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Decomposition of Vetiver Shoot and Effect of Vetiver Mulching on Super Sweet Corn Hybrid Yield

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ABSTRACT

Two experiments were conducted on Hupkapong Soil Series. In the first experiment, the decomposition of vetiver shoot, and the nutrients released during the process were measured. The second experiment investigated the mulching effect of vetiver shoot on yield of super sweet corn hybrid in the wet and dry seasons. The results from the decomposition study indicated that, within 90 days, more than 80% of the buried vetiver shoot decomposed but less than 30% of the same material left on soil surface disintegrated. It was also found that one ton of dry vetiver shoot buried at the depth of 10 cm would yield mineral nitrogen, available phosphorus, and extractable potassium up to 4.4, 2.2 and 20.5 kg while that left on soil surface would yield only 0.85, 0.74 and 7.20 kg, respectively. In the second experiment, the application of 31.25 t/ha fresh weight of vetiver shoot for mulching in addition to a half rate (35.5-35.5-35.5 kg of N-P_2O_5-K_2O/ha) of the recommended fertilization produced the same yield of super sweet corn hybrid as applying the full rate of the recommended fertilizer alone. Mulching the soil with vetiver shoot, therefore, could reduce 50% of chemical fertilizer needed for the super sweet corn hybrid production.

Key words: vetiver, plant nutrient, mulching, compost, super sweet corn

INTRODUCTION

The two major problems of soil deterioration in Thailand are low soil fertility and soil erosion. Low organic problem is commonly found, covering as high as 30 million hectares or 59.5 % of Thailand total area while soil erosion has caused plant nutrient loss of approximately 17 million hectares or 33 % of the whole country (Land Development Department, 2004). These problems have affected physical soil resources and caused economic and social imbalance. Restoration of soil fertility can be done by incorporating organic matter as well as soil mulching as shown by several reports on the positive influence of soil mulching on soil and water conservation (Borthaker and Bhattacharyya, 1992; Kitoh and Yoshida, 1994; Roongtanakiat *et al*., 2000). Mulching provides a good protection against raindrops and runoff energy, limits weed competition, improves water storage and faunal activity and releases nutrients progressively (Roose and Barthes, 2001).

Vetiver grass (*Vetiveria zizanioides* (L.) Nash.) is a tropical plant with special feature of having a long and dense root. Utilizing vetiver grass in Thailand was initiated by His Majesty the King for the purposes of soil and water conservation, preventing soil erosion and improving deteriorated environment (Office of the Royal Development Projects Board, 1998; Roongtanakiat and Chairoj, 2001). On farm land, cultivation of vetiver grass in rows with a spacing

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of 6 m produces approximately 11.25 – 26.28 kg/ha of dry biomass each year. Dry vetiver shoot contains 1.29, 0.20, 1.3 and 0.15 % of N, P, K and S, respectively (Office of the Royal Development Projects Board, 2000). Therefore, vetiver grass has a potential for soil mulching and can help preserving soil, as well as releasing plant nutrients into the soil. Super sweet corn is one of the high value cash crops. It is an early maturing crop and can grow all year round. In 1999, Thailand exported 27,000 tons of super sweet corn with the value of 729 million baht (Department of Agricultural Extension, 2004). However, growing super sweet corn in a low fertility area needs a proper soil management for good production.

This research was aimsed to determine the decomposition of vetiver shoot, and the nutrients released during the process, in sandy soil of extremely low productivity. The possibility of using vetiver shoot as soil mulching and composting material to increase the yield of super sweet corn hybrid was also investigated.

MATERIALS AND METHODS

Experiment 1

A study on using vetiver shoot as mulched material and buried material for compost was carried out to investigate plant nutrient releasing. The experiment was conducted on the Hupkapong low fertility sandy soil at the Huai Sai Royal Development Center, Phetchaburi Province. Dry vetiver shoot was cut into small (1-1.5 cm) pieces and then 10 grams were put into each 20-mesh nylon-net bag with 12.5 ¥ 16.0 cm in size. In one set, fifteen bags were left on the soil surface as mulched vetiver shoot treatment. In an adjacent site, fifteen bags of another set were buried at the depth of 10 cm below soil surface as buried vetiver shoot or composting treatment.

Decomposition of the vetiver shoot in the bags and nutrient contents in the soil at about 10 cm beneath the bags were determined on 0, 30, 60, 90, and 120 days of experimentation. The procedure was replicated three times. Mineral N, available P and extractable K were determined according to the methods described by Bremner (1965), Bray and Kurtz (1945) and Knudsen *et al*. (1982), respectively.

Experiment 2

A field experiment to investigate the effect of mulching and composting by vetiver shoot on grain yield of a super sweet corn hybrid was carried out in the wet and dry seasons of the crop year 2000-2001 at the Huai Sai Royal Development Center as in the experiment 1. A completely randomized block design with 6 treatments and 5 replications was employed. Plot size was 6.25 ¥ 4.25 meters. Details of treatments and their descriptions are illustrated in Table 1. Grain yield of the super sweet corn hybrid was recorded at 90 days after planting. In the dry season, sprinkler irrigation was done throughout the growing period while in the wet season, the irrigation was added if necessary to keep sufficient soil moisture for the plants.

RESULTS AND DISCUSSION

1. Vetiver shoot decomposition

The soil analysis indicated that the soil used in the experiment was very low in fertility. It had pH of 5.7, 0.9 % of organic matter and low macronutrients with 7 mg/kg N, 4 mg/kg available P and only 70 mg/kg extractable K. Dry vetiver shoot contained 39.9 % C, 1.1 % total-N, 0.19% total-P and 1.7% total-K.

A significant difference of decomposition between the treatments of mulched vetiver shoot and buried vetiver shoot was observed during the 120-day experimentation period. The decomposition of buried vetiver shoot was 60 % at 30 days and it gradually increased to 75 % and 85 % at 60 and 90 days of experimentation respectively, afterwards it was rather stable

Table 1 Treatments used in experiment 2.

Treatment number	Description[1]
T1 (no fertilizer as control)	M
T2	$\frac{1}{2}$ CF + $\frac{1}{2}$M
T3	$\frac{1}{2}$ CF + CP + M
T4	$\frac{1}{2}$ CF + CP + $\frac{1}{2}$M
T5	$\frac{1}{2}$ CF + M
T6	CF + M

[1] CF = chemical fertilization at 75-75-75 kg N-P_2O_5-K_2O/ha
$\frac{1}{2}$ CF = chemical fertilization at half rate of CF
M = mulching with fresh vetiver shoot at 31.25 t/ha
$\frac{1}{2}$ M = mulching with fresh vetiver shoot at half rate of mulching (M)
CP = vetiver grass compost application at the rate equivalent to 37.5 kg N/ha

(Figure 1). For mulching, vetiver shoot decomposed nearly 30 % at 30 days and it was stable later on. The higher decomposition of buried vetiver shoot over that of mulched vetiver shoot was observed throughout the experiment period. This could be explained by more contact of vetiver shoot to the soil microorganisms needed for the decomposition process in the buried vetiver shoot compared to that in the mulching (Chairoj *et al*., 1990). High decomposition at 30 days (during the wet season-Table 2) might happen due to more rain at that period for accelerating the decomposition in both treatments.

2. Plant nutrients released from the vetiver shoot

2.1 Mineral nitrogen (NH_4-N and NO_3-N)

Nitrogen mineralized from the buried vetiver shoot was significantly higher than that from the mulched practice. The greater contact of the materials with soil microorganisms stimulated the decomposition and the mineralization of the nutrients from the vetiver shoot (Chairoj *et al.*, 1990). Mineral N content in the soil released from the mulched vetiver shoot during the 60 experiment days was less than 1 mg/kg, and it markedly increased to 5 mg/kg within 90 days (Table 3).

