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Responses of tree seedlings to the removal of *Chromolaena odorata* Linn. in a degraded forest in Ghana

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Abstract

Chromolaena odorata is a dominant plant species in degraded forest areas in Ghana. This species forms a very dense canopy. Although tree seedlings have been observed growing under the canopy of this species, they have scarcely been seen growing through the canopy of *Chromolaena odorata*. To study the response of tree seedlings to the removal of *Chromolaena odorata*, 108 plots were established 20 m apart in a degraded dry semi-deciduous forest in Ghana. *Chromolaena odorata* was removed from 50% of the plots to release tree seedlings and left the other half intact. Seedling height, the number of leaves per seedling, and seedling mortality were assessed in both released and unreleased plots immediately after the release treatment (June 1998) and again three months later (September 1998). It was found that the seedling height increment and the increase in number of leaves per seedling were three times greater in released plots than the unreleased plots three months after the release treatment. Twenty eight tree species were found in the plots and 89% of the species had higher height growth after the release treatment. Similarly, 93% of the tree species had more new leaves in released plots than in the unreleased plots. Sixty four percent of the species suffered various levels of mortality in the unreleased plots, but all the seedlings of all the species survived in the released plots. The results suggest that there is a great potential to restore the degraded area back to forest using natural seedlings by removing *Chromolaena odorata*, the competing vegetation.

Keywords: *Chromolaena odorata*; Competition; Degraded forests; Natural regeneration of tropical forests; Release treatment; Seedling growth; Silviculture

1. Introduction

Forests are a valuable resource for Ghana both economically and ecologically. For instance, the revenue from forest products constitutes 6% of the country's gross domestic products (GDP) and ca. 20% of the export income (Prah, 1994; TEDB, 1997). Forest products are the third major exporting goods of the country (TEDB, 1997). However, over 70% of the forests (8.13×10^6 ha) in the country have been degraded (Avoka, 1999). The degraded forest is defined as areas that used to be occupied by a forest but virtually contain no trees now and are dominated mainly by *Chromolaena odorata* Linn (Acheapong), an aggressive weed species. The invasion of *Chromolaena odorata* appears to be the primary factor responsible for the poor regeneration of the degraded forests (Swaine et al., 1997; Honu and Dang, 2000) but there is no information on the effect of *Chromolaena odorata* on the survival and growth of tree seedlings (Hawthorne, 1989).

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In an earlier study (Honu and Dang, 2000), we found that there were over 11 700 tree seedlings per ha under the canopy of *Chromolaena odorata*, but the growth of those seedlings is poor. Although measures can be taken to suppress or remove the *Chromolaena odorata* and release the tree seedlings, it is not known whether the tree seedlings will respond positively to the release. Given the wide distribution of *Chromolaena odorata*, knowledge on the response of tree seedlings to the removal of *Chromolaena odorata* will represent a significant step towards the understanding of the potential of human-assisted natural regeneration of the degraded forests in Ghana.

Tree height increment and increase in number of leaves per seedling are important indicators of tree's response because they reflect the ability of trees to compete for light and their growth potential (Philip, 1983). In this study, we examined the effect of the removal of *Chromolaena odorata* on the height increment, increase in number of leaves and survival of tree seedlings in a degraded dry semi-deciduous (DSD) forest in Ghana.

2. Study site

The study was conducted in a degraded DSD forest in the Volta Region (8°50′N to 6°9′S, 0°20′W to 1°6′E) of Ghana. The study area is characterized by the alternation of wet (major and minor rainfalls) and dry (hamattan) seasons with a total annual rainfall of 1250–1500 mm (Hall and Swaine, 1976). The site (4 ha) is flat and generally well drained. The soil in the site is Forest Ochrosols (Hall and Swaine, 1981) and is friable reddish brown and fine granular silty loam. A Munsel chart (Anonymous, 1973) was used to describe soil color characteristics. There had been no disturbances to the site since a wildfire occurred in 1983 (J. Kyekye, personal communication).

