THE PENETRATION AND ADSORPTION OF CESIUM IN BEAN LEAVES*

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SUMMARY

The foliar uptake of ^{134}Cs in the primary leaves of beans has been studied under conditions of varying temperature, humidity and air flow on the leaf surface. Enhanced penetration was obtained by increasing air humidity or leaf moisture content through a decrease in transpiration. Accumulation and transport followed the same pattern and were influenced more by temperature than by humidity.

1. INTRODUCTION

The penetration and subsequent translocation of foliarly applied chemicals has been reviewed among others by CURRIER & DYBING (1959) and SARGENT (1965). Evidence from a variety of experiments shows that ambient temperature and relative humidity have been assumed to play important roles in the processes involved.

GUSTAFSON (1956) and MEDERSKI & HOFF (1958) found increased absorption, respectively of Co and Mn, with increased temperature. RICE (1948) and BARRIER & LOOMIS (1957) found similar correlations with 2,4-D uptake but the last authors could not detect it in the absorption of ^{32}P. BROUWER & LEVI (1969) studied the influence of root temperature while air temperature and humidity were kept constant and found a clear effect of the pretreatment root temperature on the rate and quantity of ^{22}Na, ^{32}P and ^{134}Cs taken up by bean leaves. OLAND & OPLAND (1956) and THORNE (1958) found no increased uptake of magnesium or phosphate when increasing the humidity factor by rewetting the treated leaf. ZUKEL *c.s.* (1956), PALLAS (1960), CLOR *c.s.* (1962, 1963) and PRASAD *c.s.* (1967) reported marked increases in herbicide uptake when placing the treated plants or plant parts in polyethylene bags to increase ambient humidity. MIDDLETON & SANDERSON (1965) found that air humidity was more significant than air temperature in determining uptake of Cs and Sr by barley leaves.

This paper reports results of experiments designed to determine factors enhancing the foliar uptake of ^{134}Cs. Cs was chosen as the element under investigation because of its hazard to man from residues deposited on plants.

2. MATERIALS AND METHODS

Bean plants, *Phaseolus vulgaris* L. c.v. "Beka" used in these studies were grown in individually aerated glass jars containing a slightly modified Hoagland nu-

* EURATOM Biology Division Contribution No. 472

trient solution (1950). They were kept at optimum temperatures of 23 °C for a 16 hour light period and 20 °C for the 8 hour dark period. Relative humidity (RH) was kept at 50 % and light intensity was constant at 25,000 lux.

In a series of experiments, the room air temperatures were changed to 15 or 30 °C and the relative humidity brought to 40 or 80 % one hour before treatment and kept unchanged throughout the experimental period. In another series of experiments, plants were enclosed immediately after treatment in clear polyethylene bags supported in such a way that the plants did not touch them. The length of the bags varied. In one case it reached to just below the cotyledons and thus allowed a free exchange of air with the rest of the room while eliminating the direct flow of air on the leaf surface. In the other, the plant and pot were enclosed in tightly fitting bags. In both cases room air temperature was 23 °C and RH 40 %. Finally, in one experiment only, plants were kept under conditions of high humidity by enclosing them in tightly fitting bags for 24 hours before treatment. The latter was carried out immediately after removal of the bags and the plants were kept at 23 °C and 40 % RH during the whole experimental period.

Leaf treatment was as described by LEVI (1966). Briefly it consisted in applying a drop of 0.01 ml aqueous solution of 1 mM Cs*Cl containing 0.1 μCi ^{134}Cs to the tip of one primary leaf of plants, the first trifoliate of which was expanding. No wetting agent or spreader was added. At set times after treatment the fraction of Cs* not retained by the plant was washed off the treated area with 10 ml of water and the plant harvested in a number of separate fractions to determine the amount still held in the treated area as well as the distribution of the Cs taken up.

At least 5 plants were used for each treatment which was always carried out 3 hours after illumination had started. Experiments reported were repeated a number of times over a one year period and values given are averages of all replicates.

Temperature measurements were made with thermocouples. Counting of the γ activity present in each fraction was made in a well-type NaI(Tl) cystal scintillator in a definite region of the spectrum to include the two main peaks of the isotope. To avoid geometry problems, the plant material was digested in hot H_2SO_4 and H_2O_2 prior to counting.

3. RESULTS AND DISCUSSION

Preliminary experiments showed that in periods longer than 6 hours, condensation occurring in closed bags allowed free water to drip from the bags onto the plants introducing a possible contamination error. The experiments reported here therefore concern only the 1–6 hours period following treatment.

While the temperature of the air circulating in the room was 23 °C that of the treated leaves was 24.5 °C; in completely closed bags containing silica gel or $CaCl_2$ leaf temperature reached respective maxima of 27.5 and 26.0 °C 6 hours after placement of the bag; it was 28.2 °C for the plants within the closed bags

containing extra water and 27.0 °C when the bags were left open at the base. Air relative humidity in the room was kept at desired levels but consistently at 40% when bags were used. Although it was not possible to measure humidity accurately within closed bags, condensation appearing on the walls of the bags indicated that a high RH had been reached. This was not noted 6 hours after treatment in the cases where silica gel or $CaCl_2$ were present.

