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Attenuation Coefficient and Water Content Determination Of Almond leaves using Beta Radiation

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Abstract:

This paper presents water content in the plant leaves of Almond and is determined based on their attenuating characteristics to beta particles. The transmitted intensities and mass attenuation coefficients, for beta particles of Tl-204 radioactive source, through leaves of different thickness are measured. These parameters vary as the amount of water content in selected leaves gets changed. The mass attenuation coefficient is obtained as the slope of leaf thickness versus logarithm of relative transmission intensity. The transmission intensity decreases with increase of water amount in plant leaves.

Keywords: *Water content of leaves, linear attenuation coefficient, Mass attenuation coefficient, Beta particle transmitted intensity*

I. INTRODUCTION

Attenuation is a kind of absorption or scattering of radiations as they travel through the matter. The interactions of radiation with matter occur at the fundamental levels of atoms or their more elementary constituents such as electrons and the nuclei. Beta particle attenuation is a basic physical process yielding fundamental information on material composition. The attenuation studies in matter have helped a lot in solving variety of problems in physical sciences, bio-sciences, agricultural sciences and medical physics. Water content of the individual leaves is an important variable in physiological plant processes. It is an important production limiting factor and a strong indicator of vegetation stress. It can determine whether there is water shortage that can reduce yields or if there is excessive water application that can result in water logging or leaching of nitrates below root zone. Leaf is a heterogeneous, hygroscopic, cellular and anisotropic material composed of epidermis, chloroplasts, mesophyll, cuticle and veins. Actual water content of plants and trees vary according to the tissue type and depends upon environmental and physiological conditions. When leaves dry up, they mainly lose their water content.

In order to detect leaf water status, several workers have established various methods during past few decades [1-4]. They have witnessed the measurement of mass attenuation coefficients through different materials as a function of energy, atomic number of the absorber and experimental geometries. Gurler and Yalcin [5] obtained the attenuation coefficients as the slope of transmission versus foil thickness. Recently, Mahajan [6] measured attenuation coefficients for some elements and found to be in agreement with empirical relation. Mederski [7] introduced beta radiation gauge for measuring relative water content in leaves of soya bean plant. Nakayana and Erhler [8] used the technique for cotton leaf. But they were incapable of monitoring continuous changes in plant water status. Later Jarvis and Slatyer [9], Obrigewitsch *et al.* [10] made an attempt to calibrate the beta gauge for determining the leaf water status using cotton leave as absorber. For calibration purpose, the methods require the fully turgid leaf in addition to completely dry and fresh leaves. Beta gauging technique makes the method little awkward due to the loss of organic matter. However, in present work the technique is modified by estimating the absolute water content through fresh leaves using Geiger Muller counter.

Some spectroscopic methods have also been used to determine water content in leaves. Xiangwei et al. [11] used parameters such as leaf

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reflectance, correlation coefficients and spectral index for determining crop water content. Ullah et al. [12] estimated leaf water content from the mid to thermal infrared (2.5–14.0 μm) spectra, based on continuous wavelet analysis. Yi et al. [13] used hyperspectral indices to estimate water content in cotton leaves. It aimed on the relation between water content and hyperspectral reflectance.

It aimed at identifying an index for remote water content estimation and correlated field spectral measurements to leaf water content. Recently, Giovanni et al. [14] detected crop water status in mature olive groves using vegetation spectral measurements and regression. However, this technique requires the availability of full spectra with high resolution, which can only be obtained with handheld spectro-radiometers or hyper-spectral remote sensors.

A more reliable beta attenuation technique overcomes the sophistication of instruments/ techniques used in spectroscopic methods and measure the water content in a convenient way. Although the beta-gauging technique has been explored in the past for several applications, yet the direct use of measured mass attenuation coefficient has not been utilized successfully for the purpose. To the best of our knowledge there is no study of this type, plotting moisture content versus transmitted intensity, for Broccoli leaves using beta particles using Tl-204 radioactive source.

II. THEORY

The attenuation of Beta radiation is due to the effect of all the energy exchange mechanisms (Photoelectric attenuation and Compton effect) as it interacts with the atoms contained in a material, thus reducing the transmitted intensity. The transmitted intensity depends on the density, thickness of the absorbing layer and the cross-sectional properties of the material.