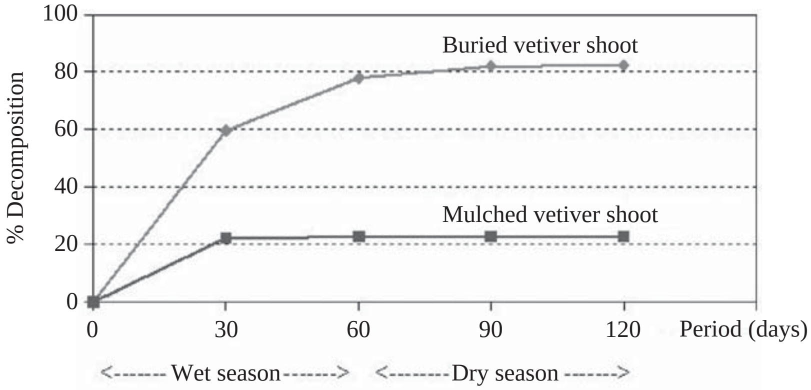

Figure 1 Percentage of decomposition of dry vetiver shoot left on the soil surface (mulched vetiver shoot) and that buried at the depth of 10 cm (buried vetiver shoot).

Table 2 Precipitation at the Huai Sai Royal Development Center during the experiment on decomposition of vetiver shoot.

Day/Month/Year	Period (days)	Precipitation (mm)
24/09/2000 - 24/10/2000	0	207.7 (wet season)
25/10/2000 - 24/11/2000	30	484.7 (wet season)
25/11/2000 - 24/12/2000	60	0 (dry season)
25/12/2000 - 24/01/2001	90	2.8 (dry season)

Higher content of mineral N (11 mg/kg) from the buried vetiver shoot was observed in the first 30 days of the experiment, and remained constant thereafter. Heavy precipitation during September to October 2000, 60 days after the beginning of the experiment, might leach mineral N out of the collected soil layer. Average mineral N contents released from the mulched and the buried vetiver shoot treatments during the 90 days after the experiment were 2 and 10 mg/kg, or equivalent to 0.085 and 0.440 % of the vetiver shoot used respectively. Therefore, it could be estimated that one ton of the dry vetiver shoot mulched on the soil surface and that buried at the depth of 10 cm would release mineral N to soil layer about 0.85 and 4.4 kg, respectively.

2.2 Available phosphorus

Available P released from the mulched vetiver shoot during the 60 experiment days was <1 mg/kg and subsequently increased at the same trend as mineral N. This suggested that P in the vetiver materials was released in a similar fashion as N. Likewise, the buried vetiver shoot was far more effective to supply available forms of N, P and K to the soil over the mulching technique. Higher available P content (4 mg/kg) was obtained from the buried vetiver shoot in the first 30 experiment days (Table 3). During 90 experiment days, average available P contents released from the mulched and the buried vetiver shoot methods were 4 and 6 mg/kg, or equivalent to 0.074 and 0.22 % of the vetiver grass shoot used respectively. It could therefore be estimated that one ton of the dry vetiver shoot mulched on the soil surface and that buried at the depth of 10 cm would release the available P to the soil of about 0.74 and 2.20 kg, respectively.

2.3 Extractable K

Extractable K released from both treatments reached the peak at 30 days. However, the extractable K released from the buried vetiver shoot treatment was almost 3 times higher than

Table 3 Contents of mineral N, available P and extractable K in soil layer released from the mulched and buried vetiver shoots.

Period	Mineral N (mg/kg)		Available P (mg/kg)		Extractable K (mg/kg)	
(days)	Mulched	Buried	Mulched	Buried	Mulched	Buried
0	0.0	0.0	0.0	0.0	0.0	0.0
30	0.1	11.0	0.6	4.0	18.0	46.0
60	0.9	11.0	0.6	5.0	16.0	49.0
90	5.1	8.0	4.0	6.0	16.0	46.0
Average	2.0	10.0	1.7	5.0	17.0	47.0

The values of nutrient content already deducted by the control treatment.

that from the mulched treatment (Table 3). Average extractable K contents at 90 days of the mulched and the buried treatments were 17 and 47 mg/kg, which were equivalent to 0.71 and 2.07 % of the vetiver shoot used respectively. Again, it could be estimated that one ton of the dried vetiver shoot mulched on soil surface and that buried at the depth of 10 cm would release extractable K to the soil about 7.2 and 20.5 kg, respectively. Buried vetiver shoot would provide substantial amount of K to the crop (46-49 mg/kg) quite steadily from 30 days to 90 days after incorporation. This level of extractable K seems to be adequate for growing any field crop (Department of Agriculture, 1998).

3. Yield of the super sweet corn hybrid

In general, the grain yield of super sweet corn hybrid in the dry season was higher than that of the wet season. Vetiver mulching in the absence of chemical fertilizer (T1) in both wet and dry seasons was unable to supply sufficient nutrients for regular yield of the super sweet corn hybrid, as compared to those in the presence of chemical fertilizer (T2-T6) (Figure 2). Low initial nutrient composition of this soil as described earlier might attribute to the low corn yield in the T1 treatment. However, there were no significant differences among treatments T2-T6 in yield in both seasons. For all studied treatments, the dry season produced a better yield than the wet season. Putative causes included more favorable nutrient composition and environmental factors, such as light intensity, temperature, consistent soil moisture (due to irrigation), etc. Moreover, treatments T5 and T6 were not significantly different in yield, therefore, it could be postulated that mulching with vetiver shoot at the rate of 31.25 t/ha (T5) would reduce at least 50% of chemical fertilizer required for growing super sweet corn hybrid. Economically, the farmers would benefit from the lower cost of input.

CONCLUSION

Results of the field experiment on the effect of vetiver shoot on the supply of plant nutrients and yield of super sweet corn hybrid could be concluded as follows:-

1. The decomposition rate of the vetiver shoot buried in the soil at the depth of 10 cm was found to be 2-3 times faster than that left on the soil surface and also resulted in higher plant nutrient releases.

2. One ton of the dry vetiver shoot buried

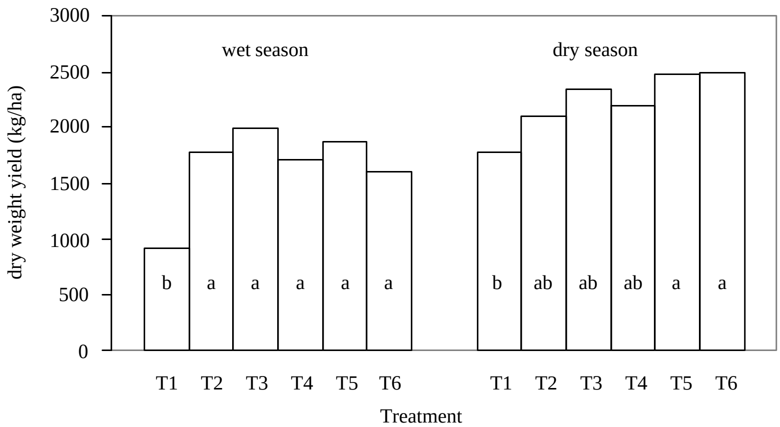

Figure 2 Yield of super sweet corn hybrid under different soil managements in wet season and dry season. (The treatment columns embedded with a common letter are not significantly different at the 95% level by DMRT.)

in soil at the depth of 10 cm would release mineral nitrogen, available phosphorus and extractable potassium of 4.4, 2.2 and 20.5 kg, while that of the mulched technique yielded only 0.85, 0.74 and 7.20 kg, respectively. Significant increases of the plant nutrients were due to better mineralization of buried materials by soil microorganisms.

3. The maximum yield of super sweet corn hybrid was obtained from the treatment of vetiver shoot mulching at the rate of 31.25 t/ha together with applying a half rate (35.5-35.5-35.5 kg of N-P_2O_5-K_2O/ha) of the recommended fertilization.

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Effect of Nitrogen Fertilizers on Branched Broomrape (*Orobanche ramosa* L.) in Tomato (*Lycopersicon esculentum* Mill.)

