GLEAMS COMPUTER MODEL PESTICIDE PREDICTION IN TWO SOILS

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Abstract

*Recent concerns about the presence of pesticide residues in surface and groundwater have resulted in a need for computer model simulation to assess the impacts of agrichemicals on potential surface and groundwater contamination. GLEAMS (**G**roundwater **L**oading **E**ffects of **A**gricultural **M**anagement **S**ystems), is a mathematical model developed for field-size areas to evaluate the effects of agricultural management systems on the movement of agrichemicals. It can be used as a tool to evaluate the effects of different tillage systems on pesticide, and nutrient losses.*

Agriculture is being increasingly criticized for the deterioration of surface and subsurface water resources all over the world. In the Balochistan province of Pakistan, almost all the urban and rural population depend on groundwater resources for drinking water, irrigation, and the water for livestock use. The objective of this study was to simulate pesticide (Metolachlor) losses from conventional tillage and no-till systems using the GLEAMS pesticide submodel. The pesticide submodel simulated results showed that the runoff losses of Metolachlor from convectional tillage were 94%, and by sediment, the losses were 92% higher than that for the no-till system. However, the percolation losses of Metolachlor were 61%, and the total Metolachlor losses were 39% higher from no-till system as compared to conventional tillage system. The total Metolachlor losses were higher for no-till system because 91 to 99% of the annual total no-till losses were by percolation as compared to 41 to 90% for conventional tillage.

Key Words: GLEAMS, Simulation, Computer Model, Prediction, Runoff, Hydrology

INTRODUCTION

GLEAMS (Ground Loading Effects of Agricultural Management Systems) is a mathematical model developed for field-size areas to evaluate the effects of agricultural management systems on the movement of agricultural chemicals within and through the plant root zone. GLEAMS is a management oriented based model, and should not be used as an absolute predictor of pesticide losses. It can be used as a tool to evaluate the effects of different tillage systems on pesticide losses through runoff, erosion (sediment), and percolation. GLEAMS output includes pesticide losses in runoff, sediments and in percolate. Output frequency can be by daily (storm-by-storm), monthly, yearly, or a combination of these [1]. On a daily basis, the pesticide component simulates up to 10 pesticides. GLEAMS can simulate the pesticide in runoff, sediment, and percolate; and the redistribution of on a daily basis, the pesticide component simulates up to 10 pesticides. GLEAMS can simulate the pesticide in runoff, sediment, and percolate; and the redistribution of pesticide in the root zone. Daily, monthly or annual outputs can be generated for periods of up to 50 year [2].

Soil physical conditions are affected by site preparation techniques. Soil compaction may occur as a result of conventional and some other tillage systems. The soil properties affected by compaction are bulk density, porosity, and field capacity. These important properties are regarded as sensitive parameters in the water balance computations in GLEAMS. They affect runoff, percolation, evaporation, and transpiration. These four components are sensitive in determining the fate of pesticide and nutrient, additionally runoff is a sensitive input in erosion (sediment yield), which in turn is sensitive to chemical transport [3].

Soil organic matter content is soil, climate, and management dependent. Organic matter is not sensitive in hydrology except as it affects water retention. Organic matter content is sensitive in erosion since it affects soil particle aggregation and sediment transport as well as the sediment enrichment ratio. It is sensitive in pesticide adsorption extending from sediment yield and pesticide transport. Organic matter is also important in mineralization and denitrification.

Porosity may be another sensitive parameter in the water balance computation of GLEAMS that is affected by tillage. Its effects are opposite to those of bulk density [3].

Manning's•"n"•for•overland•flow•profile•is•a measure of the resistance to flow. Different tillage systems have different impacts on surface roughness. Soil cover and roughness slow overland flow and reduces its sediment transport capacity. The higher the•"n"•value•the•greater•the•resistance•and lower the flow velocity. Flow velocity and sediment transport are inversely related to Manning's•"n"•[3].

Surface residue is crop residue on the soil surface when simulation begins. Surface residue affects soil temperature, and nitrogen and phosphorus mineralization. The parameter is not sensitive in long-term simulation, but may be very sensitive in short-term simulation of a low-input production system [3].

