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Chapter 9

Nursery and field establishment

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1. INTRODUCTION

Nurseries are established and maintained for raising various materials for planting. These include seedling stumps, budded stumps and advanced planting materials like polybag plants, stumped buddings and soil core plants. Mother plants or source bushes for the multiplication of budwood are also grown in nurseries. The practice of raising plants is easier and cheaper in nurseries than in the main field. Moreover, nurseries offer an opportunity for selection of vigorous and uniform plants. The requirement of area under different types of nurseries for raising materials for planting 100 ha plantation is given in Table 1.

Table 1. Requirement of area for various types of nurseries for producing planting materials necessary for 100 ha

Planting material to be produced	Spacing (cm)	Density (per ha)		No. of plants* required for 1 ha of main field	Area required (ha)	
		Initial	Final		Effective	Gross**
Budded stumps	30 x 30	111110	74074	500	0.675	0.750
Seedling stumps	30 x 30	111110	88000	550	0.625	0.695
Stumped buddings, Maxi	90 x 90	12350	9880	500	5.000	5.550
Stumped buddings, Mini	60 x 60	27775	22220	500	2.000	2.500
Polybag 2 - 3 whorls	–	–	25000	500	2.000	2.500
Polybag 6 - 7 whorls	–	–	18000	500	2.750	3.400

* Includes the number of plants required for vacancy filling during the first year

** Includes additional space required for footpaths, drains, *etc.*

2. NURSERY ESTABLISHMENT

Planting materials for establishing rubber plantations are generated in ground and polybag nurseries.

2.1 Ground nursery

Ground nurseries are established for the production of budded stumps, stumped buddings and budwood.

2.1.1 Selection of site

The site selected for a ground nursery should have good accessibility for supervision and transport of materials. If the purpose of the nursery is to raise materials for planting a large area in the estate, it may preferably be located at a suitable site within this area itself. A good soil depth of at least 75 cm is essential. Loamy soils are ideal for ground nurseries. Extremely sandy soils are not suitable since leaching of plant nutrients is faster. Retention of moisture is poor in such soils, necessitating frequent watering during summer months. Soils containing too much of clay are also unsuitable mainly because of poor drainage. A well-drained, level area is ideal for a nursery since the various operations will be easy and cheap in such sites. However, undulating lands are also suitable if adequate soil conservation measures are adopted. Contour terracing is done where the slope is in excess of two per cent. Waterlogged areas should be avoided. Water table should be sufficiently low to allow sufficient depth in the soil for root development. Shade free areas are preferred. Land with a history of intensive cropping needs proper build up of the nutrient status to the satisfactory level.

2.1.2 Preparation of land and nursery beds

For the preparation of a ground nursery, the soil is first dug to a depth of 60 to 75 cm. Stones, stumps, roots, *etc.* present in the soil are removed and the soil is brought to a fine tilth. Beds should be 90 to 120 cm wide and of convenient length. In level lands, raised beds are made with footpaths of about 45 cm width between the beds, and in undulating lands beds are prepared along the contours, one below the other. At the time of preparation of nursery beds, 25 kg of compost or well-rotten cattle manure and 3.5 kg of powdered rock phosphate (20 - 24% P_2O_5) are incorporated for every 100 m^2 of nursery bed (Rubber Board, 1999). When nurseries are established in newly cleared forest areas rich in organic matter, compost or cattle manure need not be applied during the first year. Similarly when the same area is repeatedly used as a nursery, rock phosphate need be applied only once in three years. Drainage and pathways should be provided appropriately.

2.1.3 Seed germination beds

Rubber seeds are first germinated in germination beds and then planted in nursery. A well-drained area with moderate shade is the ideal site for germination beds. Level beds of 90 cm width and convenient length are prepared with walking space in between. The beds should be raised 10 to 15 cm above the soil surface to avoid waterlogging. A free draining friable material, like river sand, spread above the bed to a thickness of 5 cm is used as the medium for germination. Rubber seeds are viable only for a short period and are put in germination beds as soon as obtained. Seeds are washed thoroughly (Plate 13. a) to remove charcoal and other packing debris and spread over the bed in a single layer touching one another and pressed gently into the sand (Dijkman, 1951). In order to prevent loss of too much moisture from the rooting medium, the beds are covered with a thin layer of gunny bag, coir matting or similar material (Plate 13. b). A high level of moisture is maintained in the bed by evenly sprinkling water early in the mornings and late in the evenings (Plate 13. c). Germination of the seeds starts within six to seven days after sowing (Plate 13. d). The beds should be inspected daily and the germinated seeds picked up and collected in a bucket containing water as soon as the radicle emerges for planting in the nursery beds or main field (Plate 13. e,f). If the picking of germinated seeds is delayed, chances of damage during handling will be greater. Seeds which do not germinate within two to three weeks should be discarded as they are likely to give rise to weak seedlings (Edgar, 1958).

2.1.4 Planting in nursery

For planting germinated seeds in the nursery beds, small holes enough to accommodate the seeds in a horizontal position and approximately 5 cm deep are made. The seeds are carefully placed in the holes with the radicle pointing downwards and covered with soil. The sprouted seeds should be planted when the young root is less than 2 cm long (Plate 13. g). The germinated seeds should be carefully handled, to prevent damage of the radicle. Spacing varies according to the type of planting material to be raised in the nursery. The common spacing adopted for raising seedling stumps is 30 x 30 cm. To produce green-budded stumps 23 x 23 cm spacing may be followed. For brown-budded stumps a spacing of 30 x 30 cm or staggered pairs of rows 60 cm apart and 23 cm between plants may be adopted (Edgar, 1958). A spacing of 60 x 60 cm, 90 x 30 cm, 90 x 60 cm or 90 x 90 cm is required to produce various kinds of stumped buddings. For raising soil core plants, a spacing of 35 x 35 cm, 38 x 30 cm or 60 x 60 cm may be followed (RRIM, 1976a). The spacing adopted for budwood nursery is 90 x 60 cm or 120 x 60 cm., wider spacing being between rows.

The rows are first marked on either end of each nursery bed using row markers. A long cord of coir rope, wire or country twine, with the planting distance along the row marked on it, is stretched tight along the length of the bed on the row markers on either end and germinated seeds are planted at each mark along the line (Plate 13. h). In budwood nursery, budded stumps are planted at the required spacing. Alternatively, seeds can be directly sown in the beds at the required spacing and budded *in situ*. After budtake they are cut back and the scion allowed to develop.

2.1.5 Nursery for seedlings and budded stumps

For rapid and economic production of good quality planting materials, very careful management of the nursery is necessary. In India, seed fall is generally from July to September and hence the period available for nursery growth is about 10 months. Therefore, efficient nursery management should aim at production of the maximum number of buddable or transplantable seedlings at the end of the 10 month period (Plate 14. a-c). Unhealthy and weak seedlings should be removed. The ideal time for this culling is three to four weeks after the first fertilizer application, by which time the vigorously growing and stunted plants can easily be distinguished (Abdulkalam and Punnoose, 1975).

The nursery beds should always be kept free of weeds. Generally three rounds of weeding are needed. In India, hand weeding is commonly practised (Plate 14. d). The first weeding is done just before application of the first dose of fertilizers and the second weeding before the second dose. The third round of weeding is done just before commencement of budding during May or June. The first round of manual weeding can be replaced with the application of pre-emergence herbicides (Mathew and Punnoose, 1975; Lakshmanan *et al.*, 1995a). After the final preparation of the nursery beds, diuron at the rate of 2 kg per ha in 700 L water is sprayed on the beds and germinated seeds planted five days later. However, planting germinated seeds on the same day of herbicide application does not result in any harmful effect (Lakshmanan and Punnoose, 1999) that there is only minimum disturbance to soil while planting the seeds. The beds can be kept free of weeds till the first round of fertilizer application (6 - 8 weeks) by adopting this method.

Mulching is an important operation to be followed in seedling nurseries before the beginning of the summer season and after the second round of fertilizer application. Natural materials such as tree loppings, dry leaves, undergrowth from forests, grass cuttings and cut cover crop material are commonly used after they are dried (Plate 14. e). Field trials indicate that 'African payal' (*Salvinia* sp.), a noxious weed found in the waterways, could also be used as mulch material in nurseries. Mulching is very effective in retaining soil moisture in the nursery beds during summer months. Apart from conserving soil moisture, it also lowers soil temperature, checks weed growth and adds organic matter to the soil in nurseries (Potty *et al.*, 1968; Lakshmanan *et al.*, 1995b). The mean percentage of available soil moisture measured at 15 cm depth in April was 88.6 in the mulched beds. The unmulched beds retained only 32.8 per cent available moisture which was insufficient for the proper growth of the plants (Abdulkalam and Punnoose, 1975). A single round of good mulching in December is adequate (Potty *et al.*, 1968). Black polythene sheets (Plate 14. f), properly anchored to the soil to prevent them from being blown away by wind, can also be used for mulching (Yeoh *et al.*, 1987; Lakshmanan *et al.*, 1995b). Spreading a thin layer of soil above the sheet is an effective way to achieve this.

Experiments conducted in five different regions to study the effect of nitrogen, phosphorus, potassium and magnesium on Tjir 1 seedlings in nurseries showed that the optimum fertilizer requirements could be fixed at 500, 250 and 100 kg per ha of N, P_2O_5 and K_2O respectively (Abdulkalam and Punnoose, 1975). Application of magnesium at the rate of 37.5 kg per ha was also found beneficial in places where the soil was deficient in magnesium. Field experiments indicate that ammonium sulphate, urea and ammonium sulphate nitrate were equally efficient in improving the growth of seedlings, but considering the unit costs, urea is the cheapest source of nitrogen (Punnoose *et al.*, 1976). Different sources of phosphatic fertilizers like rock phosphate, super phosphate, ammonium phosphate sulphate, basic slag and bonemeal had similar responses. However, based on unit cost and long residual effect, rock phosphate is recommended for nurseries. Lack of response of nursery seedlings to micronutrients has been reported (Potty *et al.*, 1976). Manuring may preferably be carried out after ascertaining the specific requirements of individual nurseries by soil analysis. If this is found difficult, the general fertilizer recommendation may be followed.

