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PLANTS AND THEIR RELATIONSHIP TO SOIL MOISTURE AND TRACER MOVEMENT

by

B. Perkins

ABSTRACT

To obtain a better understanding of the mechanisms for possible movement of radionuclides or other toxic materials from waste burial sites located in arid or semiarid regions, this experiment compared (1) change in soil moisture as a function of time and (2) tracer (Co, Cs, Sr, and tritium) movement for bare vs vegetated soils composed of crushed tuff.

During the course of two growing seasons, comparing vegetated with bare soils, plant transpiration processes significantly reduced the soil moisture. In the vegetated soils, most of the Co, Cs, and Sr remained in the region of original emplacement. In bare soils, Co and Cs underwent minimum movement but the peak concentration of Sr moved downward. For all tracers in the vegetated soils there was some evidence that slight amounts of tracer had been absorbed in the plant roots and brought to the surface through plant translocation processes. In all cases, there was no significant upward movement of Co, Cs, and Sr. For tritium, the vegetated soils, compared with the bare soils, retained the maximum inventories near the original emplacement location. Although all soils showed some tritium loss, it was greatest in the vegetated soils.

A literature review associated with the experiment indicated that plant species alone does not determine rooting depth, rate of transpiration, nutrient uptake, and other plant-associated processes. Environmental conditions are just as important as plant species and and must be included in modeling plant-related effects.

More data are needed on the effects of tracer concentration, soil water composition, variations in precipitation with time and intensity, evaporation rates, variations in soil composition, soil microorganisms, other invertebrates and vertebrates that inhabit soils, litter decay, and colloid movement on contaminant movement under conditions of unsaturated flow.

I. INTRODUCTION

Burial of wastes, including low-level radioactive wastes, in shallow land fills is one technique for their disposal. However, to achieve safe disposal, toxic material from the wastes must not move out of the burial site in such quantities as to pose a hazard.

Toxic elements in buried wastes may be mobilized and transported by mechanisms that include (1) leaching and (a) transport in soil water by diffusion or (b) movement, including capillary movement of the leachate in soil water as saturated or unsaturated flow, (2) movement of gases (either originally in the wastes or produced by decomposition), (3) plant uptake and translocation, (4) surface erosion (in particular, gully erosion) intersecting the waste, and (5) activities of burrowing animals or human intruders.

Plants growing on burial sites can both inhibit and promote mobilization of buried toxic wastes. Plants remove soil water from the root zone, thus reducing the potential for leaching and leachate movement. On the soil surface, plants decrease both water and wind erosion. In these respects, plants reduce mobilization of toxic waste.

Conversely, plants may increase mobilization. They allow for increased infiltration of moisture. Plants and their associated subsurface microbiological and invertebrate colonies affect the pH and other chemical processes, including decomposition, in the soil matrix. Plant roots create a difference in water potential, which moves water and trace elements toward the plant roots. Roots affect concentration gradients of trace elements in the soil water through plant root absorption of these elements. After absorption, plants may translocate trace elements, including toxic materials, in the plant system and may respire gases such as tritium.

Therefore, because plants growing on burial sites may have a strong influence on mobilization of toxic wastes, the purpose of this experiment was to compare, under controlled conditions, the changes in soil moisture and the mobilization and transport of representative tracers in bare vs vegetated soils.

II. LITERATURE REVIEW

A. Purpose

In order to place the present experiment in the context of the general knowledge afforded by various fields that it covered, a brief literature review will be summarized in this section.

The present experiment covered three major areas: (1) the influence of plants on levels of subsoil moisture, (2) the influence of plants on tracer movement (Co, Sr, Cs, and tritium), and (3) tracer movement, specifically Co, Sr, Cs, and tritium, under unsaturated flow in bare soils.

B. Influence of Plants on Subsoil Moisture

1. Species

In relating species to transpiration rates, which, in turn, relates to soil moisture loss, wide variations between species have been noted. Certain plants have long been known to be especially large users of water. For example, Kiesselback et al. (1929) state "It is a well established fact that alfalfa requires more water per unit of dry matter produced than any other commonly grown field crop." Requirements for commercial crops are given in Table I.

Other species of plants may require even more water. For example, for phreatophyte communities, the plants may transpire 110 inches of water annually (Molz et al. 1974).

2. Roots

In relating plant transpiration to the region of the subsurface in which soil water is removed, plant root growth is important. Weaver and Clements (1938) report that factors influencing root growth are heredity, i.e., type of plant, and environment, including water content, aeration, soil temperature, soil structure, nutrients, and aerial environment. The depth at which roots remove water is also dependent upon moisture availability as a function of depth.

a. Heredity. Considering heredity for alfalfa, clover, and barley, Foxx and Tierney* found, in a review of the literature, the following for maximum and minimum rooting depths of these plants growing under field conditions.

Plant	Rooting Depth (cm) Maximum	Minimum
Clover (*Melilotus Spp.*)	152	85
Alfalfa (*Medicago sativa*)	3932	31
Barley (*Hordeum leporinum* and *Hordeum vulgare*)	198	12

TABLE I

WATER REQUIREMENTS FOR COMMERCIAL CROPS

Species	Weight of Water Consumed / Weight of Dry Matter
Alfalfa	800
Cotton	600
Oats	390
Wheat	380
Corn	268

Source: Kiesselback et al., 1929; Molz et al., 1974.

*This information provided by T. S. Foxx, 1983.

The shallow roots were, in general, associated with hardpan or clay soils.* These data not only illustrate the wide variability by species, but also indicate the variability within species just for the three types of plants grown in the present experiment.

b. Environment. Relative to the effect of environment on root growth, Weaver and Clements (1938) state "Sometimes the root variation is so great and the growth habit so profoundly changed that the roots are scarcely recognizable as belonging to the same species."

1. Soil. The work of Lamba et al. (1949) demonstrates, under both greenhouse and field conditions, the importance of soil, including type, texture, and aeration, in determining the type of root growth. Although poor soil conditions may inhibit growth, it should be noted that Weaver and Crist (1922) stated for native species growing on Sterling, Colorado grasslands "Thus, among the six species examined at this station, four had a working level below or well within the hardpan layer." For buffalo grass they report, "At Sterling the fine, well branched, fibrous roots penetrated the hardpan and extended into a very dry layer of gravel and small pebbles mixed with sand, many roots reaching a depth of over 5.5 feet." Thus, soil conditions alone may not be the limiting factor in root growth.

In a review of tree root growth, Lyr and Hoffman (1967) comment, "The results show that it is difficult to establish intraspecific rules of root development because site and soil conditions modify root formation to such a degree that peculiarities of the species are partly or entirely obscured." Huck (1977) reports similar results. Hermann (1977), in another study of tree roots, reports, "Inception, rate and cessation of root growth are governed by a complex array of constantly varying factors whose interplay is only imperfectly understood." The importance of mycorrhiza in the soil on plant growth has also been stressed (Trappe and Fogel 1977, Davidson and Christensen 1977).

2. Temperature. Temperature is also important in root growth. Weaver and Clements (1938) have noted that if other conditions are favorable, roots of various plants will grow at soil temperatures below 4.4°C and as high as 49°C. In a literature review of the growth of tree roots, Lyr and Hoffman (1967) found that root growth can continue longer than shoot growth and can go on after leaf abscisson. In some tree species, root growth can continue down to a minimum of 2°C. In the growth of *Atriplex confertifolia*, Fernandez and Caldwell (1977) found that the roots continued growth in the fall after shoot growth ended. In the spring, the start of shoot and root growth were at about the same time and occurred at a soil temperature of approximately 4.5°C.

Arctic plant roots can grow in soils that are cold enough to inhibit root growth in most temperate species but have a higher below-ground/above-ground biomass ratio than do temperate plants, thus compensating for the depressing effect of low soil temperature on rates of nutrient absorption (Chapin 1977).

In grasses in semiarid cool rangelands, it has been found that certain grass roots can grow at temperatures of 2°C. Where the species have grown also influences the temperature at which growth occurs. For *A. spicatum* primary roots of a collection from Morgan, Utah grew 10 times as fast at 2°C as a collection from Moscow, Idaho (Harris 1977).

3. Moisture Availability. Although root growth influences subsoil moisture, subsoil moisture also seems to influence root growth, with the process being extremely complex. For some species and conditions, it has been observed that a low water content within certain limits stimulates increased root development. For example, Lamba et al. (1949) report, "The roots of alfalfa, brome grass, and red clover penetrated more deeply the first season in all three soils when moisture was deficient." In other studies of various plants it has been found that in drier soils the length of the main roots may not increase but the development of secondary and tertiary branches increases (Weaver and Clements 1938). Of course, if the soil is too dry, the plant dies. Nedrow (1937) reports, "Greatest production of roots in relation to shoots occurred when competition was for water, and the soil consequently the driest." Lyr and Hoffman (1967) state for tree root growth, "In dry soils, roots have a tendency to grow toward more humid zones."

However, the increased production of roots to compensate for dry conditions may not always occur. In a study of grasslands, Marshall (1977) found that the proportion of total biomass production going below ground tended to be lower at the drier and wetter extremes than at intermediate water availabilities. Partitioning varied with the grassland, between grasslands, the extent of fertilization, etc.

In another study for arid regions, Ludwig (1977) states, "Root:shoot ratios are highly variable within

*This information provided by T. S. Foxx, 1983.

and between species. Root:shoot ratios do not increase with increasing aridity as has been suggested, in fact evidence indicates the reverse is true." He also indicates, however, that some desert plants can adapt their root systems to the environment in which they are growing.

4. Moisture Location. Plant root growth influences subsoil moisture and vice versa and plant roots appear to be able to withdraw water from selective depths. Experiments indicate that plant root water uptake can vary as a function of soil water content and depth. Weaver and Clements (1938) report that barley was grown in such a way that every 6 inches the roots in that region were sealed off from any water movement above or below that region. They state "When the crop was ripe it was found that the water had been absorbed from the several levels in the following amounts, beginning at the surface: 20, 19, 16, 16, 14, 12, and 11 per cent respectively, based on the dry weight of the soil." It was further shown that most of the water absorption during development of the grain (the last of the growing season) was carried on by the younger portions of the roots in the deeper soil. Similar results were obtained with various other plants. At times, surface soil moisture may be so low that the plant roots can not remove any moisture from this region. If the roots penetrate to deeper levels where moisture is available, water will be removed from these levels. Nedrow (1937) reports, "Deeply rooted forbs were able to produce their normal growth during a season of drought when no available moisture occurred in the first four feet of soil. After the roots were encased so as to prevent absorption to depths of 3 to 5 feet, they continued to develop normally, during a second summer, absorbing only in the deeper subsoil." Alfalfa has also been found to be productive by using water at depths as much as 30 feet (Kiesselback et al. 1929). It has been reported that more ^{14}C accumulated in roots of deeper layers of a mixed-grass prairie when water stress was greater (Singh and Coleman 1977). Teare (1977) reports, "Much of the uptake by any one root system may take place from a relatively small proportion of the total root zone."

Thus it can be concluded that, although the species is important in determining transpiration rates and maximum depths at which plant roots may remove soil moisture, environmental factors are so important in plant root development and in the rate and region of moisture removal that it is difficult to make any general rules to apply to a "generic" situation.

3. Biomass/Plant Leaf Area

In determining the effect plants have on soil moisture, it has been suggested that instead of relating species to transevaporation, biomass production (or leaf area) might be used. However, as expected, many factors influence the ratio of surface biomass production to subsurface water use. A plant can not produce more total biomass than moisture, nutrients, and energy allow. If any one of these factors is limited, water availability alone will not produce biomass. Therefore, plant species, combined with external factors, give a wide range of surface biomass production to subsurface water use ratios.

Wight and Black (1977) state, "On semi-arid grassland, dry matter production is governed by plant - soil - climate relationships, of which temperature, water, and nutrient availability are most dominant." In a study area near Sidney, Montana, dry matter production was measured annually for six years and it was found that water use efficiency (defined as kg dry matter/ha $\times$ cm H_2O) varied by a factor of approximately 1.7.

In a study of the manner in which biomass production is partitioned in seven North American grassland types between above- and below-ground production, Marshall (1977) found that the division of production varied within the grasslands, over the growing season, between growing seasons, and between grasslands! The range of values found for the portion below ground at peak standing crop ranged from 0.56 to 0.96. He states, "These values are higher than in most other biomass with the exception of some associations of the Tundra Biome."

In studies of warm weather grasses, the above-ground biomass has been compared to the amount of water used. The results for one study are given in Table II. The ratio of surface biomass production to water use was found to differ according to water availability and type of grass (Teare 1977).

4. Modeling

In the present experiment it would not appear that the species/soil water data nor the biomass production/soil water data can be extrapolated under any environmental conditions other than those present at the time of the experiment. In developing any model of water movement in burial sites, a range of values for transpiration and water removal as a function of depth by any given species must be used.

TABLE II

ABOVE GROUND BIOMASS, WATER USE, WATER USE EFFICIENCY, AND BELOW GROUND BIOMASS OF FIVE WARM-SEASON FORAGE SPECIES AS AFFECTED BY THREE SOIL WATER REGIMES, ALABAMA
(Modified after Doss et al. 1960, 1962)

Grass	Soil Water Regime[a]	Above Ground Biomass (kg/ha)	Water Use[b] (mg/ha)	Water Use Efficiency	Below[c] Ground Biomass (kg/ha)	Root[c] Depth (cm)
Coastal	W_1	14 443	2702	5.15	7048	190
Bermuda grass	W_2	14 633	5107	2.87	9300	168
	W_3	15 903	5568	2.86	9606	135
Common	W_1	10 615	2725	3.90	5348	203
Bermuda grass	W_2	11 769	5148	2.29	3346	196
	W_3	12 694	5316	2.39	4872	132
Pensacola	W_1	10 765	2865	3.76	3464	152
Bahia grass	W_2	11 637	5196	2.24	3430	130
	W_3	12 252	5464	2.24	2910	122
Lespedeza	W_1	7 308	2624	2.79	4028	130
sericea	W_2	7 980	4751	1.68	3300	107
	W_3	7 778	5077	1.53	4720	99
Dallis grass	W_1	5 333	2278	2.34	4436	122
	W_2	6 966	4290	1.62	4209	114
	W_3	7 255	4512	1.61	5688	89

[a]Irrigated at 85% soil water (SWD) (W_1), 65% SWD (W_2), and 30% SWD (W_3).
[b]Mean of 3 years.
[c]Soil core samples.

Source: I. D. Teare

C. Influence of Plants on Tracer Movement

In the literature review covering the influence of plants on mobilization of trace elements (particularly radionuclides), many factors were indicated as having an effect. Some of these will be discussed in the following paragraphs.

1. General Considerations

Twenty elements are believed to be needed for the growth of at least some plants. These include C, H, and O obtained from the air and water, and N, P, K, Ca, Mg, S, Fe, Mn, Mo, Cu, B, Zn, Cl, Co, V, and Si, which are mainly absorbed by the plant root. Nutrients arrive at the root surface either by mass flow or diffusion. It is believed that nutrients that are at relatively high levels in the soil solution move to the root mainly by mass flow, whereas nutrients at relatively low levels in the soil solution move to the root by diffusion. Mass flow may bring more nutrients to the root than the root can absorb, which results in accumulation and back diffusion. The same accumulation/back diffusion occurs for transported trace elements that the root does not remove. In

addition, plant roots may absorb trace elements that are not nutrients but some of which may "act chemically" like nutrients (Barber 1977, Elgawhary et al. 1972, Menzel 1965). Uptake of particular nutrients and trace elements can vary with the species (Menzel 1965, Myers 1960).

In analyzing crop plants, approximately 60 elements have been positively identified. Robinson and Edgington (1945) report, "Very little is known of the minor element composition of many plants and plant parts, such as tree leaves, mosses, shrubs and wild grasses, that have modified the chemical composition of great areas of soils."

Plants cycle the nutrients and other trace elements through the plant and back into the environment. Return of elements to the subsurface includes exudation/leaching processes, ingestion by soil dwelling herbivores, and root death and decay. Elements are deposited on the surface soil through loss of leaves and branches (litterfall) and canopy leaching. Trace elements in the plant material are ingested by surface-dwelling herbivores (Cox et al. 1977).

Plant roots change the nature of the soil. Uptake of cations and anions causes pH changes in the soil around the root. Roots also change the bulk density of the soil near them, changing nutrient concentrations and diffusion rates (Barber 1977).

Roots release soluble materials (root exudates) consisting of low molecular weight organic compounds and inorganic ions into the surrounding soil. These, in turn, influence soil microorganisms, higher plant interactions, and nutrient cycling (Smith 1977).

Also present in the soil, influenced by the exudates and, in turn, influencing the soil plant environment, are fungi and other organisms forming mycorrhizal associations. Mycorrhizal fungi are believed vital for uptake and accumulation of ions from soil and translocation to hosts. They produce enzymes, auxins, vitamins, cytokinens, and other compounds that increase rootlet size and longevity and they absorb and translocate water to the host (Trappe and Fogel 1977).

Decaying plant material may increase the mobility of certain radionuclides and other trace elements by producing complexing agents or cations that tend to displace those adsorbed on the soil. On the other hand, decaying plant material furnishes a major part of the exchange capacity in many soils, which, in turn, favors retention (Menzel 1965).

Thus, it would be expected that if trace elements, including radioactive elements, are found in soils in which plants are growing, the plant systems will have an effect on movement. Specific studies on uptake of radionuclides by plants were included in the literature review.

2. Uptake and Translocation

Because of the possibility of radionuclide uptake and concentration from the soil and surface environment into plant leaves and fruits, there have been a large number of studies of plant uptake of radionuclides deposited on a plant's exterior surface, deposited on the ground surface, and located in the plant's root zone. These studies indicate the importance of soil type, chemicals in the soil, nutrient availability, species, age of species sampled, part of plant sampled, and rainfall on uptake (the same parameters that were found to influence plant growth). The reader is referred to Garland et al. 1983, Cummings et al. 1971, Handley 1973, Francis 1978, Squire 1966, Russell 1963, Christenson and Fowler 1961, Corey et al. 1983, Lassey 1979, Nishita 1962, and review articles by Nielsen (1981) and Menzel (1965).

a. Cs, Sr, and Co. Because Cs, Sr, and Co were the soluble salt tracers used in the present experiment, the literature was searched for information on uptake and translocation of these specific elements.

Menzel (1965) presents a summary (see Table III), indicating the relative concentration factor for many elements, including Co, Cs, and Sr. Of the three elements, Sr appears to have the greatest uptake, with Co being less than Sr and Cs less than Co. Menzel (1965) cautions, "Concentration factors for each element are found to vary over a wide range with changing soil and plant combinations."

Menzel (1965) has also noted that the concentration can vary, depending on the particular part of the plant (i.e., leaf, fruit, stem, and root) or even within a specific part (i.e., leaf margin or leaf vein). More recent studies, for example Garland et al. (1983), also note the variation of uptake, depending on species and rooting behavior.

For Cs, soil types appear to be important in determining plant uptake, with sandy soils, with their lower fixing capacities, having a higher plant Cs uptake (Cumming et al. 1971). In addition, Christenson and Fowler (1961) found that the depth at which Cs was found in the soil made a large difference in plant concentration factors.

Once an element is absorbed into the plant root it can follow various pathways for release back into the environment. For Cs, Russell (1963) reports "Cesium is readily absorbed by plants and like potassium is freely redistributed within them." Cox et al. (1977) state, "Radiotracer experiments with *Liriodendron* seedlings tagged with ^{134}Cs indicated that root processes (death and decay, exudation-

TABLE III

RELATIVE CONCENTRATION OF ELEMENTS IN THE FIRST CROP PLANTS GROWN AFTER THE ELEMENTS HAVE BEEN APPLIED IN WATER-SOLUBLE FORM AND MIXED INTO SURFACE SOIL

Relative concentration factor $\frac{\text{ppm in dry plant material}}{\text{ppm in dry soil}}$				
10–1000 Strongly Concentrated	1–100 Slightly Concentrated	0.1–10 Not Concentrated	0.01–1 Slightly Excluded	<0.01 Strongly Excluded
K	Mg	Ba	Cs	Sc
Rb	Ca	Ra	Be	Y
N	Sr	Si	Fe	Zr
P	B	F	Ru	Ta
S	Se	I		W
Cl	Te	Co		Ce
Br	Mn	Ni		Pm
Na	Zn	Cu		Pb
Li	Mo			Pu
				Sb

Source: R. G. Menzel, US Soils Laboratory, Soil and Water Conservation Research Division, Agricultural Research Service, US Department of Agriculture, Beltsville, Maryland.

leaching) contributed 67% of the total annual return of cesium to the soil by both above and below ground processes." Myers (1960) reports wide variations among species in Sr uptake and distribution. Table IV indicates the variability of Sr uptake among plant parts of four crops. In experiments on absorption of alkaline earth cations by barley roots, Epstein and Leggett (1954) found two modes of uptake for strontium: (1) exchange adsorption, in which the roots act as a cation exchange, and (2) active transport of the ions mediated by metabolizing processes. Russell (1963) indicates that Sr is not appreciably translocated. However, he reports, "Very different situations may occur, depending on whether entry occurs into roots or through the aerial tissues," whereas, Myers reports studies that indicate, "Foliar absorption does occur, but there is little translocation from the site of absorption downward in contrast to the rapid movement of strontium upward from root absorption." Some researchers believe that because of limited movement of strontium in a plant, grain should have less strontium than exposed leaves. In contrast, some experimenters have found accumulations of strontium in grain (Myers 1960). Mecklenburg and Tukey (1963) indicate that for Sr-contaminated foliage, if Sr is not transported to the roots from the leaves, root uptake may be due to foliar leaching into the ground.

Hill et al. studied cobalt in crops and weeds grown under uniform soil conditions. The variation in cobalt concentration was from 0.01 to 0.32 ppm. They concluded that the nature of the plant is probably the most important factor determining the degree of cobalt uptake (Meyers 1960).

Thus, in determining Sr, Cs, and Co absorption by a plant and the final fate of the element, many factors, including species, are involved. Meyers (1960) concludes that further research on the genetic mechanisms involved in conditioning physiologic processes would be fruitful.

b. Tritium. The literature was reviewed for information on tritium because tritium was also used as a tracer in the present experiment.

There have been a number of experiments conducted in several countries in which plant uptake of tritium in the form of HTO has been investigated. Modes of introduction of HTO included spraying, irrigation, and contaminated soil. These experiments indicated that HTO behaves very much like water. It

TABLE IV

THE UPTAKE OF Sr BY FOUR CROPS AS AN AVERAGE OF TWO TEMPERATURE TREATMENTS, TWO LEVELS OF pH OF THE MEDIUM, AND THREE TIMES OF HARVEST (AFTER JOHNS, 1955)

Plant Part	Counts/Min/Unit Dry Weight			
	Radish	Tomato	Corn	Bean
Root	2063	780	219	376
Stem	355	456	163	216
Leaves	257	309	74	167
Average	892	515	152	252

Source: W. M. Meyers (1960).

can be evapotranspired by the plant or bound as tissue-bound water or cell water and other easily exchangeable organic forms in the tissues. In addition, a small amount can be organically bound in the tissue in such a manner that it is not easily exchangeable.

Hakonson and Bostick (1976) measured tritium concentrations in bees and concluded that some part of the assimilated tritium originated in the nectar of plants that had absorbed HTO. It appeared that the plants had absorbed the tritium both from the air and from contaminated soil. Other studies indicate that the amount of tritium that undergoes uptake and evapotranspiration depends on the growing conditions, including concentration in the soil water, amount of soil water, air humidity, and temperature. Plant evapotranspiration was found to have a major effect on the behavior of tritium that falls as HTO on the soil surface. For more detailed information on specific studies, the reader is referred to the review article, "Tritium in Some Typical Ecosystems" (1981) and the references given in this review.

The literature review would indicate that the effect plants have on the movement of trace elements, including Sr, Cs, Co, and tritium, is dependent on plant species and environmental conditions. Therefore, the results of the present experiment are valid only for the conditions under which the study was conducted.

D. Tracer Movement

In addition to examining the effect plants might have on tracer movement, the present experiment involved movement of tracer both as soluble salts and tritium. Therefore, a literature review of tracer movement was undertaken.

1. Methods of Transport

For nongaseous elements, water is the chief transport medium for movement of ions and colloids in the soils. In arid climates, the soil water usually does not completely fill the pores of the soil, at least at shallow depths. Ions and colloids can move in the soil water either by mass flow with the soil water or by diffusion through the soil water. In considering mass flow with the soil water, the movement of water itself is of concern. Water movement is, in general, governed by the gravitational attraction downward (gravitation potential), properties of air/water interfaces (pressure potential), and attraction between water molecules and between water and soil particle molecules (absorptive potential). It is common practice to combine pressure and absorptive potential into a single quantity known as matric potential. Movement is influenced by the soil water composition (osmotic potential) and temperature (thermal potential). Flow is also influenced by the ability of the total medium to transmit flow at that particular moisture level. Although the gravitation potential usually predominates, there are times when the absorptive potential is sufficient to cause upward movement (capillary movement).

Various mathematical models have been derived for describing movement of water in situations where soil water does not completely fill the pores. For a further discussion of unsaturated flow, the reader is referred to Hamilton (1979), Hillel (1980), Gibbs and Baca (1981), and Kearl (1982).

If an ion is in the soil water, it may move in the liquid phase by diffusion if a continuous film of water exists between the soil particles. The type of soil, soil particle size distribution, and total volumetric soil water are some of the factors influencing film thickness and continuity. Diffusion is a concentration-controlled process, therefore, there is both downward and upward movement of the ion from regions of high to low concentration.

Another factor of primary importance in movement of soluble salts is the ability of the soil to retain soluble components by sorption mechanisms. This retention is related to ion species and is also dependent on physical and chemical characteristics of the soil, composition of the soil water, the presence of organics and biological organisms, volumetric moisture, and changes in the composition of soil

water moving through the soil column. Thus, the ability of a soil column to transmit contaminants (trace elements) in soil water is dependent on many parameters, some of which can vary with time. A particular trace element may be in the soil water in several different forms, including colloids, and these forms may behave very differently in moving through the soil column.

2. Specific Tracers Influencing Transport

a. Cs, Co, and Sr. In relating specifically to the present experiment, there appears to be little published data on movement of Cs, Co, and Sr through the Bandelier tuff. Experiments on cores of Bandelier tuff, which were conducted during the late 1950s, found that Cs was very tightly bound to the tuff and resisted leaching by any of the common agents. On the other hand, strontium was not retained on the tuff nearly as well as cesium (Christenson et al. 1958).

b. Tritium. Movement of tritium in the soil can occur both in the liquid and gaseous phases. When tritium is found as HTO in soil water, it will, in general, move similarly to an ion that undergoes no sorption (conservative tracer); HTO will diffuse in response to concentration gradients in soil water, as well as be carried by mass flow of the water. Incoming water containing no HTO will reduce the concentration of HTO in soil water. In addition, TO may exchange with hydroxyl groups in mineral lattices, clay mycelles, or organic matter; the HTO may enter into hydration reactions. Miettinen (1979) reports, "Compared with other variables — rainfall, gravity flow, diffusion, evapotranspiration — the exchange reactions have little effect however." Tritium may also move as a gas through soil pores in the form of TH, CTH_3, and HTO.