Identification of the Problem

The presence of pesticide residues in surface and groundwater is cause for increasing pubic concern for non-point source pollution from agricultural lands. Agriculture is being increasingly criticized for the deterioration of surface and subsurface water resources of countries all over the world. Pesticides have a tremendous economics importance in helping to provide sufficient supplies of food and fiber to a very rapidly growing world population at a reasonable cost. As a result of intensive cropping, agricultural chemicals use has become an integral part of most agricultural production systems. Roughly 3, 30,000 tons of nitrogen fertilizer and 10 million tons of nitrogen through manures, crop residues, rainfall, and biological fixation are applied to agricultural crops yearly [4].

The primary purpose of using pesticide is to control harmful insects, and to increase production. They pose no environmental hazard as long as they are not transported from their original place of application, but these chemicals may move and accumulate at harmful concentration in a sink such as a lake or ground water. Runoff water flowing towards streams and lakes may carry sediments, nutrients, and pesticides in harmful quantities that can be potential danger to aquatic life.

Rationale

Simulation models are essential tools in designing and developing water management systems to satisfy both environmental and agricultural goals. For economic reasons, continued use of pesticide and fertilizers is expected for the foreseeable• future• in• worlds'• agriculture. Recent concerns about surface and ground water contamination by agricultural chemicals have resulted in a need for mathematical models to assess the impacts of agricultural management practices on potential surface and ground water loadings of agrichemicals [4]. If agrichemicals losses in surface runoff from the farms are found to be excessive, no demands can be made to change the farm management practices unless it can be shown that, current practices make a comparatively important contribution to the water pollution problem. Therefore, the need for development of sound site-specific chemical management schemes which will minimize the transport of agrichemicals away from its place of application necessitates that, different farm management system be compared for minimum losses of agrichemicals. Intensive regulations of agricultural chemicals use may be effective in preventing surface and groundwater contamination. However, over strict regulations could needlessly limit the use of effective agrichemicals thereby resulting in an increase in production costs and a possible reduction in product quality and yield. Therefore, recommendations and regulations on surface and groundwater contamination must be based on sound technology and an awareness of all costs, benefits, and risks.

Objectives

The objectives of this study were to study the sensitivity of the GLEAMS model to conventional and no-tillage systems simulating pesticide (Metolachlor) losses, and to recommend a tillage system based on least pesticide losses.

RELATED RESEARCH

Studies on the GLEAMS models sensitivity to different tillage systems, and research related to tillage systems on runoff, soil, pesticide, and nutrient losses have provided a better understanding of the effects of some tillage practices on soil physical, chemical, and biological properties. These properties directly or indirectly affect surface runoff, soil, pesticide, and nutrient losses.

GLEAMS Studies

[1] studied the chemical transport in a representative agricultural management

system near coastal plains, Georgia. The experimental plots were 0.8 hectare in size; the soil was loamy sand, and the crop was corn. The plots were treated with Atrazine, Alachlor, Carbora, and a Bromide tracer. Comparisons of observed and GLEAMS model simulated concentrations were found to be reasonable. On the basis of limited comparisons with actual data the GLEAMS model appeared to give reasonable predictions. The controlled-release high mobility pesticide applications study using the GLEAMS model, were simulated using a 50-year climatic record at Tifton, Georgia on two representative soils that occur in groundwater recharge areas of the coastal plains. They concluded that application of the GLEAMS model comparing controllers-release formulations of pesticides with conventional controlled release formulations might provide potential benefits in reducing pesticide movement to groundwater. [2] reported that GLEAMS simulated mass of Fenamiphos, Fenamiphos Sulfoxide, and Fenamiphos Sulphone in the root zone compared favorably with field data. Simulated and observed concentrations with depth in the soil at selected dates also corresponded.

[4] studied the potential pesticide contamination in groundwater recharge areas in the Georgia coastal plains using the GLEAMS model. Soil data were mapped and grouped according to their textural characteristics that showed that clayed soils covered 50% of the total study area. The GLEAMS model was applied to generate 50-year simulations of the transport and degradation of three classes of pesticides. A simulation was made for the pesticides in each of three soils (sand, loam and clay). The model results indicated that the predicted mass loss of pesticides ranged from 12.2% in the sandy soils to less than 0.0001% for the pesticide simulated in clayey soils. They concluded that soil characteristics and agricultural management have a profound effect on the quality of groundwater in aquifer recharge areas.

