MANAGEMENT PRACTICES EVALUATION

Nonpoint source pollution from nutrients and pesticides application has the potential to degrade water resources. The pollution threat could be minimized by identifying and adopting Best Management Practices (BMPs) at or near the source areas. Thus, BMPs may have to be developed for locations known to be affected by nonpoint source pollution. Several cultural or management practices could be put together to constitute the various components of BMPs. For example, Izuno et al. (1995) evaluated cultural practices for developing appropriate BMPs intended to reduce phosphorus loading in the Everglades Agricultural Area in southern Florida. While BMPs have the potential to alleviate or minimize the pollution problem, it is imperative to tailor appropriate BMPs for specific problems and areas for optimum results (Watson et al. 1994).

BMPs involve the use of an integrated approach to solving environmental problems or achieving the maximum desired goal. Thus, practices thought to assist in maintaining environmental quality or increasing crop production could be grouped together. For example, soil conservation practices such as conservation tillage, contouring and terracing, use of sedimentation ponds, cover cropping and plant residue use, strip cropping, and laser leveling of field surfaces could be used to control nonpoint pollution (Reay et al. 1992; Hamlett and Epp 1994). These practices could minimize runoff losses by increasing water infiltration and water application uniformity. Additionally, cover crops are sources of plant biomass helpful in restoring or maintaining high levels of soil organic matter and soil biological activity (Bruce et al. 1991), which consequently minimize the bulk of organic pesticides carried in runoff and leached under favorable conditions.

Nutrient management may be included in the BMPs selected to control nonpoint source pollution. Crops require nutrients for optimum growth. However, nutrient use varies within the growing season. Such variation must be taken into consideration when formulating a crop fertilization scheme for an area. Nutrients not used by the crops could be subject to loss through leaching, runoff, or they could be transformed into forms not available to the crops. Nutrient management practices should include proper fertilizer placements (Watson et al. 1994) and nutrient application in suitable amounts, form, and at the appropriate time, making use of most residual nutrients in the soil profile (Hamlett and Epp 1994).

Care is needed when applying pesticides on the field. More important, an appropriate amount of the required pesticide must be applied at the most opportune time for maximum impact on the target pests to minimize repeated applications later in the growing season. If possible, pesticides should be applied at the time the crop is most sensitive to pest infestation. Heavy irrigation following pesticide application could result in runoff losses and leaching into deep soil layers where microbial activity and plant uptake are limited, thereby increasing the pesticides' potential to move toward ground water under high soil moisture conditions. Thus, poor pesticide management can increase the pollution potential of pesticides especially under irrigated conditions.

It is highly likely that applied agricultural chemicals will leach and run off under an irrigated agricultural setting, especially if adequate irrigation management practices are not in place. Adopting good irrigation management practices could minimize nonpoint source pollution from irrigated fields. The main focus of irrigation management is to determine how to use irrigation water most effectively to sustain optimum crop growth and yield as well as to minimize runoff and leaching. The amount of irrigation water applied and time of application are very critical. Best results can be achieved by using climate data or tensiometers to schedule irrigation. Also, the pollution potential of applied pesticides and nutrients could be minimized by avoiding over-irrigation which will curtail leaching and runoff losses. Other sound irrigation management practices include land leveling, installing subsurface and surface drains, recovering tailwater, checking valves for leaks on the water distribution network to ensure efficient delivery of an appropriate amount of water to the field, and using flow measuring devices to record the exact amount of water delivered to the field.

The degree of success in minimizing nonpoint source pollution in irrigated agriculture depends in part on the type of irrigation system being used. Irrigation systems range from basin, furrow through sprinkler, to trickle irrigation systems. Each system commands a different degree of efficiency, overhead cost, maintenance cost, and other associated costs. Even though overhead and maintenance costs dictate the choice of irrigation system, it is imperative that attention is paid to other factors such as the field slope and soil type when selecting an irrigation system to match a particular field condition. Once an appropriate system has been selected within the constraints, it should be well designed and managed effectively to reduce surface runoff and leaching losses of applied pesticides and nutrients. Ranjha and others (1992) used appropriate furrow design to reduce leaching losses of carbofuran and hexazinone in alfalfa fields. Short furrow lengths and a high head inflow rate reduced carbofuran and hexazinone leaching losses. On the other hand, long furrow lengths and a low head inflow rate increased leaching losses, especially in coarse textured soils because of low water storage efficiency and higher infiltration rates (Ranjha et al. 1992). Thus, leaching losses of applied pesticides below the rooting zone under furrow irrigated conditions could be reduced by adopting short furrow lengths with a high head inflow rate to maintain high water storage efficiency.