There have been several studies of the movement of tritium under various conditions. In general, although environmental conditions caused variations during the early parts of the experiments, tritium was removed from the upper soils by evapotranspiration as well as diffusion and gravity flow. Thus, short half-time values were observed. As the tritium moved downward, less could evaporate from the soil surface or be transpired by plants. It is reported that in deeper strata of dense soils, HTO is retained, except for natural radioactive decay, for years (Miettinen 1979).

III. EXPERIMENT DESIGN

The following factors determined the specific experimental design.

- Because semiarid and arid regions may be particularly suitable for toxic waste disposal, the experiment was conducted under climatic conditions of a semiarid region and unsaturated soil moisture.

- To limit variables, the experiment was conducted on level terrain. Thus, the effect of surface runoff and erosion caused by surface runoff were not included in the experiment.

- To reproduce field conditions as much as possible, large containers were used.

- The tracers were placed in the region of the root zone to simulate a worst case condition. To determine whether depth of tracer in the root zone affected movement, tracer layers were located at both 34 cm and 64 cm below the soil surface. Different types of tracers were used. To simulate elements that have high ion exchange capacity, cesium and cobalt salts were chosen, whereas, to simulate elements that might be more mobile, strontium was chosen. Radioactive isotopes of these elements are produced as fission fragments and are thus found in some radioactive wastes. Because, in the experiment, a minimum of radioactive material was desirable, nonradioactive salts of Co, Cs, and Sr were used. To achieve the desired analytical sensitivity, these salts were applied at higher concentrations than would normally be found in low-level wastes. Because tritium was expected to behave much differently than Co, Cs, and Sr, and because tritium is usually present in low-level wastes, tritiated water was included as a tracer.

- Waste backfill and trench caps often have different water contents. To study the effects of initial moisture, two different moisture conditions were used in the initial experiment emplacement.

- Because crushed tuff is the backfill and cap material in the low-level waste sites at Los Alamos, the experiment was conducted in crushed tuff.

- Common plants, at least one of which was known to be deep rooted, found on low-level waste burial sites in arid regions, were selected for planting on the vegetated soils. To establish and maintain these plants, supplemental watering was necessary. Supplemental watering, at least initially, would probably be needed on any shallow landfill to reduce erosion until native plants became established, and might be needed longer if native plants failed to provide adequate cover.

- To better define seasonal changes, the experiment was conducted over two growing seasons.

- To determine the effects of subsoil temperature on plant transpiration processes, soil temperature as a function of depth and season was measured.

The specific details of the experiment will be given in the succeeding paragraphs. The methods of data collection are described in the next section. The data obtained will then be given in the next section and will be used to make calculations. Finally, conclusions will be made as to the role plants may play in reducing soil moisture and in toxic waste mobilization.

IV. EMPLACEMENT

Sixteen containers were constructed by cutting 90 cm diam galvanized corrugated metal culverts into 153 cm long segments. Steel bottom plates were tack welded to the bottom of each container (Fig. 1). Holes for thermocouple leads were drilled and copper-constantan thermocouples were installed at the surface and bottom and starting at the surface at successive 1, 2, 4, 8, 16, 32, and 64 cm spacings.

A large pit, approximately 14 m long by 3.4 m wide by 1.5 m deep was dug into Bandelier Tuff at the Los Alamos Experimental Engineered Test Facility. The containers were positioned in the pit in a double row with approximately 2 m spacings between the center of each; material removed during pit construction was placed around the containers to within approximately 4 cm of the rim of each container (Fig. 2).

Aluminum neutron moisture probe access tubes 5.08 cm o.d., 0.026 cm wall thickness were placed in the center of each container. These tubes extended from the bottom to approximately 62 cm above the top of the soil surface.

Crushed Bandelier tuff from the original pit construction, screened to −1.2 cm, was mixed in a cement mixer with water to achieve the desired moisture level and placed in each container in compacted layers (for details on characteristics of Bandelier tuff, see Abeele et al. 1981). A level was placed on each aluminum access tube during filling in order to ensure that the tube remained vertical.

Upon reaching the desired layer for tracer emplacement in each container, 13.2 ℓ of water in which approximately 28 g of $CoCl_2$, 28 g of $Co(NO_3)_2 \cdot 6H_2O$, 9 g of CsCl, and 2000 g of $Sr(NO_3)_2 \cdot 4H_2O$ had been dissolved was sprinkled uniformly on the compacted surface, after which 0.55 $\times 10^{-3}$ Ci of tritium, added to 2.6 ℓ of water, was similarly applied. The container was filled with crushed tuff to within 4 cm of the top of the container.

Thus, the experimental variables were (1) location of tracer layer and (2) moisture content. These are indicated in Table V, whereas the way in which the containers were labeled (i.e., 1A, 1B, etc.) in the plot is shown in Fig. 2.

Barley is representative of a fast-growing annual suitable for growing in semiarid regions. Alfalfa is representative of a deep-rooted species. Both alfalfa and clover have been found growing on Los Alamos burial sites.* On July 7, 1981, 5 days after filling was completed, a mixture of Bavarian barley *(Hordeum vulgare)*, developed to be grown at high elevations, Colorado red alfalfa (*Medicago sativa)*, and yellow sweet clover (*Melilotus officinalis)*, seeds were applied to the containers receiving the vegetated treatment, noted as B in Fig. 2. The corresponding paired containers noted as A were left bare. The seeds were then covered with approximately 1-2 cm of topsoil/peat moss and a 0-46-0 triple superphosphate (0% nitrogen, 0% potash, and 46% phosphoric acid) fertilizer was sprinkled on the surface. On June 1, 1982, 100 mℓ of fertilizer per container was sprinkled on uniformly. No other fertilizer additions were made.

V. METHODS

A. Supplemental Moisture

To maintain a good plant cover, all containers received, in addition to the natural rainfall, supplemental moisture. Uniform distribution of this supplemental moisture was achieved by placing a tight-rimmed disperser, in which holes had been

*This information provided by T. S. Foxx, July 1983.

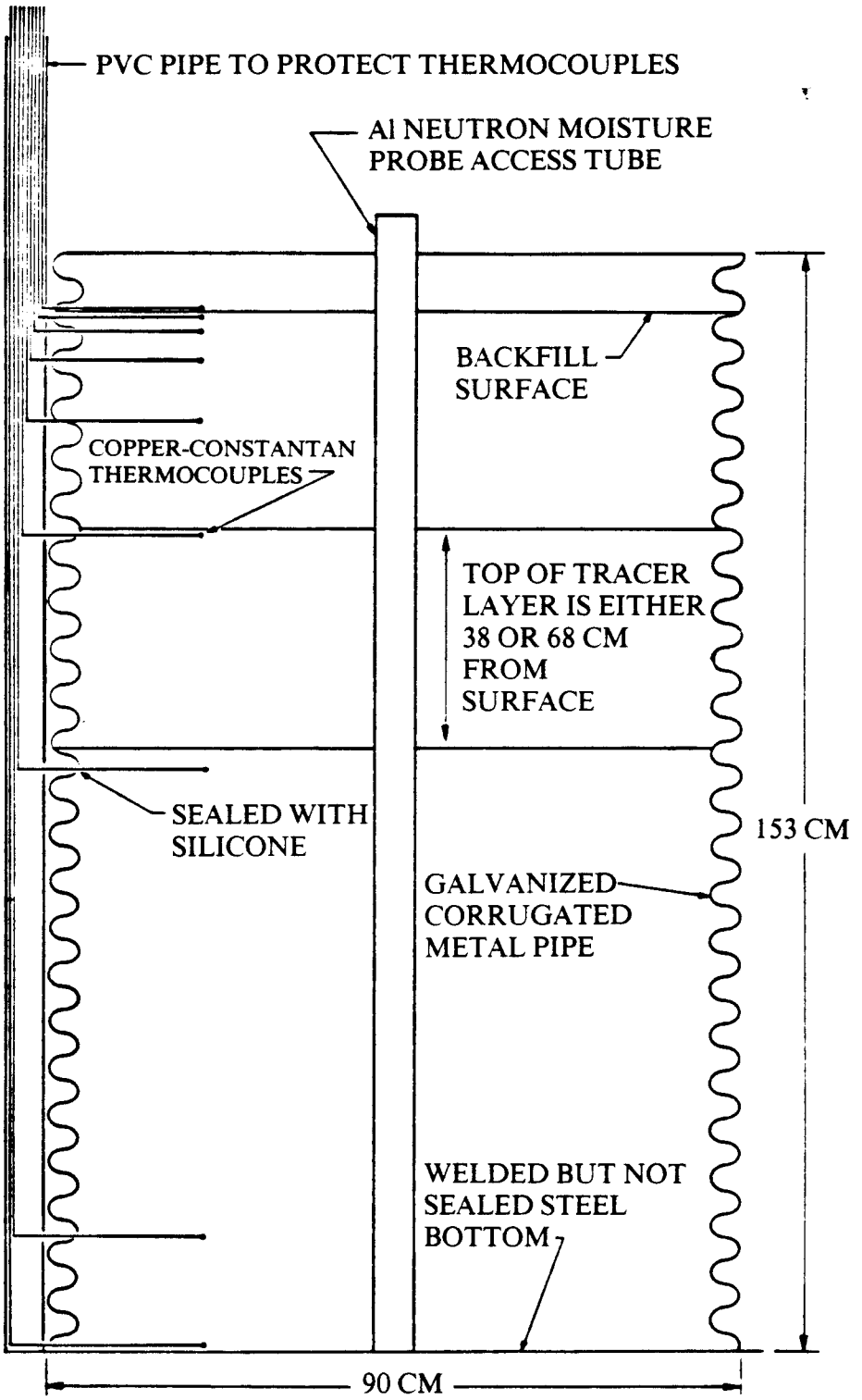

Fig. 1. Container layout.

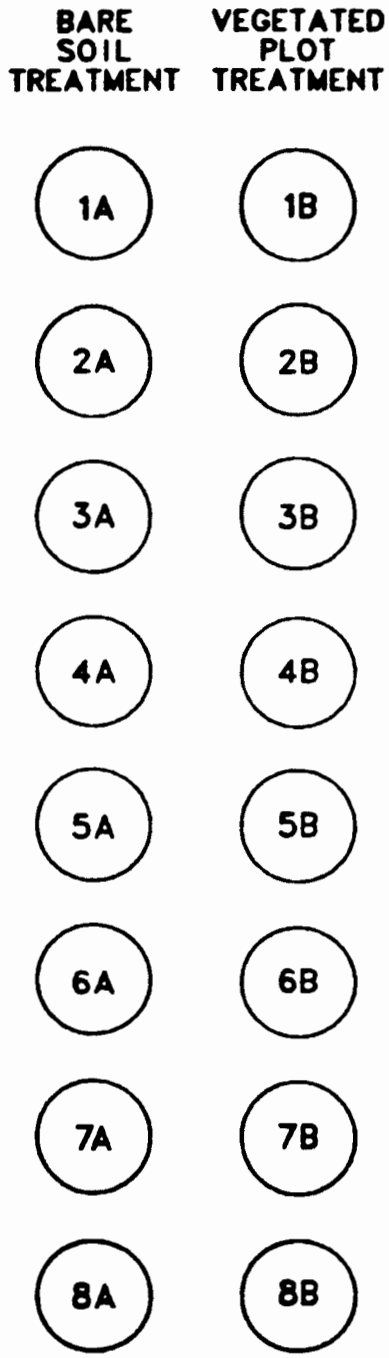

Fig. 2. Layout of experimental plot.

TABLE V

VARIABLES IN FILLING THE CONTAINERS

Container Number	Target Initial Moisture Per Cent Saturation	Depth from Container Rim to Top of Tracer (cm)	Plant Cover
1A	25	38	No
1B	25	38	Yes
2A	25	38	No
2B	25	38	Yes
3A	25	68	No
3B	25	68	Yes
4A	25	68	No
4B	25	68	Yes
5A	50	38	No
5B	50	38	Yes
6A	50	38	No
6B	50	38	Yes
7A	50	68	No
7B	50	68	Yes
8A	50	68	No
8B	50	68	Yes

uniformly drilled, over each container before the addition of the desired amount of water. The amount of natural precipitation was obtained from a rain gauge located next to the experimental site.

B. Soil Temperature Measurements

Soil temperature data were obtained regularly by using an Omega compensator in conjunction with a millivolt meter and recording the meter readings at each thermocouple level for all the containers. Temperatures were then read off the standard millivolt/temperature tables for copper-constantan thermocouples using an ice bath reference junction.

Before installation, each thermocouple was checked by placing each of the ends in an ice bath and boiling water, reading the emf, and making the appropriate correction for the elevation at Los Alamos. Since an Omega compensator, rather than an ice bath, was used as the reference junction for taking the actual measurements, there was some question as to whether the Omega would perform properly at winter temperatures. Therefore, when the outside temperature was 2°C, the same type of thermocouple compensator arrangement was set up outside. One end of the thermocouple was placed in boiling water and the emf measured. The compensator and associated equipment was then brought inside, allowed to warm to room temperature, and an emf again measured. In both cases, the standard emf was measured for the elevation of Los Alamos and no difference was noted between operation at room temperature and 2°C. It was concluded that no errors resulted from using the compensator at low temperatures.

C. Neutron Moisture Gauge Determinations of Soil Water Content

The instrument used for detecting soil moisture was a neutron moisture gauge. The neutron probe of this instrument was positioned directly on top of a series of 20, 50, 80, and 110 cm long aluminum spacers inserted into the Al access tube. The neutron probe had its detector/source module 9 cm above the bottom of the probe and this point has been used as the center for the moisture measurements (see Fig. A1). The probe was attached to a scaler conversion instrument with a direct readout of soil moisture as per cent by volume.

The errors in making the measurements included the following:

(1) Integration of Soil Moisture

A neutron moisture probe does not respond to moisture at the exact position of the probe because the instrument detects scattered neutrons, and this scattering takes place over a finite region. Thus, the probe is an integrating instrument, giving an indication of the hydrogen (water) content of a finite area surrounding the probe, with the size of the area inversely proportional to the volumetric moisture. Previous experiments indicate that all the neutrons should be contained within a maximum 30 cm radius.* Therefore, no measurements were taken 29 cm below the bottom and 30 cm above the top of the containers.

(2) Neutron Absorption

In the present experiment, aluminum tubes and spacers were used to reduce neutron absorption or scattering.

(3) Instrument Drift

Before any moisture readings were taken, a standard count was obtained using a hydrogen standard and all counts were divided by this standard before the conversion to per cent moisture was made. This procedure would correct for any instrument drift; however, during the measurements, no change in the standard was detected.

(4) Calibration

The calibration supplied by the manufacturer was checked at one data point (~12%). A large 3.0 m diam caisson was filled with moist, compacted, crushed tuff. A port in the caisson was used to obtain a core of known volume. The moisture content of this core was determined experimentally, giving the moisture as a per cent by volume. The hole left by collection of the tuff sample was cased with a thin-walled aluminum tube identical to the tubes used in the containers. The neutron probe was then inserted into the tube and moisture readings were determined at regular intervals along the tube. The average moisture reading of the neutron probe as given by the manufacturer's calibration was the same as that determined by coring. However, calibrations at other volumetric moistures were not obtained.

At low moisture levels and, thus, low counting rates, counting errors ran as high as 10%. Considering all errors and the reproducibility of the data under similar conditions, it is felt that total errors in absolute moisture measurement were approximately 20%.

*This information provided by J. W. Nyhan, April 1983.

D. Collection and Analysis of Plant and Soil Samples

When the experiment was terminated on October 15, 1982, plant mass was collected and cores of soil to determine the distribution of tritium, Sr, Cs, and Co were taken. The techniques used for collection and analysis are described in the following paragraphs.

1. Plant and Litter Collection

When the experiment was terminated on October 15, 1982, the green and brown plant material and litter from each container was collected separately and placed in labeled plastic bags. It is possible that some soil was also collected with the litter because of soil movement into the litter. The collected material in each category for each container was then weighed without drying or any other treatment.

2. Coring

After the plant and litter material had been recovered, the top of each container was covered with plastic, which was tied to the top rim. This cover prevented any additional moisture from entering or leaving and prevented surface contamination while the containers were being excavated.

To avoid cross contamination from vertical coring, horizontal cores were taken first. The original pit into which the containers had been placed was reexcavated and each container was marked at the tracer layer, 4, 8, 16, and, for the lower tracer, 32 cm above the tracer layer and 4, 8, 16, 32, and 64 cm below the tracer layer. A 2.5 cm diam hole was drilled through the wall of the container at each mark and just below the location of the top soil layer and the bottom. A 2.06 cm i.d. steel coring rod was then driven horizontally across the container at each drilled location. Each core sample was placed separately in a labeled plastic bag and stored in a freezer until ready for analysis. A level was frequently placed on the rod during coring to ensure that the core was horizontal. To avoid any possible cross contamination, the rod was washed with deionized water between coring each horizon.

To determine a total tritium inventory after horizontal coring was complete, each container was also cored through the entire vertical depth with a 2.06 cm i.d. steel rod in a manner similar to that used in the horizontal cores. Again, each sample was labeled, separately bagged, and placed in a freezer.

In addition to the cores, just after a container was removed from its location in the large pit, a sample of tuff underneath each container was collected and stored in a freezer. It was noted that after the containers were removed from the pit, the tack welded plate of the A containers became damp, indicating some drainage from these units after removal.

The errors in sampling include those caused by coring techniques and sample preparation. Original misplacement of the tracer layer, mixing the tracer with soil, or misplacement of a horizontal core near the tracer layer would give a significant error. During coring, vertical movement of the rod at or near the tracer layer would be expected to have a large effect, particularly if a core sample was not well mixed before analysis. From the scatter of data points, it would appear that slight misplacement of the tracer layer and misplacement of cores was probably the major source of error in analyzing for movement of tracer. Since tracer concentrations in the roots, which were also contained in the core sample, would be expected to be different than in soil, this was a source of error.

Because of the care taken in washing equipment, cross contamination should not have occurred during sample preparation. Because the results from analysis of fill under the containers were not expected, new samples were prepared using new equipment. The results from the analysis of this second set of samples from below the containers are given in Tables XI through XVI and show no significant differences from the first set.

3. Tritium Analysis

All the cores and selected samples from under the containers were submitted for unbound tritium analysis. Approimately 5 mℓ of water was removed from each sample and counted for tritium.

The equipment of the first laboratory was more sensitive, with lower internal background than the second laboratory. Because of internal contamination problems, the uncertainty for data from the second laboratory is approximately ±2500 pCi/ℓ and, therefore, several of the cores analyzed by the second laboratory have been indicated as having nondetectable tritium because the levels were below 2500 pCi/ℓ (see data presentation).

To determine if any tritium had been added during the experiment, a sample of snow that had fallen at the experimental site and the water used for supplemental watering was analyzed for tritium. The supplemental water came from deep wells and would be expected to be very old and low in tritium. These waters had no detectable activity within the uncertainty limits of the second laboratory.

After internal clean up procedures had been undertaken at the second laboratory, the vertical cores were analyzed. The error associated with these measurements is approximately 200 pCi/ℓ.

4. Co, Cs, Sr Analysis

After removal of the sample of soil water for tritium analysis, the horizontal cores were oven dried at 105°C for 24 hours. From each dry core sample, 50 g of soil was randomly collected, placed in a plastic bottle, and ground (using teflon rods to prevent contamination). A small portion of the ground sample was then placed in a sample holder and submitted for analysis of Co, Cs, and Sr by neutron activation at the Los Alamos reactor. Further details on sample analysis by neutron activation are given in Gladney et al. (1980) and Gladney et al. (1982).

In addition to determining Sr, Cs, and Co concentrations by use of neutron activation, a representative set of samples was also analyzed using chemical techniques. For these analyses, the total sample from each core remaining after neutron activation was run through a split sampler twice to achieve a 5 g representative sample. The sample was then ground, using an alumina mortar and pestle, to less than 100 mesh. Approximately 1 g of the sample was mixed with 4 g of Na_2O_2 and fused in a zirconium metal crucible. The material was then mixed with water and centrifuged, thus separating the Cs with the liquid and retaining the Sr and Co in the solid material. The liquid was analyzed for Cs using atomic absorption. The solids centrifuged from the liquid were dissolved in HCl and the resultant solution was analyzed for Sr and Co using an ICP with a Be internal standard. The results of the chemical analyses are given in parentheses in Tables XI through XVI.

VI. DATA

In this section, the collected data will be presented. Calculations using these data will then be discussed in the next section.

Table A-I indicates date and centimeters of natural and supplemental water. Each container received a total of 52.8 cm of water as natural precipitation and 66.0 cm as supplemental.

Table VI gives a summary of the average temperature readings at approximately monthly intervals from the start of the experiment (July 1981) to the end (September 1982). Some of the data include morning and afternoon temperatures to indicate the extent of variation of temperature on a daily basis.

The moisture data used in the moisture calculations and in the general conclusions were (1) at the start of the experiment, July 3, 1981, (2) just before plant growth had begun to remove soil water, August 3, 1981, (3) when plant growth became dormant, November 3, 1981, (4) when plant growth began in the spring, March 1, 1982, and (5) when the experiment terminated, October 15, 1982, and are given in Table VII. Figures 3 through 10 indicate in graphical form the moisture profile at these five different times. The complete data set for soil moisture is given in Appendix B.

The results of plant biomass production are given in Table VIII. It was difficult to separate green from brown material and the total weight of green and brown material is included to give a more representative weight of plant mass.

The concentrations of unbound tritium in the soil water in the horizontal cores and soil beneath the containers for the tracer at 38 cm from the container rim are given in Table IX and for the tracer at 68 cm from the container rim in Table X. As indicated in the section on methods, the analysis was done by two different laboratories; data from the first laboratory are noted with an asterisk. The data are plotted in Figs. 11 through 14.

The results for Co are given in Tables XI and XII, for Sr in Tables XIII and XIV, and for Cs in Tables XV and XVI. Figures 15 and 16 graph the concentration distributions of Sr, Figs. 17 and 18 graph the distributions of Co, and Figs. 19 and 20 graph the distributions of Cs. To ensure that no additional tracer elements were added during supplemental watering, a sample of the water was analyzed for Sr, Cs, and Co. These results are given in Table XVII.

VII. CALCULATIONS

The data can be used to calculate (1) water content in different intervals of each container and total water content as a function of time, (2) moisture changes, and (3) tritium inventories.

A. Water Content

The most interesting intervals for calculations involving soil moisture are (1) start of the experiment, July 3, 1981, (2) just before the plant roots began actively withdrawing soil moisture, August 3, 1981, (3) end of 1981 growing season, November 3, 1981, (4) beginning of 1982 growing season, March 1, 1982, and (5) termination of the experiment, October 15, 1982.

To calculate moisture content in a given layer (interval) of the container, each container was divided into the top, T, (which extended from the top to a depth of 15 cm), the intervals from 15 to 45 cm, 45 to 75 cm, 75 to 105 cm, and 105 to 135 cm, and bottom, B, (from a depth of 135 to 149 cm). Moisture measurements at the midpoints of the intervals were assumed to give an average of the moisture for that interval. It was also assumed that the moisture measured at 30 cm below the surface was similar to that at the top, and the moisture measured at 120 cm below the surface was similar to the moisture at 135-149 cm. The water content of each interval was then calculated and added together to give total water in the container (Table A-II).

B. Moisture Changes

From moisture content in each layer of the container, moisture changes in these layers in the time periods July 3 to August 3, 1981, August 3 to November 3, 1981, November 3, 1981 to March 1, 1982, March 1 to October 15, 1982, and July 3, 1981 to October 15, 1982 can be determined (Table A-III).

C. Tritium Inventory

The total tritium inventory (Table XVIII) in each container was estimated by taking the calculated total water in each container at the termination of the experiment (Table A-II) and multiplying by the tritium concentration measured in the vertical core samples.

