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# Considerations regarding the agronomical variables associated to the performances of SWAT model simulations in the Romanian eco-climatic conditions

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## Abstract

The main objective of the study is to optimize the agronomical variables for prediction of water quality at river basin scale for various time intervals using the numerical modeling of the cumulative impact of agricultural operations due to the use of chemical inputs and specific tillage. SWAT (Soil & Water Assessment Tool) model was developed to determine with reasonable accuracy the effect of potential management decisions regarding the water use, sediment transport, and chemical transformations of substances discharged into surface waters in rural ungauged basins. The information flow must start with the adaptation of the inputs required by the SWAT model for the accurate definition of Hydrological Response Units that include unique combinations between slope, soil type, and land use/land cover. All thematic layers must be related to the same coordinate system using the 1970 stereographic projection and Dealul Piscului 1970 geographic coordinate system that are in force in Romania. The meteorological inputs used in SWAT include rainfall, maximum and minimum temperature, solar radiation, relative humidity and wind speed. The prediction of SWAT model considering the diffuse sources of pollution (land areas with intensive agriculture) were analyzed considering the cropping technologies used in various Romanian hydrographical basins, i.e. Ialomita River, Calmatui River, Teleajen River, and Mostistea River. The main constraints observed in the use of SWAT model for efficient predictions in various control sections can be adjusted by the careful selection/adaptation of inputs, the optimal calibration/sensitivity analysis of the model, and the updating of information regarding the land use/land cover in a specific river basin.

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*Keywords:* nitrates; phosphates; numerical model; nitrogen processes; crop growth parameters.

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## 1. Introduction

The monitoring of water quality must be performed at the scale of the river basin. The dedicated numerical models should be used to extend the results of monitoring in time and space, taking into account the hydrological and geomorphological conditions of riverbeds. The parameters that influence mostly the pollutants load of a watercourse are dilution flow, transport capacity, dispersion and biodegradation capacities of pollutants, as well as the oxygen intake by re-aeration and photosynthesis (Oprea and Dunea, 2008). Water quality is influenced by the characteristics of the river basin, namely the land use / land cover, and geology of the basin, the seasonal influence, the river flow, and the chemical properties of tributaries water of the main channel. Important factors in the quantitative balance of surface waters are precipitation and snowmelt with quantitative and qualitative influences, mainly because of surface transport of sediment, pesticides, fertilizers, germs etc. (Neitsch et al., 2011). The current knowledge about the water cycle at basin scale is relatively incomplete due to some random and complex processes, which are difficult to measure or estimate in an integrated way. Furthermore, the hydrological and water quality data for the rivers that form a river system are often dispersed or discontinuous, making difficult to assess the information regarding the river flow in view of insuring the water resources management in case of flood risk or high pollutants load. If the monitoring data are missing, the most reliable support for making pollutant load predictions of surface waters in catchment areas that are not covered by continuous measurements within a surveillance or operational monitoring program is the use of numerical geo-models. **SWAT** (*Soil & Water Assessment Tool*) model was developed to determine with reasonable accuracy the effect of potential management decisions regarding the water use, sediment transport, and chemical transformations of substances discharged into surface waters in rural ungauged basins (Srinivasan et al., 2010).

SWAT quantifies also the pollutant loads from point sources (Arnold et al., 2012) and provides predictions of the influence of land management practices on crops in a particular catchment area and thus, on water quality in various control sections of the main channel. An extended literature review regarding the use of SWAT model pointed out the future trends of model utilization, together with an assessment of the strengths and weaknesses of the model (Gassman et al., 2007). Recently, another study of literature has examined the impact of SWAT utilization for the assessment of specific processes in river basins (Pechlivanidis et al., 2011). A significant increase of the use of SWAT model to estimate or predict specific environmental problems was observed in the recent years such as:

- identification of critical areas that contribute mostly to the pollutant load in a river basin (Manciola et al., 2005; Niraula et al., 2013);
- impact assessment of individual land management strategies at basin scale (Naramngam and Tong, 2013; Sommerlot et al., 2013);
- evaluation of the potential impact for growing area enlargement of “energy crops” on the quality condition of main channel (Einheuser et al., 2013);
- or to model flow rates and sediment quantities in rural areas (Shrestha et al., 2013).

In addition, SWAT was used to determine the effect of surface runoff in an agricultural catchment on a lagoon in order to estimate future sediment depositions (Santra and Das, 2013). Other studies have examined the separated and combined impact of future climate change and land use/ land cover on the river main channel (Kim et al., 2013). Furthermore, the SWAT model allowed the evaluation and improvement of the numerical modeling applied at basin scale to characterize the impact of climate change on water resources and ecosystems’ stressors (Luo et al., 2013). Application of SWAT model has facilitated the estimation of the land use and basin specific conditions effects on water quality, on sediments and nutrients load in an ungauged section of a river basin (Iordache et al., 2012). SWAT model provided predictive values of the loads with different forms of nitrogen and phosphorus because of the cumulative effect of the land use/land cover and the contribution of point sources i.e. wastewater treatment plants, and direct discharges (Dunea et al., 2013).

