Emir. J. Agric. Sci. 2004. 16 (1) : 15 - 31
http://www.cfs.uaeu.ac.ae/research/ejas.html

Management of pesticides in the United Arab Emirates

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Abstract: A total of 835 pesticides are registered in the UAE with insecticide products having the greatest share of use at about 50%. This study showed that the average amount of pesticides used in the UAE is about 10 kg per hectare per year, which is much higher than the corresponding values reported in India, USA and Europe but comparable to that reported in Japan. The number of pesticide poisoning as reported by two main hospitals in Al Ain, UAE in 1999 reached 246 cases of adults and 298 cases of children. None of these pesticides exposure was fatal and less than 10% of the cases needed hospitalization. Many poisoning problems, however, may have not been reported to the hospitals and the data may have been skewed. This study also focused on the potential leaching of used pesticides to UAE groundwaters. It was found that 3 out of 11 pesticides that are widely used in the UAE have the potential to leach to groundwater due to their solubility that exceeded the US EPA threshold values. Five pesticides have the potential to leach due to their low vapor pressure and four pesticides possibly leach to groundwater due to their weak sorption to the soil. Metalaxyl is the single pesticide that exceeded all threshold values set for leaching, indicating a high potential to reach groundwater. The high field dissipation rates of cymoxanil and dimethoate may prevent substantial amount of these pesticides to reach groundwater. From a regulatory standpoint, pesticides are among the most regulated chemical products in UAE. All pesticides that pose high risks to human health and the environment are banned in the UAE. The Ministry of Agriculture and Fisheries imposes strict restrictions on the amount of pesticides imported and used, as well as the amount of their residues that are allowed in the environment. Greatly lacking is a sound management program for pesticide application in the UAE. Recommendations are presented in relation to the selective use and application of pesticides that may lead to a reduction in pesticide use in the country.

Key words: groundwater contamination, transfer, poisoning, pesticide management, pesticide registration.

إدارة المبيدات في دولة الإمارات العربية المتحدة

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ملخص: وصل عدد المبيدات المسجلة في الإمارات العربية المتحدة إلى 835 مبيد، منها ما يعادل 50% مبيدات حشرية. ووصل معدل استخدام المبيدات في الدولة إلى 10 كغ لكل هكتار سنوياً، ويعتبر هذا المعدل أعلى من مثيلاته في الهند وأمريكا وأوروبا، ولكنه متقارب مع معدل استخدام المبيدات في اليابان. وقد أظهرت هذه الدراسة أن حالات التسمم بالمبيدات، حسب التقارير المتوفرة في مستشفيين في مدينة العين لعام 1999 هو 246 حالة للكبار و 298 حالة للأطفال، ولم تكن أي من حالات التسمم هذه مميتة، بل إن أكثر من 90% منها لم يكن بحاجة إلى عناية طبية. إلا أن العديد من حالات التسمم بالمبيدات الحاصلة فعلاً قد لا يتم الإبلاغ عنها. ومن المواضيع التي ركزت عليها هذه الدراسة إمكانية تسرب المبيدات المستخدمة إلى المياه الجوفية. وخلصت الدراسة إلى أنه من بين المبيدات الأكثر استخداماً هناك 3 مبيدات لها القابلية للوصول إلى المياه الجوفية بسبب ذوبانها في الماء، و 5 مبيدات بسبب انخفاض قدرتها على التطاير، و 4 مبيدات بسبب ضعف امتصاصها من قبل التربة. وأظهرت الدراسة أن مركب الميتالكسيل هو المبيد الوحيد ذو الخصائص التي مكنته من الوصول إلى المياه الجوفية، بينما المركبان السيموكسانيل والدايمثاويت قد لا تصل للمياه الجوفية بتراكيز عالية نظراً لارتفاع معدل التآكل في الحقل لهذين المبيدين. وتعتبر المبيدات من أكثر الكيماويات التي يتم مراقبتها في الدولة. فقد منع استعمال المبيدات التي تؤثر إلى حد بعيد على الصحة البشرية أو على البيئة. وقد قامت وزارة الزراعة والثروة السمكية بفرض قيود مشددة على كميات المبيدات التي يتم استيرادها أو استخدامها، وكذلك على الكميات المتبقية من هذه المبيدات في البيئة. إلا أن ما تحتاجه الدولة في الوقت الحاضر هو برنامج إداري فعال لكيفية استخدام المبيدات. وقد عنيت هذه الدراسة بوضع توصيات خاصة باستخدام المبيدات والتي قد تؤدي إلى التقليل من معدل استخدامها.

كلمات مفتاحية: تلوث المياه الجوفية، نقل، تسمم، إدارة المبيدات، تسجيل المبيدات

Introduction

Insecticides are the most powerful tool available for use in pest management. They are highly effective, rapid in curative action, adaptable to most situations, flexible in meeting changing agronomic and ecological conditions, and relatively economical (Metcalf, 1994). Despite these impressive credentials, much use of insecticides has been ecologically unsound, leading to such disadvantages as insect pest resistance, outbreaks of secondary pests, adverse effects on non-target organisms, objectionable pesticide residues, and direct hazards to the user (Smith, 1970). The misuse, overuse, and unnecessary use of insecticides have been the most important factors in the growth of interest in pest management; therefore, we need to maximize the advantages of their use and to minimize the disadvantages. It should always be remembered that the application of insecticides represents environmental contamination and can be justified only where benefit/risk ratios are clearly tilted in favor of insecticide use.

