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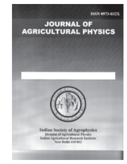

Research Article

Water Content Estimation of Wheat Leaves Through Transmission of Beta Radiation

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ABSTRACT

The relationship between water content in wheat (*Triticum aestivum* L.) leaves and beta (β) transmitted intensity has been established for ^{204}Tl and ^{60}Co radioisotopes. The semi-logarithmic plots of percentage relative intensity versus thickness were plotted for fresh and dry leaves. The value of mass attenuation coefficient is obtained from the slope of these curves which is further employed to estimate water content. A strong negative correlation was found between transmitted intensity and water content i.e. the transmitted intensity increases with the decrease in water content. The correlation coefficients are -0.998 and -0.988 for ^{204}Tl and ^{60}Co β-sources respectively which validate the linear dependence of β-transmission on water content. The use of different β end-point energies verifies the applicability of the technique for different radioisotopes. The linear relation between water content and β-transmission can be of great applicability in the real field practices.

Keywords: Beta radiation, Mass attenuation coefficient, Transmitted intensity, Water content, Wheat

Introduction

Water is vital for plant life and is a major chemical reactant in photosynthesis. The water content (WC) of leaf or of the whole canopy is an essential variable in plant physiological processes. Plant water content measurement is also helpful to evade conditions like water stress or waterlogging. Many methods had been employed by researchers to estimate the water content of plants. Hunt and Rock (1989) employed near and middle infrared reflectance to investigate leaf water content changes. But remote sensing using thermal infrared, the visible and near-infrared wavelength ranges alone or in established vegetation indices was proved inappropriate for retrieving vegetation water content at leaf level (Ceccato *et al.,* 2001). Colombo *et al.* (2008) applied hyperspectral indices and inverse modeling for the estimation of leaf and canopy water content in poplar plantations. Cheng *et al.* (2011) estimated leaf water content as a percentage of dry mass (LWC_D) by a technique of continuous wavelet analysis for a wide range of tropical forest species. But to obtain the spectra, there is a requirement of hyperspectral sensors and spectroradiometers.

Leaf relative water content (RWC) had also been used to study water status in winter wheat (Lugojan and Ciulca, 2011). Although RWC measurement is easier, the accuracy of result depends on the methodology used which can vary from species to species. Measuring RWC requires a considerable amount of time and it is destructive in nature. A technique is required which does not alter the physiological activities of plant and can continuously monitor the plant water content.

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Since the water content plays a major role in crop productivity, researchers are in the quest to find a method that is technically feasible and efficient for the determination of water content. In the past, beta gauging technique was found applicable to continuously monitor the changes in plant water status. But the gauging technique was found to have limited utility to measure plant absolute water status. However, the β gauging method with a parallel sampling technique was found suitable for following both diurnal and long-term changes in water status (Jones, 1973). Batra *et al*. (1992) proposed a new method of β attenuation which overcame the limitation of the β gauging technique. To obtain the absolute water content, the mass attenuation coefficient (μ_m) was related to measured relative intensities of fresh and dry leaves. Thus, the β ray attenuation technique increases the accuracy and overcomes the sophistication of the other techniques.

Beta-decay is the spontaneous decay process in which the atomic number of nucleus changes but the mass number remains the same. The β particles are strongly ionising than gamma radiation and have ranges higher than those of alpha particles. The β particle when passing through the absorber, lose energy by inelastic collision with atomic electrons of the absorber, elastic scattering from nuclei or bremsstrahlung. This penetration of radiation can be qualitatively evaluated by the attenuation coefficient. Nathu Ram *et al.* (1982) made transmission studies of β particles of end point energy from 0.167 to 3.60 MeV in different absorbers and given empirical relation between μ_m and end point energy of the β spectrum. The μ_m is the ratio of linear attenuation coefficient (μ) to density. The μ describes the fractional loss in the intensity of incident radiation as it crosses the given thickness of the absorbing material. Singh and Batra (1987), Yalcin and Gurler (2005) and Mahajan (2012) had given different practical methods to measure the β attenuation coefficient. Many methods have been employed to study μ_m like Ermis and Celiktas (2012) used timing method and Ahmed *et al.* (2017) used the equation of Kisse and Vertes. The validity of the exponential absorption law has also been explored on Asoka plant leaves using two different sources i.e. Cs and Tl (Chaudhari, 2013).

