Improving the spatial arrangement of planting rubber (Hevea brasiliensis Muell. Arg.) for long-term intercropping

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Abstract
Fluctuation in rubber prices has been a serious problem to growers and intercropping with economically important crops offers a practical solution to this issue whilst increasing overall productivity. However, shade given by the rubber canopy limits possibilities of incorporating other sun-loving crops into rubber-based systems. Therefore, the present study aimed to determine suitable spatial arrangements for planting rubber in order to facilitate long-term rubber-based intercropping systems. A field experiment was established in a commercial estate in the Kalutara district of Sri Lanka with five systems of spatial arrangement comprising: (1) single row; (2) double row; (3) three row systems; as well as, (4) three plant triangular; (5) four plant square cluster systems of planting. Planting density of rubber remained constant across the treatments and systems were assessed for a period of 9 years. Plants in single row alleys and in cluster systems performed better than those in other systems with respect to growth and yield. However, canopy closure was rapid in these systems resulting in poor light penetration. Both double row and three row systems provided the highest unshaded area and hence light penetration. Considering overall performance, the double row system was identified as the best system for long-term intercropping. In view of improving the plant growth in the double row system and further facilitating long-term intercropping, a revised version of the double row system was proposed reducing the planting density of rubber.

Keywords: Hevea; Plant spatial arrangements; Planting systems; Intercropping

1. Introduction
Being a plantation crop, rubber (Hevea brasiliensis Muell. Arg.) plays an important role in the countries where it is grown. For instance in Sri Lanka, it provides a significant share in export earning (2175 million rupees in 2000 (Plantation Sector Statistical Pocket Book, 2001)) and employment to over 500,000 people (CARP, 1992). However, poor market prices together with increased urbanization in traditional rubber growing areas has caused a drastic decline in rubber cultivation during the recent past. The total area under rubber in Sri Lanka has dropped from $161 \times 10^3$ to $157 \times 10^3$ ha during 1995–2000 and few people have been interested in either re- or new-planting of rubber on their lands (Plantation Sector Statistical Pocket Book, 2001). Price fluctuation of basic commodities such as rubber is inevitable, however, the
The downfall of an industry should not be allowed on the basis of short-term price decline. Global demand for natural rubber has never shown any sharp decline and it tends to increase annually (IRSG, 2002) with increase in population and people’s living standards. In addition, rubber is a timber crop which is important in long-term atmospheric carbon fixing. If rubber cultivation is threatened, few if any, alternative crops could be found to satisfy the country’s need, and particularly for the terrain where rubber is grown (Stirling, 2001). Therefore, it is necessary to identify practical approaches to address the above issues. Intercropping rubber with financially attractive crops would be the ultimate answer if it reduced risk on any crop. In addition, intercropping systems carry spatial agronomic advantages which may be achieved from the more efficient use of light in heterogeneous canopies of intercrops than in homogeneous canopies of sole crops (Tournebize and Sinoquet, 1995; Rodrigo, 1997; Rodrigo et al., 2001).

Unlike in natural ecosystems, crops with direct economic benefits are grown in intercropping systems which should be designed to minimize inter-specific crop competition. Such measures are extremely important with combinations of perennial crops since crop competition tends to increase over the time with plant growth. For instance, increased competition between timber crops and rubber has been evident from the fourth year of growth onwards (Rodrigo et al., in press). Unlike random planting, the use of improved spatial planting arrangements would facilitate less inter-specific competition and maintain efficient resource capture in the system.

In general, intercropping practices in rubber have been limited to the immature phase when rubber plants are not large enough to capture all available resources. It has been shown that the fractional interception of radiation of a two-and-half-year-old sole rubber crop was only ca. 30% and this was improved largely with the addition of banana (Rodrigo et al., 2001); as many as three rows of banana could be planted between two rows of rubber (Rodrigo et al., 1997). Most other crops generally do not grow as tall as rubber; hence with the development of the rubber canopy, the practicality of interplanting crops which demand fairly high amounts of radiation is not feasible (Rodrigo, 2001). Most economically important crops cannot be grown under the heavy shade of a mature rubber crop. It is not always possible to advise farmers to select shade tolerant species for long-term intercropping. Should rubber-based cropping systems be diversified for improved returns, traditional planting systems of rubber will have to be altered in order to allow greater light penetration to facilitate intercropping with economic crops.