The site was occupied by *Chromolaena odorata*, a weed species with a 95% coverage. The flux density of photosynthetically active radiation under the *Chromolaena odorata* was only 7% of the ambient level as measured by Li-Cor Li-250 light meter at 12 : 00 noon (Honu and Dang, 2000). Other environmental factors (e.g. soil moisture and temperature changes) were not measured. There were tree seedlings of 55 species grew under the canopy of *Chromolaena odorata*, but the growth was generally poor. The North Eastern (NE) and South Western (SW) sides of the site were bounded by natural forest stands. Most of the tree species in those natural forest stands grow very big, for example *Triplochiton sclerozylon* had a diameter at breast height (DBH) of 1.6 m and *Ceiba pentandra* was 130 m tall (tallest species in the stand). The seeds of most species in the forests are dispersed by the wind (e.g. *Ceiba pentandra*, *Piptadenistrum africanum*, *Triplochiton sclerozylon*), and birds (e.g. *Milicia exelsa*). The South Eastern (SE) and North Western (NW) sides were bounded with farms (see Honu and Dang, 2000 for a detailed description of the study site).

3. Experimental design

A total of 108 square plots of 5 × 5 m were established at 20 m apart in the degraded area (see Honu and Dang, 2000 for more details). A circular plot of 1.26 m radius was set up at the center of each of the square plots. The height and the number of leaves per seedling were measured on all tree seedlings (trees ≤2 m tall) in early June, 1998. A 2.5 m measuring pole was used to measure seedling heights to the nearest centimeter (Philip, 1983). All fresh fallen leaves under tree seedlings were removed from the plots and all the mature leaves that were likely to fall during the study period were marked with an indelible ink for the convenience of easy identification of fallen leaves. The seedlings were identified according to Hawthorne (1990) and classified into three commercial classes according to the Ghanaian System of Tree Classification (Ghartey, 1989). Class 1 contained tree species that have been exported from Ghana in the past 15 years. Class 2 contained tree species that can attain 70 cm DBH and/or occur at a frequency of at least one tree per 100 ha but have not been exported. All other trees were classified as Class 3 tree species. This classification system was adopted because information regarding the response of the three commercial classes of trees is critical for the Forest Managers in Ghana. The identified tree seedlings were labeled with plastic tags for easy identification.

Chromolaena odorata and all other non-tree plants were removed manually using cutlass from 50% of the square plots (every other) between 29 May and 1 June 1998. The tree seedlings were exposed to full sunlight after the release treatment. Changes in other environmental factors were not measured. A second removal of weeds was done on 22 July 1998. The first plot for weed removal was determined randomly by using a random number generator. These plots and the seedlings in them will be referred to as released plots and released seedlings, respectively. Other plots were left intact and those plots and the seedlings in them will be referred to as unreleased plots and unreleased seedlings, respectively. The reason that sampling plots (5 m^2) were much smaller than the release plots (25 m^2) is to avoid edge effect. The height and the number of leaves per seedling in all sampling plots were measured again in early September of the same year.

Height increment and changes in number of leaves were calculated from the difference between the measurements in June and September. Seedling mortality was calculated as the difference in the number of seedlings in each species in June and September. Dead seedlings were visually inspected for symptoms of pathogen infection.

4. Statistical analyses

The height increment and number of leaves per seedling were graphically examined for the normality of distribution using probability plots and for homogeneity of variances using Levene Test (Norusis, 1993). Since the data did not follow a normal distribution, $\log_{10}$ transformations were performed. Analysis of covariance (Steel and Torrie, 1980) was used to test the difference between released and unreleased plots (first all species combined, then by individual species) using the June measurement as the covariant. A total of 55 species was recorded in the study, 18 of which were present only once either in the released and/or unreleased plots. These 18 species were eliminated from the analysis because no statistics could be calculated for them. An additional five species were present only in released plots and four other species were present only in unreleased plots. These nine species were also eliminated from the analysis. Therefore, 28 tree species were used in the analysis.

