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Global Nuclear Radiation Monitoring Using Plants

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ABSTRACT

Plants exhibit complex responses to changes in environmental conditions such as radiant heat flux, water quality, airborne pollutants, soil contents. We seek to utilize natural chemical and electrophysiological response of plants to develop novel plant-based sensor networks. Our present work focuses on plant responses to nuclear radiation – with the goal of monitoring plant responses as benchmarks for detection and dosimetry. In our study, we used plants include Cactus, Arabidopsis, Dwarf mango (pine), Euymus, Azela, and Arborvitae. We demonstrated that these plants' Chlorophyll-a to Chlorophyll-b ratio can be changed according to the radiation dose amount. The recovery processes and speed are different for different plants. Some plants recover fast some slow and some may not recover. In our experiment, an InGaN blue laser (405nm) is used as the pump laser. The PL spectrum shows a relatively weak and broad green peak near 550 nm (carotenoids) and two narrower and stronger peaks near 685nm (chlorophyll-a) and 735 nm (chlorophyll-b). Sample tree subjects were placed at a distance of ~3m from NIST BT-2 reactor gate capable of producing a neutron field of about 13 mrem/h. This corresponds to an actual absorbed dose of ~ 1 mrad/h. Our results shows that some plants are sensitive to nuclear radiation and some are less. We can use their characteristics to do differential detection, extract nuclear activity information out of measurement results, and avoid false alarms produced by environmental changes. Certainly the ultimate verification will be obtained from genetic mutation information, which only needs to be done when we have seen noticeable changes on plant optical spectra, mechanical strength and electrical characteristics.

KEYWORDS Nuclear Monitoring, Nuclear Detections, Forensics, Chlorophyll Fluorescence, Plant Electricity.

I. INTRODUCTION

Recently, we demonstrated that nearly all plants produce electricity and act as electrical power sources [1]. We also found that nuclear radiation alters plant electricity and produces voltage and current changes, which can be used for nuclear detections [1]. We further found that nuclear radiation can change plant optical characteristics and cell mechanical structure, which can be associated to macroscopically measurable quantities. This lead to the idea that one can explore the history of nuclear activities in an area by examining the recorded information from local plants through a two-tier approach: First, a quick survey through simple electricity response, optical absorption or fluorescence, mechanical strength, etc.

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measurements to identify possible nuclear activity records and second, a detailed examination through molecular biology techniques to verify both short term and long term nuclear activities with low false alarm.

The physical condition and health of plant vegetation as a whole can be monitored by optical spectroscopic methods. Several optical methods can be applied to characterize the leaves and plant by specific spectral signatures.These are absorbtion spectra, reflectance spectra, flurorence spectra as well as photo acoustic spectra [2-5].

2. Experimental Setup for radiation beam and Measuring fluorescence

The plant radiation studies were done with neutron beam facility located at NIST Center for Neutron Research Beam Tube 2 (BT-2). The NCNR BT-2 provides an intense source of thermal neutrons that is collimated using a tapered plug (1 and 2 in Fig. 1). This conically shaped beam is nearly uniform in intensity across the area of the beam at image planes downstream. This type of optical arrangement is generally referred to as pinhole optics. Although the CNR produces mostly thermal neutrons there are still a significant amount of high energy neutrons and gamma rays as a byproduct. These high energy neutrons and gamma rays represent a background that can be dangerous to electronic equipment. Therefore, a high energy neutron and gamma ray filter is placed directly downstream of the tapered collimator. This filter consists of 10 cm of bismuth single crystal cooled to liquid nitrogen (LN) temperatures (77 K). Cooling the bismuth dramatically reduces the vibrational phonon modes in the crystal, which strongly scatter thermal neutrons. The cooled crystal becomes nearly transparent (60 % transmission) to thermal neutrons and strongly filters the high energy neutrons by diffraction and gamma rays by absorption coming from the reactor core.