The paper presents the main adaptations to the SWAT input files required to simulate various scenarios regarding the impact of agricultural operations on the water quality in Romanian river basins.

## 2. Materials and Methods

SWAT model uses a continuous time step being a multi-component model, including routines for meteorological, hydrological, erosion, sediment, plant growth, nutrients, pesticides, agricultural crops technologies, as well as hydrological characteristics of the river main channel, tributaries or water reservoirs. The agricultural technologies components of the model include the following: the use of fertilizers, crop growth parameters, agricultural operations, and grazing. It has the ability to estimate the pollutant loads from agricultural point sources.

The SWAT model simulates the movement between nitrogen pools, such as mineralization, decomposition/immobilization, nitrification, denitrification, and ammonia volatilization. Other soil nitrogen processes such as N fixation by legumes and $NO_3$-N movement in water are also included in the model (Neitsch et al., 2011).

The simulation of the hydrological processes in a basin uses the partitioning of the main basin into subbasins. Each subbasin contains the corresponding streams, which route within the subbasin and form the stream network (Dunea et al., 2013). The subunits of the subbasins are the *Hydrologic Response Units* (HRU), which are unique and hydrological homogeneous combinations of land use/land cover, soil type and slope characteristics. In each HRU, the hydrologic cycle, nitrogen and phosphorus cycles, and crop growth are simulated based on climatic variables, hydrology, and the agricultural management in that unit (Neitsch et al., 2004).

Consequently, the model calculations are made on a HRU basis. An HRU is a complex unit that differs from an individual field. Such fields having a specific land use, management and soil may be scattered throughout a subbasin. These similar areas are assembled together to form one HRU (Neitsch et al., 2011). The resulted HRUs that are the main entities for running SWAT routines simplify the modeling of river loadings (runoff with sediment, nutrients, etc. transported by the runoff). The loadings are calculated separately and then summed together to determine the total loadings from the subbasin. SWAT was integrated in various GIS platforms i.e. ESRI ArcGIS and the open-source MapWindow GIS to maximize the geospatial analysis features.

In this paper, we used the ArcSWAT 2.3.4 version of SWAT model integrated in ArcGIS, which has provided the georeferenced information for the tested Romanian basins regarding the movement and transformation of the various forms of nitrogen and phosphorus originating from diffuse agricultural sources.

## 3. Results and Discussions

### *Editing of the agronomical variables in SWAT model to comply with Romanian eco-climatic conditions in a river basin*

ArcSWAT interface requires three layers i.e. the Digital Elevation Model - DEM, land cover/land use - LCLU, and soil distribution map - SD) to perform simulations in a river basin. First adjustment is needed to match the CORINE Land Cover codes to the SWAT Land use classification categories (Figure 1).

After this step, SWAT provides a classification using its own codes that are required to define the HRUs in the specific basin. Figure 2 shows as an example, the land use/land cover classification in Teleajen River basin.

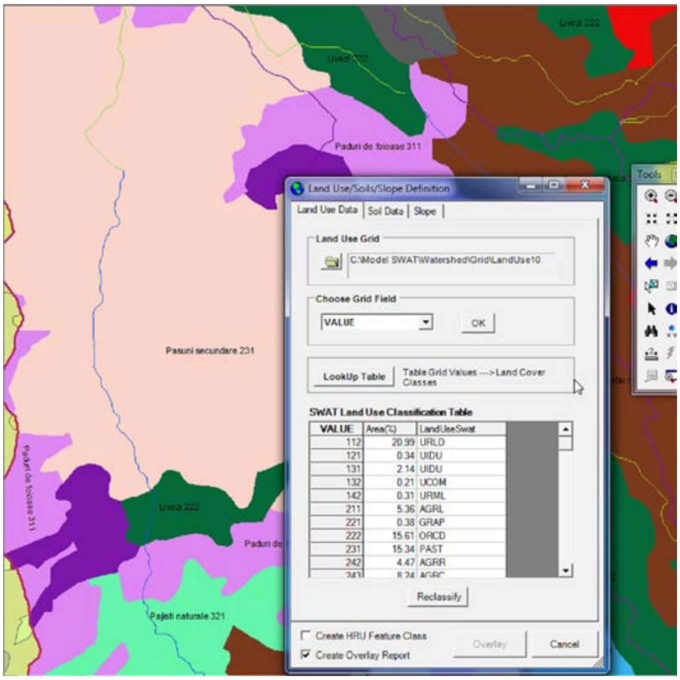
The HRU analysis needs the following steps:

1) data entries based on the criteria of user according to the basin specificity (category of land use, soil type) and thematic reclassification;

2) data overlapping using the three components (land use/land cover – Figure 2, soil type – Figure 3, and slope – Figure 4);

3) defining the HRUs;

4) generation of reports and statistics of HRUs.