Field Plot Studies

[5] studied the movement of bromide in a Flanagan silt loam managed under five different tillage systems. They found that bromide movement in the soil involved an interaction between tillage systems and rainfall intensity. Bromide movement in the soil was not significantly different for the selected tillage treatments under the medium and low rainfall intensities. Under the high rainfall intensity, bromide movement in the soil managed under long-term continuous no-till system was greater than that which occurred in the other tillage systems. [6] studied pesticide runoff losses from small plots subjected to simulated rainfall. Their study determined that the reduction in pesticide losses did not occur for the herbicides, which are transported primarily with runoff water.

MATERIALS AND METHODS

A long-term (10-year) tillage study was conducted by establishing experimental plots (each 0.0037 ha) of an average slope of 5%, to determine the effects of different tillage systems on pesticide losses. The topsoil within the plots was loam and subsoil was silt loam. Two tillage systems, conventional and no-till were used. Some of the soil physical and chemical properties used as GLEAMS input parameters of both upper (0-15 cm) and lower soil layers (15-60 cm) were determined by taking soil samples•and•analyzed•in•the•Department's Soil Testing Laboratories, while, some were taken from unpublished local field data. The Hydrometer Method [7] was used for particle size analysis, Bran and Lubbe Technicon Auto Analyzer based on Colorimetric Method was used for labile phosphorus measurement, Mehlick-III Extracting Procedure, Brinkmann D.C.800 Colorimeter for total phosphorus determination, and Flash Combustion Method (CARLO ERRA Nitrogen Analuzer 1500) was used for total nitrogen determination. Simulations with the GLEAMS model (PC Version 2.10) were conducted for the 10-year period for pesticide losses.

Most of the initial parameters were based on the physical and climatic conditions of the areas (plots) and the values recommended in the GLEAMS user's• manual• [3].• Parameter• values• used in the pesticide submodel are defined in Tables 1-3. Daily rainfall and mean monthly minimum and maximum temperature data for Greensboro, North Carolina were obtained from the National Climatic Data Center Asheville, North Carolina, and mean monthly solar radiation data from the GLEAMS climatic data base for Reidsville, North Carolina (about 20km north of the experimental plots), were used. Metolachlor pesticide has been simulated using the pesticide submodel of GLEAMS for monthly and annual summary output. Input parameter values for Metolachlor characteristics were used from the GLEAMS•user's•manual.

Table 1: GLEAMS input parameter values

PARAMETER	DEFINITION	VALUE	SOURCE
DAREA	Total Drainage area of the field (ha)	0.0037	Field Local Data
BST	Fraction of Plant available water in the soil when simulation begins (cc/cc)	0.40	Assumed
CONA	Soil Evaporation Parameter	4.5	GLEAMS manual [10]
CHS	Hydraulic slope of the field (m/m)	0.50	Field Local Data
WLW	Ratio of field length to field width	2.75	Field Local Data
RD	Effective rooting depth (cm)	60	Field Local Data
ISOIL	Code for soil horizons in the root zone	2	Field Local Data
NOSOHZ	Number of Soil Horizons in the Root Zone	2	Field Local Data
BOTHOR	Depth to bottom of each soil horizon	15, 60	Field Local Data
BR15	Wilting point of each soil horizon (cm/cm)	0.11,0.22	GLEAMS Manual [10]
OM	Organic matter content of each soil horizon (percent)	1.00, 0.50	Assumed
CLAY	Clay percent in each soil horizon	19.00,32.15	Field Local Data (Hydrometer Method)
SILT	Silt percent in each soil horizon	36.96, 45.17	Field Local Data (Hydrometer Method)
TEMPX	Mean monthly maximum temperature for each month (^0C)	---	National Climatic Data Center Asheville, NC
TEMPN	Mean monthly minimum temperature for each month (^0C)	---	National Climatic Data Center Asheville, NC
RAD	Mean monthly solar radiation for each month (MJ/cm^2)	----	GLEAMS data base

