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Research article

Interplanting banana at high densities with immature rubber crop for improved water use

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Abstract – Consumptive water use of the rubber/banana intercropping systems was assessed. Five systems were tested; sole rubber (R) and banana (B) crops and three intercrops comprising additive series of one (BR), two (BBR) and three (BBBR) rows banana to one row of rubber. Planting density of rubber remained constant across the treatments, hence the rate of transpiration associated closely with the planting density of banana with ca. 140% increase from banana-rubber to banana-banana-banana-rubber intercrops. Although water use efficiency (WUE) at whole stand basis was comparable among treatments, water use efficiency of component rubber during the latter part of the experiment increased by 118% in intercrops compared to that of the sole crop. Amount of water transpired even in the banana-banana-banana-rubber intercrops was small by comparison to the water received from rainfall, hence in wet tropics with heavy rainfall, agricultural systems should be designed to enhance the productivity through increase water use with less emphasis on water use efficiency.

agro-forestry / plantation / water use / density

1. INTRODUCTION

Perennial tree crops such as rubber (*Hevea brasiliensis* Muell. Arg.) demands greater amount of per plant ground space at maturity, hence land-use efficiency and resource capture are poor during the establishment phase. Also, rubber requires long time lag to provide any economic return; for rubber it is ca. 5–6 years and poses significant problem to resource poor farmers. Intercropping with short-term cash crops such as banana provides a practical means to alleviate the problem allowing farmers to obtain early returns. Economic and social importance of rubber/banana intercropping in Sri Lanka has been elaborated at different stages [23, 25, 28]. In particular, agronomic compatibility of these two crops in intercropping has been well understood by the facts that this has been the most widely adapted intercrop by rubber smallholders in Sri Lanka [23] and growth of component crops has not been affected in rubber/banana intercropping even at high density planting [22].

Agronomic advantages in intercropping over sole cropping have often been attributed to the improved resource capture [24, 33, 34, 36, 37] resulted by heterogeneous crop canopies and/or root systems. Improved light capture together with light use efficiency in heterogeneous crop canopies is the largest and direct contributor for intercropping advantages [20] and was also evident in rubber/banana intercrop [24]. However such advantages in light-use could be mitigated by absence of other resources such as sufficient soil moisture [38], hence importance of water-use studies in intercrops cannot be totally ignored. The water use efficiency (WUE) of C_3 crops grown under trees is expected to be greater than that of the sole crop. This is because partial shading is likely to decrease transpiration to a greater extent than CO_2 assimilation which, in many cases, would be operating at, or close to, light-saturation for most of the day under field conditions [19, 29]. Nevertheless according to a review [18], WUE of intercrops varies widely and differs in a range of –42 to +99% from that of the respective sole crops.

Crop water use is determined by either direct or indirect estimates of water loss through transpiration. Transpiration rate can be estimated by the diffusion porometry from a knowledge of the major driving forces; vapour pressure deficit, D [1, 3], or D and radiation [5] using the Penman-Monteith equation [17] or determined indirectly by the soil water balance approach [35]. The soil water balance approach provides a good

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understanding of total water use of crops, but has potentially serious practical limitations in that accurate measurements of some of the parameters (e.g. deep percolation) are rather difficult to obtain. Also, it is difficult to use for evaluating the water use of component crops in intercropping systems. Among other techniques which include diffusion, small chamber gas analysis systems [14], deuterium labeling [4] and heat balance techniques [5], heat balance technique provides most accurate measurements with advantages of direct, continuous and non destructive nature of measurements. Although this technique is widely used for the woody perennials [5, 9], there are limited instances with field crops such as maize and potato [11]. This technique could be ideal for the water use studies of woody rubber crop, but has limited use for the rubber/banana intercrop since banana plants contain very high moisture levels in its tissues leading to erroneous in reading [19]. Use of Penman-Monteith equation for transpiration studies is quite popular since it estimates transpiration with reasonable accuracy and requires measurements which are generally combined with weather monitoring that is done anyway. An advantage of the Penman-Monteith equation is that it counts both D-driven adiabatic water vapour loss and irradiance driven diabatic transfer of water.

Generally, increasing canopy cover of crops increases total water use [39], but not proportionally, due to effects on the boundary layer conductance (g_a) which is one of the most important features of crop canopies determining the rate of evapotranspiration. Boundary layer conductance is dependent on properties of the vegetation and varies with cropping density. As density decreases, g_a per individual plant increases as a result of increase in the ventilation rate and turbulent exchange within the canopy of widely spaced stands. This suggests that transpiration rate is not linearly related to planting density and some researchers have used a power function to relate g_a to planting density in a spruce plantation [31].

No systematic studies have done before on rubber based intercropping and more specifically rubber/banana intercropping. This paper aims to show how the water use of rubber/banana intercrop explains its productivity and follows the works described earlier, i.e. effect on planting density [22] on growth and development of component crops and [24] on light use of the system. Basically, earlier papers showed the improved productivity and related light use of the rubber/banana intercrop over those of either component crop grown under the sole cropping condition.