The attenuation of β particles as they pass through a material provides information regarding the thickness of the material. Thus, β rays are widely used in numerous industries to measure the thickness of various coatings, sewn seam, aluminium foils or paper. In recent decades, due to environmental concerns the β attenuation mass monitors (BAM) are commonly used to monitor ambient aerosol particle concentration. (Chueinta and Hopke, 2001; Raja *et al*., 2017).

In the present study, beta radiation is used to estimate water content in wheat leaves. Although the beta gauging technique has been used for many applications in the past, presumably there is no study present that explores the dependence of transmission of β radiation on the water content of wheat leaves.

Materials and Methods

Determination of Mass attenuation coefficient

To study the attenuation of radiation, Geiger Muller (GM) counter has been used whose randomicity of data was checked before performing the experiment. The Chi-square test has been applied on a set of counts recorded for 200 seconds from ^{60}Co (strength – 0.07 μCi) having 0.31 MeV as end-point energy. For 9 degrees of freedom and $\chi^2 = 8.85$, a P-value of 0.5 was obtained which shows that variation in data is exactly as expected according to the Poisson distribution and counter was functioning properly. Also, the operating voltage was determined and the counter was operated at 450 V, near the middle of the plateau region.

To standardize the arrangement, the mass attenuation coefficient of aluminium absorber was measured using β-particles with a maximum energy of 0.77 MeV from ^{204}Tl having the strength of 0.04 microcurie, procured from BARC, India. The attenuation of radiation through absorber follows approximately exponential behaviour given as

$$I = I_o e^{-\mu x} \qquad \ldots(1)$$

In the above equation, I_o represents the counting rate without any absorber, I is counting rate recorded after passing through thickness x and μ (in cm^{-1}) is the linear attenuation coefficient. The equation (1) can also be written as follows

$$I = I_o e^{-\left(\frac{\mu}{\rho}\right)x\rho} = I_o e^{-\mu_m t} \qquad \ldots(2)$$

The ratio of linear attenuation coefficient to the density (ñ) is the mass attenuation coefficient (μ_m) of a material. The product of density with thickness is known as mass thickness (mass per unit area).

To measure the μ_m of aluminium plates, they were placed exactly in mid-way of source and detector. The semi-logarithmic plot between percentage relative transmission and thickness of aluminium absorber is shown in figure 1. The obtained μ_m of aluminium is 21.1±0.74 cm^2/g and agrees well with previously measured values (Ram *et al.*, 1982; Mahajan, 2012). The calibration of the Geiger Muller counter and agreement of aluminium's mass attenuation coefficient with earlier data confirmed the validity of the experimental setup to measure μ_m of wheat leaves.

The wheat (cultivar - PBW 550 Unnat) leaves were picked from the wheat research farm of Punjab Agricultural University, Ludhiana located

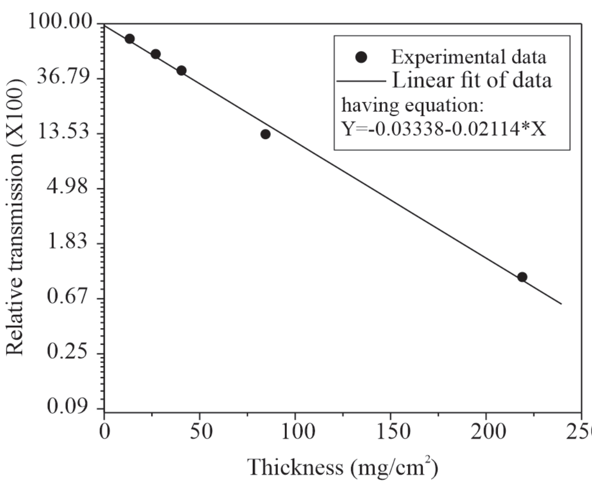

Fig. 1. The fitted semi-logarithmic plot of percentage relative transmission versus thickness of aluminium foil

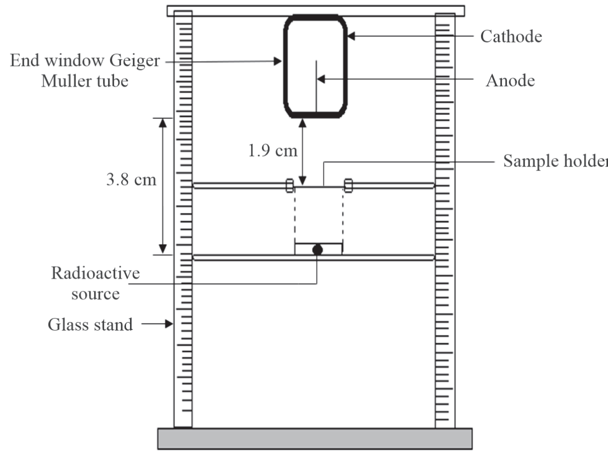

Fig. 2. Schematic diagram of the experimental arrangement to measure the β transmission through wheat leaf

