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Study on the Relationship between Plant and Soil Water Potential to Estimate Growth Pattern of Some Drought Resistant Tree Species in Dry Zone Areas

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အပူပိုင်းဒေသရှိ ခြောက်သွေ့မှုဒဏ်ခံနိုင်ရည်ရှိသည့် သစ်မျိုးအချို့၏ အရွက်အတွင်းရှိရေပမာဏနှင့်မြေအစိုဓါတ်ဆက်စပ်မှုအရ ကြီးထွားမှုကိုလေ့လာခြင်း

ဒေါက်တာညီညီကျော် (ဒုတိယညွှန်ကြားရေးမှူး၊ သစ်တောသုတေသနဌာန)
ဒေါ်ဆွေဆွေထွန်း (သုတေသနလက်ထောက်-၂၊ သစ်တောသုတေသနဌာန)

စာတမ်းအကျဉ်း

အပူပိုင်းဒေသတွင် သစ်တောစိုက်ခင်းတည်ထောင်ခြင်းနှင့် သစ်တောပြန်လည်တည်ထောင်ခြင်းတို့တွင် ဒေသနှင့်သင့်လျော်မည့်သစ်မျိုးများ ရွေးချယ်ခြင်းသည် အလွန်အရေးကြီးသော အချက်ဖြစ်ပါသည်။ ဒေသ၏ အခြေအနေကို လွယ်ကူလျှင်မြန်စွာ တိုင်းတာသိရှိ အကဲဖြတ်နိုင်ရန်အတွက် ပင်တွင်းရေပမာဏ နှင့် မြေဆီလွှာတွင် ရေအစိုဓါတ်ပမာဏ ဆက်စပ်မှုတို့ကို လေ့လာခဲ့ပါသည်။ သာစည်၊ နွားထိုးကြီးနှင့် ညောင်ဦးစသည့် မြို့နယ် ၃ မြို့နယ်တွင် ခြောက်သွေ့မှုဒဏ်ခံနိုင်ရည်ရှိသည့် အချို့သော ဒေသခံသစ်မျိုးနှင့် နိုင်ငံခြားသစ်မျိုး စုစုပေါင်း ၅ မျိုးအား ရွေးချယ်ခဲ့ပါသည်။ ဤလေ့လာမှုတွင် သစ်မျိုးများ၏ ပင်တွင်းရေပမာဏ အခြေအနေအား ရှိုလန်ဒါကရိယာ အသုံးပြု၍လည်းကောင်း၊ မြေဆီလွှာတွင် ရေအစိုဓါတ်ပမာဏကို ဂျစ်ပဆန်တုံး အသုံးပြု၍လည်းကောင်း၊ ခြောက်သွေ့ရာသီတွင် တစ်ကြိမ်၊ မိုးရာသီတွင် တစ်ကြိမ် တိုင်းတာ၍ စူးစမ်းလေ့လာခဲ့ပါသည်။ နေ့နှင့်ည ပင်တွင်းရေပမာဏကို ၄၅° ဖြတ်မျဉ်း အသုံးပြု၍ အကွက်ချရာ၌ ဒေသအားလုံးတွင် ကန့်သတ်ရေပမာဏ အခြေအနေသို့ မရောက်ရှိကြောင်း ဖော်ပြထားပါသည်။ သစ်မျိုးများ၏ နေ့နှင့်ည ပင်တွင်းရေပမာဏအခြေအနေအား တိုင်းတာခြင်းဖြင့်၊ ဒေသနှင့် စပ်လျဉ်းသည့် အမှန်တကယ် ရေရရှိနိုင်မှုကို သိရှိနိုင်ပါသည်။ သာစည်နှင့် ညောင်ဦးမြို့နယ်များရှိသစ်မျိုးများသည် ခြောက်သွေ့ရာသီတွင် ဆံချည်မျှင်ရေ ရရှိနိုင်ပါသည်။ သို့သော် နွားထိုးကြီးမြို့နယ်ရှိသစ်မျိုးများသည် မြေဆီလွှာတွင် နုန်းပါဝင်မှုပမာဏကြောင့် ရေရရှိနိုင်ရန်ခက်ခဲကြောင်းတွေ့ရှိရပါသည်။ မိုးရာသီတွင် ဒေသအားလုံးရှိ သစ်မျိုးများသည် မြေအောက်ရေ မှတဆင့် အလွယ်တကူ ရေရရှိနိုင်ပါသည်။ ခြောက်သွေ့ ရာသီတွင် အပင်နှင့် မြေဆီလွှာအတွင်းရှိ ရေပမာဏသည်၊ မျှခြေ အခြေအနေတွင်မရှိပါ။ မိုးရာသီတွင် အပင်နှင့် မြေဆီလွှာအတွင်းရှိရေပမာဏသည် မျှခြေအခြေအနေသို့ ရောက်ရှိပါသည်။ ထို့ကြောင့် မိုးရာသီတွင် ရေအစိုဓါတ်ပမာဏကို ခန့်မှန်းရန် ညအာရုဏ်မတက်ခင် ပင်တွင်း ရေပမာဏကို တိုင်းတာခြင်းဖြင့်သိရှိနိုင်ပါသည်။ သစ်မျိုးများ၏ နှစ်စဉ်ပျမ်းမ**ပြ**အမြင့်ကြီးထွားနှုန်းနှင့် နေ့နှင့်ည ပင်တွင်းရေပမာဏ ခြားနားမှုသည်၊ ဆက်စပ်မှုရှိကြောင်း တွေ့ရှိရပါသည်။

Study on the Relationship between Plant and Soil Water Potential to Estimate Growth Pattern of Some Drought Resistant Tree Species in Dry Zone Areas

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Abstract

Species site matching is very important in re-afforestation activities in dry zone area. To know easy rapid measurement for the assessment of site conditions, five drought resistant exotic and indigenous tree species were chosen in three study sites in Thazi, Nahtogyi and Nyaung-Oo Townships. In this study, the internal water potential of tree species was investigated by using Scholander apparatus and soil water potential by using gypsum soil block method during dry and rainy seasons. The plotted diagrams with 45° bisecting line of midday and predawn water potential revealed that trees were not in water limited condition in all study sites. The midday and predawn water potential of tree species at different sites with respect to the actual water availability in dry and rainy seasons were investigated. Tree species in Thazi and Nyaung-Oo can get capillary water in dry season. However, tree species in Nahtogyi are hardly access water due to the amount of silt content in soil. In the rainy season, tree species in all sites can easily be available through the accessible ground water. There was no equilibrium of water potential between plant and soil in the dry season. In the rainy season, predawn plant water potential and soil water potential reach equilibrium stage. Therefore predawn water potential can be used to estimate the soil water potential in rainy season. The result of direct measurement of leaf water potential under field conditions shows that the mean annual increment of tree height is positively correlated to the difference between midday and predawn water potentials.

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1. Introduction

Owing to increasing population, re-afforestation is crucial in dry zone area to meet local demand for fuel wood. Dry zone is notably difficult for tree planting because of poor soil and low rainfall conditions. Site-species matching is therefore important in plantation establishment. There has been a number of field research on site-species matching done by the Forest Research Institute (FRI) tackling both exotic and native species. Local species tried were *Azadirachta indica, Acacia catechu A. arabica, A. leucophlorea, Albizzia lebbek, Senna siamea*. The exotics included *Eucalyptus camaldulensis, Acacia auriculiformis, Leucaena leucocephala,* etc,.

For a site-vegetation analysis in dry zone, not only the climate and soil factors are important, but also the internal reactions of the plant growth to external factors. Trees reflect their conditions by measuring midday and predawn water potentials as well as standardized osmotic potentials. It is possible to quantify the current water regime of the soil and of the plant itself.

The approach proposed here of using plant as an indicator makes it possible to identify the requirements of a particular site and therefore to choose tree species which are appropriate for the environment. This hold true especially in the case of re-afforestation areas in dry zone where more vitality of established stands could be achieved in order to reduce risks of mortality.

2. Objectives

1. To study the internal status of plant water potential during dry and wet season.
2. To study the relationship between leaf water potential of drought resistant species and soil water potential of the area.
3. To estimate plant growth condition of dry zone greening plantations by using easy rapid measurement.

3. Literature Review

Water is the primary factor limiting plant physiological and ecological performance in many habitats. Plant water potential and a surrogate measurement made with a pressure chamber on the stem of leafy shoots are generally accepted as biological meaningful of plant water status, soil water availability, and components of the driving force for water transport through the soil -plant -atmosphere continuum (Lisa et. al., 2003).