During the dry period which usually extends from December to April, the nurseries should be irrigated. In areas where distinct dry season is experienced, growth will not be satisfactory without watering (Webster, 1989). In a seedling nursery, when summer irrigation was given to supply 25 per cent of the estimated soil moisture deficit for a period of six months, there was an increase in dry matter production by 17 per cent over unirrigated control plants (Haridas, 1980). Field experiments have indicated that the efficiency of applied fertilizers increases with summer irrigation (Pushparajah and Haridas, 1977). In large nurseries, overhead sprinkler irrigation systems are ideal (Plate 14. g). Manual watering is convenient and cheap for small nurseries. The nursery beds should be mulched before commencement of irrigation. The quantity of water required varies with soil, climate and age of the plants. Daily watering is preferred during the initial weeks. Later, the frequency of irrigation can be reduced to once in two or three days. When the seedlings are sufficiently grown they are used for budding or directly used as seedling stumps.

2.1.6 Budwood nursery

Buds required for budgrafting are collected from budwood, obtained from plants raised specifically for this purpose. Budwood nurseries are of two types, namely brown budwood nursery (Plate 15. a) and green budwood (bud shoot) nursery (Plate 15. c). The former produces brown buds while the latter, green buds.

Site selected for establishing the budwood nursery is first cleaned and levelled. Terracing is done on slopes. Soil is first dug to a depth of 45 to 60 cm. Planting can be done with polybag plants, budded stumps or seed at stake followed by *in situ* budding. Spacing usually adopted for brown budwood nursery is 90 x 60 cm. For green bud shoot nursery the spacing is 1 x 1 m or 90 x 90 cm. Proper fertilizer application may be carried out to ensure good growth. Other agronomic practices such as irrigation, mulching, weeding, shading, protection against diseases and pests are followed in a similar manner as for seedling nursery. During the first year of planting only one shoot is allowed to grow. About 1 m of brown budwood can be obtained from this after one year. From the second year, two or three shoots are allowed to develop on a plant depending on the spacing adopted. To remove the leaves present in the brown-coloured budwood, the leaflets are first removed by clipping the tip of the leaf stalk. After about one week the leaf stalk dries and falls off. Budwood is then harvested by sawing off, leaving about 15 cm at the base (Plate 15. b). From this portion shoots develop in the subsequent season. Green bud shoot plants are shaped from brown budwood plants. For this, a well-established brown budwood plant is first cut back at a height of about 75 cm. A number of shoots emerge below the cut end. Among these, three to five most vigorous ones alone are retained and the rest removed. When these shoots have grown and produced brown wood to a length of about 5 cm they are pruned at the point where the brown colour ends so as to produce more branches. Two to three most vigorous branches are retained on each shoot and the others cut off. When these secondary branches develop brown colour at the basal 5 cm they are again pruned. New branches arise from these and give the budwood plant a bushy appearance. For producing green shoots, all the branches of a green bud shoot plant (also called source bush) are pruned. The new branches arising are harvested (Plate 15. d) when one whorl of leaves develops (Tinley, 1962; RRIM, 1964; RRIM, 1976b). The harvested budwood (Plate 15. e) is cut into pieces of convenient length before being taken to the nursery beds for budding.

2.1.7 Nursery for stumped buddings

The establishment and maintenance of nurseries for raising stumped buddings are similar to that of budwood nurseries. However, green budding at four to five months age is recommended for stumped buddings. Every cultural operation should be done in such an intense manner that the plants grow at a fast rate. Mulching and irrigation during dry weather should be practised efficiently. Regular manuring with NPKMg 10:10:4:1.5 mixture is to be done once in two months starting from one month after cutting back. Manuring can be started with 25 g per plant which may gradually be increased to 50 g for every application. Frequent rounds of weeding and prophylactic spraying against shoot rot and leaf spot diseases and pests are to be strictly followed to facilitate healthy growth of the plants.

Stumped buddings can be prepared either as maxi stumps or mini stumps. For the production of maxi stumps, plants are grown in the nursery until the scions develop brown colour to a height of 2.4 m. This takes about 18 months after cutting back. In order to produce mini stumps, the scion should produce brown bark up to 60 cm from bud union, which requires about five to six months after cutting back. The planting of maxi or mini stumps should be done when rains are continuously received. The percentage of establishment has been found to be poor in the case of stumped buddings. Since the introduction of polybag plants, the use of stumped budding is no longer popular. Core stumps and soil core plants are other planting materials that are not popular now.

2.2 Polybag nursery

Planting materials in polybags can be prepared by two different methods. Budded stumps can be planted in polybag and the scion allowed to develop till they are ready for planting in the field. In the other method, germinated seeds are planted in polybags and bud-grafted when five to six-month-old. The former gives greater opportunity for selection of the most vigorous plants and avoids wastage of bags containing poor seedlings and budding failures. The roots of budded stumps can be treated with indolebutyric acid (IBA), a hormone which enhances root growth (Pakianathan *et al.*, 1978). Dipping root in cow dung slurry before planting enhances root development.

The bags may be of black or transparent polyethylene. Transparent bags, when used, should always be kept buried in soil, as otherwise, the development of roots will be affected. The use of black polyethylene bags is generally preferred. Depending on the size of the plant to be produced, bags of different dimensions may be used. Polythene bags of lay flat dimension 55 to 60 cm length and 25 to 30 cm width which can hold about 8 to 10 kg soil, are usually used for raising plants up to two to three whorl stage. For producing plants of six to seven whorls, larger bags of 65 x 35 cm size and holding about 23 kg soil should be used (RRIM, 1973). In order to facilitate drainage, sufficient number of holes should be punched on the lower half of the bags. Low density polyethylene (LDPE) sheet of 400 gauge and 500 gauge thickness are usually used for making small bags and large bags respectively. Bags made of high density polyethylene (HDPE) sheets can also be used for this purpose. However, such bags are likely to deteriorate when exposed to sunlight for long periods.

The soil used for filling the bags should have good moisture and nutrient retention capacity, promote root development and bind the roots firmly to prevent damage during transport (Taryo - Adewiganda and Hasanudin, 1995). Soils with clay-loam texture, good structure and friability are ideal for this purpose (Marattukalam and Saraswathyamma, 1992). The fertile topsoil collected after removing the surface vegetation and leaf litter is ideal for filling the bags (Plate 16. a). Before filling, large clods of soil are broken, and if too wet, partially dried. The soil is cleaned by removing stones, roots and stubbles. While filling, the bag should be gently tapped to ensure compact filling of soil without leaving air spaces. The bag is filled up to about 2 cm below the brim (Plate 16. b). Powdered rock phosphate at the rate of 25 g for small bags and 75 g for large bags is mixed with the top layer of soil. The filled bags can be kept in the nursery either in trenches (Plate 16. c,d) or on the ground supported with wooden poles (Marattukalam and Saraswathyamma, 1992). The former method is better as it would give greater protection of the bags and better growth of the plants. Trenches having width equal to the diameter of the bag are usually dug in pairs. For small bags, depth of trench may be about 20 cm and the distance between rows in a pair of trenches 15 cm. The corresponding depth and distance for large bags are 30 cm and 20 cm . The gap between bags of same trench is 10 cm (Marattukalam, 1981). Footpath of 75 cm width may be left between two pairs of trenches. After placing the bag in the trench, the excavated soil is filled in the gap between them. The remaining soil is mounted around the bags. Planting of budded stumps or sprouted seeds is undertaken thereafter. When budded stumps are used, the bud patch should face the footpaths to facilitate growth of sprouts. Regular cultural operations like manuring, watering, weeding, shading and plant protection are adopted. Application of NPK Mg 10:10:4:1.5 mixture is done at monthly intervals. During the first month 10 g of the mixture is given per bag which is gradually increased to 30 g in four months time (Rubber Board, 1999). Fertilizer application should be avoided when the leaves are very tender. While applying fertilizer, care should be taken to prevent it from coming in contact with the young plant as it may cause scorching. Watering should be done soon after manuring. During dry periods, irrigation should be done regularly (Zehari-Husny and Aidi-Daslin, 1995). Watering can be done manually in small nurseries while sprinklers or drip irrigation system is more economical in large nurseries. Too much watering should be avoided to prevent waterlogging. During summer months, partial shade may be provided to the plants by erecting overhead shade (Plate 16. e,f). Appropriate prophylactic and curative measures may be taken against diseases and pests.

Polybag plants are advanced planting materials which contribute to reduction in immaturity period. Bagged plants should be transplanted to the field, with minimum disturbance to the root system for proper establishment (Marattukalam and Nair, 1982; Marattukalam and Saraswathyamma, 1992). Such plants also help to achieve a uniform stand and are also useful for vacancy filling and late planting. Because of these advantages the use of polybag plants has become very popular.

3. FIELD PLANTING

In India, the area available for planting rubber can be categorized into forest clearings, cropped lands (where other crops were grown) and rubber replantings.

Considerable portion of the existing rubber plantations was established in forest clearings. However, in future, the availability of such areas is limited. There is a growing tendency for converting other cropped lands to rubber. The incidence of the root wilt disease of coconut in the central region of Kerala has resulted in the conversion of some coconut gardens to rubber plantations. Areas under less profitable crops like cashew and cassava are also being planted with rubber in South India. Areas once under rubber are generally being replanted with rubber.

3.1 Preparation of land

This includes various operations such as land clearing and construction of roads and buildings.

3.1.1 Clearing

The nature and extent of clearing required will depend on the previous land use. The land should be cleared off the existing vegetation. These operations will be more elaborate and tedious when planting is planned in forest clearings compared to other crop lands and rubber replantings. Since June-July is the best season for planting in India, all the pre-planting operations should be completed well in advance. The clearing operations for jungle lands are more elaborate and therefore should be started sufficiently early to avoid delay in planting. Large trees of good timber value are removed first, followed by removal of smaller ones. Lastly the undergrowth is slashed and left in the field for about one month for drying. Appropriate herbicides also can be used to kill the weeds and undergrowth. Uprooting of stumps of trees may be avoided, if expensive. However, large stumps which interfere with planting lines in terraces have to be removed. A light burn may be given after the slashed material is sufficiently dried. Most of the woody material including small branches are recovered for firewood before burning. Light burning reduces the bulk of the stubble and trash left in the field and helps to have closer supervision of the field operations. This would slow down the regeneration of weeds and help establishment of cover crops. However, excessive burning is harmful as it will destroy humus and adversely affect the structure and fertility of the soil.

