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STUDYING THE COMPETITION IN NATURAL STANDS OF *ACACIA SEYAL* DEL. VARIETY *SEYAL*

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Abstract

In this study, above ground competition was assessed for individually selected *Acacia seyal* Del. var. *seyal* trees growing in natural stands of different densities. The main objective was to develop a model to estimate the competition index (CI) depending on measuring diameter at breast height (DBH). Data were collected from Umfakarin reserve forest, south Kordofan, Sudan, between September 2007 and February 2008. A total of 286 subject trees of *Acacia seyal* were selected in stands of three different densities, related to different number of stems per hectare. A method for identifying the competitors (adjacent trees) of the subject trees was developed. Tree dimensions such as DBH, height, height of crown base and crown radii for each subject tree and its competitors were measured. Polar coordinates were used to describe the positions of competitors to each subject tree. Eight competition indices were quantified using CroCom program for each subject tree and correlated with its dimensions. The results of the study indicated a remarkable decrease of tree dimensions, especially DBH, when the competition index increased. Regression models between selected indices and tree dimensions showed significant relationships. The results of the study could serve in defining and improving silvicultural treatments, such as thinning programs, of *Acacia seyal* in natural stands.

Key words: *Acacia seyal*, competition index, CroCom, South Kordofan, Umfakarin forest.

Introduction

Competition is a process which occurs among individuals using the same limited resource (Kimmins 2004, Begon et al. 2006). In forest stands, trees often grow close together and compete for resources, such as light, space, water and soil nutrients. Trees that receive few resources will usually perform and produce less than the trees receiving enough resources. As a result of competition among trees, available growing space for each individual decreases, and very severe competition leads to mortality. Ford and Sorrensen (1992) summarized the concept of competition among trees in forest stands into five axioms (as cited in Vanclay 1994):

1) plants modify their environment as they grow, reducing the resources available for other plants;

2) the primary mechanism of competition is spatial interaction;

3) plant death due to competition is a delayed reaction to the growth reduction following resource depletion;

4) plants adjust to environmental change, responding to competition and altering the nature of the competition and

5) there are species differences in the competition process.

A competition index (CI) is any index that describes the degree of competition caused by adjacent trees to the growth and production capability of a subject tree. Various approaches have been developed in order to estimate the degree of competition. Most of these approaches (Hegyi 1974, Biging and Dobbertin 1992, Pretzsch 1995, Nagel 1999, Münder and Schröder 2001) for quantifying the competition indices can be classified in the following categories (Vanclay 1994): a) competitive influence zone;

b) area potentially available;

c) size-distance including horizontal and vertical variants, and

d) sky-view and light-interception approaches.

However, Alder (1995) classified the methods for computing the competition indices into three categories based only on spatial distribution of the trees, i.e. similar to the first three categories mentioned by Vanclay (1994).

Competition is either distance-dependent or distance-independent (Vanclay 1994, Alder 1995, Wimberly and Bare 1996). The distance-dependent or spatial competition is based on tree coordinates or locations (Hegyi 1974, Biging and Dobbertin 1992, Pretzsch 1995, Münder and Schröder 2001) while distance-independent or non-spatial competition is based on crown dimensions and other variables such as light interception (Wykoff et al. 1982, Nagel 1999).

Acacia seyal is widely distributed in eastern and central clay plains of the Sudan, often dominating the vegetation community and forming pure stands (MacAllan 1993) of different densities or mixed stands. In Sudan, *A. seyal* is managed only for firewood and charcoal and is subject to clearing for agricultural machinery. The species is also an important source of commercial gums (gum *talha*), building poles, forage, and source of nectar for honey bees (Elamin 1990, von Maydell 1990, Mustafa 1997). Additionally, *Acacia seyal* has valuable ecological functions such as reducing soil erosion and serving as a defence line for desert encroachment in many parts of the Sudan.

The objective of the study was to investigate competition among trees of *Acacia seyal* growing in natural stands of different densities and to derive different competition indices (CIs) depending on diameter at breast height (DBH), which is the simplest parameter to be measured in the forest stands.