Major Constituent in a plant leaf is Water. Thus changes in water content of plant leaves are reflected by changes in the absorber thickness. The attenuation of beta radiation through a plant leaf depends upon mass per unit area of the leaf. The intensity of transmitted beta radiation through a plant leaf, is given as

$$I = I_0 \exp^{-\mu t} \qquad (1)$$

Where I_0 is the intensity of the no attenuated beta radiation, t and μ are the thickness and mass attenuation coefficient of leaf respectively (organic matter and water). From this equation mass attenuation coefficient (μ) can be calculated by knowing the other quantities. Rewriting equation (1) for a fresh leaf as

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

Where t_f, I_f and μ_f are the mass per unit area, intensity and mass attenuation coefficient respectively of fresh leaf.

And for a completely dry leaf

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

Where t_d, I_d and μ_d are the mass per unit area, intensity and mass attenuation coefficient respectively of completely dry leaf (organic matter)

Since leaves contain organic matter and water, we can write

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

where t_w is the mass of water per unit leaf area. Using equations (2), (3) and (4), we get,

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

And $n = \mu_d/\mu_f$; the ratio of mass attenuation coefficients of completely dry leaves to those of fresh leaves. Thus, using the experimental values of μ_d, μ_f and I_d/I_0 and measuring the ratio I_f/I_0 for a fresh leaf, equation (5) provides the absolute water content. For direct weighing measurements of leaf, the percentage water content is given by the following formula [15].

$$\%\ water\ content = \left[\frac{fresh\ leaf\ mass - dry\ leaf\ mass}{fresh\ leaf\ mass}\right] \times 100 \qquad (6)$$

III. EXPERIMENT

The experimental arrangement is shown in Fig.1. Radioactive source Tl-204 (end point energy 0.766 Mev) has been used as a source of beta particles.

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Fig. 1: Experimental Arrangement

The Geiger Muller counter is used for intensity measurements and the plant leaves are held between two rectangular equal sized aluminium sheets, having 2.5cm diameter matching holes used as attenuating medium. The source-absorber-detector geometry is centrally aligned. A Geiger Muller tube operating with an operating voltage 600volts is used for measuring the beta intensity.

Leaves of sides 3cm are cut from the whole leaf sample and thickness and mass of each leaf is determined by weighing with a single pan digital balance. The transmission studies of beta particles are made through these fresh leaves. The observation time chosen for each absorber thickness is 60s. The stability of the apparatus was checked by keeping it on for 30 minutes and taking three readings for each leaf.

The leaf is kept to dry for a week. This evaporates some water of leaf and reduces its thickness (g/cm^2) as done for fresh leaf samples and the transmission of beta particles through these dry leaf samples is measured. Corresponding calculations are done as represented in tabular forms and respective graphs are plotted.

IV. RESULTS AND DISCUSSION

The data for Almond tree leaf thickness and logarithm of relative transmission intensity has been shown in Table 1 for fresh leaf and in Table 2 for Dry leaf. The column 3 in data table contains the values for thickness of leaf. This thickness (mass per unit area) includes water content and organic matter of Almond leaf. The column 4 shows the logarithmic values of relative transmission through leaves with different thickness.

Table 1: Fresh Almond leaf for Tl-204 source

Sl. No	Thickness (cm)	Thickness (gm/cm^2)	Counts per sec	ln (N_o/N)
1	0.019	0.01978	97.6611	0.52737
2	0.040	0.04089	70.8778	0.84791
3	0.061	0.06222	45.4889	1.29140
4	0.081	0.08322	29.3222	1.73052
5	0.100	0.10233	17.6778	2.23656
6	0.120	0.12311	12.9556	2.54735
7	0.141	0.14333	8.0556	3.02251
8	0.161	0.16367	5.9389	3.32735
9	0.180	0.18456	2.7778	4.08722
10	0.200	0.20300	1.4778	4.71833

Table 2: Dry Almond leaf for Tl-204 source

Sl. No	Thickness (cm)	Thickness (gm/cm^2)	Counts per sec	ln (N_o/N)
1	0.013	0.00733	121.4722	0.24051
2	0.026	0.01544	106.0222	0.37655
3	0.040	0.02344	90.4333	0.53558
4	0.054	0.03133	73.3944	0.74435
5	0.066	0.03878	66.9889	0.83567
6	0.079	0.04667	57.3500	0.99102
7	0.092	0.05433	49.7444	1.13330
8	0.105	0.06178	40.3722	1.34205
9	0.118	0.06956	33.1944	1.53781
10	0.131	0.07644	29.5611	1.65373

The plot of table-1 data of fresh Almond leaf, thickness (cm) versus logarithm of relative transmission intensity has been shown in Fig.2, from which linear mass co-efficient is determined. The thickness (gm/cm^2) and counts per second of dry Almond leaf has been shown in Fig. 3, from which mass attenuation coefficient is determined.