When rubber is planted on a land where other tree crops are grown, land preparation is similar to that of forest clearings. In replanting areas, the old rubber trees are cut as close to the ground as possible and the timber removed. The stumps of trees may be left in the field and allowed to rot. The twigs and leaves of trees along with the existing weeds may be burnt or collected and stacked along the contour. Lining and digging of pits before felling of the trees is also practised in some plantations. Although cutting terraces before felling may help in saving time, the terraces may be damaged when the trees are felled and removed. Poisoning of trees using sodium arsenate or 2,4,5-T, though followed in some countries, is not practised in India.

3.1.2 Roads, fences and buildings

A network of well-laid out roads and footpaths is necessary for easy transportation of inputs to various fields and latex to the processing factory and also for efficient supervision of field operations. It is estimated that a minimum length of 25 km road may be required for a plantation of 1000 ha. The position of roads may be traced before the commencement of lining for rubber, so that sufficient strips of land could be reserved for roads.

Adequate provision should be made for estate office, stores, processing factories, residential accommodation, *etc*. The requirement of buildings varies depending on the size of the plantation and the type of processing of the produce. The sites of these buildings may be suitably located and reserved. The plantation should be protected all around by erecting fences or walls to keep away grazing cattle and to prevent pilferage. Barbed wire fences with five or six strands fixed on wooden, stone or concrete posts are commonly used.

3.1.3 Planting density

It is important to ensure that adequate space is provided for each rubber plant so that there is good exposure to sunlight for development of the aerial portions and sufficient volume of soil for spread of the root system. In addition to the direct influence on growth and yield, the density of planting can affect the duration of immature period (Westgarth and Buttery, 1965). The thickness of the bark and rate of its renewal after commencement of tapping, and the incidence of panel diseases are also influenced by density of planting

(Napitupulu, 1977; Leong and Yoon, 1982; Webster, 1989). It is also reported that planting density determines the yield per tapper and the cost of tapping (Barlow and Lim, 1967).

The yield per ha may, up to certain limit, be higher when the density is high, but yield per tree will be high when the stand is less. When rubber prices are high or when family labour is employed for tapping, higher yield per ha resulting from higher density may be more profitable. On the other hand, when labour costs are high and rubber prices low, it is desirable to have higher yield per tree resulting from a lower stand per ha. Therefore, a compromise between the two is necessary to decide the density of planting and the final stand in an area.

The density of plants recommended is 420 to 445 plants per ha in the case of buddings or plants proposed to be field-budded and 445 to 520 plants per ha in the case of seedlings. Some common spacings adopted in the above cases are given in Table 2.

Table 2. Density of plants under different terrains and planting materials

Planting material and terrain			Spacing (m)	Stand/ha
Buddings:	in hilly areas		6.7 x 3.4	445
	in flat areas :			
		square	4.9 x 4.9	420
		triangular	4.9 x 4.9	470
Seedlings:	in hilly areas		6.1 x 3.0	539
	in flat areas : square		4.6 x 4.6	479

Seedlings show genetic variability and the poor ones may have to be removed progressively. A higher initial stand is recommended for allowing proper thinning out. Table 3 gives the number of trees per ha at different spacings in square and rectangular planting systems.

3.2 Lining

The procedure for lining depends on the planting system and spacing to be adopted. Rubber can be planted adopting square, rectangular, triangular (equilateral triangle or quincunx system), avenue or hedge planting system (Edgar, 1958). Of these, the triangular and square systems offer well-balanced growth of the crown and root system. However, these systems are suitable only for level or near level lands. The rectangular system can be adopted in level areas and slopes. In this system, trees along the rows become closer and rows wide apart as in avenue planting. Because of this, the distance to be walked for tapping becomes shorter. The shading of the inter-rows is delayed and consequently the ground covers persist longer. However, avenue planting is more susceptible to wind damage because of the widely exposed inter-rows. Hedge planting is an extreme type of avenue planting in which the rows are so far apart that the branches of trees do not meet overhead to form a closed canopy. The wider rows increase the risk of wind damage and the growth is less uniform than in avenue planting. The absence of shade increases the danger of invasion of the inter-rows by noxious weeds. Hedge planting is not commonly practised now and it is advantageous only when intercropping is attempted.

Table 3. Number of trees per ha at different spacing* (square or rectangular)

cm (ft)	180 (6)	200 (7)	240 (8)	270 (9)	300 (10)	340 (11)	370 (12)	400 (13)	430 (14)	460 (15)	490 (16)	520 (17)	550 (18)	580 (19)	610 (20)	640 (21)	670 (22)	700 (23)	730 (24)	760 (25)
180 (6)	2990	2562	2244	1994	1794	1631	1495	1379	1282	1196	1122	1055	996	944	897	862	815	781	749	717
200 (7)		2197	1922	1707	1537	1399	1282	1184	1097	1025	961	904	855	810	768	731	699	670	633	615
240 (8)			1683	1495	1347	1223	1122	1035	961	897	840	791	749	709	672	640	613	586	561	539
270 (9)				1329	1196	1087	996	919	855	798	749	702	665	630	598	568	544	519	499	479
300 (10)					1077	979	897	828	768	717	672	633	598	566	539	511	489	467	450	425
340 (11)						890	815	754	699	652	613	576	544	514	489	467	445	425	403	390
370 (12)							749	689	633	598	561	529	499	472	450	427	408	390	376	358
400 (13)								638	591	551	516	487	460	442	415	395	376	361	346	331
430 (14)									549	511	479	452	427	405	385	366	348	334	321	309
460 (15)										479	450	423	398	378	358	341	326	311	299	293
490 (16)											420	395	376	353	336	321	306	292	279	269
520 (17)												373	351	334	316	301	287	274	264	252
550 (18)													331	314	299	284	272	259	250	240
580 (19)														299	284	269	257	247	237	227
610 (20)															269	257	245	235	225	215
640 (21)																245	232	222	213	205
670 (22)																	222	213	203	195
700 (23)																		203	195	188
730 (24)																			188	180
760 (25)																				173
790 (26)	689	591	516	460	415	400														
850 (28)	640	549	479	427	385															
910 (30)	598	511	447	398	358															
970 (32)	561	479	427	385																
1030 (34)	529	452	395																	
1090 (36)	499	427	373																	
1150 (38)	472	405																		
1210 (40)	447	385																		

* Spacing (ft) has been converted to the nearest 10 cm

The figures in the brackets are the corresponding space in ft

3.2.1 Rectangular or square planting

For rectangular planting, the lines should be oriented east to west to intercept maximum sunlight. A compass, a number of marking pegs and two ropes are required for lining (Edgar, 1958). One of the ropes can be used for the base line and the other for the guide lines. The planting distances are marked with coloured rags on the ropes.

As the initial step, a base line is fixed in the cleared area. The longest straight boundary running north to south would be the most convenient base line. One guide peg is fixed at the beginning of the proposed base line at one end, say, the southern end, and the compass kept over this guide peg No. 1 (corner peg).

A shot is taken due north and the guide peg No. 2 fixed at the extreme end of the lining rope. The planting points are then pegged at the marks along this base line using smaller pegs. Again, with the compass over the corner peg, another shot is taken east or west, depending on the shape of the land, and another guide peg and smaller pegs are fixed. The process is repeated at the other end where guide peg No. 2 has been fixed. In this way,

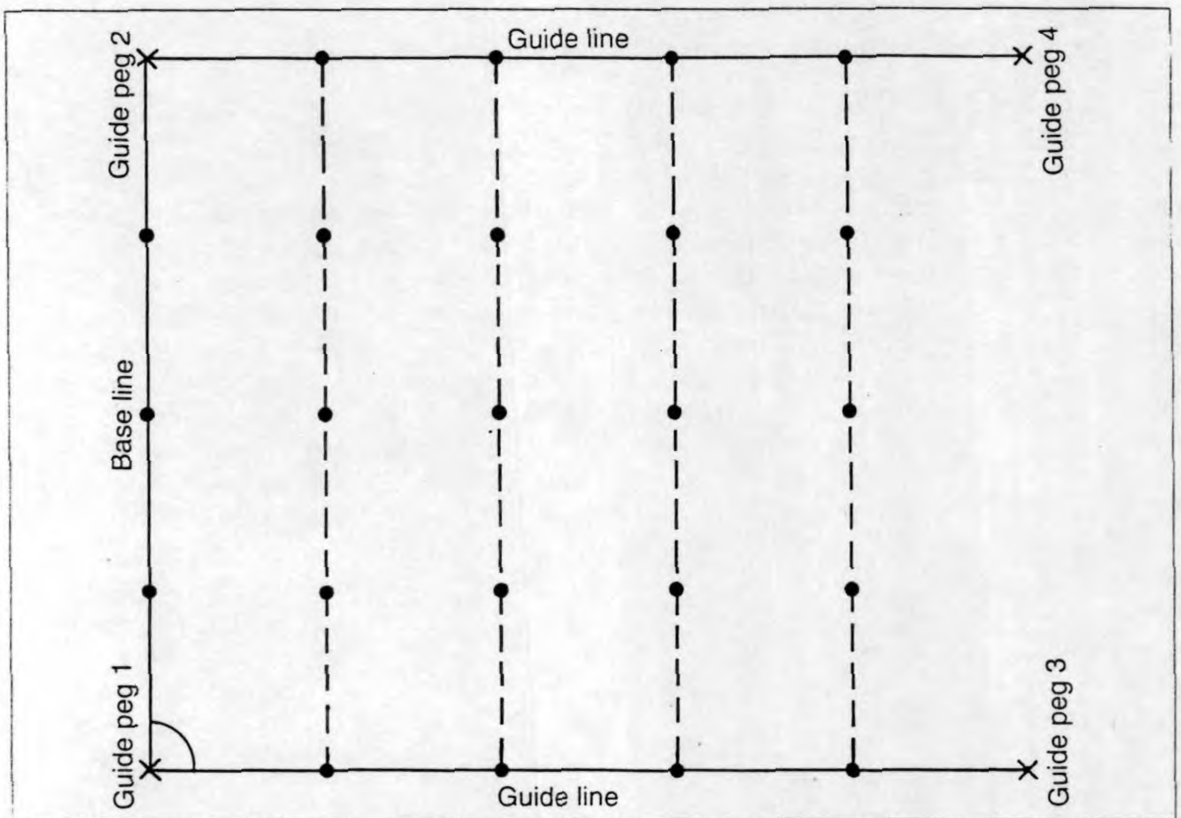

Fig. 1. Lining for rectangular or square planting

the three sides of the square or rectangle are formed. Advances are made from the base to the open end of the square or rectangle with the lining rope held (north – south) at each peg on the guide lines and pegging done along the ropes at the rag marks (Fig. 1).