Many factors influence the distribution and fate of pesticides in soil. These include adsorption to clay and organic matter, leaching and washing off by water, evaporation into the air, uptake by soil organisms or plants, movement with runoff water or eroded soil, microbial degradation, and chemical degradation. Of primary importance is the chemical nature of the pesticide and the soil type. If we are to predict possible environmental effects due to pesticide use under Emirati weather conditions, or to maximize the effectiveness of soil-active pesticides, the physical and biological processes in Emirati soil must be understood. Not enough data is known about these points. From an environmental standpoint, it is important to understand what predominant mechanisms affect the transport and fate of pesticides. From a pest control standpoint, the effectiveness, rates, and frequency of pesticide application are dependent primarily on sorption phenomena and the tendency of the pesticide to be degraded.

The greatest potential for unintended adverse effects of pesticides is through contamination of the hydrologic system, specifically water in the aquifers. In fact, water is one of the primary media in which pesticides are transported from application areas to other locations. Pesticide contamination of groundwater is a global issue because groundwater is used for drinking purposes by about 50% of the population in the United States. In the UAE, about 70% of the total water consumed goes for irrigation, with most of this water coming from underlying aquifers.

Prior to the 1970's, it was generally assumed that soil provided a protective "filter" that stopped infiltrating contaminants before they reached groundwater. The detection of pesticides and other contaminants in groundwater, however, has demonstrated that this is not always the case. Over 300 studies of pesticide occurrences in groundwater and soils have been carried out during the past 30 years (USGS web site). Results of these studies revealed the presence of at least 143 pesticides and 21 transformation products in groundwater, including compounds from every major chemical class. However, these studies showed that detected pesticides are commonly present at low concentrations in ground water beneath agricultural areas, and seldom exceeded water-quality standards. For two of the multistate studies, the National Pesticide Survey (US EPA, 1990 and 1994) and the midcontinent investigation by Kolpin et al. (1995 a and b), the most frequently detected pesticides in groundwater were transformation products, rather than parent compounds. Pesticides that have been detected more frequently include those that have been extensively used, such as triazine and acetanilide herbicides, and those for which sampling has been most extensive because of contamination problems (aldicarb and its transformation products, DBCP, and ethylene dibromide). All these results have focused attention on the question of how to control pests without contaminating groundwater.

The extent of soil contamination potential from pesticides, and transport of pesticides is not fully understood in the UAE. Originally it was believed that pesticides were not a threat to soil and groundwater since available testing techniques did not detect contamination. Studies suggested that effect of microorganisms, environmental factors, and soil degradation or adsorption were the common phenomena for most pesticides before they could reach groundwater sources. Pesticides that did enter groundwater were believed to be rapidly decomposed. More recently, however, new detection methods have shown that small amounts of agrochemicals, including certain pesticides, can be leached in some groundwater locations.

The objectives of this study were to (1) determine the extent of pesticide use in the UAE, and the level of human exposure and toxicity of these pesticides, (2) determine pesticide transport mechanisms, (3) determine the properties of pesticides used in the UAE, (4) describe the characteristic soils in the UAE and other factors affecting pesticide mobility, and (5) review registration and regulation procedures and risk assessment procedures for registered pesticides with respect to human health and the environment. Recommendations for preventative measures that would reduce the potentials for pesticides to reach groundwater are given.

Extent of pesticides use in the UAE

Basically, pesticides used in UAE fall under one of the following classes or groups according to their use: insecticides, fungicides, nematicides, acaricides, rodenticides, defoliants, growth regulators, etc. Table 1 shows the breakdown of all registered agrochemicals in the UAE and overall quantities imported during the years 1996-1998 (Ministry of Agriculture and Fisheries, 1999). In the UAE, a total of 835 pesticides were imported and registered during the years 1996-1998, weighing approximately 2,600 ton. 49.9% of which were insecticides used for both agricultural and public health purposes. Fungicides accounted for 22%. Other types of pesticides constituted the remaining percentage (28.1%). Approximately 2,600 ton of pesticides were imported to the UAE during the period 1996-1998. Table 1 shows the amount of each type of registered pesticide in the UAE. Insecticides (for agricultural and public health use) have the greatest share in total amount of 1,554 ton for only 148 products out of 417 registered insecticides. Fungicides accounted for the second largest quantity of pesticides imported (i.e. 793 ton for only 67 products out of 184 registered fungicides).

The differences in the amount of pesticides imported during this period may be attributed to a variety of factors, including weather conditions, variations in planted acreage, crop plantings, and pest infestations.

The average cultivated area in UAE was reported by the Ministry of Agriculture and Fisheries (1999) as approximately 72,539 ha per year, between 1996-1998 (Table 2). Most pesticides were being used to control pests on fruits (mainly date palm and citrus), vegetables, crops and fodders, and ornamental trees and shrubs in cultivated lands and greenhouses. The average amount of pesticides (201 out of the 500 registered products) used only for agricultural purposes (this mainly included agricultural insecticides, agricultural acaricides, fungicides, herbicides, and nematicides) reached 715 ton of products per year (a total of 2,146 ton for the three years).

Table 1. Number of registered pesticides and quantities imported to UAE during the years 1996 - 1998.

