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GLEAMS MODEL[1]

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ABSTRACT

The GLEAMS model is a computer program used to simulate water quality events on an agricultural field. GLEAMS has been used in the U.S.A. and internationally to evaluate the hydrologic and water quality response of many different scenarios considering different cropping systems, wetland conditions, subsurface drained fields, agricultural and municipal waste application, nutrient and pesticide applications, and different tillage systems. It has been used both as a research model and as a management model, depending upon the user=s desire.

In order to simulate the many events occurring on a field, the model is divided into three separate submodels, or parameter files. These submodels include hydrology, erosion/sediment yield, and chemical transport. The chemical transport submodel is further subdivided into nutrient and pesticide components so that one, or both, may be simulated as desired by the user. The parameter files contain variables which are entered by the user in order to best simulate the management events occurring on the particular field of study. The hydrology component simulates runoff due to daily rainfall using a modification of the SCS curve number method. Hydrologic computations are determined using a daily time step. A modification of the Universal Soil Loss Equation (USLE) is used to estimate interrill and rill detachments, and a modification of Yalin=s equation is used to estimate the sediment transport capacity. Different topographic configurations and surface flow processes may be selected to properly assess the sediment detachment and deposition on the land surface. The chemistry component of the GLEAMS is divided to pesticide and nutrient submodels. The user may select to run any or all of the specified components during each simulation. The pesticide component of the GLEAMS incorporates the surface pesticide response of CREAMS with a vertical flux component to route pesticides into, within, and through the root zone. Characteristics of pesticide adsorption to soil organic carbon are used to partition compounds between solution and soil fractions for simulating extraction into runoff, sediment, and percolation losses. Pesticide dissipation in soil and on foliage is treated as a first-order process with a different apparent half-life for each. The nutrient component of the GLEAMS is a complex submodel and considers both nitrogen and phosphorus cycles. The nitrogen component includes: mineralization, immobilization, denitrification, ammonia volatilization, nitrogen fixation by legumes, crop N uptake, and losses of N in runoff, sediment, and percolation below the root zone. It also considers fertilizer and animal waste application. The phosphorus component includes: mineralization, immobilization, crop uptake, losses to surface runoff, sediment, and leaching, and it also includes fertilizer and animal waste application. Tillage algorithms are included in the model to account for the incorporation of crop residue, fertilizer and animal waste.

Keywords: Nonpoint Source Pollution Models, Water Quality, Hydrology, Erosion

INTRODUCTION

The complexity and expensive nature of experimental procedures necessitate the use of mathematical models for evaluating the hydrologic and water quality response of a watershed. Variations in soil, climate, and management practices make the experimental evaluation of the occurrence and movement of agricultural chemicals impractical through the soil and plant system. Moreover, available experimental data are usually site-specific and may not be used to describe the processes for a condition other than the one for which the data were obtained. Simulation models have been developed to resolve this difficulty.

In selecting a particular simulation model, one may consider the components, strength, weaknesses, and level of calibration and testing to which that model has been exposed. Russell et al., (1994) pointed out several factors to consider when selecting an appropriate model to use in the regulatory arena. Those factors include the original purpose for which the model was developed, the capabilities of the model, the extent of model validation, and the ease of use and documentation of the model. To assess the fate of agricultural chemicals, Shirmohammadi and Knisel (1994) pointed out that a model should consider the following contaminant loading pathways:

1. surface runoff to streams and lakes,
2. lateral movement of chemicals through unsaturated and/or saturated soil media to bodies of surface water, or
3. vertical percolation of chemicals through unsaturated and/or saturated soil media to underlying groundwater.

Many models with varying degrees of complexity exist (Shoemaker et al, 1990). Examples of such models are ANSWERS-2000 (Bouraoui and Dillaha, 1996), CREAMS (Knisel, 1980) and Hydrograph Simulation Program Fortran, HSPF (Donigian et al., 1983). Simulation models for environmental screening of pesticides also exist. Examples of these models are PESTAN (Enfield et al., 1982), CMLS (Nofziger and Hornsby 1986), LEACHM (Wagenet and Hutson 1986) and MACRO (Jarvis, 1991). Most of the later models are deterministic and describe the movement of pesticides through porous media with limited consideration for the impact of BMP's on both surface water and groundwater quality.

