**ABSTRACT**  Midday transpiration rates and daily pan evaporation from forest floor and open area were measured to determine an effective way of controlling water loss from a *Melia volkensii* plantation. The research was conducted at an *M. volkensii* plantation in Tiva Pilot Forest, Kenya, during April and May 2014. A leaf porometer (LI-1600) was used to measure midday transpiration rates per unit leaf area (*T*<sub>a</sub>) from 11:00 h to 13:00 h for four trees at three different leaf heights: top (A), middle (B), and bottom (C) layers of a crown. Midday transpiration rate per layer (*T*<sub>l</sub>) and midday transpiration rate per tree (*T*<sub>t</sub>) were estimated based on *T*<sub>a</sub> and leaf area (LA) of layers. Daily pan evaporation from forest floor and open area were measured using 25 and two evaporation pans, respectively. *T*<sub>a</sub> values for layer A were not significantly different among sample trees, while *T*<sub>a</sub> values for layer A were significantly different, indicating the influence of LA on water loss through transpiration. Since *T*<sub>t</sub> from layers B and C accounted for half of *T*<sub>a</sub>, pruning of these layers could cause a 50 % reduction in water loss through transpiration. Daily pan evaporation in the plantation was approximately 70 % lower than that in the open area. Therefore, the layer A left after pruning should keep water loss through evaporation from the forest floor lower than that from the open area. Further research is required to determine the effect of pruning on reduction of water loss from the plantation.

**Key words:** local water resources, leaf area index, dry environments, forest management, leaf porometer

**INTRODUCTION**

More than 80 % of Kenya's land consists of arid and semi-arid lands containing sparse dry bush and open wooded grassland (Government of Kenya 2010). Approximately 12 % of the remaining land covered by closed canopy forests in 1963 was progressively reduced to 1.7 % in 2006, as a result of the development of agriculture (Bosire 2006, Government of Kenya 2010). Moreover, illegal logging, grazing, and mining have led to an accelerated rate of destruction of forests (JIFPRO 2012). Therefore, it is vital to conserve the remaining forests for future generations.

The planting of trees produces wood, and also helps to conserve natural forests. However, the evergreen tree species *Grevillea robusta* and *Eucalyptus camaldulensis*, which have been planted extensively in Kenya, consume large amounts of water, and have led to the depletion of water resources (Rumley et al. 2006). The climatic conditions in the Loess Plateau in China are similar to those of the arid and semi-arid lands of Kenya, and the river flow in this area was expected to decrease by 9 % when trees were planted on its bare land (Zhang et al. 2008). Thus, in arid and semi-arid areas, the conservation of water resources must be taken into consideration when planning the planting of trees (JIFPRO 2014b).

*Melia volkensii* is grown widely in East Africa (Ethiopia, Somalia, Kenya, and Tanzania), and is used by local people as timber (Maundu and Tengnäs 2005). *M. volkensii* is a deciduous tree that grows rapidly. It sheds its leaves in the early dry seasons, and continues to produce new leaves towards the end of the dry seasons (Stewart and Blomley 1994). JIFPRO (2014a) reported that *M. volkensii* had active midday transpiration rates per unit leaf area (*T*<sub>a</sub>) from 10:00 h to 14:00 h (most active *T*<sub>a</sub> at 10:00 h). Maximum *T*<sub>a</sub> values obtained for *M. volkensii* were approximately three times higher than those of *Acacia senegal*, another popular deciduous plantation tree (JIFPRO 2014a). Hence, transpiration rates of *M. volkensii* need to be examined more closely to determine an efficient management strategy that can help in reducing the tree’s water consumption. *T*<sub>a</sub> data of different
leaves in a crown can be useful for devising a pruning strategy since transpiration rates can differ depending on the leaf’s position in a crown. Transpiration rates of leaves expanding at different positions in a crown of *Eucalyptus pilularis* were different, but this was not the case in *Eucalyptus cloeziana* (Alcorn et al. 2008). This suggests that before pruning is conducted, \( T_i \) values need to be measured, and the transpiration rates of *M. volkensii* need to be evaluated with respect to the leaf positions in a crown. Moreover, by partitioning the crown into layers, midday transpiration rates per layer (\( T_l \)), and per tree (\( T_t \)) can be quantified. These data can help towards deciding the optimum crown length that needs to be removed, and for estimating the amount of water suppressed by pruning.

