Initial Growth of Agroforestry Trees in Wetland Rice Fields, as Influenced by Top and Root Pruning to Regulate Crop Impact

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Abstract

Trees of 21 species were grown in wetland rice field under farmers' management, including varying degrees of annual root pruning and top pruning to regulate impact on understory crops. Tree height and girth were measured and pruning intensity was observed twice annually. Rooting intensity of a few trees annually was observed by trenching. The fastest-growing trees (mean annual increments in m^3/ha at 100 trees/ha and specified ages in brackets) were *Gmelina arborea* (10.5 at 6 yrs), *Eucalyptus camaldulensis* (3.5 at 9 yrs), *Faidherbia albida* (1.6 at 9 yrs), *Albizia saman* (1.2 at 8 yrs), *Melia azaderach* (0.9 at 9 yrs), *Cassia siamea* (0.9 at 9 yrs), and *Acacia mangium* (0.8 at 7 yrs). Growth of most tree species was slower on poor soil types and where vulnerable to flooding. On such sites, *E. camaldulensis*, *A. mangium*, and *Terminalia arjuna* were less affected than other species. Tree management by top and root pruning reduced overall growth by up to 19% for gbh and 41% for volume, depending on intensity of pruning. Stand volume and mean annual increment on an area basis in crop fields of average site quality were broadly equivalent to forest plantations on average or poor sites.

সারসংক্ষেপ

বিভিন্ন পরিমাণে শিকড় এবং ডালপালা প্রুনিং এর মাধ্যমে গাছের নিচে আবাদকৃত ফসলের বৃদ্ধির বিষয়টি নিয়ন্ত্রণ করতে কৃষকদের ব্যবস্থাধীনে আর্দ্র ধান ক্ষেতে ২১ প্রজাতির বৃক্ষ লাগানো হয়েছিল। গাছের উচ্চতা ও বেড়ের পরিমাপ এবং প্রুনিং এর মাত্রা বছরে দু'বার রেকর্ড করা হয়। পরিখা খননের মাধ্যমে কয়েকটি গাছের বার্ষিক শিকড় গজানোর মাত্রা লক্ষ্য করা হয়। সবচেয়ে দ্রুত-বর্ধনশীল গাছগুলো (বন্ধনীর মধ্যে নির্দিষ্ট বয়সে হেক্টর প্রতি ১০০ গাছের বার্ষিক গড় বৃদ্ধি ঘন মিঃ/হেঃ) ছিল *Gmelina arborea* (১০.৫, ৬ বছরে), *Eucalyptus camaldulensis* (৩.৫, ৯ বছরে), *Faidherbia albida* (১.৬, ৯ বছরে), *Albizia saman* (১.২, ৮ বছরে), *Melia azaderach* (০.৯, ৯ বছরে), *Cassia siamea* (০.৯, ৯ বছরে) এবং *Acacia mangium* (০.৮, ৭ বছরে)। যে জায়গা বন্যাপ্রবণ এবং যে জায়গার মাটিতে পুষ্টিহীনতা বিদ্যমান সেখানে বেশিরভাগ গাছের বৃদ্ধি অপেক্ষাকৃত ধীরগতিসম্পন্ন। এ ধরনের জায়গাতে *E. camaldulensis*, *A. mangium* ও *Terminalia arjuna* অন্যান্য প্রজাতির চেয়ে অপেক্ষাকৃত কম ক্ষতিগ্রস্ত হয়েছিল। গাছের বৃদ্ধি নিয়ন্ত্রণের ক্ষেত্রে শিকড় ও ডালপালা প্রুনিং এর মাধ্যমে গাছের গড় বৃদ্ধি ১৯% এবং ভল্যুম ৪১% কমে যায়। গড়পড়তা মানের ফসলের মাঠে গাছের ভল্যুম এবং বার্ষিক গড় বৃদ্ধির পরিমাণ গড়পড়তা মানের বা খারাপ মানের বনাঞ্চলের সাথে তুলনীয়।

Key words : Rice-based cropping systems, multipurpose trees

Introduction

Farming systems based on lowland rice *(Oryza sativa)* occupy 150 million ha in south and south-east Asia (FAO 1992). This is a region of scarcity and rising prices of tree products, especially for poor and risk-prone rural households (Alemayehu *et al.* 1992). The fact that forests once grew in rice-producing areas, and that traces of ancient forest residues can still be found (Grandstaff *et al.* 1986), suggests potential for systematic reintroduction of trees. Such potential appears particularly high where long dry periods and lack of irrigation limit paddy cultivation to one or two crops per year, which is the case in north-western Bangladesh. The potential for rice-based agroforestry systems there is worth investigation.