Land Use Grid

C:\Model SWAT\Watershed\Grid\LandUse10

Choose Grid Field

VALUE

Table Grid Values ---> Land Cover Classes

SWAT Land Use Classification Table

| VALUE | Area(%) | LandUseSwat |
|---|---|---|
| 112 | 20.99 | URLD |
| 121 | 0.34 | UIDU |
| 131 | 2.14 | UIDU |
| 132 | 0.21 | UCOM |
| 142 | 0.31 | URML |
| 211 | 5.36 | AGRL |
| 221 | 0.38 | GRAP |
| 222 | 15.61 | ORCD |
| 231 | 15.34 | PAST |
| 242 | 4.47 | AGRR |
| 243 | 8.24 | AGRC |

☐ Create HRU Feature Class
☑ Create Overlay Report

Fig. 1. Adjustment of the CORINE Land Cover codes to the SWAT Land use classification categories (e.g. 112 is for URLD – urban residential low density; 211 is for AGRL – agriculture land).

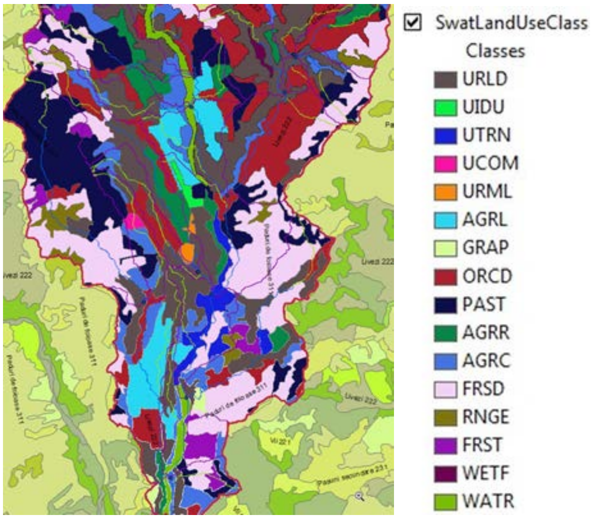


Fig. 2. Classification of LULC in Teleajen River basin.

Figure 3 presents the reclassification of the soil performed in a Romanian river basin i.e. Teleajen. The previous step in achieving this result was the definition of the soil types according to the Romanian SRTS system of classification. This adaptation is important because the soil database included in SWAT contains U.S. soil types. The definition of the soils in Romanian river basins must be performed by adding new soils (see Figure 6). The main parameters are HYDGRP (*Soil hydrologic group* i.e. A – high infiltration, B, C, or D – slow infiltration); SOL_ZMX (*maximum rooting depth* of soil profile in mm); texture; hydraulic properties and organic content.

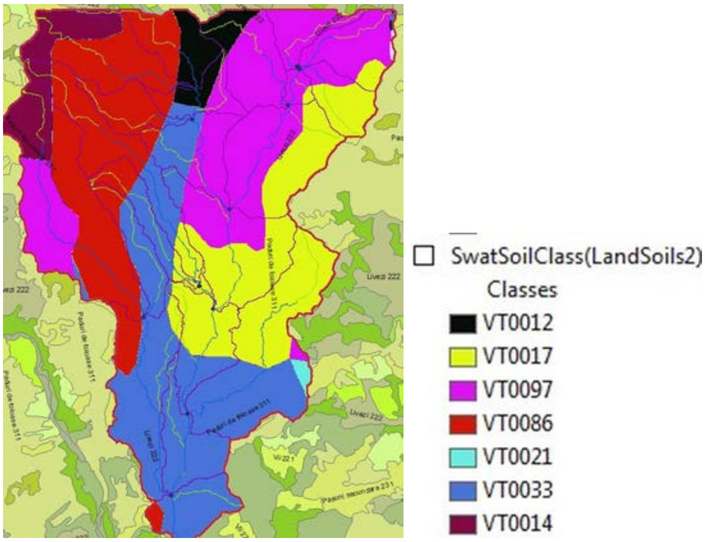


Fig. 3. Classification of soils in Teleajen River basin.