Ground water evaporation inside the plantation and outside of the plantation should also be investigated before devising an appropriate forest management strategy in arid and semi-arid areas. A number of studies on evaporation on dry land were conducted in cultivated areas, and showed that evaporation from the arable fields accounted for 30–75% of the annual rainfall (Cooper et al. 1987, Stewart and Burnett 1987). These studies indicate that the amount of water lost through evaporation varies depending on the plant species present in the plantation, and that the effect of *M. volkensii* plantation on ground water evaporation needs to be assessed to manage the water loss through evaporation.

We examined the characteristics of midday transpiration rates and daily pan evaporation in order to determine ways of reducing water consumption by the *M. volkensii* plantation. Our focus was on dominant and suppressed trees in the plantation because they have distinct physiological traits (O’Grady et al. 2010). We determined \( T_i \) at different positions in a crown, where the light intensity is influenced by cumulative leaf area index (LAI) (Monsi et al. 1953). We also determined transpiration rates as \( T_a \), \( T_l \), and \( T_t \), and measured daily pan evaporation from the forest floor and open area.

**STUDY SITE AND METHODS**

**Study Site**

This study was carried out at an *M. volkensii* plantation in the Tiva Pilot Forest (1°21’ S, 37°52’ E), Kitui, Kenya (Fig. 1) from April to May 2014. The plot was square with an area of approximately 0.27 ha. Based on data from a tree census conducted in 2013 (Yoshikawa et al. unpublished), 197 trees were growing at 11 years after planting. The plantation was surrounded by natural vegetation consisting of shrubs smaller than 2 m in height. The east side of the plantation was an open area with sparse grass.

The mean annual temperature and rainfall were 22.9°C from 2010 to 2011 (JIFPRO 2012), and 619 mm from 1995 to 1999 (Kondo et al. 2006), respectively. The research site’s climate is considered to be semi-arid (UNEP 1997), with two dry seasons (from January to March, and June to August), and two rainy seasons in between.

For this study, another tree census was conducted in May 2014. Tree height and stem diameter at breast height (DBH) were measured for all the trees in the plantation. The horizontal width (\( CW_h \)) and vertical width (\( CW_v \)) of the crown were measured manually as the distance between two tips of a green crown on opposite sides. Canopy projection area (CPA) was calculated as follows (based on the assumption that the crown was elliptical in shape):

\[
CPA = \pi \times \frac{CW_h}{2} \times \frac{CW_v}{2}
\]

where the value of \( \pi \) was considered to be 3.14. Twenty-five hemispherical photographs were taken at random in the plantation with a fish-eye lens (FC-E8, Nikon, Tokyo, Japan), using a camera (Coolpix 4500, Nikon, Tokyo, Japan) at a height of 1.2 m above the ground. Canopy cover and LAI of the plantation were calculated from the hemispherical photographs with LIA32 (Yamamoto 2004).
Selection of sample trees and division of crowns

We selected four dominant and suppressed trees in total (see Table 1). Based on the tree census conducted in 2013, those trees with DBH values lower than the mean DBH of all plantation trees were defined as suppressed trees (Tree-1 and Tree-2), while those with DBH values higher than the mean were defined as dominant (Tree-3 and Tree-4) (Yoshikawa et al. unpublished). Tree-1 was higher than Tree-2, while Tree-3 was higher than Tree-4. We classified a crown into three layers: top layer (A) consisting of 0 to 33% of the crown length from the top, middle layer (B) consisting of 33 to 67% of the crown length, and bottom layer (C) consisting of 67 to 100% of the crown length (Fig. 2). The crown length was determined as the distance between the lowest live branch and the top of the crown. Light intensity, midday transpiration rates, leaf area (LA), and cumulative LAI were measured at each layer. The details of each measurement are described below.

Light intensity

Light intensity ($I'$) was measured in lux using a digital luxmeter (T-1 H, KONICA MINOLTA, Inc., Tokyo, Japan) between 10:00 h and 11:00 h on 1st of May, 2014. Measurements were conducted at 17% of the crown length from the top for layer A ($I'_{A}$), at 50% of the crown length from the top for layer B ($I'_{B}$), and at 84% of the crown length from the top for layer C ($I'_{C}$). Measurements were conducted on two, three, and three sample leaves at A, B, and C layers, respectively of Tree-1, two leaves at each layer of Tree-2 and Tree-4, and two, six, and three leaves at A, B, and C layers, respectively.
respectively of Tree-3. The same leaves were used as the sample leaves for $T_a$. The number of the leaves was selected based on the crown architecture of each tree. $I'$ measured outside the research site was denoted as $I_o$. The sky was overcast when the measurements were conducted.

