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## Performance of *Eucalyptus* Clones in Auto and Allocompetition

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### Abstract

This study was performed to estimate the abilities of eucalyptus clones to exercise as well as to tolerate competition and to compare their behaviors under auto- or allocompetition. Six commercial clones, belonging to PLANTAR S/A enterprise were evaluated for breast height circumference (BHC), total height (TH) and volume (VOL). At three locations of Minas Gerais, Brazil (two in Curvelo and one in Felixlândia) the clones were planted in two spaces. At 36 months of age each clone was evaluated for exercising and toleration competition amongst each other. The design for each experiment was similar to that of the nine-hole system; the center clone being under competition and the eight surrounding the

center clone exercising competition. Each clone under competition was repeated eight times; therefore, for each spacing and location, six contiguous experiments were conducted. From the mean values; the parameters of ability to exercise competition ( $c_i$ ), ability to tolerate competition ( $t_j$ ), the specific competitive ability ( $s_{ij}$ ) and the performance *per se* of the clones ( $a_i$ ) were estimated using a model similar to that of diallel crosses. The clones differed as to their  $c_i$ ,  $t_j$  and  $a_i$ . No one clone exhibited high and positive  $c_i$  and  $t_j$ . Regardless of location, spacing, or clone, the performance of autocompetition is similar to that of allocompetition. This indicates that a mixture of clones, if advantageous from the management or industrial point of view, may be performed without harm to the volume of wood produced.

**Key words:** *Eucalyptus*, competition, mixture, clone, autocompetition, allocompetition, uniformity.

### Introduction

With the refinement of clone propagation techniques and its application to produce eucalyptus saplings at a commercial scale, it has been possible to establish uniform forests that are now widely used in production of raw material for industrial use. Companies generally have a few clones available which are planted in blocks

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For preparation of the area, subsoiling was performed at a depth of 45 cm with the application of 400 kg of phosphate and 150 kg of KCl + 1% of boron per hectare. In the topdressing fertilization, 100 g of 6-30-6 fertilizer with 1% boron and zinc per plant was used. The other crop treatments (replanting, weeding, irrigation and others) were performed when necessary, according to the recommendations provided by the company for commercial planting.

In all the experiments at 36 months of age data on breast height circumference (BHC), in centimeters, and total height (TH), in meters, were collected on the plants situated in the center of the nine holes. To obtain individual volume (VOL) data, volumetric equations were used that are routinely used by the company, adjusted for age and expressed in cubic decimeters. Initially, an analysis of variance between and within each type was performed (STEEL et al., 1997), per experiment (clone exercising competition), using the following model:

$$Y_{jq} = \mu + t_j + e_{jq} \quad (\text{Model 1})$$

Where  $Y_{jq}$ : observation in reference to clone j under competition, in replication q;  $\mu$ : general mean value of the experiment;  $t_j$ : effect of clone j under competition,  $j=1, 2, \dots, 6$ ;  $e_{jq}$ : experimental error associated with observation  $Y_{jq}$ , with  $e_{jq} \cap N(0, \sigma^2)$ , with q being the number of replications ( $q=1, 2, \dots, 8$ ).

Analysis of variance was carried out involving all the experiments at a given spacing and location, using the following model:

$$Y_{ijq} = \mu + a_i + t_j + (at)_{ij} + \bar{e}_{ijq} \quad (\text{Model 2})$$

Where  $Y_{ijq}$ : observation in reference to the competition exercised by clone i (experiment), under clone j in replication q;  $\mu$ : general mean value of the experiment;  $a_i$ : effect of clone i exercising competition (experiment),  $i=1, 2, \dots, 6$ ;  $t_j$ : effect of clone j under competition,  $j=1, 2, \dots, 6$ ;  $(at)_{ij}$ : effect of interaction between clone i which exercises competition and clone j under competition;  $\bar{e}_{ijq}$ : mean experimental error associated with observation  $Y_{ijq}$ , with  $\bar{e}_{ijq} \cap N(0, \sigma^2)$ .