Materials and Methods

Study area

The present study was conducted at Umfakarin Natural Forest Reserve (2,689 ha), south Kordofan State, Sudan. The forest lies between 12° 29′ and 12° 35′ N, and between

31°17′33″–31°20′ E. Annual rainfall ranging from 350 to 900 mm commences in May and lasts until September or October with a peak in August. Seasonal flooding is the most conspicuous feature of this forest. Every year most parts of the forest, especially the dense vegetation patches, are inundated for almost more than two months. Temperature ranges from 30 to 35°C. The prevailing soil types are clay plains and sandy clay locally known *Gardud* (non-cracking). In general, the forest reserve can be described as slightly undulating land surface with the exception of few seasonal streams penetrating some parts of the forest. No physical features seem to be clearly bounded the forest reserve.

The structure of Umfakarin forest can be characterized either by type and/or density of vegetation cover prevailing. *Acacia seyal* with different densities is dominating the forest. These densities can be categorized based on number of trees per unit area (hectare) into three strata i.e. dense, medium and slight stratum. Other tree species are also found such as *A. mellifera, Balanites aegyptiaca, A. polycantha, A. senegal, A. nilotica, A. sieberana, Cordia africana, Boscia senegalensis* and *Dichrystachst sinaria*.

Identifying the competitors and tree measurements

Different methods have been used to identify the competitors (adjacent trees) of subject trees. For example, Arney (1973, ex Wimberly and Bare 1996) used a radius equivalent to open-grown crown radius. Hegyi (1974) included all competitors within a radius of ten feet (3.05 m). In this study, the radius used to identify the competitors was defined as the radius of a circle equal to the height of the subject tree multiplied by a factor (1.25), i.e. $R=h*1.25$ where R is the growing space radius (m) and h is tree height (m). All trees falling within this radius were considered as competitors to the subject tree.

A total of 286 subject trees were selected in three stands of different densities (i.e. dense = 104, medium = 91 and slight = 91). The selection was based on the diameter at breast height (DBH, cm) of the subject tree. The following variables were measured for each subject tree and its competitors: tree coordinates, DBH, height, height to the crown base, crown radii, canopy class, i.e. overstory or understory and crown permeability factor (CPF, estimated as 0.4 for *A. seyal*).

Statistical computations and data analysis

Some statistical indicators for DBH, height and crown diameter were obtained. Competition indices (CIs) were quantified using the computer program CroCom (Münder et. al. 2008). The models used for quantifying competition indices by CroCom are shown in Box 1. The necessary input variables for the program (for each subject tree and its competitors) are tree code, species and number, tree location or coordinates, DBH, height, crown radii, height of crown base, canopy class and CPF. Locations of the competitors were identified by polar coordinates (θ, d), which were converted to Cartesian coordinates (x, y).

Distance-dependent competition indices

1. CI_HEGYI (Hegyi 1974, Eq. 1): Also known as "Jack-Pine-index" was found in 1974 by Hegyi and is considered as a famous and simple index (Münder 2005; Schröder 2003) for quantifying competition in forest stands. The index is based only on the DBH values of the subject tree and its competitors and the horizontal distance between each competitor and the subject tree.

2. CI_HEGYI_2 (Hegyi 1974, Eq. 2): Similar to the above mentioned index, but using basal area instead of DBH.

3. CI_KV (Biging and Dobbertin 1992, Eq. 6): The index uses crown volume based on height of intersection of search cone and tree axis.

4. CI_KF (Biging and Dobbertin 1992, Eq. 7): Based on horizontal crown area and the height of intersection of search cone and tree axis.

5. CI_PRETZSCH (Pretzsch 1995, Eq. 4): The index is part of forest growth simulator SILVA developed at the Chair of Forest Yield Science at Technische Universität München, Germany. It is used to quantify the competition based on the identification of competitors by means of the search cone method.

6. CI_VKF (Münder and Schröder 2001, Eq. 3): The index is based on the vertical crown area and the horizontal distance between the competitors and the subject tree.