In this context, the present study was aimed at determining suitable spatial arrangements for planting rubber to provide sufficient radiation for long-term intercropping, thereby allowing rubber farmers to select economically important crops at their discretion.

2. Materials and methods

2.1. Planting material

Fifteen-month-old healthy seedling nursery plants of rubber were selected to raise plants for the experiment. Seedling plants were bud grafted with one of the most popular clones in Sri Lanka, RRIC100. Successfully grafted plants were then transplanted in the experiment in the form of bare root budded stumps. The full protocol for raising bare root budded stumps is given in Seneviratne (2001).

2.2. Experimental layout

The experiment was established in 1992 in the Uskvally estate situated in Kalutara district of Sri Lanka. The area was in the low country wet zone at a latitude of 6°30’–7°00’N and longitude of 80°00’–80°30’E. Treatments comprised five spatial arrangements of planting rubber (Fig. 1): (1) traditional single row system (SR) with an interrow spacing of 8.1 m and an interplant spacing of 2.4 m; (2) double staggered row system (DR) with an interplant spacing of 2.4 and 14.1 m gap between double rows; (3) three staggered row system (TR) with an interplant spacing of 2.4 and 20.1 m gap between triple rows; (4) three plant triangular cluster system (CT) with an interplant spacing of 2.4 and 14.1 m gap between double rows; (5) four plant square cluster system (CS) with an interplant spacing of 2.4 m within clusters and 7.75 m between the mid-point of clusters; (5) four plant square cluster system (CS) with an interplant spacing of 2.4 m within clusters and 8.9 m between the mid-point of clusters. Planting density was constant at 500 trees/ha in each
treatment. In row planting arrangements, i.e. SR, DR and TR, other crops could only be planted in between the row systems, whilst in cluster systems, i.e. CT and CS, other crops could be planted on any side around the clusters. Treatments (spatial arrangements) were laid out in three randomized blocks in an area of ca. 5 ha. Each block comprised one set of all five treatments in an area of ca. 1.6 ha.
2.3. Crop husbandry

Fertilizer application was conducted as per the recommendations of the Rubber Research Institute of Sri Lanka (Samarappuli, 2001). In brief, rubber plants were fertilized with a mixture of urea 26%:rock phosphate 50%:muriate of potash 24%. Before planting, 50 g of the mixture together with 100 g of rock phosphate and 10 g of kieserite was applied to each planting hole. During the first year, 275 g of the mixture with 50 g of kieserite was applied to each plant in four split doses. From the second year onwards, kieserite, i.e. the Mg source, was replaced by dolomite. In the second, third, forth, fifth and sixth years, 75, 100, 100, 150 and 150 g of dolomite was applied, respectively, as a single dose per plant separately from the main mixture. With respect to the mixture, 550 g was applied to each plant in the second year of planting in four split doses. In the third and forth year after planting, 800 g of the mixture was applied in each year in three split doses. Similarly in three doses, 1100 g of the mixture was applied in the fifth and sixth years of planting. After the commencement of tapping, i.e. after 6 years, each tree was given 800 g of the mixture and 100 g of kieserite annually in a single dose. The leguminous ground cover, Desmodium ovalifolium, which had been established before the experiment, was maintained throughout the period for soil conservation and weed control; however any weeds that grew over the cover crop were removed periodically.