To determine how the tritium inventory was distributed in each container, the container was divided into the intervals used in calculating water content. The water content of the various intervals at the termination of the experiment (Table A-II) were multiplied by the average tritium concentration as read at the midpoint of the interval from the tritium

TABLE VI

TEMPERATURE (°C) AS A FUNCTION OF DEPTH (cm) FROM SURFACE FOR BARE (A) AND VEGETATED (B) CONDITIONS

		0	1	2	4	8	16	32	64	150
7/14/81	A	19.5	17.0	15.5	15.5	18.0	21.0	20.5	20.0	19.0
AM	B	19.0	16.0	16.5	15.5	19.5	20.0	22.0	19.5	21.0
PM	A	36.0	31.0	26.5	22.0	20.5	18.0	21.0	18.0	20.5
	B	31.[illegible]	27.0	25.0	22.5	19.5	20.0	19.0	20.5	19.0
8/13/81	A	19.0	17.5	16.5	16.5	17.0	20.0	21.5	22.0	22.0
AM	B	19.5	17.0	17.0	17.0	17.5	20.0	21.5	22.0	21.5
PM	A	26.5	26.0	23.5	22.0	20.0	20.0	21.5	22.0	22.0
	B	23.5	22.0	22.0	21.5	20.0	20.5	21.5	22.5	22.0
9/15/81	A	14.0	13.0	12.0	12.5	13.5	16.5	18.5	20.5	20.5
AM	B	13.0	13.5	13.0	14.0	14.0	17.5	18.5	20.5	20.5
PM	A	22.5	21.5	19.5	18.5	16.0	16.5	18.5	20.5	20.5
	B	17.0	17.0	16.5	16.0	15.5	17.0	19.0	21.5	21.0
10/16/81	A	8.0	8.0	8.5	9.0	10.5	13.0	15.0	17.5	17.5
AM	B	9.0	9.5	10.0	10.5	11.0	13.5	15.5	17.5	18.0
PM	A	15.0	14.0	14.5	13.5	12.5	13.5	16.0	18.5	18.5
	B	11.0	11.5	11.0	12.0	11.5	13.5	16.0	18.5	18.5
11/18/81	A	10.5	10.5	9.0	8.5	7.5	9.5	10.5	13.5	13.5
PM	B	7.0	7.5	7.0	7.5	7.0	9.5	10.5	13.5	13.5
12/07/81	A	0.0	1.0	0.5	2.0	2.5	4.0	6.5	11.0	11.5
AM	B	0.5	1.5	1.5	2.5	2.5	4.0	7.0	11.0	12.5
1/4/82	A	−2.0	0.0	−0.5	1.5	1.0	3.0	4.0	9.0	8.5
AM	B	−0.5	−1.5	−1.0	0.0	1.0	3.5	4.0	8.5	9.0
2/24/82	A	3.5	3.5	2.5	4.0	4.0	5.0	4.5	5.5	6.5
AM	B	4.0	4.0	3.5	4.5	4.5	5.0	4.0	6.0	6.0
3/24/82	A	17.0	15.5	11.0	8.5	5.5	4.5	6.0	5.5	6.0
PM	B	9.5	8.0	6.5	5.5	4.5	5.0	5.0	6.0	6.0
4/21/82	A	12.5	14.0	10.0	10.5	8.0	10.5	11.0	10.0	10.0
PM	B	7.0	7.0	6.5	7.5	7.0	10.5	9.5	10.5	8.5
5/21/82	A	14.0	15.0	12.0	12.5	12.0	16.5	14.5	14.0	12.5
AM	B	12.5	11.5	11.5	13.0	13.5	16.0	13.5	12.5	11.5
6/11/82	A	26.5	25.0	24.5	24.0	22.0	21.0	20.5	17.5	17.5
PM	B	22.5	21.5	21.5	24.5	21.5	21.5	21.0	18.0	17.0
8/6/82	A	24.0	23.0	20.0	20.0	19.0	21.5	20.5	20.5	19.5
AM	B	18.5	18.5	17.5	18.5	19.5	20.5	20.5	19.5	19.5
9/28/82	A	19.0	19.0	15.5	15.5	14.5	17.0	19.0	20.0	20.0
PM	B	14.5	16.0	13.5	15.5	14.5	18.5	18.5	21.0	19.0

TABLE VII

SOIL MOISTURE SUMMARY SHEET

Container Number	30 cm Depth					60 cm Depth					90 cm Depth					120 cm Depth				
	1981			1982		1981			1982		1981			1982		1981			1982	
	7/3	8/3	11/3	3/1	10/15	7/3	8/3	11/3	3/1	10/15	7/3	8/3	11/3	3/1	10/15	7/3	8/3	3/1	11/3	10/15
1A	20.4	20.5	20.9	22.2	23.2	14.9	17.1	21.7	22.0	24.4	9.7	11.3	20.2	22.0	26.8	9.7	10.1	18.8	25.0	36.8
2A	18.5	18.9	20.8	22.0	20.5	18.0	18.3	21.0	22.6	24.6	14.4	16.8	18.4	24.6	27.6	11.2	12.4	19.0	23.8	34.8
1B	19.1	22.2	5.2	14.9	6.5	19.7	19.4	12.0	11.4	9.2	12.2	14.4	15.9	12.5	5.9	13.8	14.1	13.8	13.7	6.4
2B	19.3	19.8	4.3	15.5	5.2	19.0	20.0	11.5	12.2	11.9	10.1	15.4	14.8	12.7	11.5	9.9	10.3	11.8	11.6	10.3
3A	14.2	19.5	21.3	21.6	19.0	23.0	19.1	21.1	23.0	22.6	19.9	18.3	17.5	22.5	27.4	10.9	14.7	20.5	23.5	30.4
4A	19.4	21.1	20.1	23.1	20.3	18.4	18.7	20.4	21.6	23.1	16.5	16.5	17.0	21.7	26.5	10.7	13.0	19.6	22.5	32.0
3B	12.1	19.7	3.0	14.8	3.0	19.9	18.7	7.5	7.7	7.2	16.8	17.0	14.4	11.2	8.5	9.1	11.5	12.8	12.0	6.9
4B	16.3	21.0	4.0	14.5	3.4	14.1	14.4	6.9	7.6	8.0	16.1	15.5	14.2	11.4	11.2	11.2	11.5	11.3	11.3	11.7
5A	31.0	25.9	25.9	27.2	26.1	26.3	24.3	24.2	25.3	25.7	24.1	25.0	25.6	29.0	30.0	18.9	21.0	26.9	27.7	33.6
6A	27.5	24.6	25.5	24.9	23.8	24.0	21.5	23.2	24.2	23.6	19.6	22.1	23.0	26.6	28.6	22.4	23.8	26.9	27.6	30.0
5B	24.8	23.1	11.8	20.1	6.4	27.0	25.2	17.7	20.3	8.2	23.1	24.4	20.5	18.5	5.0	23.8	25.8	21.7	20.1	4.6
6B	24.7	22.1	7.3	19.3	6.4	28.9	23.7	18.4	19.2	10.8	22.3	23.2	20.5	17.8	6.7	21.1	22.5	19.4	17.8	5.6
7A	24.7	22.5	24.5	25.8	20.5	27.6	26.7	26.0	26.6	26.4	24.6	22.7	22.8	23.7	24.8	21.8	21.8	25.1	25.8	28.7
8A	27.3	22.5	24.1	25.4	21.3	28.7	26.0	26.6	26.3	26.0	25.8	24.4	24.6	25.4	26.0	25.5	25.8	30.2	30.3	30.7
7B	26.0	24.8	4.7	18.1	5.3	24.9	24.3	13.7	14.4	9.0	25.1	25.4	24.1	18.9	8.0	23.3	24.4	20.8	17.8	5.4
8B	25.7	25.5	4.7	10.2	4.1	23.9	23.0	12.3	10.2	9.0	25.0	24.4	20.3	16.9	7.3	22.0	22.1	18.3	17.0	6.3

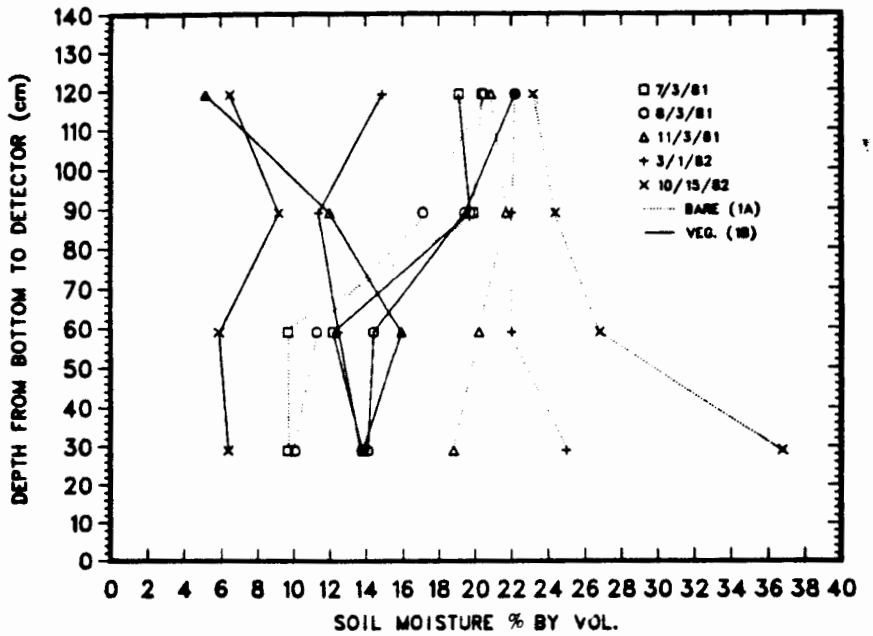

Fig. 3. Containers 1A & 1B moisture distribution as a function of time. Initial moisture, 25% saturation; tracer level 38 cm from rim.

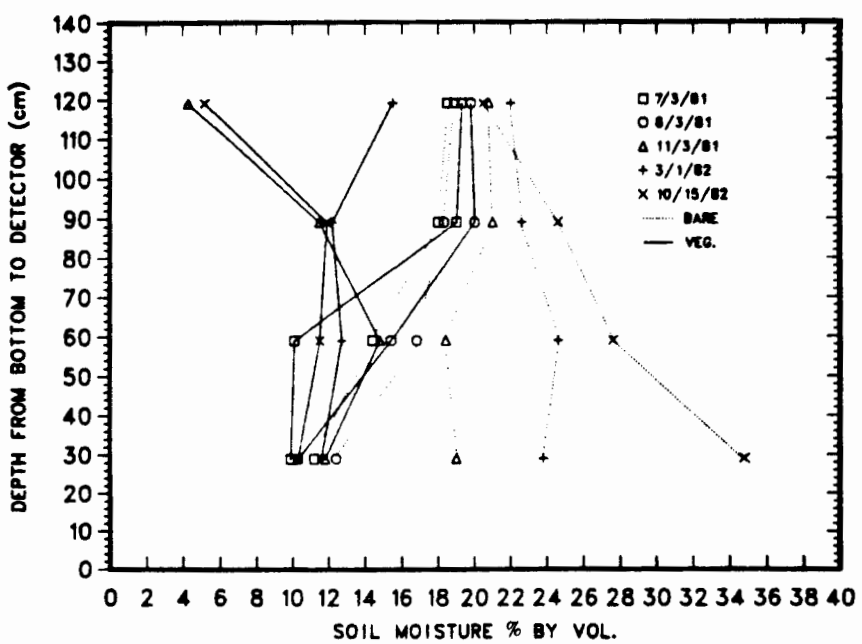

Fig. 4. Containers 2A & 2B moisture distribution as a function of time. Initial moisture, 25% saturation; tracer level 38 cm from rim.

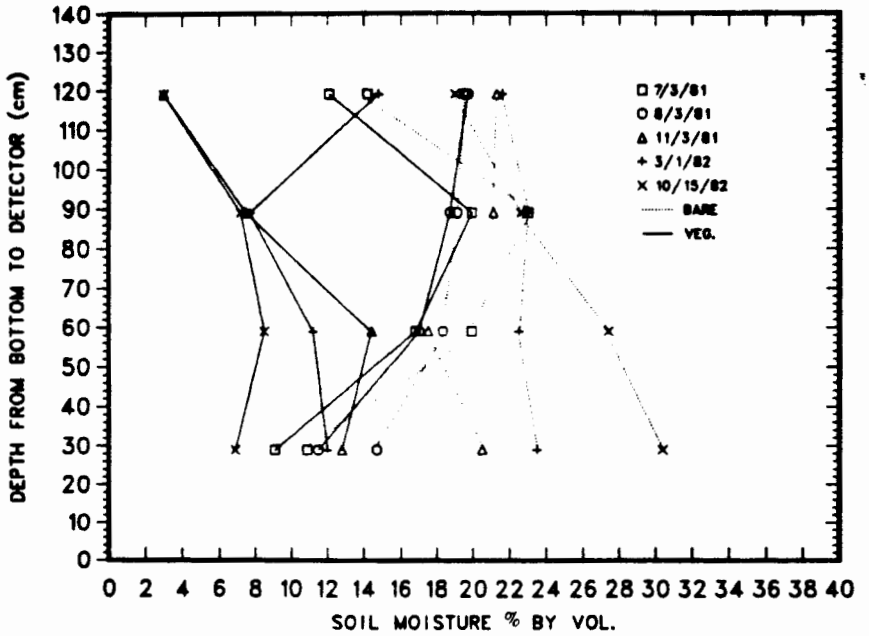

Fig. 5. Containers 3A & 3B moisture distribution as a function of time. Initial moisture, 25% saturation; tracer level 68 cm from rim.

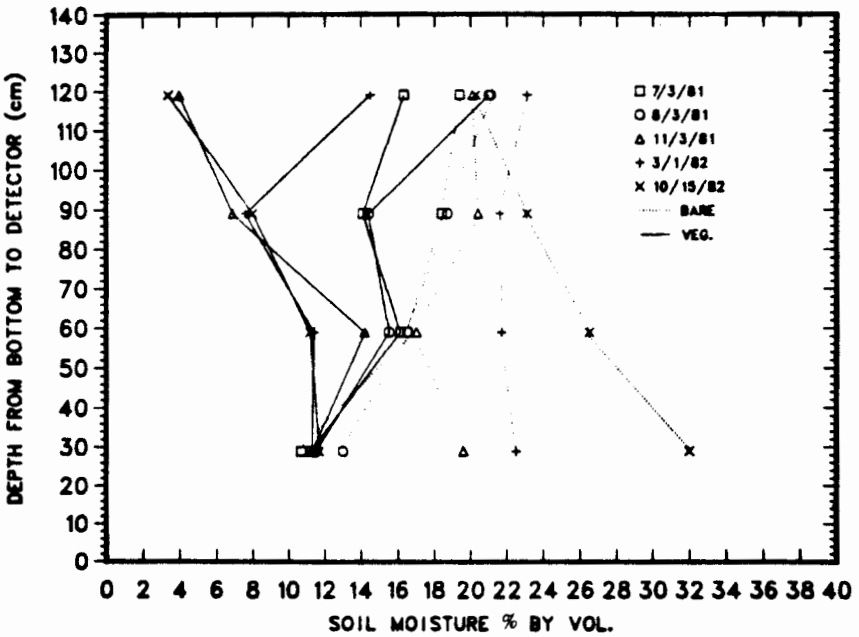

Fig. 6. Containers 4A & 4B moisture distribution as a function of time. Initial moisture, 25% saturation; tracer level 68 cm from rim.

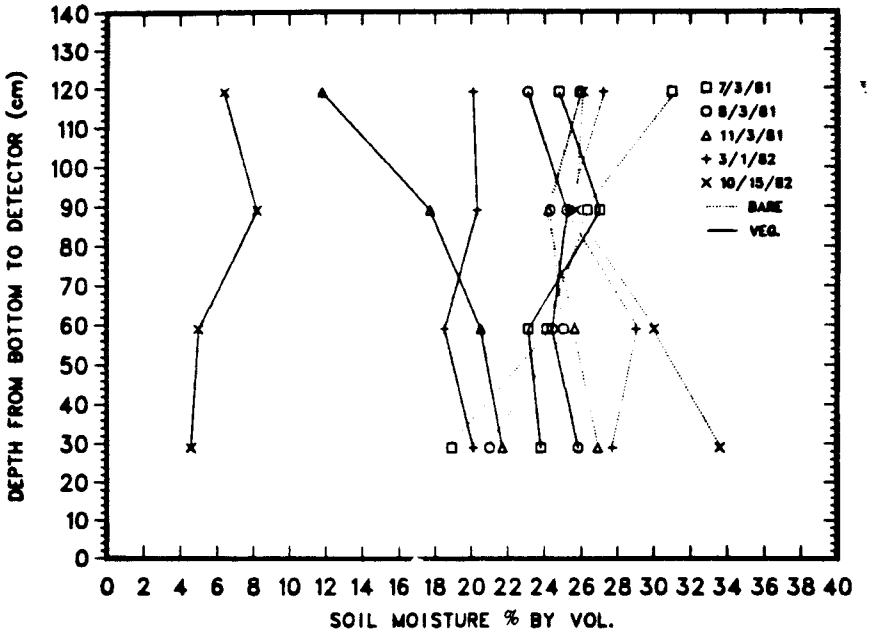

Fig. 7. Containers 5A & 5B moisture distribution as a function of time. Initial moisture, 50% saturation; tracer level 38 cm from rim.

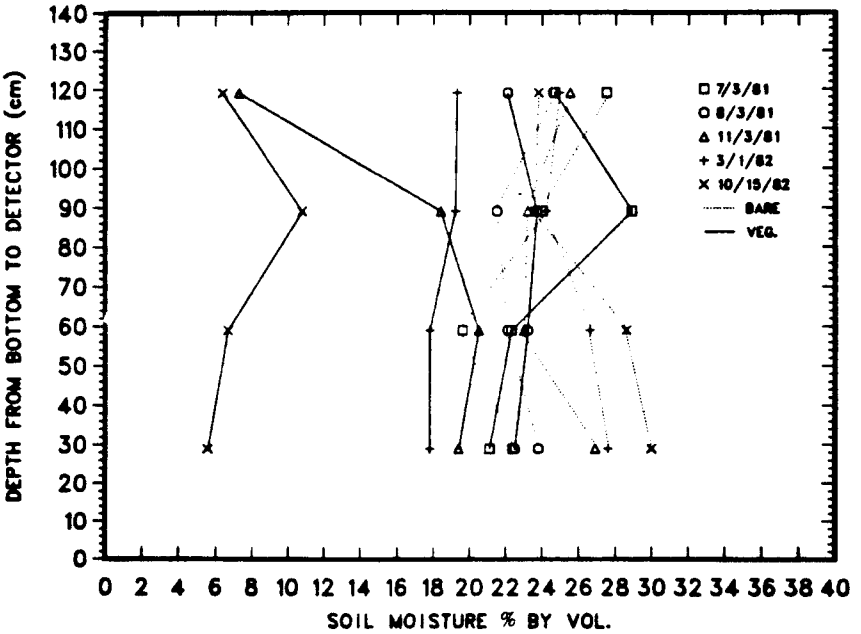

Fig. 8. Containers 6A & 6B moisture distribution as a function of time. Initial moisture, 50% saturation; tracer level 38 cm from rim.

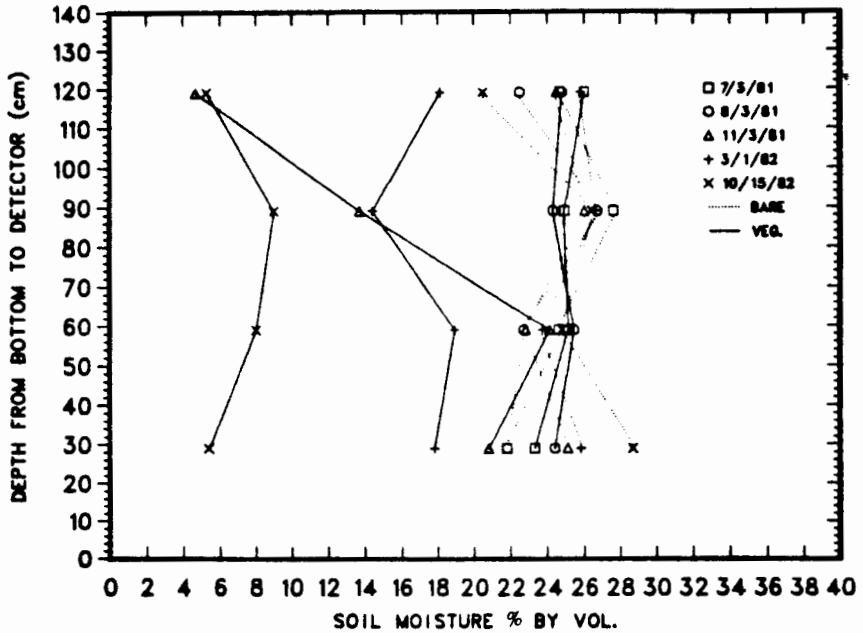

Fig. 9. Containers 7A & 7B moisture distribution as a function of time. Initial moisture, 50% saturation; tracer level 68 cm from rim.

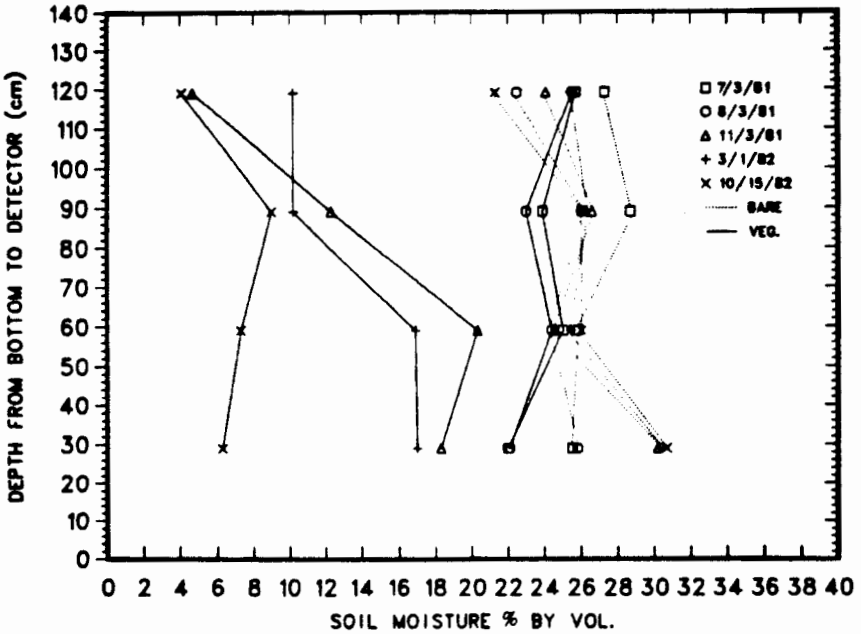

Fig. 10. Containers 8A & 8B moisture distribution as a function of time. Initial moisture, 50% saturation; tracer level 68 cm from rim.

TABLE VIII

WEIGHT OF VEGETATION PRODUCTION IN GRAMS

Container	Green	Brown	Litter	Green and Brown	Total
1B	352.3	195.4	1099.2	547.7	1647
2B	342.7	188.5	1275.1	531.2	1806
3B	297.1	176.4	949.2	473.5	1423
4B	263.2	132.7	1387.7	395.9	1784
5B	300.8	182.2	996.2	483.0	1479
6B	531.9	99.3	1112.8	631.2	1744
7B	277.3	209.1	925.0	486.4	1411
8B	378.5	92.0	1144.1	470.5	1614

distribution graphs. Results of these calculations are given in Table XIX. Bar graphs of some of the tritium inventory distributions are shown in Figs. 21-24. The data from calculating total inventory from the horizontal cores and vertical cores can be compared in Table XVIII.

D. Soluble Salt Inventories

Because the soil density is not known, it is not possible to calculate total inventories for Co, Cs, and Sr. If soil densities are the same, final total relative inventories for Sr can be calculated by integrating concentration as a function of depth to obtain ppm-cm (Table XX).

VIII. RESULTS AND CONCLUSIONS

The data and the calculations given in the preceding sections will be used to derive the results of the experiment.

A. Soil Temperature

The temperature data would indicate (1) down to approximately 4 cm below the soil surface, midday temperatures were lower for vegetated vs bare soils, (2) beginning in September, temperatures began to decrease throughout the soil column, (3) in the lower soil column, temperatures continued to decrease through February, (4) during March the upper soils began to warm, and by April 21, an increase in soil temperature was noted even at the 150 cm depth, (5) the maximum soil temperature at 150 cm was not reached during the second year until late summer, and (6) in the depth below 4 cm, there was little noticeable difference in soil temperature between bare and vegetated soils.

B. Effect of Plants on Soil Water

When the moisture data (Appendix B) of the vegetated containers are compared with those for the bare containers, it is evident that the vegetated containers began showing less moisture at the 30 cm depth on about August 7, and, by September 1, this difference had become very large. Seeds were planted on July 7 and plant roots had become active in withdrawing water at the shallow depth about a month after planting. At the 60 cm depth, a decrease in moisture for the vegetated containers was noted on September 1, whereas, at the 90 cm depth, a decrease in moisture was noted on October 29, with a slight decrease in relative soil moisture at the 120 cm depth. This information is summarized in Table XXI.

The calculations for moisture changes (Table A-III) can be used to indicate the effect plants have on moisture change as a function of depth and total moisture removed. Before the seeds sprouted and root development occurred, the dryer (1-4) containers (25% initial saturation) all had an increase in total moisture. The wetter containers (5-8) (50% initial saturation) all showed evaporation-drainage being dominant.

Once the plants were established, during the period August 3 to November 3, all the planted

TABLE IX

UNBOUND TRITIUM
(pCi/ℓ in horizontal core samples)

	Distance Above Tracer (cm)					Distance Below Tracer (cm)						
Container	Surface of Soil +34	+16	+8	+4	Tracer	−4	−8	−16	−32	−64	Bottom of Container −115	Soil Below Container
1A	ND	800*	ND	ND	3 600*	ND	ND	ND	70 721	917 567	3 350 000*	17 018
2A	ND	4800*	7 207	9 459	26 000*	29 730	41 892	125 630	475 225	2 703 600	2 380 000*	NSA
1B	336 846	1 163 000*	1 550 000	1 892 791	2 200 000*	2 229 277	2 444 142	2 714 862	2 271 169	747 296	45 300*	ND
2B	285 450	866 000*	1 104 954	1 679 728	2 020 000*	2 253 601	2 523 421	2 987 835	2 938 285	964 413	71 000*	NSA
5A	20 720	144 000*	239 300	309 400	434 000*	518 900	746 400	1 200 449	2 379 730	3 224 321	725 000*	NSA
6A	10 360	34 300*	38 739	73 423	123 400*	166 300	210 800	335 405	931 080	3 413 960	1 620 000*	48 063
5B	346 711	1 010 000*	1 206 305	1 440 989	1 730 000*	1 759 007	1 808 557	2 125 223	1 886 034	453 603	23 900*	ND
6B	319 504	1 127 000*	1 450 449	1 819 818	1 870 000*	2 315 763	2 114 412	2 530 178	2 153 151	319 054	9 300	NSA

ND - Not detectable by second laboratory with detection limits of ±2500 pCi/ℓ.
NSA - Not submitted for analysis.
*First laboratory.

TABLE X

UNBOUND TRITIUM
(pCi/ℓ in horizontal core samples)

	Distance Above Tracer (cm)						Distance Below Tracer (cm)						
Container	Surface of Soil	+32	+16	+8	+4	Tracer	-4	-8	-16	-32	-64	Bottom of Container -115	Soil Below Container
3A	ND	16 700*	69 500*	132 400	181 700	219 000*	341 300	482 400	855 800	2 049 500	3 438 300	1 357 000*	22 446
4A	ND	14 700*	53 900*	97 297	142 000	196 000*	281 100	400 500	650 900	1 705 400	3 743 700	4 250 000*	65 676
3B	333 423	2 250 000*	3 620 000*	4 321 167	4 401 347	6 220 000*	4 693 689	4 400 446	4 188 734	2 872 520	842 341	436 000*	ND
4B	277 567	1 740 000*	3 880 000*	4 179 275	4 635 130	4 710 000*	4 842 337	4 837 833	4 315 311	2 992 790	863 062	552 000*	NSA
7A	ND	56 900*	303 000*	363 900	538 700	674 000*	807 206	831 500	1 532 900	3 399 100	2 611 700	5 240 000*	51 351
8A	9 910	283 000*	748 000*	1 023 400	1 191 400	1 440 000*	1 687 400	2 053 100	2 729 700	3 856 300	2 747 700	2 500 000*	NSA
7B	394 459	2 240 000*	3 310 000*	3 583 780	3 598 645	3 770 000*	3 406 753	3 031 078	2 513 961	1 144 143	194 099	71 700*	4 189
8B	392 792	1 860 000*	3 670 000*	3 362 609	3 422 519	4 120 000*	3 404 510	3 272 519	2 868 466	1 862 611	311 486	154 000*	ND

*First Laboratory

ND - Nondetectable by second laboratory, with detection limits of ±2500 pCi/ℓ.

NSA - Not submitted for analysis.

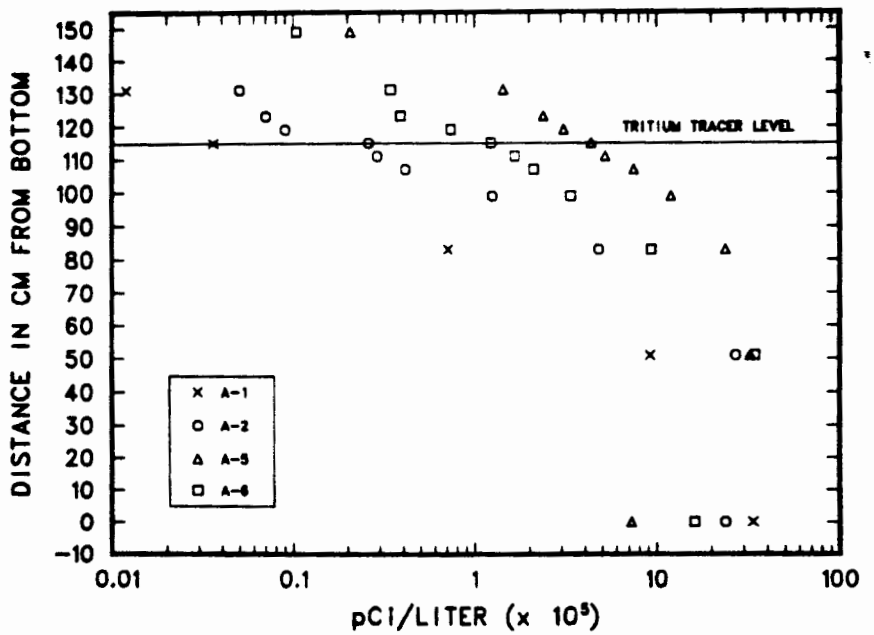

Fig. 11. Tritium concentrations in bare containers—upper tracer level.