Distance-independent competition indices

1. CI_C66 (Nagel 1999, Eq. 5): Based on the horizontal crown area at the height of greatest crown width. The C66 of a subject tree is calculated by summing up the horizontal crown areas of all trees cut at the height of its greatest crown width, which is fixed at 66.6% of crown length from the top (Nagel 1999 ex Schröder et al. 2007). The C66 index identifies competitors either as all trees belonging to the same stand (distance-independent mode) or by checking a fixed critical radius (distance-dependent mode) (Schröder et al. 2007). The later method was used in this study for identifying the competitors.

2. CI_BAL (Wykoff et al. 1982, Eq. 8): The index is also termed as "G_{cum}" or shading index (Schütz 2001, Schütz and Röhnisch 2003) and can be calculated by summing up the basal areas of the trees larger (BAL) than the subject tree.

Box 1 shows the models used for quantifications of various CIs in CroCom programme.

Partial correlation was used to check if any association exists between the competition index and the tree size e.g. DBH, when the effect of all other tree dimensions is removed. The association between tree dimensions (DBH, height and crown diameter) and various competition indices was tested by the following non-linear regression model (Eq. 9).

$$CI = a_0 + a_1 * \ln(x) \tag{9}$$

Where: CI = competition index; x = tree dimension; $\ln$ = natural logarithm; a_0 and a_1 = coefficients.

Results

Results of partial correlation analysis indicate that DBH is positively correlated with height and crown diameter for all three strata (different stand densities).

Box 1. Models used for CIs quantification in CROCOM Programme.

Distance-dependent competition indices

$$CI\_HEGYI = \sum_{j=1}^{nj} (d_j . d_i^{-1}).(dist_{ij} + 1)^{-1} \quad \text{.....(1)}$$

$$CI\_HEGYI\_2 = \sum_{j=1}^{nj} (g_j . g_i^{-1}).(dist_{ij} + 1)^{-1} \quad \text{.....(2)}$$

$$CI\_KV = \sum_{j=1}^{nj} KV_j (SH).KV_i^{-1} \quad \text{.....(3)}$$

$$CI\_KF = \sum_{j=1}^{nj} KF_j (SH).KF_i^{-1} \quad \text{.....(4)}$$

$$CI\_PRETZSCH = \sum_{j=1}^{nj} Beta_{ij} .KQF_i .KQF_j^{-1} \quad \text{.....(5)}$$

$$CI\_VKF = \sum_{j=1}^{nj} VKF_j .VKF_i^{-1}.(dist_{ij} + 1)^{-1} \quad \text{.....(6)}$$

Distance-independent competition indices

$$CI\_C66 = \sum_{j=1}^{nj} KF_{j(HGK_i)} \quad \text{.....(7)}$$

$$CI\_BAL = \sum_{j=1}^{n_{max}} (g_j) \quad \text{.....(8)}$$

Source: (Schütz 2001, Schröder 2003, Schütz und Röhnisch 2003, Münder 2005, Rivas et al. 2005)

Where: i = focal tree; j = competitor; d = diameter at breast height (DBH); BAL = basal area of larger tree than the subject; gj = basal area, m²; Gcum = cumulative basal areas of trees larger than the subject; nmax = number of trees having basal area larger than the subject tree; nj = number of competitors; $dist_{ij}$ = distance $tree_i$ - $tree_j$; *Beta* = gradient of straight line connecting base of search cone and top of competitor tree; *KF* = horizontal crown area; *KQF* = *KF* at height of search-cone base; *HGK* = height of greatest crown width (fixed at 66% of crown length from the top); SH = height of intersection of search cone and tree axis; *KV* = crown volume; *VKF* = vertical crown area; *h* = height.

The partial correlation coefficient (r) ranges from 0.228 to 0.405 for height and 0.503 to 0.731 for crown diameter.

Descriptive statistics of the variables are shown in Table 1. Stands of dense, medium and slight density have mean diameter at breast height (DBH) equals to 13.9, 14.7 and 12.8 cm with mean height 7.3, 7.8 and 6.7 m respectively.

Competition index in relation to tree dimensions

The results of the data analyzed by CroCom are intra- and inter-specific

Table 1. Statistics parameters for some variables of *Acacia seyal* dimensions, Umfakarin natural forest reserve south Kordofan, Sudan 2007/2008.