The swiss-sponsored "Village and Farm Forestry Project" (VFFP) was initiated in Bangladesh in 1986 to develop management systems for trees in paddy fields that will minimise potential for adverse crop impact and so encourage farmers to grow more trees of a wider species range in a systematic intensification of crop field agroforestry (Hocking and Islam 1994). A general description of the agroecological conditions is included in Hocking and Islam (1994). Tree management recommendations include wide spacing (8 m x 8 m) and regular pruning of roots and branches (Hocking and Islam 1995). The range of tree species planted has been broadened annually through farmer choice and introduction of selected exotics. Survival in paddy fields was reported in Hocking and Islam (1995). The present paper reports growth at ages of five to nine years. Tree impact on yield of undercrops is reported separately (Hocking and Islam 1998).

The literature contains considerable data on growth of trees in rice, wheat, or rice-wheat rotations. For example, Misra *et al.* (1994) report on growth of *Eucalyptus* hybrid *(E. tereticornis)*, *Bombax ceiba* (syn : *B. malabaricum)*, *Tectona grandis*, and *Populus deltoides* at 4 m x 4 m spacing on an irrigated mollisol in Uttar Pradesh, India. Height and diameter growth after six years was best for *P. deltoides* and *E. tereticornis.* Also in India, Tewari *et al.* (1992) report on height and diameter growth for irrigated *Dalbergia sissoo* at 5 m x 5 m. Growth of rubber trees *(Hevea brasiliensis)* was reduced when intercropped with food crops (including paddy rice), but by less than when intercropped with a forage legume (*Pueraria* sp.) (Keli Zagbahi *et al.* 1990). This difference was arrtibuted to the effect of improved soil fertility due to additions of fertilizers for the food crops.

Although in general, removal of any plant parts reduces overall growth (e.g. Moeller 1960), there is little information in the literature about the precise effects of root and branch pruning on tree growth for the species under trial in the present study. It was found for a number of species including *Eucalyptus* spp. that top and root pruning in the nursery produced sturdier, thicker stems than untreated controls, without adverse effects on growth and development (Karschon 1960, Harris and Davis 1971). Miah (1993) reports on the effect of branch pruning of trees on the yields of associated field crops grown underneath, without giving data on the effect on growth of the trees.

In assessing performance of farm trees, the ultimate aim is to determine the trees' yield of useful products of all kinds. However, the wide range of tree species in this study and the variety of useful products makes it impractical to monitor the full range of products for all trees every year. The most valuable product common to most of the tree species grown in crop fields, and for most farmers, is wood. Therefore, the main objectives of the research now reported were : (a) to identify the factors affecting tree growth in wetland rice fields on north-western Bangladesh, (b) to provide farmers with information concerning growth rates of trees capable of being grown with rice, and (c) to provide quantitative information to the policy debate on suitability of agroforestry technologies in rice-based farming systems.

Materials and methods

The research was done entirely under farmer management on their own farms in north-western Bangladesh. A general description of the agroecological and socioeconomic conditions, location map, planting layout, and tree management recommendations are included in Hocking and Islam 1994).

Each participating farmer planted at least three tree species in random sequences at a minimum tree-to-tree spacing of 8 m in crop fields or on the margins. Planting at least three tree species is recommended in order to avoid the potential for single-species market glut as observed in India for *Eucalyptus* sp. (Saxena 1991). Tree and crop management was the owner's responsibility throughout. Farmers were encouraged to prune the roots of the trees regularly to crop rooting depth (25 cm) in a circle about 30 cm radius from the tree trunk, and to prune branches annually to about one third of tree height or whenever they felt there was an adverse shading effect on their field crops. The actual intensity of tree management was highly variable.

Trees were selected for monitoring of growth by sequential stratified sampling, excluding individuals that were obviously abnormal due to such factors as early damage or distorted growth, and limiting sample numbers on any one farm to not more than one tree per species. Primary selection strata were species, agroecological zone (AEZ) and soil type. Soil types and AEZ's were interrelated and not all possible combinations were represented in the final sample. For each combination of these factors that existed there were at least 25 trees, except for three tree species in some locations for which there were somewhat fewer.

Data collection was done by trained field staff of partner organizations of the VFFP with the help of the farmer owners. Growth of the trees was measured twice annually in April-May and October, but not all partners achieved this for all trees. Data are included up to October 1995, for all trees that were more than four years old at that date.

Tree heights were estimated with a "Suunto" optical hypsometer, with height defined as the distance from the ground to the highest growing point (Stewart and Salazar 1992). Crop effects are often related to crown diameter of the trees, which is itself correlated with trunk diameter or girth (Dawkins 1963). Girths were measured over bark at a height of 1.3 m above ground. Intensity of branch pruning was estimated visually on a crude 0-4 scale in which 0 = unpruned and 4 = pollarded, usually at about 2.5 m height ; 1, 2, and 3 = branches pruned to 1/3 of canopy, 2/3 of canopy and all branches somewhat pruned.