Table 2: Parameter values used in Pesticide Sub-model

PARAMETER	DEFINITION	VALUE	SOURCE
H2OSOL	Metolachlor water solubility (mg/L)	530	Table P1, GLEAMS manual [10]
HAFLIF	Foliar residue half-life (days)	5	Table P1, GLEAMS Manual [10]
KOC	Partitioning coefficient	200	Table P1, GLEAMS manual [10]
FOLRES	Concentration of Metolachlor residue on the foliage when simulation begins (ppm)	0.00	Assumed
WSHRFC	Fraction of Metolachlor on the foliage available for washoff by rainfall.	0.60	Table P1, GLEAMS manual [10]
COFUP	Coefficient of Metolachlor uptake by plant	1	Table P1, LGEAMS Manual [10]
SOLLIF	Soil half-life (days)	90	Table P1, GLEAMS manual [10]
APRATE	Rate of application of active ingredient (Kg/ha)	2.53	USDA Extension Service Office, Greensboro, NC

Table 3: Tillage Updateable Parameter Values (CT – Conventional Tillage, NT - No-till)

PARA-METER	DEFINITION	TILLAGE	
		CT	NT
RC	Effective saturated conductivity of the soil horizon immediately below the root zone (cm/hr)	0.11	3.29
CN2	SCS curve number for moisture condition II	85	78
POR	Porosity of each soil horizon (cc/cc)	0.50, 0.49	0.50, 0.45
FC	Field capacity of each soil horizon (cm/cm)	0.22, 0.44	0.21, 0.24
SATK	Saturated conductivity of each soil horizon (cm/hr). These SATK values were adjustments from the local SATK values that were too high to be entered as GLEAMS input.	9.50, 0.11,	16.0, 3.29
CFACT	Soil loss ratio for overland profile segment	Varies	
NFACT	Manning's•"n"•for•overland•flow•profile segment	Varies	
RESDW	Crop residue on the ground surface when simulation begins (Kg/ha)	118	1066

RESULTS AND DISCUSSION

Simulated pesticide (Metolachlor) losses to surface runoff, sediment, and percolation from 1981-90, are given in Table 4. Runoff losses of Metolachlor (Fig. 1) by conventional tillage (CT) were from 88% to 99% more than from No-Till (NT) system. The overall 10-year annual averaged runoff losses of Metolachlor from conventional tillage were 35% of total losses as compared to 1% from No-Till. The sediment losses of Metolachlor (Fig. 2) were 54 to 99% more in conventional tillage than from no-till system. No-till sediment losses of Metolachlor were 0 to 0.50% of the total metolachlor losses, and conventional tillage sediment losses of metolachlor were 0.1 to 4% of the total metolachlor losses. This showed that sediment losses of pesticide from conventional tillage were 88 to 100% higher than no-till.

Table 4: GLEAMS Predicted Metolachlor (pesticide) losses from 1981-90. (g/ha) - gram per hectare, CT- conventional tillage, NT - no-till.

Year	Runoff Losses (g/ha)		Sediment Losses (g/ha)		Percolation Losses (g/ha)		Total Losses (g/ha)	
	CT	NT	CT	NT	CT	NT	CT	NT
1981	23.9	1.90	0.07	0.03	60.6	162.0	84.5	163.9
1982	132.6	16.0	6.51	1.00	95.2	168.6	234.0	185.0
1983	35.8	0.65	1.74	0.09	72.0	167.7	110.0	168.0
1984	33.0	1.00	1.72	0.08	140.2	354.7	175.0	356.0
1985	14.4	0.38	0.72	0.03	63.45	158.5	78.6	158.9
1986	18.0	0.64	1.06	0.04	21.39	104.9	40.4	105.6
1987	45.3	3.13	2.18	0.22	101.4	277.6	149.0	281.0
1988	43.2	1.67	2.66	0.13	24.81	98.09	70.6	99.9
1989	73.3	0.16	3.44	0.01	75.40	246.9	152.0	247.0
1990	11.1	0.53	0.70	0.03	111.7	240.3	123.0	240.0
Average	43.0	2.60	2.08	0.17	76.61	197.9	121.0	200.0