5. Results

5.1. Height increment

The height increment was significantly greater in the released than in the unreleased seedlings for all species together (Fig. 1, $p = 0.000$). The height increment of released seedlings (all species) was generally three times of that in the unreleased seedlings, three months after the release treatment (Fig. 1). The level of response, however, varied with species. The height increment (species mean) of released seedlings ranged from 1.6 to 13.5 cm while that of unreleased seedlings ranged from 0.6 to 4.5 cm (Fig. 1). *Steculia tragacantha* (Sttr) showed the highest response among all species (Fig. 1). *Celtis zenkeri* (Ceze) showed the lowest response among the species that responded significantly to the release treatment (Fig. 1).

All the released seedlings of Class 1 species had significantly higher height increment than their unreleased counterparts and the difference ranged from 1.0 to 8.5 cm (Fig. 1, $p \leq 0.04$). All the Class 2 species had significant higher height increment than their unreleased counterparts ($p \leq 0.04$) except *Trichilia prieuriana* (Trpr) and *Maranthes chrysophylla* (Mach, $p \geq 0.48$) and the difference ranged from 1.4 to 10.5 cm (Fig. 1). The height increment of all Class 3 species were significantly higher than their unreleased counterparts ($p \leq 0.02$) except *Newbouldia laevis* (Nela, $p = 0.71$) and the difference ranged from 2.2 to 9.3 cm (Fig. 1).

5.2. Increase in number of leaves

The released seedlings grew significantly more new leaves than the unreleased ones for all species combined (Fig. 2, $p = 0.000$). The increase in number of leaves per seedling (all species) was generally three times more in released seedlings than the unreleased ones three months after the release treatment (Fig. 2). The increase in number of leaves in released seedlings ranged from 1.5 to 7.6 while that of unreleased seedlings ranged from 0.0 to 3.7 (Fig. 2). The level of response varied with species. *Mallotus oppositifolius* (Maop) showed the highest response among all species while *Celtis zenkeri* had the lowest response among the species that showed a significant response (Fig. 2).