at 30°53' N latitude, 75°47' E longitude and altitude of 246 m from mean sea level. The leaves were selected from the top of the canopy as the width and thickness of leaves were almost maximum and constant there. The leaves were immediately taken to the research laboratory and washed with distilled water. Then leaves were cleaned with filter paper to remove any extra water or dirt. The mass thickness of 10 to 12 leaf strips of approximately 5 cm in length was measured by weighing them on a digital balance having an accuracy of 0.1 mg. The narrow beam geometry set up was employed using two identical rectangular aluminium plates having matching holes acting as collimator and leaves were held between these plates. The experimental set-up used to determine transmitted intensity is shown in figure 2. The detector-absorber-source geometry was kept same throughout the experiment to reduce any error due to geometry. To reduce the statistical uncertainty, a sufficiently large observation time (200 seconds) was chosen and two or more observations were taken.

The percentage relative intensity versus thickness curves were plotted on the semi-logarithmic plot for the fresh and dry state of leaves to obtain their μ_m. For drying, leaves were placed under an infrared (IR) lamp between the aluminium plates with one plate having holes for evaporation of water so that wrinkling and shrinkage of dry leaves considerably get reduced.

Determination of water content (WC)

The intensity of emerging attenuated beam through the fresh leaf is given by the following equation

$$I_f = I_o \exp(-\mu_f t_f) \quad \ldots(3)$$

I_o is the unattenuated intensity of β radiation, μ_f and t_f are the mass attenuation coefficient (cm²/g) and mass thickness of the fresh leaf. From equation (3), for the fresh leaf

$$t_f = \left(\frac{1}{\mu_f}\right) \ln\left(\frac{I_o}{I_f}\right) \quad \ldots(4)$$

and for dry leaf

$$t_d = \left(\frac{1}{\mu_d}\right) \ln\left(\frac{I_o}{I_d}\right) \quad \ldots(5)$$

where I_d represents the intensity of β radiation after passing through the dry leaf, μ_d and t_d are mass attenuation coefficient and mass thickness of dry leaf respectively. The absolute water content is obtained from the following equation:

$$t_w = t_f - t_d \quad \ldots(6)$$

where t_w is the mass of water per unit area. From equation (4), (5) and (6), we get

$$t_w = \left(\frac{1}{\mu_d}\right) \ln\left[\left(\frac{I_o}{I_f}\right)^n \times \left(\frac{I_d}{I_o}\right)\right] \quad \ldots(7)$$

where $n = \frac{\mu_d}{\mu_f}$, the ratio of the mass attenuation coefficient of the completely dry leaf to fresh leaf. Therefore, using the measured values of μ_f, μ_d, I_f/I_o and I_d/I_o, equation (7) gives the absolute water content in the plant leaf. The water content obtained from experimental values was compared with the direct weighing method, which is defined by the following equation,

$$WC(\%) = \frac{\text{fresh leaf mass} - \text{dry leaf mass}}{\text{fresh leaf mass}} \times 100 \quad \ldots(8)$$

To study the dependence of transmitted intensity (counts per minute) on water content, the leaf is placed for one minute under the IR lamp which leads to evaporation of some amount of water consequently decreasing the thickness. Then leaf sample is placed between source and detector and transmitted counts were recorded. Again, the leaf is kept under the IR lamp for further reduction in water content of leaf and counts were measured. The process was repeated until the detector recorded a significant change in the transmitted intensity.

Results and Discussion

The semi-logarithmic plots between percentage relative transmission and thickness for fresh and dry leaves are shown in Figs. 3 and 4 for ^{204}Tl and ^{60}Co β-source respectively. To obtain

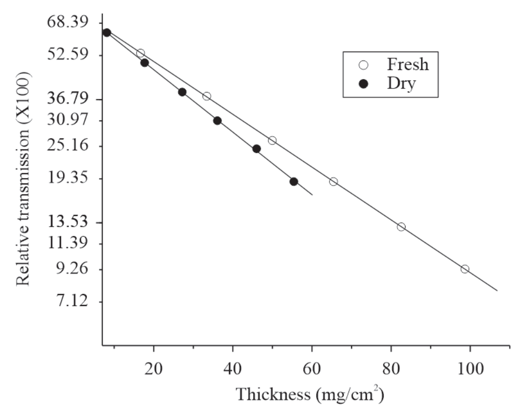

Fig. 3. The semi-logarithmic plot between percentage relative transmission and thickness of wheat leaves using ^{204}Tl as β-source