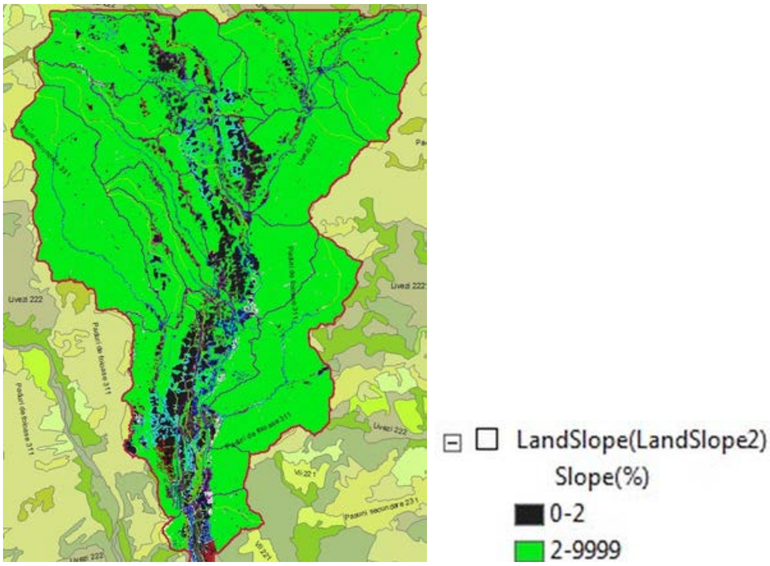


Fig. 4. Classification of slopes in Teleajen River basin.

Table 1 summarizes the main input files related to the agronomical variables used to run the SWAT model i.e. soils, land cover/plant growth, tillage, pesticides and fertilizers.

To use the appropriate input data that are corresponding to the Romanian eco-climatic and operational conditions in a watershed, the SWAT geodatabase must be modified using the *Edit SWAT Input* command from the menu bar, and then clicking on *Databases* (Figure 5).

Figure 7 presents the crop database having as example the alfalfa crop (*Medicago sativa* L.). The main parameters related to a crop are presented as follows:

- BIO_E is the *Radiation Use Efficiency* (RUE) or the biomass-energy ratio [(kg/ha)/(MJ/$m^2$)] (Dunea and Dincă, 2014).

Table 1. The main agronomical input files required to run the SWAT model that must be adapted to the Romanian eco-climatic and cropping conditions

| File name | Specifications |
|---|---|
| .sol<br>(HRU level file)<br>*Soil input file.* | contains information about the physical characteristics of the soil in the HRU. |
| crop.dat<br>(watershed level file)<br>*Land cover/plant growth database file*. | contains plant growth parameters for all land covers simulated in the watershed. |
| till.dat<br>(watershed level file)<br>*Tillage database file.* | contains information on the amount and depth of mixing caused by tillage operations simulated in the watershed. |
| pest.dat<br>(watershed level file)<br>*Pesticide database file.* | contains information on mobility and degradation for all pesticides simulated in the watershed. |
| fert.dat<br>(watershed level file)<br>*Fertilizer database file* | contains information on the nutrient content of all fertilizers and manures simulated in the watershed |

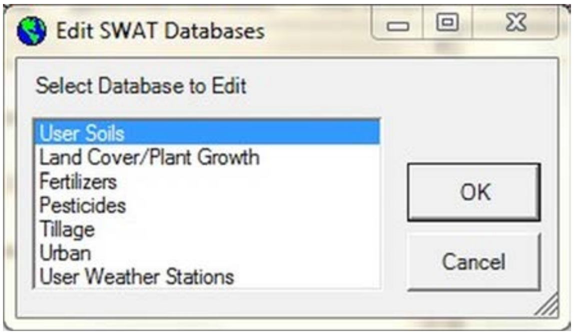
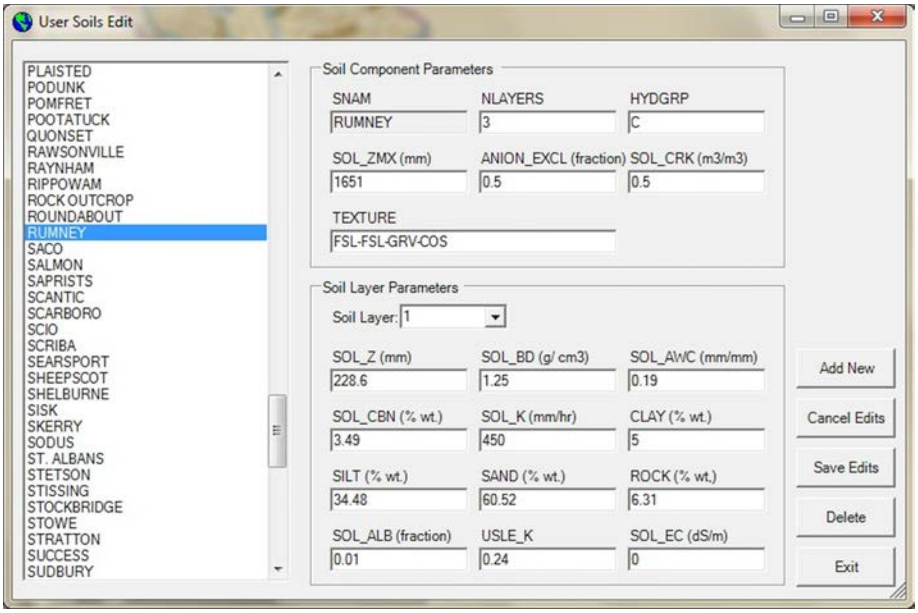


Fig. 5. Editing of databases in SWAT model.