Fig. 2: Plot of Thickness Vs relative transmission intensity for Tl-204 Source

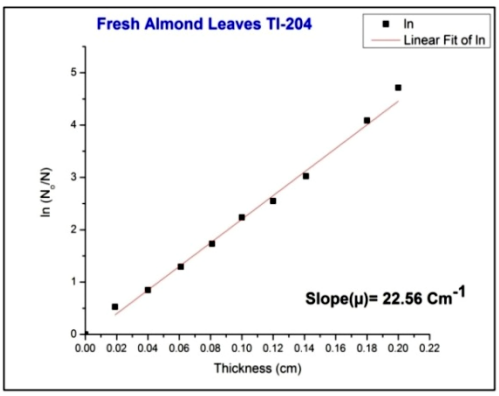
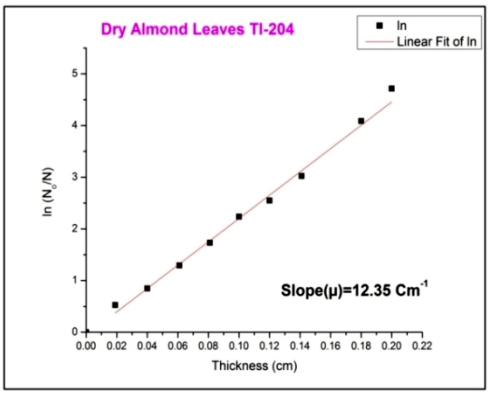


Fig. 3: Plot of Thickness Vs Counts per second for Tl-204 Source



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The plot of table-2 data of Almond leaf, thickness (cm) versus logarithm of relative transmission intensity has been shown in Fig.4, from which linear mass co-efficient is determined. The thickness (gm/cm^2) and counts per second has been shown in Fig. 5, from which mass attenuation coefficient is determined.

Fig. 4: Plot of Thickness Vs relative transmission intensity for Tl-204 Source

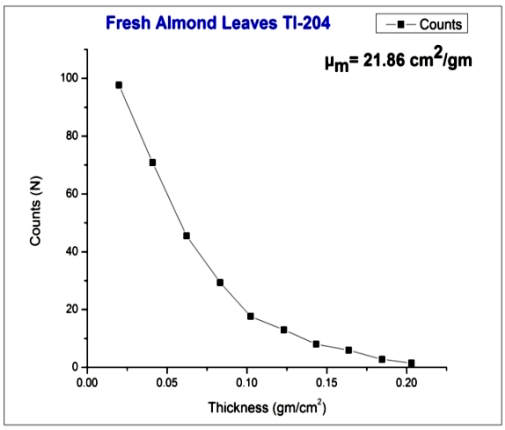
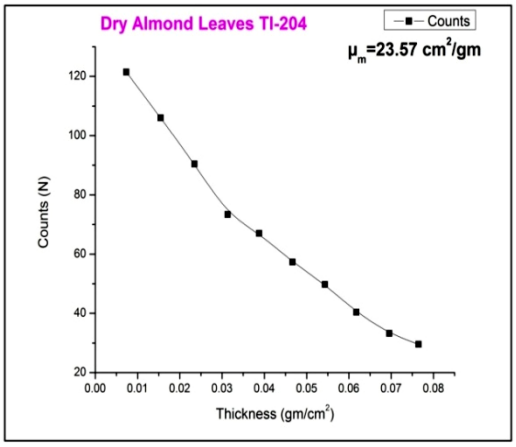