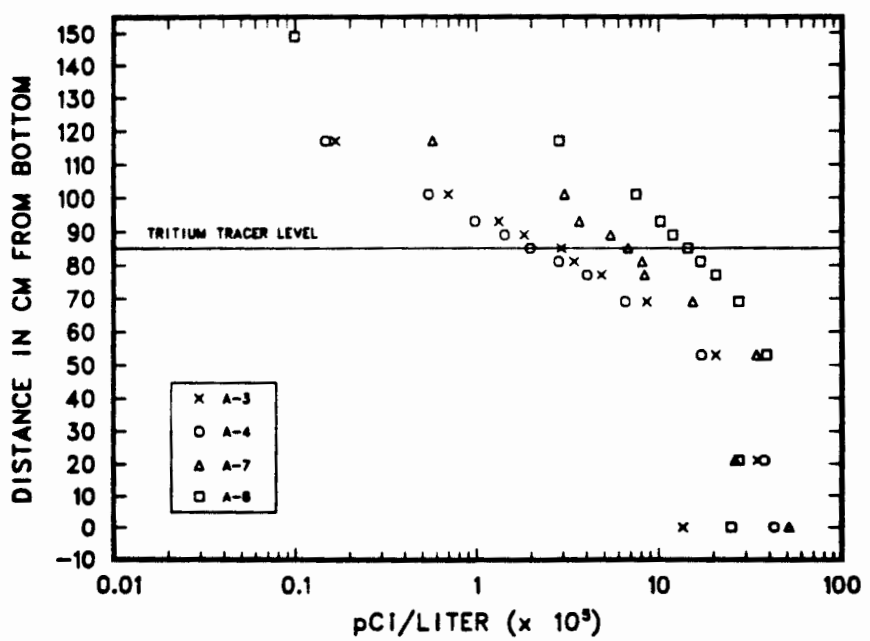

Fig. 12. Tritium concentrations in bare containers—lower tracer level.

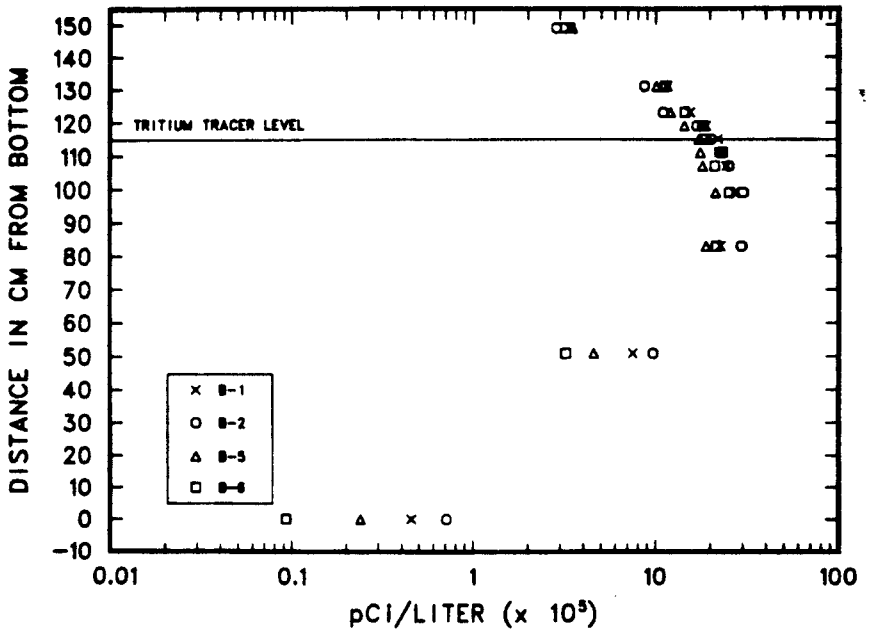

Fig. 13. Tritium concentrations in vegetated containers—upper tracer level.

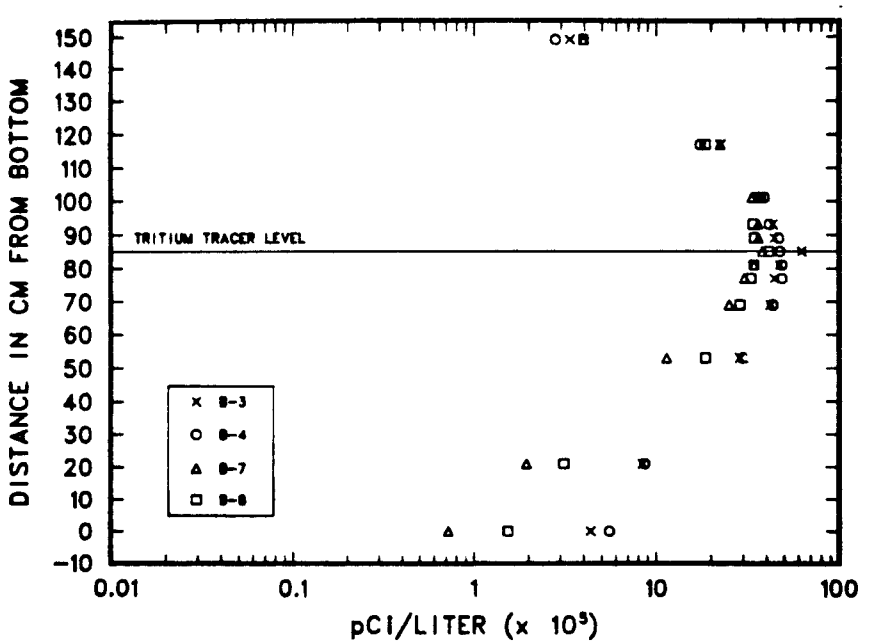

Fig. 14. Tritium concentrations in vegetated containers—lower tracer level.

TABLE XI

COBALT CONCENTRATIONS (ppm) IN HORIZONTAL CORE SAMPLES FOR THE TRACER LAYER AT 38 CM BELOW CONTAINER RIM

	Distance Above Tracer (cm)					Distance Below Tracer (cm)							
Container	Just Below Soil Surface +34	+16	+8	+4	Tracer Layer	-4	-8	-16	-32	-64	Bottom of Container -115	Sample #1 Below Container	Sample #2 Below Container
1A	2.63	2.12	1.52(<1)	2.20(<1)	6.99	207.69	82.20	(1)	3.09	3.07	2.81	8.39	4.92
2A	2.26	1.37	1.66(<1)	1.53(<1)	2.25	224.76	166.13	(2)	3.07	2.50	2.71	16.95	5.19
1B	3.54	1.67	1.76	58.40	186.49	189.75	47.52	NA	2.88	2.81	2.57	3.71	4.55
2B	4.36	1.81	2.07	1.88	9.92	206.80	105.52	(8)	2.69	3.09	3.11	4.15	3.79
5A	2.93	2.14	2.10(<1)	141.65(145)	206.79	95.14	6.88	(2)	3.33	2.76	2.48	7.92	9.08
6A	3.17	2.10	1.95(1)	2.04(1)	105.49	152.43	78.05	(4)	3.00	2.14	2.11	7.99	8.55
5B	2.85	1.59	2.14	2.82	28.25	120.16	83.22	(2)	2.47	2.76	2.69	8.38	7.43
6B	2.41	1.81	2.25	17.12	79.02	208.22	114.20	(7)	2.48	2.40	2.59	8.32	9.23

Note: parentheses indicate chemical analytical techniques.

TABLE XII

COBALT CONCENTRATIONS (ppm) IN HORIZONTAL CORE SAMPLES FOR THE TRACER LAYER AT 68 CM BELOW CONTAINER RIM

	Distance Above Tracer (cm)						Distance Below Tracer (cm)							
Container	Just Below Soil Surface +64	+32	+16	+8	+4	Tracer Layer	−4	−8	−16	−32	−64	Bottom of Container −85	Sample #1 Below Container	Sample #2 Below Container
3A	2.31	1.74	1.89	1.89(1)	2.8(<1)	15.79	208.96	82.99	(<1)	3.05	2.70	2.68	8.97	10.60
4A	2.45	2.13	2.13	1.66(<1)	1.78(1)	2.06	142.66	70.94	(3)	2.53	2.68	3.00	8.97	9.89
3B	3.97	1.50	1.64	1.90	2.01	61.13	222.49	97.47	(4)	2.70	2.68	2.91	8.09	8.19
4B	2.94	2.13	2.49	2.17	2.08	1.96	212.31	248.28	(2)	2.44	2.56	2.47	7.16	6.65
7A	2.43	2.02	1.73	1.99(3)	60.71(63)	125.57	142.66	40.56	(3)	2.54	2.13	NA	7.99	9.48
8A	2.73	1.66	1.89	1.58(1)	47.57	139.28	104.77	120.98	(3)	4.64	2.47	2.04	3.71	4.11
7B	3.00	1.91	1.71	11.19	51.04	165.78	182.60	24.08	(<1)	2.42	2.46	2.22	7.28	6.98
8B	2.72	2.00	1.62	1.95	2.02	58.68	154.93	87.28	(1)	2.60	2.65	2.47	8.06	7.98

Note: parentheses indicate chemical analytical techniques.

TABLE XIII

STRONTIUM CONCENTRATIONS (ppm) IN HORIZONTAL CORE SAMPLES FOR THE TRACER LAYER AT 38 CM BELOW THE CONTAINER RIM

	Distance Above Tracer (cm)					Distance Below Tracer (cm)							
Container	Just Below Soil Surface +34	+16	+8	+4	Tracer Layer	−4	−8	−16	−32	−64	Bottom of Container −115	Sample #1 Below Container	Sample #2 Below Container
1A	40	15	28 (100)	58.(72)	206	966	1645	(1625)	1587	402	46	168	55
2A	33	32	64 (71)	33 (65)	105	1166	1494	(1850)	1987	853	138	176	197
1B	177	126	1767	2853	2980	3125	2870	NA	226	55	48	79	115
2B	274	32	99	853	2486	3231	3193	(2250)	490	61	80	66	145
5A	59	34	215 (305)	977 (935)	1239	1580	1268	(1450)	1478	137	112	110	152
6A	39	54	29 (105)	146 (201)	469	937	1264	(1550)	1321	724	65	125	113
5B	317	498	1483	2221	2544	2608	2094	(1950)	136	86	63	141	167
6B	101	638	2636	2991	3454	2820	2635	(1775)	311	38	79	149	165

Note: parentheses indicate chemical analytical techniques.

TABLE XIV

STRONTIUM CONCENTRATIONS (ppm) IN HORIZONTAL CORE SAMPLES FOR THE TRACER LAYER AT 68 CM BELOW THE CONTAINER RIM

	Distance Above Tracer (cm)						Distance Below Tracer (cm)							
Container	Just Below Soil Surface +64	+32	+16	+8	+4	Tracer Layer	-4	-8	-16	-32	-64	Bottom of Container -85	Sample #1 Below Container	Sample #2 Below Container
3A	103	29	22	28.(107)	43 (122)	302	883	1494	(1850)	1989	971	569	154	134
4A	66	24	26	28 (80)	61 (110)	188	3028	1442	(1880)	1470	840	632	129	141
3B	342	9	542	3283	4912	4039	3426	2824	(1480)	102	44	45	145	118
4B	153	50	982	2238	3806	3839	1160	3121	(1150)	91	41	58	175	98
7A	48	25	26	157 (250)	598 (725)	904	1207	1605	(1650)	1488	67	NA	122	145
8A	30	18	20	75 (130)	402	825	1459	1067	(1515)	1525	81	27	81	59
7B	138	135	2917	3233	2745	2172	1977	1221	(550)	37	55	85	92	126
8B	104	27	1906	3309	2700	2349	1810	2027	(1090)	126	41	57	126	104

Note: parentheses indicate chemical analytical techniques.

TABLE XV

CESIUM CONCENTRATIONS (ppm) IN HORIZONTAL CORE SAMPLES FOR THE TRACER LAYER AT 38 CM BELOW CONTAINER RIM

	Distance Above Tracer (cm)					Distance Below Tracer (cm)							
Container	Just Below Soil Surface +34	+16	+8	+4	Tracer Layer	−4	−8	−16	−32	−64	Bottom of Container −115	Sample #1 Below Container	Sample #2 Below Container
1A	2.47	2.85	2.24(<3)	2.98(<3)	43.08	126.39	40.53	(8)	2.98	2.78	2.78	3.28	2.35
2A	2.59	2.26	2.12(5)	2.26(3)	8.83	124.71	75.71	(4)	3.52	3.21	2.83	4.04	3.18
1B	6.68	2.89	6.39	64.96	140.00	89.24	6.65	(4)	3.19	3.01	2.14	3.09	2.87
2B	28.32	3.56	3.24	3.24	32.07	123.34	37.94	(4)	2.78	3.28	3.09	3.61	2.66
5A	2.52	2.92	12.76(25)	112.26(207)	101.23	22.91	2.62	(6)	2.74	2.85	2.06	3.07	3.14
6A	2.91	2.97	2.44(2)	7.10(2)	85.09	74.19	33.38	(3)	2.60	2.47	2.42	3.31	3.39
5B	2.13	2.64	3.08	22.35	56.67	88.52	54.14	(2)	2.29	2.67	2.51	4.25	2.90
6B	5.61	2.81	5.28	32.03	83.96	98.55	56.34	(3)	2.65	2.75	2.68	3.76	3.05

Note: parentheses indicate chemical analytical techniques.

TABLE XVI

CESIUM CONCENTRATIONS (ppm) IN HORIZONTAL CORE SAMPLES FOR THE TRACER LAYER AT 68 CM BELOW CONTAINER RIM

	Distance Above Tracer (cm)						Distance Below Tracer (cm)							
Container	Just Below Soil Surface +64	+32	+16	+8	+4	Tracer Layer	-4	-8	-16	-32	-64	Bottom of Container -85	Sample #1 Below Container	Sample #2 Below Container
3A	2.39	2.30	2.83	2.11(9)	3.02(10)	43.85	125.90	34.86	(6)	2.92	2.74	2.70	3.89	3.63
4A	2.12	2.66	2.75	2.33(4)	2.30(3)	19.24	86.24	46.98	(4)	2.53	2.75	2.93	4.11	3.77
3B	6.19	2.15	2.59	2.91	6.15	75.35	104.53	18.42	(4)	2.68	2.95	2.90	3.58	3.09
4B	2.96	2.48	2.28	2.65	3.01	7.81	99.31	97.23	(<3)	2.87	2.21	2.71	3.59	3.17
7A	2.50	2.53	2.72	5.59(17)	52.26(111)	94.47	68.87	8.07	(3)	2.42	2.21	NA	3.44	3.74
8A	2.51	2.37	2.62	3.23(3)	41.44	81.70	41.83	54.16	(4)	2.56	2.68	2.73	3.12	2.85
7B	2.91	2.48	2.24	15.00	44.47	79.91	70.11	2.98	(4)	2.41	2.47	2.72	4.06	3.05
8B	2.71	2.60	2.70	2.64	10.00	83.28	107.88	37.79	(<3)	1.99	2.62	2.75	3.90	3.43

Note: parentheses indicate chemical analytical techniques.

TABLE XVII

STRONTIUM, COBALT, AND CESIUM IN SUPPLEMENTAL WATER

Element	Solution	Sediment*
Sr	<0.02 ppm	<0.0005 ppm
Co	<0.01 ppm	<0.0006 ± 0.0002
Cs	<2 ppb	<0.1 ppb

*Sediment was separated from solution phase by filtration (Nucleopore 1μ) diluted to 25 mℓ and analyzed. Equivalent original water concentrations are reported.

containers showed a large moisture decrease (in general throughout the profile), whereas all the bare containers had an increase in total moisture. It is also interesting to note that in the vegetated wet containers, the roots appear to have been more active at the 75-135 cm depth regime than in the dry. As noted in the literature review, wet subsoil may encourage deeper rooting.

During the winter (November 3, 1981-March 1, 1982), the planted containers had a moisture deficit in the 75-135 cm depth. Referring to the temperature data, it can be seen that temperatures at this depth remained above 5°C. It would appear that at these temperatures these lower root systems continued to withdraw moisture from the soil.

During the winter, the vegetated containers had a greater increase in moisture in the upper layers than did the bare containers. Moisture levels in the bare containers were, in general, above 20% moisture by volume, whereas the moisture levels in the vegetated containers were below 20% moisture by volume. Because of the high moisture levels, it is probable that the lack of moisture increase in the upper layer of the bare containers was caused by downward movement of moisture out of the upper layers and greater surface evaporation/sublimation (due to the increased difference in air/soil moisture and lack of dead plant mulch).

Beginning in March, an increase in plant activity could be detected by the rapid decrease (compared with the bare containers) in upper soil moisture (see Appendix B). This increase in plant activity coincides with the increase noted in the upper soil temperature (temperature greater than 5°C). Thus, soil temperature appears important in plant transpiration processes.

From March 1 through October 15, 1982, a decrease in soil moisture was detected in all vegetated containers at all depths. In general, the opposite of this was true in the bare containers.

This experiment demonstrates that plants, through their respiration processes, are an effective mechanism in removing upper soil moisture, thus reducing downward infiltration into the subsoil. These rather striking differences in soil moisture between bare and vegetated soils are shown graphically in Figs. 3-10. In these figures, the loss of water throughout the root zone in the summer, buildup in the winter, and loss the following summer is clearly seen for the vegetated soils!

Comparing the subsoil moisture shown in these figures for the initial 25% saturation containers with that for the 50% saturation containers indicates that there was little difference in the moisture levels at the termination of the experiment. Leakage and evaporation, plus, in the cases of the vegetated containers, transpiration, removed this "extra" water.

It should be noted, however, that the experiment was conducted on a horizontal soil in which no runoff of precipitation was possible. At a burial site having

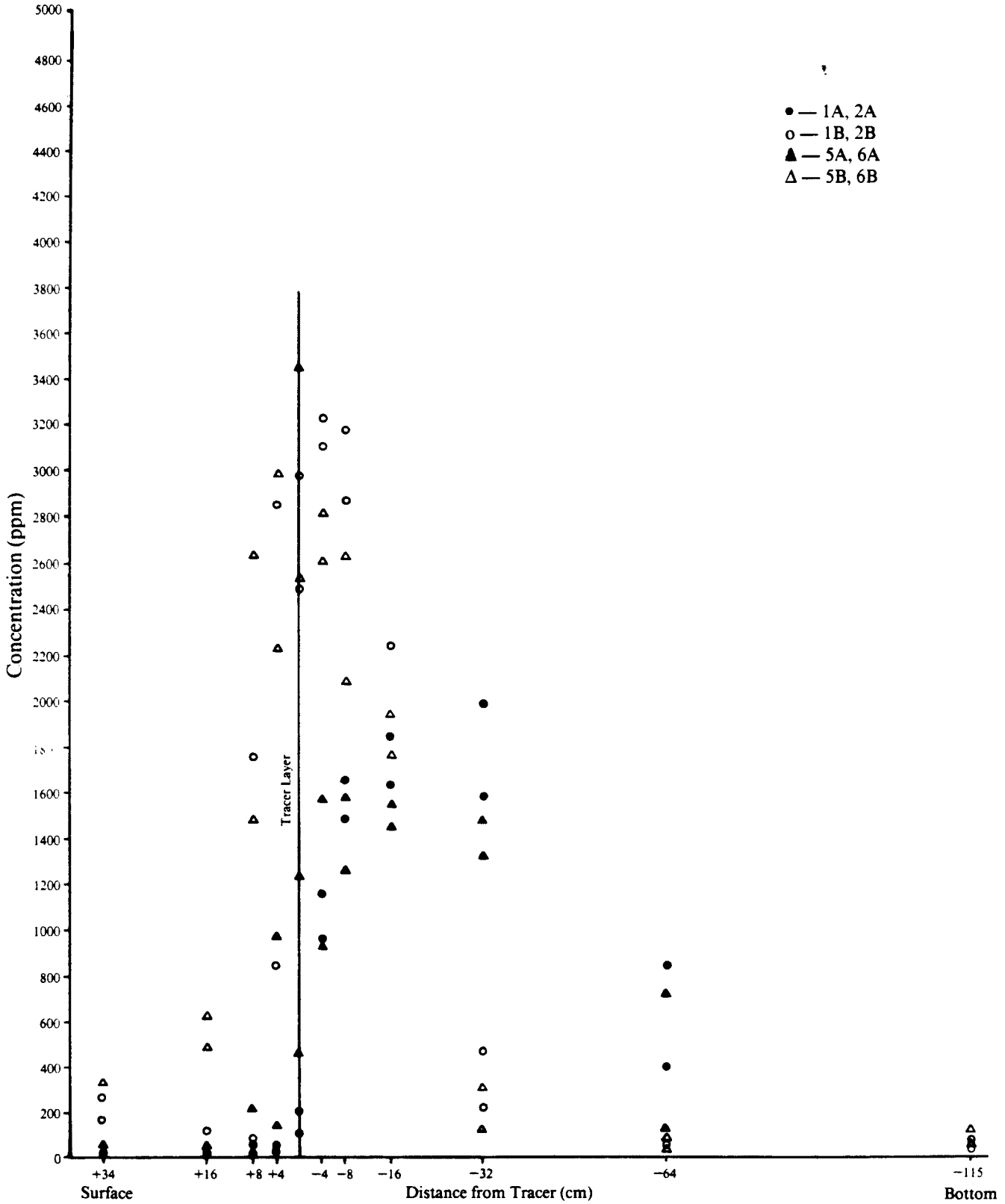

Fig. 15. Sr shallow tracer.

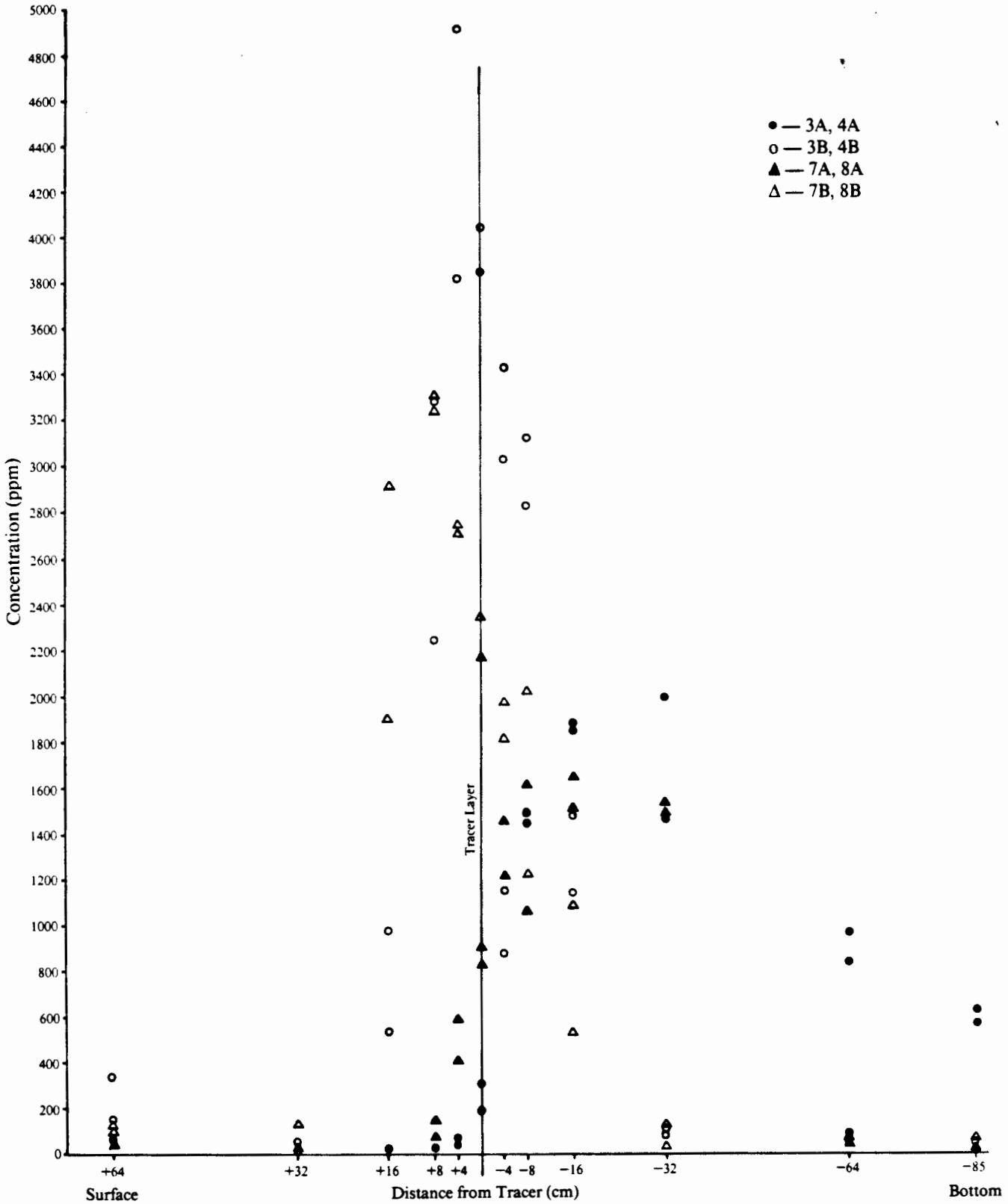

Fig. 16. Sr deeper tracer.