Measurement of water potential is a most useful approach to quantification of water status. Conductivity of water within the plant, and from soil to atmosphere via the plant, is regulated by gradients in water potential. The dimensions of water potential are energy per unit mass (Jkg^{-1}), or per unit volume, and are convertible into pressure via the relationship 1 Jkg^{-1} = 1MPa (mega Pascal). Water potential is mostly expressed in terms of force per unit area (NM^{-2}) pressure in bar. It has + or - value, depending on the amount of free energy of water altered (Jeffery, 1987). Generally the free energy of pure water at standard temperature, pressure is zero MPa ($1MPa=1x10^6$ Pa=10 bars). The water potential in plant is lower than that of pure water and is therefore always negative. The influence of various components of water potential on the total water potential may be described as following expression (Stephen et. al., 1991).

$$\Psi w = \Psi\pi + \Psi p + \Psi g$$

where Ψw = total water potential

$\Psi\pi$ = osmotic or solute potential

Ψp = turgor or pressure potential

Ψg = gravitational potential

Total water potential and osmotic potential are the widely used parameters to evaluate plant water status but the meaning and interpretation of each one under natural conditions may differ widely. While water potential is a direct indicator of water status in the plant, and minimum values of healthy leaves during periods of water stress could be taken as an indicator of drought tolerance, osmotic potential seems to reflect the water conditions in the habitat during prolonged periods (Nyi Nyi Kyaw, 2003).

The water potential is equivalent to the suction force which a tree actually develops to extract from the soil. At a stage of fully saturated leaves with water, the water potential is around 1 bar (0.1 MPa). However, it can go as high as 80 bars (8MPa) in arid regions. At noon (midday) the water potential value is at a negative maximum, at night (predawn) at a negative minimum, as the stomata are closed and the atmospheric water saturation deficit is often lower. The predawn water potential is regarded as the actual power with which" the soil keeps the water back"(Miltöhner, 2000)**.**

The difference between midday and predawn refers to the water availability that the tree undergoes. If the differences is very high (midday values is higher than predawn), it implies that the tree undergoes high water stress during the daytime and it has to spend more energy to adjust according to that particular environment .Therefore, it recovers in the night by resaturation (relaxation phase). The predawn value shows how far the tree can recover overnight from midday water stress (Miltöhner, 1997)**.**

Zobel et al., (2001) stated that water is easily available to plant if the water potential is high (low negative value) i.e., near zero and it is less available to plants if the water potential is low (high negative value). Plant species differ in their transpiration rates, patterns of root distribution and response to water stress. These different patterns of water use likely result from differences among species in morphological and physiological characteristic that affect the rate of soil moisture depletion and the distribution of water removal at different soil depth.

Predawn plant water potential are widely used to estimate soil water potential and thus the accessible soil moisture based on the assumption that plant water potential equilibrates with the "wettest" soil layer around active roots (Hinckley, et al., 1978). The assumption of predawn plant-soil equilibration explicitly or implicitly underlines ecological interpretations of species or treatment differences in predawn as differences in rooting depth, habitat partitioning, water sources, water stress or competitive ability (Davis & Mooney, 1986).

4. Materials and Methods

4.1. Study Area

The experiment was conducted in fuelwood plantations established in 1999 in the following areas;

1) Shwe Nat Taung Protected Public Forest, Thazi Township
2) Minson Taung Protected Public Forest, Nahtogyi Township
3) Dahatsi Protected Public Forest, Nyaung- Oo Township

Site condition and soil profile for each study area are shown in Appendix 2. The species used in Thazi were Eucalypt (*Eucalyptus camaldulensis*), Sha (*Acacia catechu*) and Bawzagaing (*Leucaena leucocephala*). The tested species in Nahtogyi and Nyaung-Oo were Eucalypt (*Eucalyptus camaldulensis)*, Sha (*Acacia catechu*) and Tama *(Azadirachta indica).*

The soil in study areas included in red brown soil of tropical dry savannas (Bender, 1983). Climate is influenced by tropical savanna climate with a pronounced dry period between the monsoon rains. Rains commence in mid-May, almost stop from July to mid August and then resume intermittently from mid August to September. Climatic data (1997-2006) for Thazi, Nahtogyi and Nyaung-Oo Townships were collected from the nearest weather stations. The climatic characteristic of the study areas are shown in table 1.

Table 1. Monthly mean temperature, mean precipitation and DE MARTONNE aridity index of study areas.

Month	Thazi			Nahtogyi			Nyaung-Oo		
	Rainfall (mm)	Temp (ºC)	Aridity Index	Rainfall (mm)	Temp (ºC)	Aridity Index	Rainfall (mm)	Temp (ºC)	Aridity Index
Jan	2.03	22.31	0.85	0.51	19.66	0.21	0	22.21	0
Feb	6.09	25.34	2.06	3.05	23.73	1.08	0	25.63	0
Mar	10.01	29.04	3.08	3.56	27.89	1.13	0	30.34	0
Apr	23.75	31.83	6.81	12.45	31.53	3.60	7.37	32.45	2.08
May	171.93	30.48	50.97	99.82	32.19	28.39	25.40	34.38	6.86
Jun	110.68	28.99	34.06	90.17	31.52	26.06	111.60	32.32	30.90
Jul	75.13	28.70	23.30	76.71	30.78	22.58	27.69	31.63	7.98
Aug	117.55	28.54	36.60	110.70	30.19	33.05	91.06	31.36	26.25
Sep	115.50	28.53	48.49	115.30	28.84	35.62	120.60	30.78	35.49
Oct	115.10	28.22	47.46	110.60	28.03	34.90	111.40	30.15	33.30
Nov	32.99	25.53	11.14	35.56	24.2	12.48	9.53	27.36	3.06
Dec	45.04	22.90	16.42	8.89	20.81	3.46	23.11	23.67	8.24
Annual	**825.8**	**27.53**		**667.32**	**27.45**		**527.76**	**29.36**	

Source: The Meteorology and Hydrology Department, 2007

The aridity indices of Thazi and Nahtogyi sites gave the same result of 6 dry months and Nyaung-Oo site exhibits a prolonged dry season of 8 months. The climatic diagram of the study areas are shown in Figure 1.

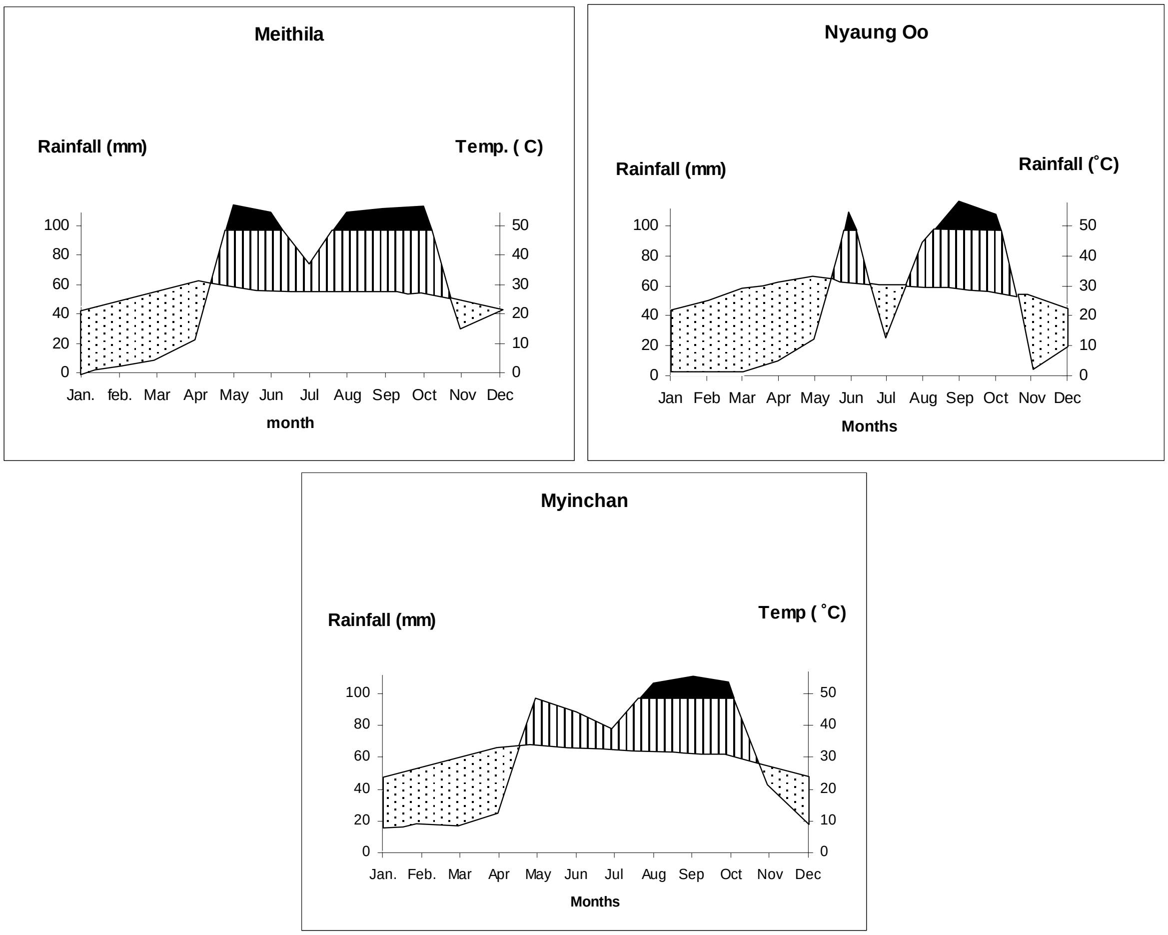


Figure 1. Climatograms of study areas (1997-2006)