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ABSTRACT

A pot experiment was conducted under natural conditions at Melkasa Agricultural Research Center, Central Ethiopia to study the effects of various levels of nitrogen, applied as ammonium nitrate (NH_4NO_3), ammonium sulfate $(NH_4)_2SO_4$, urea (NH_2CONH_2), chicken, cow, and goat manure on branched broomrape (*Orobanche ramosa* L.). Parasitism occurred most in untreated and treated pots with low N fertilizer and manure. Urea at 276 and 207 kg N/ha, ammonium nitrate, and ammonium sulfate at 207 kg N/ha and the goat manure at 20 and 30 t/ha were found to be most effective in reducing parasitism and enhancing growth of tomato plants. Even though drastic reduction of branched broomrape infestation was obtained, ammonium nitrate and ammonium sulfate at 276 kg N/ha seemed to be injurious to tomato plants. As nitrogen rates increased, the numbers and dry weights of shoot of branched broomrape decreased and the yields of tomato increased linearly except the yields obtained from the highest rate of ammonium nitrate and ammonium sulfate. This result indicated that branched broomrape infestation of tomato decreased with increases of soil nitrogen.

Key words: branched broomrape, tomato, animal manure, nitrogen fertilizer, parasitic weeds

INTRODUCTION

The branched broomrape is an obligate root parasite of many economically important dicotyledonous crops such as tomato (Figure 1), tobacco, potato, cabbage, eggplant, carrot, mustard, and sunflower. Its area of distribution is predominantly in the Middle East, Eastern Europe, the Mediterranean basin, Western Asia, East Africa and America (Pieterse, 1979; Jain and Foy, 1989; Parker and Riches, 1993; Press and Grave, 1995; Yokota *et al*., 1998; Yoneyama *et al*., 2001).

Among the four species of the genus *Orobanche* occurring in Ethiopia *Orobanche ramosa* L. is the most prevalent and devastating in the central rift valley, where the main vegetable crops are grown in the country. It mainly threats tomato production. Many tomato fields are abandoned and replaced by other crops in the area (Ahmed and Mohammed, 1992; Parker, 1992; Beyenesh and Geberemariam, 1994). Ecologically, branched broomrape is found in open, sunny habitats that would favour increased transpiration (Musselman, 1980).

The seeds of this parasitic weed are dark brown oval and tiny, measuring approximately 0.2 by 0.3 mm. They are known to remain viable in the soil for up to 20 years. In order to germinate, broomrape seeds require a period of preconditoning and the presence of a germination stimulant, a chemical signal exuded by a host (or non-host). In the total-host relationship, two phases must be

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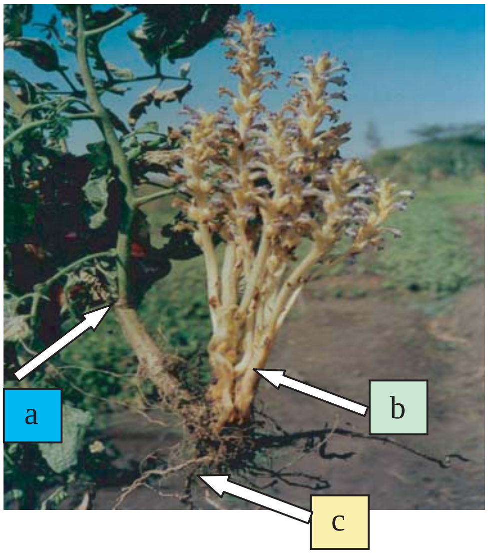

Figure 1 Branched broomrape attached with tomato roots a: tomato plant; b: branched broomrape; c: root attachment.

recognized. In the first phase, the host root stimulates the seed to germinate and induces it to produce an independent seedling; in the second phase, the seedling becomes attached to the root of the host and thereafter exists parasitically upon it. The restriction of host species refers in many instances to the second phases; the first stimulation can be probably given by the roots, which are never parasitized (Musselman, 1980; Jain and Foy 1989; Westwood and Foy, 1999; Joel, 2000; Morozov *et al*., 2000).

Like all members of the family which totally lack of chlorophyll hence it lacks the ability to synthesize its own food. It severely reduces crop yield by drawing carbon, nutrients, and water through haustoria that connect the parasite to the host's vascular system. Severe infestations of tomato field by this parasite seriously reduce yield and can lead to total crop failure, especially if plants are infested during their early stages of development (Kasrawi and Abu-Irmaileh, 1989; Nandula *et al*., 1996; Westwood and Foy, 1999; Morozov *et al*., 2000). Hand pulling is used widely to control branched broomrape but it is inefficient because damage from the parasite normally occurs prior to broomrape emergence. It is also injurious to tomato plants (Abu-Irmaileh, 1979; Parker and Wilson, 1986; Thahabi, 1994). Options for branched broomrape control are limited for most crops because of lack of mechanical control and reliable, selective herbicides. Various alternative control strategies have been tested, and one that has received considerable attention is the use of nitrogen fertilizers. High nitrogen application reduces development of *O. aegyptica* Pers. and *O. crenata* Forsk. Similarly, nitrogen reduces *O. ramosa* L. infestation on tomato and tobacco and reduces *O. crenata* infestation on faba beans.

Ghosheh *et al*. (1999) suggested a possible use of olive jift as an inexpensive organic material for branched broomrape control. Farmers in Jordan have commonly observed that the addition of manure to soil reduced the infestation of broomrape in their fields (Abu- Irmaileh, 1979). Few farmers in Ethiopia suggested that the goat manure showed effective control of *Orobanche* spp. Hence, this experiment was initiated to investigate the influence of nitrogen fertilizers and animal manures on branched broomrape (*Orobanche ramosa* L.) and tomato (*Lycopersicon esculentum* Mill.).

MATERIALS AND METHODS

A pot experiment was carried out under natural conditions at Melkasa Agricultural Research Center, Central Ethiopia. Randomized complete block designs with four replications were used. Three inorganic fertilizers, each at four rates were used as treatments in experiment I, whereas three organic fertilizers (manure), each at three rates were used in experiment II.

Branched broomrape seeds were collected from Nura Era state farm tomato fields. Soil and sand were sterilized in oven at 105°C for 24 hours before planting. The organic matter content and chemical composition of the soil and manure were analyzed before planting (Table 1 and 2). Plastic

Table 1 Organic matter content and chemical composition of the soil used in the potting media.

Texture (%)			Texture	pH	EC	CEC	OM	Total N	P
Sand	Silt	Clay	class	1:2.5	1:2.5		(%)	(%)	(ppm)
57.3	94	11.3	Sandy loam	7.8	0.449	55.25	1.96	0.097	14.96

Table 2 Analysis of animal manure after decomposed for 7 years and stored under shading condition.

Type of manure	PH	OM (%)	Total N (%)	P (ppm)
Chicken	6.53	21.08	1.82	237.13
Cow	7.68	21.93	1.89	83.33
Goat	8.15	31.32	2.7	150.50

pots (22 cm diameter) of 18 cm in height with holes at the bottom were filled with soil mix (3 soil: 1 sand), 4 kg per pot. Composted manure for 7 years also mixed with the soil mix and filled the pots. The soil was sandy loam, with pH of 7.8 and electrical conductivity of 0.449 (Table 1). Tomato seeds were planted in the seedling trays (30 cm^3 / cell). The variety of tomato used was Roma VFN. A hundred mg of branched broomrape seeds were mixed with 200 g sand and thoroughly mixed with 600 g soil mixed by passing through a plastic funnel five times in each case and added to the upper 2 cm of the pots. The pots were irrigated with 200 ml of tap water every day for three weeks in preconditioning. Five weeks-old tomato seedlings (at four leaves stage) were transplanted into plastic pots (one plant/pot). Recommended rate of phosphurous (92 kg P/ha) for tomato was applied as blanket application on all pots treated with inorganic fertilizers including controls. Triple super phosphate (TSP) and urea were used as source of P and N, respectively. All N sources of inorganic fertilizers were splitted in to three and applied at 15 days after transplanting, at flowering and at fruiting stages. These fertilizers were applied on moist soil by spreading on the soil surface and irrigating immediately. Emerged branched broomrape flower shoots were counted every week. The average air temperature and rainfall over the growing period were 23°C and 59 mm respectively.