Cropping sequence or cropping pattern may be altered to break continuous pesticide application over several years. This approach is most applicable when the alternate crops being grown require different types of pesticides. Alternatively, a cover crop could be sandwiched between two or more sequential cropping seasons to break pesticide application events. This crop management practice could limit the frequency and pesticide or fertilizer amounts normally applied, which, consequently, may reduce the pollution potential. Incorporating a cover crop in the cropping sequence may increase soil organic matter, a soil constituent having the ability to retard organic pesticides movement in soils.

Because pest infestation impairs crop growth and decreases yield, the pest eradication method or management program used must be effective and efficient. Pest management involves different approaches, each approach most applicable at different levels of pest infestation. For example, vigilance is required to ensure that no new pest establishes on the farm. If a new pest is identified, it should be eradicated promptly without leaving it room to propagate in the future. Although chemicals are effective in controlling pests, their use should be the last resort. Complete eradication of pests may not result in maximum profit or returns. Schweizer and others (1988) showed that systematic reduction of herbicide use over a four-year period did not result in a significant reduction in crop yield and adjusted gross returns. Thus, it may be appropriate to design pest management practices to achieve less than 100% pest eradication for a minimum yield lost. Such an approach may lead to a significant reduction in the amount of pesticide applied over a time period. Reducing the amount of pesticide used may lessen the quantity of pesticide leached under high soil moisture conditions. Also, an integrated approach that encompasses the use of appropriate cultural practices such as vigilance, crop rotation and mechanical pest control, along with the planting of resistant crop varieties, using biological pest control if available, sparing use of pesticides, and timing of pesticide application are recommended (Swanton and Weise 1991). The integrated approach for pest control is intended to produce the highest pest control results achievable since individual control measures operating alone may not be very effective. The integrated approach could help limit the amount of pesticide needed and even reduce the potential for the target pest to develop resistance to the pesticide. Once a pest develops resistance to a pesticide, large amounts of the pesticide may have to be used to achieve the desired level of pest control. Alternatively, a new chemical may have to be substituted in order to control the pest, thereby continuing the pesticide-use cycle in the environment.

Current Farming Practices

Farmers in Doña Ana County were surveyed to record current management practices used for farming operations. Specific practices recorded were cropping sequence including planting and harvest dates, irrigation scheduling practices indicating the time and amount of water applied for each cropping season, and the type, time, and amount of pesticide applied. Farm locations were recorded and used to identify the soil type in the

Soil Survey Report for the Doña Ana County Area. For each soil type, the field capacity, permanent wilting point, saturated hydraulic conductivity, air entry potential, and the exponential parameter of Campbell's soil water retention model (b-value) were estimated following the procedure described in the section: *Soil Hydraulic Parameters*.

Proposed Best Management Practices

Most farmlands in Doña Ana County are fairly level with the mean depth-to-water table being about 1.8 meters (about 6 feet). Crop production is supported by intense irrigation practices. Under these conditions, ground-water contamination through runoff losses was expected to be minimal. Leaching of applied agricultural chemicals is the most likely route through which ground water could be contaminated. Proposed modifications of farming practices in the county were those intended to control leaching losses of applied chemicals. The proposed BMPs are:

Crop Rotation

Crop rotation is practiced to break the continuous use of one particular chemical over an extended period and thereby preventing pest buildup in the environment.

Irrigation Scheduling

Irrigation scheduling is very critical in controlling leaching because of the intense irrigation practiced in this area. Scheduling irrigation to provide an adequate amount of water to the crops at the right time could limit over-irrigation and thereby reduce leaching losses. A simple approach is to schedule irrigation using tensiometers installed within the root zone. Soils vary with respect to both their water holding capacity and the tension at which different amounts of water are held. For example, NRCS office in Las Cruces, with qualifications, has recommended that crops being grown on sandy loam soils should be irrigated when the tensiometer reading is about 23 KPa (centibars) and about 74 KPa (centibars) for a clayey soil (Appendix A). The NRCS further recommends that the porous cup of the tensiometers be spaced throughout the active root zone, which will vary depending on the crop. Another tensiometer installation scheme allows the position of the porous cup to change with the dynamic crop root zone. Alternatively, an irrigation scheduling model could be used to estimate when and how much water to apply to meet a desired yield and leaching fraction levels. The use of such a model requires local weather data. In the absence of readily available data, the weather data could be generated using the model WGEN (Richardson and Wright 1984) or any available daily weather generating model. The advantage of using irrigation scheduling models lies in their flexibility to experiment with different water management schemes (different time and amount of water applications) before selecting the scheme that gives best results.