To allow comparisons of data obtained over a large number of experiments, values are expressed as percentages of the ^{134}Cs activity applied to each plant and are presented graphically in *figs 1–12*. Three values are given for each harvest time: that of the Cs* which could be removed by simple water washing, that which was held in the treated area and that which was transported out of that area and circulated in the rest of the plant.

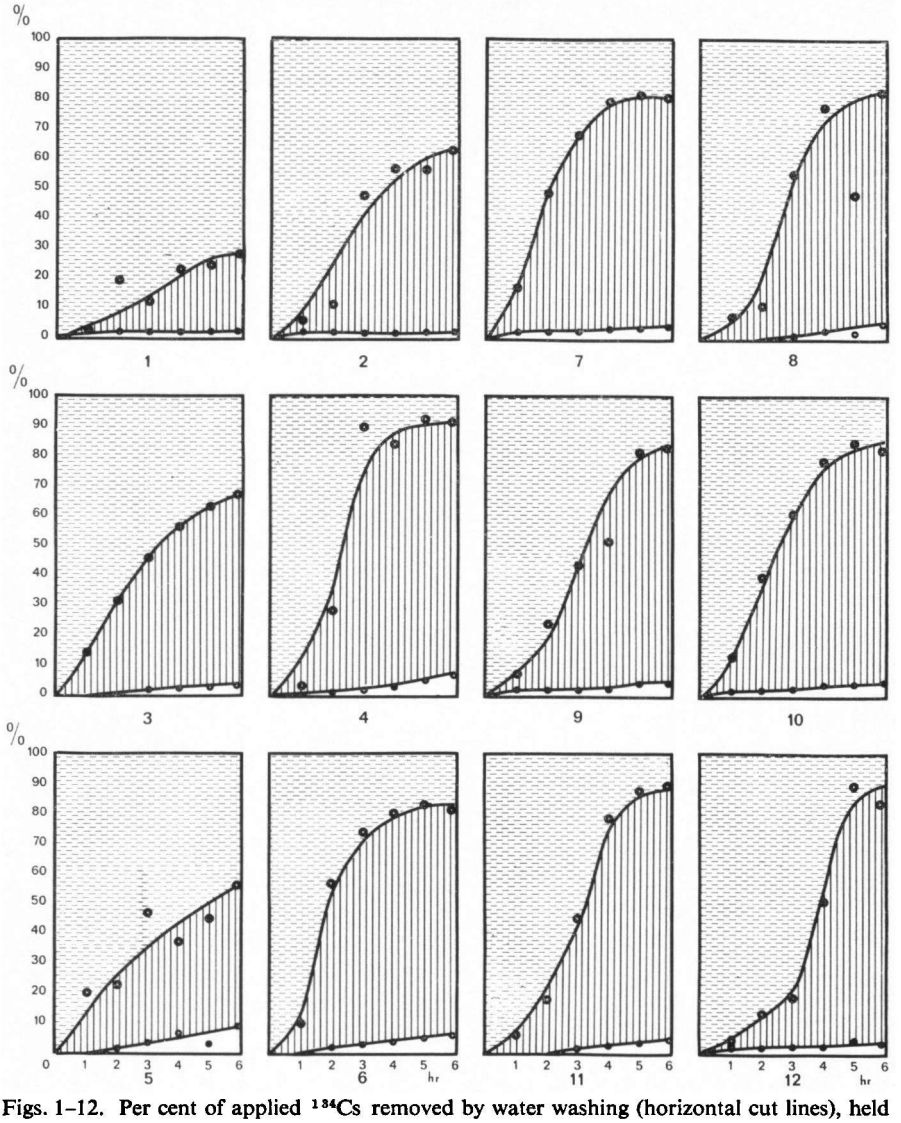
It is apparent from *figs 1–6* that at constant RH, the air temperature plays an evident role in Cs uptake. One hour after treatment 98.0, 85.6 and 80.0% of the total applied Cs could be removed by washing the treated leaves of plants at 15, 23 and 30 °C. Differences between 23 and 30 °C were however not significant at 1% level. The same relation is even more evident at the six hour harvest but by that time some transport of Cs, itself temperature dependent, had occurred away from that area.

The quantity held in the treated area, while very low at 15 °C (1.1%) was considerably greater (14.2%) at the optimal temperature of 23 °C and still significantly greater at 30 °C (19.4%) one hour after treatment of the leaves. Six hours later, more than twice as much Cs was held by plants at 23 °C than at 15 °C. The difference between plants at 23 and 30 °C was much smaller and not significant.

When the RH was doubled, there was a significant increase in the total Cs taken up in the six hour experimental period for each of the temperatures considered. While differences in the Cs which could be washed off after one hour were not significant at 1% level, 3 hours after treatment maximal penetration had occurred in the bean leaves and differences were then highly significant in all cases comparing the results at each temperature separately. Although there appears to be at the 6 hour harvest a consistent increase in quantities of Cs held in the treated area with increase in temperature at 80% RH, this was not significant for plants kept at 23 and 30 °C.

