100	145	200	200	285
Shoot production ratio per mother plant, at each harvest	0.99	1.16	1.03	1.11	1.10
Clonal garden mortality (%)	7.5	4.6	14.4	4.4	8.8
Harvests frequency per month	2	2	2	2	2
Rooting rate (%)	98.6	98.6	98.6	98.6	98.6
Survival rate in acclimatization (%)	95	95	95	95	95
Final plant quality control (%)	15	15	15	15	15
Time-span in weeks for producing a cutting	8	8	8	8	8
CPI = Cutting number m^2 $month^{-1}$	66	115	126	152	206
Productivity increment (%)	0	74	91	130	212

some values registered per tree species, as a reference for other clonal propagation programs elsewhere. Values were obtained through several research activities as well as from operative clonal programs [20], [14], [16], [4], [13], [5], [18]. These reference values could be improved through increments in sprouting rate in the clonal garden, due to better fertigation programs, that may raise harvest frequency as well.

Another important question is whether any of the nine variables have greater weight in the CPI? All variables undoubtedly have a significant weight in the index. A detailed simulation study would be required to determine the specific weight of each of them. However, the time variable is undoubtedly the most important one, and its position in the numerator attests to this. Perhaps a simple approach is to determine which of the variables has the least weight. In this case, both mortality variables (in mini-garden and in acclimatization zone) should not significantly affect the index since under good management practices, they should not register high values or greater variation. Sprouting rate in mini-garden is another variable that is not expected to show greater variation. Under this analysis both quality control variables (at harvest and final dispatching material), rooting rate, planting density at mini clonal garden and harvest frequency are those that could more significantly affect the index. Nevertheless, given that there are nine variables in the index, it does not seem advisable to assign them differentiated weights, since its effect would be too small. This could be a topic for future investigation with the index proposed.

Table 3. Clonal Propagation Index for eight tree species, reported in Costa Rica.

Cuadro 3. Índice de propagación clonal de ocho especies de árboles, reportado en Costa Rica.

Species	CPI
Gmelina arborea	280
Tectona grandis	200
Cordia alliodora	275
Enterolobium cyclocarpum	50
Samanea saman	40
Hieronyma alchorneoides	35
Acacia mangium	25
Dipteryx oleifera	18

Conclusions

CPI is an easy and accurate index, sensitive enough to determine the effect of any improvement in mass clonal production systems.

The proposed index comprehends all factors affecting mass clonal production in forestry systems.

Referencias

[1] Tomar, A., Kumar Singh, B., Priya, S., Yadav, A.,Singh, S, "Clonal Forestry: The Future of Tree Growing", in Clonal

Forestry: Principles and Practices, Singh, S & Tomar, A, New Delhi, Narendra Publishing House, 2023, pp.1-22

[2] Assis, T. "Hybrids and Mini-Cutting: A Powerful Combination that Has Revolutionized the Eucalyptus Clonal Forestry", BMC Proc. Vol. 5, Suppl. 7, Sept., pp. 1-2, 2011

[3] Xavier, A., Wendling, I., da Silva, R.L, Silvicultura Clonal. Princípios e Técnicas, Viçosa: 2da Ed. UFV, 2013.

[4] Murillo, O., Badilla, Y., Rojas, F., Montero, W., Barboza, S. Informe final Proyecto de Investigación: Producción a gran escala de clones de teca y melina para la región latinoamericana mediante la gestación de un consorcio empresarial en GENFORES. Instituto Tecnológico de Costa Rica. Escuela de Ingeniería Forestal. Cartago, Costa Rica, 2018

[5] Rodríguez, A., Badilla, Y, Murillo, O. "Mejoramiento de la productividad clonal de Cordia alliodora en ambiente protegido en Costa Rica", presentado en: XII Simposio Internacional sobre Manejo Sostenible de los Recursos Forestales, Universidad de Pinar del Río, Cuba, 2023

[6] Vilasboa, J., Da Costa, C., Fett-Neto, A. "Environmental Modulation of Mini-Clonal Gardens for Cutting Production and Propagation of Hard- and Easy-to-Root Eucalyptus spp.", Plants, vol. 11, no. 23, Nov., pp. 1-23, 2022

[7] Ebling, G., Wendling, I., Grossi, F., Ferreira, L., & Araujo, M. A. "Miniestaquia de Eucalyptus benthamii x Eucalyptus dunnii: (i) sobrevivência de minicepas e produção de miniestacas em função das coletas e estações do ano", Ciência Florestal, vol. 22, no. 1, pp. 11–21, 2012

[8] Batista AF, GA Santos, LD Silva, FF Quevedo, TF Assis. "The use of mini-tunnels and the effects of seasonality in the clonal propagation of Eucalyptus in a subtropical environment", Australian Forestry, vol. 78, no. 2, May., pp. 65-72, 2015.