In a joint analysis, analysis of variance was performed involving all the locations and spacings according to the following model:

$$Y_{ijwuq} = \mu + a_i + t_j + (at)_{ij} + s_w + (as)_{iw} + (ts)_{jw} + (ats)_{ijw} + l_u + (al)_{iu} + (tl)_{ju} + (atl)_{iju} + (sl)_{wu} + (asl)_{iwu} + (tsl)_{jwu} + (atsl)_{ijwu} + \bar{e}_{ijwuq} \quad (\text{Model 3})$$

Where:  $Y_{ijwuq}$ : observation in reference to competition exercised by clone i (experiment), under clone j, at spacing w, in location u and in replication q;  $\mu$ : general mean value of the experiment;  $a_i$ : effect of clone i exercising competition (experiment),  $i=1, 2, \dots, 6$ ;  $t_j$ : effect of clone j under competition,  $j=1, 2, \dots, 6$ ;  $(at)_{ij}$ : effect of interaction between clone i which exercises competition and clone j under competition;  $s_w$ : effect of spacing w,  $w=1, 2$ ;  $(as)_{iw}$ : effect of interaction between clone i exercising competition and the spacing w;  $(ts)_{jw}$ : effect of interaction between clone j under competition and the spacing w;  $(ats)_{ijw}$ : effect of the interaction between clone i exercising competition, clone j under competition and spac-

ing w;  $l_u$ : effect of location u,  $u=1, 2, 3$ ;  $(al)_{iu}$ : effect of interaction between clone i exercising competition and location u;  $(tl)_{ju}$ : effect of interaction between clone j under competition and location u;  $(atl)_{iju}$ : effect of interaction between clone i exercising competition, clone j under competition and location u;  $(sl)_{wu}$ : effect of interaction between spacing w and the location u;  $(asl)_{iwu}$ : effect of interaction between clone i exercising competition, spacing w and location u;  $(tsl)_{jwu}$ : effect of interaction between clone j under competition, spacing w and location u;  $(atsl)_{ijwu}$ : effect of interaction between clone i exercising competition, clone j under competition, spacing w and the location u;  $\bar{e}_{ijwuq}$ : mean experimental error associated with observation  $Y_{ijwuq}$ , with  $\bar{e}_{ijwuq} \cap N(0, \sigma^2)$ .

To verify whether or not the clones differ in their abilities to exercise and tolerate competition, a Scheffé test was performed to test the significance between the contrasts of the mean values of each clone exercising and tolerating competition (PIMENTEL-GOMES, 2009).

With the mean data, the competition parameters were estimated using modeling similar to partial diallel analysis for hybrid combinations (FEDERER et al., 1982; SILVA et al., 2007) following the model:

$$\bar{Y}_{ij} = \mu + c_i + z_j + s_{ij} + e_{ij} \quad (\text{Model 4})$$

Where  $\bar{Y}_{ij}$ : mean value of clone j undergoing competition from clone i;  $\mu$ : general mean value of the experiment;  $c_i$ : ability to exercise competition of clone i;  $z_j$ : tolerance to competition from clone j, whose component involves the *per se* effect of the clone under competition ( $a_j$ ) and the effect of tolerance to competition strictly speaking ( $t_j$ ); in other words,  $z_j = a_j + t_j$ ;  $s_{ij}$ : specific competitive ability of the pair of clones i and j;  $e_{ij}$ :

Table 1. – Joint analysis of variance (Model 3) for the volume (VOL) variable, expressed in cubic decimeters (dm<sup>3</sup>).

Source of variation	VOL		
	DF	MS	p-value
Locations (L)	2	55877.8	<.0001
Spacings (S)	1	596435.5	<.0001
L x S	2	1427.0	0.0113
Treatments (T)	35	7105.7	<.0001
GEC <sup>1/</sup>	5	4159.1	<.0001
GTC <sup>1/</sup>	5	43032.0	<.0001
SCA <sup>1/</sup>	25	506.5	0.0316
L x T	70	1471.7	<.0001
L x GEC	10	4796.1	<.0001
L x GTC	10	2050.4	<.0001
L x SCA	50	688.6	<.0001
S x T	35	1402.5	<.0001
S x GEC	5	3399.7	<.0001
S x GTC	5	3596.8	<.0001
S x SCA	25	573.7	0.0087
L x S x T	70	1381.3	<.0001
L x S x GEC	10	4964.7	<.0001
L x S x GTC	10	1322.8	<.0001
L x S x SCA	50	676.6	<.0001
Error	1497	317.5	
Mean		80.48	

<sup>1/</sup> GEC – General ability to exercise competition; GTC – general ability to tolerate competition and SCA – specific competitive ability.