4.2 Data collection

The water potential measurements are carried out under field condition using a Scholander apparatus in dry season, February 2006, before all leaves were shed, and in the rainy season, September 2007. Six trees for each species were selected for plant water potential measurement. The study in a particular tree consists of two measurements of leaves at midday (12:00 -14:30 pm) when water potential is expected to be in daily minimum and during predawn (3:30-6:00 am) at the time of presumed highest water potential. At the time of measurement, freshly cut mature leaves from tree branches of south exposition and situated at the same insertion of height were taken. At every sampling time, six leaves were cut from each tree. These leaves were immediately enclosed in plastic bags and taken quickly to the pressure chamber and balancing pressure was measured. The number of sampled leaves has to be adequate to maintain the standard error below 7% of the mean.

Soil water potential at different soil layers (0-10cm, 40-50 cm and 80-90 cm) was also collected under the sampled trees selected. For soil test, the samples were collected and soil profile was investigated in each location at the time of first measurement. Height measurement of sampled trees was done in September 2007.

4.3 Field measurements

4.3.1 Plant water potential

The plant water potential of leaf samples from the study areas was measured both at midday and predawn by a pressure chamber (Scholander et. al., 1965), which is one of the most useful equipment developments in plant water relations research, particularly for field study. Construction of the pressure chamber is shown in Figure 2.

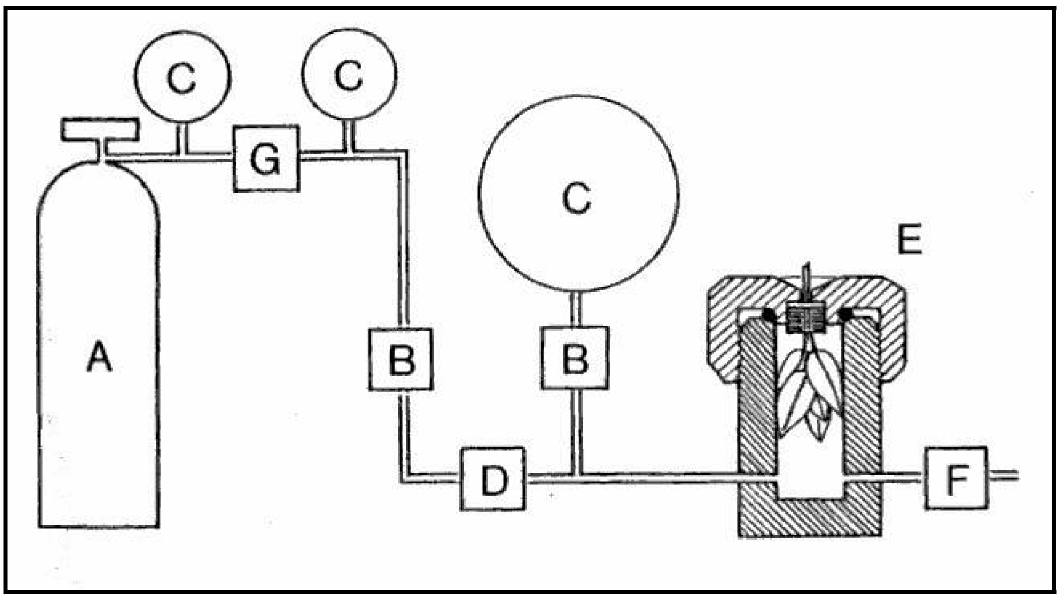


Figure 2. Scholander-apparatus with pressure chamber. A: pressure air cylinder, B: shut-off valves, C: pressure gauges, D: metering valve, E: pressure chamber, F: exhaust valve, G: pressure reduction valve, (Miltöhner, 1997).

The instrument consists of a pressure-safe vessel machined from stainless steel with screw-top removable head, gas lines, pressure gauge, safety pop-off valves as appropriate. In operation, a leaf is exactly cut with a razor blade and positioned in the chamber head so that only the petiole protrudes from the chamber through a flexible gasket. Once sealed, pressure air is fed to the chamber and the cut end is carefully examined the appearance of water through a magnifying glass. When water first appears on the cut surface, an event usually marked by darkening of xylem elements, pressurization is stopped and a small amount of pressure is released to cause slight recession of the water column. Finally, the chamber is pressurized very slowly and a balance pressure gauge reading taken at the clear appearance of the endpoint. The chamber may then be depressurized rapidly and the sample discarded. (Nyi Nyi Kyaw, 2003). According to Lassoie and Hinckley (1991), the measuring error is between ±0.1 and 0.2bar (±0.01 and 0.02 MPa). Demonstration of measuring plant water potential with the Scholander apparatus in the field is shown in figure 3.

Figure 3. Measuring plant water potential with the Scholander apparatus in the field.

4.3.2 Soil water potential

Soil water potential was measured by Delmhort soil moisture meter Model KS-D1 (see figure 4). Soil moisture measuring system consists of two parts: the gypsum soil blocks (sensors) and the measuring instrument. Firstly, gypsum soil block is soaked in water for 3 minutes and a soil and water slurry of creamy consistency is made and then the block is installed at the depth of 0-10 cm, 40-50 cm and 80-90cm until its moisture content approaches equilibrium with the moisture content of the soil. Afterwards, the block is connected to the meter, current flows between the electrodes and the electrical resistance of the gypsum is measured. Such reading is an indication of block resistance and then converted into moisture tension or soil water potential (bar).

Figure 4. Measuring of soil water potential with Delmhort soil moisture meter Model KS-D1.

4.3.3 Soil properties

Composite soil sampling was made at the depth of 0-10 cm, 40-50 cm and 80-90 cm from each location using an auger and analyzed at the Forest Soil Laboratory of Forest Research Institute to be recorded as site characterization.

4.3.4 Data analysis

Plant water potential and soil water potential data were entered into Excel worksheets as the basic data format for analysis. Before analysis, the data files were rechecked for errors such as, mis-measurement of trees or mis-reading of measuring apparatus, illegible hand-writing or mis-writing, striking the wrong keys or entry into the wrong column in worksheets. Microsoft excel 2003 was used for the data analysis.

5. Results and Discussions

5.1 Results

5.1.1 Soil condition

Some physical and chemical properties of study areas are shown in Appendix 4. Most of the plantation soils from Thazi, Nahtogyi and Nyaung-Oo sites are associated with active alkalinity. Soil texture in Nahtogyi and Nyaung-Oo site are loamy sand while Thazi site is sand. Available phosphorous is low and extractable potassium and calcium is subjected as medium level for normal plant growth. Total nitrogen content is found to be medium in study sites except Nyaung-Oo. Organic matter was observed low level in Thazi and Nyaung-Oo, where as Nahtogyi was medium level.

5.1.2 The status of plant water potential

The values of plant water potential measured in the study areas are shown in Appendix 3. All species exhibited their lowest values during midday followed by substantial increases in predawn. To know water internal status of tree species in all study sites, the values of midday and predawn water potentials were plotted in a scatter chart comparing pairs of values as the Y and X axis respectively and 45° bisecting line was drawn on the graph for each sample. As shown in figure 5, the values of the (negative) plant water potential of tree species from all study areas are above the bisecting line in both dry and rainy season.