2. MATERIALS AND METHODS

2.1. Crop establishment and basic layout of the experiment

The experiment was established under rain fed conditions in an area of 5 ha in Ratnapura, low country wet zone of Sri Lanka (6° 30'–7° 00' N and 80° 00'–80° 30' E). Five treatments, i.e. sole rubber (R), sole banana (B) and three intercrops comprising additive series of one (BR), two (BBR) and three (BBBR) rows of banana to one row of rubber, were laid out in four randomized blocks. The density of rubber was 500 plants ha^{-1} across the sole and intercrops with a spacing of 2.4 m × 8.1 m. Banana was spaced at 2.4 m × 2.4 m in the sole crop with a density of 1700 plants ha^{-1} and, 2.4 m along the row with varying spacing between rows in intercrops giving densities of 500, 1000 and 1500 plants ha^{-1} for BR, BBR and BBBR treatments, respectively. In order to maintain homogeneity, poly bagged plants of clone RRIC 100 [32] and tissue cultured poly bagged plants of cultivar "Kolikuttu", "AAB" triploid genome group and sub group "Silk" [30], were used as planting materials of rubber and banana, respectively.

2.2. Crop husbandry

Organic manure (i.e. ca. 5 kg poultry litter) was applied to each planting hole of banana before planting. Starting from 2 months after planting (MAP), ca. 750 g fertilizer (urea 2: super phosphate 1: muriate of potash 3) was applied to each plant with an interval of 4 months. Rubber was fertilized with a mixture of urea 26: rock phosphate50: muriate of potash 24. As a basal dressing, 50 g of the mixture together with 100 g of rock phosphate and 10 g of kieserite were applied to each planting hole of rubber. During the first and second years, 275 g and 550 g of the fertilizer mixture was applied per plant together with 50 g kieserite and 75 g dolomite, respectively.

2.3. Growth analysis

Harvesting was done in whole plant basis in each plot keeping ca. 4 months interval between 8 and 28 months after planting and with, two rubber and banana plants in respective sole crops and, two rubber plants and one banana plant representing the row position in intercrops. Both above- and below-ground components were separated and oven dried at 80 °C in a forced draught oven to a constant weight for dry weight analysis. Before the oven drying of leaves, leaf area measurements were carried out. In addition, coinciding with destructive harvesting, crop height was measured for ten plants of both crops in each treatment [22].

2.4. Climatological measurements

Environmental conditions, i.e. irradiance, air temperature, relative humidity, rainfall, wind-speed and direction, of the experimental site were monitored and hourly and daily values recorded by a automatic weather station (Campbell Scientific, UK) installed at the experimental site.

2.5. Estimation of water use

Water use, i.e. potential transpiration rates, Tr of sole crops and their components in the intercrop treatments were estimated using the Penman-Monteith equation (Eq. (1)) on weekly basis (mm wk^{-1}) [16, 17] for the daylight hours (i.e. 0600–1800 h). The BBR treatment was excluded in the measurements of stomata conductance hence estimation of transpiration was confined to the rest of the treatments. Total transpiration rates for the intercrop treatments were the sum of the transpiration rates of the component crops. Cumulative water loss by transpiration was calculated for all crops and their components by integrating weekly mean transpiration rates.

$$Tr = \frac{302\,400[(\Delta \cdot R) + \rho \cdot Cp \cdot D \cdot g_a]}{\lambda[\Delta + \gamma \cdot (1 + r_s \cdot g_a)]} \quad (1)$$

where,

R - intercepted radiation (W m^{-2})

ρ - density of air (1.183 kg m^{-3} at 25 °C)

Cp - mass specific heat of air (1010 J kg^{-1} K^{-1})

D - vapour pressure deficit (Pa)

g_a - crop boundary layer conductance (m s^{-1})

λ - latent heat of vaporisation (2.442×10^6 J kg^{-1} at 25 °C)

γ - psychrometric constant (66.5 Pa K^{-1} at 25 °C)

r_s - stomatal resistance (s m^{-1})

Δ - slope of curve of the relation between saturation vapour pressure and temperature, T (Pa °C^{-1}).

A multiplication factor of 302 400 was used to convert estimates from seconds to a week. The vapour pressure deficit, D was estimated as a function of temperature (T) and relative humidity (%RH), whilst "Δ" using T [13]. Values of %RH and T were obtained from the weather station (Campbell Scientific Ltd., UK) installed in the experimental site. The protocol of assessing the intercepted radiation (i.e. R in Eq. (1)) of component crops are fully described in a previous paper [24] and briefly, were estimated with solarimeters mounted above and below the canopies, ceptometer and pyranometer (SP1110 Campbell Scientific Ltd., UK).

2.5.1. Boundary layer conductance (g_a)

Although the general practice is to measure g_a in the field using leaf replicas [1, 21], it was limited in the present study by the massive size of banana leaves and difficulties in running sufficient number of replicas under varying microclimatic conditions at the field level. Among the available mathematical model, application of empirical relationships developed by Teklehaimanot and Jarvis [31] on association of g_a with planting density and wind speed for spruce forest, appeared to be practically feasible in the present study, hence further developed for improved compatibility. These relationships were,

$$g_a = a \cdot N^b \quad (2)$$

where,

N - planting density (plants ha^{-1})

a and b are constants which were estimated for spruce forest as 0.0153 and 0.3401, respectively.

And for a given density, g_a was found to be a linear function of wind speed 2 m (U) above the canopy,

$$g_a = c + d \cdot U \quad (3)$$

where, 'c' and 'd' are constants for a specific planting density.