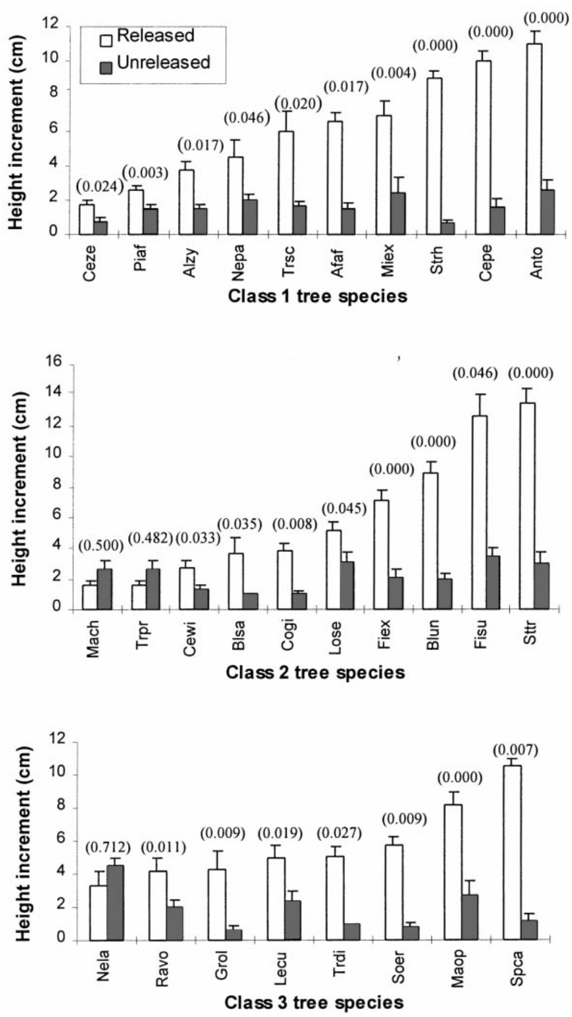

Fig. 1. Height increment in released and unreleased tree seedlings in the degraded area three months after the release treatment (mean + 1 SE, $n = 2$–29). Numbers in parentheses represent probabilities of the covariance analysis. Afaf, *Afzelia africana*; Alzy, *Albizia zygia*; Anto, *Antiaris toxicaria*; Blsa, *Blighia sapida*; Blun, *Blighia unijugata*; Cepe, *Ceiba pentandra*; Cewi, *Celtis wightii*; Ceze, *Celtis zenkeri*; Cogi, *Cola gigantia*; Fisu, *Ficus sur*; Fiex, *Ficus exasperata*; Grol, *Greenwayodendron oliveri*; Lecu, *Lecaniodicus cupanioides*; Lose, *Lonchocarpus sericeus*; Maop, *Mallotus oppositifolius*; Mach, *Maranthes chrysophylla*; Miex, *Milicia exelsa*; Nepa, *Nesorgodonia papaverifera*; Nela, *Newbouldia laevis*; Piaf, *Piptadenistrum africanum*; Ravo, *Ravolfia vomitoria*; Soer, *Solanum erianthrum*; Spca, *Spathodea campanulata*; Strh, *Steculia rhinopetala*; Sttr, *Steculia tragacantha*; Trdi, *Tricalysia discolor*; Trpr, *Trichilia prieuriana*; and Trsc, *Triplochiton sclerozylon*.

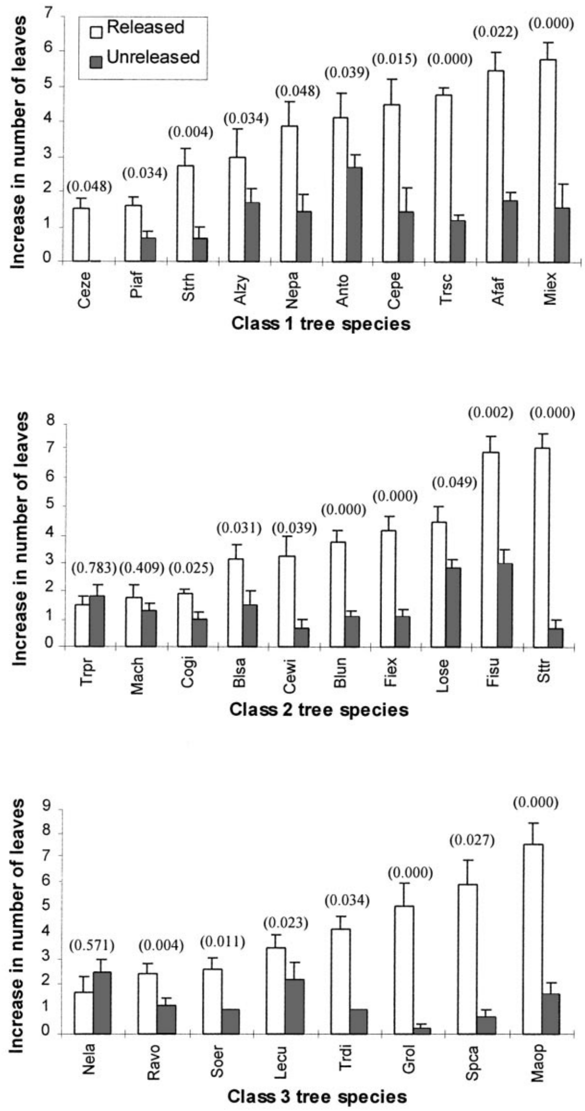

Fig. 2. Increase in number of leaves per seedling in released and unreleased tree seedlings in the degraded area three months after the release treatment. See Fig. 1 for more explanations.