2.4. Measurements

All measurements were confined to the center part of the plots and plants at the boundaries were disregarded in assessments. Considering the nature of the spatial arrangement, the plot size of each treatment, hence the number of plants could not be fixed. For instance, the plots of double and three row systems of planting (i.e. treatments 2 and 3) was kept larger and had more plants in order to maintain a reasonable number of effective trees in addition to boundary rows. Therefore, the number of plants used for continuous monitoring per treatment varied among treatments with 10 in SR, 20 in DR, 24 in TR, 12 in CT and 16 in CS. Plant girth at the height of 150 cm from the bud-grafted union were measured yearly for the period of 9 years. At maturity, i.e. 6 years after planting (YAP), bark thickness at the height of 150 cm was measured for 4 years on a yearly basis with a standard bark gauge (And Mattson, Sweden). Canopy spread along the gap between the row/cluster systems was assessed for three consecutive years from 7 YAP. The distance of the spread of branches of rubber trees was determined using a pole placed vertically touching the end of the branches and taken as the shaded distance. Then the unshaded distance, i.e. the distance without any branches was calculated by subtracting the shaded distance from the total distance between the row/cluster systems. The unshaded distance was transformed to unshaded percentage area with the knowledge of overall geometry of the plant arrangements in each treatment. Transmitted radiation across a horizontal profile of each treatment (at 0.9 m intervals) was measured together with a measurement under the open condition using a ceptometer 9 YAP (Delta-T Devices Ltd., UK) for 2 days and during the period 11:00–13:00 h. The number of trees that survived and were exploited for latex (i.e. trees with a girth of 45 cm or above at 120 cm height) were assessed at 9 YAP. A tapping system of half spiral cut every 3 days during the first year of tapping (i.e. 1/2S D/3 in international notation) and then on every other day (i.e. 1/2S D/2 in international notation) was practiced for latex harvests. Latex yield of each treatment was measured as the actual latex yield collected on each harvested day from individual treatment plots for a full year 9 YAP.

2.5. Data analysis

Data sets were analyzed by analysis of variance of randomized blocks using the Proc. ANOVA procedure of the SAS statistical package (SAS Institute, Cary, NC). Standard error of means was estimated and any linear changes in the mean values over the time assessed through simple linear regression procedure.

3. Results

In general, girth increase of rubber plants in all treatments was biphasic with initial rapid linear increase (i.e. on average, 8.2 cm per year) until 6 years after planting (YAP) and thereafter marginal
increases approaching a plateau (Fig. 2). The initial rate of girth increase, i.e. during the linear phase of the first 6 years, was significantly greater \( (P < 0.05) \) in the cluster systems than in the double and three row systems. Mean initial rate of girth increase in descending order was 9.09, 8.66, 8.15, 7.58 and 7.40 cm per year for triangular cluster (CT), square cluster (CS), single row (SR), double row (DR) and three row (TR) systems, respectively. Depicting the initial rate of girth increase, rubber trees in the cluster systems showed improved final growth over the traditional single row planting system (SR) with the mean value for the CT system differing significantly \( (P < 0.05) \) by ca. 7% at the end of 9 YAP. The growth of the TR system was always poor and by end of the experimental period, it was the only system with a mean girth below 50 cm. Mean girth of DR system was less than that of the traditional SR by 3.3 cm at 9 YAP, however, the difference was not statistically significant. Similar to the girth values, bark thickness was lowest in TR systems, whilst highest values were recorded in cluster systems (Fig. 3). However, for the period under consideration, the mean rate of increase in bark thickness was similar among treatments with an average value of 0.76 mm per year.

