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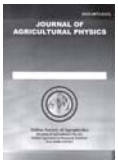

Research Article

Mass Attenuation Coefficient and Water Content Determination of Plant Leaves using β-Radiations

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ABSTRACT

The water content in plant leaves of Brinjal, Pumpkin, Spinach and Tomato has been determined using beta radiations from ^{204}Tl via their attenuation through fresh and dry leaves. The water content values obtained using β-ray attenuation measurement and by direct weighing method are in close agreement and differ from each other by 2% at the most. This technique can provide information regarding water status in the whole plant. The method used here is fast, an easy-to-handle and thus a useful tool to determine the water content of the plants.

Key words: Attenuation, Mass attenuation coefficient, Water content, Relative transmitted intensity, β-particle

Introduction

The amount of water content is an important parameter for various physiological processes in plant leaves. Further, it is also an important production limiting factor and strong indicator of vegetation stress. The presence of large water can results in water logging, leaching of nitrates below root and on the other hand the deficiency of water can reduce the quality as well as quantity of the yield. The studies of attenuation of β-radiations in the matter have always played an important role in the field of physical sciences, medical physics, bio-sciences and agricultural sciences. Attenuation measures the loss of intensity of a beam of radiation due to its scattering, absorption, divergence and other causes as the beam propagates through the matter. A large number of radiation workers have showed the potency of using this non-destructive β-ray attenuation for determining the leaf thickness and water content of plants.

Several radiation workers (Takhar, 1967, 1968; Spanel *et al*., 1973; Nathu Ram *et al*., 1981, 1982, 1987; Thnontadarya, 1984) have developed various methods during past few decades for determining water content of plant leaves. Singh and Batra (1987) measured mass attenuation coefficients of β-particles through different materials including the rare-earths. The inside water status of plant is responsible for its interaction with surrounding environment, thus leading to its growth and is normally determined by the Diffusion Pressure Deficit method, the relative turgidity method and the β-gauging technique (Mederski, 1961; Barrs and Weathereley, 1962). The first two methods are not so much useful for constantly monitoring the change in plant water status as required a controlled environment and considerable time. However, the β-rays attenuation is being widely used to constantly monitor the water contents of plant leaves (Mederski, 1961; Nakayama and Ehrler, 1964; Rolston and Horton, 1968; Mederski and Alles, 1968). The relative water content in leaves

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of soybean (*Glycine max)* plant was determined by Mederski (1961). Nakayana and Erhler (1964) and used the same technique for cotton (*Gossypium hirsutum*) leaves. Jarvis and Slatyer (1966), Obrigewitsch *et al.* (1975) also made an attempt to calibrate the β-gauge for determining the moisture content of cotton leaves. However, this method requires the fully turgid leaf in addition to completely fresh and dry leaves for calibration purpose. Chaudhari (2013) determined the linear and mass absorption coefficients of various leaves (fresh and dry) of Asoka plant using beta source ^{204}Tl. In the present work, the technique is modified by determining the absolute water content of fresh leaves using Geiger Muller counter. The determination of absolute water content of selected plant leaves is carried out by measuring transmission of β-radiation through fresh and completely dry leaves.

Material and Method

The experimental setup used in the present study is depicted in Fig. 1. The β-radiations of 776 keV from ^{204}Tl (13 kBq) have been used in the present study and the cylindrical shaped end-window Geiger Muller (G-M) counter of diameter 1.67 cm is used for intensity measurement. The G-M counter operating at 450 V, slightly below the middle of plateau region was used for measuring the β-particles transmitted intensity. The goodness of the detector was tested by applying Chi-square (χ^2) test on the detector background data. The observations were repeated ten times for background counts with each observation was recorded for 200 seconds, and obtained probable error of measurement is 96.5±10. The calculated value of the coefficient of divergence is 1.05 which implies that dispersion of data is normal. The calculated value of χ^2 is 13.89 for nine degree of freedom (F) which corresponds to probability (P) is equal to 0.1 which clearly shows that in one out of ten similar tests, we would expect fluctuation greater than those observed here.