By combining equations (2) and (3), the function 4 which is dependent on both planting density (N) and wind speed (U) was derived;

$$g_a = e \cdot U \cdot N^f \quad (4)$$

where, e and f are constants.

However, differences in leaf area density limit the use of equation (4) for other studies as the original model was based on spruce. Therefore, in order to overcome this limitation, the planting density (N) was substituted by leaf area index (LAI) in equation (4). Using LAI [27] and wind speed measurements at a height of 2 m above the spruce canopy [31], obtained from the same experimental site from which the original model derived, a new model (5) was developed to estimate g_a, whereby LAI was used in place of N. The procedure ' Proc. Nlin' of the SAS statistical package (SAS Institute Inc., Cary, NC, USA) was used to derive the LAI and U dependent function of g_a with $r^2 = 0.973$.

$$g_a = 0.048 \cdot U \cdot LAI^{0.381} \quad (5)$$

where,

U - wind speed at 2 m above the canopy (m s^{-1})

LAI - leaf area index.

Wind speed above the canopy (U) for each treatment was estimated from the wind speed measured by the anemometer (A100R Campbell Scientific Ltd., UK) with the knowledge of crop height [13].

2.5.2. Measurements of stomatal resistance (r_s)

Stomatal resistance (r_s) of both rubber and banana crops was measured periodically starting from 35 weeks after planting (WAP) using a steady state porometer (LI1600, Li-Cor, Lincoln, USA). Of rubber, two leaves within each whorl and from three plants in the sole crop and the BR and BBBR intercrops (i.e. two extreme densities) were used for r_s measurements. Since the leaves of rubber are hypostomatous, all measurements were restricted to the lower leaf surface. Three sets of measurements were carried out within a day, at 0900–1000 h, 1130–1230 h and 1430–1530 h. Each set of measurements was completed within an hour (in order to minimise variation coursed by change in microclimate) and so the number of treatments and replicates had to be restricted. As the trees grew, the number of whorls and plant height increased and so the number of plants that could be measured in each treatment had to be reduced to two after 73 WAP. Measurements were discontinued after 87 WAP, due to the difficulties in reaching the upper whorls of the rubber trees.

As was the case for rubber, three sets of diurnal measurements of r_s for banana were taken at 0900–1000 h, 1130–1230 h and 1430–1530 h and restricted to the sole crop, BR and BBBR treatments. Also, in order to cope with time limitation, measurements were restricted to two plants per treatment in the sole and BR treatments and, considering row positions in the BBBR treatment, measurements were taken for two plants in both the edge row (on the eastern side) and the central row. Leaves of banana are amphistomatous, with only ca. 25–30% of stomata on the upper surface [7, 15]. Preliminary studies showed that the adaxial to abaxial leaf surface ratio of r_s was 5.84 (± 2.06), which was similar in magnitude to the values recorded earlier [7]. Because of the limitations of time, measurements were restricted to the lower leaf surface and the ratio of adaxial: abaxial r_s was used to calculate total leaf resistance which was required to estimate crop transpiration on the basis of both resistances are running in parallel [17]. There was no significant variation of r_s in the active portion of the canopies of both crop (except the leaves under senescence), hence with the parallel principle, mean canopy r_s was weighted by the Leaf Area Index (LAI) of

Table I. Summary of mean dry matter and leaf area production of component banana and rubber under both sole- and inter-crop situations at 8 and 28 months after planting (MAP).

	Planting density of components (plants/ha)	Total crop density (plants/ha)	Total dry matter (kg/plant)		Leaf area index of components	
Component banana;			8 MAP	28 MAP	8 MAP	28 MAP
Sole crop	1700	1700	3.74	2.96	1.5	0.54
Single row intercrop	500	1000	2.58	3.13	0.27	0.22
Triple row intercrop	1500	2000	3.12	6.48	1.03	1.49
Component rubber;						
Sole crop	500	500	0.83	7.2	0.12	0.41
Single row intercrop	500	1000	0.96	12.32	0.13	0.62
Triple row intercrop	500	2000	0.91	14.28	0.12	0.69

the crop to estimate the crop r_s [i.e. crop r_s = (mean canopy r_s/LAI)].

2.6. Estimation of water use efficiency

Regression analysis of dry matter accumulation against cumulative water loss from both rubber and banana was performed in order to calculate the water use efficiency (WUE), derived from the slope of the regression, of both component crops and whole stands. Considering the growth pattern of banana, the analysis was separated in time corresponding to the mother and ratoon crop periods of banana. The WUE for the mother crop period was based on the whole plant growth analyses at 8, 12 and 16 Months After Planting (MAP) , whilst 20, 24, 28 MAP were for the WUE during the ratoon crop period.

Since Fusarial wilt caused severe loss of productivity in the sole banana crop by final harvest [22], WUE of this treatment during the ratoon crop period was based only on data from two harvests.

2.7. Soil water measurements

Soil water content for all cropping practices was monitored periodically using a neutron probe (Model 50 1DR, CPN, USA). Three access tubes, each of 2 m length, were installed in each replicate plot of the sole rubber and three intercropping treatments and were placed at an equal distance from the centre of rubber rows. In the sole banana treatment, however, only two tubes, one mid-way between rows and the second within the row and between banana plants, were installed. In each tube, the neutron count ratio (i.e. the ratio of counts to standard counts) was recorded at 0.2 m intervals between a depth of 0.4 to 1.6 m, using a 16 second counting time at each depth. The count ratio was converted to volumetric moisture content by applying the field calibration curve derived at the site.