Recently, process-oriented models have been developed that describe the influence of agricultural best management practices (BMP's) on contaminant transport to surface and groundwater resources. Most notable among these are PRZM/PRZM-2 (Carsel et al., 1985, and Mullins, 1993) and GLEAMS (Leonard et al., 1987). VULPEST (Villeneuve et al., 1987) and RUSTIC (Dean et al., 1989) are also management models that have recently been developed and are being tested and validated for evaluating the fate of pesticides under different BMP's.

Nonpoint source pollution models are many and each has its own appeal for the user, depending upon the need and application objectives of the user. The selection of an appropriate model is a major criteria in nonpoint source pollution assessment. However, concise literature on the functional capabilities and experiences with model applications is rare. This paper describes the functional components of the GLEAMS (Knisel et., 1993) model and different scenarios for which GLEAMS has been applied.

Functional Components of the GLEAMS Model

The Groundwater Loading Effects of Agricultural Management System (GLEAMS) model (Leonard et al., 1987 and Knisel, 1993) is a functional model used to simulate processes affecting water quality events on an agricultural field. It is the modified version of the well-validated CREAMS (Knisel, 1980) model. It is a continuous simulation model that provides more detailed prediction of water, sediment, nutrient, and pesticide movement within and through the root zone while maintaining the surface sensitivity of the CREAMS model. In order to simulate the many processes occurring on a field, the model is divided into three separate submodels (Fig. 1). These submodels include hydrology, erosion/sediment yield, and chemical transport. The chemical transport submodel is further subdivided into nutrient and pesticide components so that one or both may be simulated as desired by the user. As presented in Figure 1, each submodel requires a specific parameter file for data input, and specific file to write the output results. The input parameter files contain parameter values that are entered by the user in order to best represent the particular conditions for the study site. For example, data such as drainage area and soil hydrologic characteristics in the hydrology parameter file, and watershed flow profile (e.g. overland flow, overland-channel flow, etc.) is entered in the erosion parameter file. Default parameter values are often provided by the model when site specific data are not available. Knisel et al. (1989), Leonard et al. (1987), and Knisel (1993) discuss the components in detail.

The model distributes the soil=s physical and hydraulic characteristics into a maximum of twelve computational layers taking input from one to five soil horizons based on the user=s selection. Saturated hydraulic conductivity and volumetric water content at saturation, at field capacity, and at wilting point are examples of input to each of the specified soil horizons. Additionally, organic matter content, pH, clay content, silt content, base saturation, and calcium carbonate content are entered for each user specified soil horizon.

The hydrology component simulates runoff due to daily rainfall using a modification of the SCS curve number method. Hydrologic computations for evapotranspiration, percolation, infiltration, and runoff are determined using a daily time step (Knisel, 1993). Two options are provided in the hydrology component to estimate potential evapotranspiration. The Priestly-Taylor method (1972) using daily temperature and radiation data computed from mean monthly data is one option. The other option is the Penman-Monteith method (Jensen et al., 1990) and it requires additional data such as wind speed and dew point temperature. Water routing through the soil profile is based on the Astorage routing@ concept which allows the downward movement of water in excess of field capacity water content from one layer to the next. A comprehensive detail is provided in Knisel (1993). GLEAMS may also consider irrigation based on the soil water content specified by the user.

The erosion component is similar to the one developed for the CREAMS model (Knisel, 1980). This component considers overland, channel, impoundment, or any combination of these routes. The model uses the universal soil loss equation (USLE) and the concept of continuity of mass to predict erosion and sediment transport under different topographic and cultural conditions. Computation begins at the upper end of the overland slope. The overland flow may be selected from several possible overland flow paths. Its shape may be uniform, convex, concave, or a combination of these slopes. The processes of detachment and deposition are both considered and each condition occurs based on the relationship between transport capacity of runoff water and sediment load.