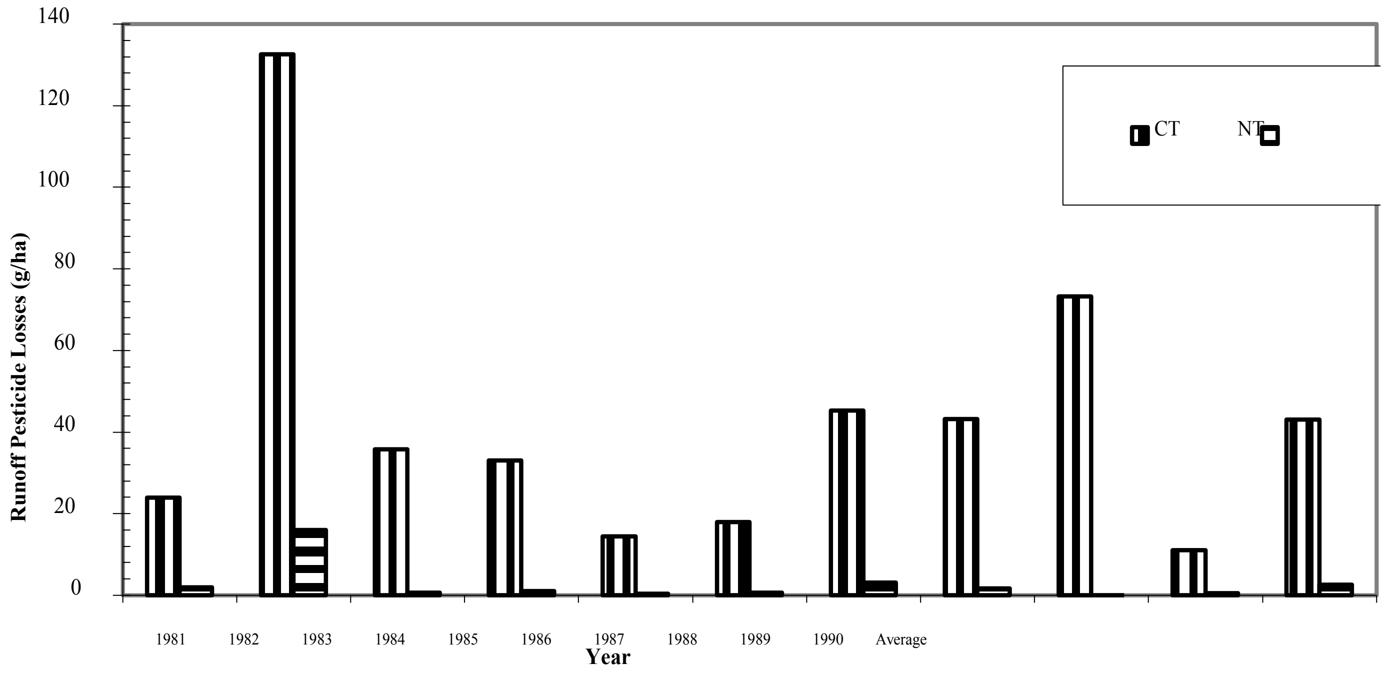

Fig 1: GLEAMS predicted metolachlor (pesticide) losses by runoff for conventional tillage (CT) and no-till (NT) from 1980-90.