All farmers pruned tree roots in the first year after planting, and root pruning to plough depth became a routine during cultivation, usually three times per year. Intensive and deliberate pruning of tree roots as a separate operation tended to be neglected after the second or third year.

Non-destructive observations of tree roots were made annually on a small sub-sample of trees. Two circular trenches about 30 cm wide and deep were carefully dug by hand at 1 m and 2 m radius from the tree trunk, with minimal disturbance of tree roots. Tree roots occurring in each trench were counted by diameter ranges < 2 cm, 2.5 cm, and > 5 cm. The excavated soil was then returned to the trenches and gently compacted to its original position. Clearly, this method would not distinguish between "natural" root distribution and regenerated pruned roots ; it determines what roots are present, whatever the reason for the distribution. Hence the parameter is called "rooting intensity", rather than a term that would imply a response variable controlled by degree of pruning alone.

The main response variables were thus tree height and tree girth at breast height (gbh); and computed tree volume (see detail below). The independent variables were : tree species

(21 species of different ages and sizes), tree canopy management (whether pruned or lopped, or not ; if pruned, the intensity), tree rooting intensity (counts by size and distance), tree location (within the field ; on the field margin), age of tree at date of observation (in years), years (seasonal observations were made in each of four years from 1991 to 1995 inclusive), agroecological zone (AEZ) (eight zones of UNDP/FAO (1988) were covered at nine sites in five districts namely Dinajpur, Bogra, Natore, Rajshahi and Kushtia as in Hocking *et al.* 1997), soil type (five soil types were distinguished), land elevation (high, medium-high or medium-low with respect to vulnerability to flooding), associated field crop (long duration sugar cane, 4 months or less duration all others), irrigation (available at time of planting; not available), age of tree when irrigation became available, and NGO (the field-level cooperating partners to the VFFP).

For soil type, AEZ, and NGO, not all levels existed independently because of "aliasing" ; some AEZ's and some soil types were represented only in the area of operations of a particular NGO.

Routine procedures were used for range and consistency checks, and standard tests were applied for extreme outliers. Data were processed using the advanced statistical package, "GENSTAT", Release 3.2.

Owing to varying representation of independent variables and varying numbers of replications, the data were non-orthogonal ; that is, the numbers of observations for certain factor combinations were uneven. This was handled by using the General Linear Model for analysis of variance. Normality of the data was improved by the log transformation of volume, so logvolume was used in the final model. Model building was done as follows. An initial series of analyses established which factors were most important (alone and serially) to the response variable, and these were included in the main model. Minor factors were then tested individually and those significant at the 5% of probability were included. Data for some factor combinations were available in relatively small numbers of replications, so their significances were tested separately using the same model with sequential sub-sets of the data.

Data are reported here for 5,482 observations of height and girth at breast height (gbh) of 19 tree species, planted during the period 1987-1990. The numbers of observations by species and ages are shown in Table 1. The data sub-set for trees with top pruning consisted of 987 records and for tree rooting intensity consisted of 359 records, both well-distributed across tree species. The data sub-set for combined effects of intensity of branch pruning and rooting intensity of the trees consisted of 78 records with patchy distribution across tree species.

Tree volume is commonly expressed as the volume of a regular cylinder modified by species-and-site-specific form factors that account for variations in branchiness and log taper. No form factors are available for any tree species growing under these conditions and under farmer management. Values for form factors for plantation trees normally lie within the range of 0.25 to 0.50 (Philip 1994). The simplified conical volumes used here assume a uniform factor of 0.33. Use of a uniform form factor for tree volume of all species is a temporary expedient that ignores variation due to differences in branchiness and taper. The volumes computed here are for comparison across levels of other independent site variables. They provide a crude guide to growth rates of species within the limits of variation in form and they set some boundaries upon absolute growth, which go some way towards meeting the objectives. Open-grown, isolated trees such as in the present programme tend to be shorter for given girths and more branchy than plantation trees thus tending towards higher form factors, so these values are probably conservative.

Results and discussion

Overall tree growth by species

Tree volumes (estimated using form factor of 0.33) by species and ages are presented in Table 1. Mean gbh by age and species and controlling for all other factors are presented in Fig. 1, grouped into faster, average, and slower-growing sets relative to a grand mean for all species reported here. Relatively slow growth of *L. leucocephala* is because almost all trees of this species were pollarded and regularly lopped for their fodder production. Slow growth of the popular *T. arjuna* is probably because the bark of this tree is always stripped for medicinal purposes.

Comparable growth data for single-species forest plantations on a range of site qualities in Bangladesh are available for *Acacia auriculiformis*, *A. mangium*, *Cassia siamea*, *E. camaldulensis* and *Gmelina arborea* (Latif 1992). Mean diameter growth of trees (including pruned trees) in crop fields of average site quality was broadly equivalent to that of tree plantations on superior sites (Table 2). Mean height growth, stand volume and mean annual increments on an area basis in crop fields of average site quality were broadly equivalent to forest plantations on average or poor sites.