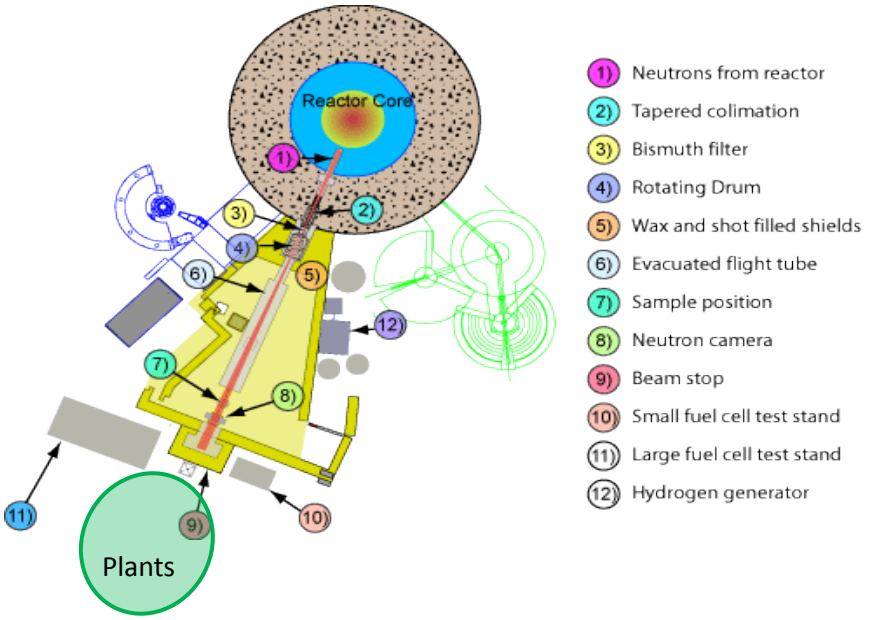


Fig1: a**.** Neutron imaging facility b. Plan view of the neutron imaging facility pointing out some major features.

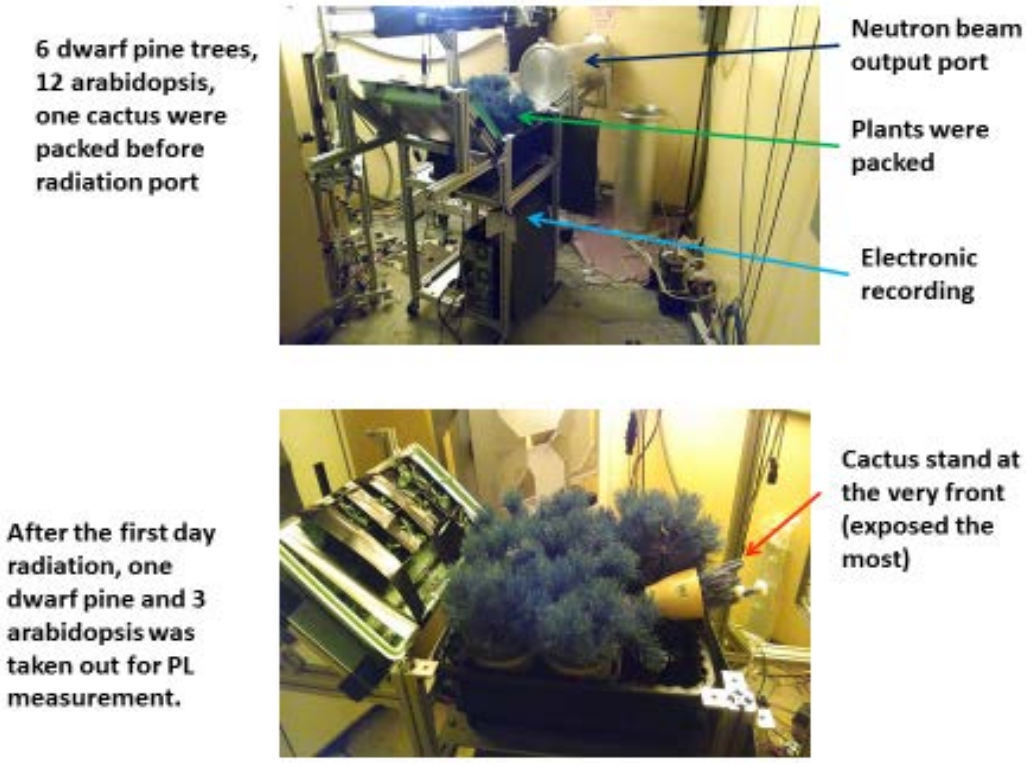


Fig. 2. Plant arrangement for the in front of neutron beam.