First Irrigation after Chemical Application

The time at which the field is irrigated following pesticide application is critical for chemical leaching, especially if the field is irrigated intensively. Management practices may appropriately impose a three to four day delay of irrigation following an agricultural chemical application. This practice may allow some of the applied chemical to degrade or be adsorbed by soil colloidal particles, resulting in less of the chemical being available for leaching under favorable soil moisture conditions.

Changing Irrigation System

Irrigation efficiency varies with the irrigation system. Generally, irrigation efficiency increases from a surface to a drip/trickle irrigation system. High irrigation efficiency results from good control over water application and distribution on the field. Maintaining high irrigation efficiency could minimize the amount of water that moves past the root zone and, consequently, helps control chemical leaching. Thus, changing from a furrow irrigation system to a sprinkler system could result in a substantial reduction in the amount of applied chemical that leaches below the root zone, reducing the potential for ground-water pollution.

Increasing Soil Surface Layer Organic Matter Content

The organic matter content of the soil surface layer may be increased by incorporating organic material (plant materials) into the soil layer. The resultant increases in organic matter leads to an increase in organic chemical adsorption, a process that retards organic chemical movement in soils. Thus, occasionally incorporating organic material into the soil surface layer may restrict pesticides from moving readily with soil water into lower soil depths. Additionally, the carbon constituent of the organic material could serve as an energy source for enhancing microbial degradation of applied pesticides. Because the area's climate is semiarid and adequate soil moisture is maintained through irrigation, rapid decomposition of added organic materials could occur. Therefore, it may be necessary to apply organic materials to the soil surface layer every three to four years.

Integrated Pest Management Practices - Sparing Use of Pesticide

The principle behind integrated pest management practices is the use of several pest control measures concurrently to control pests. For example, mechanical pest control and vigilance could be combined with minimal pesticide use to achieve a thorough pest control on the field. Because each pest control measure reduces infestation by some amount, the combined effects of the different pest control measures could be more promising. By complementing pesticide use with other means of pest control, the amount of applied pesticide could be reduced.

SETTING UP THE IRRSCH MODEL

The IRRSCH model was designed to simulate the scenarios of interest. This entailed providing appropriate input data to drive the model. IRRSCHM requires the following inputs: soil organic matter distribution in the soil profile, pesticide half-life values in the soil profile, cropping sequence for multiyear simulations, irrigation scheduling data for each cropping sequence, planting date, harvest date, and time of pesticide application. Procedures used for acquiring the appropriate input data are as follows:

Soil Hydraulic Parameters

The purpose of this section is to evaluate the different methods for estimating field capacity (FC) and permanent wilting point (PWP) values and to determine the simplest method that gives satisfactory values for different soil types.

Irrigation scheduling models (Shayya et al. 1990, 1991; Shayya and Bralts 1994; Fox et al. 1992), and volume-based water quality models such as PRZM (Carsel et al. 1984, 1985) and CMLS (Nofziger and Hornsby 1985) require either soil information about FC and PWP or information about the soil's available water capacity. The soil's available water capacity is defined as the field capacity minus the permanent wilting point. The soil's available water capacity is used in the models to maintain a tipping bucket approach to flow where the soil profile is divided into discrete layers. Water fills each layer up to FC with the excess moving into the next layer below. Field capacity and permanent wilting point for different soil types are reported as a range of values in the NRCS soil survey for each county in the United States. The water balance models are sensitive to the FC and PWP values used in the input file. Consequently, selecting the maximum, minimum, or mean value from the range can affect the calculated time to irrigate or the amount of pesticide or nitrates that enter the ground water.

Conventional methods used to determine FC and PWP from field or laboratory measurements are costly and time consuming (Mualem 1992). Predictive methods, based on regression analysis in which soil particle size fractions and/or other soil data are correlated with soil hydraulic properties, have been developed by several workers including Campbell (1985), Saxton and others (1986), and Gregson and others (1987). The accuracy of predicted soil hydraulic properties are not known. Even if measured values are available for direct comparison, they may not reflect the physical properties of the soil type because of extensive spacial variability that exists in field soils (Yeh et al. 1986).