The nutrient component of the GLEAMS model is a complex submodel and considers both nitrogen and phosphorus cycles. The nitrogen component includes: mineralization, immobilization, denitrification, ammonia volatilization, nitrogen fixation by legumes, crop N uptake, and losses of N in runoff, sediment, and percolation below the root zone. It also considers fertilizer and animal waste application. The phosphorus component includes: mineralization, immobilization, crop uptake, losses to surface runoff, sediment and leaching, and it also includes fertilizer and animal waste application. Tillage algorithms are included in the model to account for the incorporation of crop residue, fertilizer and animal waste. Soil temperature and soil moisture algorithms are also included in the model to provide proper adjustments for ammonification, nitrification, denitrification, volatilization, and mineralization rates. Rainfall nitrogen is an input for the model and may vary depending upon the study region. Initial soil total N and total P are sensitive parameters in the model. Thus, proper attempts must be made to obtain a reasonable database, if available. Figures 2 and 3 show the schematics of the nitrogen and phosphorus cycles considered in GLEAMS. For a detailed description of the nutrient component, the reader is referred to Knisel (1993).

The pesticide component of the GLEAMS model is designed to allow simulation of interactions among pesticide properties, soils, climate, and management and the effects on pesticide losses in surface runoff, attached to transported sediment, and in percolate below the root zone or any other specified depth. To trace the fate of surface applied or incorporated pesticides, GLEAMS considers degradation, adsorption, and convective processes in each of the computational soil layers in the root zone. Upward movement of pesticides due to evaporation and plant uptake is also included. In each simulation, GLEAMS can consider 10 pesticides or their metabolites. Initial pesticide residue in the soil is an input to the model, and the model is very sensitive to this parameter. For a detailed discussion on model algorithms regarding the fate of pesticides, readers are referred to the publications by Leonard et al., (1987) and Knisel (1993).

Applications of GLEAMS Model

The extent of a model=s application is a testimony for its versatility. GLEAMS has gone through extensive testing and validation under diverse conditions. The GLEAMS= predecessor, CREAMS (Knisel, 1980) was developed, calibrated and tested with a set of data from Watkinsville, Georgia, and later was applied to many diverse conditions (Knisel, 1980). Similarly, the GLEAMS (Leonard et al., 1987 and Knisel, 1993) has been tested and applied to numerous diverse scenarios. To better understand the extent of GLEAMS= applications, this section will shed a light on the applications of CREAMS and then follow it with some examples of GLEAMS applications.

CREAMS (Knisel, 1980):

1. Runoff and erosion from vineyards on steep valley flanks of Napa Valley, California. Source of erosion showed where controls were needed to reduce the sediment yield at the bottom of the slope (Foster, G. R., 1982, Personal Communication, Davis, California).

2. Hydrology component applied on stony pasture land in Pennsylvania. The soil water characteristic data had to factor in the fraction of stones to give good runoff comparisons with observed data (Gburek et al., 1989).

3. Nutrient cycling on pasture land in New Zealand (Cooper et al., 1989).

4. Simulated runoff and erosion for rotation grazing in New Mexico (Renard, K. G., 1980, Personal Communication, Albuquerque, New Mexico). Their study determined the size of "gully plug" (detention basin) necessary to control sediment.

5. Sediment yield from strawberries grown on ridges under plastic on sandy soils in California. Designed channel/pipe delivery system to prevent sediment from covering roads (Moffitt, D. M., 1982, Personal Communication, Davis, California).

6. Rain-fed rice in Malaysia. This was work conducted by Nicks on one of his WMO trips to Malaysia (Nicks, A. D., 1988, Personal Communication, Malaysia).

7. Runoff and sediment yield from pineapple fields in Australia (Silburn, M., 1983, Personal Communication, Towoomba, Queensland, Australia).

8. Runoff and sediment yield from hops field in Germany (Stemler, S., 1982, Personal Communication, Goettingen, Germany).

9. Dairy lagoon effluent application on spring oats in Alaska (Moffitt, D. M., 1988, Personal Communication, Anchorage, Alaska). The study determined the proper size of fields for annual application of effluents.