Percentage casualties of rubber plants in cluster systems were greater than those in other systems with no casualties in the traditional SR system (Table 1). Percentage of weak plants was highest in the TR and then in the DR systems, whilst no weak plants were found in other treatments. Traditional SR system showed the greatest number of plants affected with tapping panel dryness (TPD), however, differences were not statistically significant. Percentage of trees under tapping was calculated subtracting the percentages of casualties, weak and TPD plants from the original planting density and, though not statistically different, the highest value was recorded in the SR systems.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Casualties (%)</th>
<th>Weak plants (%)</th>
<th>Plants with TPD (%)</th>
<th>Trees in tapping (%)</th>
<th>Yield per hectare (kg/ha)</th>
<th>Yield per tree (g/t/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR</td>
<td>0.00</td>
<td>0.00</td>
<td>9.29</td>
<td>90.71</td>
<td>1530.20</td>
<td>29.33</td>
</tr>
<tr>
<td>DR</td>
<td>11.43</td>
<td>2.56</td>
<td>0.00</td>
<td>86.00</td>
<td>1179.93</td>
<td>23.90</td>
</tr>
<tr>
<td>TR</td>
<td>10.47</td>
<td>5.13</td>
<td>2.19</td>
<td>82.22</td>
<td>1063.70</td>
<td>22.65</td>
</tr>
<tr>
<td>CT</td>
<td>21.11</td>
<td>0.00</td>
<td>1.85</td>
<td>77.04</td>
<td>1379.63</td>
<td>31.12</td>
</tr>
<tr>
<td>CS</td>
<td>12.94</td>
<td>0.00</td>
<td>1.75</td>
<td>85.31</td>
<td>1368.32</td>
<td>28.34</td>
</tr>
</tbody>
</table>

SR: single row; DR: double row; TR: three row; CT: three plant triangular cluster; CS: four plant square cluster planting systems; TPD: tapping panel dryness of rubber trees.
Mean tree yield per day (g/t/t) was significantly different ($P < 0.05$) among treatments with the lowest value recorded in the TR system (Table 1). Similarly, the lowest value for overall yield on the basis of kilogram per hectare per annum (YPH) was recorded in the TR system. Nevertheless, YPH of all treatments was above 1000 kg and statistically similar.

Time-cause canopy spread of rubber towards the space available between alleys/clusters was observed and the greatest spread was recorded by the TR system (Table 2). At 7 YAP, the canopy of the TR system had spread over 3.7 m and additional 1 m by 9 YAP. Similarly, canopy spread of DR system was 3.68 m at 7 YAP and 4.71 m at 9 YAP. Canopy spread of the cluster systems and the SR covered the maximum distance available sooner than that of rest. As shown by the unshaded distance, by 7 YAP, virtually no space without canopy cover was available in both cluster systems, and even in the traditional SR system, only ca. 0.5 m was available at 9 YAP. The widest gap (over 10 m) without any canopy cover was found in the TR system followed by the DR system. Even at 9 YAP, the mean unshaded distance in the DR system was well over 4.5 m. Overall unshaded area (%) with respect to total land area showed a similar trend with highest values recorded in the TR and DR systems, respectively. In the traditional SR system, the final unshaded area was below 7%.

Continuous clear sky conditions could not be obtained when the radiation was measured due to moving clouds. This together with variation in solar angle to the row position of treatment plots resulted in increased standard error of means for percentage light penetration (Fig. 4). Overall light penetration in SR and CT systems was extremely poor with highest values recorded in both the DR and TR systems. Determined over the different positions in each treatment, the mean percentage light penetration was 8.5, 35.3, 53.9, 11.5 and 21 in SR, DR, TR, CT and CS treatments, respectively. Mean percentage of light penetration did not exceed 30% at any point measured in the SR and cluster planting systems, whilst it was always above 30% beyond 3.6 m from the rubber rows in both the DR and TR systems (Fig. 4).

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Summary of canopy spread in different rubber planting systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>7 YAP</td>
</tr>
<tr>
<td></td>
<td>Unshaded distance (m)</td>
</tr>
<tr>
<td>SR</td>
<td>0.75</td>
</tr>
<tr>
<td>DR</td>
<td>6.74</td>
</tr>
<tr>
<td>TR</td>
<td>12.65</td>
</tr>
<tr>
<td>CT</td>
<td>0.00</td>
</tr>
<tr>
<td>CS</td>
<td>0.13</td>
</tr>
</tbody>
</table>

SR: single row; DR: double row; TR: three row; CT: three plant triangular cluster; CS: four plant square cluster planting systems. Unshaded distance and area indicate the space available between rubber rows/clusters without the canopy cover, with respect to absolute distance and overall ground area, respectively. Shaded distance shows the distance covered by the canopy across the transect from the rubber trees. Term YAP refers to years after planting.
4. Discussion