Stratum*	Variable	Parameter			
		Minimum	Maximum	Mean	Std. Deviation
Dense	DBH, cm	5.0	36.9	13.9	2.6
	Height, m	4.5	11.5	7.3	1.0
	CD, m	2.0	1.05	5.5	1.5
Medium	DBH, cm	5.8	33.4	14.7	2.3
	Height, m	4.0	9.5	7.8	1.3
	CD, m	1.7	8.4	4.6	1.3
Slight	DBH, cm	6.7	15.1	12.8	2.3
	Height, m	3.0	10.0	6.7	1.2
	CD, m	1.8	8.4	4.6	1.2

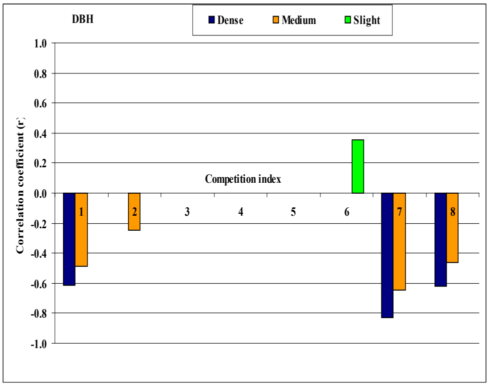
*Number of trees per hectare (dense = 396; medium = 271; slight = 209); DBH = diameter at breast height; CD = crown diameter.

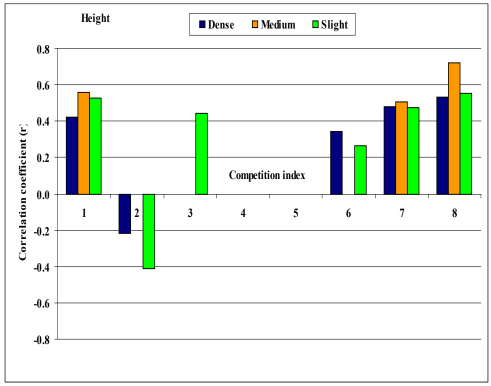
competition indices. According to CroCom definition intra-specific competition is expressing the competition between trees sharing the same crown layer while inter-specific competition is between trees growing in different layers. However, in ecology, inter-specific competition refers to the competition that occurs whenever two different species attempt to utilize the same limiting resource, while intra-specific is the competition between individuals of the same species (Kimmins 2004, Begon et al. 2006). To avoid confusion between the two concepts (in CroCom and ecology), intra- and inter-layer competitions were termed referring to the competition between trees sharing the same layer and competition between trees growing in different layers, respectively. The final competition index induced by the competitors is the sum of inter- and intra-layer competition.

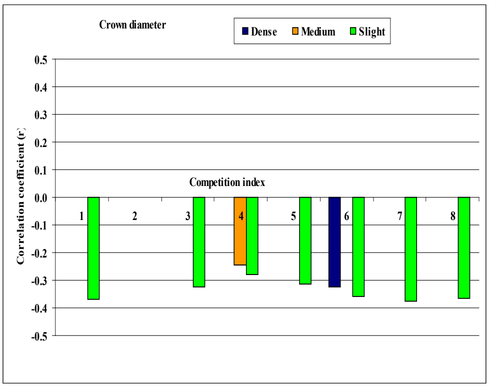
Fig. 1 shows the significance of partial correlation between various competition indices and tree dimensions. Results of partial correlation indicate that only few indices show a clear and significant correlation (CI_HEGYI, CI_PRETZSCH, CI_C66, CI_HEGY_2, and CI_BAL) with DBH in the three different strata (Fig. 1). The maximum partial correlation coefficient (–0.829) was obtained by CI_HEGYI_2 in dense stratum. With exception to CI_BD_KV and CI_VKF, tree height encountered a clear relationship with all indices in all strata with a maximum correlation coefficient (r) of 0.559 in medium stratum. Crown diameter revealed negative partial correlation with all indices except CI_PRETZSCH, which showed no correlation.

Selection of competition index

The criterion for selecting the appropriate competition index that better relates







Definition of indices:

1 = Hegyi index (CI_Hegyi)
2 = Pretzsch index (CI_Pretzsch)
3 = Biging and Dobbertin index (CI_KF)
4 = Biging and Dobbertin index (CI_KV)
5 = M□nder and Schr□der index (CI_VKF)
6 = Nagel index (CI_C66)
7 = Hegyi index (CI_Hegyi_2)
8 = BAL index (CI_BAL).