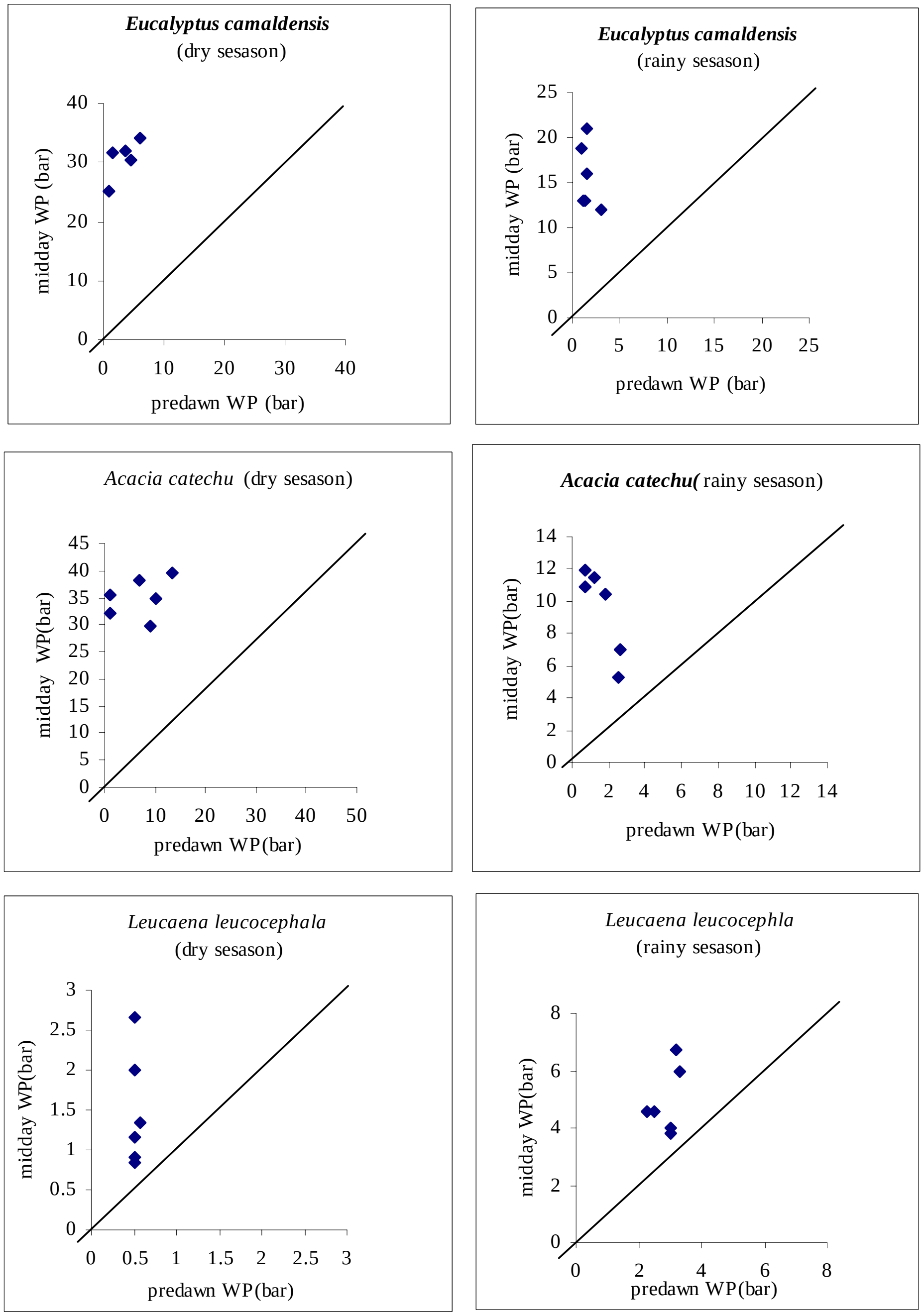


Figure5a. Midday and predawn plant water potential measured in bar for tree species in Thazi.

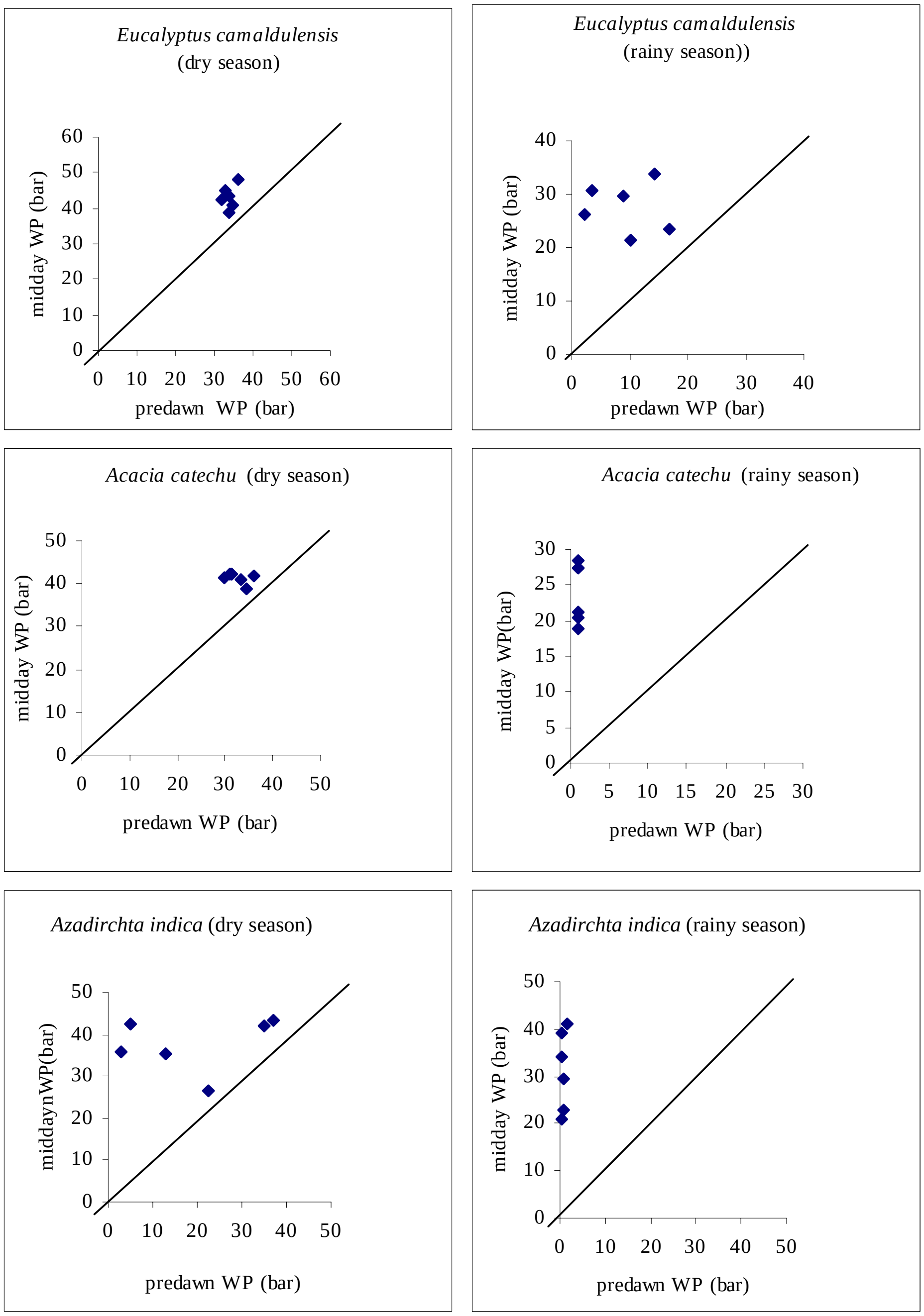


Figure5b. Midday and predawn plant water potential measured in bar for tree species in Nahtogyi.