At the end of the experiment (four months after transplanting), the soil was washed carefully from the roots, and the heights and fresh weights of tomato shoot and root were taken from each pot. Tomato shoots and roots, branched broomrape shoots were dried in the oven at 70°C for 48 hours. Number, dry weight of branched broomrape flower shoot, fruit number, yield, tomato shoot height and root length, tomato shoot and root dry weight were taken as parameters (Ahmed and Parker, 1986; Jain and Foy, 1992). The data were subjected to analysis of variance and the means were separated by Duncan's multiple range test at 5% level of significance.

RESULTS AND DISCUSSION

Effects of nitrogen fertilizer on the parasitism of tomato plant by branched broomrape

Parasitism occurred mostly in pots, untreated and treated, with low N- fertilizer. Urea at 276 kg N/ha and ammonium nitrate at 207 kg N/ha were the most effective in reducing parasitism and enhancing growth of tomato plants. The application of ammonium nitrate and ammonium sulfate at 276 kg N/ha caused reduction in branched broomrape but they were injurious to tomato plants. Similar results were obtained by Abu-Irmaileh (1981), who reported that the higher rates of NH_4NO_3 and $(NH_4)_2SO_4$ were injurious to tomato and tobacco plants.

The average number of branched broomrape attachment on tomato plants in the non-fertilized pots was 21 (Table 3). The high numbers of branched broomrape also occurred in pots treated with lower rates (69 kg N/ha) of ammonium nitrate, ammonium sulfate and urea with average numbers of branched broomrape attachment on tomato plants were 13, 16 and 15 respectively. The average number of branched broomrape in pots with high fertility was 3-5. Mean shoot dry weight of branched broomrape per tomato plant in untreated pot was high as 5.5 g, whereas mean of shoot dry weight of branched broomrape per tomato plant was 0.6-1.35 g in well fertilized pots. The growth of tomato plants, in untreated and treated with lower rates of nitrogen was considerably poorer than that of tomato plants treated with higher rates.

The average shoot height and dry weight, average root length and dry weight, and yield were 38 cm, 16 gm, 25 cm, 3 gm and 147 g respectively in untreated pots. This reduction in growth of tomato plant was partly related to the numbers of broomrape parasite attached to each tomato plant. In general, the maximum reduction in branched broomrape parasitism occurred in pots fertilized with ammonium nitrate, ammonium sulfate and urea at 276 and 207 kg N/ha. The highest rates of ammonium nitrate and ammonium sulfate could not be acceptable due to a severe injury to tomato plants. There was no significant difference of parasitism between pots treated with urea at 207 and 276 kg N/ha, ammonium nitrate at 207 and 276 kg N/ha and ammonium sulfate at 207 and 276 kg N/ha. Hence ammonium nitrate, ammonium sulfate and urea at 207 kg N/ha were the optimum levels in controlling branched broomrape.

Abu-Irmaileh (1981) reported that ammonium nitrate and ammonium sulfate reduced the biomass of branched broomrape on tomato and tobacco grown in pots. Ammonium nitrate with potassium phosphate or ammonium phosphate alone was the most effective in reducing *O. aegyptiaca* parasitism by enhancing growth of tomato plants (Jain and Foy, 1992). Westwood and Foy (1999) confirmed that nitrogen in the ammonium form was more inhibitory than nitrate. Yoneyama *et al.* (2001) reported that the production of clover broomrape seed germination stimulant was inhibited by phosphate (NaH_2PO_4) and ammonium sulfate $(NH_4)_2SO_4$. High nitrogen application was also reported to reduce parasitism of scalloped broomrape on broad beans and parasitism of witchweed on sorghum (Abu-Irmaileh, 1981).

Effects of animal manure on the parasitism of tomato plant by branched broomrape

No much work has been done on the organic fertilizer to control *Orobanche* spp. As the results indicated, the higher average number and dry weight of branched broomrape shoots and the lowest yield were obtained from untreated pots. The recommended fertilizer without parasitic weed gave the yield of tomato equal to that by the application of goat manure at 20 and 30 t/ha with parasitic weed (Table 4). As the weight of manure increased, the average number and dry weight of branched broomrape decreased and yield increased linearly. The application of goat manure at 20 and 30 t/ha reduced branched broomrape infestation effectively but the rate of 30 t/ha reduced more. This might be due to high content of nitrogen compound (Table 2). There was no significant difference of yield between these two rates of goat manure. That goat manure at 20 t/ha could be adequate to reduce parasitism of branched broomrape in tomato. This result agreed with Haidar *et al.* (2002), who indicated that goat manure 20 t/ha significantly reduced *Orobanche ramosa*

Table 3 Effects of nitrogen fertilizer on the parasitism of tomato plant by branched broomrape.

Treatment	Fertilizer rate (kg/ ha)	Tomato						Branched broomrape	
		Shoot		Root		Fruit (no/pt)	Yield (g /pt)	No. of parasite / tomato pt	Shoot dry wt. (g/ tomato pt)
		Height (cm)	Dry wt. (g/pt)	Length (cm)	Dry wt. (g/pt)				
No- N – parasite		57.0 e[1/]	25.0 de	41.0 c	4.0 bc	7.0 bc	444.0 bc	0.0 a	0.0 a
No- N + parasite		38.0 a	16.0 a	25.0 a	3.0 a	3.0 a	147.0 a	21.0 g	5.5 f
Urea + parasite	69 N	46.0 b	23.0 bc	33.0 b	4.0 ac	6.0 b	390.0 bc	15.0 e f	3.7 e
Urea + parasite	138 N	56.0 de	28.0 f	42.0 c	5.0 c	8.0 cd	516.0 cd	10.0 c	2.4 cd
Urea + parasite	207 N	73.0 g	33.0 g	46.0 d	7.0 d	9.0 de	657.0 e	5.0 b	1.4 b
Urea + parasite	276 N	84.0 h	37.0 h	49.0 d	11.0 e	10.0 e	768.0 e	3.0 b	0.7 ab
NHO_4NO_3 + parasite	69 N	50.0 bd	23.0 c	33.0 b	3.0 ab	7.0 bc	441.0 bc	13.0 de	3.4 e
NHO_4NO_3 + parasite	138 N	71.0 g	27.0 ef	40.0 c	4.0 ac	8.0 cd	531.0 d	9.0 c	2.3 d
NHO_4NO_3 + parasite	207 N	86.0 h	37.0 h	48.0 d	11.0 e	10.0 e	771.0 e	3.0 b	0.8 ab
NHO_4NO_3 + parasite	276 N	54.0 be	24.0 cd	35.0 b	3.0 a	7.0 bc	471.0 bc	3.0 b	0.6 b
$(NHO_4)_2SO_4$ + parasite	69 N	48.0 bc	21.0 b	32.0 b	4.0 ab	6.0 b	375.0 b	16.0 f	3.8 e
$(NHO_4)_2SO_4$ + parasite	138 N	61.0 f	25.0 de	41.0 c	5.0 c	7.0 bc	471.0 bc	11.0 cd	2.7 d
$(NHO_4)_2SO_4$ + parasite	207 N	73.0 g	32.0 g	46.0 d	7.0 d	9.0 de	648.0 e	5.0 b	1.1 bc
$(NHO_4)_2SO_4$ + parasite	276 N	55.0 ce	22.0 bc	35.0 b	4.0 ac	7.0 bc	435.0 bc	4.0 b	1.0 bc
C.V %	7.92	4.5		7.03	10.62	22.83	18.77	19.64	25.5

[1/] Means followed by the same letters within the same column are not significantly different according to Duncan's multiple range test at 5%level

Table 4 Effects of animal manure on parasitism of tomato plant by branched broomrape.