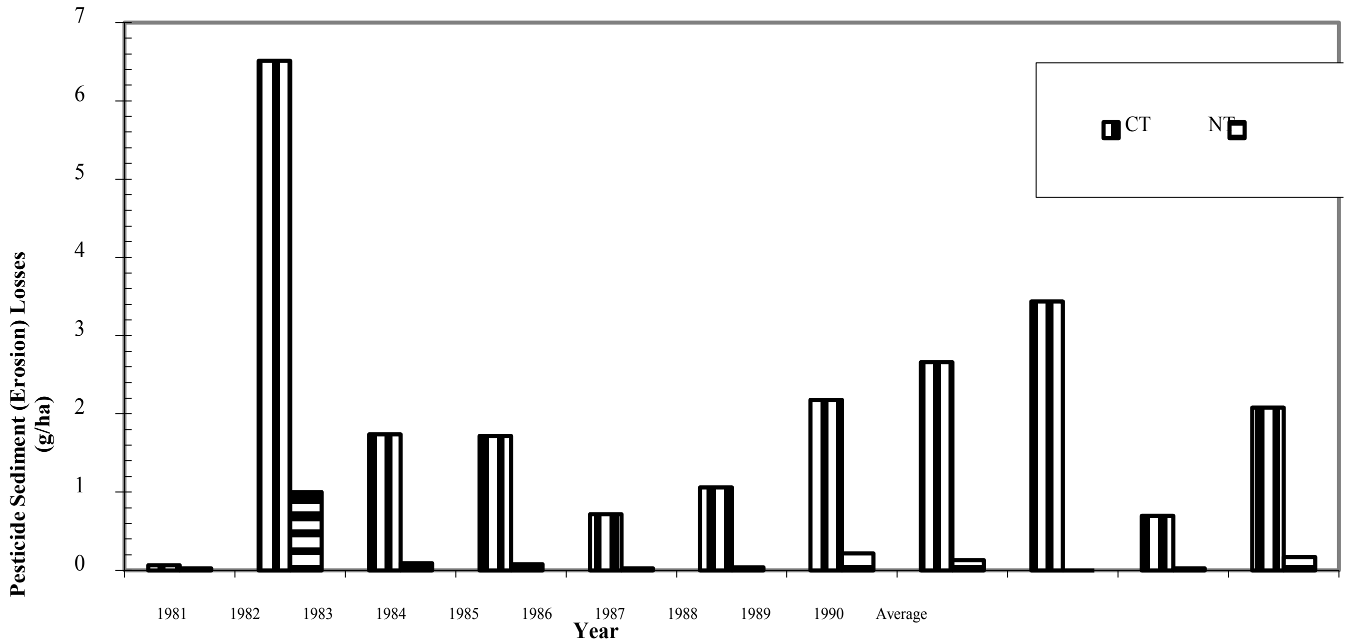

Fig 2: *GLEAMS predicted sediment (erosion) losses of metolachlor (pesticide) for conventional tillage (CT) and no-till (NT) from 1981-90.*

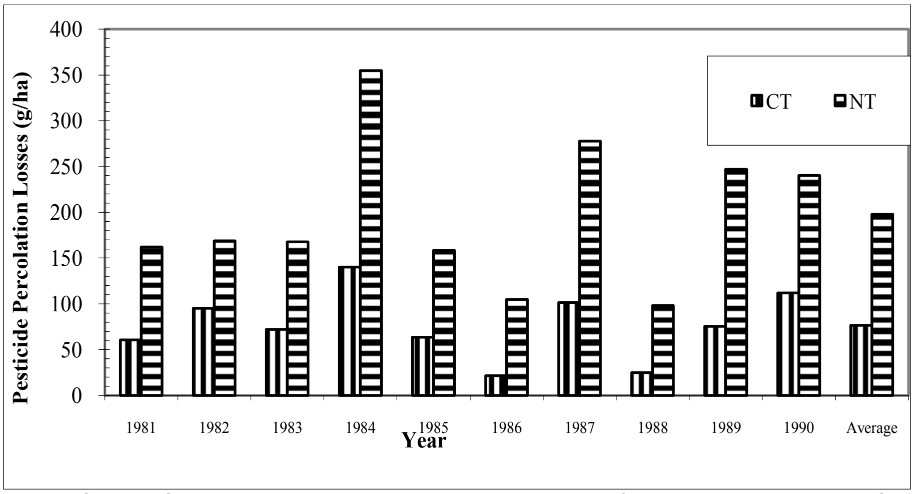

Fig 3: *GLEAMS predicted percolation metolachlor losses for conventional tillage (CT) and no-till (TN) systems from 1981- 90.*

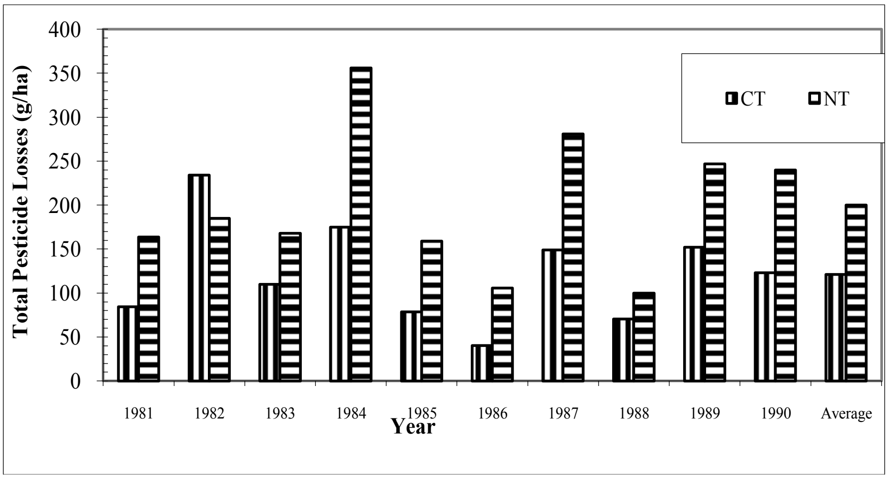

Fig 4: GLEAMS predicted total metolachlor (pesticide) losses for conventional tillage (CT) and no-till (NT) systems from 1981-90.