3.2.2 Quincunx or equilateral - triangle planting

The system is also known by the names quincunical or triangular planting system. Here also, the base line is aligned in the same way as in the case of square planting. The guide lines are put by diagonal lining at an angle of 60 or 120° to the base line. The plant points are marked along the guide lines at the required spacing which is marked on the rope. The distances between any two plant points of a set of three adjacent points which constitute an equilateral triangle, are equal. In this system the spacing can be expressed by single number *e.g.* 4.9 or 5 m. An alternate method for lining in this system is to first align the guide lines at a spacing equal to 86.6 per cent of the required spacing. For example, if 5 m is the required spacing, the guide lines may be aligned at a spacing of 4.33 m. An extra half planting distance may be marked beyond the last tree point on the rope. In the second and subsequent alternate rows, this marker is brought against the guide peg, and smaller pegs are placed in the normal way against the coloured rags on the ropes (Fig. 2). The guide pegs in these alternate rows are removed after the lining is completed. The spacing along each row which is marked on the rope should be the actual planting distance *viz.* 5 m in the case of the example cited above. By adopting this system of planting, about 15 per cent more plants can be accommodated in a given area compared to the square system for the same spacing.

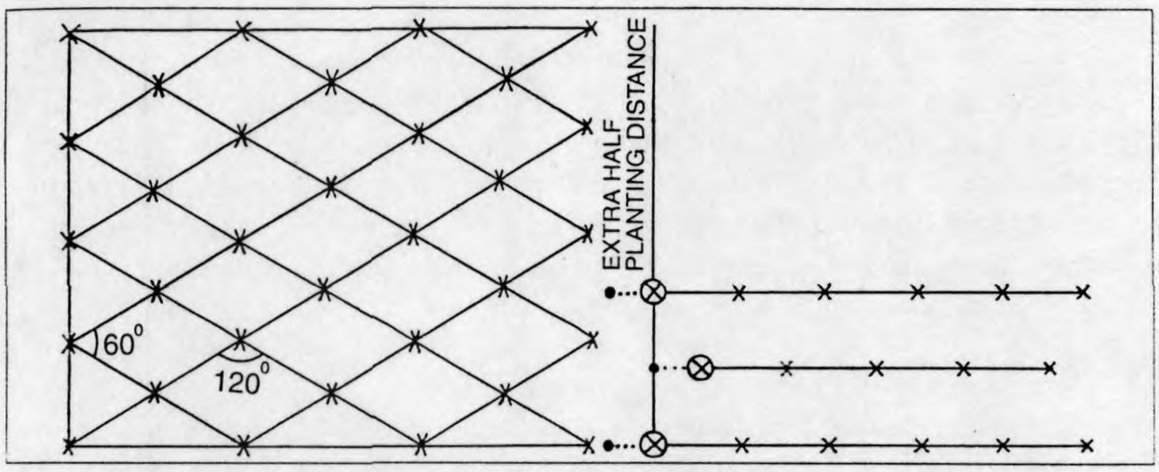

Fig. 2. Lining for quincunx system planting

3.2.3 Contour planting

This system is suited for undulating and hilly lands where the slope is generally more than eight per cent. Here the planting points are marked as lines passing through points of the same elevation. A guide line is selected down the hill along an average slope of the clearing. Guide pegs are driven in along this guide line to mark the contour intervals. For this, the horizontal interval is measured by holding the tape level. Once the guide lines are aligned and marked, it is possible to commence marking of the planting points using a road tracer or other suitable instrument for levelling. Contour lines are aligned right and left of the guide lines with pegs to indicate planting points. The degree of slope varies from place to place in a field and because of this reason the distances between contours also vary. When gradient increases, contours converge, and when the slope is less, they widen. If the distance between contour lines does not vary greatly, it is possible to maintain a fairly uniform planting density by varying the spacing between the planting points in the rows. When this is not practicable, it is necessary to stop a contour line where the adjacent contours come too close, and to start additional contours when the rows become too wide. A rule of thumb is that when the distance between terraces is reduced to two-thirds of the normal distance, alternate terraces are stopped, and where it exceeds one and one third of the normal, additional terraces are introduced.

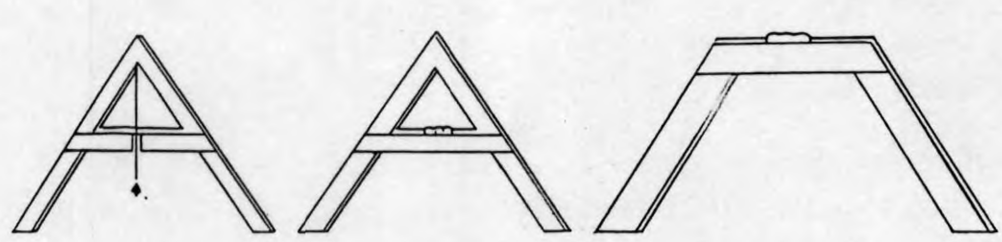

Fig. 3. Levelling triangle and trapezium

When the area to be lined is smaller, a useful instrument would be triangular or rhomboid wooden frame with the points of its legs at the required planting distance (Fig. 3) and fixed with a spirit level or plumb line to ensure the correct level. The levelling triangle is placed with one leg against the guide peg and when the instrument is correctly levelled, a peg is driven in where the second leg meets the ground. Subsequent points are marked using the preceding point as the guide, taking care to alternate the legs of the frame to minimize any possible error.

3.3 Pitting and refilling

In order to provide favourable conditions for the early establishment and growth of the young plant, a pit is dug at the planting point and refilled with fertile topsoil. The standard size of the pit is 75 cm^3. The size of pits can vary depending upon the type of planting material used and the nature of the soil. Stumped buddings need wider and deeper pits, while smaller pits are sufficient for small and medium-sized polybag plants. Larger pits are advantageous on hard, compact or stony soils. The cost of digging very large pits cannot be justified unless there is definite advantage for root development. The main consideration is that the pit should be big enough to accommodate the root system of the plant. On economic consideration, in deep, loose and friable soils, the pits are sometimes dug wider at the top and tapering towards the bottom, or the depth reduced to about 60 cm with a central crowbar ('alavang') hole of 15 cm or more depth for the tap root.

Pitting can be initiated as soon as the work of clearing and lining has sufficiently progressed (Plate 17. a). While digging the pit, the topsoil may be deposited on one side and the subsoil on the other (Plate 17. b). It is important to complete the refilling operation before the onset of the monsoon and well ahead of planting so that there is sufficient time left for the soil to settle. Filling should be done using fertile topsoil as far as possible. Apart from the topsoil obtained while digging a pit, sufficient surface soil has to be collected from the surroundings, stones and roots removed and used for filling. When organic and phosphate manures are to be applied to the pits, they are thoroughly mixed with the top 20 cm soil in the pit. The pit should be filled to about 5 cm above ground level. A peg may be fixed at the centre of the pit to locate the position at the time of planting (Plate 17. c). When large rubber areas are replanted, lining and pitting operations are sometimes undertaken before felling the trees during September to December period previous to the year of planting in order to minimize the rush of operations during the planting season (Plate 17. d).

3.4 Soil conservation

Cutting of terraces along contours is a recommended practice on hilly and undulating lands for conserving moisture and preventing soil erosion. Construction of continuous terraces along planting rows, though initially expensive, provides the best method of protection against the risk of erosion. Moreover, the terraces serve as footpath and help to conduct many operations along the rows, such as weeding, pruning, tapping, collection and inspection in a cheap, easy and effective manner.

For making contour terraces, the soil on the hillside is cut from a distance of about 60 to 75 cm in front of the planting row and thrown back, so that the terrace thus formed will have a width of 1.25 to 1.50 m and an inward drop of 20 to 30 cm. The angle of the slope to the back of the terrace should depend on the type of soil and intensity of rainfall. For example, steeper slope is necessary in light soil than in clay or gravely soil. Similarly, the slope should increase with increasing intensity of rainfall. The soil, cut and removed, is used to extend the front of the terrace and sometimes also to provide a small bund on the outer edge. Narrow blocks of uncut earth protruding from the backwall at intervals of 10 to 20 m should be left along the terrace to check lateral flow of excess rain water along the terrace. In order to reduce expenses during the year of planting, planting on hillsides can also be done on square platforms of size about 1.25 x 1.25 m (honeycomb terrace). These individual tree platforms are joined together later to make complete and continuous terraces. Alternatively these platforms can be connected with narrow outer edges of about 60 cm width to facilitate easy movement of workers and staff .

In order to further reduce soil erosion, silt pits are taken and maintained in steep areas. Trenches of about 120 cm length, 45 cm width and 60 cm depth are taken along the contours at suitable intervals depending on the degree of slope. More pits are advisable when the slope is more. About 100 to 200 pits are desirable for a hectare of plantation. They are aligned in between the planting lines or contour terraces in such a way that the pits in adjacent inter-rows are in a staggered manner. The soil from the pits should be thrown below the pit to form small earth bunds. The water and soil particles washed off from above are partly collected in these pits. The silt deposited in the pits is periodically removed and placed on the lower side of the pit.

Construction of level contour terraces with stone-pitched retaining walls ('edakayyala') is another effective method of soil and water conservation. The washed off soil is deposited on the upper sides of the terraces while water filters through the terraces. The distance between terraces depends on the degree of slope. The contour terraces, 'edakayyalas', *etc.* should be periodically repaired.