Fig. 1. Summary of the results about the significance of partial correlation between various competition indices (CIs) and tree dimensions of *Acacia seyal* at Umfakarin natural forest, south Kordofan, Sudan (2007/2008).

to tree dimension in a specific stratum was based on coefficient of determination (R^2). The higher the value the better index expresses the relationship. Values of R^2 vary according to tree dimension, competition index and stratum (Table 2). The maximum R^2 (0.651) was obtained as a result of relationship between DBH and HEGYI_2 index. Effect of competition on the tree dimensions is depicted in Fig. 2. The figure shows that while height is increasing, DBH and crown diameter are decreasing with increasing competition intensity.

Discussion

Tree diameter is the most sensitive variable to competitive stress. Additionally, variations in tree dimensions are caused by stand density. Tree density has been recognized as a major factor determining the degree of competition among trees in forest stands. Growth or production performance of individual trees decreases as the density per unit area increases. In dense situations, many trees may not be able to develop their crowns because of

Table 2. Results of the model used for testing the relationship between CIs and tree variables in different stand strata of *A. seyal* at Umfakarin forest, south Kordofan, Sudan.

Index	Dense stratum (number of target trees = 104)								
	Diameter at breast height, cm			Height, m			Crown diameter, m		
	a_0	a_1	R^2	a_0	a_1	R^2	a_0	a_1	R^2
Hegyi	7.529	-2.290	0.314			0.029	2.889	-0.641	0.081
Pretzsch			0.020	76.413	-36.878	0.074			0.002
BD_KF	96.245		0.029	149.507	-66.822	0.046			0.007
BD_KV			0.021	301.333	-140.953	0.053			0.003
VKF	7.587	-2.332	0.054	10.150	-4.187	0.064	3.230		0.026
C66			0.015	-267.331	215.252	0.122	216.584		0.031
Hegyi_2	15.749	-5.410	0.651			0.002	4.139	-1.101	0.089
BAL	12,062.205	-3,571.910	0.227		454.653	0.073	5,001.285	-1112.286	0.073
	Medium stratum (number of target trees = 91)								
Hegyi	4.632	-1.349	0.154		1.082	0.085	2.697	-0.905	0.149
Pretzsch	26.332	-9.682	0.230	13.158	-5.362	0.061	11.508	-5.861	0.181
BD_KF			0.003			0.000			0.011
BD_KV			0.008			0.001			0.016
VKF	7.116	-2.253	0.114			0.002	4.303	-1.792	0.156
C66			0.001			0.001			0.000
Hegyi_2	11.186	-3.811	0.387			0.008	4.580	-1.788	0.183
BAL	4,284.817		0.005	-2,511.140	768.168	0.356	3,721.466		0.011
	Slight stratum (number of target trees = 91)								
Hegyi	1.596		0.021		0.742	0.095	1.635	-0.562	0.109
Pretzsch	3.692		0.028	7.453	-3.660	0.241	2.764	-1.303	0.061
BD_KF			0.006		7.058	0.073	12.111	-4.748	0.066
BD_KV	17.987		0.027	13.380		0.016	16.482	-7.028	0.097
VKF	2.202		0.028	2.151	-0.746	0.042	2.084	-0.858	0.112
C66	-115.222	71.538	0.106	-83.023	76.549	0.112	55.491		0.000
Hegyi_2	3.052	-0.875	0.072			0.033	2.509	-1.033	0.184
BAL			0.009	-1,763.153	471.395	0.242	2,103.253		0.022

The non-indicated values for a parameter mean that the parameter is not statistically significant ($\alpha = 0.05$).
a_0 and a_1 = coefficients; R^2 = coefficient of determination.

competition. Whenever the competition decreases trees start to develop their crowns and their growth and production capability increase. Sometimes in com-