**Midday transpiration by M. volkensii**

We measured $T_a$ for four sample trees. One to six leaves were selected from each layer, and $T_a$ was measured with a leaf porometer (LI-1600, LI-COR, Inc., Nebraska, USA). The measurements were conducted on each leaf between 11:00 h and 13:00 h every day from 26th to 30th of April. For each layer, $T_a$ was calculated by multiplying $T_i$ with LA. $T_i$ was calculated as the sum of $T_i$ of each layer. We ensured that the sky was clear, and without any clouds when we conducted transpiration measurements at daytime from 25th to 30th of April.

**Determination of LA and cumulative LAI**

The western part of Tree-1 and eastern parts of Tree-2, Tree-3, and Tree-4 (a quarter of whole leaves per tree) were harvested at each layer, and their dry weights (DW) were measured in grams. Specific leaf area (SLA) of each layer was measured in m²/g for the sample leaves. LA was measured in m² for each layer, and total leaf area (TLA) calculated as the sum of LA of all the layers was determined as follows:

$$LA = DW \times SLA \times 4$$
$$TLA = LA_A + LA_B + LA_C$$

where $LA_A$, $LA_B$, and $LA_C$ denote LA at layers A, B, and C, respectively. We calculated cumulative LAI for layers A, B, and C to compare with light intensity. Because we measured $I_A$, $I_B$, and $I_C$ on the sample leaves that expanded at the middle height of each layer, cumulative LAI of each layer was defined as LAI at the middle height of each layer from the top of the tree (Fig. 2). The cumulative LAI of each layer was calculated using the following equations:

$$Cumulative \, LAI_A = \frac{LA_A}{2} \div CPA$$
$$Cumulative \, LAI_B = \left( \frac{LA_A + LA_B}{2} \right) \div CPA$$
$$Cumulative \, LAI_C = \left( \frac{LA_A + LA_B + LA_C}{2} \right) \div CPA$$

where cumulative $LAI_A$, $LAI_B$, and $LAI_C$ are cumulative LAI of layers A, B, and C, respectively.

**Meteorological Data**

Daily precipitation at the Tiva nursery was recorded using a rain gauge (RG3-M, Onset Computer Corporation, Massachusetts, USA) (Fig. 1). Atmospheric relative humidity and temperature were recorded at the open area next to the plantation plot at 15-minute intervals from 25th of April to 14th of May, 2014, using a thermal recorder (TR-72 U, T&D Corporation, Matsumoto, Nagano, Japan). Vapor pressure deficit (VPD) was calculated based on humidity and temperature (Campbell and Norman 1998). A straight wooden bar was placed at the open area, and the thermal recorder was attached to the bar at a height of 1.3 m above the ground. An aluminum shield was placed on the device to prevent contact with direct sunlight.

**Pan evaporation from forest floor and open area**

A cylindrical evaporation pan that had a surface area of 147 cm² was used for measuring daily pan evaporation. This was determined by calculating the difference in the volume of water between 6:00 h and 18:00 h. The measurement was conducted from 26th of April to 14th of May, except for seven days when measurements were not conducted owing to weather conditions. Twenty-five pans were placed on the forest floor at approximately 3 m intervals along two parallel 39 m lines. We avoided placing the pans at the fringes of the plantation and under the conditions with direct sunlight in the plantation. Two pans were placed on the open area, and grass within 1 m radius of the pans was removed.

**Statistical analysis**

Differences between $T_a$ values among layers and sample trees were evaluated by two-way analysis of variance (ANOVA), followed by Tukey’s honest significant difference (HSD) multiple comparison test ($P<0.05$). ANOVA was performed to test the effects of layers and sample trees on $T_a$. Tukey’s HSD test was used to assess significant differences between midday transpiration rates among layers of the same sample tree, and among sample trees at the same layer. Relationships between $T_a$ and $I'/I_o$ and between $I'/I_o$ and cumulative LAI were investigated.
using simple linear regression and logarithmic regression, respectively. We examined the relationship between mean daily pan evaporation at open area and forest floor using linear regression through the origin. Regression correlations were analyzed using Pearson’s product-moment correlation coefficient. All statistical analyses were performed in R 3.1.3 GUI 1.65 (R Core Team 2016).