The indirect methods develop regression equations for predicting the parameters needed to describe the moisture release curve. Field capacity and permanent wilting point values are then estimated using a moisture release curve model and setting the soil matrix potential at -33 and -1500 KPa, respectively. For light sandy soils, the water content at -10 KPa appears more representative for FC (Donigian and Carsel 1992; Walker and Skogerboe 1987). Jensen and others (1990) stated that FC for coarse textured soils could be estimated at -10 KPa and at -20 KPa for medium to fine textured soils. Ratliff and others (1983) compared field measured and calculated available water (difference between soil moisture estimated at -33 KPa and that estimated at -1500 KPa) and concluded that the estimated water contents at -33 KPa were significantly less than the field measured for sands, sandy loams, and sandy clay loams. In contrast, the calculated soil moisture contents at -33 KPa were significantly more than the field measured values for silty loams, silty clay loams, and silty clays. However, Ratliff and others (1983) defined FC as the water content of a soil after drainage became practically negligible. For some of the clayey soils, the time to reach field capacity was 20 days. Besides, the plots were subject to evaporation losses and rainfall inputs. Consequently, the heavier soils would have a lower FC value than were normally calculated. Plants can take water out from the soil immediately after irrigation. In most irrigation management models, the FC value is the upper limit value for soil water content. The calculated soil water contents at -1500 KPa were significantly less than the field measured permanent wilting point values for sands, silty loams, and sandy clay loams, and significantly more than the field measured values for loams, silty clays, and clays. Consequently, Ratliff and others (1983) recommended that available soil water should be measured in the field instead of using laboratory procedures. An array of choices is listed below:

1. measure in the field, the soil moisture content 48 hours after an irrigation to determine FC and select PWP from the general values for that soil type

2. use a general value for different soil types for both FC and PWP

3. select either the minimum, mean, or maximum value from a range of available FC and PWP values presented in the county NRCS soil survey report

4. estimate the coefficients that describe the moisture release curve based on soil particle size fractions (percent sand, silt, and clay) for the soil type from the center point of the soil textural class in the soil textural triangle; use the soil moisture release curve model to calculate field capacity at soil matric potential taken from a range between -10 and -33 KPa depending on the soil type; then, calculate PWP at -1500 KPa

5. use the indirect method to parameterize the soil moisture release curve model and the saturated hydraulic conductivity, and then solve Richard’s Equation for infiltration and redistribution; after 48 hours of redistribution, use the predicted soil moisture content to estimate the field capacity value; then, run the model until the soil matric potential reaches -1500 KPa to determine the soil moisture content at PWP

FC values of six soil types presented by Israelsen and Hansen (1962) were regressed against percent sand, silt, and clay taken from the center point of each soil textural class as shown in the USDA soil textural triangle. The linear coefficients were determined using a multiple regression model. The soil moisture content at FC was estimated using the resultant regression model. The same approach was used to find the regression model PWP values using the data in Israelsen and Hansen (1962).

The data in Israelsen and Hansen (1962), though not referenced, represents the average FC values for the different soil textural classes listed. The approach used to verify that the values given by Israelsen and Hansen (1962) are reasonable or could be improved is to take the percent sand, silt, and clay values from the center of the USDA soil textural triangle for each soil class and use them in the equations presented by Campbell (1985) to estimate the parameters for the soil moisture release curve model. The FC values could be estimated at a soil matric potential value that ranges from -10 to -33 KPa. Likewise, the soil moisture content at PWP could be estimated at a soil matric potential value of -1500 KPa. Parameters were determined for the soil moisture release curve model shown in Equation 1:

$$\psi = \psi_e \, (\theta/\theta_s)^{-B} \tag{1}$$

where ψ is matric potential (KPa), ψ_e is air entry potential (KPa), B is b-value, and θ and θ_s are unsaturated and saturated soil moisture content ($m^3\ m^{-3}$), respectively.

Air entry potential and B were estimated based on Campbell's model (1985), which requires particle size fractions for input. Geometric particle diameter (d_g) and the geometric standard deviation (σ_g) were used to estimate ψ_e and B. d_g and σ_g are calculated as follows:

$$d_g = \exp(a) \tag{2}$$

$$\sigma_g = \exp(b) \tag{3}$$

and

$$a = \Sigma m_i \ln(d_i) \tag{4}$$

$$b = \sqrt{[\Sigma m_i \, (\ln \, d_i)^2 - a^2]} \tag{5}$$

respectively.

B is estimated as

$$B = 2\psi_{es} + 0.2\sigma_g \tag{6}$$

and ψ_e (KPa) calculated as

$$\psi_e = \psi_{es}(\rho_b/1.3)^{0.67B} \tag{7}$$

where:

$$\psi_{es} = 0.5(d_g)^{-0.5} \tag{8}$$

and σ_b is soil bulk density in g cm^{-3}.