Table 2. – Mean values of the clones in autocompetition and allocompetition for volume and mean annual increment (m<sup>3</sup>/ha/year) in the mean value of the locations for spacings, and mean values of the clones for volume in the mean value of the spacings for locations. Data obtained at 36 months of age.

Clones	Spacings						Locations							
	3.0 x 1.5m			3.0 x 3.0m			Meleiros		Buritis		Lagoa do Capim		Mean	
	Auto MAI	Alo MAI		Auto MAI	Alo MAI		Auto	Alo	Auto	Alo	Auto	Alo	Auto	Alo
A	58.2	43.1	37.9	28.1	80.2	29.7	83.9	31.1	60.1	65.3	58	52.1	89.5	65.9
B	56.1	41.6	69.0	51.1	103.2	38.2	97.2	36.0	68.3	80.7	70	71.9	100.7	97
C	54.6	40.4	53.9	39.9	88.7	32.9	89.9	33.3	65.6	72.6	73.5	61.4	76.3	81.7
D	65.6	48.6	68.1	50.4	91.1	33.7	95.7	35.4	70.3	79.1	72.6	73.2	92.2	93
E	72.7	53.9	75.5	55.9	123.7	45.8	117.9	43.7	95.8	82.7	92.7	96.7	106.0	110.6
F	65.7	48.7	67.7	50.1	103.4	38.3	112.6	41.7	80.1	85.5	70.5	85.4	103.4	99.6
Média	62.1	46.0	62.0	45.9	98.4	36.4	99.5	36.9	73.4	77.7	72.9	73.4	94.7	91.3
													80.3	80.8

experimental error associated with observation  $\bar{Y}_{ij}$ , with  $e_{ij} \cap N(0, \sigma^2)$ .

To estimate  $a_j$ , it was considered that  $i = j$ , in other words, the clone exercising competition on itself (autocompetition). Thus,  $a_j = \bar{Y}_{jj} - \bar{Y}_{..}$  and  $t_j = z_j - a_j$ , where  $\bar{Y}_{jj}$ : mean value of clone  $j$  in autocompetition;  $\bar{Y}_{..}$ : general mean value of all clones in autocompetition.

The Ordinary Least Squares method was used for estimating the parameters of the model. The significances of the  $c_i$  and  $s_{ij}$  parameters were obtained by a t-test. All statistical analyses were performed using the software R (R DEVELOPMENT CORE TEAM, 2010).

## Results

Most of the experiments showed a significant effect between the clones ( $P \leq 0.05$ ) for BHC, TH and VOL. Of the 36 experiments regarding volume, the source of vari-

ation between clones was not significant in four experiments ( $P \leq 0.05$ ; data not presented). In the joint analysis of variance, the results were very similar for the variables BHC, TH and VOL. As BHC and TH show high correlation with wood volume, special attention will be directed to volume (Table 1).

From the mean values of the clones in auto and allocompetition throughout the different spacings and locations, it may be observed that there was an increase of approximately 23% in volume when the mean value obtained in Lagoa do Capim was compared with Buritis. With an increase in spacing between the plants from 3.0 x 1.5 m to 3.0 x 3.0 m, there was an increase of approximately 60% in individual volume; however, there was a decrease of approximately 20% in mean annual increment (Table 2).

From the behavior estimates of the clones in each location and spacing, it may be observed that the difference between the mean performance of the clones in autocompetition and allocompetition was very similar. The most expressive difference within the locations was in Meleiros, showing mean performance of the clones in allocompetition (77.7 dm<sup>3</sup>) 5.85% greater than autocompetition (73.4 dm<sup>3</sup>) (Table 2). Considering the mean data of locations and spacings, there was practically no difference between the performance in autocompetition (80.3 dm<sup>3</sup>) and allocompetition (80.8 dm<sup>3</sup>). Only clones A and E showed autocompetition performance slightly greater than allocompetition (Table 2).

To compare mean performance of each clone exercising and tolerating competition, the Scheffé test was performed (Table 3). It was observed that clones B and D

Table 3. – Contrasts between the mean performance of each clone exercising and tolerating competition, and their significances relative to the minimum significant difference calculated by the Scheffé test at the level of 5% probability, at 36 months of age.