Treatment	Nutrient rate (t / ha)	Tomato						Branched broomrape	
		Shoot		Root		Fruit (no./pt)	Yield (g/pt)	No. of parasite/ tomato pt	Shoot dry wt. (g/ tomato pt)
		Height (cm)	Dry wt. (g/pt)	Length (cm)	Dry wt. (g/pt)				
No- N fertilizer - parasite		50.0 bd[1/]	22.0 e	33.0 df	5.0 ab	7.0 bc	414.0 bd	0.0 a	0.0 a
No- N fertilizer + parasite		36.0 a	12.0 a	20.0 a	2.0 a	3.0 a	117.0 a	23.0 h	6.4 j
Recommended fertilizer - parasite	138 kg N + 92 kg P	65.0 g	37.0 i	47.0 i	9.5 e	10.0 e	759.0 e	0.0 a	0.0 a
Recommended fertilizer + parasite	138 kg N + 92 kg P	56.0 de	25.0 f	36.0 ef	7.0 bc	8.0 cd	513.0 d	9.0 d	1.6 cd
Chicken manure + parasite	10	44.0 b	14.0 ab	22.0 ab	3.0 ab	6.0 b	330.0 b	16.0 g	4.2 I
Chicken manure + parasite	20	53.0 de	18.0 cd	29.0 fg	4.0 cd	7.0 bc	423.0 bd	13.0 ef	2.8 fg
Chicken manure + parasite	30	58.0 e	24.0 ef	36.0 hi	6.0 cd	8.0 cd	507.0 cd	10.0 d	1.8 de
Cow manure + parasite	10	46.0 b	16.0 bc	24.0 ac	3.0 ab	6.0 b	348.0 b	16.0 g	4.0 hi
Cow manure + parasite	20	54.0 ce	19.0 d	30.0 ce	5.0 bc	7.0 bc	438.0 bd	12.0 e	2.4 ef
Cow manure + parasite	30	59.0 e	25.0 ef	37.0 ef	6.0 ce	8.0 cd	519.0 d	9.0 d	1.4 cd
Goat manure + parasite	10	47.0 bc	19.0 d	28.0 bd	4.0 bc	6.0 b	381.0 bc	14.0 f	3.4 gh
Goat manure + parasite	20	58.0 e	29.0 g	39.0 fh	7.0 de	9.0 de	645.0 e	6.0 c	1.1 bc
Goat manure + parasite	30	61.0 fg	34.0 h	44.0 gi	9.0 e	10.0 e	726.0 e	3.0 b	0.6 ab
C.V %		7.8	8.4	12.5	27.0	20.8	17.2	12.3	19.9

1/ Means followed by the same letters within the same column are not significantly different according to Duncan's multiple range test at 5%level infestation throughout the growing season in potato.

The higher rates (30 t/ha) of cow and chicken manure also gave good reduction of branched broomrape. There was no significant difference between these two treatments. However, goat manure at 20 t/ha was more effective and economical to reduce branched broomrape as compared with cow and chicken manures at 30 t/ha (Table 4). Not only animal manure but the green manure also reduces broomrape infestation. Ghosheh *et al*. (1999) revealed that olive jift (a solid by-product of olive) in soil also reduced broomrape infections.

Branched broomrape infestation of tomato decreased with increases of soil nitrogen. Because of the complex interaction among host, parasite, and the environment, it has been difficult to determine the mechanism by which N reduces branched broomrape infestation. The different experiments pointing to different nutrient or soil factors may indicate that the nutrients are influencing the host parasite relationship in more than one way (Westwood and Foy, 1999). As reviewed by Jain and Foy (1992), some researchers have reported that the addition of manure and certain synthetic nitrogenous fertilizers result in improved crop yields due to a detrimental effect of the fertilizers on the parasitic infestations, but others have attributed the beneficial effects of nitrogenous fertilization directly to improve crop performance and tolerance to attack by parasite. Abu-Irmaileh (1994) reported that the mechanism by which nitrogen affecting seed germination might be through its effect on reducing potassium uptake, since broomrape seeds had a high demand for potassium. In other parasitic weeds as reviewed by Westwood and Foy (1999), who suggested that nitrogen reduced damage by witchweed (*Striga hermontica*) growing on sorghum by enhancing the host's ability to maintain a favorable osmotic potential. Several authors reported direct toxicity by nitrogen fertilizers to seeds of broomrape and witchweed. Westwood and Foy (1999), reported nitrogen in ammonium form to be more inhibitory than nitrate but they concluded that it was the elongation of the seedling radicle that was primarily inhibited by ammonium, rather than the seed germination itself.

CONCLUSION

The influence of nitrogen from inorganic fertilizers (NH_4NO_3, $(NH_4)_2SO_4$, $NH_2CO\ NH_2$) and organic fertilizers (chicken, cow, goat manure) on parasitism of tomato plant by branched broomrape was investigated on sandy loam soil in pot experiments. The results revealed that urea, ammonium nitrate, and ammonium sulfate at 207 kg N/ha and the goat manure at 20 t/ha were effective in reducing parasitism and enhancing growth of tomato plants. Hence, the effect of these nitrogen fertilizers and animal manure should be tested in the field.

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Respiration Rate and a Two-component Model of Growth and Maintenance Respiration in Leaves of Rubber (*Hevea brasiliensis* Muell. Arg.)

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ABSTRACT

The future information of leaf selection for studies on respiration rate and leaf greenness, and position variations of different rubber clones was investigated. Respiration rate and greenness were non-significantly different between leaf position (leaf No. 1, 2 and 3) and leaflet position (left, middle and right), but they were significantly different among clones. During leaf expansion, respiration rate per unit leaf area declined with leaf age, but the differences were not obviously detected among clones. Leaf expansion rate was sigmoid shaped curves, and increased with leaf age. Relative growth rate on an area basis (RGR_{area}) of leaf declined with age. At fully expanded leaf of PB 235, RRIM 600, PB 260 and GT 1 clones, the greatest leaf area was found in PB 235, and the least in GT 1. For crop growth model development and environmental response studies, a two- component model of growth and maintenance respiration was used in leaves of rubber. Growth respiration coefficients were non-significantly different (ranging from 4.928×10^5 to 5.678×10^5 $\mu molCO_2\ m^{-2}$) among 4 rubber clones. While, the greatest maintenance coefficients were in RRIM 600, PB 60, GT 1, the least was in PB 235. In particular, strong positive correlation between respiration rate and RGR_{area} was found for all clones. Maintenance respiration was weakly related with leaf temperature, but growth respiration was not significantly related with leaf temperature.

Key words: relative growth rate, leaf expansion, growth respiration, maintenance respiration, leaf greenness, hevea and rubber

INTRODUCTION

Respiration is an important process to transform the substrate into necessary intermediates and transform some of stored energy into usable energy. These products are necessary for growth, maintenance, uptake of nutrient and transport of materials. However, the process often uses a significant fraction of the carbon fixed daily via photosynthesis and it is an important component of plant productivity and carbon balance (Amthor, 1989). Carbon loss from respiration process accounts for over 50% of gross primary productivity. Respiration is widely recognized as an important process in studies of plant response to environmental change (Wullschleger *et al*., 1992).

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Total respiration is the sum of growth respiration and maintenance respiration. Growth respiration is the respiration required in the synthesis of new phytomass, while maintenance respiration supplies the energy to keep existing phytomass in a healthy state (Amthor, 1989). Growth respiration can be used to calculate the conversion efficiency and maintenance respiration is used to determine the maintenance coefficient. Both the conversion efficiency and maintenance coefficient are important parameters in crop growth models (Iersel, 2000). Moreover, respiration model has been used in the study of plant response to water deficit, salinity and ozone (Amthor, 1988; Wullschleger *et al*., 1996) CO_2 (Hrubec *et al*., 1985; Wullschleger *et al*., 1992; Thomas *et al*., 1993; Ziska and Bunce, 1993; Thomas and Griffin, 1994; Wullschleger *et al*., 1994; Bunch, 1995).

A positive correlation between respiration and growth rates is commonly observed (Amthor, 1989; Poorter *et al*., 1990). However, a negative correlation between yield and respiration is found in forage crop, and the respiration rate has been used as an index for breeding selection in this species (Wilson and Jones, 1982; Kraus *et al*., 1993).