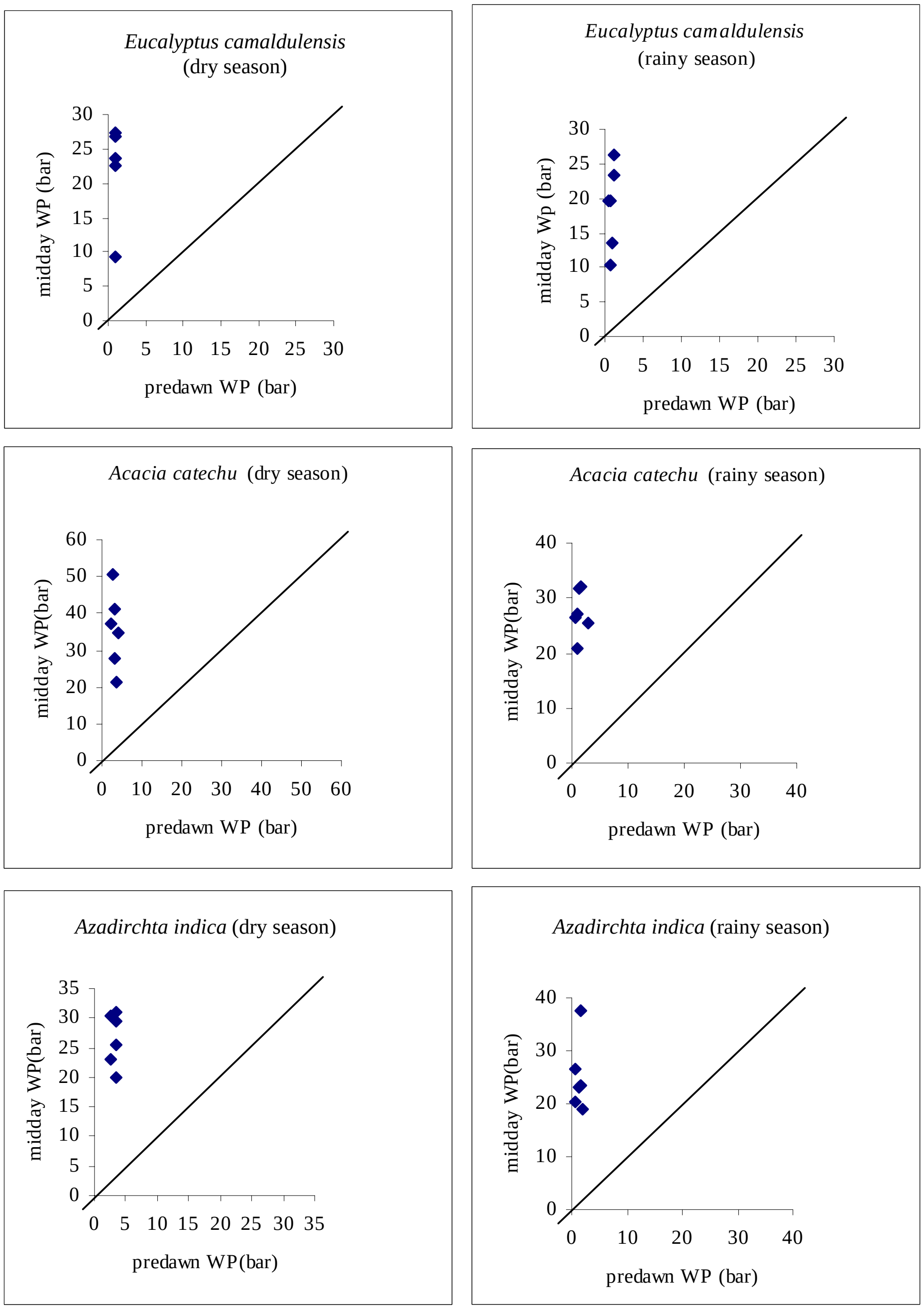


Figure 5c. Midday and predawn plant water potential measured in bar for tree species in Nyaung-Oo

5.1.3 The status of soil water potential at different soil layers

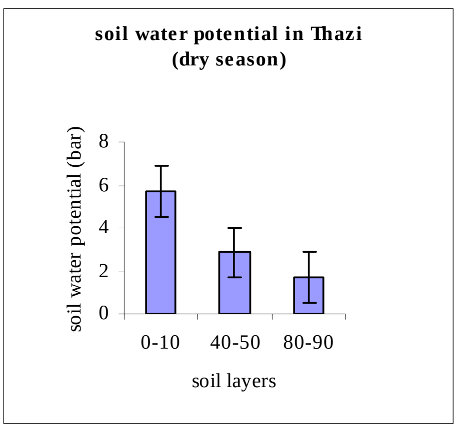
The analysis of variance for soil water potential at different soil layers of study sites for dry and rainy season are shown in Appendix 1. F test indicated that a significantly different at 1% level. Mean comparison of soil water potential at different soil layers in all study areas for dry and rainy season are shown in figure 6 and described as follow;

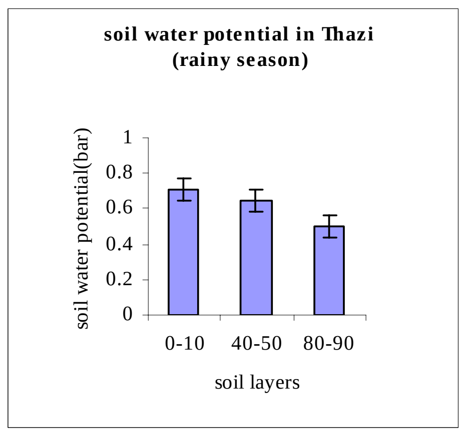
Dry season

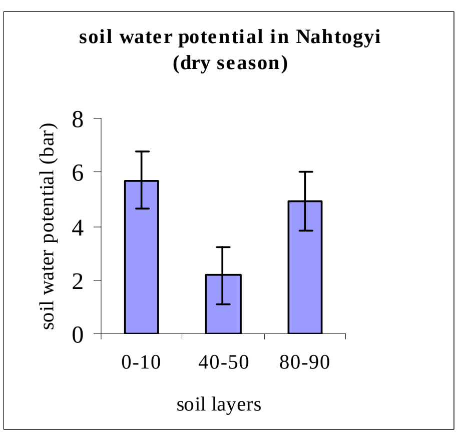
- Maximum soil water potential was found 1.72 bar in 80-90 cm and followed by 2.87 bar in 40-50 cm and 5.69 bar in 0-10 cm layer in Thazi.
- In Nahtogyi, 40-50 cm was found to have the highest soil water potential. 0-10 cm layer and 80-90 cm layer were not significantly different at 5% level by DMRT.
- In Nyaung-Oo, 80-90 cm layer was significantly different from 0-10 cm layer which was the lowest soil water potential.

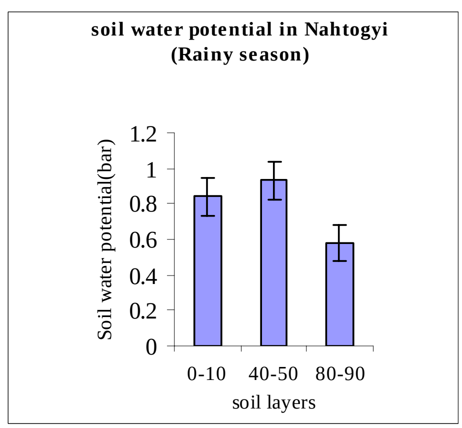
Rainy season

- In Thazi, 0-10 cm soil layer was the lowest soil water potential and followed by 40-50 cm and 80-90 cm.
- In Nahtogyi, 80-90 cm soil layer showed the highest soil water potential and followed by 0-10 cm layer and 40-50 cm layer.
- In Nyaung-Oo, 0-10 cm layer was found the minimum soil water potential. 40-50 cm layer and 80-90 cm layer were not significantly different at 5% level by DMRT.









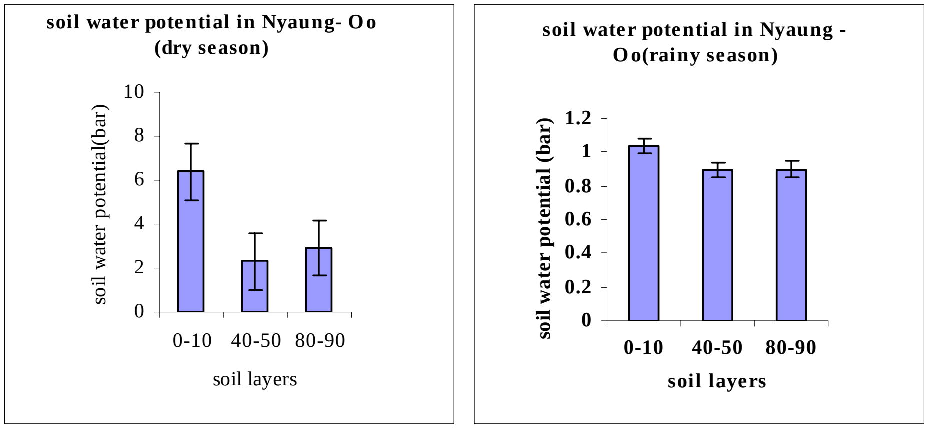


Figure 6. Soil water potential at different soil layers in Thazi, Nahtogyi and Nyaung-Oo

5.2 Discussions

5.2.1 The internal water status of tree species

The value of plant water potential of tree species and soil water potential under the trees tested showed different responses to obvious site differences. The water potential values of tree species in all study areas are above the bisecting line in both dry and rainy season. The bisecting line was assumed to express site specific limit of trees species (permanent wilting point) in that particular site. Therefore ,when the species fail to recover from the water stress during the day persistently, the value would be under the line, which could lead to leaf shedding and/or decline in the growth of the tree in that particular site (Mitlöhner, 2000). It could be assumed from this study that tree species tested were not under water limited conditions in all study areas.