3.5 Drainage

Drainage is important on flat land or gentle slopes with a permanent or seasonal high water table. Adequate drainage enhances soil aeration and stimulate beneficial microbial activity and proper establishment of ground covers leading to improved growth of rubber. Proper drainage also enhances good root development and consequent better absorption of water and nutrients. The drainage systems designed should keep the water table 1.0 to 1.5 m below the soil surface. The natural waterways available in the area may be cleared, dressed or deepened to form a satisfactory drainage system. If such outlet drains do not exist, proper drainage has to be provided. Depending on the drainage requirement, main drains are dug at intervals of 100 to 200 m and lead to an outlet drain. If necessary, side drains or contour drains at required intervals are dug subsequently such that they meet the outlet drains at right angles. The drainage system once constructed should be desilted and repaired periodically.

3.6 Materials for planting

Different kinds of planting materials are used for establishment of rubber plantations. The important ones among them are seeds, seedling stumps, budded stumps and advanced planting materials comprising of stumped buddings, polybag plants and soil core plants.

3.6.1 Seeds and seedling stumps

Seeds can be used either for seed at stake planting or for preparing seedling stumps. For raising seedling stumps only polyclonal seeds are recommended.

3.6.2 Budded stumps

Budded stump is a very convenient form of planting material. It can easily be transported and planted with much less effort compared to polybag plants. Green-budded stumps are mostly used for raising polybag plants.

3.6.3 Advanced planting materials

With the object of shortening the period of unproductive phase in the field, advanced planting materials are now being used. Maintenance in the field is more expensive than in the nursery. Therefore, new techniques have been developed for growing the planting materials in nurseries for longer periods and transplanting them to the field without disturbing the root system. Stumped buddings, stumped three part plants, polybag plants, soil core plants and core stumps are the different types. Advanced planting materials are also useful for gap filling during subsequent years.

3.6.3.1 Stumped buddings

These materials are already grown for one to two years in the nursery and are expected to come to tapping in a shorter period after planting. The cost of raising stumped buddings is less than that of polybag plants. However, in India, the use of stumped buddings on commercial scale is not popular because of the difficulty in their maintenance during the long dry period.

3.6.3.2 Polybag plants

Polybag plants (Plate 17. e) are definitely advantageous for easy establishment and for shortening the immaturity period (Marattukalam and Nair, 1982). This method is useful for reducing vacancies to the minimum. This will also lead to uniform growth of the stand. The initial cost is high and careful handling is necessary.

3.6.3.3 Soil core plants

Transplanting at the three whorl stage with an intact core of soil holding the root system is most ideal. The success depends on the clayey nature of the soil. Handling the soil core is also difficult.

3.6.3.4 Core stumps

Core stumps combine the advantages of polybag plants and budded stumps. The problem faced by stumped buddings is also not experienced here.

3.6.4 Seedlings vs. clones

Both seedlings and buddings have merits and demerits. Seedlings are generally more vigorous and hence attain tappability earlier than buddings, show greater tolerance to adverse soil and climatic conditions and hence are more easy to establish and maintain. Seedlings generally possess thicker bark and hence are easier to tap. Owing to the genetic diversity, the damages caused by disease and unfavourable climatic factors are only partial or generally less in seedling populations. Because of the vigorous growth, seedlings give higher timber yield. However, seedling populations have certain serious defects such as high susceptibility to brown bast (TPD) and tolerance to only low intensities of tapping. They also exhibit high variation in growth, vigour and yield and this necessitates initial higher stand and subsequent thinning out which cause wastage. Variations in thickness of bark and properties of latex also cause many practical difficulties in tapping and processing. Seedling trees have tapering trunk and therefore initial opening for tapping has to be made at a lower level, resulting in formation of bark islands when subsequent panels are opened. On the other hand, clones are noted for their uniformity. Since there are different clones possessing different specific characters, selection of materials suited for specific purposes is possible. The production potential of many modern clones is substantially higher than that of seedlings. Under ideal agroecological conditions clones are considered better planting materials than seedlings. Seedlings are preferred only in areas where establishment of plants is difficult.

3.7 Planting

The success of planting depends on the prevailing weather conditions, quality of the planting materials used and the care with which the planting operation is done. It is very important that planting is always done during favourable weather. Periods of continuous heavy rains should be avoided, because the soil in the pits becomes slushy and this would lead to high rates of casualty. Continuous wet weather can be expected during June-July in the major rubber growing areas in India and hence this period is considered to be ideal for planting rubber. The actual method of planting will depend on the materials used for planting.

3.7.1 Seed at stake

Three or four germinated seeds are directly planted in the centre of the refilled pits in the field. After establishment of the seedlings, the weak plants are removed. The plant bases are always kept free of weeds. During the initial year, the seedlings are manured with NPK Mg 10:10:4:1.5 fertilizer mixture at the rate of 225 g per plant in a single dose, six weeks after planting the germinated seeds. Seedlings other than approved high yielding polyclonal ones are field-budded during April-May subsequent to planting when the plants attain the required size. If the conditions are not very favourable, plants may attain buddable size only during September-October. The field-budded plants are cut back *in situ* and the bud allowed to grow.

3.7.2 Seedling and budded stumps

Both seedling stumps and budded stumps should be planted in the main field as early as possible after pulling them out from the nursery. About 5 cm of the surface soil is first removed from an adequate area at the plant point to accommodate the lateral roots attached to the stump. Using a crowbar, a planting cavity is made to a depth equal to the length of the pruned tap root. The stump is then carefully inserted in the cavity sufficiently deep in such a way that the lateral roots are properly accommodated in the area dug around the cavity for the purpose. Care should be taken to ensure that the tip of the root is in actual contact with the soil at the bottom of the cavity. The presence of air gap in the planting cavity results in failure of the stump. It is important to pack sufficient loose soil in the cavity around the tap root by pushing the crowbar into the edge of the planting hole as deep as the tap root, or more, in a slanting manner, and then pulling it towards the stump which is firmly held in position. This process is repeated from the other three sides of the stump.

Under favourable conditions, the bud usually sprouts in three to four weeks after planting. Sprouting may be delayed up to several months if the budded stock seedlings were left in the nurseries for periods longer than a month before they are cut back and transplanted as budded stumps. The delay is due to the overgrowth of callus. Too long a portion of the stock seedling above the bud patch also will cause delay in bud sprouting as well as formation of too many offshoots.

3.7.3 Stumped buddings

The planting holes are refilled and allowed to settle as in the case of planting budded stumps. Just before planting, a hole is dug 15 to 25 cm shallower than the length of tap root of the stumped budding to be planted. A smaller cavity is made in the centre of this hole using a crowbar to a further depth of 15 to 25 cm, depending upon the length of the tap root. The end of the tap root of the stumped budding is firmly wedged into this hole. The soil is filled into the planting hole and pressed firmly around the base of the plant to ensure firm anchorage. The plant base is thickly mulched.

The success of stumped budding depends much on the receipt of frequent and adequate rain after planting. A prolonged dry period immediately after planting will seriously affect the success of establishment. Under such conditions, watering at the rate of 10 to 15 L per plant, once in four to five days, is recommended. All shoots which develop towards the top of the stem are allowed to grow until the plant is well established. Subsequently, the number is reduced to three well-spaced shoots. If die-back is noticed soon after planting, the stem has to be cut back to healthy tissues and suitable wound dressing compounds applied. Mini stumps are planted more or less in the same way as budded stumps. However, pre-planting operations such as pollarding, root pruning and whitewashing are essential. Plant bases should be mulched immediately after planting.

3.7.4 Polybag plants

At the time of transplanting, the top whorl of leaves of the polybag plant should be fully mature. Just before removing the plant from polybag nursery, all the plants are watered well. The soil around the bag is removed and the bags are taken out of the trench. Dressing of the lateral roots and tap root, if grown out of the bags, may be necessary. Then they are carried to the planting points. A planting hole slightly bigger than the size of the bag is made. The bottom of the bag is completely cut and then the bag along with the plant is inserted into the planting hole. A vertical cut is made at the bottom of the plastic sleeve, taking care not to damage the roots. Then the cut is continued as the hole is gradually filled so that the cylinder of soil is unbroken. When the hole is

SELECTION OF STABLE CLONES FOR SUSTAINED YIELD IN *HEVEA*

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Abstract

Integration of stability of performance with yield is essential in the evaluation of clones. Selection of high yielding clones that performs consistently from year to year would benefit growers in their adoption decision. Twelve clones of rubber (*Hevea brasiliensis*) viz, PB 217, PB 235, PB 255, PB 260, PB 280, PB 310, PB 311, PB 312, PB 314, KRS 25, KRS 128 and KRS 163 introduced from Malaysia and Thailand were evaluated in a large scale trial along with the control clone RRII 105 for high yield and stability over four years. The data on annual yield over four years, yield during the peak season over four years, combined yield during the peak and dry seasons were subjected to Additive main effects and multiplicative interaction (AMMI) analysis. Analysis revealed that the chosen clones, environments and their combinations were highly variable and interactive. Clones viz., PB 314, PB 255, PB 280 and PB 260 showed non-sensitive relationship with interactive forces hence preferable for their yield and stability. The superiority of clones PB 314 and PB 255 was reported from other location also. Clones PB 312 and KRS 163 may be considered for further improvement since they have high potential with specific suitability for favourable environments. This study carried out with emphasis on performance stability during selection helped in identifying stable clones for the benefit of small growers.

Key words: Dry rubber yield, G x E interaction, *Hevea*, stability, Additive Main effects and Multiplicative Interaction (AMMI).

SELECTION OF STABLE CLONES FOR SUSTAINED YIELD IN *HEVEA*

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INTRODUCTION

In *Hevea* the crop productivity can be maximized by planting high yielding clones, which have been selected effectively for the target production system. But the effectiveness of selection is complicated by the failure of clones to perform relatively same across environments ie., genotype x environment interaction. To reduce the effect of genotype (clone) – environment (G x E) interaction and to make selection of clones more precise and refined, both yield and stability of performance should be considered simultaneously in the evaluation of clones for yield performance. Selection of high yielding clones that performs consistently from year to year would benefit growers in their adoption decision. A better understanding of the genetic basis of G x E interaction for rubber yield can lead to higher productivity through enhancing breeding efficiency and / or better agronomic management. With this objective thirteen clones were evaluated over four years for their yield predictability and dependability from year to year over seasons at the central rubber growing region of Kerala.