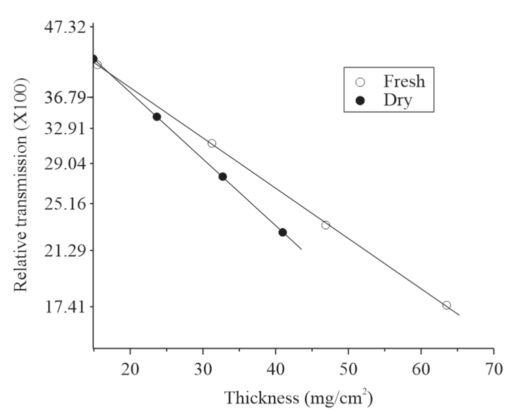

Fig. 4. The semi-logarithmic plot between percentage relative transmission and thickness of wheat leaves using ^{60}Co as β-source

the μ_m, a least-square fit analysis was applied to the data and the following equation was used:

$$I = I_o d^x \qquad \dots(9)$$

where d and I_o are the fitting constants and x is the mass thickness (mg/cm^2). Taking natural logarithm, we can write equation (9) as:

$$\ln I = \ln I_o + x \ln d \qquad \dots(10)$$

The μ_m corresponds to the negative of the slope of equation (10).

$$\mu_m = -1000 \ln d$$

The value of the slope is multiplied with 1000 to express μ_m in cm^2/g. The obtained value of μ_m for the fresh and dry state using ^{204}Tl as a source is 21.44±0.12 cm^2/g and 25.27±0.23 cm^2/g respectively. Also, the obtained value of μ_m for the fresh and dry state using ^{60}Co as β source is 17.96±0.16 cm^2/g and 23.88±0.09 cm^2/g respectively. The error in μ_m is calculated by adding error due to fit, error due to measurement of the thickness of leaves and error on the observed counts in quadrature. It was observed that the μ_m is more for dry state of leaves than for the fresh state. It could be due to the complex structure of leaf that mainly consists of carbohydrates, lipids, protein, and nucleic acid. The molecules of compounds mostly composed of carbon, hydrogen, oxygen, and nitrogen. The effective atomic number (Z_{eff}) of proteins, lipids, and carbohydrates is 6.97, 6.06 and 6.97, respectively (Amewode, 2010). The mean Z_{eff} of water for the energy region between 10 keV and 1 GeV for electron is reported as 3.50 (Kurudirek, 2016). As the μ_m is a product of the Z_{eff} and effective stopping power of absorber (Burek and Chocyk, 1996; Kumar, 2018), the possibility of more value of Z_{eff} for dry leaf might result in more value of μ_m.

Absolute water content is determined by using equation (7) where the uncertainties in absolute water content are due to uncertainty from μ_m measurement. The obtained values of leaf thickness, transmitted intensity and water content are listed in tables 1 and 2 for ^{204}Tl and ^{60}Co β-source respectively. When the wheat leaf is placed under heat radiation from the IR lamp, its thickness decreases. As the major part of leaf is

Table 1. The thickness of wheat leaf, absolute water content, transmitted intensity and % of water content using ^{204}Tl having 689 as zero absorber intensity

Thickness (mg/cm^2)	Absolute water content t_w (mg/cm^2)	Transmitted intensity	Water content (%)	
			β-attenuation	Direct weighing
17.30±0.26	9.02±1.47	376	52.14±8.55	53.59
15.49±0.23	6.91±1.47	393	44.61±9.53	48.17
14.25±0.21	5.43±1.47	406	38.11±7.29	43.67
12.55±0.19	3.74±1.04	421	29.80±8.26	35.99
10.93±0.16	2.69±1.03	430	24.61±7.62	26.55

Table 2. The thickness of wheat leaf, absolute water content, transmitted intensity and % of water content using ^{60}Co having 1232 as zero absorber intensity

Thickness (mg/cm^2)	Absolute water content t_w (mg/cm^2)	Transmitted intensity	Water content (%)	
			β-attenuation	Direct weighing
14.64±0.22	8.87±1.24	653	60.59±8.54	57.24
13.69±0.21	7.76±1.24	666	56.68±9.11	54.29
11.84±0.18	6.08±1.24	687	51.35±10.48	47.12
9.48±0.14	3.41±0.75	720	36.97±7.93	33.93
8.12±0.12	2.06±0.75	738	25.37±9.25	22.91