5.2.2 Soil water condition in study areas

The soil water potential at different soil layers at each site showed significant difference at both dry season and rainy season. In the dry season, soil water potential at different soil layers exhibited their lowest value in the upper layer and followed by substantial increase in the deeper layer except Nahtogyi site. The zone of lowest soil water potential is regarded as the zone of highest root density in the soil profile. However, Nahtogyi site under test was observed that 40-50cm layer has the highest soil water potential. It may be due to finer particles which contain more water at a given soil metric potential. In the rainy season, soil water potential at different soil layers are fluctuated under species tested. It may be due to the distribution of rainfall to the soil layer of different pore size influence the water flow through the profile greatly affecting the amount of water held in the soil. In addition soil water potential at 0-10cm,40-50cm and 80-90cm soil layer were less than negative 15 (bar) in the dry season and close to zero in the rainy season.

Narayana & shah (1966) stated that the moisture condition just between field capacity and permanent wilting percentage (0.1to 0.33 and 15 atm (bar)) are accepted as available water or plant available water. Tree species in study areas can get available water comfortably without any stress and even evapotranspiration occurs at the potential range.

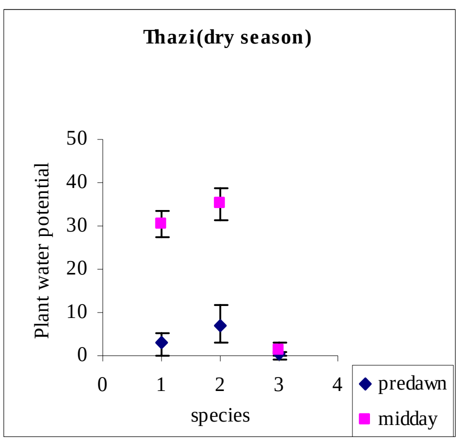
5.2.3 Water availability in study areas

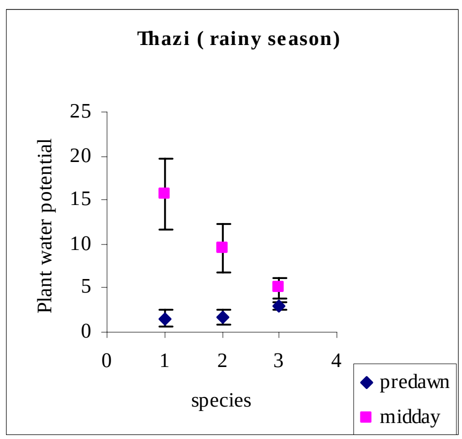
The mean and standards deviation of midday and predawn water potential of tree species in all study areas are shown in figure 7. In Thazi and Nyaung-Oo, tree species except bawzagaing (*Leucaena leucocephala*) showed low predawn value and higher midday value in the dry season. Midday and predawn water potential of tree species in Nahtogyi site are much higher in the dry season.

This result is found to be in accord with the study by Mitlöhner (1998) in water availability of vegetation in Paragauayan Chaco of South America. According to this study, tree species except bawzagaing (*Leucaena leucocephala*) in Thazi and Nyaung-Oo sites can get capillary water from 1m deep ground water. Bawzagaing (*Leucaena leucocephala*) in Thazi seemed direct contact with the ground water although the higher demand at the noon time.

Soil profile in Nahtogyi seemed silt-rich A horizons (0-48 cm) (see appendix 4). It could be generally said that the more fine grained the soil substrate is the more suction force is involved to extract water from the soil. So tree species in Nathogyi site can get less water availability in the dry season.

In the rainy season, tree species except bawzagaing (*Leucaena leucocephala*) in all sites were found lower predawn and higher midday water potential. Tree species in all sites can easily be available water through the accessible ground water.





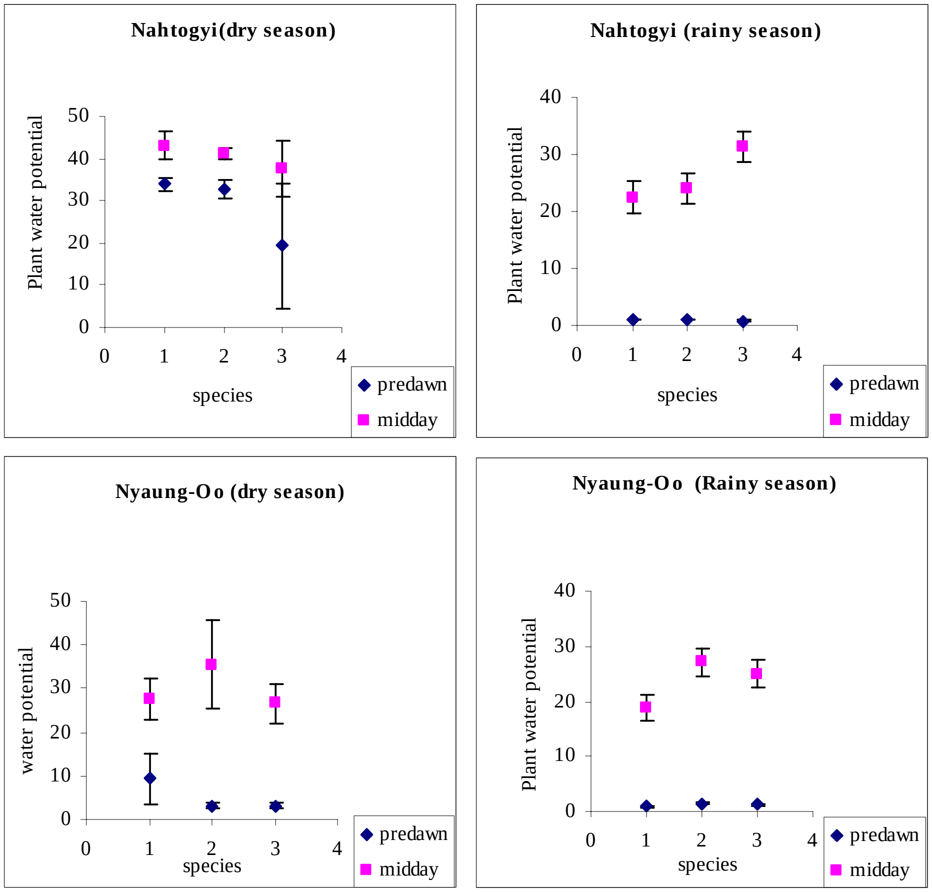


Figure 7. Mean and standard deviation of 6 midday and 6 predawn plant water potential (bar) for tree species in study areas: species1. *Eucalyptus camaldulensis*, 2. *Acacia catechu*, 3. *leucaena leucocephala* (Thazi) 3. *Azadirachta indica* (Nahtogyi and Nyaung-Oo)

5.2.4 The relationship between soil water potential and predawn plant water potential

In all study areas there was no relationship between soil water potential and plant water potential in the dry season. In this study, plant water potential was more negative than that of soil in the root zone due to the alkaline soil found in all study sites. In dry season, salt accumulations often remain high and plant water becomes a limiting factor. This may reduce the gradient of water potential from soil to plant resulting in reduced absorption of plant.

In rainy season, predawn water potential was highly correlated with the water potential of the wettest soil layer (80-90 cm) shown in figure 8. In all sites, the negative predawn plant water potential seems to be increasing with increasing of soil water potential. The values of predawn plant water potential and soil water potential are close to zero in rainy season. Therefore, predawn water potential of tree species may be reached an equilibrium stage with water potential of wettest soil layer.