Along with the equations for estimating the moisture release curve the equation (Eq. 9) given by Campbell (1985) was used to estimate the saturated conductivity (K_s):

$$K_s = C \times \exp(-6.9m_c - 3.7m_s) \tag{9}$$

where m_s and m_c are silt and clay mass fractions and C is a constant. The saturated conductivity and the soil moisture release curve models were used in Campbell's (1985) finite difference solution to Richard's Equation for infiltration and redistribution:

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial z}\left(K(\theta)\frac{\partial H}{\partial z}\right) \pm U(z,t) \tag{10}$$

where θ is volumetric soil moisture content (m^{3}m^{-3}), H is hydraulic head (m), t is time (s), K is hydraulic conductivity (m/s), z is soil depth (m) and U is source/sink term (s^{-1}).

Water was allowed to infiltrate for two hours and then redistributed in 24-hour and 48-hour periods for field capacity (FC) determination. FC is defined as the soil water content when drainage is negligible. After employing Campbell's (1985) model for infiltration/redistribution, the soil water contents in the top 60 cm of the profile were averaged to represent FC. Permanent wilting point (PWP) was determined by running

Campbell’s (1985) infiltration/redistribution model until the soil matric potential, during evapotranspiration events, reached -1500 KPa. The PWP also was calculated based on the -1500 KPa using the soil moisture release curve model.

Soil samples were collected from selected fields of different soil types which varied from sandy to clayey soils 48 hours after the soils had been flood irrigated. Samples were collected at 30 cm increments to a depth of 90 cm. The soil moisture content was determined by drying the sample in an oven for 24 hours at 104°C. The soil sample was then analyzed for percent sand, silt, and clay and then rewetted to PWP, which was measured using a soil psychrometer.

The linear regression relating FC and PWP data given by Israelsen and Hansen (1962) and percent sand (S_a), silt (S_i) and clay (C_l) resulted in a coefficient of variation of 0.99. The equation for FC is :

$$FC = -2.28667 + 0.0331 \times C_l + 0.0321 \times S_i + 0.0296 \times S_a \tag{11}$$

where FC is expressed as the soil’s gravimetric moisture content (g/g) at FC.

The equation for PWP is:

$$PWP = -1.3307 + 0.0156 \times C_l + 0.0148 \times S_i + 0.0137 \times S_a \tag{12}$$

where PWP is expressed as the soil’s gravimetric moisture content (g/g) at PWP.

The FC and PWP values obtained by regressing Israelsen and Hansen (1962) data against percent sand, silt, and clay and values obtained by running Cambell’s model for 24- and 48-hour redistribution are shown in Table 9. As shown in Table 9, FC and PWP values generated by the multiple regression equations and by Campbell’s model for 24-hour and 48-hour redistribution are very close. Comparing FC values generated by the two procedures yielded correlation coefficients of 0.988 and 0.998 for Campbell’s (1985) infiltration/redistribution model simulation with 24- and 48-hour redistribution events, respectively. Thus, the estimated FC using Campbell’s (1985) infiltration/redistribution model with 48-hour redistribution correlated better with FC values given by Israelsen and Hansen’s (1962) data. Even the moisture content in a sandy soil computed by Cambell’s (1985) infiltration/redistribution model with 48-hour redistribution was closer to Israelsen and Hansen’s (1962). Comparison results suggest that the 24-hour redistribution is not long enough for all the large pores to drain.

Field capacity (FC) values obtained using the soil moisture release curve model (Eq. 1) must be adjusted depending upon the soil type. Corresponding matric potentials for the adjusted FC values could range from 10 KPa for sandy soils to 50 KPa for the heavy clayey soils.

Permanent wilting point (PWP) values for clayey and silty soils determined by Campbell’s (1985) infiltration/redistribution model and by soil moisture release curve model, with soil moisture potential set at -1500 KPa, were high compared to Israelsen and Hansen’s (1962) data. However, both procedures gave almost identical PWP values for loamy soil. For sandy soil, PWP values produced by both procedures were lower than Israelsen and Hansen’s (1962) values.