The superior diameter growth of trees in crop fields over plantations is attributable to the greater space available to each tree, and possibly also partly to the higher soil fertility and irrigation. In a related study of tree growth in widely-spaced alleys, Dagar *et al.* (1995) found that all tree species benefited by having crops in the interspace because additional water was made available to them through irrigation.

Forest plantation growth data are normally also given as volumes per hectare by site quality and age. The data given here are on a per-tree basis. Volume per hectare can be computed by assuming a certain number of trees/ha. For the VFFP, the minimum spacing of 8 m x 8 m implies a planting density of 156/ha; allowing for average survival after replanting of about 65%, expected net tree density is about 100 trees/ha. On this basis, the area-basis volume production and mean annual increments of trees grown in crop fields as reported here were roughly comparable to the volume production of pure plantations on low site qualities, except for *A. mangium* which was somewhat less.

Factors affecting tree growth in paddy fields

The principal factors found to be significant and included in the tree growth model were (species) + (age) + (year of planting) + (agroecological zone) + (soil type)+(elevation) + (age x species). This model explained 80% of the variance in logvolume. Table 3 indicates the significance levels for the choice of model terms and the accumulated analysis of variance .

Soil texture and agroecological zone

Controlling for all other factors, trees of most species grew best on deep, fertile silty soils, followed closely by growth on sandy clay and sandy loam (Table 4). Diameter growth of trees in crop fields of the better soils was superior to growth of plantations on the best site qualities. Growth was almost 25% less on infertile red soils and on poorly-drained loams. There were important differences among the tree species in growth on different soils. On the infertile red soils of the *barind* tract, *E. camaldulensis*, *D. sissoo*, *G. arborea* grew much better than the other species and *G. arborea* grew better there than on any other soil. On the infertile, poorly drained loams, *E. camaldulensis*, *T. arjuna* and *A. mangium* grew relatively better than other species. Correspondingly, these five species grew relatively less well on the deep, fertile soils that favoured most other species ; although all of them except *T. arjuna* still grew faster than most other species even on sandy clay or silt.

Elevation

The best growth of most tree species was observed on relatively high sites that were free from surface water for most of the year, where

Table 1. Mean volumes per tree (m^3/tree x 100; or m^3/ha) by species and ages, of trees in paddy fields in northwestern Bangladesh, 1987-1996.

