A Protected Diffusion Zone (PDZ) to Conserve Soluble Production Chemicals

James L. Green, Shaun Kelly, and Bryan Blackburn
Horticulture Department ALS 4017, Oregon State University, Corvallis, Oregon 97331-7304

James Robbins
3425 Gibraltar Ct , Olympia, Washington 98501

Bruce Briggs and Doris Briggs
Briggs Nursery, Inc, 4407 Henderson Blvd, Olympia, Washington 98501

Inefficient, repeated applications and waste discharge of agricultural production chemicals can be curtailed if means, such as the protected diffusion zone (PDZ), are provided to retain the chemicals within the plant root zone and to deliver them at appropriate times in adequate concentrations to meet requirements for plant growth and pest control. Application of fertilizers and pesticides in the PDZ of the closed, insulated pallet system (CIPS) or in the "Conserver" within the open plant root zone will decrease waste discharge of the applied, soluble chemical, e.g., potassium nitrate or Subdue.

INTRODUCTION

Inefficient application and waste discharge of fertilizer and pesticides from agricultural production areas is a worldwide concern. Methods to target delivery and retain effective plant-available concentration of applied agricultural chemicals in the plant root zone decrease quantities applied and discharged

In open root zone systems (ORS) with evaporative top surface and a draining bottom surface, flowing water moves through, dissolves, and convects fertilizer salts. A major portion of the fertilizer may be rapidly convected away as leachate before it can be intercepted and taken up by plant roots. Conversely, upward movement of water in the root zone in response to surface evaporation carries dissolved salts to the surface where they accumulate as salt deposits.

In surface irrigated fields and containers (open root zone systems), fertilizer is rapidly convected or flushed in the irrigation water. The movement of fertilizer by chemical diffusion in these "flushing" systems is insignificant. However, diffusion is the primary mode for movement of soluble fertilizer within a zone shielded or protected from gravitational and evaporative water flow. The rate of movement of fertilizer ions by chemical diffusion is very slow compared to the rate of convective movement. This slow rate of diffusion of ions within a protected diffusion zone (PDZ) allows time for root growth into the PDZ and efficient interception/uptake of the ions prior to their diffusion beyond the PDZ. The process embodied in the Fertilizer Apparatus, U.S. patent number 5,212,904, is the "protected diffusion zone." The PDZ of the closed, insulated pallet system (CIPS) and the PDZ of the

Conserver are designed to protect fertilizer ions and other water soluble chemicals of environmental pollution concern (e.g., nitrates) from convection in leaching and evaporative water flow.

RESULTS AND DISCUSSION

The Protected Diffusion Zone. The "protected diffusion zone" is a 3-dimensional zone or volume within the plant root zone (soil or container media) with a moisture-impermeable material enclosing the top and sides to prevent downward convection of gravitational water or upward movement of evaporative-capillary water through the soluble chemical. The soluble chemical is placed on the top surface within the protected zone The purpose for placing the soluble chemical (e.g., fertilizer, soluble fungicide, etc) within the PDZ is to prevent rapid convection of the chemical downward with gravitational flow of surface-applied water or movement of the chemical upward to the soil or media surface in the evaporative water flow pathway. Within the protected zone, the soluble chemical moves primarily by chemical diffusion. Plant roots grow in the protected diffusion zone and intercept the chemical ions prior to their diffusing from the protected zone.

Results from research to evaluate the feasibility of conserving fertilizer within a PDZ in both the CIPS and in the open root zone systems at Briggs Nursery and Oregon State indicated that movement of K^+ and NO_3^- fertilizer ions within the PDZ is between rates reported for diffusion in water and in soil (Olsen and Kemper, 1968). Rates of ion movement downward in the PDZ in the media are compatible with ion diffusion being the dominant component of fertilizer movement.

Fick's laws (Crank, 1975) were applied to determine relationships among the variables in the PDZ research. Diffusion zone cross section area (diameter of the diffusion tube), diffusion zone length (length of the diffusion tube), and effective diffusion coefficient of the applied fertilizer. The length of the protected diffusion zone (diffusion tube length) can be varied to protect the diffusing ions for different lengths of time. The longer the diffusion tube (diffusion distance) the greater the amount of time before the chemical exits the diffusion tube. The diameter of the diffusion tube can be varied to provide delivery of different quantities of diffusing chemical. The greater the diameter of the diffusion tube (cross-section area through which diffusion can occur), the greater quantity of a given chemical delivered at any time. The solubility of the applied chemical as well as the volume of moisture, the cation exchange capacity, and other characteristics of the media within the diffusion tube can be altered to tailor the effective diffusion rate of the diffusing chemical The effective diffusion rate (D_e) will determine the rate of fertilizer movement in the PDZ For a given fertilizer salt, effective diffusion coefficient, and diffusion tube length and diameter, the movement of fertilizer within the PDZ over time can be predicted to allow tailoring the PDZ to specific crops and conditions.

Embodiments of the Protected Diffusion Zone. A PDZ can be created in the root zones of various plant production systems. Major embodiments are illustrated in Fig. 1 (left to right, top to bottom).