Metolachlor losses through percolation (Fig. 3) were 43 to 79% (2 to 5 times) more from no-till systems as compared to conventional tillage systems. From no-till system the metolachlor losses by percolation were 91 to 99% of total losses. The 10-year average percolation losses of metolachlor from no-till system were 61% more than that from conventional tillage. The total metolachlor losses (Fig. 4) from no-till systems were 1 to 2 times more than that from conventional tillage system. This difference is mainly due to high water solubility, low adsorption characteristics of metolachlor and more percolation losses from no-till system. Since the no-till system reduces runoff and increases infiltration and percolation therefore, in case of no-till systems, the subsurface losses were more than that of surface losses.

SUMMARY

Experimental plots (each 0.0037 ha) of average slope of 5% were established to study the pesticide losses from conventional and no-till systems using GLEAMS computer model. GLEAMS parameter values and other input data were obtained from the experimental plots, CREAMS users guide, and the GLEAMS users manual.

The pesticide submodel simulated results showed that the runoff losses of Metolachlor from convectional tillage were 94%, and by sediment, the losses were 92% higher than that for the no-till system. However, the percolation losses of Metolachlor were 61%, and the total Metolachlor losses were 39% higher from no-till system as compared to conventional tillage system. The total Metolachlor losses were higher for no-till system because 91 to 99% of the annual total no-till losses were by percolation as compared to 41 to 90% for conventional tillage.

CONCLUSIONS

It• can• be• concluded• from• this• study's simulated results that the GLEAMS model is sensitive to conventional tillage and no-till system, and that the no-till system may be good for reduced runoff and sediment losses of pesticide but it is no good for percolation and total losses of pesticide. It can further be concluded from these simulated results that no-till is not effective in reducing the losses of highly soluble chemicals. Since there is no or minimum compaction of soil as a result of no-till, that is why the water losses by percolation is higher as compared to runoff.

RECOMMENDATIONS

No-till may not be a very effective system in reducing the losses of highly soluble agrichemicals and the GLEAMS model can be used as an effective tool for evaluating different tillage systems for pesticide losses by runoff, sediment and percolation.