Clone	Y <sub>i</sub>	Y <sub>j</sub>	Y <sub>i</sub> - Y <sub>j</sub>
A	91.39	61.08	*
B	79.96	83.26	n.s
C	84.02	71.89	*
D	77.74	81.84	n.s
E	76.15	96.69	*
F	75.88	90.38	*

\* – significant; n.s – not significant.

Table 4. – Competition parameters (Model 4) for the volume (VOL) variable in the mean value of the locations by spacing, at 36 months of age.

Clones	3.0 x 1.5m			3.0 x 3.0m		
	$c_i$	$a_j$	$t_j$	$c_i$	$a_j$	$t_j$
A	10.36*	-3.93	-16.84	3.67*	-18.21	2.17
B	-5.01*	-6.07	10.89	3.05*	4.84	-5.95
C	1.04	-7.56	-0.43	1.53	-9.66	0.01
D	-1.99	3.44	2.20	-3.72*	-7.28	2.85
E	-4.90*	10.58	2.42	2.84*	25.26	-5.74
F	0.51	3.55	1.76	-7.36*	5.04	6.67

\* Estimate differs from 0 by the t-test at 5% probability.

Table 5. – Competition parameters (Model 4) for the volume (VOL) variable in the mean value of the spacings by location, at 36 months of age.

Clones	Meleiros			Buritis			Lagoa do Capim		
	$c_i$	$a_j$	$t_j$	$c_i$	$a_j$	$t_j$	$c_i$	$a_j$	$t_j$
A	0.65	-13.28	0.78	8.10*	-14.85	-5.44	12.04*	-5.19	-16.84
B	-6.99*	-5.10	6.77	2.79	-2.89	1.13	1.54	6.02	-0.30
C	-0.44	-7.76	2.28	4.97*	0.62	-10.58	-0.75	-18.41	7.31
D	-6.07*	-3.07	3.78	1.94	-0.32	0.08	-4.49*	-2.48	3.48
E	11.84*	22.44	-14.47	-7.55*	19.86	2.80	-7.32*	11.35	6.67
F	1.00	6.76	0.86	-10.25*	-2.40	12.00	-1.02	8.71	-0.33

\* Estimate differs from 0 by the t-test at 5% probability.

Table 6. – Estimates of the Spearman classifying correlations between the clones in each spacing and location, at 36 months of age.

Spacing	Locations	$c_i$	$a_j$	$t_j$
3.0 x 1.5 m	Meleiros / Buritis	0.20	-0.31	0.03
	Meleiros / Lagoa do Capim	0.94	0.77	0.94
	Buritis / Lagoa do Capim	0.27	-0.03	0.14
3.0 x 3.0 m	Meleiros / Buritis	-0.75	0.89	0.20
	Meleiros / Lagoa do Capim	-0.29	0.54	-0.77
	Buritis / Lagoa do Capim	-0.09	0.66	-0.31
Location	Spacings	$c_i$	$a_j$	$t_j$
Meleiros	1,5 / 3,0	0.23	0.26	-0.71
Buritis	1,5 / 3,0	0.20	-0.09	-0.37
Lagoa do Capim	1,5 / 3,0	0.21	0.49	0.26

Table 7. – Estimates of ability to exercise ( $c_i$ ), effect *per se* ( $a_j$ ), and tolerate ( $t_j$ ) competition (Model 4) for the volume in the mean value of the spacings and locations, at 36 months of age.

Clones	$c_i$	$a_j$	$t_j$
A	6.93*	-11.14	-7.20
B	-0.86	-0.68	2.58
C	1.19	-8.68	-0.24
D	-2.93*	-1.98	2.47
E	-0.95	17.85	-1.69
F	-3.38*	4.63	4.08

\* Estimate differs from zero by the t-test at 5% probability.

were the only ones in which ability to tolerate was equal to that of exercising competition. Clone A exercised the least competition regardless of the location and spacing. In other words, the other clones when in the vicinity of A showed the greatest mean values. In contrast, clones E and F were those which expressed most exercised competition.