3. RESULTS

3.1. Biomass productivity

Total dry matter productivity and the leaf area index increased with the increase in planting density and over the time. Being a perennial plant, this was more prominent in the component crop rubber compared with that in banana of which the life time of individual sucker is seasonal (Tab. I). There was no sign of any detrimental effect on either component crop in any intercropping system. More interestingly, all intercrops, particularly the high density BBBR system showed an improved growth in component crops. Details of the crop development were discussed in pervious papers [22, 24].

3.2. Transpiration

The rate of transpiration (Tr) and cumulative water use (ΣWU) were closely associated with the planting density (Fig. 1), with the B and BBBR treatments giving similar values of Tr, particularly during the early stages of the experiment. The highest Tr was recorded in the BBBR treatment with the mean Tr over the period of measurement and ΣWU of 10.5 mm week^{-1} and 922 mm, respectively. All treatments, with the exception of the sole banana crop, showed a marginal increase in Tr over the experimental period of 0.03–0.04 mm week^{-1}. Although the values of Tr in the sole banana crop were similar to the BBBR treatment during the mother crop period, Tr declined dramatically during the ratoon crop period to values similar to those of the sole rubber crop. By the end of the experimental period, the absolute rates of Tr were 4.9, 5.9, 9.4 and 16.9 mm week^{-1} in the R, B, BR and BBBR treatments, respectively. Also, total water use in the R, B, BR and BBBR treatments was 172, 726, 384 and 922 mm, respectively (Fig. 1b).

Values for Tr and ΣWU of component crops in each intercrop and sole crops are summarised in Figure 2. Tr of rubber showed a weekly increase of 3–4%, whilst that of banana was generally static during the experimental period. However, values recorded for banana was greater than those for rubber. During the initial stage of the experiment, Tr of component rubber in the intercrops (BR and BBBR treatments) was higher than that of the sole rubber crop, but all treatments showed similar values towards the latter part of the experiment. In the case of banana, the Tr of BR gave the minimum value at any given time, reflecting the effects of planting density on water use. The maximum value achieved by banana in the BR treatment was less than 50% of that of the BBBR crop for the same time point.

3.3. Water use efficiency

Water use efficiency (WUE) on a whole stand basis, remained rather constant among treatments throughout the experimental

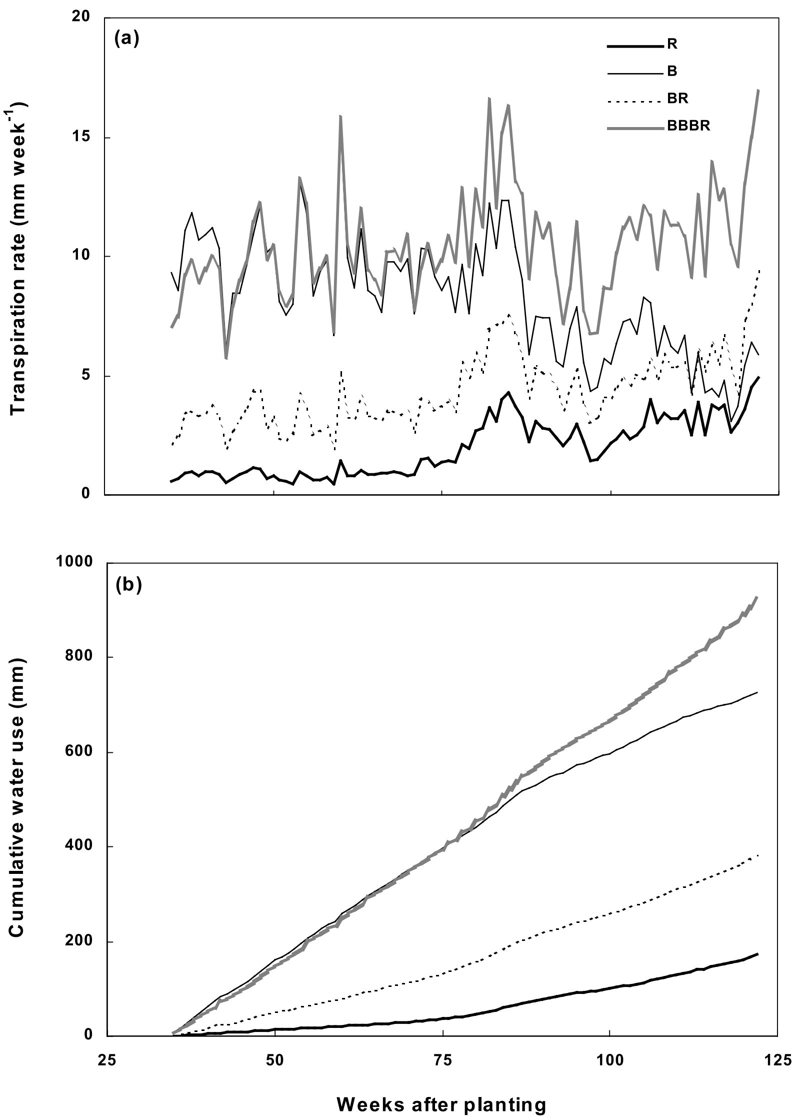

Figure 1. Seasonal time-course variation in (a) transpiration rate, and (b) cumulative water use in cropping systems for the period 35 to 122 weeks after planting. Treatment codes R, B, BR, and BBBR refer to the sole rubber and banana crops and single and triple row banana/rubber intercrops, respectively.