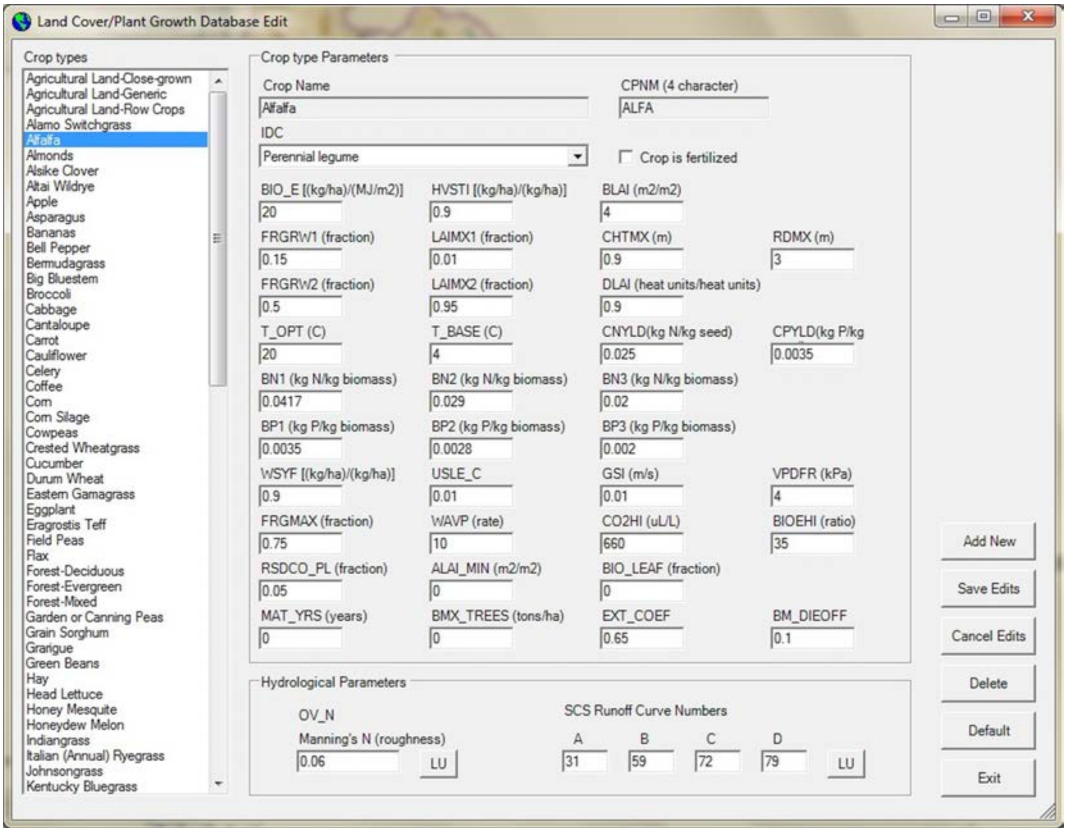
Soil Component Parameters

SNAM: RUMNEY
NLAYERS: 3
HYDGRP: C
SOL_ZMX (mm): 1651
ANION_EXCL (fraction): 0.5
SOL_CRK (m3/m3): 0.5
TEXTURE: FSL-FSL-GRV-COS

Soil Layer Parameters

Soil Layer: 1
SOL_Z (mm): 228.6
SOL_BD (g/ cm3): 1.25
SOL_AWC (mm/mm): 0.19
SOL_CBN (% wt.): 3.49
SOL_K (mm/hr): 450
CLAY (% wt.): 5
SILT (% wt.): 34.48
SAND (% wt.): 60.52
ROCK (% wt.): 6.31
SOL_ALB (fraction): 0.01
USLE_K: 0.24
SOL_EC (dS/m): 0

Fig. 6. Editing of Soil database in SWAT model



Crop type Parameters

| | | | |
|---|---|---|---|
| Crop Name | | CPNM (4 character) | |
| Alfalfa | | ALFA | |
| IDC | | | |
| Perennial legume | | ☐ Crop is fertilized | |
| BIO_E [(kg/ha)/(MJ/m2)] | HVSTI [(kg/ha)/(kg/ha)] | BLAI (m2/m2) | |
| 20 | 0.9 | 4 | |
| FRGRW1 (fraction) | LAIMX1 (fraction) | CHTMX (m) | RDMX (m) |
| 0.15 | 0.01 | 0.9 | 3 |
| FRGRW2 (fraction) | LAIMX2 (fraction) | DLAI (heat units/heat units) | |
| 0.5 | 0.95 | 0.9 | |
| T_OPT (C) | T_BASE (C) | CNYLD(kg N/kg seed) | CPYLD(kg P/kg |
| 20 | 4 | 0.025 | 0.0035 |
| BN1 (kg N/kg biomass) | BN2 (kg N/kg biomass) | BN3 (kg N/kg biomass) | |
| 0.0417 | 0.029 | 0.02 | |
| BP1 (kg P/kg biomass) | BP2 (kg P/kg biomass) | BP3 (kg P/kg biomass) | |
| 0.0035 | 0.0028 | 0.002 | |
| WSYF [(kg/ha)/(kg/ha)] | USLE_C | GSI (m/s) | VPDFR (kPa) |
| 0.9 | 0.01 | 0.01 | 4 |
| FRGMAX (fraction) | WAVP (rate) | CO2HI (uL/L) | BIOEHI (ratio) |
| 0.75 | 10 | 660 | 35 |
| RSDCO_PL (fraction) | ALAI_MIN (m2/m2) | BIO_LEAF (fraction) | |
| 0.05 | 0 | 0 | |
| MAT_YRS (years) | BMX_TREES (tons/ha) | EXT_COEF | BM_DIEOFF |
| 0 | 0 | 0.65 | 0.1 |