Rubber is taller than most other economical crops grown under similar conditions. Therefore, success of intercropping rubber with other sun-liking semi-perennials or perennials depends mostly on the amount of radiation penetrating the rubber canopy. In general, the rubber canopy is quite dense allowing little radiation through to the understorey. According to Ibrahim (1991), only about 20% of incoming solar radiation is available under a 4–5-year-old rubber canopy. In intercropping systems, the heterogeneous nature of the canopy improves light use efficiency in the system (Rodrigo et al., 2001) however, if the understorey crop does not receive sufficient radiation, its agronomic performance, and hence the financial viability of the return, is dubious. For example, in the case of rubber, pepper has not provided sufficient yield under mature rubber canopies (Rodrigo, 2001). Having recognized the poor light penetration through the rubber canopy, rubber/tea intercropping system was designed with ca. 30% reduction of the standard density of rubber in order to provide improved light penetration, however, dramatic yield decline in tea was found after the sixth year of growth of rubber plants (Rodrigo, 2001).

The planting density recommended for the rubber crop in Sri Lanka, is 500 trees/ha. The present study aimed to find suitable spatial arrangements for planting rubber for improved light penetration in order to facilitate long-term rubber-based intercropping systems without compromising the planting density of rubber. Obviously, the TR system followed by DR system provided the highest unshaded area, hence light penetration, allowing the greatest area for intercropping. However, as indicated by girth development and bark thickness, growth of rubber, particularly in the TR system was reduced resulting in poor yields. Even in DR, growth of rubber was been affected, although this was not statistically significant. Cluster planting systems performed well in terms of girth expansion over the other systems, however casualties were greater and the ground was fully covered in the early stages of growth.

Since the canopy of the SR and cluster systems almost fully spread out, light penetration of these systems was extremely poor (i.e. less than 25%) and more or less the same across the gap between alleys/clusters. In the DR and TR systems, in agreement with canopy spread, light penetration improved dramatically beyond 3.6 m identifying the area that could be utilized in long-term intercropping. The distance covered by the rubber canopy across the transect in DR and TR systems was ca. 4.7 m at the same age (i.e. 9 YAP) and would expand further with tree growth. Therefore, light penetration would further reduce and its spatial distribution would change. However, light transmission in the present study was measured in the middle of the day and particularly at times when direct-light dominates over the defused-light. Light penetration through the canopy is stronger under defused- than direct-light. The fraction of defused-light is high under overcast conditions and at lower solar elevations (Monteith and Unsworth, 1990), hence overall percentage of light penetration is expected to be greater than the values recorded in the present study.

Based on the spatial distribution of light penetration across the transect of DR and TR systems, it could be appropriate to plant other crops in avenues leaving a gap of 3.6 m on either side of the rubber alley (i.e. double/three rows). However, should crops which provide early returns (e.g. tea in 2 years) be intercropped, the gap could be narrowed allowing more plants to be grown, and hence higher yields could be obtained. Also, canopy spread of the second crop together with cultural practices required, should be considered carefully in effectively utilizing the gap between crops.

Rubber yield per hectare per annum (YPH) was little affected by the various treatments, hence statistically comparable among spatial systems; however, the lowest yield was given by TR and highest by the traditional SR system. Latex yield per tapping at individual tree level (g/t/t) was significantly different among treatments with highest values recorded in the SR and CT systems. Number of tapping days remained the same across the treatments, hence YPH depended on g/t/t and number of trees being tapped. Mean percentage of trees being tapped was greatest in the SR system resulting in the highest YPH. As evident in previous studies, latex yield at individual tree level tends to decrease with increased planting density (Westgarth and Buttery, 1965; Rodrigo et al., 1995) and in the present study, the greatest number of casualties in CT might have resulted in the highest g/t/t diminishing the competition among trees. For a
given spatial system and certain limits of plant density. YPH is expected to be approximately constant due to an inverse relationship between the number of trees being tapped and g/t/t. Spatial distributions of trees in the cluster systems CT and CS were more or less the same; however, casualties were less in CS hence the greater number of trees being tapped and lower g/t/t lead to comparable YPH between CS and CT.