Tree species		Ages (years)							
		2	3	4	5	6	7	8	9
Acacia auriculiformis	volume	*	0.1	0.7	1.7	3.3	5.9	*	*
	std.dev.	*	0.3	0.5	1.0	2.7	3.9	*	*
	N	82	60	68	72	59	51	0	0
Acacia catechu	volume	*	0.3	1.0	1.9	*	*	*	*
	std.dev.	*	0.2	0.4	1.5	*	*	*	*
	N	0	4	8	4	0	0	0	0
Acacia mangium	volume	1.1	3.7	3.7	4.5	4.9	5.7	*	*
	std.dev.	0.6	2.3	2.3	4.4	2.8	3.8	*	*
	N	57	34	36	22	8	13	0	0
Acacia nilotica	volume	0.1	0.3	0.7	1.3	2.1	2.5	3.5	3.8
	std.dev.	0.0	0.5	0.8	1.3	1.8	2.1	2.7	2.8
	N	52	99	128	158	143	101	65	45
Albizia lebbeck	volume	0.1	0.8	*	1.9	*	*	*	*
	std.dev.	0.1	0.6	*	1.2	*	*	*	*
	N	24	18	0	5	0	0	0	0
Albizia procera	volume	0.1	0.4	1.3	3.0	*	*	*	*
	ste.dev.	0.0	0.4	1.1	2.3	*	*	*	*
	N	22	15	26	14	0	0	0	0
Albizia saman	volume	0.1	0.3	2.3	5.5	7.3	8.8	9.4	*
	std.dev.	0.1	0.2	1.9	4.9	6.2	7.9	4.0	*
	N	71	46	92	63	40	7	40	0
Anthocephalus cadamba	volume	0.1	0.3	2.1	5.2	10.6	*	*	*
	std.dev.	0.0	0.3	2.3	5.5	8.5	*	*	*
	N	5	13	16	17	15	0	0	0
Azadirachta indica	volume	*	0.1	0.2	0.4	0.8	1.2	*	*
	std.dev.	*	0.2	0.1	0.7	0.7	0.7	*	*
	N	37	46	22	16	23	16	0	0
Cassia siamea	volume	*	*	*	1.4	2.5	4.1	6.0	8.2
	std.dev.	*	*	*	1.2	1.5	2.6	2.8	3.4
	N	0	0	0	4	14	22	19	19
Dalbergia sissoo	volume	0.2	0.6	1.4	3.7	4.2	7.4	*	*
	std.dev.	0.3	0.8	1.1	2.5	3.7	6.1	*	*
	N	163	126	132	60	22	3	0	0
Eucalyptus camaldulensis	volume	0.5	1.5	3.7	7.6	9.1	11.6	21.2	27.5
	std.dev.	0.5	1.3	3.3	5.7	6.2	6.8	10.8	14.5
	N	124	170	189	177	182	146	62	42
Faidherbia albida	volume	0.1	0.6	1.5	2.8	3.6	5.6	10.3	14.8
	std.dev.	0.1	0.7	1.5	2.4	2.2	4.6	10.8	9.6
	N	9	33	35	19	10	6	10	19
Ficus bengalensis	volume	*	0.5	0.8	*	*	*	*	*
	std.dev.	*	0.3	0.6	*	*	*	*	*
	N	0	22	11	0	0	0	0	0
Ficus religiosa	volume	*	0.7	1.9	*	*	*	*	*
	std.dev.	*	0.2	0.8	*	*	*	*	*
	N	0	14	7	0	0	0	0	0
Gmelina arborea	volume	0.1	0.6	2.1	4.8	6.3	*	*	*
	std.dev.	0.1	0.5	1.9	2.7	3.3	*	*	*
	N	22	28	42	41	12	0	14	0
Leucaena leucocephala	volume	*	*	0.3	1.7	2.6	4.1	6.4	6.3
	std.dev.	*	*	0.0	2.8	3.6	2.9	3.0	6.3
	N	0	0	2	6	9	32	30	9
Melia azaderach	volume	0.4	1.0	2.3	5.0	6.0	6.8	7.5	8.0
	std.dev.	0.6	0.9	1.9	3.4	6.1	3.9	3.6	5.2
	N	91	80	111	57	25	14	35	28
Swietenia mahagoni	volume	0.1	0.2	0.3	0.5	*	*	*	*
	std.dev.	0.1	0.1	0.1	0.0	*	*	*	*
	N	20	24	12	3	0	0	0	0
Terminalia arjuna	volume	*	0.2	0.6	1.6	2.9	3.6	*	*
	std.dev.	*	0.2	0.8	1.6	2.8	1.6	*	*
	N	121	117	87	48	29	12	0	0
Terminalia bellirica	volume	*	*	0.1	0.3	0.9	*	*	*
	std.dev.	*	*	0.1	0.2	0.8	*	*	*
	N	5	5	7	9	3	0	0	0

Note : N = Numbers of observations, * = No data, or value is less than 0.05.