All the released seedlings of Class 1 species had significantly more leaves than their unreleased counterparts and the difference ranged from 0.9 to 4.2 (Fig. 2, $p \leq 0.04$). All the Class 2 species had significantly more new leaves than their unreleased counterparts ($p \leq 0.04$) except *Maranthes chrysophylla*, and *Trichilia prieuriana* ($p \geq 0.41$) and the difference ranged from 0.9 to 4.2 (Fig. 2). All the released seedlings of Class 3 species had significantly

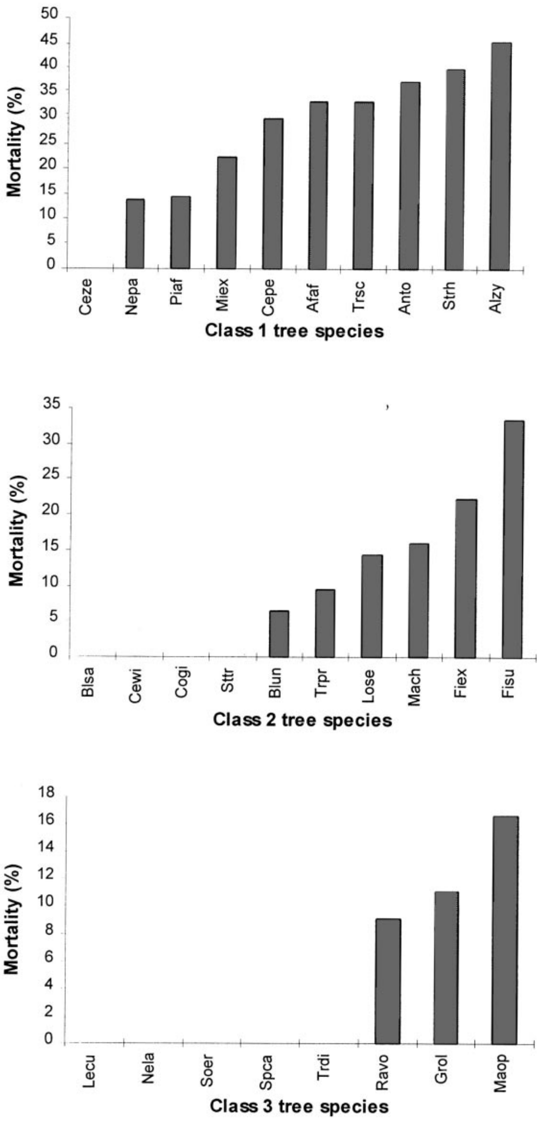

Fig. 3. Mortality (%) of tree seedlings in unreleased plots. No mortality was observed in the released plots. See Fig. 1 for more explanations.

more new leaves than their unreleased counterparts ($p \leq 0.03$) except *Newbouldia laevis* ($p = 0.57$) and the difference ranged from 1.3 to 6.0 (Fig. 2).

5.3. Mortality

Seedling mortality was observed only in unreleased plots and the rate of mortality varied from species to species. In general, faster growing species suffered higher mortality (Figs. 1 and 3). Seedling mortality was highest in Class 1 trees and lowest in Class 3 tree species (Fig. 3). The seedling mortality of Class 1 species ranged from 0 to 45% (Fig. 3). All the Class 1 species but *Celtis zenkeri* suffered mortality with an average mortality of 28% (Fig. 3). Seedling mortality of Class 2 species ranged from 0 to 33% (Fig. 3). Sixty percent of the Class 2 species suffered mortality with an average of 12% (Fig. 3). Only three out of eight Class 3 species suffered mortality (Fig. 3). Symptoms of pathogen infection were not observed on dead tree seedlings.