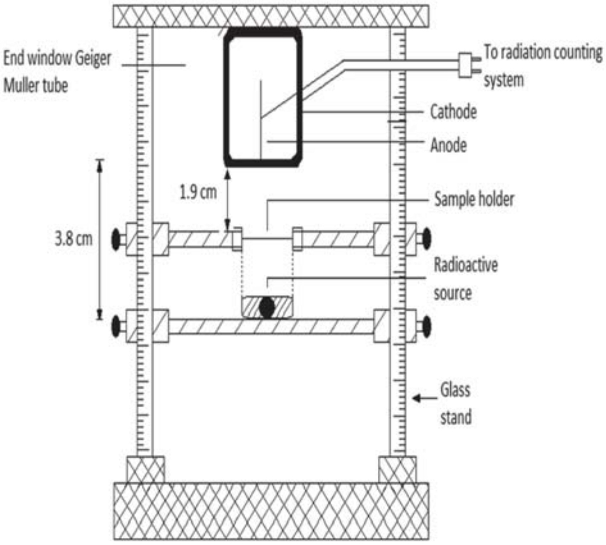

Fig. 1. Schematic diagram to measure β-transmission through a plant leaf

To study the effect of geometry on mass attenuation coefficient, the distance (S_{AD}) between standard absorber (Al) and detector was varied and it was observed that value of mass attenuation coefficient (μ) for standard absorber aluminium first increases with S_{AD}, reaches a maxima and then decreases with further increase in S_{AD} within the limits of the experiment. The distance at which μ reached a maxima was found to be 1.9 cm. The distance between source and detector window was kept 3.8 cm while placing leaf sample almost at the middle of this distance. Further, the geometry of source-absorber-detector was centrally aligned and was kept same throughout the experiment, resulting in non-varying air absorption effects and scattering.

Within certain limits, the attenuation of β-radiations through leaf of a given thickness and water content can be expressed by Lambert-Beer law:

$$I_f = I_0 e^{-\mu_f t_f} \qquad \ldots(1)$$

where I_f and I_0 is the intensity of the attenuated and un-attenuated β-radiations, respectively, t_f and μ_f are the thickness (mass per unit area) and mass attenuation coefficient, respectively, of fresh leaf (organic matter and water). On re-writing the above equation for a fresh leaf as:

$$t_f = \frac{1}{\mu_f} \ln\left(\frac{I_0}{I_f}\right) \qquad \ldots(2)$$

Similarly for a completely dry leaf as:

$$t_d = \frac{1}{\mu_d} \ln\left(\frac{I_0}{I_d}\right) \qquad \ldots(3)$$

where t_d, I_d and μ_d are the thickness (mass per unit area), attenuated intensity and mass attenuation coefficient respectively for completely dry leaf (organic matter). Hence, the absolute water content (t_w) per unit leaf area is given by following equation:

$$t_w = t_f - t_d \qquad \ldots(4)$$

On substituting, the eqn. (2) and (3) in the above equation, the (t_w) can be re-written as;

$$t_w = \frac{1}{\mu_d} \ln\left[\left(\frac{I_0}{I_f}\right)^n \times \left(\frac{I_d}{I_0}\right)\right] \qquad \ldots(5)$$

where $n = \frac{\mu_d}{\mu_f}$; the proportion of mass attenuation coefficient of completely dry leaf to that of fresh leaf. Thus, from the measured experimental values μ_f, μ_d, $\frac{I_f}{I_0}$ and $\frac{I_d}{I_0}$, the above equation equation (5) can be used to determine the absolute water content of the plant leaf.

The calibration of experimental setup was done by bombarding 776 keV β-particles through aluminium foils of different thickness and measuring attenuation coefficient. The plot of relative transmitted intensity versus thickness for aluminium foil on semi-log plot is shown in figure 2. The obtained value of mass attenuation coefficient (μ) for aluminium foil is 21.75±0.26 cm^2 g^{-1} which is in good agreement with earlier measured values (Nathuram *et al.*, 1982; Thontodarya, 1984; Singh *et al.*, 1987). Thus, the measurement of mass attenuation coefficient of aluminium of confirms the validity of experimental setup and method adapted to measure mass attenuation coefficient of the leaves to be selected.