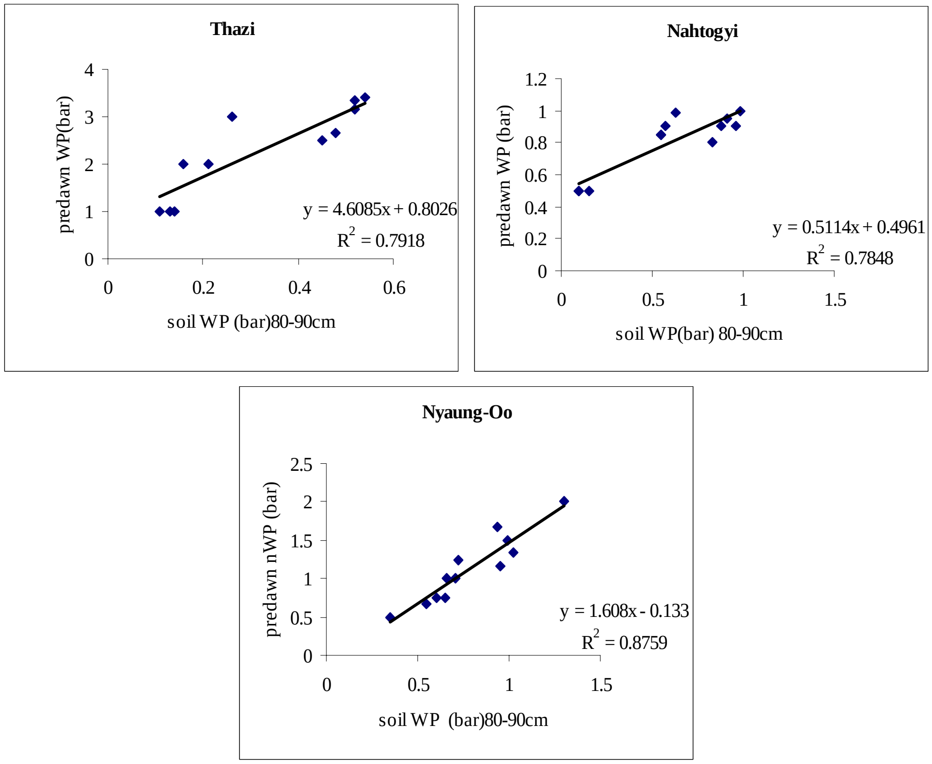


Figure 8. The relationship between soil water potential and predawn plant water potential

5.2.5 The relationship between mean annual increment (MAI) and plant water potential difference

The relationship between mean annual increment (MAI) in height and water potential difference in all study sites is shown in figure 9. MAI is positively correlated with water potential difference of leaf of tree species in all study sites. It is found that MAI increases with the increases of difference in midday and pre-dawn water potential of tree species. It is found to be in accord with the study by Mitlöhner (1998) who generalized that the wider the difference between midday and predawn water potential (diurnal range), the better the growth of plant. According to this, it could be said that if water potential difference is less, there will be a water deficit in the plant, which affects the growth and development. However, it has to be taken into account that especially the water potential can be varied strongly seasonal changes.

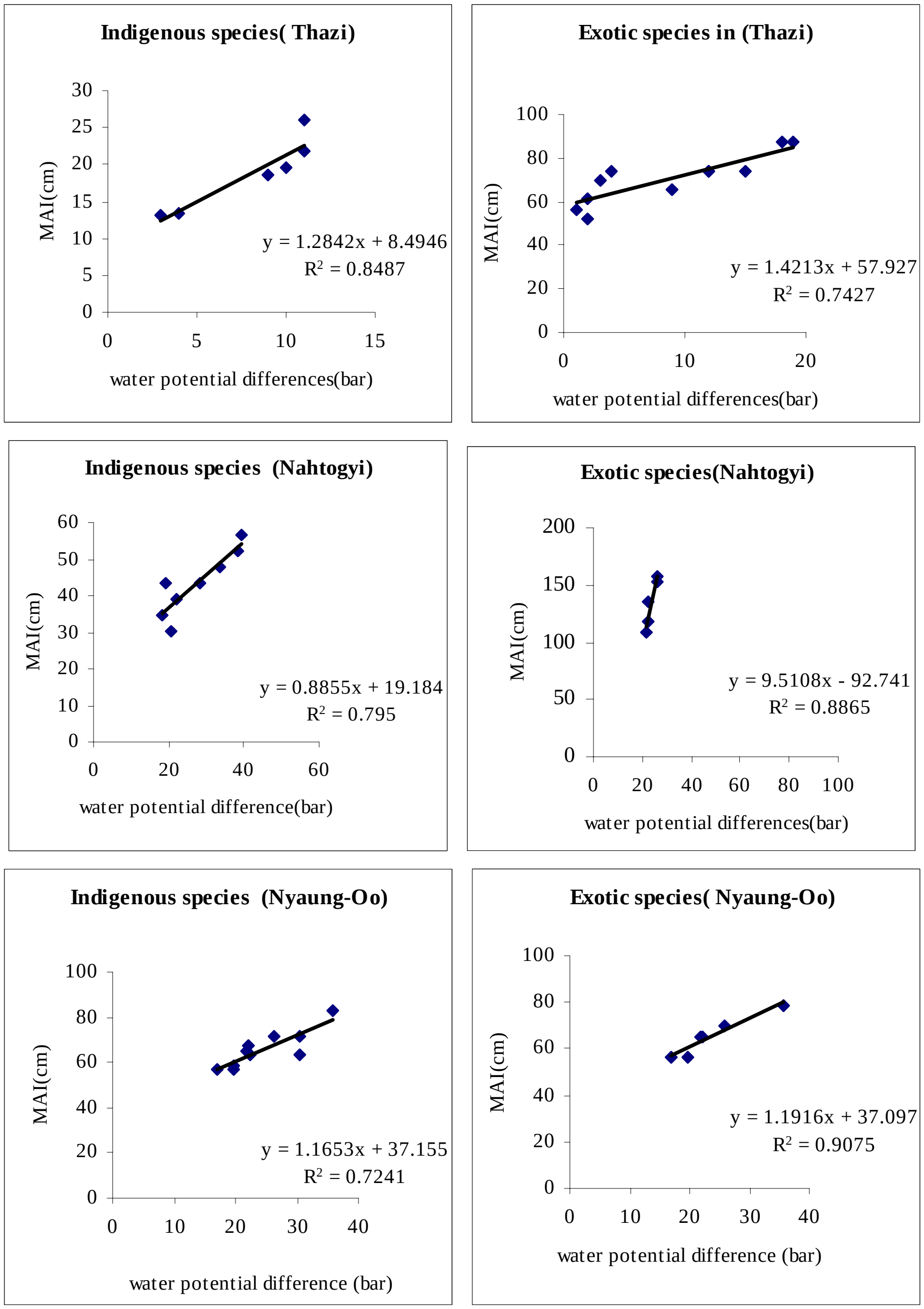


Figure 9.The relationship between MAI and leaf water potential difference of indigenous and exotic species in study areas

6. Conclusion and Recommendation

In this study, the internal water potential of tree was investigated by pressure chamber method using Scholander apparatus and soil water potential by using gypsum soil block method during dry and rainy season in all areas.

By comparing pairs of values of midday and predawn water potential of tree species in all study areas, plotted points occur above the bisecting line in both dry and rainy season. It shows that tree species do not reach site specific limit although the plant water potential varies strongly with seasonal changes. Therefore, this criterion is a suitable indicator for the selection of tree species for particular areas. In addition the water potential differences of the same species at different sites with respect to the actual water- availability can be examined. Tree species in Thazi and Nyaung-Oo can get capillary water in dry season. However tree species in Nahtogyi hardly access water due to the amount of silt content in soil. In rainy season, tree species in all sites can easily reach the accessible ground water. So trees reflect specific site conditions and characterize the water availability of sites.

There was no equilibrium of water potential between plant and soil in the dry season. In rainy season, predawn plant water potential and soil water potential reach equilibrium stage. Therefore predawn water potential may be used as a baseline water stress to estimate the soil water potential in rainy season.

The results of direct measurement of water potential under field condition show that the mean annual increment in height is positively correlated to the difference between midday and predawn water potentials. The water potential difference between midday and predawn could be used as an indicator to differentiate the site condition. In order to get reliable results it is necessary to have a large data base, which should be obtained from the simultaneous measurements in the field condition.

Based on the findings of the current study, it could be concluded as follows;

- In areas where water is a limiting factor, water potential measurements are good indicators of water status of the site for that particular species. Hence they can be used for site-species matching in re-afforestation programmes.
- The predawn water potential values indicate the soil water status of the site. The midday values indicate the evaportranspiration demand and water potential differences (diurnal range) in the dry season shows the tolerance range of the species to water stress. Measuring plant water potential by using Scholander apparatus can estimate soil water status and water stress in the species
- Using the range of the water potential values, the suitability of the species and site for afforestation and reforestation could be evaluated.