RESULTS AND DISCUSSION

The heights of trees in the plantation were in the range of 2.7 to 11.6 m, with a mean ± s.d. height of 8.6 ± 1.5 m, while DBH values ranged from 2.3 to 21.0 cm, with a mean of 14.0 ± 3.6 cm. CPA values were within the range of 2.2 to 49.4 m² and the mean value was 22.2 ± 9.9 m². The values of canopy cover and LAI in the plantation were 73.4 ± 3.1 % and 1.3 ± 0.2, respectively. Therefore, the plantation had a closed canopy.

The daily maximum and minimum temperatures recorded during our study were 33°C and 15°C, respectively, while the average temperature was 22.5°C (Fig. 3). Humidity varied from 100 % to approximately 40 %, and the daily average was approximately 80 %. On some days, VPD was higher than 3 kPa, although the daily mean was lower than 1 kPa. Rain fell on three days during the measurement period of 19 days. These climatic conditions were similar to those observed during April and May in 2011 and 2013 (JIFPRO 2014a). The climatic conditions in 2012 were not recorded owing to technical issues.

The values of $I_{A}$ and $I_{C}$ were approximately one-half and one-fourth of $I_{B}$, respectively (Table 1). Therefore, our division of the crown into three layers enabled us to efficiently investigate the changes in $T_{a}$ with respect to $I'$ within each tree. Relative light intensity ($I'/I_{o}$) at the same layer was different within the sample trees, perhaps because of the number of leaves in a crown and the crown shape (Table 1). For example, Tree-1 had a small and sparse crown, through which light would be able to penetrate easily, while Tree-3 had a large and dense crown, through which light penetration might be difficult. Because we measured $I'$ at the same percentage of crown length from the top for all the sample trees, comparison of $T_{a}$ and $T_{i}$ at the same layer was based on $T_{o}$ at the same relative position.
in crowns, and not on the same light condition.

Significant differences were observed between $T_a$ values of different layers ($F = 72.9, P < 0.001$), and different sample trees ($F = 5.48, P < 0.05$) (Table 2). Significant interaction was also observed between the layer of the crown and sample tree ($F = 3.58, P < 0.05$). $T_a$ values of layer A for Tree-1, Tree-3, and Tree-4 were not significantly different from those obtained for layer B, but were significantly higher than those of layer C, indicating a drastic decrease in $T_a$ at layer C (Fig. 4a top panel). On the other hand, Tree-2 did show such a change at layer B. $T_l$ values for all sample trees decreased from layer A to layer C (Fig. 4a bottom panel). $T_a$ values obtained for layer A for all sample trees did not show any significant differences (Fig. 4b top panel). $T_a$ values obtained for layer B for the sample trees were not significantly different, except for the difference between Tree-1 and Tree-2. $T_a$ values obtained for layer C for Tree-3 was significantly lower than those for the other sample trees. $T_l$ values of layers A and B for Tree-3 and Tree-4 were significantly higher than those of Tree-1 and Tree-2 (Fig. 4b bottom panel). Since Tree-3 and Tree-4 had higher TLA than Tree-1 and Tree-2 (Table 1), the difference observed between the trends in $T_a$ and $T_l$ indicates a greater contribution of TLA than $T_a$ towards water loss through transpiration.

A positive correlation was observed between $I'/I_0$ and $T_a$ ($R^2 = 0.40, P < 0.001$) (Fig. 5). Moreover, $I'/I_0$ decreased as cumulative LAI increased (Fig. 6). Correlation was also observed between cumulative LAI and $I'/I_0$ ($R^2 = 0.90, P < 0.001$), suggesting that transmission of light through the canopies was in accordance with Beer-Lambert's Law (Monsi et al. 1953). Light penetration in the lower layers was less than that in the upper layers. Therefore, $T_a$ at layer C was significantly lower than that at layers A and B. This observation was in agreement with the findings of previous studies (Pons et al. 2001, Alcorn et al. 2008).

Dominant and suppressed trees showed a clear
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Difference with respect to $T_a$, namely the values of $T_t$ obtained for Tree-3 and Tree-4 were significantly higher than those obtained for Tree-1 and Tree-2 (Fig. 7). Since $T_t$ is largely dependent on LA and not on $T_a$, the results indicate that the difference in $T_t$ within the sample trees resulted from the difference in TLA. Therefore, in *M. volkensii*, TLA has a major influence on water loss through transpiration. This observation is in accordance with the results of previous studies (Martin et al. 2001, Benyon et al. 2006, Feikema et al. 2010, Forrester et al. 2012). Thus, the determination of dominant and suppressed trees helps in predicting potential $T_t$ for trees in the plantation.