6. Discussion

This study shows there is a great potential to restore the degraded area back to productive forests by removing *Chromolaena odorata*. Most tree species responded positively and significantly to the removal of *Chromolaena odorata*, the competing species (Figs. 1 and 2). The seedlings obtained greater height growth and more new leaves after being released from *Chromolaena odorata* (Figs. 1 and 2). The increase in number of leaves per seedling was positively related to height increment ($r = 0.70$, $p = 0.0000$, SE $= 1.90$). The significant increase in these two parameters suggest that releasing from competition greatly increased the growth momentum of those trees. According to the height increment of the released seedlings during the study period (3 months), it may take the trees up to 2.5 years to grow taller than the maximum height of *Chromolaena odorata*. However, the increased growth momentum will most likely produce even faster growth in those trees in the future, suggesting that the tree species will likely grow taller than the maximum height of *Chromolaena odorata* in <2.5 years. Additionally, *Chromolaena odorata* is very intolerant of shade and cannot grow under the canopy of trees. Therefore, *Chromolaena odorata* will no longer be a concern once the trees form a certain canopy coverage. The critical level of coverage, however, needs to be examined in future research. It should be pointed out that this is a preliminary study and longer-term observations may be necessary before a more concrete recommendation can be made to forest managers.

Chromolaena odorata is widespread in degraded forest areas in Ghana. It is a high shade intolerant species and has a great capacity to invade and dorminate the degraded areas. One of the possible reasons for the aggressive invasion is the abundant number of viable seeds produced by this species (Swaine et al., 1997; Honu and Dang, 2000). The light weight of the seed gives this species an additional advantage for the wide range dispersal by wind. It grows very fast to ca. 2 m tall (Riddoch et al., 1991). This species forms such a dense woven canopy that it is almost impossible for the tree seedlings to grow through. The flux density of photosynthetically active radiation under the *Chromolaena odorata* canopy is only 7% of the ambient level (Honu and Dang, 2000).

Our results suggest that the natural tree seedlings have the potential restore the degraded forest back to high value, high quality forests after *Chromolaena odorata*, the competing vegetation is removed. The height increment of released Class 1 seedlings ranged from 225 to 625% of that in unreleased seedlings (Fig. 1). Similarly, the increase in the number of new leaves of the Class 1 seedlings ranged from 228 to 400% of that in unreleased seedlings (Fig. 2). Honu and Dang (2000) reported that the density of these Class 1 species at the site ranges from 112 to 612 seedlings per ha and the frequency of occurrence ranges from 4 to 18%. Additionally, the Class 1 species form 50% of the tree species that had a response of more than 6 cm in height growth (Fig. 1). Moreover, they constitute 44% of the species that produce more than four new leaves per species (Fig. 2). Such a significant response shown by the Class 1 species suggests that they have a great potential to be the dominant species in the future forest after being released from *Chromolaena odorata*. *Steculia rhinopetala* (Strh), *Ceiba pentandra* (Cepe), *Antiaris toxicaria* (Anto), *Milicia exelsa* (Miex), *Afzelia africana* (Afaf), and *Triplochiton sclerozylon* (Trsc) are the most important Class 1 species in the country. They are fast growing species and require strong light conditions (Taylor, 1960, 1962; Hawthorne, 1990; Riddoch et al., 1991; Molofsky and Augspurger, 1992). This may explain why their height and leaf response were very high (Figs. 1 and 2). The dominance of such species ensures a high growth rate and high value of forest products in the future. This in the long term has the potential to increase the revenue base of the forest industry. On the other hand, the growth response shown by *Celtis zenkeri*, *Piptadenistrum africanum* (Piaf), *Albizia zygia* (Alzy), and *Nesorgodonia papaverifera* (Nepa), suggests that they have slow juvenile growth (Figs. 1 and 2).