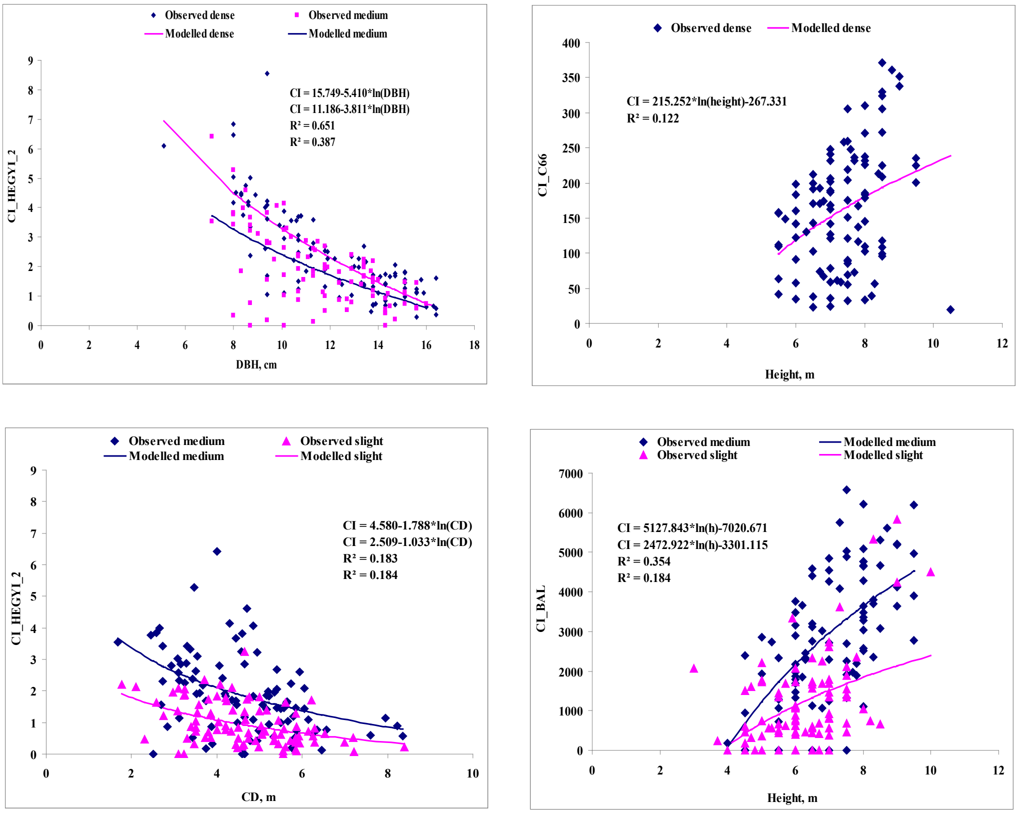


Fig. 2. Effect of competition on dimensions of *Acacia seyal* natural stands at Umfakarin forest, south Kordofan Sudan (See table 2 for models parameters).

petitive situations, trees may tend to increase in height (positive competition) in order to obtain sunlight, especially light demanding trees, like *A. seyal,* rather than enlarging cross sectional dimensions such as DBH and crown diameter (Fig. 1 and 2). This situation is clearly expressed by the positive correlation between tree height and some indices (CI_HEGYI, CI_BD_KF, CI_C66, CI_HEGYI_2 and CI_BAL). This positive association could be attributed to the method of selecting the competitors which is based on the height of subject tree. Whenever the height increases, additional competitors are included and this will increase the competition index. Competition induced by large adjacent trees may negatively affect the diameter and crown dimensions (negative competition) of individual subject trees.

As previously mentioned, non-linear regression models were used for describing the relationship between tree variables and competition indices. Based on the results of these models, CI_HEGYI_2 is considered as a suitable index to be applied for quantifying the degree of competition in natural stands of *A. seyal* of dense and medium stratum.

The results of this study could serve in defining or improving silvicultural treatments such as thinning programs for *A. seyal* trees in natural stands. Moreover, *A. seyal* is a gum Arabic producing tree in Sudan, and therefore, studying of competition among trees of *A. seyal* may play a major role in identifying the effect of competition on gum production, and hence, in developing gum production models. Establishment of permanent trial plots is necessary in order to study the effect of competition on growth of *A. seyal* and gum production as well.

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