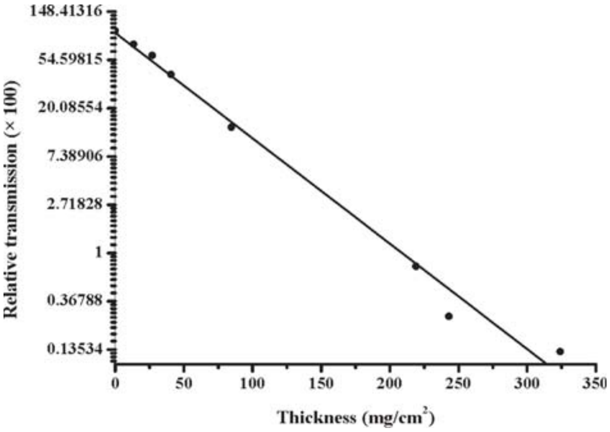

Fig. 2. The fitted plot of relative transmitted intensity versus thickness (mg cm^{-2}) for aluminium foil using ^{204}Tl

Leaves of Brinjal (*Solanum melongena*), Pumpkin (*Cucurbita pepo*), Spinach (*Solanum melongena*) and Tomato (*Solanum lycopersicum*) plants were made available from the various fields of Punjab Agricultural University, Ludhiana. The leaves were selected around half the height of the plant where the thickness of the leaves is nearly constant. Selected leaves were immediately taken to the laboratory and were first washed with water and then socked for a few minutes in layers of blotting paper. Many circles of each radius 1.8 cm were cut from the leaves and thickness (mg cm^{-2}) of 7-12 such strips was determined by weighing them on Shimazu digital balance having an accuracy of 0.1 mg. In order to obtain collimation, the leaves (fresh and dry) which act as absorber were placed between two rectangular equal sized aluminium sheets, each having 2.5 cm diameter matching hole. The recording time chosen for each absorber thickness is 200 seconds which is sufficient large to keep statistical uncertainty below 2%. The procedure was repeated two or more times for each thickness to check the stability of the apparatus.

The transmission of β-particles from ^{204}Tl was made through Brinjal fresh leaf strips and the transmitted intensity was recorded. The zero absorber count rate was recorded to 10807±104 per 200 seconds and background counts were 99±10 per 200 seconds. Then, the leaf strips were placed between two aluminium plates and dried under an infrared lamp until complete dryness (when weight of a leaf reached a constant value) was ensured. The wrinkling and shrinkage of the dried leaves have been reduced considerably by using this technique. Now, the transmission measurement was done through these dry leaves again. The same procedure was adopted for leaves of Pumpkin, Spinach and Tomato. The percentage relative transmission intensity versus absorber thickness (mg cm^{-2}) for fresh and fully dry leaf strips of Brinjal is exponential as depicted in figure 3. Similar trend is observed for Pumpkin, Spinach and Tomato leaves.

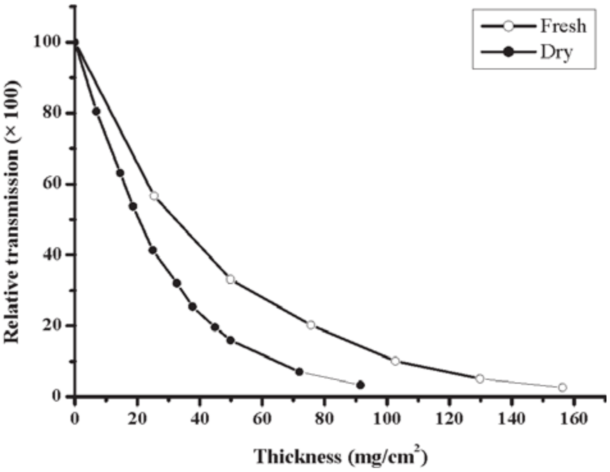

Fig. 3. Variation of relative transmitted intensity versus thickness for fresh and dry leaves of Brinjal (*Solanum melongena*)