CREATING A PDZ WITHIN THE CLOSED INSULATED PALLET SYSTEM, FIGURE 1, EMBODIMENT 1, CIPS

The entire pallet lid and sides can be considered to be a PDZ with multiple number of plants extending through the top surface of the PDZ The major features of CIPS are an array of plant units with roots enclosed within a closed, insulated pallet. Plant shoots extend upward through a seal in the pallet top. The pallet lid is essentially continuous, water-impermeable, light reflective, solar and thermal radiation opaque, and insulating Fertilizer placed on the top surface of the media is shielded from leaching and evaporative water-flow pathways within the created PDZ and diffuses to the plant roots. The fertilizer ions will diffuse in the absence of plant roots and uptake, but ion uptake by the roots will create a steeper diffusion gradient and cause the ions to diffuse more rapidly. In this sense, fertilizer ion diffusion within the PDZ is plant-driven. Water movement upward from the water reservoir in the base of the pallet is by adsorption onto the surfaces of the wick and media particles and by capillarity. After adsorption and capillary equilibria are achieved, further movement of water by capillary flow is in response to plant uptake to support plant growth and transpiration. Water uptake is plant-driven

As an alternative to placing the fertilizer or other chemical to be protected beneath the pallet lid, the chemical can be placed within a Conserver inserted through the pallet lid into each plant unit (Fig. 1, Embodiment 2, CIPS with Conserver). The Conserver can be envisioned as a tube or cylinder with a cap on the top to provide a moisture-impermeable, insulated, thermal-solar radiation opaque-reflective top and sidewalls. The soluble chemical within the Conserver is protected from convection downward in the gravitational water flow pathway and from movement upward in the evaporative water flow pathway. The duration of protection and the rate of delivery are dependent upon the length of the diffusion tube and the diameter of the diffusion tube respectively. The individual Conserver is open on the bottom side to allow root growth into the diffusion tube to facilitate interception and uptake of the diffusing chemical before it exits the protected zone. Fertilizer ions diffuse downward through the media inside the cylinder until they are intercepted and taken up by the plant roots. The Conserver allows periodic replenishment of fertilizer through the cap.

CREATING A PDZ WITHIN AN OPEN ROOT ZONE (ORZ)

The individual Conserver can be effectively used independent of the CIPS The individual Conserver can be used in an open container or used in field or landscape plantings to provide a PDZ for soluble chemicals, Fig. 1, Embodiment 3, ORS/ container and Embodiment 4, field-landscape.

CREATING A PDZ WITHIN A SEMI-CLOSED FIELD OR LANDSCAPE SYSTEM (FIGURE 1, EMBODIMENT 5, SEMI-CLOSED FIELD SYSTEM)

When digging the hole into which the plant is to be transplanted, a water-impermeable basin to act as a water reservoir is placed beneath the root zone of the transplant. The basin is filled with porous, load-bearing, capillary media (e.g., rockwool slabs) covered with a copper hydroxide coated fabric. Growth and terminal dominance of root tips will cease when they contact the copper-coated fabric. Higher order branching of the roots will occur. The root system will spread laterally beyond the subtending basin. Roots will eventually extend downward beyond the basin to deeper soil moisture regions. The basin is intended as a temporary, efficient, readily available water supply during establishment of the transplant in the landscape. Water is periodically added to the reservoir through the fill pipe on the left; the fill pipe can be placed close to the plant to also serve as a plant stake. The plant stem is surrounded at the soil surface by an impermeable, circular moisture barrier that extends from the plant stem outward to the edge of the root ball; the barrier prevents evaporative and leaching movement of water through the subtended root zone and aids in establishing stable moisture and fertilizer gradients. A long-term, extended supply of fertilizer, with the exception of calcium and phosphate, is applied in the Conserver. Calcium phosphate is uniformly incorporated in the root zone to promote root growth.

ECONOMICS OF THE PDZ

CIPS PDZ. A differential cost analysis comparison of the CIPS with five traditional container production systems including models with ebb and flood and models with leachate recycling technology showed that cost of production with CIPS was less or equal to that of the other systems (Welch et al., 1991).

Conserver PDZ. The Conserver will eliminate or reduce fertilizer discharge from the open root zones of container- and field-grown plants. The savings in annual