Pesticide Type	No. of Registered Pesticides	Quantities (kg) Imported during 1996-1998 (No. Pesticides)			
		1996	1997	1998	Total
A. Insecticides: Agricultural	249	312,354	383,395	512,255	1,208,004 (110)
B. Soil Insecticides / Nematicides	19	-	-	-	-
C. Acaricides: Agricultural	34	16,060	28,063	39,486	83,609 (17)
D. Insecticides: Public Health	168	79,185	116,917	220,111	346,213 (38)
E. Fungicides	184	199,370	235,756	358,112	793,238 (67)
F. Bactericides	3				-
G. Herbicides	20	500	1,000	1,000	2,500 (1)
H. Rodenticides	47	50,050	17,600	46,000	113,650 (11)
I. Nematicides	13	33,500	12,605	13,000	59,105 (6)
J. Molluscicides	4	-	-	-	-
K. Insecticides & Miticides (Veterinary)	4	-	-	-	-
L. Soil Sterilants	9	-	-	-	-
M. Plant Hormones, Growth Regulators, etc.	13	-	-	-	-
N. Spreaders, Stickers, Buffers, etc.	20	-	-	-	-
O. Insect Pheromone Lures	13	-		-	-
P. Active Ingredients: for local pesticides formulation	8	-	-	-	-
Q. Insecticides: locally manufactured	10	-	-	-	-
R. Insecticides + Fertilizers	3	-	-	-	-
S. Deodorizers	5	-	-	-	-
T. Leaf-Shine, Fruit and Veg. Wax, Disinfectants.	9	-	-	-	-
Total	**835**				**2,603,819 (715,485 / year)**

Source: The Ministry of Agriculture and Fisheries - Agricultural Affairs Sector, UAE, 1999.

Table 2. Cultivated areas in the United Arab Emirates.

	Cultivated Area (Hectare)				
Year	**Fruits**	**Crops & Fodder**	**Vegetables**	**Greenhouses**	**Total**
1996	33,558.7	7,907.3	16,021.2	204.9	57,692.1
1997	39,081.6	8,608.8	18,448.4	222.6	66,361.4
1998	61,707.8	8,426.6	23,198.4	230.5	93,563.3
Total	134,348.1	24,942.7	57,668.0	658.0	217,616.8
Ave. / year	44,782.7	8,314.2	19,222.6	219.3	**72,538.8**

Source: Ministry of Agriculture and Fisheries (2000)

These statistical information indicate that the average amount of pesticides per hectare per year is 9.86 kg. It should be stated that the overall usage of pesticides is 0.5 kg/ha in India, 1.5 kg/ha in USA, 1.9 kg/ha in Europe, and 10 kg/ha in Japan (Rao, 1998). The high amount of pesticides used per hectare, compared to other agricultural countries, is based on the assumption that all imported pesticides were used during the years 1996-1998 on the specified cultivated area reported by the Ministry of Agriculture and Fisheries (2000).

Human exposure and toxicity of pesticides

A prospective study of acute pesticide poisoning was performed in Tawam and Al-Ain hospitals (Al-Ain Medical district of the UAE) from 1st of January to 30th of December 1999. The records of all patients attending the emergency room or admitted to the hospital and given the diagnosis of poisoning by the physician were assessed. Direct interviews were arranged with the patients or the parents (in case of children) if the data were incomplete in the patients' files. The following information were obtained: age, sex, nationality, type of poisoning, type of formulation and route of exposure, container details, history of event, time of poisoning, place of poisoning, time before medical attention, first aid if performed, hospital management, outcome and morbidity.

The data collected here represent acute poisoning (94%). Chronic poisoning was less common and accounted for 6% of the cases. Chronic cases are poorly diagnosed at the initial hospital admission and may be part of a broad differential diagnosis picture. The diagnosis is usually confirmed and established at a later time. During the period of the study there were 246 cases of adult poisoning and 298 cases of childhood poisoning. Out of 246 adult poisoning, 34 were due to pesticides (only 4 adult incidences were intentional and the remaining 30 cases were accidental or unintentional exposures). Out of 298 poisonings in children there were 18 cases of pesticide exposure (these cases were all accidental and none were intentional). Among the agents implicated in pesticide poisoning were insecticides, rodenticides, herbicides as well as fertilizers. There were 3 incidences of fertilizer exposure, two incidences of rodenticides poisoning and only one case of paraquat ingestion in adults. Insecticides accounted for the other 29 incidences of acute pesticide poisonings in adults. Organophosphate compounds were among the most common agents reported in the case of adult poisoning. In children, pyrethrum compounds were commonly implicated. Most exposures occurred via topical and inhalation routes, followed by ingestion. None of these pesticide exposures were fatal, and hospitalization was needed in less than 10% of the cases.

Although pesticide poisoning is commonly implicated in accidental poisoning, the prevalence is comparable to many developed countries. The fact that UAE is less agricultural may indicate that the incidence of pesticide poisoning is slightly higher than other places. Intentional ingestion is much lower compared to USA and many other countries. Most accidental and unintentional poisonings are less complicated than intentional, and education may help in further reducing the incidence. Despite the higher rate of accidental cases, the outcome was not severe. The data stated above represent acute exposures and chronic cases may be underestimated. Many poisoning problems may not be reported to the hospitals and the data may be skewed.

Transport mechanisms

In addition to their application to targeted areas, pesticides are discharged to the environment through accidental spills and leaks, and through improper disposal. They may then reach groundwater not only by leaching through soil, but by a variety of other routes as well. Some of these routes include seepage of contaminated surface water into underlying groundwater reservoirs or "aquifers", transport down abandoned or poorly sealed wells, and injection through wells used to dispose of agricultural or urban runoff (USGS web site).

Once released into the environment, pesticides start their transport processes. These processes are sometimes essential for pest control as is the case for certain pre-emergence herbicides that must move within the soil to reach the germinating weed seeds (Waldron 1992). However, pesticides may move away from the target pest, leading to reduced pest control, injury of non-target species including humans, and contamination of surface and ground water.