10. Runoff and sediment yield from sugarcane in South Africa (Platford, G., 1984, Personal Communication, Mount Edgecomb, South Africa). Simulations agreed well with observed plot data.

11. Pesticide runoff from pine seed orchards in Georgia (Nutter, et al., 1993). Good agreement between simulated and observed data was obtained.

12. Soluble and adsorbed insecticide runoff into a lake in Louisiana (Nicks et al., 1984). This study evaluated the management practices designed for cost-share to reduce pesticide input to the lake from cotton and soybean fields.

13. Nitrogen leaching under both irrigated and nonirrigated conditions on sandy and clay soils in Western Skane, Sweden (De Mare, L., 1982). The model was viewed as being a vital model to evaluate different agricultural management systems. However, caution was made regarding its usage for absolute predictions.

14. Simulated runoff and leaching losses on nutrients from 10-yr rotations (including potatoes, grasses, and corn) in Poland (Sapek, 1982). Simulated losses compared favorably with observed data.

15. Simulation of erosion from strip mined areas near the headwaters of Hidden Water Creek near Sheridan, Wyoming (Neibling and Thompson, 1989). The study showed that CREAMS adequately described a number of realistic mine reclamation situations.

16. Regional evaluation of the impact of different BMP=s on hydrology, sediment, and nutrient losses from agricultural watersheds in both Pennsylvania and Maryland (Shirmohammadi et al., 1992). BMP=s simulated in this study included 7-year crop rotation, different tillage systems, contouring, terracing, diversions and grassed waterways, and nutrient management using animal waste and commercial fertilizers according to crop needs. Three different physiographic regions of Coastal Plain, Piedmont, and Appalachian regions were used to evaluate the regional effects of BMP=s.

GLEAMS (Leonard et al., 1987 and Knisel, 1993):

1. Brewery waste effluent application on sod farm in Florida (Bottcher, A. B., 1996, Personal Communication, Gainesville, Florida). Sod harvested to remove top 1-cm of soil and all forage and roots in top 1-cm. The model was used to design the frequency of effluent application.

2. Runoff, percolation, and erosion from carex peat plots in Finland (Knisel et al., 1998). This is the first known application of GLEAMS model to peat soils. Simulation results are within the plot variability for observed data.

3. Percolation and nutrient leaching from 3" deep spaghnum peat cups with pine seedlings in a forest nursery greenhouse in Finland (Juntunen, M. L., 1995, Personal Communication, Suonejoki, Finland). Simulation results compared well with observed data.

4. Pesticide leaching studies on citrus in Florida (Flaig, E., 1987, Personal Communication, West Palm Beach, Florida). Simulation results compared favorably with observed data.

5. Simulated effects of forest buffer strips along streams for herbicide application in Alabama (Smith, et al., 1993). Simulated losses compared well with the observed data.

6. Determined best "environmental window" for herbicide application within the recommended best "control window" in Alabama, Florida, and Mississippi (Michael et al., 1996).

7. Pesticide screening procedure for 10 pesticide classes on 10 soils at 54 climate locations in the conterminous U.S., with and without irrigation (Goss, et al., 1998). The CLIGEN was used to generate 50-yr climate data for each of the locations in this study.

8. Cadmium uptake by spring small grains in Finland (Yrlanta, T., 1994, Personal Communication, Jokioinen, Finland). Results were good in comparison with lysimeter data.

9. Model was used to determine if pesticides are registered in Florida based upon runoff and leaching potential (Shahane, A.N., 1997, Personal Communication, Tallahassee, Florida).

10. Pesticide redistribution and leaching on cracking clay soil in Italy (Morari and Knisel, 1997). Model was modified to represent preferential flow due to cracks in structured soils.

11. Pesticide runoff and leaching from potato fields in Wisconsin and Maine (Thrall, T. P., 1985, Personal Communication, Madison, WI). Aldicarb leaching below the root zone was comparable to observed groundwater well concentrations. This study was performed with a modified CREAMS model, which established the base for developing GLEAMS model.