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REFERENCES

- **Asmussen** L.• E.,• D.• W.• Hicks,• R.• A.• Leonard,• W.G.• Knisel,• and• H.• F.• Perkins.• "Potential Pesticide•Contamination•in•Groundwater•Recharge•Areas:•A•model•Simulation".• Proceedings•of the Georgia Water Resource Conference, University of Georgia. 161-164, Georgia, May, 1989.
- **Barisas,** S.•G.,•J.•L.•Baker,•H.•P.•Johnson,•J.•Laflen.• "Effect•of•Tillage•Systems•on•Runoff•Loses of•Nutrients,•A•Rainfall•Simulation•Study".• TRANSACTIONS•of•the•ASAE.•893-897. 1978.
- **Baker,** J.• L,• J.• M.• Laflen,• H.• P.• Johson.• "Effects• of• Tillage• Systems on Runoff Losses of Pesticides:•A•Rainfall•Simulated•Study".• TRANSACTIONS•of•the•ASAE:•886-892. 1978.
- **Bales,** J.•and•R.•P.•Betson.• "The•Curve•Number•as•a•Hydrologic•Index".• In•Proc.•Rainfall-Runoff relationship, ed. V. P. Singh. Littlelon, Co: Water Resources Publ. 1982.
- **Bicki,** T. JL, Lei Guo. "Tillage•and•Simulated•Rainfall•Intensity•Effects•on•Bromide•Movement•in an Agriudoll". Soil Science Society of America Journal (55); 794799. 1991.
- **Day,** P.•R.,•"Particle•Fraction•and•Particle•Size•Analysis. In•methods•of•Soil•Analysis".• (C.•A. Black et al., eds). Vol. I. pp. 545-567. American Society of Agronomy Madison, Wisconsin 1965.
- **Hankins,** R.•H.• "Runoff•Curve•Numbers•from•Partial•Area•Watershed".• J.•Irr.•And•Drain.•Dix. ASCE 105: 375-389. 1979.
- **Knisel,** W.G.,•"Procedure•to•Estimate•Effect•of•Conservation•Tillage•on•Rescuing•Direct•Runoff Using•the•SCS•Curve•Numbers".•CREAMS•User's•Guide.•420-425. 1980.
- **Knisel,** W.G.,• "GLEAMS:• Groundwater• Loading• Effects• of• Agricultural• Management• Systems. University of Georgia, Coastal Plain Experiment Station, Biological & Agricultural Engineering Department,•Publication•No.•5.• GLEAMS•User's•Guide.•1993.
- **Kanwar,** R.•S.,•J.•L.•Baker,•D.•G.•Baker.•"Tillage•and•Phosphorus•Split•N-Fertilization Effects on Subsurface Drainage•Water•Quality•and•Crop•Yields".• TRANSACTIONS•of•the•ASAE•31•(2): 453-461. 1988.
- **Laflen,** L. M., M. A. Tabatabai. "Nitrogen•and•Phosphorus•losses•from•Corn-soybeans rotations as•affected•by•Tillage•practices".• TRANSACTIONS•of•the•ASAE:•58 – 63. 1984.
- **Leonard,** R.•A.,•and•W.•G.•Knisel.• "Groundwater•Loadings•by•Controlled-release Pesticides: A GLEAMS•Simulation".• TRANSACTIOS• of•the•ASAE•32•(6)•:•1915-1922. 1989.
- **Leonard,** R.•A.,•W.•G.•Knisel,•F.•M.•Davis•and•A.•W.•Johnson.• "Validating•GLEAMS•with Field Data• for• Fenamiphos• and• its• Metabolites".• Journal• of• Irrigation• and• Drainage• Engineering. 116(1): 24 – 34. 1990.
- **Leonard,** R.•A.,•C.•C.•Trumman,•W.•G.•Knisel,•and•F.•M.•Davis.• "Pesticide•Runoff•Simulations: Long-Term Annual Means Vs. Event Extremes".• Weed•Technology•(6):•725 -730. 1992.
- **McDowell,** L.• L.,• K.• C.• McGrogor.• "Nitrogen• and• Phosphorus• Losses• in• Runoff• from• No-till Soybeans".• TRANSACTION•of•the•ASAE•643 – 648. 1980.
- **Mostaghimi,** Said,• J.• M.• Flagg,• T.• A.• Dillaha,• V.• O.• Shanholtx.• "Phosphorus Losses from Croplands•As•Affected•by•Tillage•System•and•Fertilizer•Application•Method".• Water•Resources Bullentin 24 (4): 735 -742. 1988a.
- **Mostaghimi,** Saied,•T.•A.,•Dillaha,•V.•O.•Shanholtz.• "Influence•of•tillage•Systems•and•residue Levels on Runoff,•Sediment,•and•Phosphorus•Losses".• TRANSACTIONS•of•the•ASAE•31•91): 128 – 132. 1988b.
- **Rawls,** W.•J.,•C.•A.•Onstad•and•H.•H.•Richardson.• "GLEAMS•user's•guide".•405 – 419. 1993.
- **Rawls,** W.•J.,•and•H.•H.•Richardson.• "Runoff•Curve•Numbers•for•Conservation Tillage".• J.•Soil and Water Cons. 38 (6): 494 – 496. 1983.
- **Yoo,** K.• H.,• J.• T.• Touchton• and• R.• H.• Walker.• "Runoff,• Sediment,• and• Nutrient• Losses• from Various• tillage• Systems• of• Cotton".• Elsevier• Science• Publications• B.• V.,• Amsterdam (Netherlands), Soil and Tillage Research 12: 13-24. 1988.
- **Yoo,** K.• H.,• J.• T.• Yoon,• and• L.• M.• Sorleau.• "Runoff• Curve• Numbers• Determimed• by• Three Methods•under•Conventional•and•Conservation•Tillage".• TRANSACTION•of•the•ASAE•36•91): 57-63. 1993.
- **Yoo,** K. H., and E. W. Rochester. "Variation•of•Runoff•Characteristics•under•conservation•Tillage Systems".• TRANSACTIONS•of•the•ASAE•3295):•1625-1630. 1989.