Practicality in field establishment and convenience for latex exploitation should also be considered in selecting spatial systems. If the gap between rows/cluster is wider, then field application of the system becomes increasingly difficult on small areas. Of the overall time taken for tapping, walking from tree to tree takes a large portion (Nugawela, 1991). Therefore, the time requirement for tapping can be reduced by changing the spatial arrangement of planting to reduce the walking distance. For a given density, if the gap between rows/clusters is increased by reducing the gap between trees within alleys/clusters, there will be more trees within a row/cluster resulting in a lower number of rows/clusters in the field planting. Undoubtedly, this will reduce the overall distance of travel required to be covered in a given area hence the time taken for tapping. Therefore, despite the difficulties in field establishment, systems with wider gaps are advantageous over those with narrower gaps with respect to tapping. Also in the case of sloped terrain, systems with wider gaps (i.e. avenue systems) require less terraces reducing the cost for land preparation. In addition, other agronomic advantages such as the feasibility of practicing intensive cultural methods for component crops in intercropping systems; acting as windbreaks; decrease in panel diseases of rubber with improved air circulation, have been recorded in avenue planting (Dijkman, 1951).

In spatial systems, competition among trees for resources can be separated into two categories, i.e. the competition within the alley/cluster and between alleys/clusters. If the space between plants is equal in all directions, less competition among plants for a given density may arise, e.g. in a square planting system, compared to the interplant competition in an alley planting systems. In equal distance arrangements, canopy closure is quicker than in avenue planting systems and there is little space available for cultivating any other crop. However, increase in competition of one dimension, i.e. either within or between rows/clusters, would be compensated by decreased competition in the other dimension within a certain limit beyond which growth will be affected. For instance, it was evident that growth and development of rubber trees in square and in avenue planting systems (2.4 m × 9 m) at a density of 450 trees/ha were similar (Chandrasekera, 1977). This together with greater space between rows indicated that avenue planting of rubber was preferred for intercropping over square planting.

Traditional single row avenue planting and cluster planting systems have minimum effect on rubber growth, however the space available for long-term intercropping was not sufficient. In contrast, improved space is available in both the DR and TR systems, however interplant competition within the double and three row systems is high and could not be compensated for by the decrease in competition between rows resulting in decreased rubber growth. In systems of intercropping with other perennials, the situation would be worse with added inter-specific competition. Therefore, the space given for plants within the double/three row systems has to be increased to a certain level to reduce interplant competition. With an additional row, it was obvious that crop competition in TR was greater than that in DR and, possibilities are limited in the TR system to provide sufficient space, particularly to the plants in the center row. Moreover, the amount of space given between triple rows may be greater than the space required for intercropping and also, this may not be practicable on small areas. As a whole, DR offers a practically feasible spatial system for incorporating perennials as rubber-based intercrops, provided the space within the double rows is increased. The gap between rubber rows (i.e. the avenue) in the presently recommended planting system for rubber/tea intercropping is 12 m and this is not sufficient to provide required light for long-term tea cultivation. Hence, with further a increase in gap between alleys, i.e. ca. 15 m, the DR system would provide a better system. In this regard, the density of planting rubber would have to be compromised, however this should not be a matter of concern, if economically important crops are intercropped. From the practical point of view, it is impossible to conduct another long field trail before making a recommendation to growers in this regard. Therefore, it is considered appropriate to issue a tentative
recommendation for an improved version of the DR system. Therefore, the authors suggest that 2.7–3 m should be considered as the appropriate space within the double rows (i.e. instead of 2.4 m), whilst a space of 15–18 m should be suitable between double rows.

Acknowledgements

We wish to thank the Rubber Research Institute of Sri Lanka (RRISL) for the funding and the management of the Uskvally estate for providing land for the experiment. Also, assistance given by Mr. L.S. Kariyawasam of the RRISL for the establishment of the experiment is highly appreciated.

References