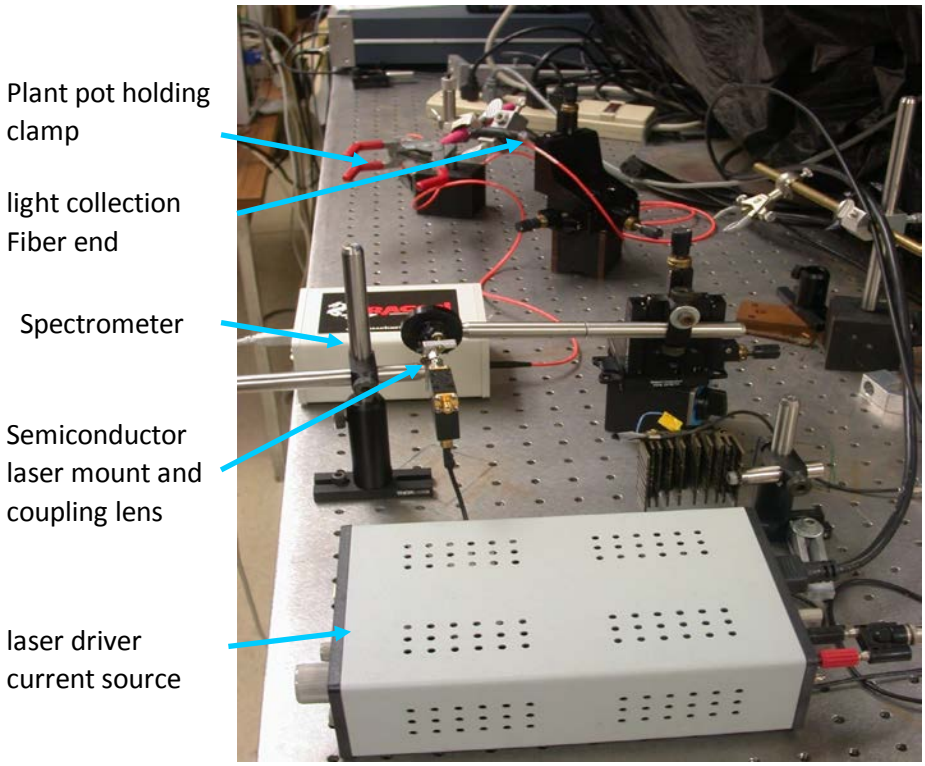


Fig. 3. Measurement set up of the plant florescence of the chlorophyll Experimental Setup.

Two exposure tests were conducted in 2014. One was in July and the other was in September. Each lasted about 3 days. Our data thus contains various dose amounts for some types of plants. In the first batch the plants include Arabidopsis, pine trees and cactus. In the second batch we again included Arabidopsis together with Azela, Euymus and Tharuja. The plant arrangement for the first run is shown in Fig. 2 and the photoluminescence set up is shown in Fig. 3.

To measure the florescence, a blue laser (400nm) was used. We take the fluorescence from leaves to spectrometer using optical fiber. One end of the fiber is connected to the spectrometer and the other end of the fiber was nearly touching leaves to couple florescent light into the fiber.

3. RESULTS AND DISCUSSION

Excitation of Arabidopsis, Dwarf mango (pine), Euymus, Cactus and Azela leaves with blue irradiation (CW laser 400 nm) led to a fluorescence emission spectrum with two maxima of the chlorophyll fluorescence in the red spectral region near 680 nm (F680) and 735 nm (F735). The chlorophyll fluorescence ratio F680/F735 is considerably higher in the aurea than green form, due to its lower chlorophyll content. At a higher chlorophyll content the 680 nm fluorescence is partly reabsorbed by the in vie chlorophyll thus leading to a decrease in the ratio F680/F735.

3.1 THE CHLOROPHYLL FLUORESCENCE EMISSION SPECTRA

Under optimum condition of photosynthesis the largest part of the light energy absorbed by the photosynthetic pigments is used for photochemical quantum conversion to drive plant photosynthesis - the fixation and conversion of inorganic CO2 into sugar and biomass. Smaller portion of the absorbed light energy are remitted either as heat or as red chlorophyll fluorescence. The exact amount of energy distribution is difficult to estimate and can vary according to the stage of development and stress condition.

$$E_{absorbed} = E_{photochemistry} + E_{heat} + E_{fluorescence}$$

When the process of photosynthetic quantum yield is reduced due to environmental stress, the de-excitation of absorbed light energy via heat and fluorescence emission increases in contrast to heat emission which is detectable by special techniques such as photo acoustic spectroscopy. On the other hand chlorophyll fluorescence is relatively easy to measure.