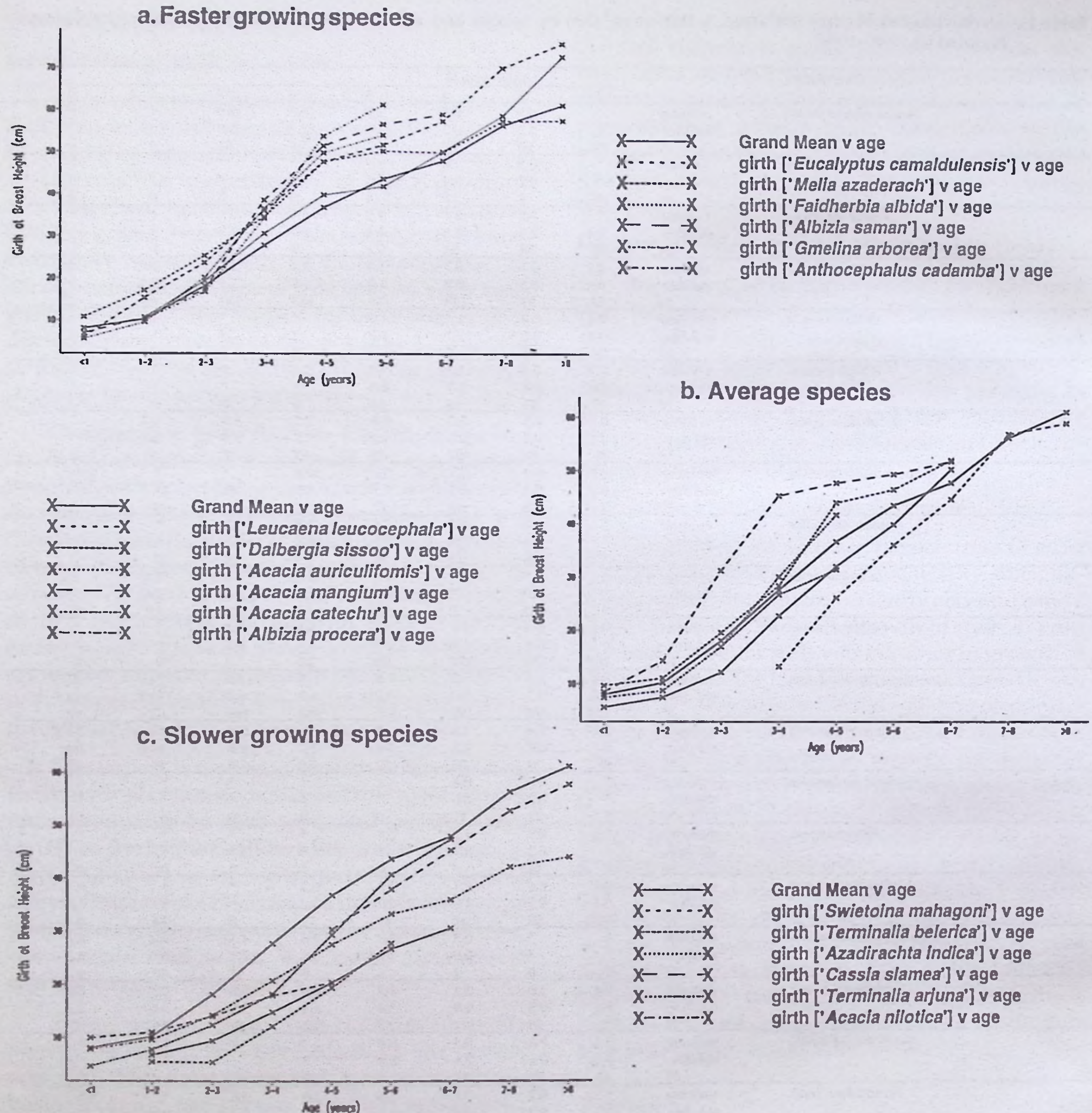

Figure 1. Growth (girths at breast height for different ages) of trees in paddy fields in north-western Bangladesh, 1987-1995. a. Faster-growing species, b. Average species, c. Slower-growing species. Grand mean of all species is shown on all three graphs.

most tree species grew almost 50% faster than on lower sites. Growth of *E. camaldulensis* was less affected by site elevation than most other species. *T. arjuna* and *A. mangium* grew better on sites of medium elevation that were waterlogged during the monsoon. Growth of *L. leucocephala* was significantly worse on lower sites relative to its growth on high sites than that of the other tree species.

Year of planting

Planting year made a large difference to growth. Controlling for all other factors including age, trees planted in the good rainfall years of 1990 and 1992 grew nearly twice as much in their first three years as trees planted in the flood years of 1987 and 1988. This effect was most pronounced in the low-lying AEZ's and was absent from the higher ones that largely escaped flooding even in bad years. Although important, this information is not of much help to farmers who are unable to predict when a flood year will occur. But, combined with the information about the influence of the site elevation, it strengthens the recommendation to select higher sites whenever possible. If the farmer owns no high land, then species that are better at tolerating waterlogging, such as *A. mangium* or *T. arjuna* should be chosen.

Availability of irrigation at planting date

Controlling for all other factors, trees that had irrigation available in the planting year grew 17% more than those without. Most tree species grew about twice as fast when under irrigation from planting date. *Azadirachta indica* and *Terminalia arjuna*, however, appeared to grow more slowly when under irrigation from planting date.

Seedling height at planting

There were large differences among and within the tree species in initial height at planting, and these differences carried through into size differences in the first 2 to 3 years. But after the third year, differences in size due to initial height were not detectable. Large initial height was previously found to be important for initial survival of some species (Hocking and Islam 1995).

Location in field and species of undercrops

The location of a tree, whether on the field margin or central in the field, had no influence on growth although it was very important to initial survival (Hocking and Islam 1995). It was not possible to distinguish growth influences among the wide variety of undercrops, probably because of similarities in undercrop stature and short duration in the field. Only sugar cane was present in the same fields consistently over several years. Controlling for other factors, there was no difference in growth rates of any tree species when associated with sugar cane compared to growth with all the other undercrops.

Influences of top pruning and rooting intensity

The smaller number of records with these factors resulted in fewer main effects being significant.

Controlling for all other factors, lopping of 1/3, 2/3 and all branches reduced gbh by 2%, 17% and 19% respectively. This is consistent with many other studies (e.g. Moeller 1960).

Almost all individual trees of *L. leucocephala* had been pollarded, so the growth without pruning, or with lesser degrees of pruning, could not be assessed. None of the other tree species had been pollarded.

In general, the larger and faster-growing tree species tended to have more and bigger roots present in the sampling trenches. Notable exceptions were *Faidherbia albida* and *Melia azaderach*, which although fast-growing had few lateral roots. The numbers of tree roots observed in the circular trenches were generally fewer than expected. It is concluded that most farmers kept the rooting zone of the undercrops free from tree roots through regular cultivation. Where numerous roots were present, it is inferred that the farmer ploughed to a shallower depth, or ploughed less often, than most farmers. The mean numbers of roots observed for each tree species are shown in Table 5. Differences among tree species were not statistically significant overall.