period with mean values of 2.2 and 1.84 g mm^{-1} m^{-2} for mother and ratoon crops periods, respectively (Fig. 3). Similarly, WUE of component banana also showed no significant difference between treatments. Although values of WUE for the mother crop of component banana were consistently greater than those during the ratoon crop period, the effect was not significant due to the relatively high variability of the data. Intercropping only during the later stages of growth (i.e. during the ratoon period) resulted in a significant ($P < 0.05$) and more than a two-fold increase in the WUE of the component rubber in intercrops compared to that of the sole rubber crop treatment.

3.4. Stomatal resistance

Seasonal variation of stomatal resistance (r_s) together with climatic conditions are shown in Figure 4. The climatic factors are summarized for periods of seven days prior to each r_s measurement. Further, each r_s value represents the mean of measurements taken at three times during the day (0900–1000 h, 1130–1230 h and 1430–1530 h), although on some days (indicated by the arrows) measurements were incomplete due to rainfall. Values of r_s of component rubber are presented for the period up to 606 days after planting (DAP) since no measurements were made after this day due to difficulties in sampling the tall rubber canopy. Of banana, no significant difference of r_s observed between row positions of the BBBR intercrop, hence values were combined to give a mean value for the treatment easing comparisons with B and BR treatments. On most days, r_s of the sole crop banana was below that of the intercrops and the mean value for the ratoon crop period, when the majority of measurements were made, was significantly ($P < 0.001$) lower in the B than in the intercrop treatments. Also, the overall

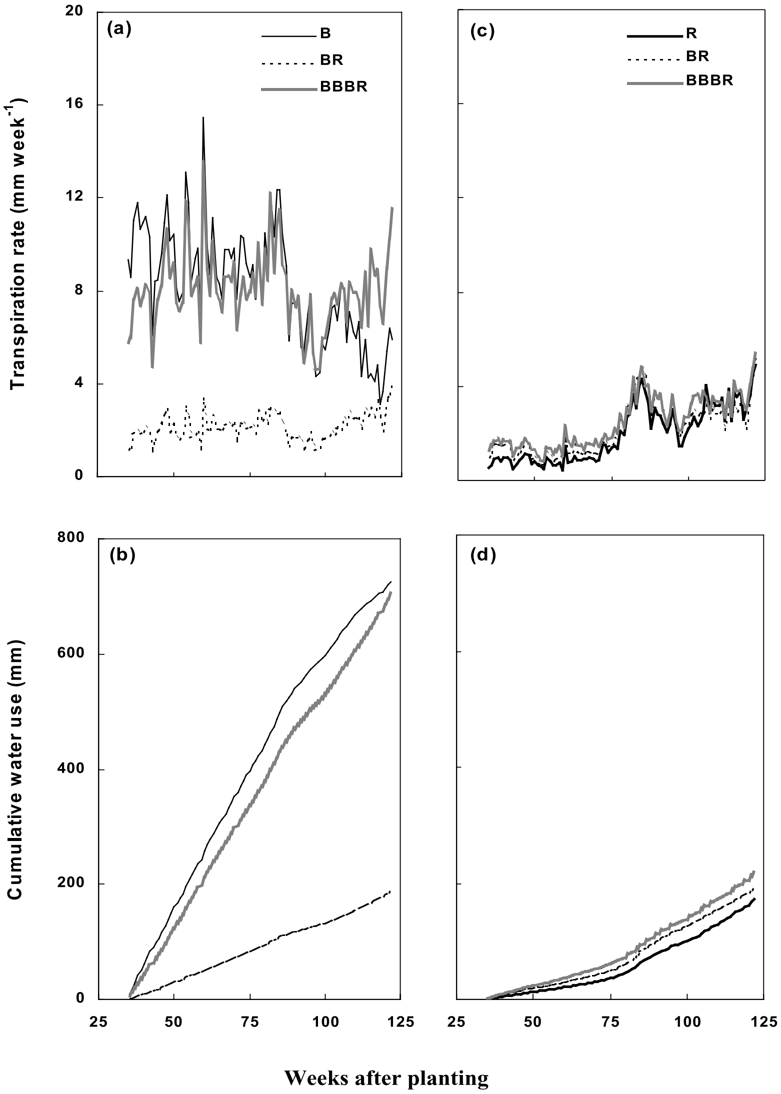

Figure 2. Seasonal time-course variation in transpiration rate and cumulative water use for the period 35 to 122 weeks after planting in component banana (a, b) and rubber (c, d) crops, respectively. Treatment codes R, B, BR, and BBBR refer to the sole rubber and banana crops and single and triple row banana/rubber intercrops, respectively.

mean r_s of rubber was significantly greater ($P < 0.001$) in the BBBR than in the BR and R treatments. However, the magnitude of the difference amongst treatment means of both crops was less than 0.6 s cm^{-1}. Although there was no clear relationship between daily mean r_s and climatic conditions, closer examination of the diurnal measurements showed that greater r_s of both crops during mid day than at other periods after a relatively dry period.