Rubber tree is a major natural rubber resource. Presently, over 9.76 million hectares of rubber tree are cultivated in the world (RRIT, 1999b). Photosynthetic rate in several rubber clones has been reported (Samsuddin and Impens, 1978 a-b, 1979; Ceulemans *et al*., 1984; Samsuddin, 1987; Nataraja and Jacop, 1999). Nonetheless, respiration rate and partitioning of respiration into the components contributing to the growth respiration and maintenance respiration are still poorly documented. The respiration knowledge in rubber leaves is required for studies on carbon balance, plant growth model development and plant environmental response. Moreover, respiration performance may be used as an early parameter in rubber breeding program.

The objectives of this study were (1) to compare respiration rate and leaf greenness between leaf position and leaflet position and also among rubber clones, (2) to partition respiration model into leaf growth respiration and leaf maintenance respiration.

MATERIALS AND METHODS

Plants materials

Experiments were conducted between October 2000 and April 2001 on six different rubber (*Hevea brasiliensis*) clones in growth rate and yield (RRIT, 1993; 1999a). The clones RRIM 600, PB 260, PB 235 PR 255, BPM 24 and GT 1 were selected. For RRIM 600, PB 260 PR 255 and BPM 24 are in the first class, while the PB 235 is the second class, and the GT 1 is not recommend clone in categorized class among clones recommended for commercial plantation of Rubber Research Institute of Thailand (RRIT, 1999a). Budded scions were grown in small containers until they produced two flushes of leaves and then transplanted in August 2000 into a 2.55×3.25 m^2 block containing Pakchong soil serie with 75×75 cm plant spacing. In addition, some plants were transplanted in February 2001 into the 150 l plastic pots containing Pakchong soil serie. Plants were placed in the nursery under natural conditions at Department of Agronomy, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand. All plants were daily watered to saturation and cultivated following the RRIT recommendations.

Experimental design

Two separate experiments were carried out. Experiment one was designed to investigate the influence of leaf position on respiration rate and leaf greenness among 5 rubber clones (BPM 24, RRIM 600, PB 235, PR 255 and GT 1). The position included three leaf positions (leaf number No.1, 2 and 3 upward from the bottom to the top in the flush) and three leaflet positions (leaflet position as right, middle and left position when see the leaf from the stem). Definition, number of leaf and leaflet position are shown in Figure 1.

Experiment two was conducted to compare leaf respiration rates among 4 rubber clones (RRIM 600, PB 235, PB 260 and GT 1) and partitioning into growth and maintenance respiration.

Leaf growth measurements

In experiment two**,** two leaves per plant (leaf position 1 and 3) were selected for leaf area determination. Leaf area was daily estimated (non destructive) on expanding leaves as well as fully expanded leaves by drawing on intact leaves under overhead projector film, and calculated leaf area from overhead projector film weight. Leaf area was estimated several days approximately 12 hours before and after gas exchange measurement. Measurement was done until leaf fully expanded.

Gas exchange measurements

For experiment one, respiration measurements were carried out between 18.00-20.00 h using a portable photosynthesis system model Li-6400 (LiCor Inc., Lincoln, Nebraska, USA). For each leaf, respiration rate were measured at *PPFD*= 0 µmol $m^{-2}s^{-1}$ and CO_2 =350 ppm. Leaf temperature and humidity in the leaf chamber were maintained at 27±2 °C and 45-60 % RH, respectively. Following each respiration measurement, leaf greenness on the leaflet was measured using a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ltd., Japan).

For experiment two, dark respiration rate (R_d) or CO_2 efflux during the night on individual trifoliate leaf was measured using a portable photosynthesis system model Li-6200 (LiCor Inc., Lincoln, Nebraska, USA). The difference between CO_2 concentration entering leaf chamber and sampling from leaf chamber was measured. Measurements on the same leaf used for leaf area estimation were made daily during 18.00-21.00 h. Respiration chambers were constructed of PVC pipe and completely enclosed one trifoliate leaf. Chamber volume was 604 or 1816 cm^3 depending on leaf area. Air entering the system passed through a 5 l buffer volume and flowed through the chamber at 1000 µmol s^{-1}. The CO_2 partial pressure during measurement was approximately 360 ppm. Leaf temperature was measured by Noncontact Thermometer model Raynger® ST (Raytek Cor.,

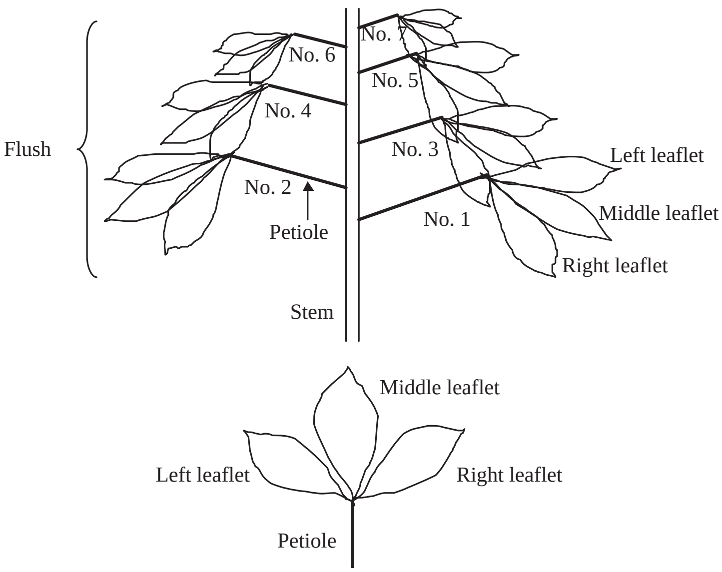

Figure 1 Leaf and leaflet characteristics of rubber and the definition of leaf and leaflet name.

CA., USA.) immediately after R_d measurement. Following each temperature measurement, leaf greenness on the leaf was measured using a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ltd., Japan).

R_d was calculated using equation,

$$R_d = \frac{\Delta CO_2 F}{L_A} \quad (1)$$

where ΔCO_2 = the difference in CO_2 concentration between sample and reference (µmolCO_2 µmolgas^{-1})

F = flow rate through the desiccant (µmolgas s^{-1})

L_A = leaf area (m^2)

The leaf area in equation (1) was calculated as

$$\text{Leaf area} = \frac{L_{Aa} + L_{Ab}}{2} \quad (2)$$

where L_{Aa} = the leaf area after gas exchange measurement (m^2)

L_{Ab} = the leaf area before gas exchange measurement (m^2)

Dark respiration was partitioned into functional components of growth and maintenance using the following equation, modified from that of Amthor (1988)

$$R = m + gRGR_{area} \quad (3)$$

where R = dark respiration rate expressed on a leaf area basis (µmol CO_2 m^{-2} s^{-1})

RGR_{area} = relative growth rate of leaf on an area basis (m^2 m^{-2} s^{-1})

Based on the regression equation of respiration rate versus RGR_{are}, the maintenance coefficient, m (µmol CO_2 m^{-2} s^{-1}), or y intercept, is the amount of carbon respired to support the existing amount of leaf area, and the growth coefficient, g (µmol CO_2 m^{-2}) or slope, is the amount of carbon respired per unit increase in leaf area. The RGR_{area} was calculated by using the equations of Thomas and Griffin (1994), Thomas *et al*. (1993), and Wullschleger *et al*. (1996):

$$RGR_{area} = \frac{\ln L_{Aa} - \ln L_{Ab}}{t} \quad (4)$$

where L_{Aa} = the leaf area after gas exchange measurement (m^2)

L_{Ab} = the leaf area before gas exchange measurement (m^2)

t = M time between leaf area measurement in seconds (s)

Data analysis

Analyses of variance of the effect of leaf position, leaflet position and clone on respiration rate and leaf greenness were analyzed using Statistical Analysis System, SAS (Institute, North Carolina, USA). Growth and maintenance coefficients were estimated using linear regression. Standard errors of mean of measurement parameters were also analyzed using the Statistical Analysis System, SAS (Institute, North Carolina, USA).