Research suggests that the movement of pesticides in the environment is complex, with transfers occurring continually among different environmental compartments. Nevertheless, we explore here several mechanisms that affect the transport of pesticides in the subsurface environment. These mechanisms (Figure 1) either affect the location of the chemical (transfer mechanisms) or the structure of the compound (transform mechanisms). Transfer mechanisms include advection, dispersion, chemical interaction with the soil and plants, and volatilization.

Advection causes pesticides to move at a velocity equal to the average pore-water velocity. Dispersion, however, is caused by several factors including deviations in the velocity of water among different flow channels, deviations in the water velocity within a flow channel, concentration differences at adjacent locations, and the existence of nonequilibrium processes. As a result of dispersion, spreading of the chemical will be enhanced but the center of mass of the contaminant plume will not be altered. Such impact is different than that caused by sorption (binding) which causes retardation of the chemical as its velocity is reduced relative to the water velocity. The extent of sorption is a function of the chemical properties of the pesticide, the soil type, and the amount of soil organic matter present.

Volatilization of pesticides is a function of their vapor pressure (the higher the vapor pressure of a pesticide, the faster it is lost to the atmosphere). This does not necessarily mean, however, that pesticides with high vapor pressures pose no threat to groundwater. For example, soil fumigants (such as EDB and DBCP) which are injected into the soil, have limited exposure to the atmosphere. If these compounds are highly soluble in water, they can leach to underlying aquifers. Both EDB and DBCP, in fact, have been detected in groundwater at several locations in the United States (Trautmann et al. 2004).

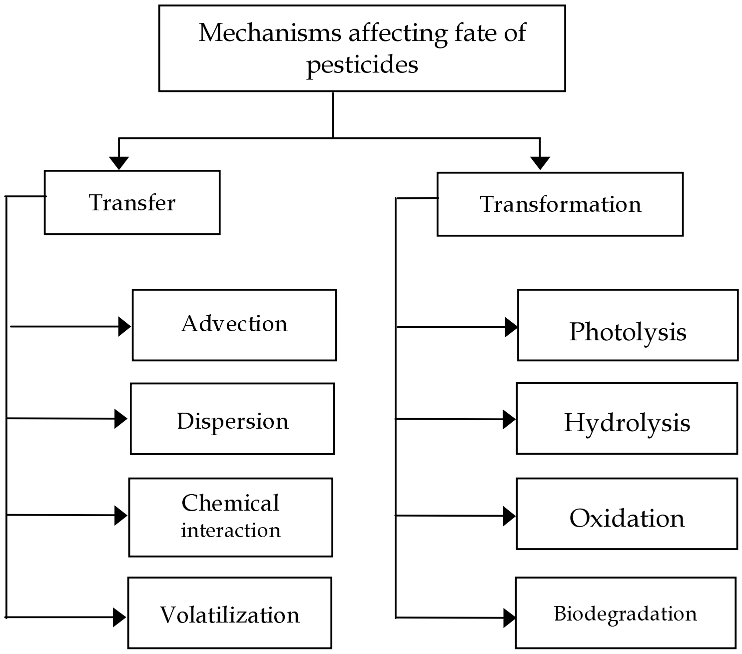

Figure1. Mechanisms affecting pesticides transport in the subsurface environment.

Transformation mechanisms cause degradation or breakdown of the pesticide. One process through which pesticides degrade is photolysis, or breakdown caused by exposure to sunlight. Another is hydrolysis, the reaction of a chemical with water. The third major form of pesticide degradation is through oxidation and other reactions mediated by microorganisms in the soil.

Commonly, a field dissipation half-life is estimated for each pesticide that takes into account physical, chemical, and biological degradation, and plant uptake. The use of half-life, however, requires caution, since these estimates are highly dependent on the chemical, physical, and biological properties of the soil being tested. Therefore, half-life estimates cannot be accurately extrapolated to soils under different conditions. Furthermore, half-lives in subsoils are usually much longer than those for the root zone because of the great reduction in microbial populations and the changes in physical and chemical conditions.

Four major factors determine whether a pesticide is likely to reach groundwater which include: (1) properties of the pesticide, (2) properties of the soil, (3) site conditions, and (4) management practices. The former two factors have a significant and independent effect on groundwater pollution by pesticides. Nevertheless, interaction between site and chemical factors represents the most important control on the occurrence of pesticide in groundwater (Worrall et al., 2002). We explore in some detail the impact of the first two factors as related to conditions in the UAE. The other two factors are discussed, however.

Properties of pesticides used in the UAE

In order to conduct the above proposed study, fifteen granular and foliar pesticides were selected, based on the quantities, usage and persistence, from the main pesticide list reported by the Ministry of Agriculture and Fisheries, 1999 (Table 3). The amount of the 15 selected pesticides, imported during the years 1996-1998 (Table 3), was approximately 514 ton of agricultural insecticides and 102 ton of agricultural fungicides.

Table 3. Quantities of agricultural insecticides and fungicides, selected for the study on the fate of pesticides in UAE subsurface Environment, imported to UAE during the years 1996-1998.