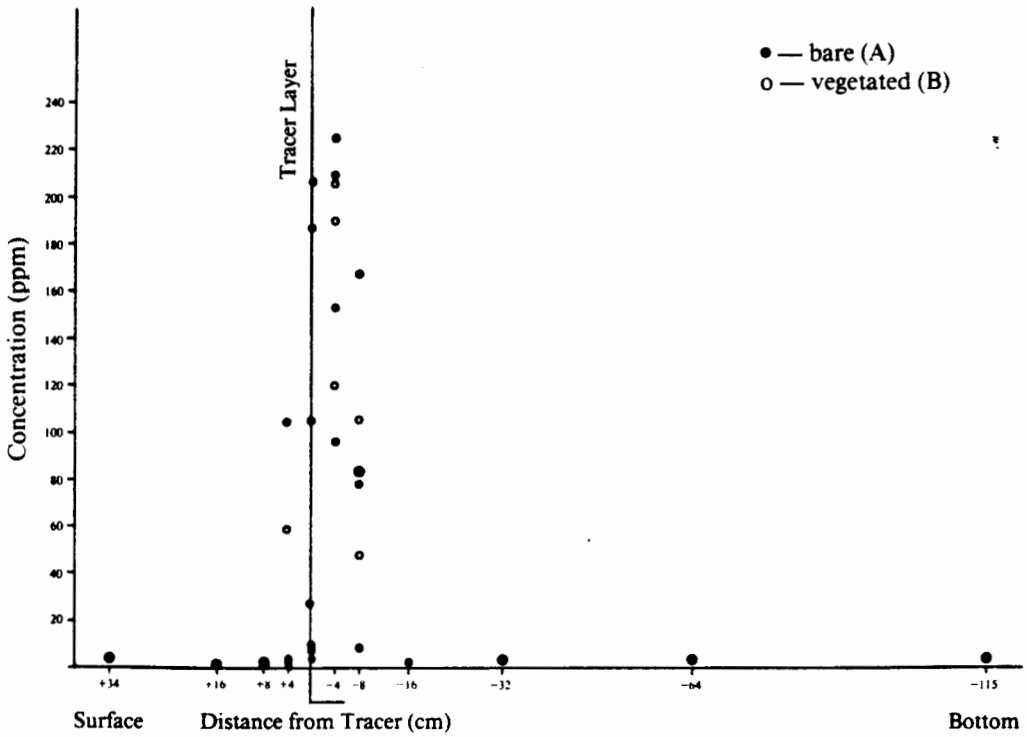

Fig. 17. Cobalt concentrations (ppm) in horizontal core samples for the tracer layer at 38 cm below container rim.

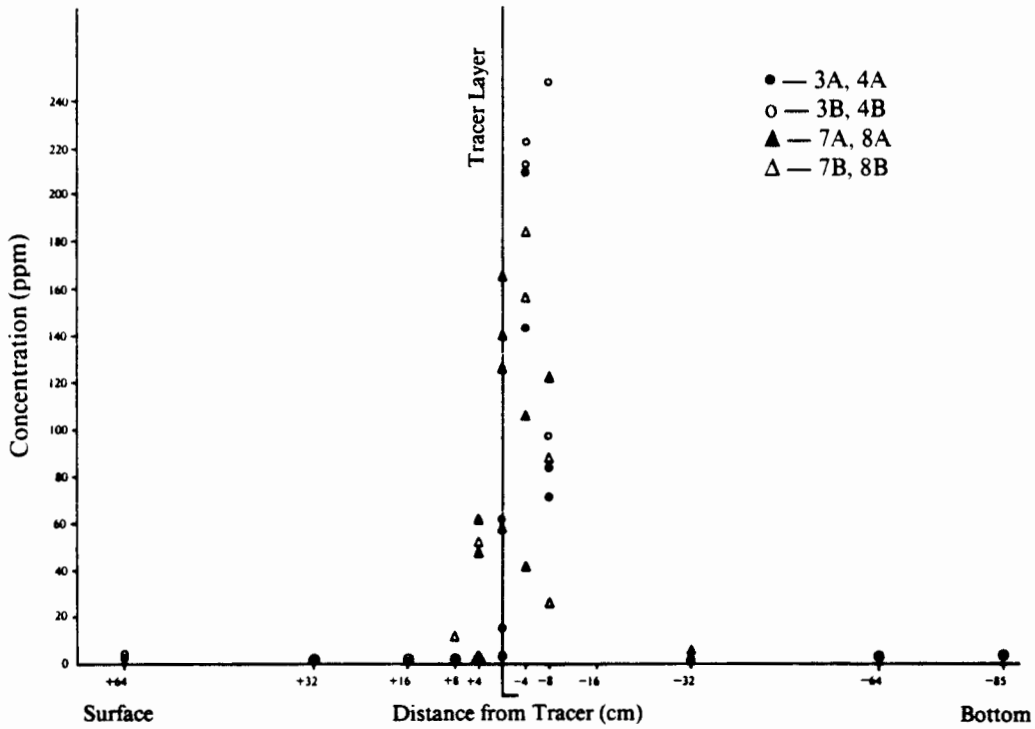

Fig. 18. Cobalt concentrations (ppm) in horizontal core samples for the tracer layer at 68 cm below container rim.

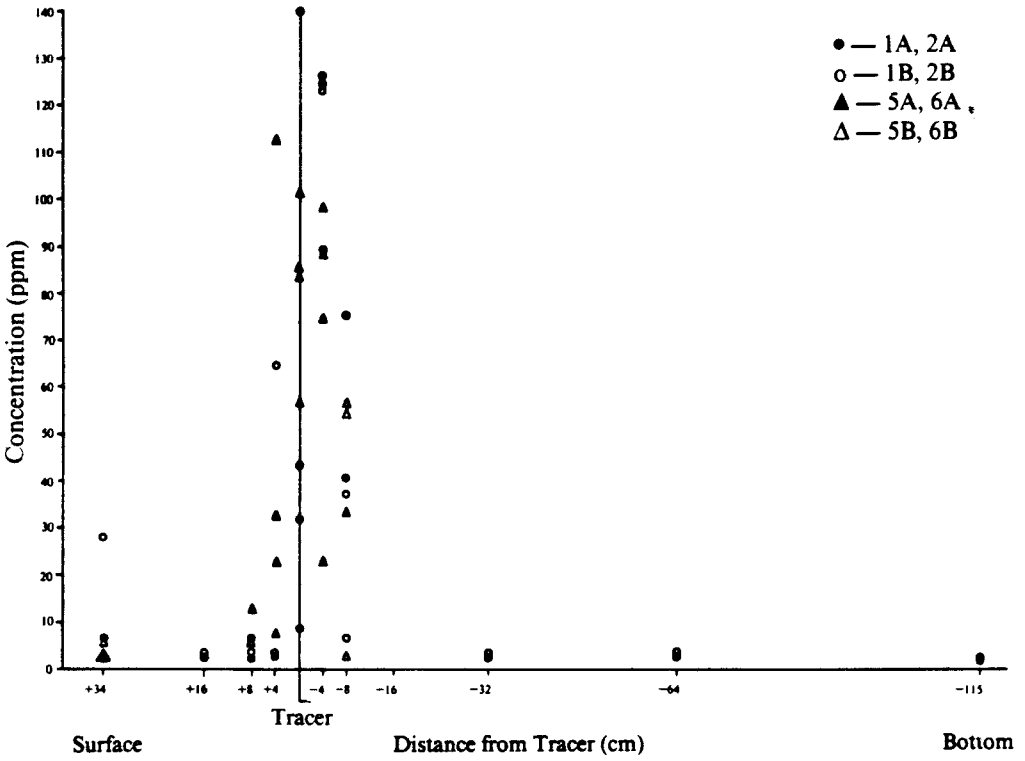

Fig. 19. Cesium concentations (ppm) in horizontal core samples for the tracer layer at 38 cm below container rim.

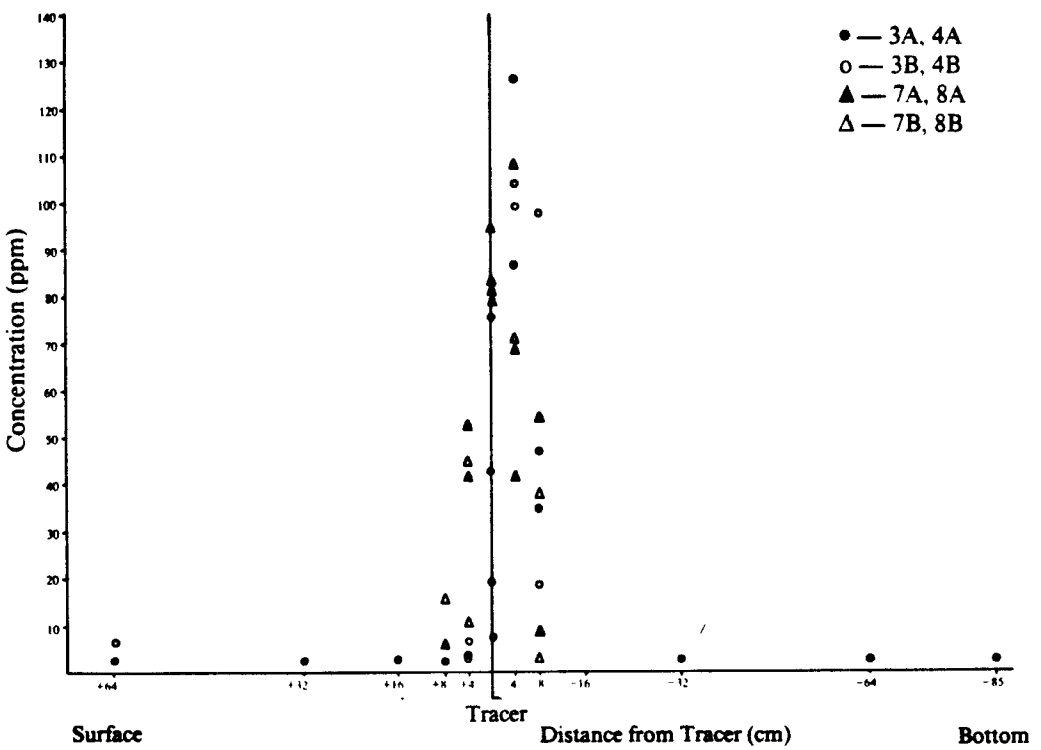

Fig. 20. Cesium concentrations (ppm) in horizontal core samples for the tracer layer at 68 cm below container rim.

TABLE XVIII

TOTAL TRITIUM INVENTORY AT TERMINATION OF EXPERIMENT
(October 15, 1982)

Container	Liters in Container	Vertical Core Tritium Concentrations pCi/ℓ × 10^3	Vertical Total pCi × 10^5	Horizontal Total pCi × 10^5	Average pCi × 10^5	Per Cent Retained
1A	266.24	882.9	2351	2654	2502	45
2A	254.85	1139.6	2904	3684	3294	60
1B	65.11	1067.6	695	883	789	14
2B	88.07	1193.7	1051	1302	1176	21
3A	234.11	932.4	2183	3300	2741	50
4A	241.53	995.5	2404	3872	3138	57
3B	57.67	2148.6	1239	1558	1398	25
4B	78.86	2319.8	1829	1941	1885	34
5A	271.15	1743.2	4779	4551	4665	85
6A	250.89	1833.3	4600	3823	4211	76
5B	56.20	734.2	413	630	521	9
6B	67.16	909.9	611	823	717	13
7A	235.94	1283.8	3029	4102	3565	65
8A	245.42	1459.4	3582	4825	4203	76
7B	62.53	1216.2	760	1153	956	17
8B	60.87	932.4	568	1193	880	16

sloping terrain, dead plant mulch, growth of associated surface soil lichen and other organisms, and the establishment of infiltration pathways along roots might allow a significant fraction of precipitation to infiltrate, which would otherwise have runoff on a bare soil. Under these conditions, subsoil moisture might be higher for vegetated than bare soils and the extreme differences in soil moisture as found in the present experiment would not occur. (On the other hand, erosion would be expected on the bare soils.)

C. Biomass Production

In comparing total plant mass, there appears to be little difference among the containers. This is, no doubt, because the amount of water added was much more than the initial stored water so that surface biomass production was the same. If very little supplemental water was available, stored water might be important in establishing vegetation.

D. Tracer Migration

1. Tritium

For the bare containers, the data shown in Figs. 11 and 12 indicate that, although some tritium moved upward, the greatest concentration occurred below the original tracer layer. The containers that had an initial moisture content of 25% saturation had lower concentrations than the corresponding containers of 50% initial saturation.

In the vegetated containers with the upper tracer layer (Fig. 13) the maximum tritium concentration occurred slightly below the tracer layer, whereas, in the vegetated containers with the lower tracer layer (Fig. 14), the highest concentration was at the tracer level. In both cases, concentration decreased rapidly with depth. In the region below the tracer, in the vegetated containers, the initially wet containers had a lower concentration level of tritium than the initially dry.

TABLE XIX

TRITIUM INVENTORY DISTRIBUTION
($pCi \times 10^5$)

Interval from Soil Surface (cm)	Container							
	1A	2A	1B	2B	5A	6A	5B	6B
0 – 15	–	–	42.0	28.6	7.4	4.5	41.4	39.6
15 – 45	–	3.5	233.6	166.1	153.9	33.0	175.2	209.3
45 – 75	16.2	135.7	427.0	674.4	943.4	273.8	310.4	497.1
75 – 105	285.4	1102.3	122.3	319.3	1774.6	1517.8	89.4	63.7
105 – 135	365.0	1694.5	51.1	98.0	1367.7	1506.4	12.2	12.8
135 – 149	986.9	747.8	6.8	15.6	304.4	487.5	1.2	1.0
Total	2653.6	3683.7	882.8	1302.0	4551.3	3823.1	629.8	823.5

Tracer at 115 cm from bottom of container or 34 cm from soil surface of container.

Interval from Soil Surface (cm)	Container							
	3A	4A	3B	4B	7A	8A	7B	8B
0 – 15	–	–	20.0	19.4	–	16.2	43.3	28.1
15 – 45	7.2	7.7	122.8	108.0	15.6	105.3	219.7	159.1
45 – 75	81.7	70.3	698.2	692.5	266.1	583.5	623.2	662.7
75 – 105	781.7	645.1	514.2	745.5	1226.4	1711.0	225.3	269.3
105 – 135	1879.1	1978.0	170.6	311.5	1528.5	1716.7	37.0	63.5
135 – 149	550.6	1170.9	31.9	64.4	1065.1	692.4	4.8	10.1
Total	3300.3	3872.0	1557.7	1941.3	4101.7	4825.1	1153.3	1192.8

Tracer at 85 cm from bottom of container or 64 cm from soil surface of container.

Comparing bare vs vegetated containers for tritium concentrations, the vegetated containers had higher tritium concentrations in the region of the tracer layer and above, whereas, at deeper depths, the bare containers had higher concentrations than the vegetated.

Data given in Tables IX and X indicate that in at least some cases, and possibly in all, tritium leaked out of the containers and into the underlying backfill.

Because of the large variations in soil moisture between containers and throughout the soil profile, to determine tritium loss and fractional movement, the total tritium inventory (Table XIX and Figs. 21-24) in corresponding soil layers must be compared. From these comparisons, several conclusions can be made.

1. There was more tritium above the tracer layer in the vegetated containers than in the corresponding bare containers, indicating that plants may mobilize tritium.
2. There is a hint of movement of tritium throughout the root system as the dry vegetated containers tended to have more tritium below the tracer level than did the wet.
3. All containers had more of the tritium inventory below the tracer layer than above the tracer layer. This may reflect greater downward movement but, in addition, it may be that when the tritium gets near the surface, evaporation reduces the concentration.

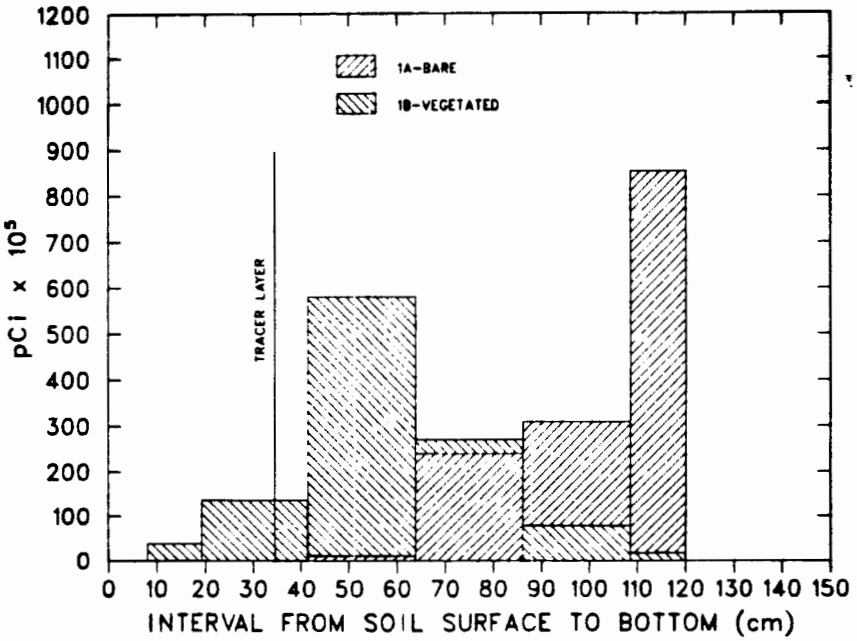

Fig. 21. Tritium inventory vs depth in dry containers.

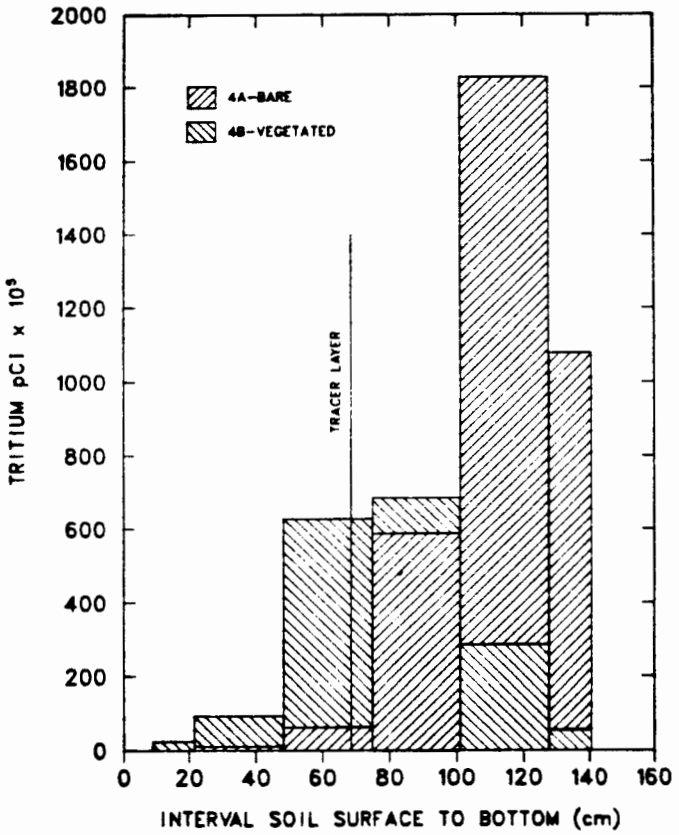

Fig. 22. Tritium inventory vs depth in dry containers.

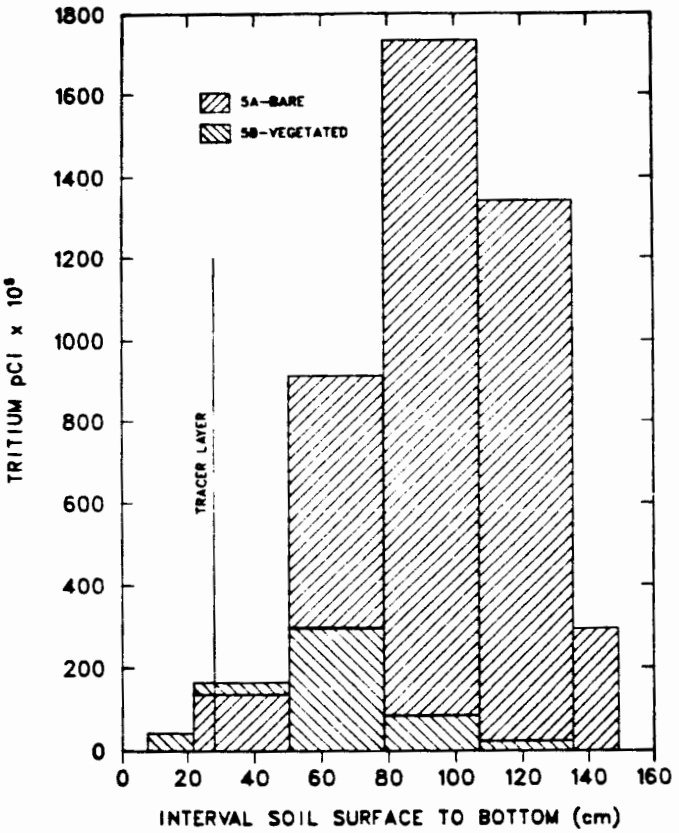

Fig. 23. Tritium inventory vs depth in wet containers.

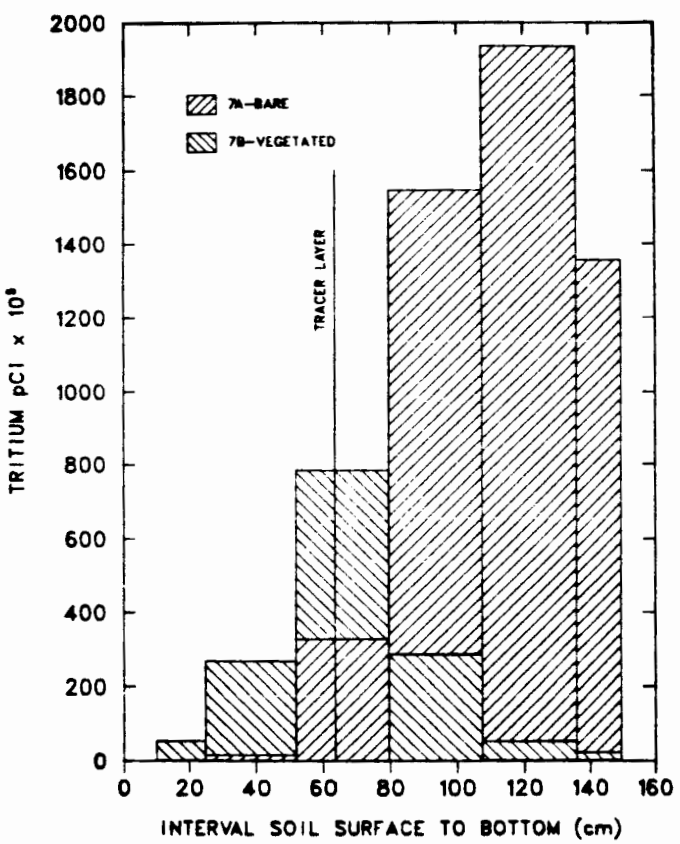

Fig. 24. Tritium inventory vs depth in wet containers.

TABLE XX

RELATIVE FINAL INVENTORIES OF STRONTIUM IN THE CONTAINERS ABOUT THE TRACER LAYER

Container	Condition	ppm–cm
1A, 2A/5A, 6A	Bare, tracer 38 cm	110 660
3A, 4A/7A, 8A	Bare, tracer 68 cm	104 700
1B, 2B/5B, 6B	Vegetated, tracer 38 cm	97 680
3B, 4B/7B, 8B	Vegetated, tracer 68 cm	97 680

TABLE XXI

TIME PERIOD AFTER PLANTING THAT ROOT ACTION WAS NOTED BY MOISTURE UPTAKE AS A FUNCTION OF DEPTH

Depth below surface (cm)	30	60	90	120
Time (days)	30	55	114	114

4. In all containers it appears that tritium moved upward from the tracer level; however, the data are incomplete for 1A and 2A.

5. Tritium was found at the bottom of all containers, with the planted containers having much less tritium inventory than the bottom segment of the bare containers.

The total tritium inventory results (Table XVIII) indicate the following:

1. Comparing bare containers,

   a. the wet containers retained more tritium (an average of 75%) than did the dry (an average of 53%). This suggests that significant amounts of tritium moved in the gaseous phase, and

   b. the level of the tracer made no significant difference (an average of 66.5% in shallow and 62% in deeper of tritium retained).

Hence, for bare soils under these experimental conditions, moisture content, rather than tracer depth, appears more important in tritium loss.

2. Comparing bare with vegetated containers,

the bare containers retained more tritium (an average of 64%) than did the vegetated (an average of 19%), suggesting that the plants removed tritiated water from the soil, transpired tritium, and incorporated it into the plant cells.

3. Comparing vegetated containers,

the dry containers retained slightly more tritium (an average of 23%) than the corresponding wet containers (an average of 14%), again suggesting that the plants, in "mining" the original soil water, withdrew the tritium. This should be compared with the case of the bare containers.

2. Co, Cs, and Sr

a. Container Fill Surrounding Tracer Layer. Figures 15-20 can be used to compare the distributions of Co, Cs, and Sr at the conclusion of the experiment. In the case of cobalt, comparing bare with vegetated containers, and assuming similar soil densities and tracer input, there were no differences outside of the experimental errors, in the concentrations in the region of the tracer layer. Thus, all the containers showed similar relative final inventories of cobalt. In the container fill, above background concentrations appear to have been limited to ±16 cm of the tracer layer, with the peak concentrations occurring near the tracer layer. Similar results were obtained for cesium.

For strontium, concentration distributions were very different in the bare vs vegetated containers. Again, assuming similar soil densities in all containers, extensive movement of strontium occurred in the bare containers, with the peak concentrations moving down to approximately 24 cm below the position of the initial peak concentration of the tracer regardless of original tracer level. Above background concentrations of strontium extended to approximately 100 cm below the original tracer layer in those containers having the tracer at 38 cm below the container lip. In the case of the deeper tracer, concentrations were well above background at the bottom of the containers, at least for 3A and 4A. In the vegetated containers, the peak concentrations at the end of the experiment were near or at the location of the peak concentration at the beginning of the experiment, and background concentrations in the container fill occurred within ±32 cm of the tracer layer. Because the initial concentration distributions and total inventories are not known, it is not possible to

indicate how much movement took place but it appears that the vegetated soils retained the Sr, probably because less downward soil water movement occurred in the vegetated soils.

From Table XX in which relative Sr inventories are given, it can be seen that the inventory was less for the bare containers having the lower tracer than the bare containers having the upper tracer; some tracer probably seeped downward out of the container. The inventories for the vegetated containers are less than the bare. This may be due to a small amount of plant uptake of strontium or may represent uncertainties in the experiment, as the differences are quite small.

b. Soil Surface. Comparing tracer concentrations outside the region surrounding the tracer layer, slightly elevated levels of cobalt, cesium, and strontium were present in some of the vegetated container core samples taken just below the soil surface. These may be, at least in part, due to plant root uptake and movement of the tracers to the leaves, deposition of the leaves on the soil as litter, and either leaching to the subsoil or sampling of the surface soil and litter in the near surface core sample.

c. Below the Containers. Tracer concentrations slightly above background levels for Bandelier crushed tuff at the experimental site were also found in the backfill samples taken from below the containers. It would be expected from the strontium distribution found in 3A, 4A, 7A, and 8A that leakage and movement of strontium from these containers occurred. However, the elevated levels of the other two tracers were unexpected and would indicate that a small fraction of the tracers, perhaps present as colloids, was very mobile. It is also possible, since the backfill contained some top soil as well as the crushed tuff used in filling the containers, that the trace element composition of the backfill was different from the container fill. No background samples of backfill were taken before the experiment was begun.

IX. SUMMARY

The data from this experiment indicate that plant transpiration processes remove soil moisture by significant amounts down to the lowest plant rooting depths. Thus, at waste burial sites, plants can be used to reduce soil moisture, which will reduce the amount of water available for downward movement, leaching, and transport of soluble toxic materials.