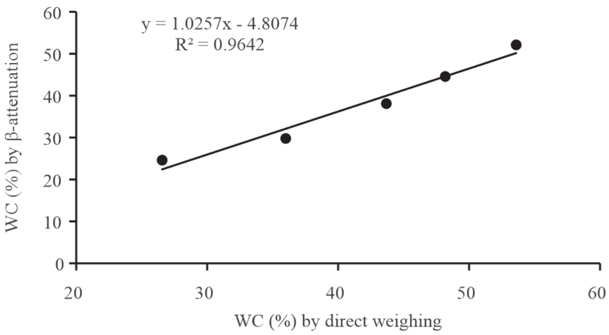

Fig. 5. The correlation between water content measured using the β attenuation technique and direct weighing method for ^{204}Tl

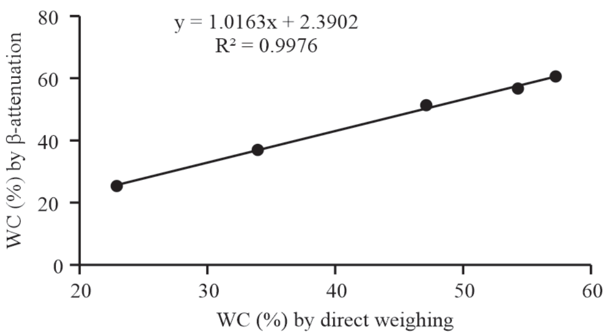

Fig. 6. The correlation between water content measured using the β attenuation technique and direct weighing method for ^{60}Co

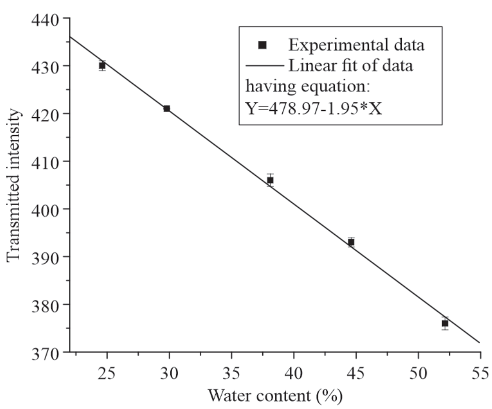

Fig. 7. The relationship between transmitted intensity and water content for ^{204}Tl as β-source

water, thus decrease in thickness can be implied to the loss of some water content. It can be observed from figs. 5 and 6 that the water content measured using β attenuation and direct weighing method are in close agreement, which validates the technique. A strong negative correlation was

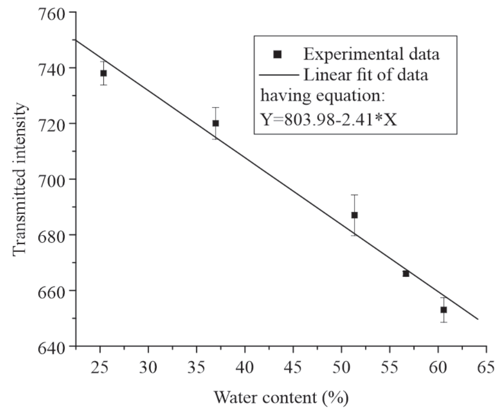

Fig. 8. The relationship between transmitted intensity and water content for ^{60}Co as β-source

found between β-transmission through leaf and water content i.e. transmitted intensity recorded by detector increased with the decrease in water content. This shows water plays a substantial role in the attenuation of beta radiation. The plots of the observed transmitted intensity as a function of the water content of wheat leaves are shown in Figs. 7 and 8. The correlation coefficients are -0.998 and -0.988 for ^{204}Tl and ^{60}Co β-sources respectively which confirms the linear dependence of β-transmission on water content.

Conclusion

It has been observed that the β-attenuation technique is useful to measure crop water content. Measuring the mass attenuation coefficient of fresh and dry leaves, one can measure water content from the relative β transmission. Therefore, after the proper calibration, only transmitted counts measurement through leaf are required to determine the water content. The linear relation between water content and β-transmission can be of great applicability in the field practices to continuously monitor the water status of the crop. The present study can be extended for other varieties of wheat to gain more accuracy and rapidity by properly simulating the prototype of the experiment with suitable Monte Carlo simulation. The agreement of measured results of water content with the direct weighing method validates the technique. Also, the use of different β end-point energies verifies the applicability of the technique for radioisotopes with different end-point energy.

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