Comparing figures and considering the interaction between temperature and humidity of the leaves, it is apparent that adsorption can be related to air temperature and is probably regulated by the metabolic activity of the plant. Cs transported out of the treated area increased significantly with increases in temperature in the three cases at 80% RH yet showed significant maxima at the optimum temperature.

Figs 6–12 indicate that a very similar quantity of Cs* was held at the end of the 2nd hour experimental period in all cases whether the plants were enclosed in bags containing water *(fig. 9)* to further enhance the moisture content of the air, or silica gel *(fig. 11)* or $CaCl_2$ *(fig. 12)* to reduce it, or were simply placed under bags open at the base *(fig. 8)* to allow a free exchange of air at the am-



Figs. 1–12. Per cent of applied ^{134}Cs removed by water washing (horizontal cut lines), held in the treated area (vertical lines) and transported away from this area (blank) under various environmental conditions.

1: No bags, air temperature 15 °C, RH 40%; 4: No bags, air temperature 23 °C, RH 80%;
2: No bags, air temperature 15 °C, RH 80%; 5: No bags, air temperature 30 °C, RH 40%;
3: No bags, air temperature 23 °C, RH 40%; 6: No bags, air temperature 30 °C, RH 80%;
7: Closed bags for 24 hours before treatment only;
8: Bags, open at base, placed immediately after treatment;
9: Bags completely closed placed immediately after treatment, extra water placed at base of pot;
10: Bags completely closed placed immediately after treatment;
11: Bags completely closed placed immediately after treatment, silica gel placed at base of pot;
12: Bags completely closed placed immediately after treatment, $CaCl_2$ placed at base of pot.

bient RH. Although temperatures within the bags also varied being 28.5 °C in some closed ones against 24.0 °C in the open ones, all the situations had one factor in common i.e. the lack of air blowing directly on the leaf surface thus avoiding a reduction in thickness of the adhering boundary layer of water and therefore decreasing transpiration. No precise relationship could be established between leaf temperature and surface water film and air temperature and humidity whithin the scope of these experiments. Available indications that leaf moisture content was directly related to recorded leaf temperatures and therefore transpiration lead, however, to believe that the increase in penetration, adsorption and translocation obtained by placing of bags may be due to increases in temperature and humidity but also if not mainly to the great reduction in air blowing on the leaf surfaces thus determining an increase of the moisture content in the leaf or leaf surface. Studies in progress to relate leaf moisture content, metabolic activity and foliar uptake will be reported separately.

CRAFTS (1961) described the structure and composition of boundary layers of leaves. He suggested that the cuticle may be somewhat spongelike with water and very hydrated pectins in the pores. Under conditions of high humidity, these pores would fill to capacity with an aqueous phase and thus extend the water continuum of the leaf as far as the surface which would then become permeable to solutes. Authors quoted in the introduction have considered the influence of increased humidity on the drying period of the applied drop and on the concentration of the applied solution during the drying process. In the experiments reported here, complete apparent drying of the drop occurred after or within the first hour after treatment at 23 °C and 40% RH. Although slower drying occurred in all cases where the plants were enclosed in bags, this was irregular and no conclusion could be drawn from these observations. In a separate series of experiments, the treatment drop was regularly refed with 0.005 ml of water or CsCl carrier to avoid its drying out without changing its area of contact with the leaf blade. This treatment was continued for 3 hours, air temperature being 23 °C an RH 40%. Although differences in uptake were effectively noted these were not significant whether the Cs concentration of the drop was decreased by addition of water or increased by addition of carrier.

Results presented indicate that Cs uptake by turgid bean leaves is more directly related to moisture conditions of the whole leaf than by that of the environment in general. The enhanced penetration and adsorption of Cs noted may be explained by an increased hydration of the cuticle causing its swelling and allowing a higher diffusion across it and/or more efficient functioning of ectodesmata in the foliar uptake process as suggested by FRANKE (1961). The increased penetration found when plants were pretreated by placing them in closed bags before application of the isotope, yet were kept during the experimental period at 23 °C and 40%RH *(figs. 2* and *7)* adds to this hypothesis.

Because of the short experimental period considered, the velocity of movement of the Cs* within the plants has not been studied intentionally under the different environmental conditions described. However, results available indicate that 6 hours after treatment the only significant increase in translocation

recorded was that in the plants treated at 30 °C and 40% RH. From the distribution pattern in all the cases considered here, it appears that the increased transport was due to enhanced downward phloem movement but not to any detectable reversal of the transpiration stream as noted by CLOR *c.s.* (1963).

From a practical point of view, Cs* reaching plant foliage under conditions of high humidity or still air would be taken up faster and accumulate more in the contaminated areas of plants. LEVI (1966) found that under constant conditions of 23 °C and 40% RH, a high adsorption of Cs could be expected in these areas for periods as long as 35 days after treatment of young beans, by which time pods would be maturing on the plants. The fraction circulating is however relatively small and influenced by environmental conditions only as far as these affect the general metabolic activity of the plant.

ACKNOWLEDGEMENTS

The skilled technical assistance of Messrs J. BEEK, K. BRANDT and J. B. M. WILMER is gratefully acknowledged.

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