12. Pesticide leaching from undisturbed monolith lysimeters in Sweden (Shirmohammadi and Knisel, 1994). Good comparison with

observed data and other pesticide leaching models such as PRZM (Carsel et al., 1984) and MACRO (Jarvis, 1991).

13. Bromide leaching and uptake from lysimeters in Ohio (Leonard et al., 1987). Simulation results were within the variability of lysimeter data.

14. Simulation of pesticide inflow to natural lakes in Italy (Magliola and Knisel, 1992). Simulations compared well with the pesticide inflow to natural lakes.

15. Simulation of N and P for a structured clay soil under subsurface drainage system in Sweden. (Shirmohammadi et al., 1998.) The results showed that with proper initial parameter values, the model is capable of producing reasonable estimates of annual and long-term averages of nitrate -N and dissolved -P losses to drain tiles. A separate submodel, PARTLE, was developed to predict leaching particulate -P into drain tiles.

Additional Studies:

1. CREAMS (Knisel, 1980) was also linked with DRAINMOD (Skaggs, 1978) to evaluate the combined effects of above ground BMP=s and below ground water table management systems (Parsons and Skaggs, 1988; Wright et al., 1992).

2. GLEAMS (Knisel, 1993) was used to prescribe appropriate BMP=s for critical areas of a mixed land use watershed identified using geographic information system (GIS) in the Piedmont physiographic region of Maryland (Searing et al., 1995).

SUMMARY AND CONCLUSIONS

The Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model was developed to simulate the relative impacts of agricultural management systems on water quality. It has three major components: hydrology, erosion, and chemistry. In addition to the well validated algorithms in its predecessor, CREAMS, the GLEAMS model is capable of simulating 10 pesticides simultaneously within and through the vadose zone. It is a user friendly model and has appropriate user-interface screens for compiling input parameter files.

GLEAMS has been built based on the strength of its predecessor, CREAMS. Therefore, the combined application scenarios for these two models are many. Both models have been applied to evaluate the hydrologic and water quality response of many different scenarios considering different cropping systems, wetland conditions, subsurface drained fields, agricultural and municipal waste applications, nutrient and pesticide applications, and different tillage systems. GLEAMS has also been used in association with the GIS technologies to prescribe appropriate BMP=s to critical areas of pollution on a mixed land use watershed. Both CREAMS and GLEAMS have been used widely in the U.S.A. and internationally by government, state, and private institutions, for differing purposes. These purposes range from management issues, such as BMP selection and pesticide screening, to research issues, such as the vadose zone transport of nutrients and pesticides.

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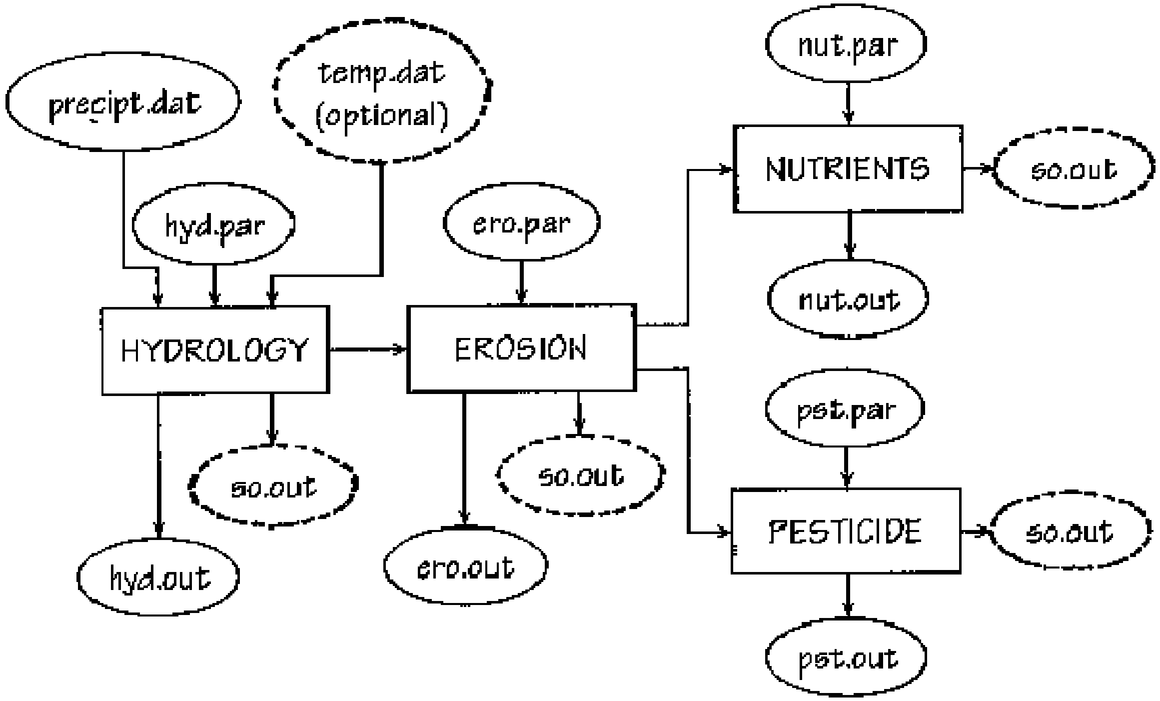
Schematic Representation of the GLEAMS (Knisel, et al., 1993) model