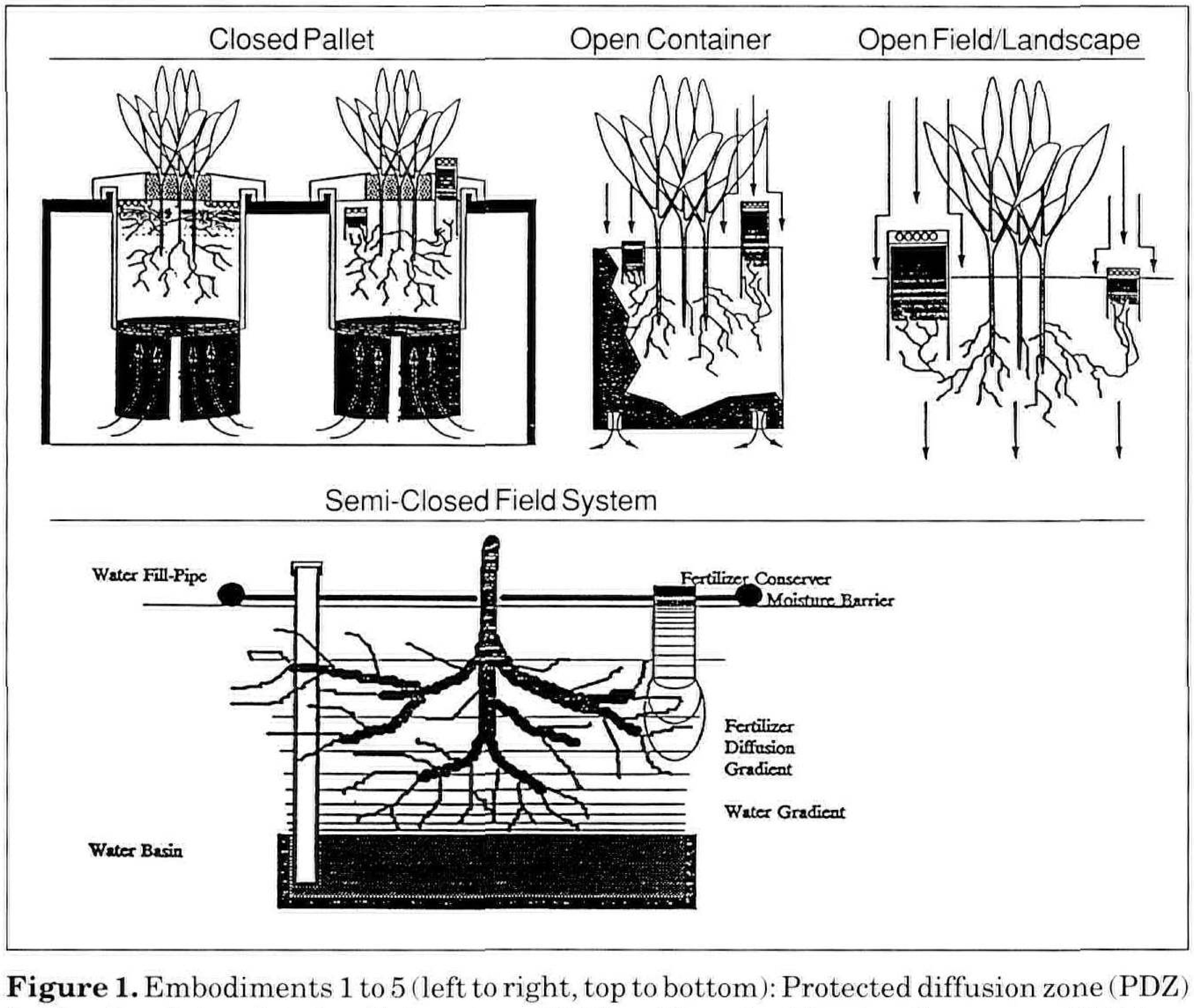

Figure 1. Embodiments 1 to 5 (left to right, top to bottom): Protected diffusion zone (PDZ) in the closed, insulated pallet system (CIPS) with and without a Conserver; PDZ in a container with an open root zone system (ORS); PDZ in a field or landscape ORS; PDZ in a field or landscape semi-closed root zone system.

differential costs/bed-acre of using the Conserver compared to the costs involved in converting an area to leachate collection, treatment and recirculation are considerable (Welch et al., 1991): $746/bed-acre annual savings in land improvements (installation of collection, treatment, and recirculation system not required with Conserver); $3297 savings in cost of fertilizer when Conserver-applied; $434 savings in cost of chemicals for water treatment plant. Assuming 43,560 plants (Conservers) per acre and that a given plant (Conserver) is in place for a 2-yr period, $4477 ($746+$3297+$434 savings) divided by 21,780 conservers/year would provide $0.20 per conserver. OR, the break even purchase-installation cost per Conserver is $0.20 or less. If there were only 10,000 1-gal plants per acre, then savings would provide $0.895 to offset cost of each conserver.

CONCLUSIONS

Decreased water availability necessitates innovative methods and technology to adjust plant-available fertilizer to the varying frequencies and quantities of plant-available irrigation water and plant growth rates. Availability of fertilizer applied in the protected diffusion zone to the plant is directly related to the quantity of water in the plant root zone since the fertilizer must be dissolved in water before it can diffuse and must be in solution prior to plant uptake. Therefore, availability of fertilizer in the PDZ is self-adjusting to the quantity of plant-available water. Because fertilizer is primarily retained within the PDZ and intercepted by plant roots prior to its exiting the diffusion zone, soluble fertilizer is not moved to and accumulated at the soil surface by water evaporation.

Water soluble, systemic pesticides such as the fungicide Subdue can also be applied and shielded within the Conserver from leaching and dispersion. The necessity of drench applying Subdue on a 3- to 4- week frequency to maintain effective concentrations against leaching of the pesticide within the root zone might possibly be replaced by less frequent application of smaller quantities of Subdue through the Conserver.

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