Table 2. Comparisons between growth of VFFP trees planted in paddy fields of northwestern Bangladesh, 1987-1996 (present data) and reported growth of plantation-grown trees on sites of different qualities 1 (after Latif 1992).

Tree species	Age (yr)	Plantation-grown on site qualities						Field-grown VFFP trees
		6	9	12	15	18	21	
A. Mean stand heights (m) for :								
Cassia siamea	9	5.0	6.9	9.4	13.0	17.8		8.9
Acacia mangium	7	5.2	8.1	11.0	13.9	16.9		6.8
Gmelina arborea	6			7.8	9.5	11.1		7.4
E. camaldulensis	9	5.7	8.2	10.7	13.1	15.5	17.9	16.5
		Site qualities						
		8	12	16	20			
A. auriculiformis		5.7	8.3	10.8	13.2			7.6
B. Mean stand diameter (cm) for :								
Cassia siamea	9	6.0	9.4	12.9	16.6	20.3		18.5
Acacia mangium	7	11.3	12.8	14.5	16.4	18.6		16.5
Gmelina arborea	6			9.9	11.4	12.6		17.1
E. camaldulensis	9	3.9	6.1	8.3	10.6	12.9	15.3	24.0
		Site qualities						
		8	12	16	20			
A. auriculiformis		4.3	7.6	10.4	12.7			15.9
C. Mean total stand volumes (m^3/ha) over bark for :								
Cassia siamea	9	22.1	41.7	66.0	98.7			8.2
Acacia mangium	7	57.7	73.6	94.0	119.9	153.1		5.7
Gmelina arborea	6		29.2	49.3	68.5	86.3		6.3
E. camaldulensis	9	4.6	18.6	36.4	54.5	71.8	88.2	27.5
		Site qualities						
	4	8	12	16	20			
A. auriculiformis	7	9.9	31.9	57.2	81.4			5.9
D. Mean annual increments (m^3/ha) over bark for :								
Cassia siamea	9	2.4	4.6	7.3	10.9			0.9
Acacia mangium	7	8.2	10.5	13.3	17.1	21.9		0.8
Gmelina arborea	6		4.8	8.2	11.4	14.4		10.5
E. camaldulensis	9	0.5	2.6	4.0	6.5	8.0	9.8	3.5
		Site qualities						
	4	8	12	16	20			
A. auriculiformis	7	1.4	4.5	8.1	11.6		0.9	

Note : Field-grown trees at density of 100/ha. Site quality is described by the dominant height achieved by the species.

Table 3. Factors influencing the growth (logvolume) of trees planted in paddy fields of northwestern Bangladesh, 1987-1996, showing statistical significance.

Factors	Sole factor	After species	When added to model	
Main effects :				
Tree species	***	included	model term	
Tree age	***	***	model term	
Year of planting	***	***	model term	
Agroecological zone (AEZ)	***	**	model term	
Soil texture	***	***	model term	
Elevation	***	***	model term	
Initial irrigation	***	**	**	
NGO	***	***	*	
Undercrop species	NS	NS	NS	
Tree location (field margin or centre)	NS	NS	NS	
Two -way interactions :				
Species x year planted			*	
Species x AEZ			*	
Species x soil texture			*	
Species x elevation			*	
Species x age			NS	
Age x year of planting			NS	
Tree sp. x undercrop sp.			NS	
AEZ x year of planting			***	
Factors analysed on reduced data set :				(N)
Initial height of tree	***	*	*	1194
Date irrigation began	**	**	*	991
Pruning intensity	*	NS	*	987
Rooting intensity	**	**	*	360
Reduced data set two-way interactions :				
Species x pruning			*	
Species x initial height			***	
Species x date of irrigation			*	
Species x rooting			NS	
Pruning x rooting			NS	

Note : One, two or three asterisks indicate probability at the 5%, 1% and 0.1% levels ; NS means non-significant.

Accumulated analysis of variance from regression analysis of tree growth in paddy field in northwestern Bangladesh, 1987-1996.

Change	d.f	s.s	m.s	v.r	F pr.
+ species	20	918.0373	45.9019	305.31	<.001
+ year	6	581.3030	96.8838	644.42	<.001
+ age	1	963.7834	963.7834	6410.57	<.001
+ age 2	1	83.6990	83.6990	556.72	<.001
+ AEZ	7	86.1629	12.3090	81.87	<.001
+ soil type	4	27.9593	6.9898	46.49	<.001
+ elevation	2	1.2937	0.6469	4.30	0.014
+ NGO	4	25.3933	6.3483	42.23	<.001
+ time*species	20	23.1686	1.1584	7.71	<.001
Residual	4774	717.7364	0.1503		
Total	4839	3428.5370	0.7085		