Hydrological Parameters

| | | | | |
|---|---|---|---|---|
| OV_N | SCS Runoff Curve Numbers | | | |
| Manning's N (roughness) | A | B | C | D |
| 0.06 | 31 | 59 | 72 | 79 |

Fig. 7. Editing of Crop database in SWAT model.

- HVSTI is a parameter for the *harvest index* in optimal growing conditions. This parameter defines the fraction of the aboveground biomass that is removed at harvesting operation.
- BLAI is the *maximum potential leaf area index* (LAI) being one of the six parameters that estimates the leaf area development of a species in the growth season.

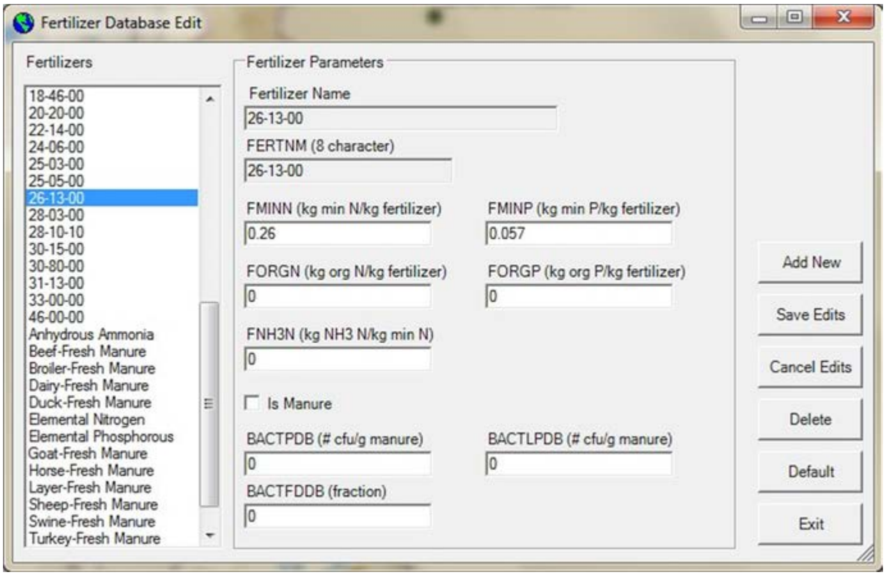
FRGRW1 and FRGRW2 are fractions of the plant-growing season or fraction of total potential heat units corresponding to the 1st and 2nd points on the optimal leaf area development curve (Neitsch et al., 2004).

- LAIMX1 and LAIMX2 are *fractions of the maximum LAI* corresponding to the $1^{st}$ and $2^{nd}$ points on the optimal leaf area development curve.
- DLAI is the *fraction of growth season* when leaf area starts to decline.
- CHTMX is the *maximum canopy height* (m), while RDMX is the *maximum root depth* (m).
- T_OPT is the *optimal temperature for plant growth* (ºC), respectively T_BASE is the *minimum temperature* (ºC).
- CNYLD represents the *normal fraction of nitrogen in yield* (kg N/kg yield), respectively CPYLD is the *normal fraction of phosphorus in yield* (kg P/kg yield).
- WSYF is the *lower limit of harvest index* [(kg/ha)/(kg/ha)].
- GSI is a parameter that estimate the *maximum stomatal conductance* at high solar radiation and low vapor pressure deficit ($m \cdot s^{-1}$). This parameter is used in the Penman-Monteith calculations of maximum plant evapotranspiration. The impact of vapor pressure deficit on stomatal conductance is given by FRGMAX and VPDFR parameters (Neitsch et al., 2004).
- WAVP is the *rate of decline in radiation use efficiency per unit increase in vapor pressure deficit*. SWAT incorporates equations that adjust RUE for elevated concentrations of atmospheric $CO_2$ (Neitsch et al., 2004). The climate change can be simulated using values for CO2HI and BIOEHI in the plant database.