RESULTS

Effect of leaf position on respiration rate and leaf greenness

Leaf position (node No. 1, 2 and 3) and leaflet position (left, middle and right) did not significantly affect leaf respiration rate and leaf greenness. However, leaf respiration rate and leaf greenness were significantly different among rubber clones. The clone GT 1 and PR 255 showed higher respiration rate than the two groups made of BPM 24, RRIM 600 and PB 235. GT 1 showed higher greenness than all the other clones. Leaf of PB 235 was greener than those of BPM 24 and RRIM 600. PR 255 was in between these two groups (Table 1).

Leaf area expansion and relative growth rate

From data collected over leaf expansion period, leaf area expansion showed similar trends, sigmoid increasing curves for all clones. During the first 5 days after leaf unfolding, leaf area

Table 1 Analysis of variances and effects of clone, leaf position, leaflet position on leaf respiration rate and leaf greenness measured on 5 rubber clones.

Effect	Respiration rate (mmol CO_2 $m^{-2}s^{-1}$)	Leaf greenness (SPAD Unit)
Clones		
BPM 24	1.17 b	22.86 c
RRIM 600	1.13 b	22.03 c
PB 235	0.57 c	26.48 b
PR 255	1.60 a	24.64 bc
GT 1	1.67 a	33.64 a
	p= 0.0001	p= 0.0001
	n= 27	n= 27
Leaf position (node)		
1	1.32 a	26.09 a
2	1.26 a	25.21 a
3	1.10 a	26.43 a
	p= 0.2726	p= 0.5908
	n= 45	n= 45
Leaflet position		
Left	1.23 a	25.88 a
Middle	1.21 a	25.98 a
Right	1.24 a	25.88 a
	p= 0.9705	p= 0.9949
	n= 45	n= 45
CV%	54.71	22.37

For each effect, data with common letters were not different at the 0.05 level by DMRT.

expansion increased slowly and then rapidly from 5-12 days. Thirteen days after leaf unfolding, leaf becomes fully expanded. Mean areas of leaf No.1 and No. 3 of the top flush, clone PB 235 and RRIM 600 were significantly greater than those of PB 260 and GT 1 (Figure 2). Relative growth rate on an area basis (RGR_{area}) of rubber leaves declined with leaf age, but there were not obvious differentces among clones. At fully expanded leaf (about 13 days after unfolding), RGR_{area} became zero (Figure 3).

Respiration rate and leaf age relationship

The relationships between respiration rate and leaf age appeared to have similar trends for the 4 clones. During the first period of 2-3 days after unfolding, leaf respiration rates of GT 1, PB 235 and RRIM 600 were high about 9-11 µmolCO_2 $m^{-2}s^{-1}$. The rate of respiration rapidly decreased during 5-10 days. At 13 days after unfolding, respiration rates of all clone ranged about 1-2 µmolCO_2 $m^{-2}s^{-1}$ (Figure 4).

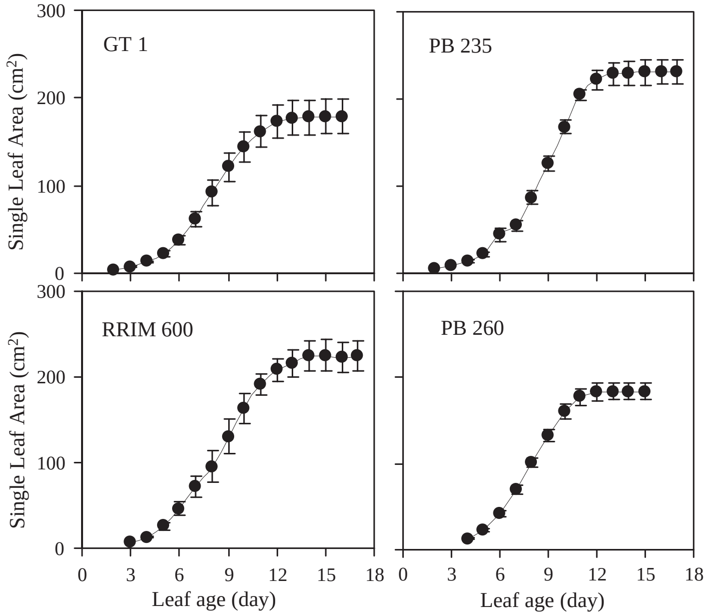

Figure 2 Mean leaf area expansion rates (leaf No. 1 and No. 3) with leaf ages of 4 rubber clone. Error bars represent one standard error of mean (n=4).

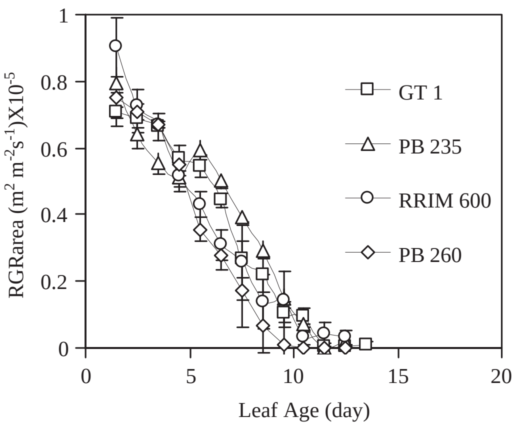

Figure 3 Relative growth rates on an area basis with leaf ages of 4 rubber clone. Error bars represent one standard error of mean (n=4).

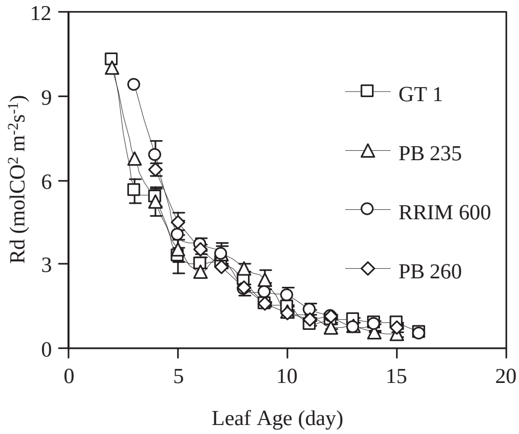

Figure 4 Relationship between respiration rates per unit of area and ages of leaf in 4 rubber clones. Error bars represent one standard error of mean (n=4).

Two components model of respiration rate

As predicted by the two-component model of growth and maintenance respiration, there was a strong positive relationship between respiration rate and RGR_{area} for all clones (Figure 5). Growth respiration coefficients estimated from the slope of this relationship were non-significantly different among 4 rubber clones (4.928×10^5 to 5.678×10^5 µmolCO_2 m^{-2}) (Table 2, line in Figure 5). In particular, growth respiration coefficients during

Table 2 Growth and maintenance coefficient respiration, leaf greenness and mean fully expanded leaf area (leaf No. 1 and 3) of 4 rubber clones.

Clone	Growth coefficients (μmol CO_2 m^{-2} x10^5)	Maintenance coefficients (μmol CO_2 $m^{-2}s^{-1}$)	Leaf area (cm^2)
RRIM 600	5.224±1.119a	0.620±0.1233a	224±36ab
PB 260	4.928±0.485a	0.617±0.127a	184±20ab
PB 235	5.376±0.373a	0.367±0.098b	231±28a
GT 1	5.678±0.663a	0.613±0.073a	178±39b

Values are means±SE. Means within a column with the same letters are not significantly different at 0.05 (n=4).