MATERIALS AND METHODS

The material for the study comprised of 12 introduced clones from Malaysia and Thailand viz.,PB 217,PB 235, PB 255,PB 260, PB 280, PB 310, PB 311, PB 312, PB 314, KRS 25, KRS 128 and KRS 163 along with the control clone RRII 105.The details of the clones are presented in Table 1. These clones were planted employing Randamised Block Design with five replications and seven plants per plot at the experiment stations of the Rubber Research Institute of India, Kottayam during the year 1989. The trees were opened for tapping during 1996. Yield recording was carried out every month by cup coagulation at fortnightly intervals. The annual mean dry rubber yield, the mean dry rubber yield during the stress period, ie, from February to May and the mean dry rubber yield during the peak period from October to January and the combined yield during the stress and peak period over four years from 1997 to 2000 were computed and statistically analysed. The data was subjected to stability analysis following AMMI analysis as proposed by Zobel *et al.*, 1988.

The AMMI (Additive Main effects and Multiplicative Interaction) model is a hybrid statistical model incorporating ANOVA procedures to separate the additive variance from the multiplicative variance (genotype by environment interaction) and then uses a multiplicative procedure – Principal Component Analysis (PCA) to extract a new set of coordinate axes which explains in more detail the pattern of interaction. The estimation is accomplished using least squares principle, which, with further graphical representation of the numerical results (Biplot analysis) often allows a straight forward interpretation of the underlying causes of the G x E. The model has, in recent past, been recommended for statistical analysis of yield trial, and was preferred over other customary statistical analysis such as ordinary ANOVA, principal component analysis and linear regression analysis. (Gauch and Zobel 1988, Zobel et al., 1988, Nichit et al 1992 a, Gauch, 1988).

RESULTS AND DISCUSSION

The ANOVA for annual mean dry rubber yield, mean dry rubber yield during dry period and mean dry rubber yield during the combined peak and dry period indicating except for yield during the dry months, all others indicated the chosen clones, environment and their combination were highly variable and interactive. The ANOVA model partitions the treatment d.f and s.s. into three sources. 1. Additive genotype effects 2. additive environmental effects and 3. genotype – environment interaction (ie.non additive residual from the additive ANOVA model).

The ANOVA for annual mean dry rubber yield of the AMMI analysis is presented in Table 2. The genotype (clone), environment (years) and G x E interaction explained 76.85, 14.50 and 8 percentage of the total treatment variation respectively. Since ANOVA provided no insight into the particular patterns of genotypes or environments that gave rise to interaction, the ANOVA model was combined with PCA model to further analyse the residuals of the ANOVA model, which infact contains G x E interaction.The G x E interaction was partitioned into interaction PCA axis (IPCA) which was found to be highly significant and explained 5% of the total variation which is 59.54% of the G x E interaction.

The results of AMMI analysis can also be easily comprehended with the help of the bi-plot graph. The mean performance and IPCA 1 scores for both the genotypes and environments used to construct the bi-plot are given in Table 3.The mean annual yield ranged from 34 to 79 08g/t/t. The bi-plot a graphical representation from AMMI analysis, is useful in understanding more comprehensively the specific patterns of main effects and G x E interaction of both the genotype and environments simultaneously. (Zobel *et al.*, 1988; Crossa *et al.*, 1991 and Kempton, 1984).The bi-plot of main effects against IPCA 1 (fig. 1) thus explained 96.35% of the total treatment variation. This bi-plot is helpful in visualizing the average productivity of the genotypes and the environments and the G x E interaction for all possible genotype environment combinations.

In figure 1 the displacement along the abscissa (horizontal axis) reflects differences in main effects where as displacement along the ordinate (vertical axis) exhibits differences in interaction effects. When a genotype and an environment fall in the upper or lower portion from the line indicating IPCA 1= 0 in the biplot, their interaction is positive. However the genotypes and the environments of opposite portions from the IPCA 1=0 line show negative interaction. According to the AMMI model, the genotypes which are characterized by means greater than the grand mean and the IPCA scores nearly zero are considered as generally adaptable to all environments. However, the genotypes with high mean performance and with large value of IPCA scores are considered as having specific adaptability to environments. Prediction of stability of genotypes on the basis of mean performance and the magnitude of IPCA 1 scores from AMMI analysis has already been reported in other crops(Zobel *etal* 1988, Crossa *et al* 1990, 1991, Zavala- Garcial *et al* 1992 and Romagossa *etal* 1993).

Among the genotypes (clones) 8 clones viz., PB 314, PB 312, PB 255, PB 280, PB 260, PB 311, PB 235 and KRS 163 have however high average yield (above the general mean) .Of these clones PB 314, PB 311 and PB 235 exhibited high mean yield and low interaction suggesting that these clones are highly suitable with general adaptability. In general clones viz., PB 314, PB 311, PB 235 , KRS 163, PB 280 and PB 255 with high mean and small IPCA score were declared by the AMMI model as stable cultivars having general adaptability to all environments. Clone PB 312 with high mean yield and with large value of IPCA score was specifically suitable for the environment 1 (E1) while clone PB 260 was particularly suitable for the environment 4 (E4). The environment fall into three groups).The environments E1, E3 and E4 had similar main effects but differed in their interaction with genotypes. Environment 1 was the highest yielding and highly interacting, hence suitable only for the specifically adapted clones. The environment 3 (E3) has small IPCA scores suggesting that they had little interaction with genotypes hence most suitable.

ANOVA for yield during the peak period is presented in Table 4. The genotype (clone), environment (years) and G x E interaction contained 80.49, 8 and 11% of the treatment ss respectively. The environment and genotype additive effects and interaction effects are highly significant. IPCA and IPCA 2 captures 5 and 4.9% of the total s.s. This accounts 48.62 and 44.07% of the G x E interaction ss. The resulting AMMI first axis bi-plot thus explained 93.48 % of the total treatment variation (Fig. 2).The mean performance and IPCA scores for both the genotypes and environments used to construct the biplot are given in Table 5. From the biplot it is clear that clone PB 314 had high average yield and low IPCA suggesting that this clone is highly suitable with general adaptability. In general clones viz., PB 314, PB 235, PB 255 ,PB 311 KRS 163 and PB 280 had high means as well as low IPCA score indicating that they are stable with general adaptation over environments.. For peak yield clone PB 217, KRS 25, PB 310 were highly stable but with low main effects. Clone PB 311 and RRII 105 are suitable for E2 while clone KRS 163 is suitable for environment 3. In this case also clone PB 312 with high mean and large IPCA score was specifically adapted for the environment E4. In this biplot the means of 4 environments are displayed. E4 falls on the positive side of x axis origin while the remaining 3 environment means are on the negative side. The distance from the origin is highly interactive on the positive side. The other environments are also highly interactive but on the negative side

The ANOVA for combined yield during peak and dry period is given in Table 7. The seasons were taken as the environment The complete AMMI model contained 98.57% of ss and the remaining % is residual, indicating that AMMI summarized these data very effectively. The IPCA 1 axes of the interaction captures 60.64% of the interaction ss in 9% of the interaction d.f. The MS for the IPCA 1, IPCA 2 and IPCA 3 were highly significant. The remaining axes are pooled in the residual which is non significant. The mean performance and IPCA scores for both the genotypes and environments used to construct the biplot are given in Table 8. Clones PB 311, RRII 105 and PB 255 have least PCA score indicating small interaction effect but differ in their main effects. . Clones PB 314, PB 255, PB 312, PB 280 and PB 311 had low PCA score with high main effects. These clones were highly suitable for the combined environments. The clone PB 314 was particularly suitable for E1 and E4.

The magnitude of interaction for each genotype and environment can be visualized by biplot of IPCA 1 vs IPCA 2. The biplot of IPCA 1 vs IPCA 2 of combined yield from year to year over stress and peak seasons is shown in Fig. 4. Basically genotype points near the origin are non-sensitive to environmental interacting forces. Those distant from the origin are sensitive and have large interaction. The genotypes occurring close together on the plot will tend to have similar yields in all environments while genotypes far apart may either differ in mean yield or show a different pattern of response over environments. Thus environments

E4, E1 and E5 exert strong interaction and clones PB 312 and PB 217 were most responsive genotypes. The clones PB 314, PB 311, RRII 105 and PB 255 were non sensitive to the interacting forces.

From the forgoing discussions it can be concluded that the AMMI analysis with its biplot was useful in analyzing the yield data effectively and explained comprehensively both the effects due to genotypes and environments and also their interaction pattern. A broad range of diversity existed among the clones and among environments, and that the performance of genotypes was different over environments. When the entire growing season partitioned in to annual, peak and combined of both dry and peak season and their yield were subjected to analysis, they revealed that among the 13 clones, the clone PB 314 was highly superior for its yield performance and stability over years followed by clones PB 311, PB 280 and PB 255. Clones, PB 312, PB 260 and KRS 163 have to be considered for further improvement since they have high potential with specific suitability for favourable environments. The mean annual and peak yield over seasons were highly influenced by the factors, which had existed in environment 3. The study carried out with emphasis on performance stability during selection helped in identifying stable clones for the benefit of small growers.