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Appendix 1

Analysis of variance for soil water potential at Thazi site (dry season)

Sv	*SS*	*df*	*MS*	*F*
REPLICATION	18.37	8	2.29	4.22ns
DEPTH	75.03	2	37.51	68.99 **
ERROR	8.69	16	0.54	
TOTAL	102.09	26		

** =significant at 1%level

Analysis of variance for soil water potential at Nahtogyi site(dry season)

Sv	*SS*	*df*	*MS*	*F*
REPLICATION	7.89	8	0.99	0.85ns
DEPTH	61.91	2	30.96	26.62**
ERROR	18.61	16	1.16	
TOTAL	88.42	26		

** =significant at 1%level

Analysis of variance for soil water potential at Nyaung-Oo site(dry season)

Sv	*SS*	*df*	*MS*	*F*
REPLICATION	17.15	8	2.14	0.34ns
DEPTH	87.71	2	43.85	7.05**
ERROR	99.47	16	6.22	
TOTAL	204.33	26		

** =significant at 1%level

Analysis of variance for soil water potential at Thazi site(rainy season)

Sv	*SS*	*df*	*MS*	*F*
REPLICATION	0.26	8	0.03	1.82 ns
DEPTH	0.21	2	0.1	5.73 **
ERROR	0.29	16	0.02	
TOTAL	0.76	26		

** =significant at 1%level

Analysis of variance for soil water potential at Nahtogyi site(rainy season)

Sv	*SS*	*df*	*MS*	*F*
REPLICATION	1.04	8	0.13	4.94 ns
DEPTH	0.59	2	0.29	11.23**
ERROR	0.42	16	0.03	
TOTAL	2.05	26		

** =significant at 1%level

Analysis of variance for soil water potential at Nyaung-Oo site(rainy season)

Sv	*SS*	*df*	*MS*	*F*
REPLICATION	1.49	8	0.19	31.67**
DEPTH	0.11	2	0.06	9.37**
ERROR	0.09	16	0.01	
TOTAL	1.69	26		

** =significant at 1%level

Appendix 2

Plate 1a. Eucalyptus plantation (1999) in Shwe Nat Taung Protected Public Forest, Thazi Township.

Plate 1.b Soil profile of Eucalyptus plantation (1999) in Shwe Nat Taung Protected Public Forest, Thazi Township.

Plate 2a. Neem plantation (1999) in Minson Taung Protected Public Forest, Nahtogyi Township

Plate 2.b Soil profile of neem plantation (1999), Minson Taung Protected Public Forest, Nahtogyi Township

Plate 3a. Sha (*Acacia catechu*) plantation (1999) in Dahatsi Protected Public Forest, Nyaung-Oo Township.

Plate 3.b Soil profile of Sha plantation (1999), Dahatsi Protected Public Forest, Nyaung-Oo Township.

Appendix 3

Maximum and mean of water potential in bar for tree species in dry and rainy season

Site/species	Max. Water potential (bar)	Midday Water potential (bar)	Predawn Water potential (bar)
Dry season			
Thazi			
Eucalyptus camaldulensis	-32	-30	-3
Acacia catechu	-36	-35	-7
Leucaena Leucocephala	-3	-2	-1
Nahtogyi			
Eucalyptus camaldulensis	-48	-43	-34
Acacia catechu	-42	-41	-33
Azadirachta indica	-43	-38	-39
Nyaung-Oo			
Eucalyptus camaldulensis	-35	-28	-9
Acacia catechu	-50	-36	-3
Azadirachta indica	-31	-27	-3
Rainy season			
Thazi			-2
Eucalyptus camaldulensis	-21	-16	-2
Acacia catechu	-12	-10	-3
Leucaena Leucocephala	-7	-5	
Nahtogyi			
Eucalyptus camaldulensis	-28	-23	-1
Acacia catechu	-29	-24	-1
Azadirachta indica	-39	-31	-1
Nyaung-Oo			
Eucalyptus camaldulensis	-26	-19	-1
Acacia catechu	-26	-27	-1
Azadirachta indica	-38	-25	-1

Appendix 4

Physical and Chemical Properties of Soil in Shwe Nat Taung Protected Public Forest,1999 Plantation, Thazi Township

Particular	Depth (cm)	pH	Total N %	Ava. P %	Extractable Nutrients (%)		OM %	Texture			Remarks
					K	Ca		sand %	silt %	clay %	
Block 1	0-10	7.73	0.06960	nil	0.0028	0.1528	1.10	92	5	4	sand
	40-50	8.06	0.05100	nil	0.0003	0.2004	0.72	91	2	2	sand
	80-90	8.30	0.03650	nil	0.0004	0.1985	0.41	92	3	1	sand
Block 2	0-10	6.43	0.09340	0.000570	0.0016	0.0612	1.89	95	0	2	sand
	40-50	9.56	0.03650	nil	0.0003	0.1804	0.66	85	10	2	sand
	80-90	9.86	0.03480	nil	0.0005	0.1872	0.70	84	8	7	loam sand
Block 3	0-10	7.28	0.15600	0.000440	0.0021	0.1573	3.20	90	3	4	sand
	40-50	8.34	0.07020	0.000005	0.0004	0.1920	1.75	86	10	4	loam sand
	80-90	8.85	0.06500	0.000009	0.0004	0.1707	1.65	93	4	4	sand
Profile	A2	7.34	0.05280	0.000009	0.0009	0.2153	1.24	88	7	0	sand
	A3	7.85	0.04060	0.000009	0.0004	0.1943	0.85	85	4	7	loam sand
	B1	8.56	0.03190	0.000003	0.0004	0.1459	0.71	92	3	5	sand

Physical and Chemical Properties of Soil in Min Son Taung Protected Public Forest, 1999 Plantation, Nahtogyi Township

Particular	Depth (cm)	pH	Total N %	Ava. P %	Extractable Nutrients (%)		OM %	Texture			Remarks
					K	Ca		sand %	silt %	clay %	
Block 1	0-10	7.08	0.0800	0.00038	0.0017	0.0586	3.74	68	19	14	sandy loam
	40-50	7.82	0.0876	0.00021	0.0013	0.1181	0.94	70	9	20	sandy clay loam
	80-90	8.12	0.0452	0	0.0006	0.2061	1.11	68	11	18	sandy loam
Block 2	0-10	7.69	0.1249	0	0.0011	0.2057	2.74	60	8	28	sandy clay loam
	40-50	7.92	0.0603	0	0.0007	0.2043	2.16	51	26	18	sandy loam
	80-90	8.02	0.0545	0	0.0010	0.2002	1.42	63	21	20	sandy clay loam
Block 3	0-10	8.13	0.1032	0.000026	0.0009	0.2115	1.15	76	11	17	sandy loam
	40-50	8.50	0.0412	0.000025	0.0006	0.2024	0.79	83	4	16	sandy loam
	80-90	8.64	0.0284	0.000041	0.0005	0.1631	0.45	88	8	6	loamy sand
	A2	8.63	0.0568	nil	0.0015	0.1652	1.45	41	28	28	clay loam
Profile	A3		0.2163	0.00017	0.0038	0.1168		56	28	13	sandy loam
	B1	8.74	0.0313	0.000009	0.0016	0.1382	1.27	72	24	1	loamy sand
	B2	8.81	0.0342	0.00011	0.0013	0.1190	0.37	76	6	20	sandy clay loam

Physical and Chemical Properties of Soil in Dahatsi Protected Public Forest, 1999 Plantation, Nyaung-Oo Township

Particular	Depth (cm)	pH	Total N %	Ava. P %	Extractable Nutrients (%)		OM %	Texture			Remarks
					K	Ca		sand %	silt %	clay %	
Block 1	0-10	7.15	0.0371	0.00021	0.0026	0.1236	1.56	78	8	15	sandy loam
	40-50	7.50	0.0592	0.00037	0.0019	0.0658	1.51	68	10	20	sandy clay loam
	80-90	7.74	0.0609	0	0.0011	0.2334	1.11	68	12	22	sandy clay loam
Block 2	0-10	7.79	0.0418	0	0.0013	0.2135	1.12	74	13	16	sandy loam
	40-50	7.90	0.0545	0	0.0017	0.2180	1.33	68	14	16	sandy loam
	80-90	8.13	0.0673	0	0.0009	0.2156	0.75	73	14	14	sandy loam
Block 3	0-10	7.67	0.0429	0	0.0016	0.2294	1.86	69	14	21	sandy clay loam
	40-50	7.91	0.0568	0	0.001	0.2105	1.73	59	21	24	sandy clay loam
	80-90	8.03	0.0568	0	0.0011	0.2013	1.25	61	20	21	sandy clay loam
Profile	A2	7.74	0.0458	nil	0.0023	0.2197	2.27	70	14	13	sandy loam
	B2	7.95	0.0870	nil	0.0013	0.2217	1.44	71	14	13	loamy sand