FIG. 4 shows the fluorescence emission spectra of Arabidopsis and Tharuja (Up and Down) before radiation after radiation (Left-Right). These are examples of typical fluorescence data we collected and some of them are collected in daily basis after the radiation. With these data sets we can construct plots of chlorophyll A and B ratio as a function of time, which reveals the recovery time for each individual plant.

The obtained spectra showed the typical chlorophyll emission spectrum with two bands corresponding to photosystems fluorescence. Several authors agree that at room temperature both PSI and PSII [11] are responsible for the band in the far red, around 735 nm, while at 680 nm emission is only attributed to PSII. The peak fluorescence ratio F680/F735 is thus connected to the balance between them, and was found to vary in the presence of several factors related to plant health.

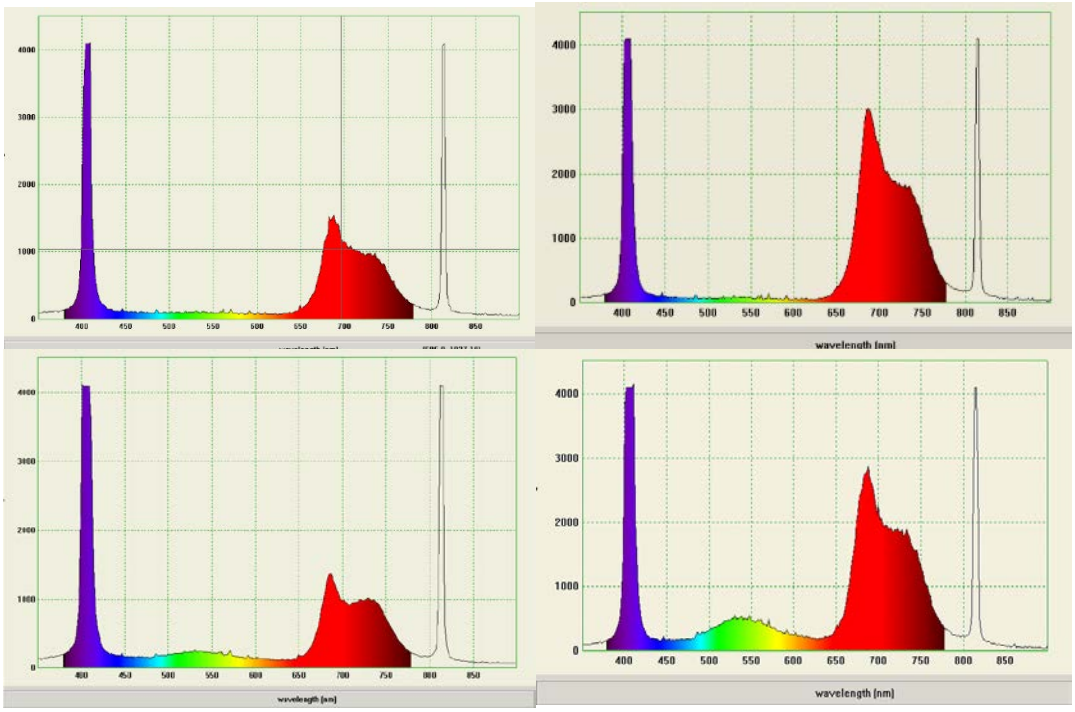
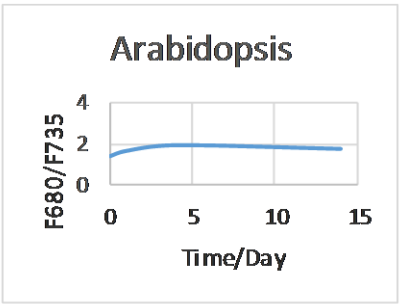
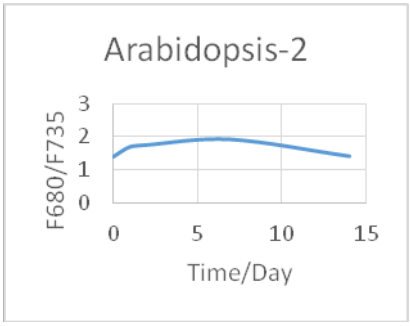