The height growth and number of new leaves produced by Class 2 species generally did not increase as much as Class 1 species did in response to the release treatment. The height growth of released Class 2 species ranged from 167 to 450% of that in unreleased seedlings (Fig. 1). The Class 2 species represent 33% of the tree species that had a response of more than 6 cm in height growth (Fig. 1). Similarly, the increase in number of new leaves of the Class 2 seedlings ranged from 190 to 1028% of that in unreleased seedlings (Fig. 2). But they form only 28% of the species that produce more than four new leaves per species (Fig. 2). These Class 2 species have 112–1112 seedlings per ha at the site and the frequency of occurrence ranges from 4 to 30% (Honu and Dang, 2000). These species have the potential to form the second stratum of the future forest. Although these species currently do not have much economic value compared to Class 1 species, they can provide significant ecological functions (e.g. watershed protection). Prah (1994) reports that deforestation may be responsible for the recent changes in climatic conditions and the transformation of many perennial rivers and streams to seasonal ones in Ghana. Moreover, some of these species may become Class 1 species in the future. For example, *Pericopsis elata* was not an economic species before 1985 but later became one of the highly priced timber species (FAO, 1985; Hawthorne and Abu-Juam, 1995). The height and leaf response of *Ficus sur* (Fisu), and *Steculia tragacantha* were very high (Figs. 1 and 2) suggesting that they may be strong light demanding and very fast growing tree species. Similarly, *Ficus exasperata* (Fiex) and *Blighia unijugata* (Blun) may also be fast growing light demanders. On the other hand, the growth response shown by *Celtis wightii* (Cewi), *Blighia sapida* (Blsa), *Cola gigantia* (Cogi), and *Lonchocarpus sericeus* (Lose) indicates that they have slow seedling growth.

The height increment of released Class 3 species ranged from 46 to 333% of that of unreleased seedlings (Fig. 1). These species form only 17% of the trees that had a response of more than 6 cm in height growth (Fig. 1). Similarly, the increase in number of new leaves of the Class 3 seedlings ranged from 154 to 1700% of that in unreleased seedlings (Fig. 2). But they represent only 28% of the species that produce more than four new leaves per species (Fig. 2). The seedling density of these Class 3 species at the site ranges from 92 to 666 per ha and the frequency of occurrence ranges from 4 to 20% (Honu and Dang, 2000). These results suggest that the Class 3 trees do not have the potential to form a significant part of the future forest. The height and leaf response of *Spathodea campanulata* (Spca), and *Mallotus oppositifolius* were very high (Figs. 1 and 2), suggesting that they may be light demanding and fast growing tree species. On the other hand, the growth response shown by *Newbouldia laevis*, *Ravolfia vomitoria* (Ravo), *Greenwayodendron oliveri* (Grol), and *Lecaniodicus cupanioides* (Lecu), *Tricalysia discolor* (Trdi), and *Solanum erianthrum* (Soer) suggests that they have slow juvenile growth (Figs. 1 and 2).

Our results suggests that *Chromolaena odorata*is primarily responsible for the poor regeneration of trees in degraded areas. The high mortality in unreleased seedlings and no mortality in released seedlings (Fig. 3), suggest that those tree species generally cannot tolerate the shade created by the *Chromolaena odorata* canopy. Seedlings of light demanding species are fast growing and intolerant of shade and can survive and grow only in gaps (Taylor, 1962; Swaine and Hall, 1988; Hawthorne, 1989). Mortality is high for seedlings of shade-intolerant species when they grow under the canopy of competing species (Richards, 1996) and is lower in gaps than in shade regardless of the seedling density (Augspurger, 1984; Augspurger and Kelly, 1984). Mortality was greatest in Class 1 trees and lowest in Class 3 trees (Fig. 3). This suggests that the light demanding characteristics of the tree species is strongest in the Class 1 trees and weakest in Class 3 trees. *Chromolaena odorata* must be removed in order to regenerate the degraded area.

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References

Anonymous, 1973. Munsell Soil Color Charts. Munsell Color, MacBeth Division of Kollmorgen Corp., Baltimore Maryland, Publ. 21218.

Augspurger, C.K., 1984. Seedling survival of tropical tree species: interaction of dispersal distance, light gaps, and pathogen. Ecology 65, 1705–1712.

Augspurger, C.K., Kelly, C.K., 1984. Pathogen mortality of tropical tree seedlings: experimental studies of the effects of dispersal distance, seedling density, and light conditions. Oecologia 61, 211–217.