Pesticide Type	Commercial Name	Active Ingredient(s) & Percentage	Manufacturing Co. sp & Country of Origin	Quantities (kg) Imported During			
				1996	1997	1998	Total
Agricultural insecticides	Actellic 50 EC	Pirimiphos-methyl 50%	Zeneca Agrochemicals, U.K.	4,900	29,000	21,000	54,900
	Action 51 EC	Phenthoate 45% + cypermethrin 6%	Isagro, Italy	27,754	32,600	70,200	130,554
	Aflix	Endosulfan 245gm/l + dimethoate 148gm/l EC	AgrEvo, Germany	11,000	13,000	10,000	34,000
	Decis 2.5 EC	Deltamethrin 25gm/l	AgrEvo (Roussel Uclaf), France	6,000	7,000	8,500	21,500
	Dimeclor	Dimethoate 22.2% + chlorpyrifos 27.8%: 50% EC	Agrides, Spain	-	3,000	2,000	5,000
	Dursban 4E	Chlorpyrifos 48% EC	Dow AgroSciences, U.K.	22,200	15,900	30,600	68,700
	Hostathion 40 EC	Triazophos 40%	AgrEvo, Germany	9,000	12,000	13,500	34,500
	Karate 2.5 EC	Lambdacyhalothrin 2.5%	Zeneca Agrochemicals, U.K.	13,000	18,000	24,000	55,000
	Marshal 25% EC	Carbosulfan 25%	F.M.C. Corporation, U.S.A.	3,000	13,824	39,494	56,318
	Rogodial 53 EC	Dimethoate 17.5% + phenthoate 35.5%	Isagro, Italy	5,000	2,000	7,949	14,949
	Rolfan 58% EC	Dimethoate 180gm/l + endosulfan 400gm/l	Isagro, Italy	20,000	4,600	14,480	39,080
	Total						**514,501**
Fungicides	Remiltine 50 WP	Cymoxanil 4% + mancozeb 46.5%	Novartis, Switzerland	13,000	6,000	12,360	31,360
	Redomil MZ 72 WP	Metalaxyl 8% + mancozeb 64%	Ciba-Geigy, Switzerland	6,450	7,750	11,750	25,050
	Tichigaren 30 L	Hymexazol 30%	Sankyo, Japan	9,000	10,000	15,000	34,000
	Topsin - M 40 WP	Thiophanate-methyl 40%	Nippon Soda, Japan	1,000	4,000	7,000	12,000
	Total						**102,410**

(**Source:** The Ministry of Agriculture and Fisheries, UAE, April 1999).

As a result of many field and laboratory studies, the U.S. Environmental Protection Agency (cited from Williams et al. 1988) has compiled a list of key chemical and physical properties called threshold values (Table 4). Although the threshold values provide only a rough guide, compounds with properties that do not satisfy these limits warrant extra attention because of their relatively high potential for leaching to groundwater.

Figure 2 shows some of the properties of the pesticides used in the UAE as compared to the threshold values in Table 4. Properties of the pesticides presented here were adopted from the USDA (2004). The values of K_{oc} (organic carbon coefficient), however, were estimated using values of K_{ow} (octanol-water coefficient) (USDA 2004) and the relationship between K_{oc} and K_{ow} developed by Rao and Davidson as cited by Fetter (1999). Figure 2 shows that three out of 11 selected pesticides have the potential to leach to groundwater due to their solubility which exceeds the threshold value. Five pesticides have the potential for leaching due to their low vapor pressure (low K_H value). Four pesticides will possibly leach to groundwater due to their weak interaction with the soil. Finally, most of the pesticides used in UAE will probably leach due to their relatively high field dissipation half-life.

Among the eleven pesticides shown in Figure 2, metalaxyl is the single pesticide that exceeded all threshold values, indicating that this pesticide has a very high potential to leach to groundwater. Although cymoxanil has three properties (water solubility, vapor pressure, and soil interaction) that favor leaching to groundwater, its field dissipation was low indicating a fast degradation rate that may not reach groundwater. This same argument applies as well for dimethoate. These three compounds have been chosen in an ongoing project to assess their mobility through sand columns (Ateeq, unpublished data). In summary, greatest care needs to be taken with pesticides that are highly soluble in water, do not adsorb strongly to soil particles, and persist for a long time in soil.

Table 4. Threshold values of potential groundwater contamination by pesticides.

Chemical or physical property	Threshold value
Water Solubility (S)	> 30 ppm
Henry's Law Constant (K_H)	$< 10^{-2}$ atm $(mol/m^3)^{-1}$
Organic carbon based coefficient (K_{oc})	<500
Field dissipation half-life ($t_{1/2}$)	> 3 weeks

US EPA, cited from Williams et al., 1988.

Characteristics of soil in the UAE

Many soil characteristics affect leaching of pesticides to groundwater including soil texture, conductivity, and soil organic matter content. To assess the leaching of the 11 selected pesticides to groundwater in the UAE, three soil samples were collected and analyzed. Two samples of Al-Oha and also Abu-Samra were collected from Al Ain area, while the third one was collected from Liwa area. Results of soil characteristics are presented in Table 5. All soil samples were classified as sandy soil with a pH near neutral. The organic matter content of these samples varied, possibly due to the nature of the soil. Both Al Oha and Abu Samara samples were collected from farms, while Liwa soil was collected from a non-agricultural area. Therefore, the organic matter content found in Liwa soil would probably reflect the organic matter for soil beneath the surface of any agricultural area.