3.5. Soil moisture content

As shown in Figure 5a, volumetric moisture content (θv) of the soil exceeded 5% in all treatments during a major period of the study, except 590, 725 and 801 DAP. Overall, θ_v among treatments did not differ significantly, with mean values of 10.57, 9.45, 9.58, 10.27 and 10.58% in the R, B, BR, BBR and BBBR treatments, respectively. The θ_v in the vertical profile, however, increased significantly ($P < 0.001$) with increasing depth and at a rate of 2.8% cm^{-1} (Fig. 5b).

4. DISCUSSION

Intercropping provides a means of maximizing resource capture and this is particularly important in immature phase of rubber plantation since planting density of rubber has been determined for the growth requirements in the mature phase. Therefore, transpiration rate (Tr) and cumulative water use (ΣWU) of the sole rubber crop were extremely poor and it increased with intercropping directly following the planting

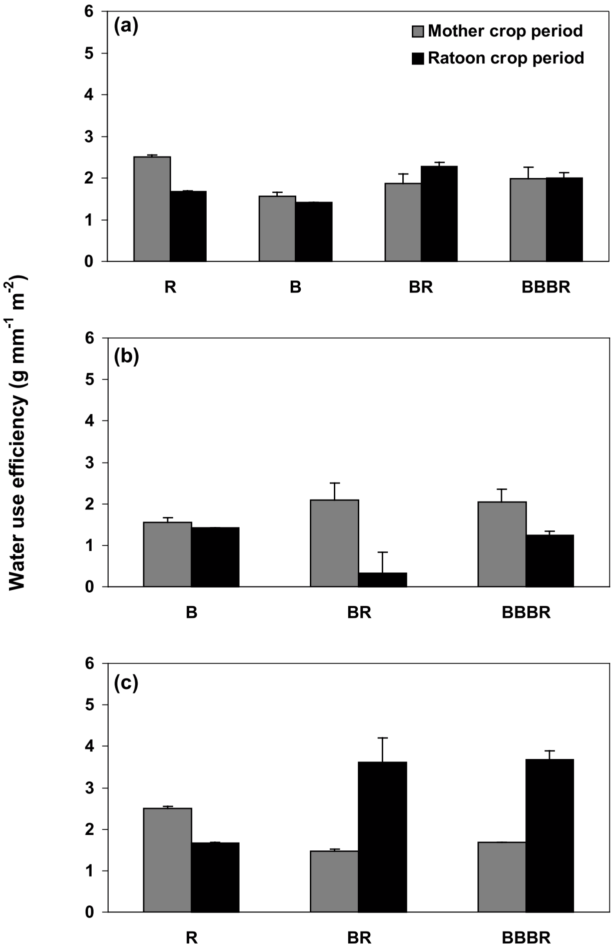

Figure 3. Water use efficiency representing both the mother and ratoon crop periods of banana; (a) is for the whole crop, whilst (b) and (c) are for component banana and rubber, respectively. Error bars represent the Standard Error of the slope of the regression analysis between cumulative dry matter and water use. Treatment codes R, B, BR, and BBBR refer to the sole rubber and banana crops and single and triple row banana/rubber intercrops, respectively.

density (Fig. 1). For example, both Tr and ΣWU in the sole (B) and component banana in the BBBR treatments differed only slightly because of a close similarity in density, whilst for component rubber, where planting density remained constant across treatments, there were only slight differences in Tr and ΣWU between the sole crop and intercrops (Fig. 2).

Although the Tr is related to the planting density, LAI is the important factor which determined the amount of water use. Leaf area index increased with increasing crop density in the present (Tab. I, [22]) and previous studies [10, 12] and the component banana with its greater LAI, transpired and used more water than component rubber (Fig. 2). Being a short term crop, planting density of sole banana was greater than that of rubber and was designed to capture more resources. Therefore, crop transpiration was predominantly controlled by the LAI which played two major roles in the transpiration process; (i) increasing total intercepted radiation which is represented by the diabatic component of the Penman-Monteith equation and (ii) increasing total conductance or reducing resistance. The dependency of transpiration on the LAI of crops has been shown early using a similar approach to estimate transpiration [26], and the slight increase in transpiration of the component rubber with increasing banana density in the intercrops could therefore be attributed to an increase in leaf area per plant [22].

Although data on quantified consumptive water use of crops in wet zone of Sri Lanka are lacking, mean evaporation based on standard class "A" pan in the rubber growing areas in the wet zone varied 2.8–4.6 mm day^{-1} [6]. With added crop and boundary layer resistances over free surface evaporation, it is not surprising to observe the low Tr values in the present study. Measurements based on irrigation water supply estimated the total daily consumptive water use of the banana crop to be between 2.8 and 4.2 mm, depending on the soil cover and the available soil moisture level when irrigation was applied [2]. Transpiration rates of groundnut have been shown to vary between 6.2 and 7.4 mm day^{-1} [3], which exceed the values in the present study by a factor of at least six. This may be due to differences in LAI which was 7–8 for groundnut, whilst in the present study LAI never reached 2.5, even in the highest density stand [22]. In addition, the mean saturated vapour pressure deficit recorded in the groundnut study [3] was ca. three times higher, compared to that of the present study confirming reasons explained before for the lower rates of transpiration.