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Table 1. Details of clones evaluated

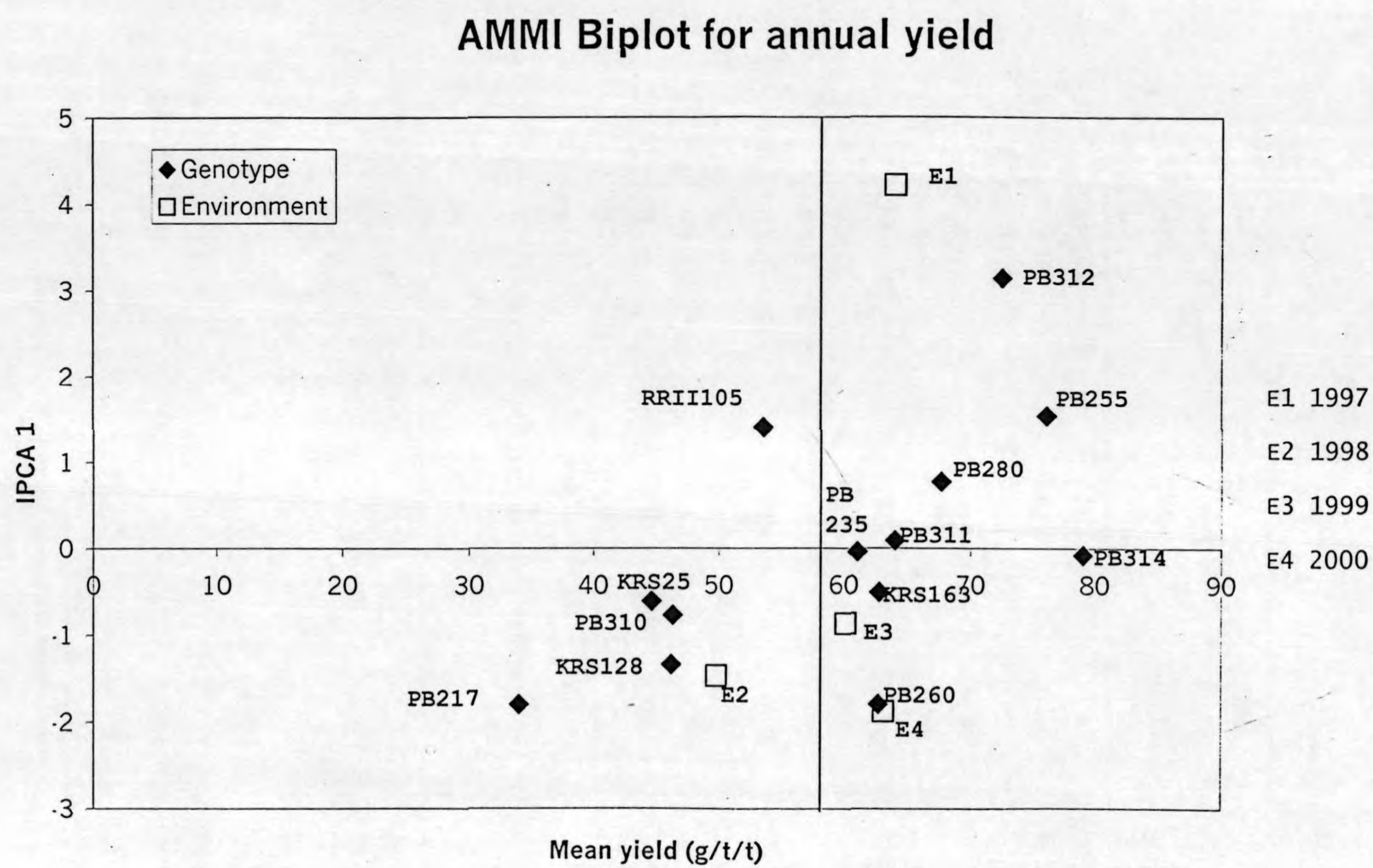
Clone	Parentage	Country of Origin
PB 217	PB5/51 x PB 6/9	Malaysia
PB 235	PB5/51 x PB S/78	- do -
PB 255	PB5/51 x PB 22/36	- do -
PB 260	PB5/51 x PB 49	- do -
PB 280	PBIG seedling	- do -
PB 310	PB5/51 x RRIM 600	- do-
PB 311	RRIM 600 x PB 235	- do-
PB 312	RRIM 600 x PB 235	- do-
PB 314	RRIM 600 x PB 235	- do -
KRS 25	Primary clone	Thailand
KRS 128	PB 5/63 x KRS 13	- do -
KRS 163	PB 5/ 63 x RRIM 501	- do -
RRII 105	Tjir 1 x Gl 1	India

Table 2. ANOVA for mean annual dry rubber yield

Sources of variation	df	Sum of squares	%	Probability
Total	51	11463.65	100	0.0000***
Genotypes	12	8809.77	76.84	0.0000***
Environments	3	1661.87	14.50	0.0000***
G X E interactions	36	992.005	8	0.04043*
IPCA 1	14	590.631	5	0.00569**
Residual	22	401.374		0.46699
Error	208	3797.982		
Total	259	15261.63		

Table3. Mean and IPCA score for annual yield

Clone	Mean yield (g/t/t)	IPCA 1
PB 217	34.00	-1.80
PB 235	61.10	-0.04
PB 255	76.16	1.54
PB 260	62.75	-1.80
PB 280	67.67	0.77
PB 310	46.28	-0.77
PB 311	64.05	0.09
PB 312	72.57	3.14
PB 314	79.08	-0.08
KRS 25	44.61	-0.61
KRS 128	46.17	-1.34
KRS 163	62.82	-0.51
RRII 105	53.58	1.40
Envt. 1	64.04	4.22
Envt. 2	49.82	-1.47
Envt. 3	60.16	-0.87
Envt. 4	63.15	-1.88



AMMI Biplot for annual yield
Genotype
Environment
IPCA 1
Mean yield (g/t/t)
5
4
3
2
1
0
-1
-2
-3
0
10
20
30
40
50
60
70
80
90
E1
PB312
RRII105
PB255
PB280
PB
235
PB311
PB314
KRS25
KRS163
PB310
E3
KRS128
E2
PB217
PB260
E4
E1 1997
E2 1998
E3 1999
E4 2000

Table 4. ANOVA for yield during the peak period

Sources of variation	df	Sum of squares	%	Probability
Total	51	16353.1728	100	0.0000***
Genotypes	12	13163.0149	80.49	0.0000***
Environments	3	1369.8668	8	0.0000***
G X E interactions	36	885.04517	11	0.01262*
IPCA 1	14	802.23132	5	0.01238*
IPCA 2	12	133.01458	4.9	0.01135*
Residual	10	6220.58318		0.92284
Error	208	22573.75603		
Total	259			

Table 5. Mean and PCA score for yield during the peak period

Clone	Mean (g/t/t)	IPCA 1
PB 217	38.77	-0.56
PB 235	77.81	0.22
PB 255	82.27	0.35
PB 260	81.10	-2.04
PB 280	84.91	1.15
PB 310	52.71	0.31
PB 311	74.25	-0.55
PB 312	84.41	4.34
PB 314	88.90	-0.18
KRS 25	51.40	0.49
KRS 128	50.95	-1.42
KRS 163	80.05	-1.12
RRII 105	61.84	-0.99
Envt. 1	65.66	-2.54
Envt. 2	64.65	-0.93
Envt. 3	72.22	-1.12
Envt. 4	77.28	4.59