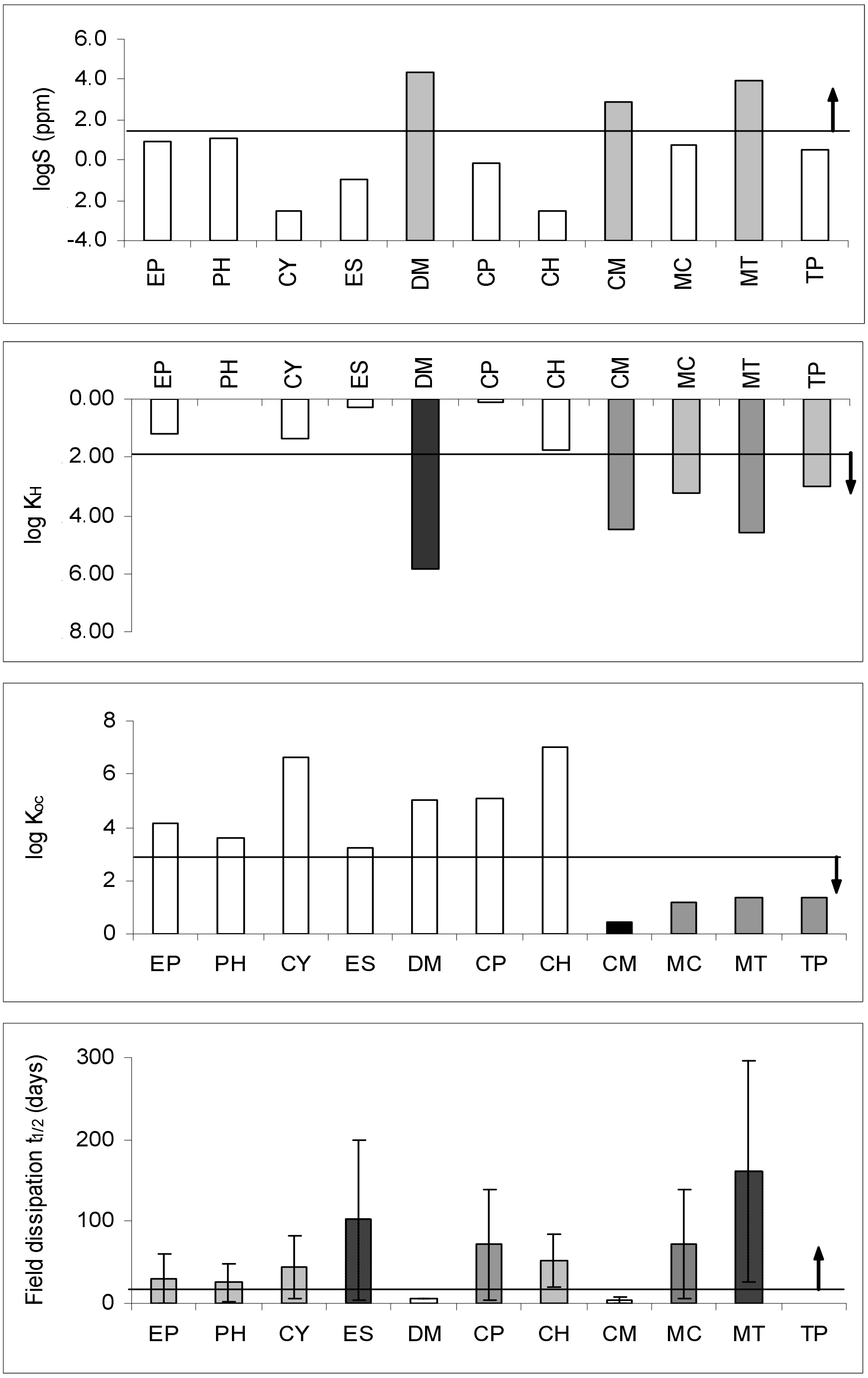

Figure 2. Properties of pesticides used in the UAE in comparison with the threshold values (lines and arrows) indicating potential for groundwater contamination. EP= Methyl-pirimiphos, PH=Phenthoate, CY=Cypermethrin, ES= Endosulfan, DM= Dimethoate, CP= Chlorpyrifos, CH=Cyhalothrin, CM= Cymoxanil, MC= Mancozeb, MT= Metalaxyl, TP= Thiophanate-methyl.

Soil organic matter has evolved as an important parameter affecting the capacity of soil to sorb organic chemicals. The strength of sorption is a function of the chemical properties of the pesticide and the amount of soil organic matter present. Figure 3 shows the linear sorption distribution coefficient (K_d) for the 11 pesticides widely used in the UAE on soil with high and low organic matter contents. The value of K_d was calculated from the value of K_{oc} and the fraction organic matter (f_{om}) of the soil, according to Fetter (1999):

$$K_d = (0.59\ f_{om})\ K_{oc}$$

The factor 0.59 was used to convert the fraction organic matter to organic carbon. The figure shows that, from a sorption point-of-view, cymoxanil would be the only pesticide that would potentially leach under Al Oha conditions. However, four pesticides (cymoxanil, mancozeb, metalaxyl, and thiophanate-methyl) would probably leach if used on agricultural land with a soil characterized as that of Liwa.

Strongly sorbed pesticides on soil are not likely to leach to groundwater, regardless of their solubility. They are retained in the root zone where they are taken up by plants or eventually degraded. However, pesticides that are weakly sorbed will leach in varying degrees depending on their solubility. It should be emphasized that most subsurface soil in the UAE has lower organic matter than that of Al Oha soil. In fact, Al Oha and Abu Samra soils represent a thin layer of a few centimeters commonly used on agricultural land. Therefore, the tendency of these soils to retain pesticides from downward movement will be restricted by the depth of this sorption layer. Since soil organic matter influences how well pesticides are sorbed, increasing the organic content on the soil, by applying manure for example, enhances the soil's ability to hold dissolved pesticides in the root zone. This technique may not, however, protect groundwater contamination from highly soluble pesticides (Worrall et al., 2001).

Texture affects the movement of water through soil and, consequently, the movement of pesticides. The coarser the soil, the faster the movement of percolating water and the less opportunity for adsorption of dissolved chemicals. Sandy soils, typical to those in UAE, are more water conductive than soils with finer texture. For saturated soil with stable structure, the hydraulic conductivity (K) is about 10^{-2}-10^{-3} cm/sec in sand soils, compared to 10^{-4}-10^{-7} cm/sec in clay soil (Hillel, 1982). Therefore, in highly permeable soils, typical to those in the UAE, the timing and methods of pesticide applications need to be carefully designed to minimize leaching losses.