The information obtained in the literature review would indicate that, although plant species is important in determining rooting depth and transpiration rate and, hence, the removal of soil water, a set of upper and lower values that have a large range for each parameter is necessary for each species because environmental conditions are important in determining root growth and behavior, plant transpiration processes, and other plant related effects. Because soil water loss is dependent on environmental conditions as well as plant species (or, alternatively, biomass or leaf area), the specific data from the experiment described in this report are valid only under the conditions of the experiment.

Although plant processes will reduce the amount of soil water, they can also influence other parameters that may affect the transport of toxic materials.

The present experiment indicated that tritium behaves as soil water and is lost in areas in which plant roots penetrate, to a greater degree than if plant roots did not penetrate. This would indicate that in burial sites containing tritium, if roots penetrate into the region containing tritium, mobilization of tritium will increase. The experiment also indicated that tritium moves as a gas and, hence, can be lost in this manner from dry soils.

For Cs and Co, the experimental data indicated no detectable differences in the final subsurface distribution of these tracers for soils penetrated by plant roots (and therefore having less downward movement of soil water) and barren soils. Although some upward diffusion of similar process may have occurred, large amounts of these tracers were not found to have moved upward in either treatment. The plants may have absorbed slight amounts of Cs and Co and translocated these to the surface leaves, thus providing a pathway to the soil surface.

Different results were obtained for Sr. In the barren soils, the peak concentration of Sr moved downward, with a wide distribution near the peak concentration. In the soils penetrated by plant roots, the peak concentration remained near the region of emplacement, probably because of less downward movement of soil water, although some upward diffusion, or similar processes, may have occurred. In neither treatment were large amounts of tracer found to have moved upward. However, again it would appear that the plants may have absorbed and translocated Sr.

A review of the literature indicated that again in influencing plant nutrient and trace element sorption and other plant processes that affect soil water composition, environmental factors such as soil composition, microbiological colonies in the soil, soil water nutrient content, and amount of soil water are so important in determining mobilization of trace elements that plant species alone, or even vegetated vs barren soils, are not the complete determining factors.

More experiments are needed to determine the effects of tracer concentration and other components in soil water, inhomogeneities in the soil profile, soil composition, evaporation rates, and moisture on tracer movement in bare soil. The extent to which insoluble elements can be transported on colloids should be investigated in detail. In addition, because the vegetated plots may not have had fully developed biological communities, the influence of a climax ecosystem on tracer mobilization needs further investigation.

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REFERENCES

Abeele, W. V., M. L. Wheeler, and B. W. Burton, "Geohydrology of Bandelier Tuff," Los Alamos National Laboratory report LA-8962-MS (October 1981).

Barber, Stanley A., "Nutrients in the Soil and Their Flow to Plant Roots," in *The Belowground Ecosystem: A Synthesis of Plant-Associated Processes*, J. K. Marshal, Ed., Range Science Department, Science Series No. 26, Colorado State University, Fort Collins, Colorado (1977), pp. 161-168.

Chapin, Stuart F., III, "Thermal Adaptations of Phosphate Absorption in Plants Along a Latitudinal Gradient," in *The Belowground Ecosystem: A Synthesis of Plant-Associated Processes*, J. K. Marshal, Ed., Range Science Department, Science Series No. 26, Colorado State University, Fort Collins, Colorado (1977), pp. 99-107.

Christenson, C. W., and Eric B. Fowler, "Depth of Feeding as it Affects the Concentration of Radioactivity Within the Plant," *Agricultural and Food Chemistry*, **9(2)**, 98-105 (March-April 1961).

Christenson, C. W., Eric B. Fowler, George L. Johnson, Elgin H. Rex, and Felix A. Virgil, "Soil Adsorption of Radioactive Wastes at Los Alamos," *Sewage and Industrial Wastes*, **30(12)**, 1478-1489 (December 1958).

Cline, J. F., "Aging Effects of the Availability of Strontium and Cesium to Plants," *Health Physics*, **41**, 293-296 (1981).

Corey, J. C., A. L. Boni, J. R. Watts, D. C. Adriano, K. W. McLeod, and J. E. Pinder, III, "The Relative Importance of Uptake and Surface Adherence in Determining the Radionuclide Contents of Subterranean Crops," *Health Physics*, **44(1)**, 19-28 (1983).

Cox, T. L., W. F. Harris, B. S. Ausmus, and N. T. Edwards, "The Role of Roots in Biogeochemical Cycles in Eastern Deciduous Forests," in *The Belowground Ecosystem: A Synthesis of Plant-Associated Processes*, J. K. Marshall, Ed., Range Science Department, Science Series No. 26, Colorado State University, Fort Collins, Colorado (1977), pp. 321-326.

Cummings, S. L., J. H. Jenkins, T. T. Fendley, L. Bankert, P. H. Bedrosian, and C. R. Porter, "Cesium-137 in White-Tailed Deer as Related to Vegetation and Soils of the Southeastern United States," Proceedings of the Third National Symposium on Radioecology, May 10-12, 1971, Oak Ridge, Tennessee, Vol. 1, pp. 123-216.

Davidson, Darwin E., and Martha Christensen, "Root-Microfungal and Mycorrhizal Associations in a Shortgrass Prairie," in *The Belowground Ecosystem: A Synthesis of Plant-Associated Processes*, J. K. Marshall, Ed., Range Science Department, Science Series No. 26, Colorado State University, Fort Collins, Colorado (1977), pp. 279-287.

Elgawhary, S. M., G. L. Molzer, and S. A. Barber, "Calcium and Strontium Transport to Plant Roots," *Soil Science Society of America* Proceedings, **36**, 794-799 (1972).

Epstein, Emanuel, and James E. Leggett, "The Absorption of Alkaline Earth Cations by Barley Roots: Kinetics and Mechanism," *American Journal of Botany,* **41(10)**, 785-791 (December 1954).

Francis, C. E., "Radiostrontium Movement in Soils and Uptake in Plants," Oak Ridge National Laboratory report TID-27564 (1978).

Fernandez, Osvaldo A., and Martyn M. Caldwell, "Root Growth of *Atriplex Confertifolia* Under Field Conditions," in *The Belowground Ecosystem: A Synthesis of Plant-Associated Processes,* J. K. Marshall, Ed., Range Science Department, Science Series No. 26, Colorado State University, Fort Collins, Colorado (1977), pp. 117-121.

Garland, Thomas R., D. A. Cataldo, K. M. McFadden, R. G. Schreckhise, and R. E. Wildung, "Comparative Behavior of ^{99}Tc, ^{129}I, ^{127}I and ^{137}Cs in the Environment Adjacent to a Fuels Reprocessing Facility," *Health Physics,* **44(6)**, 658-661 (June 1983).

Gibbs, A. G., and R. G. Baca, "Analytical Models for Simultaneous Heat and Moisture Transport in Soils," Rockwell International report RHO-LD-49 (April 1981).

Gladney, Ernest S., David B. Curtis, Daniel R. Perrin, James W. Owens, and William E. Goode, "Nuclear Techniques for the Chemical Analysis of Environmental Materials," Los Alamos Scientific Laboratory report LA-8192-MS (January 1980).

Gladney, Ernest S., Daniel R. Perrin, and William E. Goode, "Quality Assurance for Environmental Analytical Chemistry 1982," Los Alamos National Laboratory report LA-9950-MS (1982).

Hakonson, T. E., and K. V. Bostick, "The Availability of Environmental Radioactivity to Honey Bee Colonies at Los Alamos," *Journal of Environmental Quality,* **5(3)**, 307-310 (July-September 1976).

Hamilton, Jed M., "Measurement of Permeability of Partially Saturated Soils," Department of Civil Engineering, Unversity of Texas report GE79-4 (August 1979).

Handley, R., and K. L. Babcock, "Uptake and Translocation of Sr by Zea Mays," *Radiation Botany,* **13**, 273-281 (1973).

Harris, Grant A., "Root Phenology as a Factor of Competition Among Grass Seedlings," in *The Belowground Ecosystem: A Synthesis of Plant-Associated Processes,* J. K. Marshall, Ed., Range Science Department, Science Series No. 26, Colorado State University, Fort Collins, Colorado (1977), pp. 93-98.

Hermann, Richard K., "Growth and Production of Tree Roots: A Review," in *The Belowground Ecosystem: A Synthesis of Plant-Associated Processes,* J. K. Marshall, Ed., Range Science Department, Science Series No. 26, Colorado State University, Fort Collins, Colorado (1977), pp. 7-28.

Hillel, Daniel, *Applications of Soil Physics,* (Academic Press, New York, 1980), pp. 112-120.

Huck, M. G., "Root Distribution and Water Uptake Patterns," in *The Belowground Ecosystem: A Synthesis of Plant-Associated Processes,* J. K. Marshall, Ed., Range Science Department, Science Series No. 26, Colorado State University, Fort Collins, Colorado (1977), pp. 215-226

Kearl, Peter M., "Water Transport in Desert Alluvial Soil," Desert Research Institute, University of Nevada at Reno report DOE/NV/10162-2 (April 1982).

Kiesselback, T. A., J. C. Russel, and Arthur Anderson, "The Significance of Subsoil Moisture in Alfalfa Production," *Journal of the American Society of Agronomy,* **21(3)**, 241-268 (March 1929).

Lamba, P. S., H. L. Ahlgren, and R. J. Muckenhirn, "Root Growth of Alfalfa, Medium Red Clover, Bromegrass and Timothy Under Various Soil Conditions," *Agronomy Journal,* **41(10)**, 451-458 (October 1949).

Lassey, K. R., "The Transfer of Radiostrontium and Radiocesium from Soil to Diet: Models Consistent with Fallout Analyses," *Health Physics,* **37**, 557-573 (1979).

Ludwig, John A., "Distributional Adaptations of Root Systems in Desert Environments," in *The Belowground Ecosystem: A Synthesis of Plant-Associated Processes,* J. K. Marshall, Ed., Range Science Department, Science Series No. 26, Colorado State University, Fort Collins Colorado (1977), pp. 85-91.

Lyr, Horst, and Gunter Hoffman, *Growth Rates and Growth Periodicity of Tree Roots,* International Review of Forestry Research, J. A. Romberjer and P. Mikola, Eds. (Academic Press, New York, London, 1967), pp. 181-236.

Marshall, John K., "Biomass and Production Partitioning in Response to Environment in Some North American Grasslands," in *The Belowground Ecosystem: A Synthesis of Plant-Associated Processes,* J. K. Marshall, Ed., Range Science Department, Science Series No. 26, Colorado State University, Fort Collins, Colorado (1977), pp. 73-84.

Mecklenburg, R. A., and H. B. Tukey, "Uptake by the Root and Subsequent Distribution Within the Potato Plant of Strontium-89 Leached from the Foliage," *Nature* **198(4880),** 562-563 (May 1963).

Menzel, R. G., "Soil-Plant Relationships of Radioactive Elements," *Health Physics,* **11**, 1325-1332 (1965).

Miettinen, J. K., "Transfer and Uptake Mechanism of Tritium in Soil," in *Behaviour of Tritium in the Environment,* Proceedings of the International Symposium on the Behaviour of Tritium in the Environment, San Francisco, California (October 16-20, 1978), pp. 339-347, International Atomic Energy Agency, Vienna (1979).

Myers, W. M., "Genetic Control of Physiological Processes: Consideration of Differential Ion Uptake by Plants," in *Radioisotopes in the Biosphere,* R. S. Caldecott and L. A. Snyder, Eds. (University of Minnesota at Minneapolis, 1960), pp. 201-226

Molz, Fred J., S. R. VanFleet, and V. D. Browning, "Transpiration Drying of Sanitary Landfills," *Ground Water,* **12(6)**, 394-397 (November-December 1974).

Nedrow, W. W., "Studies on the Ecology of Roots," *Ecology,* **18(1)**, 27-52 (January 1937).

Nielsen, Ole John, "A Literature Review on Radioactivity Transfer to Plants and Soil," Riso National Laboratory report Riso-R-450 (July 1981).

Nishita, H., D. Dixon, and K. H. Larson, "Accumulation of Cs and K and Growth of Bean Plants in Nutrient Solution and Soils," *Plant and Soil,* **XVII(2)**, 221-241 (October 1962).

Robinson, W. O., and Glen Edgington, "Minor Elements in Plants," *Soil Science,* **60**, 15-28 (1945).

Russell, R. Scott, "The Extent and Consequences of the Uptake by Plants of Radioactive Nuclides," *Annual Review of Plant Physiology,* **14**, 271-294 (1963).

Singh, J. S., and D. C. Coleman, "Evaluation of Functional Root Biomass and Translocation of Photoassimilated ^{14}C in a Shortgrass Prairie Ecosystem," in *The Belowground Ecosystem: A Synthesis of Plant-Associated Processes,* J. K. Marshall, Ed., Range Science Department, Science Series No. 26, Colorado State University, Fort Collins, Colorado (1977), pp. 123-131.

Squire, H. M., "Long-Term Studies of Strontium-90 in Soils and Pastures," *Radiation Botany,* **6**, 49-67 (1966).

Smith, William H., "Tree Root Exudates and the Forest Ecosystem: Exudate Chemistry, Biological Significance and Alteration by Stress," in *The Belowground Ecosystem: A Synthesis of Plant-Associated Processes,* J. K. Marshall, Ed., Range Science Department, Science Series No. 26, Colorado State University, Fort Collins, Colorado (1977), pp. 289-301.

Teare, I. D., "Water-Use as Affected by Transpiring Area and Root System," in *The Belowground Ecosystem: A Synthesis of Plant-Associated Processes,* J. K. Marshall, Ed., Range Science Department, Science Series No. 26, Colorado State University, Fort Collins Colorado (1977), pp. 227-238.

Trappe, James M., and Robert D. Fogel, "Ecosystematic Functions of Mycorrhizae," in *The Belowground Ecosystem: A Synthesis of Plant-Associated Processes,* J. K. Marshall, Ed., Range Science Department, Science Series No. 26, Colorado State University, Fort Collins, Colorado (1977), pp. 205-214.

"Tritium in Some Typical Ecosystems," Technical Reports Series No. 207, International Atomic Energy Agency, Vienna (1981).

Weaver, John E., and Frederic E. Clements, *Plant Ecology,* (McGraw-Hill Book Co., Inc., New York and London, 1938).

Weaver, J. E., and John W. Crist, "Relation of Hardpan to Root Penetration in the Great Plains," *Ecology,* **III(3)**, 237-249 (July 1922).

Wight, J. Ross, and A. L. Black, "Nitrogen and Phosphorus Uptake and Soil Water Use in a Mixed Prairie Plant Community," in *The Belowground Ecosystem: A Synthesis of Plant-Associated Processes,* J. K. Marshall, Ed., Range Science Department, Science Series No. 26, Colorado State University, Fort Collins, Colorado (1977), pp. 177-183.

APPENDIX A

ADDITIONAL DATA ON MOISTURE

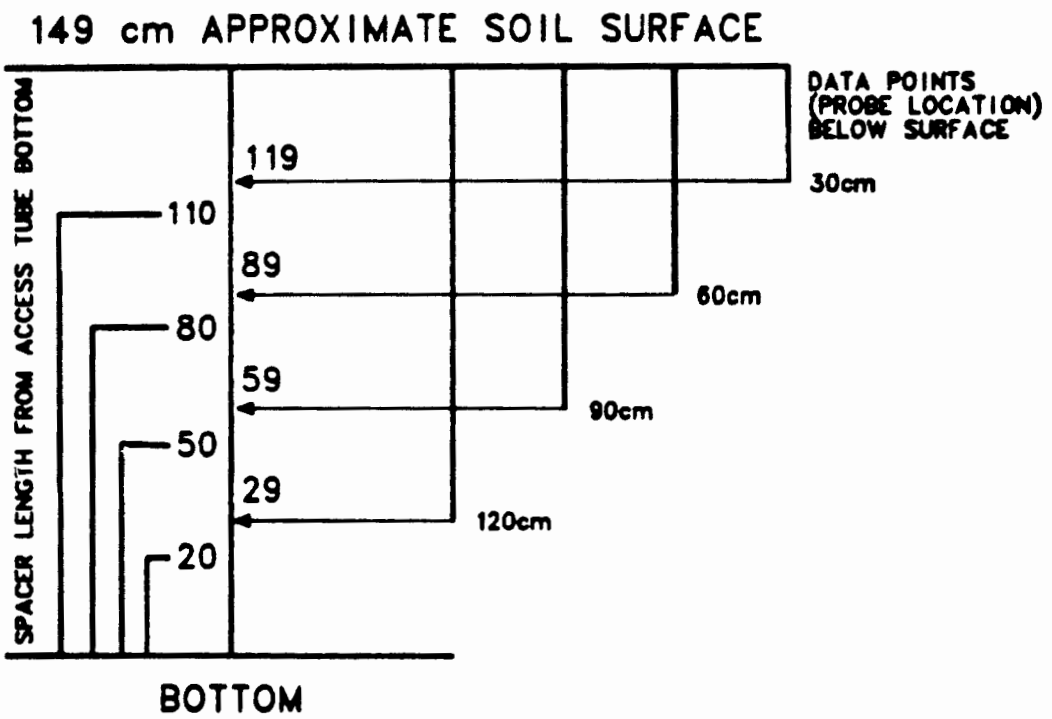

Fig. A-1. Moisture determination sampling locations.

TABLE A-I

NATURAL AND SUPPLEMENTAL ADDITIONS OF WATER
(cm)

1981	Natural	Supplement[a]
July		
6	0.15	–
7	0.28	0.79
8	0.13	–
10	–	5.79
11	–	5.79
14	0.33	5.79
15	0.13	–
16	–	5.79
17	0.20	5.79
21	–	5.79
22	0.33	5.79
24	0.20	5.79
25	0.36	–
26	0.02	–
27	0.61	–
30	0.03	2.36
31	0.03	–
Total	**2.791**	**9.43**
August		
1	0.38	–
2	0.51	–
6	0.05	–
8	0.03	–
9	0.30	–
10	0.15	–
11	0.56	–
12	0.23	–
14	0.08	–
15	0.03	–
16	0.10	–
17	–	0.79
21	–	0.79
22	0.08	–
27	0.20	–
28	0.51	0.79
31	0.38	–
Total	**3.12**	**2.37**
September		
1	0.20	–
2	–	2.36
4	1.96	–
5	0.74	–
7	0.03	–
8	0.18	–
12	0.64	–
13	0.89	–
14	0.05	–
23	0.02	2.36
24	0.18	–
30	–	2.36
Total	**4.88**	**7.08**

1981	Natural	Supplement[a]
October		
1	0.58	–
2	2.01	–
5	2.79	–
12	0.02	–
13	–	2.36
14	0.08	–
15	0.15	–
20	–	2.36
29	–	2.36
31	0.2	–
Total	**5.66**	**7.08**
November		
6	0.02	–
7	0.18	–
16	0.02	–
28	0.23	–
29	1.80	–
Total	**2.26**	**0.00**
December		
Total	**0.00**	**0.00**
January 1982		
1	0.20	–
5	0.51	–
6	0.18	–
9	0.10	–
12	0.08	–
13	0.03	–
14	0.10	–
15	0.10	–
22	0.02	–
29	0.05	–
30	0.28	–
Total	**1.19**	**0**
February		
2	0.05	–
7	0.02	–
8	0.02	–
9	0.05	–
10	0.15	–
11	1.22	–
12	0.10	–
13	0.46	–
14	0.13	–
18	0.25	–
24	0.02	–
26	0.25	–
Total	**2.74**	**0**

[a]Needed to maintain plant growth.

TABLE A-I (cont)

1982	Natural	Supplement[a]
March		
3	0.02	–
6	0.53	–
7	0.02	–
11	0.15	–
12	0.13	–
13	0.51	–
26	0.18	–
27	0.58	–
Total	**2.13**	**0**

1982	Natural	Supplement[a]
April		
21	–	0.79
22	0.13	–
23	0.25	–
30	0.15	0.79
Total	**0.53**	**1.58**
May		
2	0.02	–
5	1.90	–
12	0.10	–
13	0.33	–
14	0.02	–
16	0.02	–
17	0.30	–
20	–	2.36
22	0.69	–
23	0.02	–
24	0.25	–
25	0.13	–
Total	**3.81**	**2.36**
June		
1	–	3.14
7	–	3.14
14	–	3.14
16	0.08	–
20	1.04	–
23	–	1.57
25	–	3.14
25	–	3.14
Total	**1.12**	**17.27**
July		
2	–	1.57
6	–	3.14
9	–	3.14
11	2.39	–
14	0.23	–
16	0.13	4.71
17	0.08	–

1982	Natural	Supplement[a]
July (cont)		
18	1.40	–
19	0.05	–
26	–	3.14
27	0.30	–
28	0.15	–
29	2.64	–
30	0.18	–
31	0.2	–
Total	**7.570**	**15.70**
August		
3	0.13	–
10	–	3.14
11	0.43	–
14	0.10	–
16	0.13	–
17	0.69	–
18	0.05	–
19	0.76	–
21	1.24	–
22	0.56	–
23	0.20	–
24	1.70	–
25	0.36	–
26	0.23	–
29	0.13	–
30	0.10	–
Total	**6.81**	**3.14**
September		
4	0.69	–
6	0.10	–
7	0.28	–
12	0.28	–
13	0.13	–
15	0.20	–
16	1.50	–
17	0.25	–
18	2.18	–
19	0.02	–
20	1.37	–
30	0.10	–
Total	**7.11**	**0**
October		
2	0.02	–
11	0.48	–
12	0.58	–
12	0.05	–
15		
Total	**1.12**	**0**
Experiment Total	**52.85**	**66.04**

TABLE A-II

WATER CONTENT IN SEGMENTS OF THE CONTAINERS (ℓ)

Date	Segment Interval from Surface (cm) 0–15	15–45	45–75	75–105	150–135	135–149	0–149 Total
				Container 1A			
July 3, 1981	19.40	38.80	28.34	18.45	18.45	8.61	132.05
August 3	19.49	38.99	32.52	21.49	19.21	8.97	140.67
November 3	19.88	39.75	41.27	38.42	35.72	16.69	191.77
March 1, 1982	21.11	42.22	41.84	41.84	47.55	22.20	216.76
October 15	22.06	44.13	46.41	50.97	69.99	32.68	266.24
				Container 2A			
July 3	17.59	35.19	34.24	27.39	21.30	9.94	145.65
August 3	17.97	35.95	34.81	31.95	23.58	11.01	155.27
November 3	19.78	39.56	39.94	35.00	36.14	16.87	187.29
March 1	20.92	41.84	42.98	46.79	45.27	21.13	218.93
November 15	19.49	38.99	46.79	52.49	66.19	30.90	254.85
				Container 1B			
July 3	18.16	36.33	37.47	23.20	26.25	12.25	153.66
August 3	21.11	42.22	36.90	27.39	26.82	12.52	166.96
November 3	4.94	9.89	22.82	30.24	26.25	12.25	106.39
March 1	14.17	28.34	21.68	23.77	26.06	12.16	126.18
October 15	6.18	12.36	17.50	11.22	12.17	5.68	65.11
				Container 2B			
July 3	18.35	36.71	36.14	19.21	18.83	8.79	138.03
August 3	18.83	37.66	38.04	29.29	19.59	9.14	152.55
November 3	4.09	8.18	21.87	28.14	22.44	10.48	95.20
March 1	14.74	29.48	23.20	24.15	22.06	10.30	123.93
October 15	4.94	9.89	22.63	21.87	19.59	9.15	88.07
				Container 3A			
July 3	13.50	27.01	43.75	37.85	20.27	9.68	152.06
August 3	18.54	37.09	36.33	34.81	27.96	13.05	167.78
November 3	20.26	40.51	40.13	33.28	38.99	18.20	191.37
March 1	20.54	41.08	43.75	42.79	44.70	20.87	213.73
October 15	18.07	36.14	42.98	52.11	57.82	26.99	234.11
				Container 4A			
July 3	18.45	36.90	35.00	31.38	20.35	9.50	151.58
August 3	20.07	40.13	35.57	31.38	24.73	11.54	163.42
November 3	19.11	38.23	38.80	32.33	37.28	17.40	183.15
March 1	21.97	43.94	41.08	41.27	42.80	19.98	211.04
October 15	19.30	38.61	43.94	50.40	60.86	28.42	241.53

TABLE A-II (cont)

Date	Segment Interval from Surface (cm) 0–15	15–45	45–75	75–105	150–135	135–149	0–149 Total
				Container 3B			
July 3	11.51	23.01	37.85	31.95	17.31	8.08	129.71
August 3	18.73	37.47	35.57	32.33	21.87	10.21	156.18
November 3	2.85	5.71	14.26	27.39	24.35	11.37	85.93
March 1	14.07	28.15	14.64	21.30	22.82	10.66	111.64
October 15	2.85	5.71	13.69	16.17	13.12	6.13	57.67
				Container 4B			
July 3	15.50	31.00	26.82	30.62	21.30	9.95	135.19
August 3	19.97	39.94	27.39	29.48	21.87	10.21	148.86
November 3	3.80	7.61	13.12	27.01	21.49	10.03	83.06
March 1	13.79	27.58	14.45	21.68	21.49	10.03	109.02
October 15	3.23	6.47	15.22	21.30	22.25	10.39	78.86
				Container 5A			
July 3	29.48	58.96	50.02	45.84	35.95	16.78	237.03
August 3	24.63	49.26	46.22	47.55	39.94	18.65	226.25
November 3	24.63	49.26	46.03	48.69	51.16	23.89	243.66
March 1	25.87	51.73	48.12	55.16	52.68	24.60	258.16
October 15	24.82	49.64	48.88	57.06	63.91	29.84	274.15
				Container 6A			
July 3	26.15	52.31	45.65	37.28	42.60	19.89	223.88
August 3	23.39	46.79	40.89	42.03	45.27	21.13	219.50
November 3	24.25	48.50	44.13	43.75	51.16	23.89	235.68
March 1	23.68	47.36	46.03	50.59	52.49	24.51	244.66
October 15	22.63	45.27	44.89	54.40	57.06	26.64	250.89
				Container 5B			
July 3	23.58	47.17	51.35	43.94	45.27	21.13	232.44
August 3	21.97	43.94	47.93	46.41	49.07	22.91	232.23
November 3	11.22	22.44	33.66	38.99	41.27	19.27	166.85
March 1	19.11	38.23	38.61	35.19	38.23	17.85	187.22
November 15	6.09	12.17	15.60	9.51	8.75	4.08	56.20
				Container 6B			
July 3	23.49	46.98	54.97	42.41	40.13	18.74	226.72
August 3	21.02	42.03	45.08	44.13	42.80	19.98	215.04
November 3	6.94	13.88	35.00	38.99	36.90	17.23	148.94
March 1	18.35	36.71	36.52	33.86	33.86	15.81	175.11
October 15	6.09	12.17	20.54	12.74	10.65	4.97	67.16

TABLE A-II (cont)