AMMI Biplot for yield during peak period

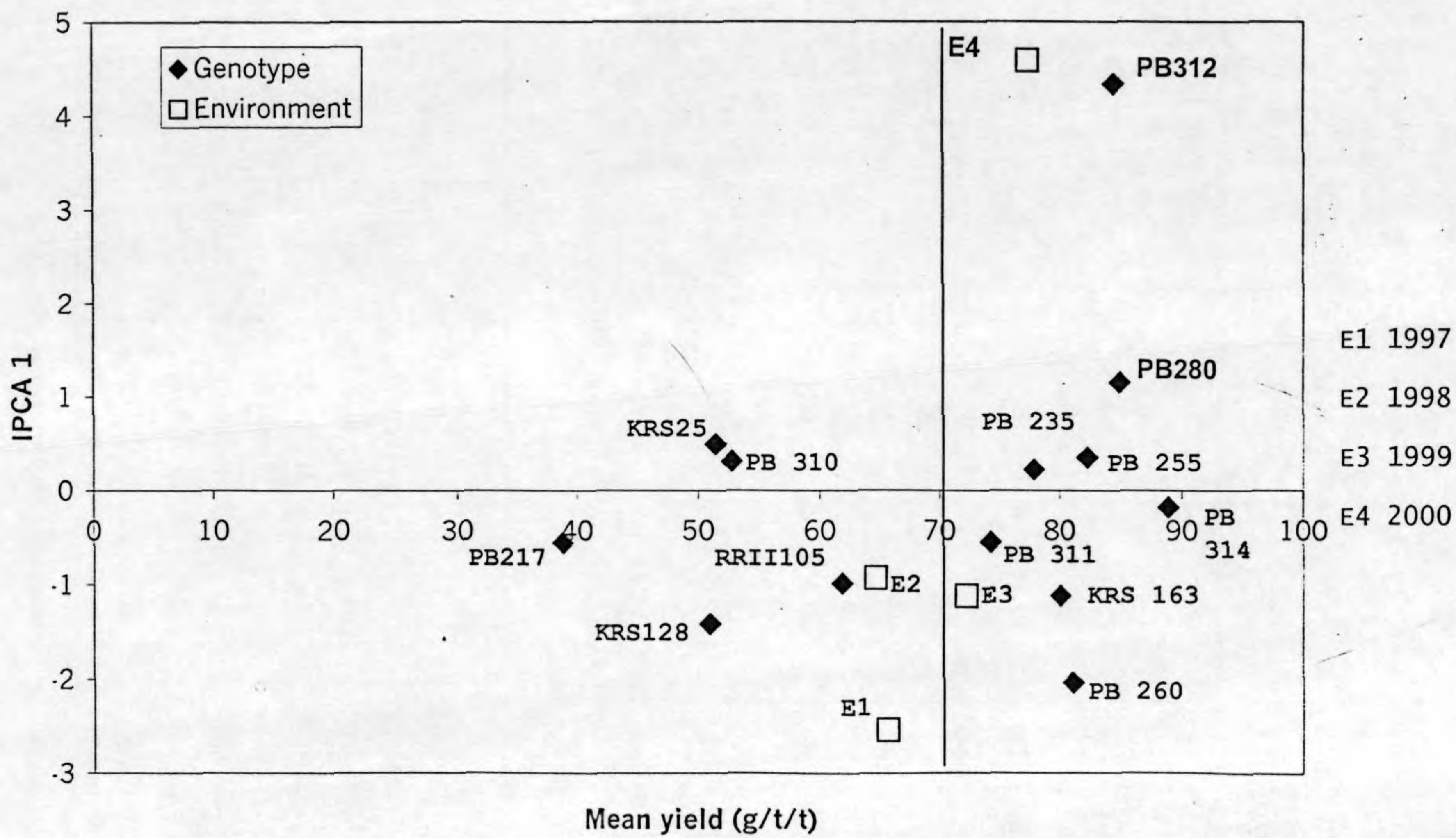


Table 6. ANOVA for yield during the stress period

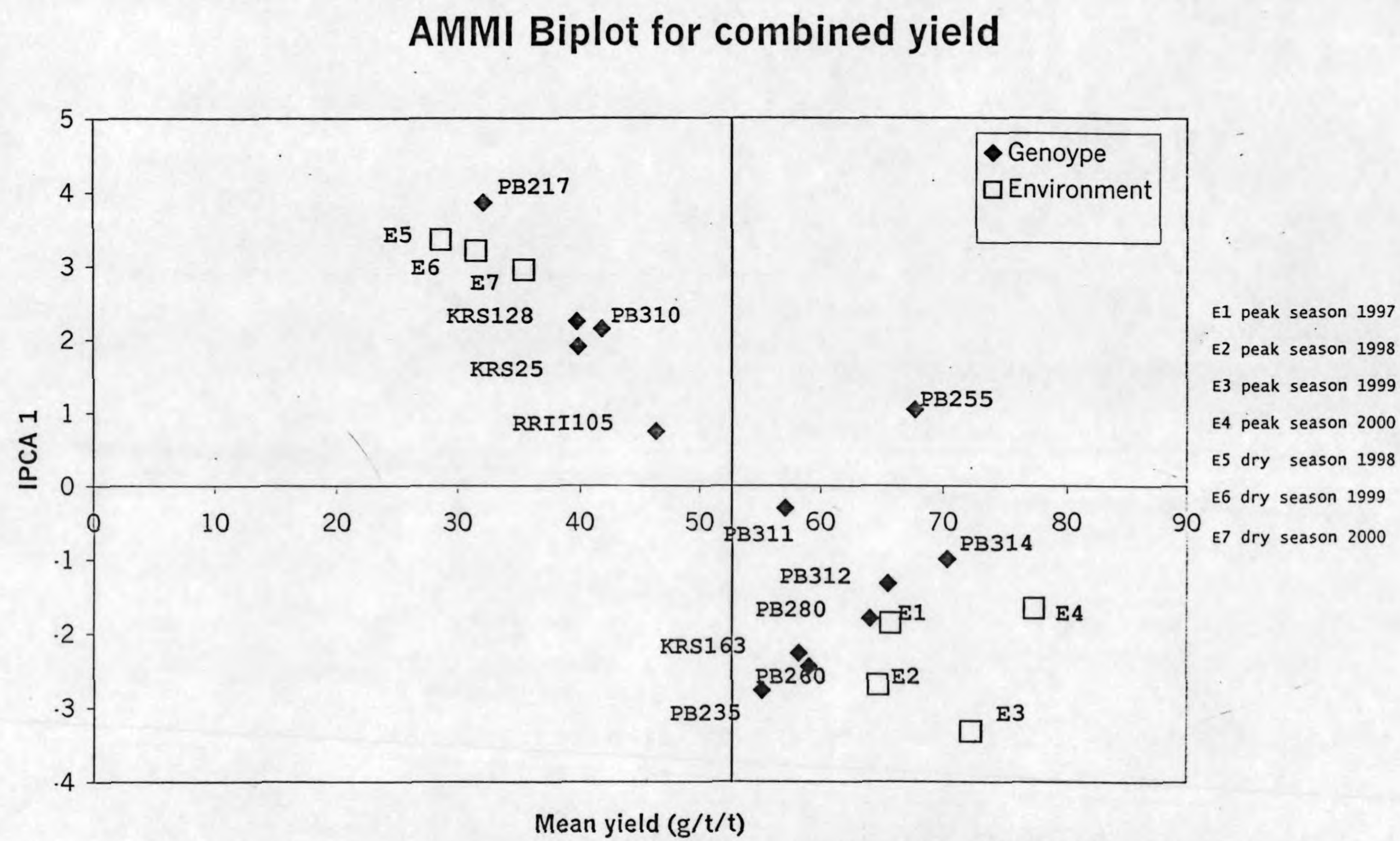
Sources of variation	df	Sum of squares	Probability
Total	38	3047.9692	0.0000***
Genotypes	12	2541.8125	0.0000***
Environments	2	302.6847	0.0000***
G X E interactions	24	203.4719	0.16395
Residual	24	203.4719	
Error	156	1008.02	
Total	194	4055.9899	

Table 7. ANOVA for combined yield during dry and peak seasons

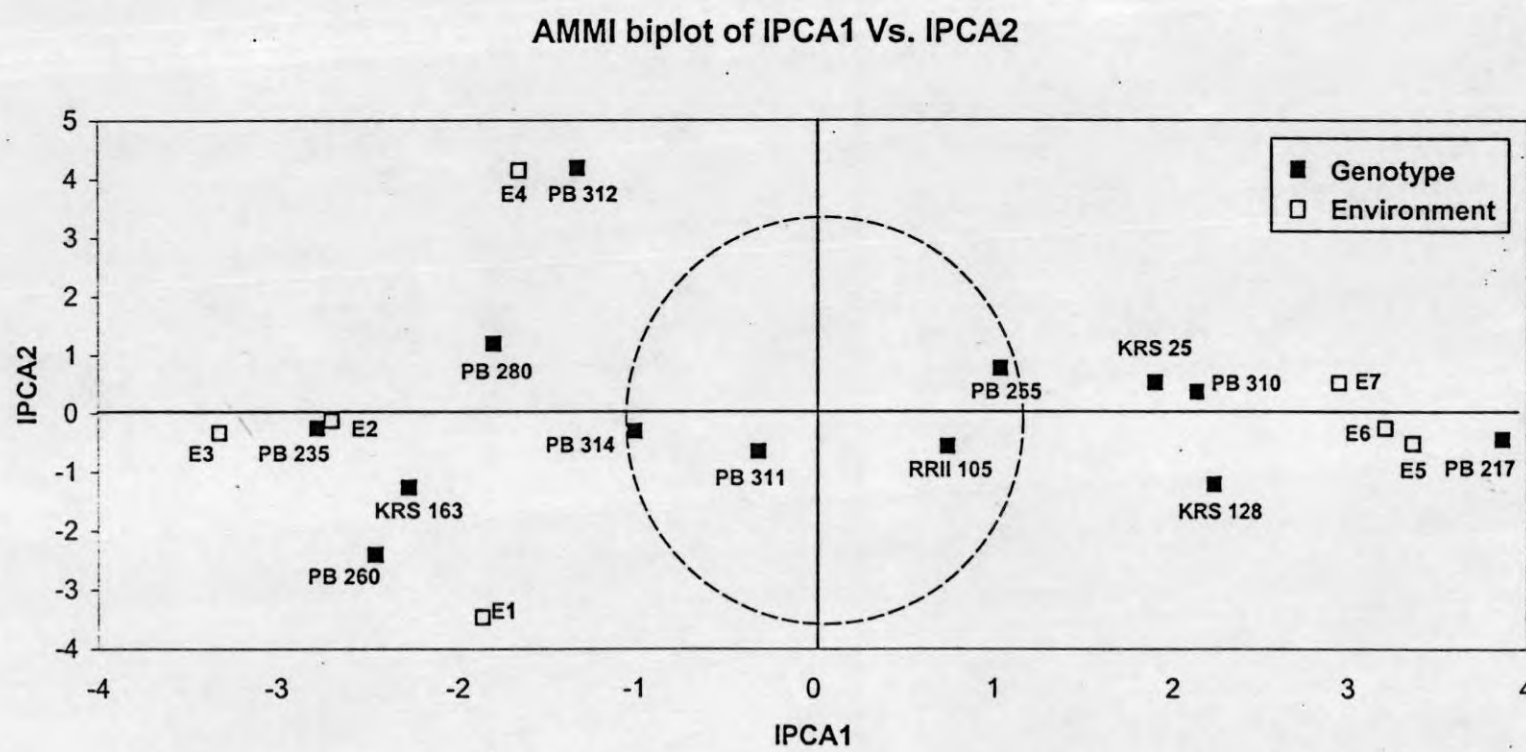
Sources of variation	df	Sum of squares	%	Probability
Total	90	51844.12109	100	0.0000***
Genotypes	12	12792.2937	24.67	0.0000***
Environments	6	34115.5336	65.80	0.0000***
G X E interactions	72	4936.29378	9	0.0000***
IPCA 1	17	2993.37305	5	0.0000***
IPCA 2	15	893.28314	1.7	0.00016***
IPCA 3	13	746.50159	1.4	0.00053***
Residual	27	303.13600		0.96235
Error	364	7228.60386		
Total	454	59072.72495		

Table 8. Mean and IPCA score for combined yield during peak and dry seasons

Clone	Mean (g/t/t)	IPCA 1	IPCA 2
PB 217	32.11	3.86	-0.44
PB 235	55.13	-2.77	-0.25
PB 255	67.68	1.04	0.77
PB 260	59.07	-2.45	-2.40
PB 280	64.00	-1.80	1.20
PB 310	41.81	2.14	0.37
PB 311	57.10	-0.31	-0.65
PB 312	65.44	-1.33	4.19
PB 314	70.32	-1.00	-0.30
KRS 25	39.82	1.90	0.53
KRS 128	39.70	2.24	-1.20
KRS 163	58.22	-2.27	-1.26
RRII 105	46.38	0.74	-0.56
Envt. 1	65.66	-1.86	-3.46
Envt. 2	64.65	-2.69	-0.12
Envt. 3	72.22	-3.32	-0.33
Envt. 4	77.28	-1.66	4.15
Envt. 5	28.56	3.36	-0.51
Envt. 6	31.47	3.21	-0.25
Envt. 7	35.36	2.95	0.52



AMMI Biplot for combined yield
Genoype
Environment
IPCA 1
Mean yield (g/t/t)
5
4
3
2
1
0
-1
-2
-3
-4
0
10
20
30
40
50
60
70
80
90
PB217
E5
E6
E7
KRS128
PB310
KRS25
RRII105
PB255
PB311
PB314
PB312
PB280
E1
E4
KRS163
PB280
E2
PB235
E3
E1 peak season 1997
E2 peak season 1998
E3 peak season 1999
E4 peak season 2000
E5 dry season 1998
E6 dry season 1999
E7 dry season 2000


AMMI biplot of IPCA1 Vs. IPCA2
IPCA2
IPCA1
Genotype
Environment
E4
PB 312
PB 280
E2
E3
PB 235
KRS 163
PB 260
E1
PB 314
PB 311
PB 255
RRII 105
KRS 25
PB 310
KRS 128
E7
E6
E5
PB 217
5
4
3
2
1
0
-1
-2
-3
-4
-4
-3
-2
-1
0
1
2
3
4