On a whole crop basis and at a component crop level, the WUE of the various treatments was fairly consistent throughout the mother and ratoon crop periods, with the exception of the sole rubber crop which showed a significant decline ($P < 0.05$) in WUE during the ratoon period of banana. WUE is rather site specific due to its dependency on environmental factors [19], and so difficulties arise in comparing the present results with those of other studies. However, similar values have been cited for banana [8] and for perennial pigeonpea in India [19]. The increased WUE of rubber in the BBBR treatment relative to the sole crop during the ratoon crop period suggests that component rubber benefited more than banana from intercropping, possibly due to microclimatic amelioration. Changes in the microclimate of intercrops relative to sole crops may favour WUE since partial shading, particularly of C_3 crops, may reduce transpiration more than CO_2 assimilation [19]. Evidence of changes in the WUE of intercrops relative to sole crops may be both positive and negative, although many studies show an improved WUE of intercrops [18].

In addition to the rubber and banana, a ground cover crop *Pueraria phaseoloides* was present and its contribution to total water use was not examined in this study. The level of abundance of the cover crop depended on the cropping system, with more dense cover in the lower density crops due to the dependence of growth on the space available and transmitted radiation. Although total water consumption increased with increasing crop density, soil water content remained unchanged across treatments. This suggests that the cover crop may have acted as a sort of buffer, such that in the low density crops more water was transpired by the cover crop than at higher densities, where a greater proportion of available soil moisture was channeled through the rubber and banana components.

With no irrigation provided, the major source of water to the system was rainfall, as a rise in ground water cannot be

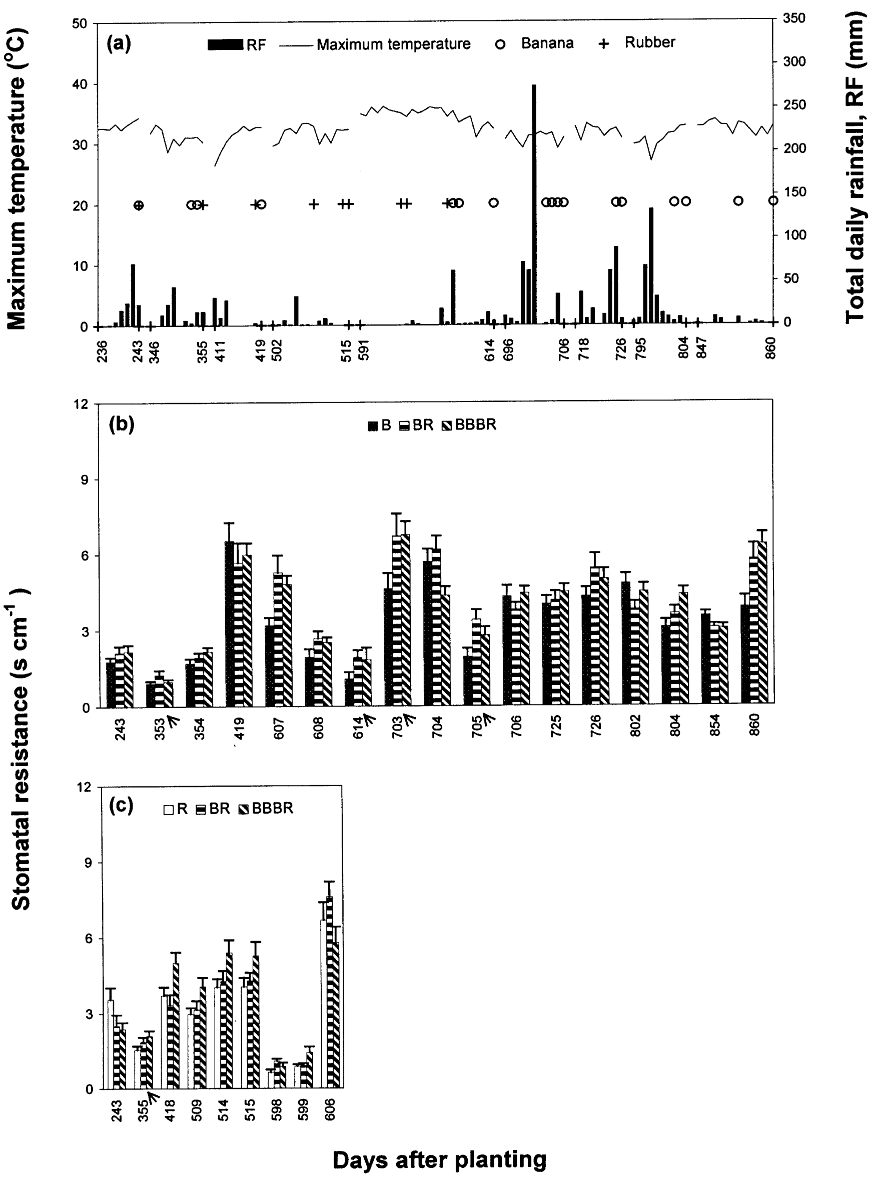

Figure 4. Summary of (a) the environmental conditions (maximum temperature and rainfall) for the period of seven days prior to each set of measurements and the seasonal time-course variation of stomatal resistance of (b) banana and (c) rubber. Dates of measurements on banana and rubber are indicated by the symbols 'o' and '+' in (a), respectively, whilst incomplete diurnal sets of measurements are marked by an arrow in (b) and (c). Error bars represent the Standard Error of means for all measurements on a particular day at leaf level. Treatment codes R, B, BR, BBBR refers to the sole rubber and banana crops and single and triple row banana/rubber intercrops, respectively.