- RSDCO_PL is the *coefficient for the residue decomposition of plants.*
- ALAI_MIN is the *minimum LAI for plant during the dormant period* ($m^2/m^2$).
- BIO_LEAF is a *fraction of tree biomass accumulated each year* that is converted to residue during dormancy, being a variable associated to the trees only.
- MAT_YRS represents the *number of years required for tree species to reach full development* (years).
- BMX_TREES is the *maximum biomass for a forest* (metric tons/ha).
- EXT_COEF is the *light extinction coefficient.*
- Another important input is the fertilizer database file (fert.dat) that summarizes the nutrient fractions for various fertilizers and types of manure (Figure 8).
- FMINN is the *fraction of mineral N* ($NO_3$ and $NH_4$) in fertilizer (kg min-N/kg fertilizer).
- FMINP is the *fraction of mineral P* in fertilizer (kg min-P/kg fertilizer).

  Values range between 0.0 and 1.0 for all the above-mentioned parameters.

  In the case of manure fertilization, SWAT allows the introduction of microbiological parameters (e.g. BACTPDB etc.).

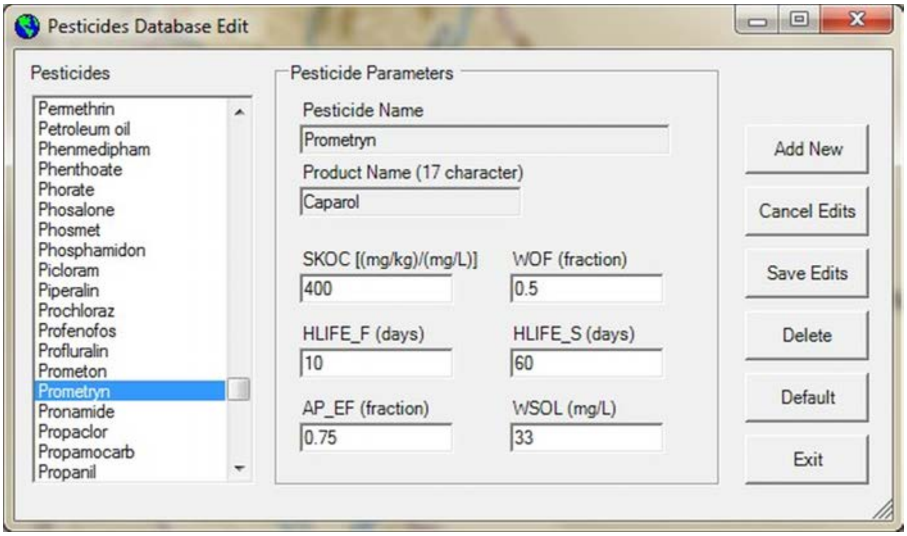


Fertilizer Name: 26-13-00
FERTNM (8 character): 26-13-00
FMINN (kg min N/kg fertilizer): 0.26
FMINP (kg min P/kg fertilizer): 0.057
FORGN (kg org N/kg fertilizer): 0
FORGP (kg org P/kg fertilizer): 0
FNH3N (kg NH3 N/kg min N): 0
☐ Is Manure
BACTPDB (# cfu/g manure): 0
BACTLPDB (# cfu/g manure): 0
BACTFDDB (fraction): 0

Fig. 8. Fertilizers database in SWAT model.

The pesticide database file (pest.dat) summarizes the pesticide attribute information for various largely utilized pesticides (Fig. 9). The main parameters for the simulation of the pesticide impact are as follows:

- WSOL is the *water solubility* parameter that defines the highest concentration of pesticide that can be reached in the runoff and soil pore water. SKOC is the *soil adsorption coefficient* normalized for soil organic carbon content [(mg/kg)/(mg/L)].
- The number of days required for a given pesticide concentration to be reduced by one-half provides *the half-life for a pesticide*. There are two components i.e. the *soil half-life* (HLIFE_S) of a pesticide (an assembled parameter that includes the net effect of volatilization, photolysis, hydrolysis, biological degradation and chemical reactions), and the *foliar half-life* (HLIFE_F) that is a lumped parameter describing the loss rate of pesticides on the plant canopy (Neitsch et al., 2004).
- WOF is the *wash-off fraction* that estimates the fraction of pesticide on the plant canopy that may be displaced. It is a function of the nature of the leaf surface, plant morphology, pesticide solubility, polarity of the pesticide molecule, formulation of the commercial product and timing and volume of the rainfall event (Neitsch et al., 2004).
- The default number for the *application efficiency* (AP_EF) for all pesticides listed in the database is 0.75.