A significant correlation was observed between mean daily pan evaporation from forest floor and open area on the 12 days from 26th of April to 14th of May (except for days when rain fell) (Fig. 8). All data points fell down below the line $y = x$ (dashed line), indicating that the values obtained at the open area were higher than those obtained at the forest floor. Based on the slope of the regression line, we inferred that daily pan evaporation from the forest floor was approximately 30% of that from the open area. These results suggest that, because of the canopy cover, planted trees suppressed pan evaporation from the ground by approximately 70%.

In arid and semi-arid areas, the limited water resources available on the plantations need to be used effectively (Yoshikawa et al. 2004). Pruning can play a substantial role in suppressing water loss through transpiration, because it is largely dependent on TLA, rather than on $T_a$. Since $T_t$ of layers B and C accounted for approximately half of $T_t$ (Fig. 4a bottom panel), we hypothesize that pruning of these parts could lead to a 50% reduction in water loss through transpiration. Cumulative LAI, however, decreased to approximately 0.23 to 0.49 owing to pruning of layers B and C (Table 1), and consequently $I/I_0$ increased to around 70% (Fig. 6). If an increase in $I/I_0$ can lead to an increase in daily pan evaporation at the forest floor, then some techniques such as covering the soil’s surface with organic matter (Mellouli et al. 2000) could help in reducing water...
loss through evaporation. Moreover, leaves remaining on layer A after pruning could transpire more actively than they did before the pruning treatment (Alcorn et al. 2008). Therefore, the effect of pruning on T_e needs to be carefully monitored.

The assessment of evapotranspiration in April was not enough to determine the best way of reducing water consumption by the plantation. Since short-term and small-scale outcomes provide only a partial explanation of the dynamics of water use in tree plantations, large-scale and long-term re-afforestation policies in these areas should be based on long-term research (Cao et al. 2010, Yoshikawa et al. 2004). Hence, we recommend that further measurements of water consumption by the M. volkensii plantation should be conducted for at least one year. In addition, we suggest that canopy interception, which accounts for a certain amount of water consumption by the plantations, e.g., 13% of annual rainfall in an arid E. camaldulensis plantation (Tsukamoto 1992), should also be included when evaluating the impact of the plantation on local water resources.

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**REFERENCE**

Alcorn PJ, Bauhus J, Thomas DS, James RN, Smith RGB, Nicotra AB. 2008. Photosynthetic response to green crown pruning in young plantation-grown Eucalyptus pilularis and E. cloeziana. *Forest Ecology and Management* 255: 3827–3838.

Benyon RG, Theiveyanathan S, Doody TM. 2006. Impacts of tree plantations on groundwater in south-eastern Australia. *Australian Journal of Botany* 54: 181–192.

Bosire B. 2006. Fighting desertification in Kenya, one tree at a time. The UNESCO Courier, June 2006: 6–7.

Campbell GS, Norman JM. 1998. *An introduction to environmental biophysics*. Springer-Verlag, New York.

Cao S, Tian T, Chen L, Dong X, Yu X, Wang G. 2010. Damage caused to the environment by reforestation policies in arid and semi-arid areas of China. *AMBIO* 39: 279–283.

Cooper PJM, Gregory PJ, Keatinge JDH, Brown SC. 1987. Effect of fertilizer, variety and location on barley production under rainfed conditions in northern Syria. 2. Soil water dynamics and crop water use. *Field Crops Research* 16: 67–84.

Feikema PM, Morris JD, Beverly CR, Collopy JJ, Baker TG, Lane PNJ. 2010. Validation of plantation transpiration in south-eastern Australia estimated using the 3PG+ forest growth model. *Forest Ecology and Management* 260: 663–678.

Forrester DI, Collopy JJ, Beadle CL, Warren CR, Baker TG. 2012. Effect of thinning, pruning and nitrogen fertiliser application on transpiration, photosynthesis and water-use efficiency in a young Eucalyptus nitens plantation. *Forest Ecology and Management* 266: 286–300.

Government of Kenya 2010. *REDD Readiness Preparation Proposal for Kenya*. Government of Kenya Publishing. http://theredddesk.org/sites/default/files/resources/pdf/2012/kenya_redd-rrp-june_12th_2010.pdf (cited September 9, 2016)

Hayashi I, Gachathi FN. 1998. A check list of the plant species at the site of the Kenya and Japan Social Forestry Training Project, Kitui. *Vegetation Science* 15: 71–77.