Table 4. Predicted growth rates (m^3 x 100) of trees on different soil textures in paddy fields of north-western Bangladesh, 1987-1996, controlling for all other factors. Data include all trees, irrspective of degree of root or top pruning

Tree species	Soil texture				
	Loam	Red	Sandy loam	Sandy clay	Silt
Acacia auriculiformis	0.60	0.81	0.77	0.96	0.63
Acacia catechu	0.52	0.65	0.95	1.26	1.08
Acacia mangium	1.05	0.93	0.64	1.80	1.55
Acacia nilotica	0.40	0.44	0.75	0.64	1.15
Albizia lebbeck	0.48	0.60	0.88	1.16	1.00
Albizia procera	0.40	0.50	1.57	0.95	0.82
Albizia saman	0.55	0.69	1.00	1.33	1.14
Anthocephalus cadamba	0.55	0.69	1.00	1.32	1.14
Azadirachta indica	0.26	0.33	0.42	0.63	0.55
Cassia siamea	0.55	0.70	1.01	1.34	1.15
Dalbergia sissoo	0.62	1.33	0.95	1.16	1.00
Eucalyptus camaldulensis	0.88	1.11	1.60	2.13	1.83
Faidherbia albida	0.59	0.75	1.08	1.44	1.24
Ficus bengalensis	0.36	0.45	0.65	0.86	0.74
Ficus religiosa	0,55	0.69	1.00	1.32	1.14
Gmelina arborea	0.48	1.65	1.11	1.20	1.01
Leucaena leucocephala	0.49	0.62	0.89	1.10	1.02
Melia azaderach	0.61	0.86	1.30	1.48	1.27
Swietenia mahagoni	0.34	0.43	0.62	0.82	0.71
Terminalia arjuna	0.74	0.53	0.59	0.94	0.81
Terminalia bellirica	0.28	0.28	0.40	0.53	0.46
All species	0.72	0.73	0.98	1.06	1.10

Table 5. Mean rooting intensity of tree species grown in paddy fields of northwestern Bangladesh, 1987-1995.

Species	Mean	N
Acacia auriculiformis	7	20
Acacia catechu	6	4
Acacia mangium	14	12
Acacia nilotica	6	61
Albizia procera	19	4
Albizia saman	4	18
Anthocephalus cadamba	5	12
Azadirachta indica	6	11
Cassia siamea	16	23
Dalbergia sissoo	5	30
Eucalyptus camaldulensis	11	67
Faidherbia albida	4	7
Gmelina arborea	23	12
Leucaena leucocephala	15	12
Melia azaderach	4	40
Swietenia mahagoni	8	8
Terminalia arjuna	21	15
Terminalia bellirica	4	2
Total		359

Note : Three tree species planted later, and so of smaller size range, are not represented in this Table.

Controlling for all other factors, the numbers of tree roots in the top 25 cm of soil that extended to 1 m or more from the tree had a statistically significant log-linear relationship to ghb and to volume ; the relation to tree height was not significant. Trees with 128, 64, or 32 such roots has gbh's that were 19%, 11%, or 5% greater than trees with only 2 or fewer such roots. For estimated volumes the respective differences were 41%, 19%, and 9%. There were too few observations to enable differences among tree species to be significant statistically.

These observations could not distinguish between tree species that have a natural tendency towards tap-rooting and those with a tendency towards lateral rooting but whose roots were well-pruned, so the conclusions have to be treated with some caution. But it is clear that leaving the tree roots to grow was significantly beneficial to tree growth, at least for those species whose natural habit is widespread lateral rooting.

Conclusions

All the tree species included showed satisfactory growth in paddy field conditions. The indigenous species *G. arborea*, *Albizia saman*, and *M. azaderach*, and the exotic species, *E. camaldulensis*, *F. albida*, and *Acacia mangium* were the fastest growing. Trees generally did better on higher ground that was flooded less often, except for *A. mangium* and *T. arjuna* which did better on medium-high fields.

Compared to available data for the same species in forest plantations and over the 5-9 years of the experiment, mean girths for trees in paddy fields of average quality was equal or greater than for trees in the best forest plantation sites. Mean tree heights tended to be similar to those of plantations on poor site quality. Computed mean volumes and mean annual increments of the faster-growing species at 100 trees/ha in crop fields were broadly similar to those of dense pure forest plantations on low site quality, except for *A. mangium*.

Management by pruning of tops and of roots slowed growth significantly, but mean girth for age of top and root-pruned trees were still equivalent to the means for plantation trees on average sites. These findings should be treated with caution as they may not apply to trees with naturally tap-rooting habit whose growth may not be affected by root pruning. The corresponding differences in interactions with the crops grown underneath the trees form the focus of the next paper in this series (Hocking and Islam 1998).

These findings are encouraging for farmers practising crop field agroforestry. Several useful observations are made concerning suitability of tree species to sites.

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