The treatment source of variation was broken down into general ability to exercise competition (GEC), general ability to tolerate competition (GTC), and specific competitive ability (SCA). As can be seen, all of these sources of variation were significant ( $P \leq 0.05$ ). All the interactions involving GEC, GTC, and SCA within locations and spacings were significant ( $P \leq 0.05$ ) (Table 1). This indicates that the behavior of the clones in toleration or exercising competition did not coincide in the different locations or in the two spacings.

This fact was reflected in the estimates of the parameters of model 4, i.e.; the ability to exercise competition ( $c_i$ ), *per se* effect ( $a_j$ ), and toleration of competition ( $t_j$ ), varied a great deal among the environments (Tables 4 and 5). The estimates of the Spearman classifying correlation presented in Table 6 reinforce the previous observation. Notice that in almost all cases, the correlation estimates were of low magnitude or even negative. The lack of coincidence in the estimates of the parameters was expected up to a certain point due to the differences in locations and, above all, of the spacings. Furthermore, the estimates of these parameters are of small magnitude and any fluctuation alters the classification. Considering the most important aspect is to verify

Table 8. – Parameters of specific competitive ability for volume in the mean value of the spacings and locations (Model 4), at 36 months of age.

i	j	$s_{ij}$	i	j	$s_{ij}$	i	j	$s_{ij}$
A	A	-0.16	C	A	0.95	E	A	5.33*
A	B	-0.34	C	B	-0.75	E	B	2.91
A	C	-2.41	C	C	-1.39	E	C	-1.76
A	D	5.52*	C	D	0.93	E	D	-3.85
A	E	-4.46*	C	E	2.59	E	E	2.19
A	F	1.86	C	F	-2.33	E	F	-4.83*
B	A	-4.42*	D	A	0.98	F	A	-2.67
B	B	-2.15	D	B	1.01	F	B	-0.68
B	C	2.35	D	C	-0.12	F	C	3.33
B	D	-3.02	D	D	0.02	F	D	0.41
B	E	3.17	D	E	-4.25	F	E	0.75
B	F	4.07	D	F	2.36	F	F	-1.14

\* Estimate differs from 0 by the t-test at 5% probability.

whether or not there is an advantage in mixing the clones of different management conditions, emphasis will be directed towards the data which is obtained from the mean value of the environments in spite of the interaction detected.

Estimates of the parameters in model 4, regardless of the locations and spacings (Table 7), were as expected; consistent with those reported previously for the clones' ability to exercise competition. The estimate of  $c_i$ , for example, was greater for clone A. Clone F exhibited a lower estimate of  $c_i$ , i.e., it exercised the greatest competition. The  $a_j$ , for its part, evaluates the deviation of performance *per se* of the clone. Clone A exhibited the lowest performance *per se* and clone E exhibited the greatest. The estimate of  $t_j$  is a very useful parameter because it evaluates the ability to tolerate competition. Clone A exhibited the lowest estimate of  $t_j$ , i.e., the least tolerance, whereas clone F tolerated the most competition. Unfortunately, the estimates of  $c_i$  and  $t_j$  act in opposite directions. In other words, among the six clones evaluated, not one of them has low ability to exercise competition while at the same time high ability to tolerate competition.

A high positive estimate of specific competitive ability ( $s_{ij}$ ) indicates a good combination if associated with a high mean value of wood volume between the two clones involved. The pair AD (5.52) and EA (5.33) were the only clones which exhibited good estimates of  $s_{ij}$ . In general, the estimates of  $s_{ij}$  were of low magnitude and statistically equal to zero by the t-test at 5% (Table 8).

## Discussion

The study of competition among a determined group of eucalyptus clones becomes more interesting when clones with different traits are included; however, they were previously tested and approved, thus providing results with practical potential and which are more applicable in the clonal management and silviculture routine. In this study, commercial clones belonging to the same enterprise are included which have recognized high performances.

Another important aspect which should be emphasized when working with perennial plants is the time period of evaluation in the experiments. As the age within the population increases, the competition for resources such as water, nutrients, and light becomes stronger. However, early selection has been practiced in forestry companies and its efficiency has been shown through diverse literature studies both for selection in forestry genetic breeding (BORRALHO et al., 1992, REZENDE et al., 1994, PEREIRA et al., 1997, TOLFO et al., 2005 e MASSARO et al., 2010), as well as for the volumetric prognosis (ABREU et al., 2002). Thus, it is expected that the estimated competitive parameters at the age of 36 months will be good predictors of behavior at the age of rotation.