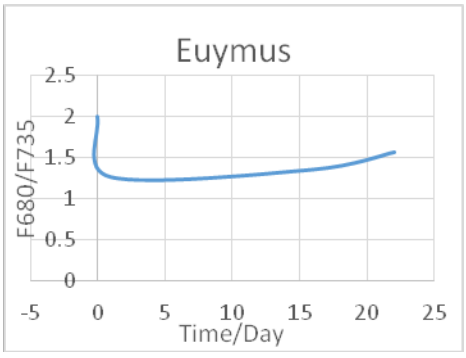
Fig 4: Change in the shape of chlorophyll fluorescence emission spectra with radiation on leaves of Arabidopsis and Tharuja (Up and down) before radiation after radiation (Left-Right)

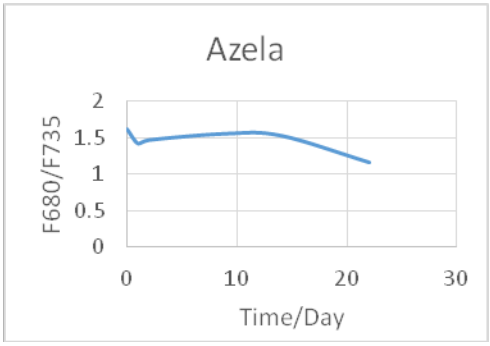
2.2 CHLOROPHYLL A TO B RATIO CHANGE DUE TO RADIATION

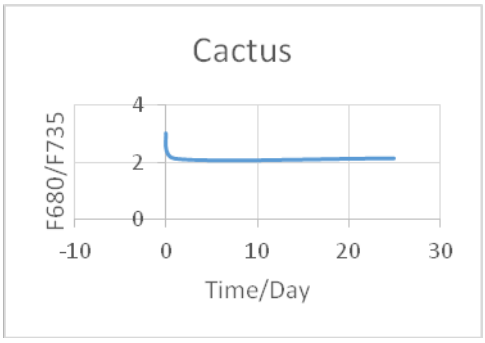
The experimental fluorescence ratios (F680/F735) for samples did vary appreciably. Results for Euymus, Dwarf Mango (pine), cactus, and Azela showed a decrease in F780/735 because either preferential damage in PSII or inhibition of e− transfer from PSI. On the other hand for the Aradopsis and Tharuja showed an increase in F780/735 because of facilitation of e− transfer from PSI. When time passes the recovery process gradually brought the ratio back to its normal value For Arabidopsis, Tharuja, and Dwarf Mango (pine) we show both shorter (weaker) and longer radiation (stronger) does radiation results. As a pine tree dies the leaves etiolated and the green spectrum (550nm) becomes equal to the red fluorescence.