[JIFPRO] Japanese International Forestry Promotion and Cooperation Center. 2012. Annual report of demonstration activities support project for the conservation of forest and water environments. JIFPRO, Tokyo. (In Japanese) http://www.jifpro.or.jp/Activities/Research/disclosure_research/Report_Forest_and_Water_H21_25/Report_Forest_and_Water_H23.pdf (cited September 9, 2016)

[JIFPRO] Japanese International Forestry Promotion and Cooperation Center. 2014a. Annual report of demonstration activities support project for the conservation of forest and water environments. JIFPRO, Tokyo. (In Japanese) http://www.jifpro.or.jp/Activities/Research/disclosure_research/Report_Forest_and_Water_H21_25/Report_Forest_and_Water_H25.pdf (cited September 9, 2016)

[JIFPRO] Japanese International Forestry Promotion and Cooperation Center. 2014b. *Re-afforestation and water conservation in drylands Guideline for Students and Researchers*. JIFPRO, Tokyo. (In Japanese) http://www.jifpro.or.jp/Activities/Research/disclosure_research/Report_Forest_and_Water_H21_25/Guideline_for_Researchers_and_Students.pdf (cited September 9, 2016)

Kondo S, Yahata H, Nakashizuka T, Kondo M. 2006. Interspecific variation in vessel size, growth and drought tolerance of broad-leaved trees in semi-arid regions of Kenya. *Tree Physiology* 26: 899–904

Martin TA, Brown KJ, Kućera J, Meinzer FC, Sprugel DG, Hinckley TM. 2001 Control of transpiration in a 220-year-old *Abies amabilis* forest. *Forest Ecology and Management* 152: 211–224.

Maundu P, Tengnäss B. 2005. *Useful trees and shrubs for Kenya*, Technical Handbook No. 33, World Agroforestry Centre, Nairobi. http://www.worldagroforestry.org/downloads/Publications/PDFs/B13601.pdf (cited September 9, 2016)

Melloulí HJ, van Wesemael B, Poensen J, Hartmann R. 2000. Evaporation losses from bare soils as influenced by cultivation techniques in semi-arid regions. *Agricultural Water Management* 42: 355–369.

Monsi M, Saeki T. 1953. *Über den Lichfaktor in den pflanzengesells chaften und seine bedeutung für die stoffproduktion*. *Japanese Journal of Botany* 14: 22–52.
Midday transpiration rates of *Melia volkensii* and daily pan evaporation

O’Grady AP, Eyles A, Worledge D, Battaglia M. 2010. Seasonal patterns of foliage respiration in dominant and suppressed *Eucalyptus globulus* canopies. *Tree Physiology* 30: 957–968

Pons TL, Jordi W, Kuiper D. 2001. Acclimation of plants to light gradients in leaf canopies: evidence for a possible role for cytokinins transported in the transpiration stream. *Journal of Experimental Botany* 52: 1563–1574

R Core Team. 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. https://www.r-project.org (cited July 18, 2016)

Rumley R, Muthuri C, Ong C. 2006. *More trees with less water: deciduous trees help farmers increase water use efficiency without overtaxing precious water resources during the dry season*. World Agroforestry Centre ICRAF, Nairobi.

Stewart BA, Burnett E. 1987. Water conservation technology and rainfed and dryland agriculture. *Water and Water Policy in World Food Supplies*, A&M University Press, College Station.

Stewart M, Blomley T. 1994. Use of *Melia volkensii* in a semi-arid agroforestry system in Kenya. *The Commonwealth Forestry Review* 73, 2: 128–131.

Tsukamoto Y. 1992. *Forest hydrology*. Bun-eido Publishing, Japan. (In Japanese)

[UNEP] United Nations Environmental Programme. 1997. *World Atlas of Desertification* (2nd ed). Arnold.

Yamamoto K. 2004. LIA for Win32: An image analysis software intended to use in the forest science and ecology. Nagoya University, Aichi. https://www.agr.nagoya-u.ac.jp/~shinkan/LIA32/index-e.html (cited May 25, 2016)

Yoshikawa K, Yamanaka N, Ohite N, Eds. 2004. *Nature and greening of dry land*. Kyoritsu Shuppan, Tokyo. (In Japanese)

Zhang XP, Zhang L, McVicar TR, Van NTG, Li LT, Li L, Yang QK, Wei L. 2008. Modelling the impact of afforestation on average annual stream flow in the Loess Plateau, China. *Hydrological Processes* 22: 1996–2004.