Table 5. Characteristics of selected soil samples[1] from certain regions.

Location	Sand (%)	pH (1:2)	CEC meq/100g	Organic matter (%)
Al Oha	97.5	7.24	NA	0.835
Abu Samra	99.8	7.22	NA	0.207
Liwa	>95	8.15	1.45	0.068

1 Soil characterization was conducted at the Department of Aridland Agriculture at UAE University.
NA = not available

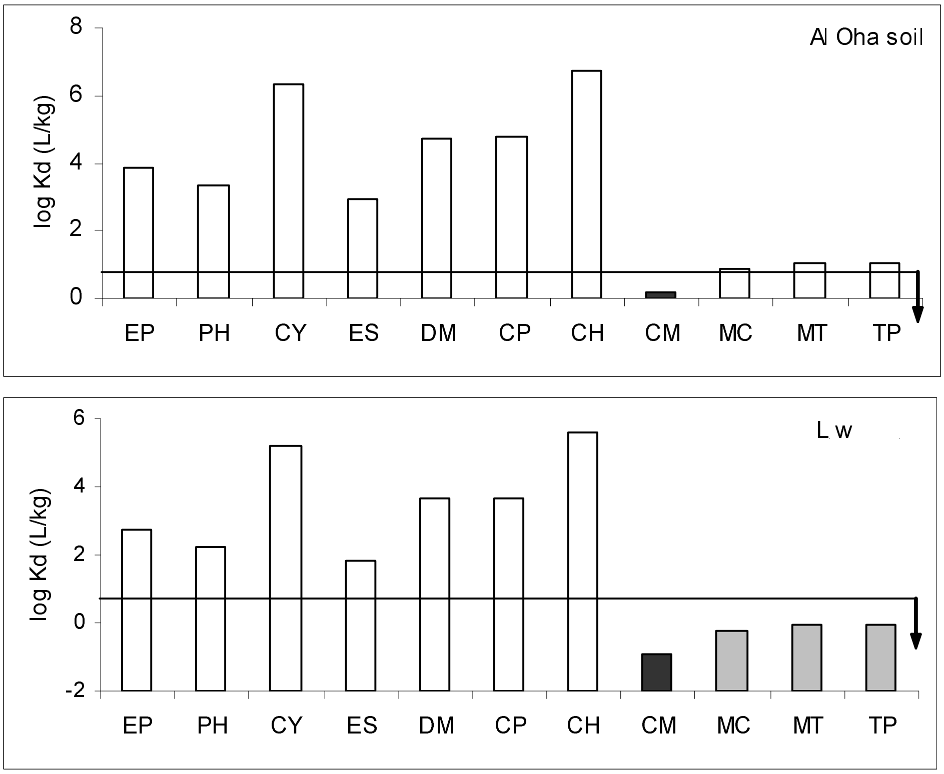

Figure 3. Sorption distribution coefficient for the pesticides used in UAE on two soils with different organic matter content. The line represents the EPA threshold value (See Figure 2 for explanation of abbreviations).

Other factors affecting pesticide mobility

Site conditions greatly affect leaching of pesticides to deeper aquifers. Conditions that could be important to UAE include depth to groundwater and climate conditions. Many aquifers in the UAE are deep, exceeding hundreds of meters in certain areas. With such deep groundwater, the opportunities for degradation or sorption of pesticides are high. Johnson et al. (2001) studied the persistence and penetration of the herbicides isoproturon and chlorotoluron in an unconfined chalk aquifer over a 4-year period. They concluded that at regions where the water table was deepest (9–20 m below surface) little or no positive herbicide detections were made. However, for regions where the water table was at only 4–5 m below surface, a regular pesticide signal was distinguished. It should be noted, however, that the sorption capacity of UAE soil would possibly be higher in the root zone and decrease in the lower layers. Furthermore, biodegradation and photolysis occur at a much higher rate near the surface as opposed to deeper layers.

Meteorological factors including temperature, humidity and wind speed affect the fate of pesticides. High temperature, low humidity and high wind speed tend to increase volatilization. This can result in reduced control of the target pest because less pesticide remains at the target site. The movement of pesticide vapors or gases in the atmosphere, can lead to injury of nontarget species. On the other hand, high temperature and intensive sunlight enhances the breakdown of pesticides by photolysis.

Another important factor that affects mobility of pesticide to groundwater is management practices (i.e., the way in which a pesticide is applied). Injection or incorporation into the soil, as in the case of nematicides, makes the pesticide most readily available for leaching. Most of the pesticides that have been detected in groundwater have been incorporated into the soil rather than sprayed onto growing crops (Waldron 1992). The rate and timing of a pesticide's application also are critical in determining whether it will leach. Over-application (by either higher application rate or higher frequency of application) to a heavy rain fall or irrigation increases the opportunities for the pesticides to leach down.

Registration and legislation procedures for pesticides

Pesticides should be one of the most regulated agrochemicals in the UAE. Despite many regulations (Ministry of Agriculture and Fisheries 1993 and 2001), pesticide residues as a result from the excessive use of pesticides may be found in soil, groundwater, or even in our food supply. Because residues are an inevitable by-product of pesticide use, many of the current regulations in the UAE are in place to address the public health implications of pesticide use. Therefore, there are very strict limits on the amount of pesticides imported and used, as well as the amount of residues that are allowed in all environmental compartments. In addition, all pesticides that pose high risks to human health and the environment (i.e., those carrying the word "Danger" or "Poison") and used in agriculture and public health, are banned in the UAE.