Pesticide Name: Prometryn

Product Name (17 character): Caparol

SKOC [(mg/kg)/(mg/L)]: 400

WOF (fraction): 0.5

HLIFE_F (days): 10

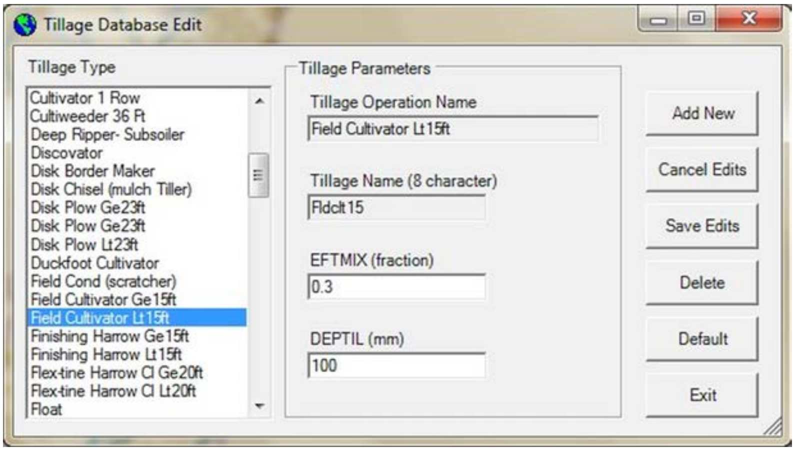
HLIFE_S (days): 60

AP_EF (fraction): 0.75

WSOL (mg/L): 33

Fig. 9. Pesticides database in SWAT model.

Figure 10 shows the tillage database based on most common global tillage types. The tillage operations redistribute the nutrients, pesticide and crop residue in the soil profile (Neitsch et al., 2004). There are two variables i.e. EFFMIX, which is the *mixing efficiency of each tillage operation* and DEPTIL. DEPTIL specifies *the soil depth*. The mixing efficiency refers to the fraction of soil surface materials e.g. residue, nutrients, pesticides etc., which are mixed uniformly throughout the soil depth. The remaining fraction of residue and nutrients is left in the original location either the soil surface or layer (Neitsch et al., 2004; Dunea et al., 2014$^{b}$).



Tillage Operation Name: Field Cultivator Lt15ft

Tillage Name (8 character): Fldclt15

EFTMIX (fraction): 0.3

DEPTIL (mm): 100

Fig. 10. Tillage database in SWAT model.

The problems that numerical modeling of water quality at river basin scale will have to find convenient solutions for Romanian eco-climatic and edaphic conditions, refer to the different potential scenarios in the catchment area of interest that can improve the action plans to be taken in case of risk situations. Considering the required precision and the number of entries in the model, these risks include low flow of the river and high loads of pollutants, floods, operational accidents, accidental discharges of effluents with high loads of pollutants, polluting agricultural technologies in the river catchment area etc. The input parameters, the state variables and some transformation functions must be adapted to the specific conditions of the studied river basin to increase the accuracy of the model, using actual field observations and measurements, thematic maps, as well as the information provided by the latest remote sensing systems e.g. Proba-V, Sentinel 2A etc. The predictive performance of the model regarding the flow simulations, especially in the case of high flows, might be improved using non-parametric methods for the analysis of recorded stream hydrographs (Petrow and Merz, 2009; Dunea and Iordache, 2014).

The main limitations observed in the use of SWAT model to forecast water quality in various control sections can be minimized by the careful selection of inputs and their validation, optimal calibration and sensitivity analysis, and by updating the information regarding the land use/land cover, which can be obtained using the products of remote sensing satellite systems. Satellite observations succeeded to improve and update the knowledge regarding the characterization of the entities and processes on the ground surface, the vegetation structure, and other biometric properties of the canopy such as PAR, LAI, chlorophyll content etc. (Darvishzadeh et al. 2008). Remote sensing applications provide the information support in mapping and control of the distribution of habitats and species (Franklin, 2009). Data regarding the surface reflectance and temperature, as well as the normalized differential vegetation index (NDVI) and other spectral indices have been used in numerous studies to determine the land cover and the phenology of growth and development of cultivated species or of natural ecosystems (Badea et al., 2011; Popovici et al., 2013; Dunea et al., 2014[a]). This valuable information originates from a wide variety of remote sensing sensors and could be linked to the radiometric information that can serve as inputs in the SWAT model routines.

## 4. Conclusions

A multidisciplinary integrated approach is required to process the multi-source information in a river basin regarding the *monitoring and evaluation of surface waters quality*, *hydrological and meteorological parameters*, *remote sensing*, *statistical and mathematical forecasting methods*, *geospatial numerical modeling*, *eco-physiological modeling of canopy growth and development of agricultural crops*, and *advanced digital processing of satellite images*. The contribution of the expert systems to the prediction optimization concerning the impact of intensive cropping systems in hydrographical basins is important, and the development of such systems provides major benefits by including the most effective methods for the decision-making process of water quality management at river basin level.

For a reliable application of the SWAT model in various river basins of Romania, the agronomical inputs must be adjusted and adapted accordingly, taking into account the specific conditions of the cropping systems, as well as the eco-climatic and edaphic variables.

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