[9] Badilla, Yorleny; Murillo, Olman; Xavier, Aloisio; Nogueira de Paiva, Haroldo, "IBA efficiency on mini-cutting rooting from teak (*Tectona grandis* Linn F.) clones", Rev. Árvore, vol. 40, no. 3, Jun., pp. 477-485, 2016

[10] Calderón-Ureña, F., Esquivel-Segura, E., y Acevedo-Tapia, M. "Manejo nutricional y de riego en minijardines clonales de *Tectona grandis* (Linn. F) en la zona sur de Costa Rica", Revista Forestal Mesoamericana Kurú, vol. 16, no. 39, Dec., pp. 43–52, 2019

[11] Machacuay, A., & Llancari, Y. M. "Efecto de dosis de nitrógeno sobre la producción de estaquillas de Eucalyptus grandis × E. urophylla en jardín clonal", Revista Forestal Del Perú, vol. 35, no. 3, Dec., pp. 5–17. 2020

[12] Canguçu, V., Titon, M., Silva, L.F., Pena, C.A., Assis, S.L., dos Santos, P.H.,de Oliveira, M.L., "Mini-tunnel models influence the productivity of eucalyptus mini-stumps?", Bosque, vol. 43, no. 3, pp. 211-219, 2022

[13] Rodríguez, A., Badilla, Y., Murillo, O. "Effect of substrate and spatial planting pattern on the productivity of clonal mini gardens of *Tectona grandis* Linn. F", Agronom. Mesoamericana, Vol 34, no. 2, Mar., 2023

[14] Badilla, Y., Murillo, O, "Enraizamiento de estacas de especies forestales", Revista Forestal Mesoamericana Kurú, vol. 2, no. 6, Nov., pp. 59-64. 2012

[15] Singh, S., Bhandari, A. S., & Ansari, S. A. "Stockplant Management for Optimized Rhizogenesis in *Tectona grandis* Stem Cuttings", New Forests, vol. 31, no. 1, Jan., pp. 91–96, 2006

[16] Badilla, Yorleny; Murillo, Olman; Xavier, Aloisio. "Storage time effect on mini-cuttings rooting in *Tectona grandis* Linn F. clones", Rev. Árvore, vol. 41, no. 3, 2017

[17] Sulichantini, E. D., Sutisna, M., Sukartiningsih, & Rusdiansyah. "Clonal Propagation of Two Clones Eucalyptus pellita F. Muell By Mini-Cutting", International Journal of Science and Engineering, vol. 6, no. 2, Apr., pp. 117–121. 2014

[18] Rodríguez, A., Badilla, Y., Murillo, O. "Efecto del uso de GA3 y BAP en la productividad de minijardines clonales de *Tectona grandis* Linn. F.", Rev. Forestal Mesoam. Kurú. Vol. 20, no. 47, Dec., pp. 58-79, 2023

[19] Murillo, O., Badilla, Y., Barboza, S. "Costos de producción de clones de especies forestales en ambiente protegido", Rev.For.Mesoam. Kurú, vol. 15, no. 37, Dec., pp. 15-24, 2018

[20] Murillo, O.; Rojas, J. L. y Badilla, Y., Reforestación Clonal, Taller de Publicaciones, Instituto Tecnológico de Costa Rica, 2003

[21] Rezende, F. A., dos Santos, V. A. H. F., de Freitas, C. M. B. M., Morales, M. M. "Biochar na composição de substratos para a produção de mudas de teca", Pesquisa Agropecuaria Brasileira, vol. 51, no. 9, Sept., pp. 1449–1456. 2016

[22] Souza, C. C., Xavier, A., Leite, F. P., Santana, R. C., Paiva, H. N. de., "Densidade de minicepas em minijardim clonal na produção de mudas de eucalipto", Pesquisa Florestal Brasileira, vol. 34, no. 77, Apr., pp. 49–56. 2014

[23] Rodríguez, A. "Productividad de minijardines clonales de *Tectona grandis* (Linn. F.) en ambiente protegido". Tesis M.Sc, Instituto Tecnológico de Costa Rica, Cartago, Costa Rica. 2022