Date	Segment Interval from Surface (cm) 0–15	15–45	45–75	75–105	150–135	135–149	0–149 Total
				Container 7A			
July 3	23.49	46.98	52.50	46.79	41.46	19.36	230.58
August 3	21.40	42.80	50.78	43.17	41.46	19.36	218.97
November 3	23.30	46.60	49.45	43.37	47.74	22.29	232.75
March 1	24.54	49.07	50.59	45.08	49.07	22.91	241.26
October 15	19.50	38.99	50.21	47.17	54.59	25.48	235.94
				Container 8A			
July 3	25.96	51.92	54.59	49.07	48.50	22.64	252.68
August 3	21.40	42.80	49.45	46.41	49.07	22.91	232.04
November 3	22.92	45.84	50.59	46.79	57.44	26.82	250.40
March 1	24.15	48.31	50.02	48.31	57.63	26.91	255.33
October 15	20.26	40.51	49.45	49.45	58.39	27.26	245.42
				Container 7B			
July 3	24.73	49.45	47.36	47.74	44.32	20.69	234.29
August 3	23.58	47.17	46.22	48.31	46.41	21.67	233.36
November 3	4.47	8.94	26.06	45.84	39.56	18.47	143.34
March 1	17.21	34.43	27.39	35.95	33.86	15.81	164.65
November 15	5.04	10.08	17.12	15.22	10.27	4.80	62.53
				Container 8B			
July 3	24.44	48.88	45.46	47.55	41.84	19.54	227.71
August 3	24.25	48.50	43.75	46.41	42.03	19.62	224.56
November 3	4.47	8.94	23.39	38.61	34.81	16.25	126.47
March 1	9.70	19.40	19.40	32.14	32.33	15.10	128.07
October 15	3.90	7.80	17.72	13.88	11.98	5.59	60.87

TABLE A-III

MOISTURE CHANGE IN LITERS AS A FUNCTION OF TIME (July 3 to August 3, 1981)

Depth (cm)	Container															
	1A	2A	1B	2B	3A	4A	3B	4B	5A	6A	5B	6B	7A	8A	7B	8B
15 – 45	0.19	0.76	5.89	0.95	10.08	3.23	14.46	8.94	-9.70	-5.52	-3.23	-4.95	-4.18	-9.12	-2.28	-0.38
45 – 75	4.18	0.57	-0.57	1.90	-7.42	0.57	-2.28	0.57	-3.80	-4.76	-3.42	-9.89	-1.72	-5.14	-1.14	-1.71
75 – 105	3.04	4.56	4.19	10.08	-3.04	0.0	0.38	-1.14	1.71	4.75	2.47	1.72	-3.62	-2.66	0.57	-1.14
105 – 135	0.76	2.28	0.57	0.76	7.69	4.38	4.56	0.57	3.99	2.67	3.80	2.67	0.0	0.57	2.09	0.19
Total 0 – 149	8.62	9.62	13.30	14.52	15.72	11.84	26.47	13.67	-10.78	-4.38	-0.21	-11.61	-1.61	-20.64	-0.93	-3.15
15 – 45	0.76	3.61	-32.33	-29.48	3.42	-1.90	-31.76	-32.33	0	1.71	-21.50	-28.15	3.80	3.04	-38.23	-39.56
45 – 75	8.75	5.13	-14.08	-16.17	3.80	3.23	-21.31	-14.27	-0.19	3.24	-14.27	-10.08	-1.33	1.14	-20.16	-20.36
75 – 105	16.93	3.05	2.85	-1.15	-1.53	0.95	-4.94	-2.47	1.14	1.72	-7.42	-5.14	0.20	0.38	-2.47	-7.80
105 – 135	16.55	12.56	-0.57	2.85	11.03	12.55	2.48	-0.38	11.22	5.89	-7.80	-5.90	6.28	8.37	-6.85	-7.22
Total 0 – 149	51.10	32.02	-60.57	-57.35	23.59	19.73	-70.25	-65.80	17.41	16.18	-65.38	-66.10	13.78	18.36	-90.02	-98.09
15.-45	2.47	2.28	18.45	21.30	0.57	5.71	22.44	19.97	2.47	-1.14	15.79	22.83	2.47	2.47	25.49	10.46
45 – 75	0.57	3.04	-1.14	1.33	3.62	2.28	0.38	1.33	2.09	1.90	4.95	1.52	1.14	-0.57	1.33	-3.99
75 – 105	3.42	11.79	-6.47	-3.99	9.51	8.94	-6.09	-5.33	6.47	6.84	-3.80	-5.13	1.71	1.52	-9.89	-6.47
105 – 135	11.79	9.13	-0.19	-0.38	5.71	5.52	1.53	0.0	1.52	1.33	-3.04	-3.04	1.33	0.19	-5.70	-2.48
Total 0 – 149	24.99	31.64	19.79	28.73	22.36	27.89	25.71	25.96	14.50	8.98	20.37	26.17	8.51	4.93	21.31	1.60
15 – 45	1.91	-2.85	-15.98	-19.59	-4.94	-5.33	-22.44	-21.11	-2.09	-2.09	-26.06	-24.54	-10.08	-7.80	-24.35	-11.60
45 – 75	4.57	3.81	-4.18	-0.57	-0.77	2.86	-0.95	0.77	0.76	-1.14	-23.01	-15.98	-0.38	-0.57	-10.27	-1.68
75 – 105	9.13	5.70	-12.55	-2.28	9.32	9.13	-5.13	-0.38	1.90	3.81	-25.68	-21.12	2.09	1.14	-20.73	-18.26
105 – 135	22.44	20.92	-13.89	2.47	13.12	18.06	-1.53	0.76	11.23	4.57	-29.48	-23.21	5.52	0.76	-23.59	-20.35
Total 0 – 149	49.48	35.92	-61.07	-35.86	20.38	30.49	-53.97	-30.16	15.99	6.23	-131.02	-107.95	-5.32	-9.91	-102.12	-67.20
15 – 45	5.33	3.80	-23.97	-26.82	9.13	1.71	-17.30	-24.53	-9.32	-7.04	-35.00	-34.81	-7.99	-11.41	-39.37	-41.08
45 – 75	18.07	12.55	-19.97	-13.51	-0.77	8.94	-24.16	-11.60	-1.14	-0.76	-35.75	-34.43	-2.29	-5.14	-30.24	-27.74
75 – 105	32.52	25.10	-11.98	2.66	14.26	19.02	-15.78	-9.32	11.22	17.12	-34.43	-29.67	0.38	0.38	-32.52	-33.67
105 – 135	51.54	44.89	-14.08	0.76	37.55	40.51	-4.19	0.95	27.96	14.46	-36.52	-29.48	13.13	9.89	-34.05	-29.86
Total 0 – 149	134.19	109.20	-88.55	-49.96	82.05	89.95	-72.04	-56.33	37.12	27.01	-176.24	-159.56	5.36	-7.36	-171.76	-166.84

APPENDIX B

SOIL MOISTURE AS A FUNCTION OF TIME AND DEPTH

(Moisture per cent by volume)

Container Number	7/3/81	7/6	7/8	7/10	7/17	7/20	7/22	7/24	7/27	7/29	7/31
30 cm depth											
1A	20.4	19.8	18.5	19.2	20.6	19.6	19.0	19.3	19.2	20.2	20.5
2A	18.5	17.2	17.1	16.7	16.8	17.8	17.3	18.2	18.1	18.1	18.9
1B	19.1	18.8	19.9	18.4	19.6	19.7	20.5	20.3	20.5	21.3	22.5
2B	19.3	17.3	17.1	16.5	17.0	18.6	17.3	18.8	18.4	18.2	20.7
60 cm depth											
1A	14.9	16.2	15.4	16.9	17.6	17.2	16.2	16.3	16.8	17.3	16.4
2A	18.0	18.0	18.5	17.8	17.3	17.6	17.2	17.0	16.7	17.5	17.2
1B	19.7	19.7	18.1	17.9	18.2	19.2	18.3	17.9	19.3	19.0	20.4
2B	19.0	18.2	18.1	18.3	18.0	19.0	18.9	19.1	18.7	18.3	19.1
90 cm depth											
1A	9.7	9.3	10.6	10.1	11.5	11.1	11.6	11.5	11.6	11.9	11.7
2A	14.4	15.4	16.3	14.8	16.8	17.2	16.3	16.5	15.7	16.7	16.2
1B	12.2	13.6	12.7	13.6	14.1	14.3	13.9	14.2	13.7	14.6	14.6
2B	10.1	10.6	11.2	10.8	12.4	12.6	12.9	12.8	13.9	14.1	14.2
120 cm depth											
1A	9.7	10.0	9.6	9.7	9.6	9.7	9.6	10.3	9.4	9.7	9.6
2A	11.2	11.1	11.5	11.5	11.4	11.6	11.5	12.0	11.6	12.0	11.8
1B	13.8	13.5	13.8	14.0	13.8	13.6	13.2	13.6	13.6	13.8	13.6
2B	9.9	10.5	10.0	10.0	10.9	10.1	10.7	10.3	10.2	10.8	10.8

	8/3/81	8/7	8/10	8/14	9/1	9/2	9/3	9/8	9/11
30 cm depth									
1A	20.5	20.3	20.3	19.2	18.5	23.4	21.3	23.2	21.4
2A	18.9	18.5	17.7	17.2	16.5	19.1	20.2	19.8	19.3
1B	22.2	20.8	20.6	17.9	6.7	8.7	8.5	12.2	11.0
2B	19.8	18.4	16.8	16.1	5.6	6.6	6.7	9.8	10.6
60 cm depth									
1A	17.1	17.8	17.3	16.8	16.8	16.9	18.9	20.3	20.2
2A	18.3	17.4	17.1	16.5	16.2	15.7	17.2	19.3	19.0
1B	19.4	19.4	19.0	18.8	15.5	14.4	15.2	15.1	16.8
2B	20.0	18.4	18.7	18.1	15.0	15.6	14.5	15.1	14.5
90 cm depth									
1A	11.3	12.3	13.6	12.6	13.8	13.4	16.0	15.5	20.2
2A	16.8	16.7	17.1	18.0	17.0	17.0	17.2	18.4	18.4
1B	14.4	14.4	15.7	15.4	15.7	14.7	15.0	14.6	15.9
2B	15.4	15.5	16.3	16.7	15.5	15.3	14.8	14.9	14.8
120 cm depth									
1A	10.1	9.3	9.8	9.5	10.7	10.5	10.8	10.5	10.6
2A	12.4	12.3	12.7	12.5	13.6	13.7	13.2	12.5	14.4
1B	14.1	14.2	14.2	14.0	14.0	13.8	14.8	14.6	16.0
2B	10.3	10.0	10.9	11.2	12.6	11.9	11.4	12.4	12.1

	10/29	11/3	11/17	11/19	12/3	12/7	12/21	1/4/82	1/25
30 cm depth									
1A	20.5	20.9	19.9	21.5	21.6	21.7	19.0	20.1	19.7
2A	20.0	20.8	19.0	22.0	20.2	21.1	20.2	19.6	19.7
1B	5.2	5.2	3.8	5.4	5.6	6.1	5.3	5.9	6.1
2B	4.3	4.3	2.9	4.5	5.6	5.5	4.7	5.2	6.2
60 cm depth									
1A	20.6	21.7	20.6	21.6	20.9	21.5	20.9	21.0	20.2
2A	21.4	21.0	20.4	19.8	20.9	21.0	20.4	21.1	19.6
1B	11.5	12.0	11.3	11.4	11.8	10.9	11.5	10.7	12.5
2B	11.3	11.5	11.0	10.3	10.7	11.6	11.1	11.0	11.1
90 cm depth									
1A	20.4	20.3	20.2	20.1	20.6	21.1	19.3	20.1	20.5
2A	22.0	22.7	21.6	21.1	21.8	21.8	21.7	21.9	21.4
1B	13.2	13.3	12.7	13.5	13.0	12.5	13.5	12.5	13.1
2B	12.7	13.0	13.5	12.5	12.3	12.7	12.1	11.9	12.9
120 cm depth									
1A	18.8	18.8	21.0	21.2	20.3	22.0	21.4	23.0	22.5
2A	18.6	19.0	19.1	20.3	19.4	20.5	21.2	21.1	22.2
1B	14.7	13.8	13.5	13.8	14.1	14.4	13.3	13.4	14.9
2B	12.7	11.8	11.6	12.7	11.9	11.9	11.7	12.7	11.9

	2/10	2/17	2/24	3/1	4/6	4/14	4/21	4/28	4/30
30 cm depth									
1A	18.8	23.4	24.6	22.2	21.9	20.6	20.1	20.8	20.3
2A	18.9	23.7	23.1	22.0	21.1	19.5	19.8	19.6	19.7
1B	6.7	8.6	15.3	14.9	12.6	6.9	5.4	5.7	5.4
2B	7.4	7.2	15.1	15.5	12.5	6.2	4.7	4.9	4.6
60 cm depth									
1A	19.8	19.6	23.7	22.0	22.5	22.0	21.5	21.6	22.0
2A	19.8	20.8	23.1	22.6	24.0	21.9	21.4	21.5	21.8
1B	11.5	11.5	10.8	11.4	12.7	12.7	12.2	12.5	12.4
2B	11.8	11.3	11.9	12.2	15.2	13.7	13.1	13.0	13.6
90 cm depth									
1A	19.9	19.7	22.6	22.0	23.0	22.8	22.4	23.2	22.7
2A	22.1	21.5	24.9	24.6	NA	23.9	23.3	23.3	23.7
1B	13.3	12.4	12.8	12.5	13.5	13.2	12.6	12.7	12.6
2B	13.0	12.3	12.1	12.7	13.5	13.5	13.0	13.3	13.3
120 cm depth									
1A	22.4	22.0	22.0	25.0	28.3	28.0	26.9	27.9	27.5
2A	22.1	21.5	22.1	23.8	NA	26.2	25.8	26.1	26.4
1B	14.8	14.2	13.9	13.7	14.1	14.7	14.2	14.2	14.2
2B	12.4	12.3	11.5	11.6	12.7	12.3	11.9	12.4	12.2

	5/7	5/11	5/17	5/25	6/1	6/10	6/14	6/21	6/30
30 cm depth									
1A	22.4	20.7	20.1	22.1	20.0	21.6	20.5	22.1	25.5
2A	20.8	19.8	19.2	20.1	19.7	20.3	19.0	20.2	23.9
1B	6.7	5.7	5.5	6.2	4.9	6.4	5.2	6.1	7.5
2B	5.2	9.5	4.4	4.6	4.0	5.7	4.9	5.0	7.0
60 cm depth									
1A	22.0	22.2	21.9	21.4	22.0	22.6	21.6	22.7	24.0
2A	21.7	21.9	21.2	21.8	21.2	21.6	22.2	22.2	22.3
1B	11.7	12.0	11.6	11.5	11.3	11.3	11.0	10.8	10.7
2B	12.9	12.6	12.5	11.8	12.3	12.1	11.7	11.7	12.0
90 cm depth									
1A	22.8	22.8	23.0	22.9	22.9	23.3	22.9	23.3	24.1
2A	23.8	23.9	23.5	24.1	23.2	24.1	23.7	23.3	24.3
1B	13.0	12.6	11.6	11.4	11.4	10.5	10.3	10.6	10.1
2B	13.3	13.0	12.8	12.4	12.6	11.8	12.9	12.7	12.0
120 cm depth									
1A	27.3	27.6	27.1	27.1	27.5	28.2	28.3	28.0	30.2
2A	27.0	26.0	26.8	26.0	26.1	25.8	26.6	27.3	27.4
1B	14.1	14.1	14.0	13.6	13.7	13.0	12.5	12.6	12.1
2B	12.4	12.7	12.9	12.0	12.2	13.0	12.4	12.9	12.4

	7/6	7/12	7/14	7/19	7/23	7/27	7/30	8/6	8/13	8/23
30 cm depth										
1A	24.3	26.9	24.0	27.5	23.4	25.4	28.6	22.5	23.8	24.6
2A	22.0	NA	22.8	25.3	21.7	23.7	26.8	21.5	21.9	22.5
1B	6.4	8.4	7.2	9.9	8.2	7.3	10.3	7.5	6.8	6.9
2B	5.4	8.3	7.8	12.7	8.0	6.7	8.7	5.2	5.7	6.2
60 cm depth										
1A	23.1	25.7	24.5	26.3	25.9	25.9	26.3	25.8	24.6	24.4
2A	22.1	24.3	24.2	25.0	24.8	24.2	28.2	24.7	24.7	23.8
1B	10.4	10.4	10.3	10.6	10.7	10.2	10.2	10.1	9.8	9.8
2B	11.7	12.3	11.1	11.8	12.6	11.7	12.4	11.5	11.6	11.3
90 cm depth										
1A	24.0	25.7	26.7	27.0	27.7	NA	28.4	27.7	27.9	27.6
2A	23.9	24.6	25.8	27.0	27.0	26.8	28.6	27.9	26.8	27.0
1B	9.8	9.9	9.5	9.9	9.5	9.8	8.9	9.3	8.3	
2B	12.0	12.4	12.4	12.0	12.6	11.5	12.4	12.1	12.2	11.5
120 cm depth										
1A	30.4	32.3	33.6	36.8	35.7	37.0	35.8	37.0	37.3	36.6
2A	26.7	28.9	30.1	33.8	33.5	32.4	35.2	35.6	35.4	33.6
1B	12.0	12.7	12.4	12.0	12.4	11.3	10.9	11.0	9.4	9.1
2B	12.5	12.0	12.2	12.8	12.4	12.1	12.2	12.6	11.5	11.9

	9/2	9/9	9/14	9/20	9/28	10/5	10/15
30 cm depth							
1A	22.4	22.7	21.3	29.6	22.4	21.2	23.2
2A	20.1	20.7	20.2	27.1	20.6	20.0	20.5
1B	6.0	6.1	5.2	12.8	11.4	7.1	6.5
2B	5.0	4.2	4.4	11.4	11.1	6.8	5.2
60 cm depth							
1A	24.3	23.6	24.2	26.4	22.4	24.8	24.4
2A	24.1	24.2	23.8	25.6	20.6	22.8	24.6
1B	9.5	9.4	9.2	8.6	11.4	9.1	9.2
2B	10.7	11.5	10.3	10.9	11.1	11.3	11.9
90 cm depth							
1A	27.8	25.9	27.4	28.0	27.4	26.3	26.8
2A	27.2	27.6	27.1	28.1	28.4	26.8	27.6
1B	7.6	6.8	7.1	6.6	7.0	6.6	5.9
2B	11.0	11.5	10.5	11.1	11.8	10.7	11.5
120 cm depth							
1A	36.6	35.9	35.4	36.7	36.9	34.6	36.8
2A	35.0	33.6	33.0	34.9	36.6	34.5	34.8
1B	7.8	7.1	6.7	6.8	5.9	5.9	6.4
2B	11.4	10.5	11.8	11.0	10.8	11.6	10.3

	7/3	7/6	7/8	7/10	7/17	7/20	7/22	7/24	7/27	7/29	7/31
30 cm depth											
3A	14.2	14.0	14.6	13.6	15.3	15.3	15.6	17.0	16.3	17.0	19.5
4A	19.4	19.4	18.5	18.3	19.4	19.0	17.9	19.8	19.4	19.3	22.2
3B	12.1	12.3	13.9	12.5	14.8	16.4	17.1	17.8	18.6	17.8	20.4
4B	16.3	15.4	14.6	15.2	18.1	18.6	18.1	19.6	18.8	19.1	21.2
60 cm depth											
3A	23.0	21.4	20.8	20.9	20.6	20.0	20.1	20.2	18.7	20.0	18.6
4A	18.4	18.3	17.7	18.8	19.0	17.5	18.4	17.2	18.3	18.1	19.1
3B	19.9	19.9	18.3	18.7	18.1	18.6	18.3	18.0	17.7	17.7	18.2
4B	14.1	13.3	13.5	13.8	13.9	14.3	14.4	14.2	14.8	13.9	14.6
90 cm depth											
3A	19.9	19.2	19.9	19.1	19.1	18.8	19.0	18.8	18.1	18.6	19.4
4A	16.5	17.4	16.5	16.5	17.0	16.6	16.8	16.3	16.4	15.6	17.0
3B	16.8	17.7	17.2	17.0	17.0	18.2	17.2	18.1	18.2	16.0	16.8
4B	16.1	16.1	16.2	15.0	16.6	15.5	15.0	15.2	14.6	16.2	15.7
120 cm depth											
3A	10.9	11.6	12.0	12.6	14.0	14.8	14.1	14.6	13.8	14.2	14.9
4A	10.7	11.8	11.2	11.8	12.0	11.6	12.3	12.4	12.0	13.2	12.9
3B	9.1	10.2	9.9	10.6	11.5	11.4	11.6	11.0	11.3	12.3	11.4
4B	11.2	11.6	11.0	10.6	11.9	11.5	11.8	11.7	11.6	11.4	11.7

	8/3	8/7	8/10	8/14	9/1	9/2	9/3	9/8	9/11
30 cm depth									
3A	19.5	18.0	17.7	15.4	16.4	19.4	19.2	23.1	20.3
4A	21.1	20.5	20.0	18.6	17.9	23.7	22.4	23.6	22.0
3B	19.7	18.1	17.9	15.4	3.36	4.9	4.9	8.5	7.3
4B	21.0	16.8	14.1	12.3	2.0	7.4	6.4	9.1	7.0
60 cm depth									
3A	19.1	20.7	19.2	17.7	20.1	19.5	19.6	20.3	20.1
4A	18.7	18.1	18.2	18.2	17.5	18.7	18.2	19.9	19.6
3B	18.7	17.3	19.1	16.8	11.0	12.2	11.3	11.5	9.3
4B	14.4	15.9	15.0	14.6	6.7	7.0	7.1	7.9	7.8
90 cm depth									
3A	18.3	17.8	17.6	17.7	17.6	18.1	18.1	17.0	17.5
4A	16.5	16.4	16.1	15.9	16.7	15.6	16.5	17.7	17.0
3B	17.0	16.5	17.4	17.1	16.2	17.1	16.3	16.3	14.4
4B	15.5	15.5	14.8	15.2	14.3	14.0	14.8	13.2	15.2
120 cm depth									
3A	14.7	14.6	15.7	14.8	15.5	14.6	15.4	14.8	16.1
4A	13.0	12.8	13.3	13.6	14.1	13.9	12.8	13.7	13.7
3B	11.5	12.2	11.2	12.2	14.0	13.7	14.2	13.6	14.1
4B	11.5	11.3	12.6	11.8	13.3	12.0	12.4	12.2	12.0

	10/29	11/3	11/17	11/19	12/3	12/7	12/21	1/4	1/25
30 cm depth									
3A	19.8	21.3	19.4	22.5	20.1	22.3	20.3	18.3	20.1
4A	21.5	20.1	19.0	22.8	21.9	20.9	19.6	18.7	22.1
3B	2.6	3.0	1.8	2.7	3.7	3.9	3.5	3.6	8.8
4B	4.7	4.0	1.9	3.6	4.2	4.3	3.2	2.6	8.1
60 cm depth									
3A	21.3	21.1	19.7	21.3	21.1	21.0	21.3	21.3	22.7
4A	20.3	20.4	20.6	20.4	21.0	20.1	20.1	19.3	22.5
3B	7.6	7.5	6.4	7.0	6.8	4.4	6.9	7.8	8.3
4B	6.7	6.9	6.6	6.3	5.8	6.4	6.3	7.4	7.0
90 cm depth									
3A	20.1	20.7	19.9	20.3	20.0	20.4	21.1	19.9	20.3
4A	20.8	20.9	20.0	21.2	20.6	21.5	21.1	20.6	20.1
3B	11.9	12.6	12.2	12.0	11.9	12.2	12.4	11.9	12.5
4B	12.4	11.8	12.0	11.6	10.9	10.9	10.9	10.4	11.1
120 cm depth									
3A	20.0	20.5	19.6	20.2	19.8	20.0	20.9	20.9	21.8
4A	21.2	19.6	21.8	21.3	20.3	20.9	20.5	21.3	21.3
3B	12.7	12.8	12.9	12.9	13.0	13.1	11.8	12.3	12.6
4B	11.5	11.3	11.8	11.8	11.6	11.3	11.0	11.4	11.8

	2/10	2/17	2/24	3/1	4/6	4/14	4/21	4/28	4/30
30 cm depth									
3A	18.3	22.5	23.4	21.6	21.0	19.5	18.5	18.7	18.0
4A	19.3	24.1	23.6	23.1	21.1	20.0	20.1	19.1	19.2
3B	4.7	5.4	15.7	14.8	12.4	5.9	2.7	2.5	2.2
4B	4.4	4.8	13.0	14.5	12.5	6.7	3.6	2.7	2.6
60 cm depth									
3A	21.3	21.3	23.3	23.0	22.7	22.3	22.0	22.2	22.5
4A	20.8	19.4	22.6	21.6	21.8	21.3	20.7	20.9	21.3
3B	7.8	8.0	11.5	7.7	9.4	9.1	8.4	8.1	7.8
4B	6.9	7.0	7.0	7.6	8.8	8.4	7.9	7.4	7.7
90 cm depth									
3A	19.8	20.6	24.0	22.5	23.2	22.7	23.3	22.9	
4A	20.4	20.1	22.9	21.7	22.9	22.5	22.0	22.3	22.2
3B	13.0	11.5	12.7	11.2	12.6	12.4	11.9	11.6	12.0
4B	11.0	11.3	11.3	11.4	11.6	11.5	11.3	11.5	11.4
120 cm depth									
3A	21.5	22.2	22.0	23.5	25.4	24.9	23.9	24.5	24.6
4A	21.2	21.6	20.4	22.5	25.0	24.7	24.5	25.2	25.3
3B	12.2	13.0	11.0	12.0	12.4	12.3	12.2	12.2	12.3
4B	11.7	11.2	11.6	11.3	11.7	11.3	11.3	11.5	11.0

	5/7	5/11	5/17	5/25	6/1	6/10	6/14	6/21	6/30
30 cm depth									
3A	20.3	18.7	17.7	19.4	16.9	18.9	17.9	18.5	22.4
4A	21.5	20.1	18.9	19.4	18.4	19.1	19.0	20.5	24.7
3B	3.3	2.5	2.2	2.3	1.7	3.9	2.6	2.5	5.1
4B	3.8	2.5	2.1	6.3	1.9	6.7	3.7	3.3	5.9
60 cm depth									
3A	22.1	22.4	22.0	21.9	21.3	21.5	21.7	23.2	22.2
4A	20.9	21.1	21.1	21.5	20.9	21.0	20.9	21.6	20.8
3B	12.6	8.0	7.7	7.3	7.0	7.9	7.4	7.6	7.6
4B	7.5	7.4	7.2	11.4	7.6	7.1	7.4	7.7	7.2
90 cm depth									
3A	23.1	23.0	22.9	22.6	22.1	21.5	23.3	24.0	22.9
4A	22.4	22.3	22.4	21.4	22.1	21.3	22.4	22.8	22.1
3B	12.9	11.9	12.3	11.2	11.5	11.1	11.4	11.5	11.3
4B	11.4	11.4	11.6	11.5	11.7	11.0	11.0	11.0	11.2
120 cm depth									
3A	24.9	24.6	25.1	24.5	23.9	25.0	24.2	24.3	24.1
4A	25.0	24.7	24.8	24.6	25.0	25.1	24.4	25.0	24.7
3B	12.1	12.4	12.2	12.4	12.0	12.8	12.1	12.0	11.9
4B	11.5	11.8	11.5	12.5	11.3	11.8	11.5	12.0	11.3