The behavior of the clones in autocompetition and allocompetition was not very different, both with very similar mean values being obtained. To begin with, the different locations and spacings did not result in change in mean behavior of the clones in regards to their performance in auto and allocompetition. However, observing the individual behavior of each clone, it is possible to identify situations where the performance in allocompetition is greater. Clone D always presented a greater mean value in allocompetition. Clone F, with the exception of Lagoa do Capim, also presented greater performance in allocompetition. Clone A presented the greatest difference among the magnitude of the mean values, but it was not possible to identify a pattern that associates its behavior in auto and allocompetition. It is fitting to emphasize that the differences found are of small magnitude. They allow the conclusion that the behavior of the high performing clones, such as clones D, E, and F, were not altered much by auto- or allocompetition. This suggests that the mixture of elite clones does not lead to neither greater increases, nor losses. Clone A, for its part, which has the worst performance *per se*, with the lowest mean values, stands out as the least competitive and suffered more with the pattern of allocompetition (Table 2).

In the study of effects on the patterns of auto and allocompetition, some strategies may be used. One of them, greatly used in diverse species, is the mixture into equal proportions of lines and/or cultivars one desires to evaluate in regards to relative performance in monoculture and mixed growing (HELLAND; HOLLAND, 2001). Another option is estimating the parameters of auto-/allocompetition by individuals, as was carried out in this study. This may be performed in a nine-hole system in which the central hole is the individual under competition and in the eight remaining holes is the clone that exercises competition. Thus, estimates may be obtained and each clone may be evaluated by three parameters: ability to exercise competition ( $c_i$ ) when the clone in question is the one which surrounds all the others in the nine-hole system; ability to tolerate competition ( $t_i$ ) obtained by the clone under competition in the center of the nine holes, eliminating the effect *per se* ( $a_i$ ) of the clone in question; and by its performance *per se* ( $a_i$ ) (FEDERER et al., 1982).

The ideal clone for use in a mixture is the one which associates low ability to exercise competition with high

tolerance to competition. The greater the value of  $c_i$ , the less it exercises competition, and the greater the value of  $t_i$ , the greater the tolerance. It was found that no one clone, in regards to the mean value of the locations and spacings, possessed the two desirable traits. In general, the clones which exercised little competition were the least tolerant. Clone A is the least competitive (greater  $c_i$ ), tolerates the least competition (lowest  $t_i$ ), and has the worst performance *per se*. Clones D and F are the most tolerant, however they are strong competitors. Clone E exhibited the best performance *per se* and its ability to exercise competition is equal to zero by the t-test at 5% (Table 7).

The  $c_i$  of the clones varied a great deal in the different locations and spacings. In general, the effect of the interactions changed the behavior of the estimates of the parameters in the model, as shown by the low correlations among the performance of the clones in the different environments (Table 6).

In principle, the mixture of clones would not be an advantage in regards to wood production. However, upon more careful analysis of the potential benefits of using a mixture of clones, some points should be highlighted. There are reports in other crops (HELLAND; HOLLAND, 2001; MASTRANTONIO et al., 2004; BISOGNIN et al., 1995; BRUZI et al., 2007; BOTELHO et al., 2011) taking for example the work of BOTELHO et al. (2011), on the bean. The two susceptible lines showed 67% less productivity per land unit than that of a mixture involving eight lines. Brazilian forestry companies had recently failed with recommended clones. If a clonal mix had been recommended, there would have been a smaller total loss than what occurred. The failure of a specific clone could be compensated by different clones in the mix, as in the case of annuals plants.

The mixture of cultivars and/or lines provides greater stability in production. Therefore, with the choice of clones that will compose the mixture, there may be optimization of available resources, such that if one clone does not respond to an environmental change, another may make up for it.

Another potential advantage is in regards to pest and disease management. Some studies report that the use of multilines for greater pest and disease control, contributes to a lower incidence of pathogens and pests than use of a pure line (MILLE; JOUAN, 1997; HELLAND; HOLLAND, 2001; BOTELHO et al., 2011). In forest plantations, the use of a mixture of clones could be a component of integrated pest and disease management; such that a block formed of a mixture of clones with different susceptibilities could minimize outbreaks or epidemics.

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