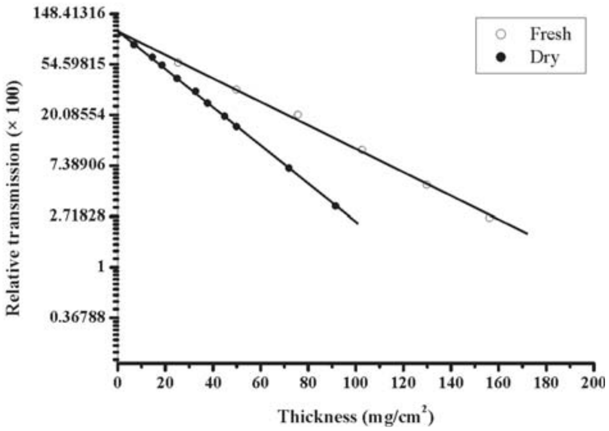

Fig. 4. The fitted plot of the relative transmitted intensity (semi-logarithmic scale) versus thickness (mg cm^{-2}) for and dry leaves of Brinjal (*Solanum melongena*)

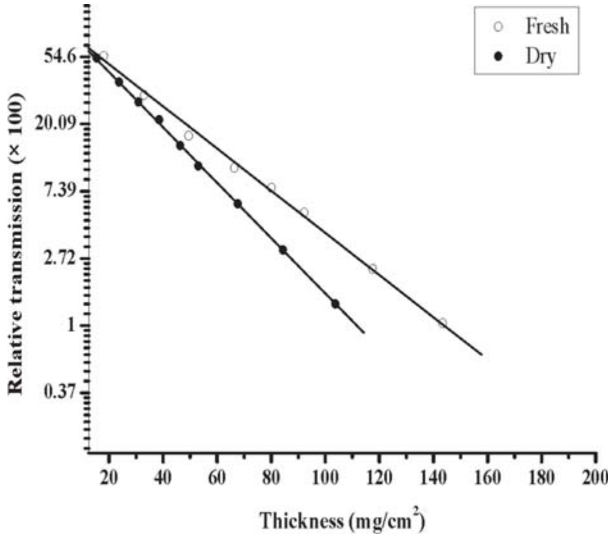

Fig. 5. The fitted plot of the relative transmitted intensity (semi-logarithmic scale) versus thickness (mg cm^{-2}) for and dry leaves of Pumpkin (*Cucurbita pepo*)

Results and Discussion

A semi-logarithmic plot of relative transmitted intensity versus thickness for fresh and dry Brinjal (*Solanum melongena*) leaves is shown in figure 4. Similar fit is applied for the leaves (both fresh and dry) of Pumpkin, Spinach and Tomato. The fit behaviour for Pumpkin, Spinach and Tomato leaves is shown in figure 5, 6 and 7 respectively. The mass attenuation coefficient for fresh and dry leaves of each type was obtained by using least-squares fit analysis. The following equation was applied to the obtained data set for fresh and dry leaf strips:

$$I = I_0 a^x \qquad \ldots(7)$$

where x is the absorber thickness (mg cm^{-2}), and I_0 and ‘a’ are the fitting constants. Using logarithmic, the above equation can be written as:

$$\ln I = \ln I_0 + x \ln a \qquad \ldots(8)$$

So, the mass attenuation coefficient corresponds to negative the slope of equation (8):

$$\mu\ (\mathrm{cm^2/g}) = -1000\ ln\ a \qquad \ldots(9)$$

where factor 1000 appears as μ has been expressed as (cm^2 g^{-1}). The mass attenuation coefficient (μ) for fresh and dry leaves of each sample is listed in Table 1, whereas, total error on mass attenuation coefficient ($\Delta\mu$) is obtained by combining, error on statistics of counting, least

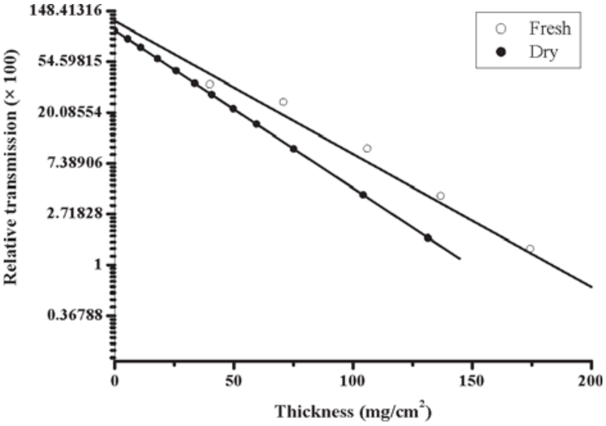

Fig. 6. The fitted plot of the relative transmitted intensity (semi-logarithmic scale) versus thickness (mg cm^{-2}) for and dry leaves of Spinach (*Solanum melongena*)