	7/6	7/12	7/14	7/19	7/23	7/27	7/30	8/6	8/13	8/23
30 cm depth										
3A	22.5	27.2	24.2	28.6	22.5	23.7	28.7	19.4	20.6	21.4
4A	22.8	26.1	24.3	28.6	22.0	22.9	28.3	20.1	21.0	22.5
3B	3.5	4.8	3.9	5.2	2.5	3.6	6.0	3.6	2.7	3.2
4B	4.5	9.3	7.1	12.8	4.1	5.3	9.1	2.4	4.8	4.8
60 cm depth										
3A	22.0	23.2	23.7	27.0	24.4	24.1	26.6	23.1	23.3	22.2
4A	21.2	22.0	22.8	25.4	22.9	22.6	24.1	22.5	23.9	22.2
3B	7.3	7.9	7.5	7.8	7.3	7.4	7.7	7.4	7.1	7.5
4B	7.1	7.4	7.4	7.2	7.3	6.8	7.6	6.6	7.4	7.1
90 cm depth										
3A	22.9	23.9	23.5	25.9	24.7	26.2	25.9	26.2	26.3	25.1
4a	22.0	23.1	23.3	24.6	25.2	24.1	25.4	24.1	25.7	24.6
3B	11.1	11.4	11.1	11.4	11.0	10.5	11.2	11.1	10.6	9.8
4B	10.5	11.0	11.3	11.3	10.5	10.9	11.1	10.7	11.4	10.6
120 cm depth										
3A	24.2	24.7	24.9	26.5	28.2	28.5	28.2	28.9	30.8	29.8
4A	24.9	25.0	25.8	27.8	30.3	39.6	29.6	29.8	31.7	31.0
3B	11.6	12.0	11.5	11.5	10.7	10.4	11.2	10.3	9.2	8.2
4B	11.5	11.8	11.2	11.1	10.7	10.9	11.3	11.0	11.5	11.4

	9/2	9/9	9/14	9/20	9/28	10/5	10/15
30 cm depth							
3A	20.5	19.2	17.6	28.5	20.0	17.8	19.0
4A	20.3	19.2	19.4	27.7	19.9	19.7	20.3
3B	2.3	2.4	2.2	8.3	8.2	3.7	3.0
4B	2.3	2.0	2.0	16.4	10.9	4.1	3.4
60 cm depth							
3A	23.5	22.6	22.9	23.7	20.0	23.6	22.6
4A	22.3	21.9	22.2	23.2	19.9	22.9	23.1
3B	7.2	7.1	7.3	7.2	8.2	7.0	7.2
4B	7.0	7.3	7.3	6.4	10.9	7.0	8.0
90 cm depth							
3A	23.8	25.5	26.8	24.9	27.6	25.4	27.4
4A	25.5	25.8	25.0	25.6	26.5	26.0	26.5
3B	9.1	9.8	9.2	10.0	8.4	9.9	8.5
4B	10.3	10.4	10.5	9.8	11.0	10.4	11.2
120 cm depth							
3A	30.9	30.1	30.0	30.4	30.6	29.4	30.4
4A	3.14	32.0	31.0	30.9	33.1	32.4	32.0
3B	7.2	6.4	6.6	6.7	6.0	6.4	6.9
4B	11.3	11.2	11.0	11.1	11.5	11.4	11.7

	7/3	7/6	7/8	7/10	7/17	7/20	7/22	7/24	7/27	7/29	7/31
30 cm depth											
5A	31.0	27.3	26.7	26.2	27.8	26.8	24.4	25.1	25.1	25.0	26.8
6A	27.5	25.7	24.3	24.2	24.2	23.7	24.4	24.8	25.0	24.2	24.3
5B	24.8	22.9	21.5	21.1	23.0	22.7	22.1	21.0	22.9	22.1	23.7
6B	24.7	23.1	22.9	22.2	24.1	22.1	21.0	21.0	21.9	21.8	22.2
60 cm depth											
5A	26.3	26.1	24.8	24.9	24.8	23.4	24.1	23.3	25.4	23.6	23.4
6A	24.0	22.8	23.2	23.0	23.0	21.3	22.6	21.9	22.7	22.1	21.3
5B	27.0	26.5	24.9	26.0	25.4	25.0	24.7	25.1	25.0	25.1	24.7
6B	28.9	25.7	25.0	24.6	24.9	24.8	24.2	24.1	24.8	23.8	24.5
90 cm depth											
5A	24.1	24.9	24.9	25.0	26.6	24.8	24.2	25.0	24.7	24.8	25.1
6A	19.6	21.8	22.8	22.0	21.8	21.2	22.3	22.0	21.5	21.5	22.3
5B	23.1	23.0	23.2	22.5	23.5	23.1	22.9	22.8	22.2	23.8	22.5
6B	22.3	24.0	22.7	23.2	23.3	23.0	22.2	23.3	22.5	24.1	23.5
120 cm depth											
5A	18.9	19.5	20.4	22.1	20.6	21.9	21.8	21.6	21.8	22.4	21.5
6A	22.4	22.3	23.1	22.4	23.6	23.7	23.5	23.0	23.6	23.2	23.8
5B	23.8	23.6	24.3	23.8	26.4	24.0	24.9	25.4	24.3	26.5	24.8
6B	21.1	21.6	20.9	21.2	21.1	22.3	21.5	21.9	20.9	19.4	22.5

	8/3	8/7	8/10	8/14	9/1	9/2	9/3	9/8	9/11
30 cm depth									
5A	25.9	24.0	23.9	23.8	24.4	26.3	26.3	27.0	25.4
6A	24.6	24.8	25.2	23.5	22.2	27.2	26.3	23.9	24.7
5B	23.1	21.8	20.5	17.9	10.5	13.1	13.6	17.2	15.9
6B	22.1	20.1	17.3	21.5	5.8	8.8	9.0	14.1	11.1
60 cm depth									
5A	24.3	23.4	23.4	23.6	22.9	22.4	22.4	23.5	24.4
6A	21.5	21.2	22.8	21.5	21.3	22.0	20.6	23.0	21.9
5B	25.2	24.0	23.1	23.0	19.2	21.2	21.1	20.3	20.9
6B	23.7	23.0	24.6	23.0	21.6	20.8	20.6	20.5	20.2
90 cm depth									
5A	25.0	24.8	25.7	23.4	24.6	24.7	24.1	25.9	25.6
6A	22.1	21.5	24.8	20.6	21.6	20.9	20.6	22.1	23.0
5B	24.4	23.4	23.5	23.0	21.1	21.8	21.0	20.3	20.5
6B	23.2	23.0	22.7	23.1	21.2	20.1	20.7	21.0	20.5
120 cm depth									
5A	21.0	22.2	22.8	23.0	21.7	21.7	21.5	22.6	23.8
6A	23.8	23.5	25.8	23.6	24.0	23.4	23.6	23.8	23.7
5B	25.8	26.1	26.5	25.8	23.9	24.9	25.4	24.2	24.3
6B	22.5	22.5	21.4	22.5	23.4	21.3	22.0	21.8	23.2

	10/29	11/3	11/17	11/19	12/3	12/7	12/21	1/4	1/25
30 cm depth									
5A	25.6	25.9	25.6	25.8	25.8	27.3	25.6	24.3	24.5
6A	23.6	25.5	24.3	25.4	25.4	24.6	24.8	23.3	24.0
5B	10.5	11.8	9.9	11.7	11.9	12.3	12.1	12.4	14.0
6B	7.7	7.3	6.1	7.5	9.9	10.3	11.0	10.1	10.8
60 cm depth									
5A	23.5	24.2	23.9	24.6	24.2	24.1	23.7	23.6	23.7
6A	23.4	23.2	22.6	23.2	22.7	24.3	23.3	24.0	22.2
5B	18.3	17.7	17.9	17.3	17.0	17.5	16.4	17.2	18.2
6B	18.2	18.4	18.4	17.6	18.3	18.0	17.0	18.3	18.2
90 cm depth									
5A	27.8	27.9	27.1	27.6	28.1	28.4	27.7	27.4	27.7
6A	26.0	27.2	26.4	25.5	26.1	27.1	26.3	25.2	25.2
5B	18.9	19.9	18.3	19.8	18.1	18.5	18.6	18.1	21.0
6B	18.5	19.8	17.0	17.8	17.2	16.2	17.4	17.8	17.2
120 cm depth									
5A	26.5	26.9	27.5	26.4	27.8	27.5	26.3	27.5	27.0
6A	27.6	26.9	26.6	27.0	26.8	27.7	26.6	26.8	28.2
5B	22.5	21.7	22.2	20.6	22.0	21.4	20.7	21.0	21.0
6B	19.5	19.4	18.1	20.3	19.7	19.7	19.0	17.6	18.3

	2/10	2/17	2/24	3/1	4/6	4/14	4/21	4/28	4/30
30 cm depth									
5A	24.6	27.9	29.0	27.2	25.9	25.7	24.6	25.0	24.4
6A	23.8	27.1	26.4	24.9	24.8	24.0	23.6	23.7	23.7
5B	13.9	17.4	21.9	20.1	15.8	10.9	9.7	9.5	9.2
6B	12.1	14.0	19.8	19.3	16.8	12.5	10.6	10.1	9.4
60 cm depth									
5A	23.2	24.4	25.8	25.3	25.3	24.6	24.9	24.2	24.5
6A	22.8	23.2	24.9	24.2	23.8	24.1	22.8	23.3	23.1
5B	17.9	17.4	19.2	20.3	21.0	20.5	18.8	18.3	18.2
6B	17.5	17.6	18.7	19.2	20.8	20.3	19.4	19.4	19.6
90 cm depth									
5A	26.9	25.9	30.0	29.0	29.2	28.9	27.1	28.5	28.0
6A	25.3	25.1	28.3	26.6	27.7	26.4	26.5	26.7	26.3
5B	19.6	17.9	18.8	18.5	20.1	19.4	19.0	19.0	19.2
6B	17.4	17.2	17.9	17.8	19.1	19.0	18.7	19.0	18.0
120 cm depth									
5A	26.4	26.4	26.5	27.7	29.8	29.5	28.6	28.7	29.1
6A	27.1	26.4	27.7	27.6	28.8	27.9	27.6	28.2	28.0
5B	21.1	20.7	20.5	20.1	21.5	21.3	20.6	21.7	21.0
6B	18.5	18.8	17.9	17.8	19.3	19.2	18.9	19.3	19.1

	5/7	5/11	5/17	5/25	6/1	6/10	6/14	6/21	6/30
30 cm depth									
5A	26.3	25.1	24.4	25.7	23.8	24.8	24.0	24.5	27.0
6A	23.9	23.0	22.7	24.0	23.0	24.5	22.8	23.9	26.2
5B	10.7	9.4	8.5	15.7	7.5	11.2	8.4	9.1	10.8
6B	10.4	9.3	8.3	10.3	7.9	13.7	10.5	11.4	15.8
60 cm depth									
5A	24.6	24.5	24.5	23.9	24.7	23.6	24.0	23.4	24.4
6A	22.8	23.4	23.2	23.6	22.8	22.9	23.2	22.5	24.6
5B	16.9	16.9	15.9	15.7	14.2	14.5	13.7	12.2	12.6
6B	19.0	19.0	19.0	17.6	18.5	17.9	18.2	18.3	17.6
90 cm depth									
5A	27.8	28.6	28.0	28.8	28.7	27.1	27.2	28.0	28.1
6A	26.4	26.2	25.5	23.2	26.1	26.4	26.3	26.9	26.6
5B	18.6	18.1	18.0	17.2	16.9	16.1	15.4	15.0	13.1
6B	18.0	18.2	18.3	18.5	18.1	17.3	17.8	17.7	17.0
120 cm depth									
5A	29.4	28.9	28.5	28.6	28.3	29.0	28.3	27.9	29.3
6A	28.2	27.3	28.0	27.2	28.1	26.6	27.3	27.6	27.7
5B	18.9	21.0	20.8	20.2	19.6	17.8	18.0	17.1	15.0
6B	19.6	19.2	18.8	18.6	19.4	18.9	18.6	19.6	18.5

	7/6	7/12	7/14	7/19	7/23	7/27	7/30	8/6	8/13	8/23
30 cm depth										
5A	26.1	27.3	27.4	29.7	26.9	26.7	30.2	25.7	24.5	25.8
6A	26.2	27.3	25.9	28.3	25.2	25.8	30.1	24.1	24.0	25.8
5B	10.1	8.0	11.8	16.0	9.0	10.1	13.9	7.6	8.3	7.9
6B	12.1	16.9	15.1	19.0	11.9	11.6	15.4	7.7	8.7	9.0
60 cm depth										
5A	24.4	26.6	25.3	26.8	22.9	25.6	26.2	25.7	25.6	24.9
6A	24.2	25.3	25.5	27.4	26.0	25.8	28.4	25.0	25.0	24.3
5B	11.5	12.0	11.3	11.2	7.3	10.6	10.6	9.7	9.3	8.7
6B	17.4	17.9	18.0	18.0	11.5	17.5	17.5	16.2	16.1	14.2
90 cm depth										
5A	27.9	28.1	29.4	31.3	30.7	31.2	31.8	29.7	30.4	29.6
6A	26.8	27.9	29.8	31.3	30.9	30.5	30.3	31.2	30.5	29.3
5B	11.5	11.0	10.3	9.9	8.9	8.4	8.2	7.2	6.4	5.9
6B	16.8	17.0	16.8	17.0	17.4	16.2	17.2	15.0	14.1	12.3
120 cm depth										
5A	29.1	30.1	30.4	32.2	34.6	33.4	34.6	34.5	35.8	32.9
6A	27.6	27.7	29.2	30.4	31.2	30.5	30.0	30.4	29.7	28.9
5B	13.4	11.7	11.7	11.7	10.0	8.1	8.3	7.4	6.5	5.5
6B	17.6	18.0	18.1	17.6	16.3	16.0	15.8	15.7	24.0	10.9

	9/2	9/9	9/14	9/20	9/28	10/5	10/15
30 cm depth							
5A	25.4	24.6	24.1	30.1	25.7	23.4	26.1
6A	24.4	22.6	23.7	29.3	24.1	22.7	23.8
5B	6.0	5.2	5.1	18.2	11.7	6.3	6.4
6B	8.2	7.3	6.4	18.2	11.6	6.1	6.4
60 cm depth							
5A	25.4	24.5	24.5	26.8	25.7	25.8	25.7
6A	24.8	24.8	23.4	27.0	24.1	23.8	23.6
5B	8.5	7.5	7.5	7.3	11.7	8.0	8.2
6B	13.8	11.9	11.7	11.6	11.6	10.9	10.8
90 cm depth							
5A	30.0	28.9	28.9	30.2	30.6	29.6	30.0
6A	30.1	28.4	27.4	28.9	29.7	29.4	28.6
5B	5.4	5.0	5.6	4.6	4.8	5.5	5.0
6B	10.1	10.5	9.4	9.1	8.3	7.0	6.7
120 cm depth							
5A	33.9	32.9	31.6	33.2	34.3	33.9	33.6
6A	30.7	30.1	29.0	28.5	31.1	28.8	30.0
5B	5.3	5.1	4.6	5.0	4.9	4.3	4.6
6B	9.6	8.6	7.8	7.5	7.0	5.7	5.6

	7/3	7/6	7/8	7/10	7/17	7/20	7/22	7/24	7/27	7/29	7/31
30 cm depth											
7A	24.7	22.7	22.1	22.0	22.3	22.1	21.4	21.1	21.2	21.1	24.1
8A	27.3	23.2	24.3	23.0	23.0	21.2	22.2	22.8	22.2	20.9	23.9
7B	26.0	21.9	22.8	22.4	23.6	22.5	22.4	23.1	24.2	23.4	26.2
8B	25.7	22.7	22.6	21.2	23.6	23.0	22.7	23.3	23.0	24.0	27.8
60 cm depth											
7A	27.6	26.5	27.3	26.3	26.5	25.3	25.6	27.0	25.3	26.6	25.2
8A	28.7	27.5	28.8	27.6	28.4	27.7	25.9	26.3	26.6	27.2	27.0
7B	24.9	24.7	23.8	22.4	23.4	23.4	23.1	24.8	22.6	23.1	23.7
8B	23.9	24.4	23.8	23.3	23.8	23.3	23.3	23.6	23.2	24.0	23.7
90 cm depth											
7A	24.6	23.3	22.9	23.3	23.5	22.5	22.1	23.3	23.0	22.3	22.3
8A	25.8	25.3	25.1	25.2	25.4	26.0	25.0	25.0	24.3	23.5	23.9
7B	25.1	26.1	25.4	24.8	25.8	25.1	25.3	25.1	25.0	25.4	25.2
8B	25.0	25.2	24.7	24.3	24.4	24.3	24.2	23.7	25.2	24.8	23.9
120 cm depth											
7A	21.8	22.0	22.0	21.7	22.5	22.4	22.2	22.1	22.1	22.6	21.7
8A	25.5	26.9	26.2	26.3	26.4	26.3	25.6	25.9	25.9	26.0	25.6
7B	23.3	23.2	23.4	23.7	24.3	25.0	23.0	24.2	24.2	23.8	24.3
8B	22.0	22.9	22.8	22.2	22.6	21.8	22.6	22.7	22.3	22.7	22.9

	8/3	8/7	8/10	8/14	9/1	9/2	9/3	9/8	9/11
30 cm depth									
7A	22.5	20.8	17.6	20.2	19.3	25.9	21.2	25.4	23.0
8A	22.5	21.4	20.3	21.0	19.9	25.5	23.3	15.6	22.7
7B	24.8	22.2	17.2	19.9	8.3	8.7	8.5	11.2	10.0
8B	25.5	21.5	17.0	19.9	10.8	19.2	17.0	18.5	14.4
60 cm depth									
7A	26.7	25.8	24.7	25.3	25.5	25.9	22.2	26.7	25.9
8A	26.0	27.0	26.7	25.1	25.9	24.9	25.6	21.9	26.9
7B	24.3	23.3	22.4	22.4	20.3	20.1	12.0	19.6	20.1
8B	23.0	23.6	24.2	22.5	19.3	19.2	20.7	19.1	18.7
90 cm depth									
7A	22.7	22.8	22.3	22.4	21.8	22.7	22.1	21.9	22.8
8A	24.4	23.8	24.5	25.0	23.6	23.3	23.6	22.1	24.6
7B	25.4	25.1	25.6	24.5	24.0	24.3	22.0	22.7	24.1
8B	24.4	23.8	24.8	23.6	22.2	22.2	21.6	21.7	20.3
120 cm depth									
7A	21.8	21.3	22.4	21.6	21.9	21.1	22.2	22.0	21.1
8A	25.8	25.6	25.9	25.2	24.4	24.0	25.8	22.7	26.3
7B	24.4	25.0	22.8	24.4	24.9	24.2	21.7	23.7	23.4
8B	22.1	21.6	22.7	21.9	21.3	21.3	21.3	20.9	24.9

	10/29	11/3	11/17	11/19	12/3	12/7	12/21	1/4/28	1/25
30 cm depth									
7A	22.3	24.5	21.8	24.3	24.1	25.0	21.5	22.0	21.6
8A	22.6	24.1	22.6	24.1	24.2	24.0	22.2	21.9	21.0
7B	4.1	4.7	4.2	4.6	5.4	5.8	5.8	10.7	10.1
8B	3.0	4.7	2.6	6.5	10.1	5.7	4.5	4.0	5.8
60 cm depth									
7A	26.9	26.0	26.4	26.0	25.5	26.3	25.9	24.0	26.0
8A	25.9	26.6	26.8	27.6	26.8	26.0	26.9	25.2	26.2
7B	14.1	13.7	13.2	13.1	13.2	13.4	14.1	17.2	17.7
8B	11.4	12.3	9.2	10.1	10.1	11.1	9.9	10.7	11.3
90 cm depth									
7A	22.9	23.4	24.6	23.5	22.2	23.0	22.5	26.5	22.9
8A	24.6	25.9	24.5	24.7	24.4	24.6	25.1	23.9	23.5
7B	20.8	21.0	20.2	19.9	19.5	20.2	19.6	18.6	17.8
8B	18.7	18.4	19.1	18.5	16.8	17.0	16.8	17.5	18.1
120 cm depth									
7A	24.9	25.1	25.3	25.2	24.4	25.0	23.3	22.0	24.5
8A	31.0	30.2	29.5	31.3	30.1	29.9	29.6	28.5	29.6
7B	21.4	20.8	20.4	19.8	18.8	19.6	19.3	18.6	18.8
8B	19.4	18.3	18.4	18.9	18.5	18.8	17.5	17.8	16.8

	2/10	2/17	2/24	3/1	4/6	4/+4	4/21	4/28	4/30
30 cm depth									
7A	21.0	26.2	26.8	25.8	22.1	21.3	20.3	19.9	19.4
8A	21.7	28.8	27.6	25.4	22.8	21.6	21.7	21.1	21.3
7B	10.7	7.6	17.4	18.1	16.5	10.7	6.7	5.7	5.5
8B	4.4	5.8	18.1	10.2	10.5	6.0	7.6	4.8	3.9
60 cm depth									
7A	19.8	26.4	28.1	26.6	26.8	26.7	25.6	25.8	25.9
8A	25.4	25.2	29.0	26.3	27.2	26.2	25.6	26.4	26.4
7B	14.7	14.3	14.1	14.4	16.6	19.1	14.5	14.8	14.1
8B	11.5	12.2	13.5	10.2	12.4	12.3	11.9	11.9	11.5
90 cm depth									
7A	22.5	22.3	24.1	23.7	24.4	23.6	22.7	22.9	23.2
8A	23.8	23.3	23.9	25.4	25.5	24.9	24.3	25.3	24.9
7B	18.1	19.2	19.2	18.9	20.0	20.0	19.1	19.7	19.8
8B	17.3	17.6	18.8	16.9	17.8	21.2	16.7	17.3	17.0
120 cm depth									
7A	27.6	24.1	24.0	25.8	27.6	27.1	26.1	26.3	26.4
8A	29.2	27.7	24.9	30.3	31.9	30.9	29.4	30.1	30.2
7B	17.6	19.6	18.1	17.8	19.8	25.6	18.5	19.0	19.4
8B	17.2	16.5	17.7	17.0	16.9	16.9	16.8	17.0	17.3

	5/7	5/11	5/17	5/25	6/1	6/10	6/14	6/21	6/30
30 cm depth									
7A	22.4	20.1	19.3	23.0	19.2	20.3	79.1	22.0	26.7
8A	22.4	21.1	20.2	22.0	20.5	21.7	20.0	22.3	24.5
7B	5.5	5.0	4.4	6.5	3.4	5.8	4.7	4.7	6.1
8B	10.9	4.0	3.3	7.4	3.2	7.4	3.9	4.3	8.8
60 cm depth									
7A	26.0	26.5	25.5	24.4	24.1	25.6	25.6	26.2	26.7
8A	26.8	26.3	26.8	25.6	24.9	26.1	26.3	25.8	27.1
7B	14.1	13.9	13.7	12.4	12.8	12.6	12.7	13.0	11.8
8B	18.1	11.8	11.6	11.1	11.5	11.3	11.1	11.2	10.8
90 cm depth									
7A	23.3	22.6	22.9	23.0	23.3	22.6	22.6	24.0	23.8
8A	24.9	24.9	24.3	24.7	24.0	24.1	24.9	23.4	24.7
7B	18.9	19.2	18.7	17.1	17.1	16.2	16.5	15.5	14.6
8B	18.7	17.2	16.4	17.5	15.9	15.1	15.9	14.9	14.2
120 cm depth									
7A	26.2	25.7	26.7	24.7	24.5	25.1	25.1	26.9	27.2
8A	30.5	30.1	29.2	28.8	29.1	27.6	29.1	28.2	29.5
7B	18.9	18.8	18.9	15.7	19.2	18.0	17.8	17.4	16.6
8B	19.0	17.2	17.0	16.3	16.8	16.8	16.8	16.0	16.2

	7/6	7/12	7/14	7/19	7/23	7/27	7/30	8/6	8/12	8/23
30 cm depth										
7A	25.0	29.7	25.0	28.7	22.3	24.1	30.3	21.2	21.3	24.0
8A	24.1	26.8	24.6	27.6	22.3	24.2	28.3	20.6	21.8	23.6
7B	5.3	6.9	5.9	8.5	5.7	10.2	6.5	5.2	4.8	5.1
8B	8.0	10.0	7.3	14.5	6.2	9.2	12.1	3.6	4.0	4.9
60 cm depth										
7A	26.1	27.8	27.2	29.8	27.6	27.7	28.6	26.8	26.6	25.9
8A	26.1	27.9	27.3	28.9	27.2	27.8	29.1	27.0	27.4	26.3
7B	11.4	11.6	11.3	11.2	11.4	12.0	10.4	10.4	9.4	9.2
8B	11.0	10.7	10.6	10.8	11.0	10.5	10.9	10.9	10.6	9.9
90 cm depth										
7A	23.2	24.5	24.8	26.1	24.9	24.4	25.6	25.0	24.2	23.4
8A	24.5	26.0	25.4	27.3	27.4	25.9	26.6	34.3	25.9	25.1
7B	13.6	12.5	13.3	11.7	11.0	10.1	12.0	9.8	9.3	7.6
8B	14.7	14.6	14.2	13.7	14.0	12.0	13.8	12.6	12.7	11.4
120 cm depth										
7A	27.8	28.3	29.4	31.0	31.0	30.6	31.9	31.8	30.6	29.0
8A	29.4	30.5	29.9	32.5	34.9	33.2	34.6	33.3	34.0	31.4
7B	14.7	13.7	13.6	12.8	11.6	24.1	10.2	8.3	7.1	5.9
8B	15.7	15.7	15.4	14.8	14.2	13.2	14.2	12.8	10.7	8.7

	9/2	9/9	9/14	9/20	9/28	10/5	10/15
30 cm depth							
7A	20.3	20.8	19.2	29.3	21.2	18.8	20.5
8A	21.2	20.8	19.9	28.7	22.3	20.0	21.3
7B	4.3	7.4	4.0	7.1	5.6	5.9	5.3
8B	4.5	3.1	3.0	13.8	7.4	3.8	4.1
60 cm depth							
7A	26.2	24.2	24.6	28.5	21.2	26.2	26.4
8A	27.5	25.5	26.4	27.0	22.3	25.9	26.0
7B	9.3	6.4	7.9	8.5	5.6	7.8	9.0
8B	10.2	10.0	9.3	9.1	7.4	9.0	9.0
90 cm depth							
7A	23.8	24.3	23.1	24.0	24.7	24.2	24.8
8A	25.3	24.9	24.9	25.3	25.1	24.6	26.0
7B	7.2	9.9	6.2	5.4	5.8	5.0	8.0
8B	10.2	9.6	8.5	9.3	8.6	7.2	7.3
120 cm depth							
7A	29.7	29.2	28.7	29.4	30.4	28.4	28.7
8A	32.8	32.1	31.8	30.1	32.2	31.4	30.7
7B	5.4	6.3	4.3	5.7	5.4	4.9	5.4
8B	8.3	7.0	7.1	7.8	6.4	6.0	6.3