Table 9. Comparison of different methods for determining field capacity and permanent wilting point values

USDA Texture Class	Average Bulk Density (g/cc)	Israelsen	FC Campbel		FC MRC								MRC 1500 KPa
			24-hrs	48-hrs	10 KPa	20 Kpa	30 KPa	40 KPa	50 KPa	Israelsen	Camp PWP	Camp Psi-value	
c	1.260	0.351	0.365	0.355	0.405	0.386	0.375	0.368	0.362	0.172	0.316	-1500.190	0.285
cl	1.350	0.264	0.305	0.293	0.305	0.282	0.270	0.261	0.255	0.125	0.179	-1500.090	0.174
l	1.390	0.223	0.263	0.252	0.247	0.221	0.207	0.198	0.191	0.102	0.105	-1500.020	0.111
lsa	1.580	0.116	0.137	0.126	0.090	0.070	0.061	0.055	0.051	0.051	0.019	-163.883	0.015
sa	1.630	0.091	0.103	0.093	0.050	0.036	0.029	0.025	0.023	0.039	0.007	-66.024	0.004
sac	1.440	0.231	0.264	0.255	0.255	0.238	0.229	0.223	0.218	0.113	0.186	-1500.040	0.156
sacl	1.470	0.200	0.236	0.227	0.219	0.199	0.188	0.181	0.176	0.095	0.124	-1500.050	0.111
sal	1.530	0.139	0.184	0.174	0.148	0.126	0.115	0.107	0.102	0.062	0.056	-426.608	0.046
si	1.160	0.332	0.398	0.378	0.442	0.398	0.375	0.359	0.347	0.149	0.167	-1500.220	0.209
sic	1.280	0.312	0.357	0.347	0.391	0.371	0.360	0.352	0.346	0.150	0.295	-1500.320	0.266
sicl	1.240	0.321	0.369	0.356	0.409	0.383	0.368	0.358	0.351	0.151	0.257	-1500.070	0.252
sil	1.280	0.276	0.330	0.315	0.338	0.305	0.288	0.276	0.267	0.125	0.138	-1500.100	0.163

Explanation of columns:

Camp and MRC mean Campbell ET/redistribution model and soil moisture release curve, respectively.

FC and PWP mean field capacity and permanent wilting point, respectively. FC and PWP values are expressed in g/g.

Israelsen: Data were obtained by multiple-linear regression on Israelsen and Hansen's (1962) published averages against percent sand, silt, and clay with the following results:

Intercept	-2.8667	-1.3307
Clay coeff.	0.0331	0.0156
Silt coeff.	0.0321	0.0148
Sand coeff.	0.0296	0.0137
R^2	0.9988	0.9968

Campbell: Data were obtained for field capacity by running Campbell's redistribution model with the root zone set to saturation, and then allowing 24 and 48 hours of redistribution. The resulting root zone water content was taken as field capacity. Data were obtained for permanent wilting point by running Campbell's ET model with initial conditions near saturation, and allowing extraction to continue until the bottom of the root zone reached 1500 KPa, or the soil became too dry for computation to continue. The resulting average root zone water content was taken as the permanent wilting point. The matric potential for the given PWP values are listed in the table.

Moisture release curve values (MRC): Data were obtained by computing the moisture content from the moisture release curve of each soil type at the stated matric potential.

Moisture content at different matric potential was also measured for a sandy soil collected from Farmington, New Mexico. A power function was fit to the data to estimate parameters for the soil moisture release curve model (Eq. 1). PWP was estimated by setting the matric potential at -1500 KPa in the soil moisture release curve model and back calculating the corresponding soil moisture content. The estimated PWP matched the value given by Israelsen and Hansen (1962) for the soil type but failed to match accurately the value obtained when the soil moisture release curve model parameters were estimated using Campbell's (1985) procedure that requires percent sand, silt, and clay as inputs (eqs. 2-8). Similar results were obtained for clay and loamy soils. Additionally, the mean percent sand, silt, and clay for soil types given in the USDA soil textural triangle were used to estimate parameters for the soil moisture release curve model, based on Campbell's (1985) procedure. The estimated PWP values, based on the new set of parameters, were higher than the values given by Israelsen and Hansen (1962) for the soil types. Consequently, Israelsen and Hansen's (1962) method, the multiple regression approach, gives better PWP estimates than the soil moisture release curve model (Eq. 1) at -1500 KPa soil matric potential. Directly measuring the soil moisture content at -1500 KPa soil matric potential produces PWP values close to the values presented in Israelsen and Hansen (1962). However, it is impossible to determine soil moisture release curves for all soils series in New Mexico for FC and PWP estimates due to the high cost of such an undertaking. The solution is to use models to estimate FC and PWP values. The simple empirical relationship developed by regressing FC and PWP data using Israelsen and Hansen's (1962) multiple regression model against soil particle size fractions provides as good a result as the more physically based models that require percent sand, silt and clay as inputs.