Input Files

Filename	Description
precipt.dat	Daily Precipitation Data
temp.dat	Daily Min. and Max. Temperature Data (optional)
hyd.par	Hydrology Parameter File
ero.par	Erosion Parameter File
nut.par	Nutrient Parameter File
pst.par	Pesticide Parameter File

Output Files

Filename	Description
hyd.out	Hydrology Output File
ero.out	Erosion Output File
nut.out	Nutrient Output File
pst.out	Pesticide Output File
so.out	Selected Output File

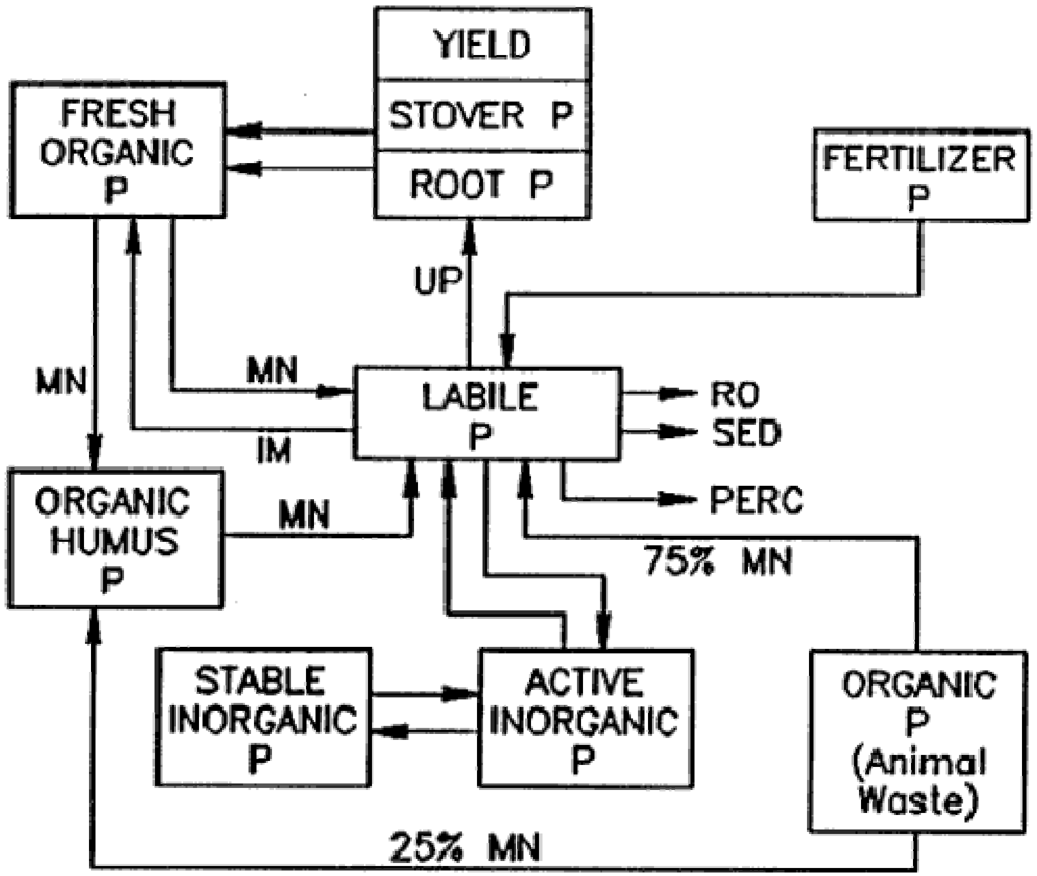


Fig. 2 Schematic representation of the GLEAMS nitrogen cycle. AM = ammonification; NI = nitrification; DN = denitrification; VL = volatization; IM = immobilization; UP = uptake; FX = fixation.

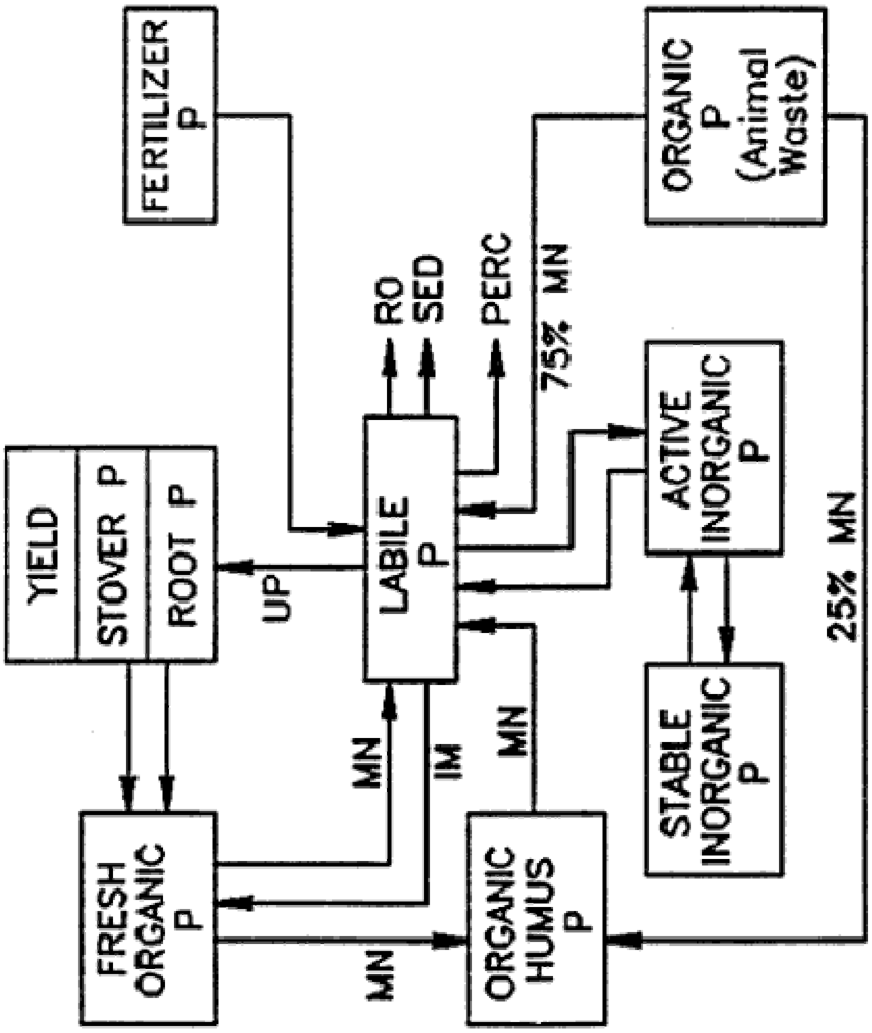


Fig. 3 Schematic representation of the phosphorus component.

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