expected to a great extent. Compared to the total amount of water received from rainfall over the period of the study, i.e. over 8000 mm [22], the percentage of water lost by transpiration was only 10.8, 4.5, 8.5 and 2% in the BBBR, BR, B and R treatments, respectively. Some rainfall is lost by evaporation of intercepted water by the canopy, which has been cited as 3 to 20% for sparse to complete canopies [35]. Even though the cover crop would have used some water, the results indicate that the amount of water lost from the system without being captured by the crops was substantial. Also being in the wet zone of the country, the rainfall was in abundance in the experimental area (Fig. 4, [22]), therefore unless for short durations, water was not a major limiting factor for crop growth in the present experiment. It appears, therefore, that improvements in the WUE of cropping systems are not so important in tropical wet zones with heavy rainfall and instead, agricultural systems should aim to maximise total crop water use in order to improve production, with less emphasis on WUE.

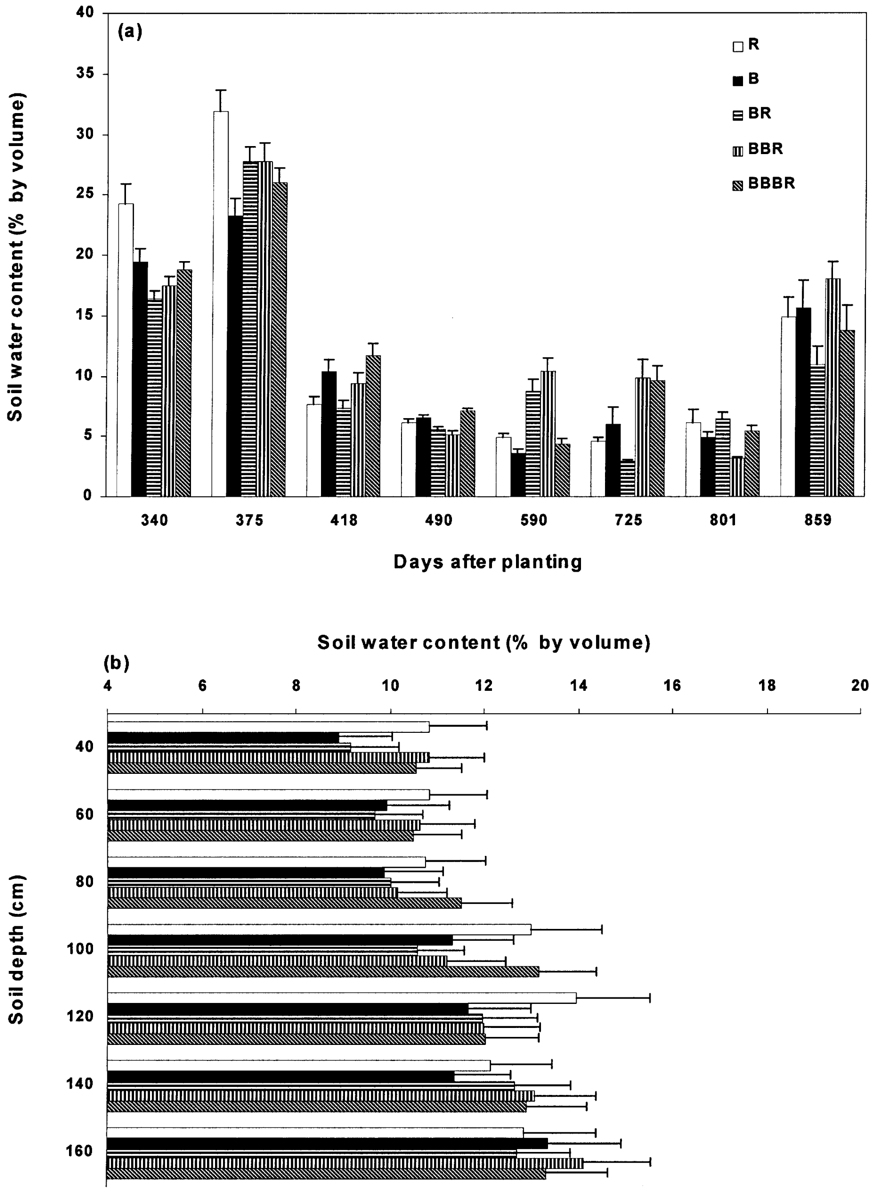

Figure 5. The (a) seasonal time-course variation and (b) vertical distribution of mean soil moisture content for the experimental period. Error bars represent the Standard Error of means of four replicate experimental blocks. Treatment codes R, B, BR, BBR and BBBR refer to the sole rubber and banana crops and single, double and triple row banana/rubber intercrops, respectively.

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