FC and PWP values used for IRRSCHM simulations were estimated using the empirical multiple regression model in which particle size fractions were regressed against FC and PWP data presented in Israelsen and Hansen (1962).

FC and PWP values are sensitive to estimation methods. Because direct measurements could be time consuming when dealing with a large number of soils, estimation models are recommended for use. However, an appropriate estimation model is needed to obtain sound values that reflect soil hydraulic properties. In this study, good FC and PWP values for different soil classes were obtained using an empirical regression model in which PC and PWP values given by Israelsen and Hansen (1962) for different soils were regressed against the corresponding soil particle size fractions.

Organic Matter Content

The problem of estimating organic content in soils can be solved by dividing the problem into two parts: 1) estimating the soil surface (top 30cm) organic content and 2) extrapolating that estimate to the lower soil depths.

Soil organic matter contents are often correlated with soil texture (South and Davey 1983). The more clay and silt in the soil, the higher the organic matter content. This is a result of fewer macro pores in a fine textured soil which favors slower decomposition of organic matter. Data from a study of organic matter content for 45 southern nurseries (South and Davey 1983) were used along with data from several fields in the Las Cruces area to obtain a linear relationship between soil texture and organic matter content. The data from the nurseries were compiled into a weighed average organic matter content by soil type. The types specified in the data were composites of basic soil classifications, and an average composition of percent sand, silt, and clay was estimated by taking the averages of the listed soil type compositions. Because the relationship between organic matter content and soil composition is said to increase as both silt and clay content increase (South and Davey 1983), the organic matter content of a soil should decrease as the sand component increases. Regressing organic matter against the percent sand in the soils, the following relationship was developed, with an R^2 value of 0.895:

$$O = -0.007 \times S + 1.581 \tag{13}$$

where:

O is percent organic matter content in the soil, and
S is percent sand composition of the soil.

Once the surface layer content is known, the remaining problem is to estimate the content of the lower depths for the soil profile. Data for organic matter content by depth for 93 soil series (Gile and Grossman 1979) was normalized for each series and the average relative content for each depth was determined. This provided the following relationship between relative organic matter content and depth, with an R^2 value of 0.67:
where:

$$O_{Relative} = -0.1733 \times \ln(x) + 1.0904 \tag{14}$$

$O_{Relative}$ is relative organic matter content, and x is depth below the surface in centimeters.

Because the soil series were in nonagricultural areas, the data were not used in the analysis of organic matter by soil type. Equations 13 and 14 were used to estimate the organic matter distribution in a soil profile, in which soil surface organic matter content was first obtained and then scaled to obtained values for lower soil depths.

Pesticide Half-Life Values

In the model assumptions, pesticide half-life estimates for different soils are related to the relative organic content of the soil. The relationship between relative organic matter and chemical half-life was determined by evaluating the relative organic matter and half-life values from studies of Aldicarb (Bowman 1988; Pennell et al. 1990) and Atrazine (Bacci et al. 1989; Ghadiri et al. 1984; Hiltbold and Buchanan 1977; Walker 1978). The relative organic matter from each series of studies was normalized with the average for the corresponding series. Likewise, the associated half-life values for each study were normalized with the corresponding mean values. Analysis of the resulting values gave the following relationship:

$$HL_n = -0.6346 \times \ln(OM_n) + 0.76316 \qquad \textbf{(15)}$$

where:

HL_n is the normalized half-life,
OM_n is the normalized relative organic matter content.

This relationship has an R^2 value of 0.725. The data were normalized to obtain a relationship independent of the particular locations from which it was collected, because published values for representative half-lives of various pest control chemicals are average values from multiple studies and sources. To obtain a useful value for any particular location, the representative value must be adjusted.

The actual values for a particular soil's half-life can be obtained by normalizing the relative organic matter content of that soil with respect to the mean value of organic matter for the soils for which studies have been conducted. The normalized value is then used in the relationship given to obtain a normalized half-life value associated with that relative organic matter content. The normalized value is then multiplied by the representative value for the chemical to obtain the actual half-life value for the chemical in the particular soil.

The mean relative organic matter content was determined by taking into account that most areas from which studies of half-life values have been done fall within three soil orders: Aridisols, Mollisols, and Alfisols. The relative organic matter content for each of these soil orders is 1, 4, and 3 percent, respectively (Brady 1990).