Avoka, C., 1999. Interview with He Mr. Cletus Avoka, Minister of Lands and Forestry, Ghana. In: Prebble C. (Ed.), ITTO Tropical Update. ANUTECH, Pty Ltd., Canberra, Australia, pp 16–17.

FAO, 1985. Incentive Multiple-Use Forest Management in the Tropics: Analysis of Case Studies from India, Africa, Latin America and the Caribbean. FAO, Rome, Italy, 180 pp.

Ghartey, K.K.F., 1989. Results of the inventory. In: Wong, J.L.G. (Ed.), Forest Inventory Project Seminar Proceedings 29–30 March 1989, Accra, Ghana, pp. 8–13.

Hall, J.B., Swaine, M.D., 1976. Classification and ecology of closed canopy forest in Ghana. J. Ecol. 64, 913–951.

Hall, J.B., Swaine M.D., 1981. Distribution and Ecology of Vascular Plants in a Tropical Rain forest. Forest Vegetation in Ghana. Junk, The Hague, 383 pp.

Hawthorne, W.D., 1989. The flora and vegetation of Ghana's forests. In: Wong, J.L.G. (Ed.), Forest Inventory Project Seminar Proceedings 29–30 March 1989, Accra, Ghana, pp. 8–13

Hawthorne, W., 1990. Field Guide to the Forest Trees of Ghana. Natural Resource Institute, for the Overseas Development Agency, Ghana Forestry Series 1, London, UK, 278 pp.

Hawthorne, W.D., Abu-Juam, M., 1995. Forest Protection in Ghana. IUCN, Gland, Switzerland and Cambridge, UK, 203 pp.

Honu, Y.A.K., Dang, Q.L., 2000. Distribution and species composition of seeds and seedlings of trees and competing vegetation in Ghana, Can. J. For. Res. (submitted).

Molofsky, J., Augspurger, C.K., 1992. The effect of leaf litter on early seedling establishment in a tropical forest. Ecology 73 (1), 68–77.

Norusis, M.J., 1993., SPSS For Windows Base System Users Guide Release 6.0, SPSS Inc., Michigan, USA, 828 pp.

Philip, M.S., 1983. Measuring Trees and Forests. A Text Book Written for Students in Africa. Division of Forestry, University of Dar es Salaam, Tanzania, 388 pp.

Prah, E.A., 1994. Sustainable Management of the Tropical High Forest of Ghana. Commonwealth Secretariat Marlborough House, Pall mall, London, UK, 73 pp.

Richards, P.W., 1996. The Tropical Rain Forest, 2nd Edn. Cambridge University Press, 575 pp.

Riddoch, J.C., Fasehun, F.E., Riddoch, B., Lapido, D.O., 1991. Photosynthesis and successional status of seedlings in a Tropical Semi-Deciduous Rain Forest in Nigeria. J. Ecol. 79, 491–503.

Steel, R.G.D., Torrie, J.H., 1980. Principles and Procedures of Statistics. Second Edition. McGraw-Hill, New York, USA, 633 pp.

Swaine, M.D., Hall, J.B., 1988. The mosaic theory of forest regeneration and the determination of forest composition in Ghana. J. Trop. Ecol. 4, 253–269.

Swaine, M.D., Agyeman, V.K., Kyere, B., Orgle, T.K., Thomson, J., Veenendaal, E.M., 1997. Ecology of Forest Trees in Ghana. ODA Forestry Series No. 7, London, UK, 76 pp.

Taylor, C.J., 1960. Senecology and Silviculture in Ghana. Thomas Nelson and Sons Ltd., Edinburgh, UK, 418 pp.

Taylor, C.J., 1962. Tropical Forestry with Particular Reference to West Africa. Oxford University Press, New York, 163 pp.

Timber Export Development Board (TEDB), 1997. Ghana Hardwoods Trade Directory. 2nd Edn. TEDB, Unit 4, Granard Business Center, London, UK, 64 pp.