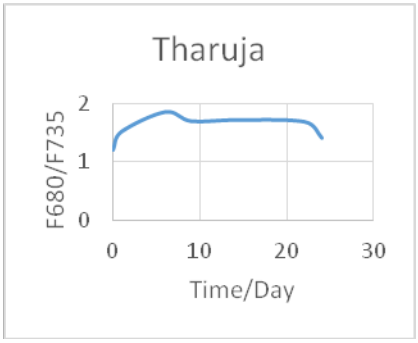


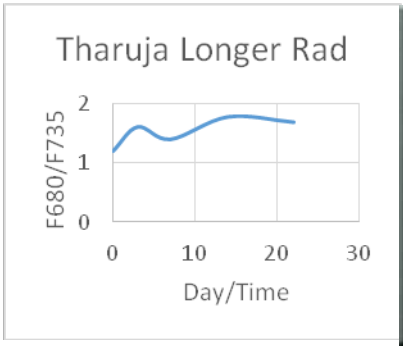












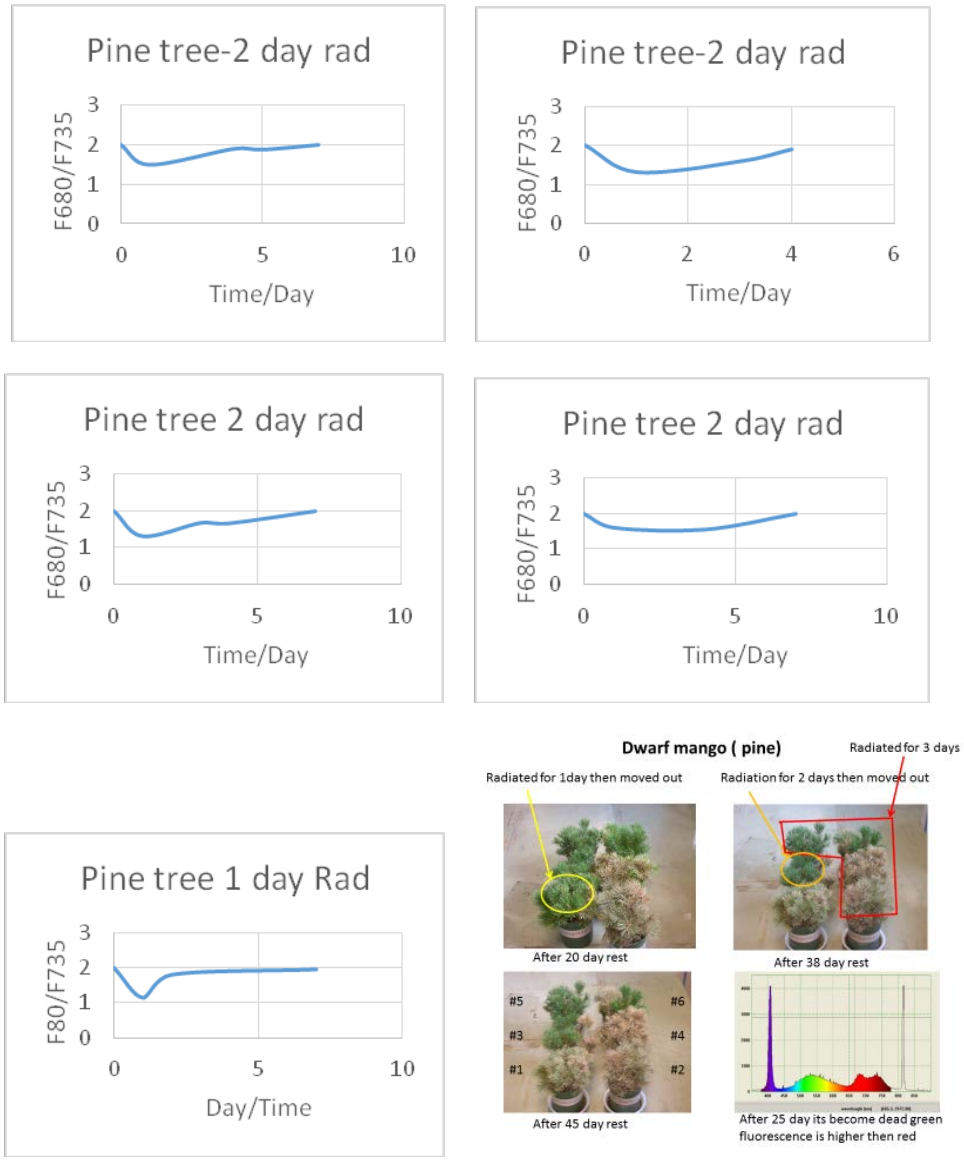


Fig 5. Dependence of the chlorophyll fluorescence ratio F680/F735 changing with time after radiation. For Arabidopsis, Tharuja, and Dwarf Mango (pine) we show both shorter (weaker) and longer radiation (stronger) does radiation results.

As observed in Fig. 5, the A/B ratio all changed after receiving either weak or strong radiation and they all recover back to their original values but at different rates. The important information is that the recovery speed is in weeks to months range, not hours or years. This basically is saying that we may apply the result in couple of ways to monitor radiation. One is related to the speed. Pine tree recovery time is faster than others. Some of them will take longer time and some may take even longer time. We may use different recovery times for event detection. For example, we may stay in town for a few days do measurement on different types of plants and observe the changes which can be helpful to project how many days earlier some nuclear activity may have occurred.

Here we can also mention that people already studied Aradopsis fluorescence A/B ratio in cold temperature [12]. Result was opposite to what we got for radiation effects. That may provide ways for differential detection of radiation. However more research necessary to identify some plants that are fully immune to radiation. Furthermore, other effects, like drought, also need to be studied to obtain a comprehensive model and data base.

CONCLUSION

In this study we have shown that all plants are sensitive to nuclear radiation and some take longer time to recover and take less. We plan to use their characteristics to do differential detection and extract nuclear activity information out of measurement results at the same time avoid false alarms produced by environmental changes. In future study and we hope we will be able to use all mechanical properties, electrical properties, optical properties, and molecules properties to provide a comprehensive model and data base to help the need of nuclear monitoring

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