Fig. 5: Plot of Thickness Vs Counts per second for Tl-204 Source



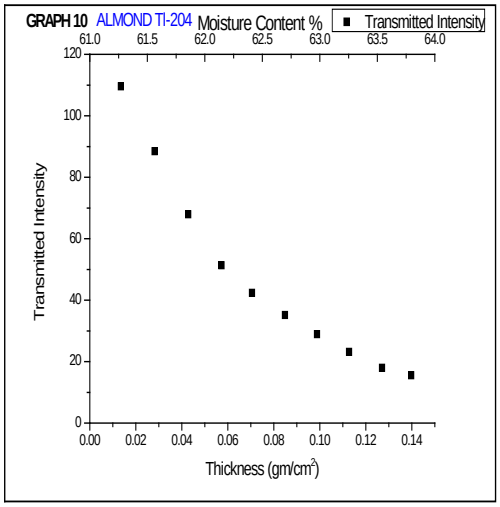
Data for leaf thickness, moisture content and transmitted intensity has been shown in Table-3 for Almond leaf of different thickness. The column 1 in data table contains the values for thickness of leaves. This thickness (mass per unit area) includes water content and organic matter of Almond leaf. On drying the almond leaf, its thickness decreases (as leaf has lost water content). The percentage moisture content of leaves by beta attenuation method and by direct weighing (calculated by equation 6) has been shown in columns 3 and 4 respectively. A comparison and close agreement of measured values by two methods provides authenticity of beta attenuation technique.

Table 3: Leaf thickness, Transmitted Intensity and % of water content of Almond leaf for Tl-204

Mean Thickness (g/cm^2)	Mean Intensity	% Water Content	
		Beta attenuation	Direct weighing
0.013555	109.56666	61.272	62.921
0.028166	88.450000	61.572	62.228
0.042833	67.961111	61.861	62.321
0.057277	51.358333	62.152	62.349
0.070555	42.333333	62.418	62.106
0.084888	35.152777	62.697	62.093
0.098833	28.900000	62.986	62.093
0.112722	23.155555	63.254	62.253
0.127055	17.986111	63.544	62.311
0.139722	15.519444	63.800	62.342

The plots of transmitted intensity as a function of moisture content and thickness of leaf are shown in Fig 6. The plots are drawn for almond leaf for Tl-204 source.

Fig. 6: Plot of Thickness and % of water content Vs Transmitted Intensity for Tl-204 Source



The slope of fitted line is negative because increase of water content causes more absorption of beta particles and hence decreases of transmitted intensity. The best-fit straight lines serving as calibration curves provide an alternative way to measure moisture content. In field situations for monitoring the water content in plant leaves these types of curves can be of great use. We believe that the present experimental findings with regard to agricultural field will be quite useful to other investigators in improving their design for field instruments.

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V. CONCLUSION

We studied the linear and mass absorption coefficients values were measured for the leaves of Almond plant by using Tl-204 source. The measured values were found to be in well good agreement with mixture rule. The linear attenuation coefficient of fresh leaves is greater than dry leaves. The difference between fresh leaves and dry leaves indicates that they contain of water in leaves.

The Linear Attenuation Coefficient & Mass Attenuation Coefficient values are measured using Tl-204 source for Almond leaves. When compared it is evident that the attenuation is high for fresh leaves than the dry leaves.

As the thickness of the leaf increases, its absolute moisture content increases which in turn leads to increase in the absorption of radiations. Thus with lesser percentage of moisture content, the transmitted intensity is high and thus attenuation reduces with lesser moisture content.

Thus the moisture content in the leaves plays a vital role in attenuation of radiations hence the “Leaves” of various trees act as “natural absorbers”.

The mass attenuation coefficient values are useful for quantitative evaluation of interaction of radiations with leaves of plants. Measuring leaf water content can build knowledge of the soil moisture status aiding in effective irrigation water management.

Water is an essential and important constituent of plants and trees. Monitoring leaf water content determines plant health, vitality, photosynthetic efficiency and helpful in timely drought assessment. Measuring leaf water content can also build knowledge of the soil moisture status aiding in effective irrigation water management. The use of Tl- 204 verifies the applicability of technique for different end point energies. It is expected that the study will be helpful for continuous monitoring of internal crop water status. It will lay an important foundation for sustainable development and modern agricultural technology. There is also a need to simulate the present experiment with some suitable Monte Carlo Simulation code for better understanding of present work to prototype the method infield practice.

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