The half-life values for each layer in a soil profile are obtained by using the empirical model (Eq. 16), using the relative organic matter in the layer. For example, a hypothetical half-life value of 20 days is given with a known relative organic matter content of 0.75 percent and the half-life value is needed for a soil which has 2 percent relative organic matter. The actual pesticide half-life used is estimated as

$$HL = 20\,days \times \left[-0.6346 \times \ln\left(\frac{2.0}{0.75} \right) + 0.76316 \right] = 2.81\,days \tag{16}$$

Observe that due to the increased organic matter, the actual half-life is much shorter than the reference value. This fact emphasizes the need to make the adjustment. If the target soil relative organic matter content is not known, an estimate can be obtained using the representative value for the soil order given in Brady (1990).

Cropping Sequence for Multiple-Year Simulations

The main field crops grown in Doña Ana County, based on acreage under cultivation, are alfalfa, chile, cotton, corn, and onions (New Mexico Department of Agriculture 1993). The proportion of each crop acreage relative to the total acreage for the five crops was estimated. A set of 100 crop-units comprising alfalfa, chile, corn, cotton, and onions was formed. The number of each crop in the set was determined based on the relative proportion of acreage cultivated with respect to the total acreage covered by the five crops. The ratio of each crop with respect to the rest in the set is cotton-0.52, alfalfa-0.20, chile-0.14, corn-0.07, and onions-0.07.

In addition to simulating the impact that farming practices may have on pesticides leaching in a single season, a multiyear simulation covering a 30-year period also was planned. This requires that a cropping sequence be generated for a 30-year period. The cropping sequence was generated by randomly selecting one crop every year from a set of 100 crop-units made up of alfalfa, chile, corn, cotton, and onions. Crop selection for each year was done independently of the previous year's selection. Thus, each crop had the same chance of being selected each year as pre-determined by the relative acreage with respect to the total acreage under cultivation.

Irrigation Scheduling Data

Irrigation scheduling data for alfalfa, chile, corn, cotton, and onions grown on clayey, clay loam, loam, sandy loam, and loamy sand soils were obtained from Elephant Butte Irrigation District (EBID). The data covered the five-year period from 1990 to 1994. For multiyear simulations covering a 30-year period under the farmers' management practices, irrigation scheduling data for each crop within the cropping sequence were randomly selected from the irrigation scheduling database and the year dates changed to correspond to the climate years used by IRRSCHM. On the other, a 7.6 cm of water per irrigation was used when irrigation was scheduled at 50 percent plant available water depletion level or when tensiometers were used for scheduling. The 7.6 cm represents an average depth of application. Actual depth of application depends on soil type, field length, and management practices.

Planting and Harvest Dates

The planting date used for each crop was the average date on which local farmers planted the crops (Table

10). However, the harvest date was estimated by calculating the average cumulative heat units, expressed in growing-degree-days, from planting to harvest for each crop. The cumulative heat units at harvest used were 550, 3205, 1379, 2015, and 1775 for alfalfa, chile, corn, cotton, and onions, respectively. The cumulative growing-degree-days (CGDD) are estimated as:

$$CGDD = \sum_{i}^{n} \left(\frac{T_{\max} - T_{\min}}{2} - T_{base} \right) \tag{17}$$

where T_{max} and T_{min} are the maximum and minimum daily temperature (°C), respectively, T_{base} is assumed to be the threshold temperature below which crop growth ceases, i and n are the planting and harvesting dates, respectively. The base temperature, maximum temperature above which and minimum temperature below which growing-degree-days are not accumulated are shown in Table 11 for each crop.

Table 10. Average farmers' planting date

Crops	Planting Date
Alfalfa	1 January
Chile	27 April
Corn	15 April
Cotton	15 March
Onions	31 January

Table 11. Maximum, minimum, and base temperatures for alfalfa, chile, corn, cotton, and onions growth

Crops	Maximum Temperature (°C)	Minimum Temperature (°C)	Base Temperature (°C)
Alfalfa	NA	NA	5.0
Chile	30.0	5.0	5.0
Corn	30.0	10.0	10.0
Cotton	30.0	12.0	12.0
Onions	25.0	7.0	7.0

Time of Pesticide Application

Pesticide application must be done at the recommended time to achieve effective results. For this study, pesticide application timing was determined based on the cumulative growing-degree-days (heat units) calculated from the planting date to the date on which specific pesticides were applied by local farmers. The growing-degree-days accumulated at Baldex and Dual applications were 341 and 890, respectively.