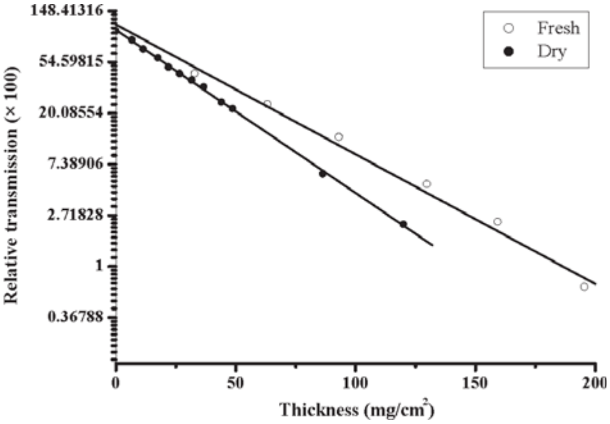

Fig. 7. The fitted plot of the relative transmitted intensity (semi-logarithmic scale) versus thickness (mg cm^{-2}) for and dry leaves of Tomato (*Solanum lycopersicum*)

squares fitting error of data, and error on measurement of thickness of leaves, in quadrature. The mass attenuation coefficient obtained for fresh leaves (μ_f) and dry leaves (μ_d) are then used to evaluate absolute moisture content (t_w) using equation (5). Absolute water content (t_w) of Brinjal, Pumpkin, Spinach and Tomato leaves is listed in column 5 of Table 1.

Also, the percentage water content obtained for the selected leaves was compared with direct weighing method. The direct water content is calculated as:

$$\%\text{ water content} = \frac{(\text{mass of a fresh leaf} - \text{mass of a dry leaf})}{(\text{mass of a fresh leaf})} \times 100 \qquad \dots(10)$$

The % water content obtained by direct weighing method for selected leaves is listed in column 7 of the Table 1. The percentage water content obtained via β-particles attenuation through leaves under study differs by 2% at the most to that from direct weighing method. The percentage water content is approximately equal in Spinach and Tomato leaves within ± 1σ. But the percentage water content of Spinach and Tomato leaves is higher than those of Brinjal and Pumpkin leaves, which implies that the lesser presence of organic matter in Spinach and Tomato leaves in comparison to Brinjal and Pumpkin leaves.

Table 1. Mass attenuation coefficient (μ), absolute moisture content (t_w) and % water content from b-attenuation measurement and direct weighing method for Brinjal (*Solanum melongena*), Pumpkin (*Cucurbita pepo*), Spinach ((*Solanum melongena*) and Tomato (*Solanum lycopersicum*) plant leaves

S. No.	Leaves	State	$\mu \pm \Delta\mu$ (cm^2/g)	Absolute moisture content, t_w (g cm^{-3})×10^{-3}	% Water content	
					β-attenuation	Direct weighing
1.	Brinjal	Fresh	23.52±0.56	18.47±1.15	72.71±5.01	72.83
		Dry	37.96±0.52			
2.	Pumpkin	Fresh	30.86±1.51	11.70±1.04	64.71±6.07	65.71
		Dry	41.16±0.91			
3.	Spinach	Fresh	27.44±1.92	33.76±2.98	84.57±7.87	86.30
		Dry	31.11±0.61			
4.	Tomato	Fresh	25.93±0.96	26.35±1.03	80.09±3.29	79.73
		Dry	31.50±0.58			

It is concluded from these measurements that transmission of β-particles follows an exponential law through leaves of various plants. The same experimental geometry and equation (5) can be used to estimate the water content of any other fresh leaf and will play an important foundation for sustainable development and modern agricultural technology. The determination of the water content of plant leaves using β-radiations is rapid, more accurate and can be made non-destructive by properly simulating the prototype of this experiment with suitable Monte Carlo simulation in field practices. Thus, this method has proven to be a useful tool to continuously monitor the water content of a plant and may help in precision agricultural technologies.

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