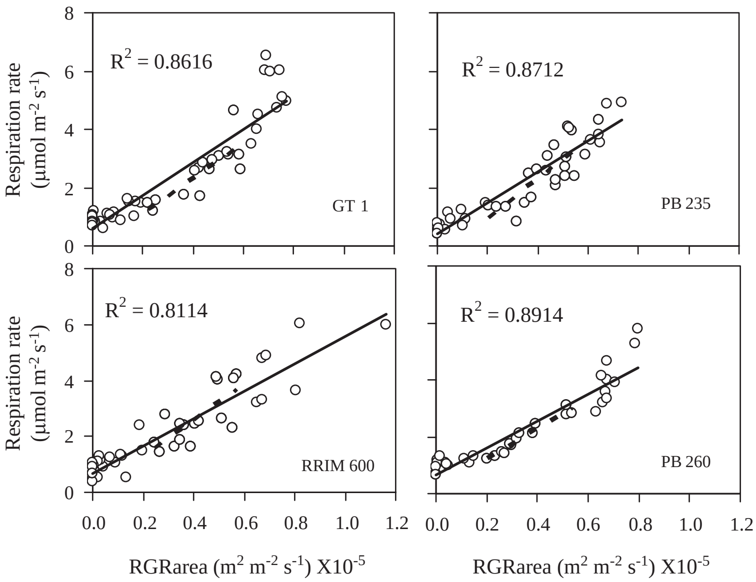

Figure 5 Respiration rates (R_d) as a function of relative growth rate on an area basis (RGR_{area}) of 4 rubber clones. Lines and statistics are linear regression of all values. Dash lines are linear regression of RGR_{area} during 0.2×10^{-5} to 0.6×10^{-5} m^2 m^{-2} s^{-1}.

liner phase of growth expansion rates (leaf ages between 6 to 10 days and RGR_{area} between 0.2 $\times10^{-5}$ to 0.6×10^{-5} m^2 m^{-2} s^{-1}) are presented in dash lines (Figure 5). The slopes were 5.38 μmolCO_2 m^{-2}, 5.97μmolCO_2 m^{-2}, 6.52 μmolCO_2 m^{-2} and 6.76 μmolCO_2 m^{-2} in PB 260, PB 235, RRIM 600 and GT 1, respectively. However, growth respiration coefficients were non-significantly different between estimated from all expansion periods (line, Figure 5) and estimated during linear phase (dash line, Figure 5). Estimates of the maintenance coefficient (the y- axis intercept) were significantly different among 4 rubber clones. Clone PB 235 (0.367 μmol CO_2 $m^{-2}s^{-1}$) was almost 2 times lower than those of other clones for this parameter (0.613 to 0.620 μmol CO_2 $m^{-2}s^{-1}$) (Table 2). Measurement respiration rates at RGR_{area} $\leq 0.01\times10^{-5}$ m^2 m^{-2} s^{-1} (just fully expanded), PB 235 (0.57 μmol CO_2 $m^{-2}s^{-1}$) were also lower than those of other clones (0.90, 0.87 and 0.70 μmol CO_2 $m^{-2}s^{-1}$ in PB 260, GT 1 and RRIM 600, respectively).

Temperature effect

When partitioning respiration rate into growth and maintenance respiration, maintenance respiration was weakly related with leaf temperature, while growth respiration was not significantly related with leaf temperature (Figure 6).

DISCUSSION

The significantly wide variations in leaf respiration rate and leaf greenness observed among 5 clones (Table 1) indicated a large genetic variability in carbon exchange capacity in this species. The result was similar to that of Nugawela *et al*. (1995) and Nataraja and Jacob (1999). It is very important for next carbon balance study in rubber.

However, node and leaflet position did not significantly affect leaf respiration and leaf greenness. According for the specific growth pattern of this species (Samsuddin *et al*., 1978), six to ten leaf emerged in the same type and in the same time in each growth flush. Thus, each node and leaflet was not different in age and development. In next respiration and greenness studies in a given clone, any leaves in the same flush could be used as a good random sample.

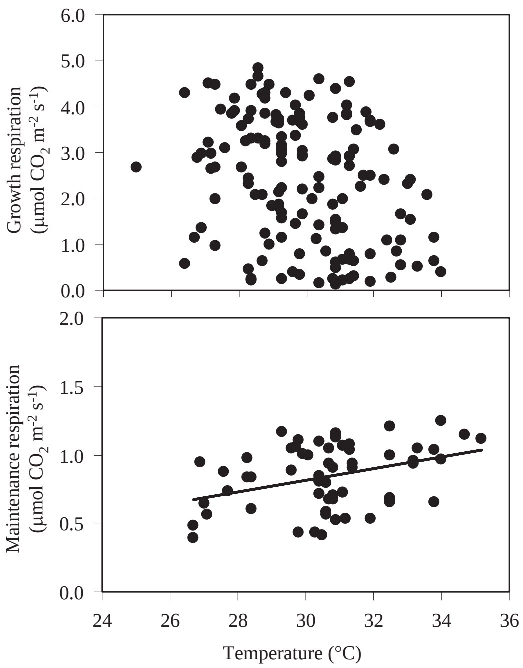

Figure 6 Relationship between growth respiration (top panel), maintenance respiration (bottom panel) and leaf temperature of rubber.

Leaf area expansion had similar result to the other tree species such as yellow poplar (Wullschleger *et al*., 1992), northern red oak (Wullschleger *et al*., 1996). Relative growth rate of rubber leaf declined with age was as observed on many species (Bunce, 1995). It closed to zero at fully expanded leaf.

Average leaf areas of leaf No. 1 and No. 3 of the third flush of a given tree were used to estimation. Among 4 clones, PB 235 had the highest leaf area and GT 1 has the lowest. It was well known that PB 235 leaf area was higher than those of other clones. However, Gomez and Hamzah (1980) investigated variation in leaf morphology and anatomy in 11 clones. There were no significant differences between clones and mean surface area per leaflet.

The clone GT 1 and PR 255 (1.6-1.7 µmol CO_2 $m^{-2}s^{-1}$) showed higher respiration rate than two groups made of BPM 24, RRIM 600 (1.13-1.17 µmol CO_2 $m^{-2}s^{-1}$) and PB 235 (0.57 µmol CO_2 $m^{-2}s^{-1}$). While, Ceulemans *et al.* (1984) observed that respiration rates of 20 rubber clone varied from 1.5 µmol CO_2 $m^{-2}s^{-1}$ to 7.9 µmol CO_2 $m^{-2}s^{-1}$. For consideration about the same clones, PR 255 showed higher respiration rate than RRIM 600, PB 235 and GT 1. Compare only RRIM 600 to those in the literature, respiration rate in this study was lower (1.13 µmol CO_2 $m^{-2}s^{-1}$) than those of observed by Nataraja and Jacob (1999), Nugawela *et al*. (1995) and Ceulemans *et al*. (1984) (2.29, 3.12 and 4.95 µmol CO_2 $m^{-2}s^{-1}$, respectively).

According to the two-component model of growth and maintenance respiration, there was a strong positive relationship between respiration rate and RGR_{area} in rubber leaves. Here was very similar to those reported on other species such as yellow poplar (Wullschleger *et al*., 1992), northern red oak (Wullschleger *et al*., 1996), cotton (Thomas *et al*., 1993) and soybean (Thomas and Griffin, 1994; Bunce, 1995). In particular, the maintenance coefficients of rubber leaf showed clonal variation. There has been few reports of clonal variation for this parameter in the literature. These results indicated that when using two-component respiration model in rubber crop modeling, such parameter should be determinated for each clone.

Maintenance respiration rate of PB 235 leaf was low as compared to the others. PB 235 is known to grow very fast before tapping (RRIT, 1999a). Due to success in use of maintenance respiration as an index for breeding selection for high growth in rye grass (Wilson and Jones, 1982, Kraus *et al*., 1993), this parameter must be tested again in widely different growth performance in rubber clones. This is very interesting information.

Difference of leaf greenness among clones, GT 1 and PR 255 were higher greenness than that of RRIM 600, which was similarly by reported by Dansagoonpon (1997).

For an example of temperature effect, the result suggested that growth respiration was not affected by temperature, but only maintenance respiration affected by temperature. However Amthor (1989) reported that temperature very strongly influenced respiration rate. Thus, the knowledge of the effect of temperature on respiration rate in rubber tree is important to understanding of the relationship between respiration and productivity in the future.

CONCLUSIONS

The main conclusions of this study were (1) leaf position and leaflet position in the same flush of rubber did not affect respiration rate and leaf greenness; (2) a linear function of respiration rate and relative growth rate obtained a two-component model of growth and maintenance respiration; (3) differences of maintenance coefficient were found among rubber clones and might be used as an index for breeding selection for high growth clone; and (4) leaf maintenance respiration affected by temperature.

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