One such regulation currently in place requires that pesticide manufacturers conduct toxicity testing on the pesticide before it can be permitted for use on products either directly or indirectly destined for human consumption (this also includes animal feed). This toxicity testing not only determines the health effects of pesticides, but also the level at which there are no toxic effects on the most sensitive population.

Risk assessment procedures

The Ministry of Agriculture and Fisheries in the UAE is responsible for evaluating the potential health risks posed by pesticides to ensure that they meet a specific standard of safety with respect to human health and the environment. It must make a finding of reasonable certainty of no harm before it registers or reregisters a pesticide, and before it establishes or completes a reassessment of an existing tolerance (pesticide residue limit). Because risk is a function of toxicity and exposure, information about how pesticides are used and their fate in the environment are global part when developing risk assessment procedures. In addition, the Ministry should assess the potential risk of cumulative exposure to pesticides and related toxicant which share a common mechanism of toxicity. To arrive at realistic estimates of cumulative risks, we first need more realistic estimates of actual pesticide usage of those pesticides imported legally or illegally. We simply cannot assume that every pesticide approved and imported for use in the UAE on a particular commodity will actually be used, and that the resulting residues will be at the maximum residue level. Also, we need information about regional differences in use patterns.

Preventative measures

Farmers in the UAE who apply pesticides rarely have adequate knowledge of the basics of pesticide application and toxicology (i.e., of the possible risks of pesticide use and handling). Consequently, although protective personal equipment and instructions on pesticide use may be supplied, they may be given little attention.

Leaching of pesticides to groundwater can be minimized by following specific protocols that would evaluate the types of pesticides used, the amount and rate applied, and the method practiced. Some guidelines that would reduce the potential for pesticides to reach groundwater are:

1. Determine the soil type and its susceptibility to leaching before using pesticides.
2. Where possible, choose pesticides with low susceptibility to leaching.
3. Where possible, select pesticides that are less toxic and less persistent.
4. Use pesticides only when necessary and in the minimum dose required for controlling pests.
5. Apply pesticides specifically to the target site.
6. Apply pesticides at the recommended dosages.
7. Read pesticide labels to avoid human hazards and groundwater contamination; apply pesticides at the appropriate time.
8. Avoid the temptation to use more product than the label directs because more product will not do a better job of controlling pests.
9. Properly calibrate and maintain application equipment.
10. Properly dispose of any leftover pesticides, tank mixes, and rinse water according to label instructions.
11. Store pesticides safely, in the original labeled container and in a cool, well-ventilated location away from wells, pumps, water sources, and residences.
12. Delay irrigation at least one or two days, if possible, after pesticide applications. Runoff should be avoided by not applying immediately prior to a heavy or sustained rain and not using an excessive amount of irrigation water.
13. Maintain records of pesticide use.
14. Integrate pest control techniques, through an Integrated Pest Management (IPM) program in an economically and ecologically sound manner by recommending alternatives to purely chemical pest control.

Conclusions

In order to minimize the problems associated with pesticide use in the UAE, a solid plan must be established to control the use and handling of pesticides at every stage. This phenomenon, called “pesticide management,” should be adapted to combat problems pesticides can cause. The concept of managing pesticides in the UAE is to assess the situation, then carry out various activities to reduce the risks pesticides may have on the human health, non-target organisms, and all environmental compartments including food commodities and drinking water.

Developing a management program for soil pesticides and determining and assessing the risks of pesticide application and transfer should improve the health of the respective workers (in agriculture and factories) and the public, provide environmental protection, minimize pesticide residue problems, facilitate national decisions regarding the importation, distribution, use, and disposal of pesticides, and create awareness of pesticide risks among agricultural workers, decision-makers, and the public.

The knowledge and techniques gained from our research aid in giving recommendations within the scope of a management program for pesticide application. The recommendations, resulted from the management program, are presented in relation to the selective use and application of pesticides that may lead to a reduction in pesticide use; development of registration and legislative procedures for pesticides based on subjective, expert-oriented assessment; risk assessment procedures for pesticide evaluation; evaluation of the possible risks of pesticide application; and development of a monitoring program after the implementation of pesticide application. Specific recommendations are outlined below.

Recommendations

1. Monitoring pesticide levels in UAE groundwater should be conducted regularly. Such a system should start at locations where groundwater is used directly for drinking purposes (in the case of remote areas) or at locations where groundwater is mixed with desalinated water before being distributed to the public.
2. There is a need for proper selection of pesticides used in the UAE based on characteristics such as toxicity and potential leachability to groundwater.
3. There is a need to provide training programs to farmers on how and when to apply pesticides. Regular inspections should be conducted by authorized personnel to assure compliance with such established protocols.
4. There is a need to develop a chemical waste management program in the UAE, as well as other Arab countries, that reveals the amount of obsolete pesticides and other toxic chemicals (originating from substandard, expired, or banned stocks, and empty containers) to be disposed of safely.
5. Samples of domestically produced and imported foods should be collected and analyzed for pesticide residues to enforce the tolerances set by the Ministry. Specialists may concentrate on the raw agricultural products, which can be analyzed as the unwashed, whole (unpeeled), raw commodity. If illegal residues for a particular food/pesticide combination are found in the samples (at any entry point), the shipment may be stopped by the Ministry or any authorized agency. The Ministry may follow the tolerances (MRL's) which are published annually by the FAO/WHO joint meeting.

Acknowledgments

This research was supported by the Scientific Research Council at United Arab Emirates University. The authors are grateful to H. Ateeq for providing the two soil samples.

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