Tropentag 2007
University of Kassel-Witzenhausen and
University of Göttingen, October 9-11, 2007

Conference on International Agricultural Research for Development

WaNuLCAS Modelling of Improved Swidden Agriculture Systems by Indigenous Fallow Management with *Melia azedarach* in the Uplands of Ban Tat, Northern Vietnam

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Introduction

In Vietnam, economic development and demographic pressure has resulted in fragmented landscapes. Especially mountainous areas are prone to environmental degradation. Government efforts to stop shifting cultivation were not successful. Until today, many hill tribe communities apply swidden agriculture on upland fields. Nevertheless, indigenous knowledge also created useful adoptions to the local environmental setup. The Da Bac Tay minority group of Ban Tat, in northern Vietnam intercrop *Melia azedarach* L., a fast growing deciduous tree, at different stages of the swidden cropping cycle, to improve the restoration of soil fertility. The Centre for Agriculture and Ecological Studies (CARES) of the Hanoi Agricultural University carried out a long-term nutrient balance analysis of selected local cropping systems. In this context, on plot erosion and runoff measurements were conducted within a small watershed of the Ban Tat area. The assessment of long-term effects of such systems is often difficult to predict. Therefore, the objective of this study was to test the applicability of the Water, Nutrient, Light Capture in Agroforestry Systems (WaNuLCAS, Vers. 3.2) model related to runoff and erosion under the local conditions of Ban Tat. In general, model applications can help to understand the behavior of a defined system per se.

The objective of this study was to compare WaNuLCAS model output parameters *BS_Net_Erosion* and *BW_Runoff* and CARES field data of erosion and runoff in 2000, 2001, 2002 and in total sum. The hypothesis was that WaNuLCAS is able to estimate erosion and runoff per year and in total sum for selected cropping patterns according to CARES field measurements.

Materials and Methods

Study site

This study is based on data collected by CARES in a field experiment on swidden agriculture between 2000 and 2002. The experimental site was located in a small watershed within the village area of Ban Tat, Da Bac District, Hoa Binh Province, Northern Vietnam (105°11’92” E and 20°92’82” N) and consisted of a total area of 3.54 ha (Vien, Rambo, 2002). The area can be subdivided into upland (3.23 ha) and paddy (0.31 ha). In total, 2.76 ha of the upland area were covered by forest and 0.76 ha by swidden fields. The watershed topography is steep with slopes of 29 – 36°. The paddy area also showed a light inclination of 3 – 5°. Paddy fields were found at an elevation of 360 m a.s.l whereas the ridgetop of the Ban Tat watershed was found at 482 m a.s.l. The dominating soil type was a Ferralic Acrisol with average initial topsoil (0-27cm) contents of 2% organic matter, 0.16% total nitrogen, 0.05% total phosphate (P_2O_5), 1.69 cmol (K_2O) kg^{-1} soil available potassium and a CEC of 9.9 cmol kg^{-1}, respectively. The climate pattern showed a distinct rainy season from May - October and a dry season from November to February/March. The total precipitation amounted 2071 mm, 2547 mm and 2163 mm in the years 2000, 2001 and 2002, respectively. (Vien, 2007; Dung et al, 2007)

Swidden Agroecosystems

Composite swiddening is defined as an agroecosystem that integrates upland rotating swidden (crop/fallow) plots and downstream permanent wet rice fields into a single household resource system. (Vien and Rambo, 2002 ; Vien, 2007; Dung et al, 2007). Swidden farmers in Northern Vietnam incorporate *Melia azedarach* L. into their farming system as an improved fallow species. It is a fast growing, deep-rooting deciduous tree. The leaves are used as green manure source. The timber has a high durability and is used for many construction purposes (Vien, 2007).

CARES measurements of erosion and runoff

In 1999, the prevailing fallow and secondary forest area within the Ban Tat experimental watershed was cut, timber and wood were taken off the fields, and the remaining vegetation was slashed and burnt. Masonry walls were constructed around selected 5 m x 20 m plots to measure nutrient losses by erosion and runoff and to prevent runon water. Two collecting tanks were installed at the lower end of each plot. The larger tank (4x1x1 m) was used to collect soil, stones and sediments removed by erosion, while a smaller tank was used to collect runoff water (Vien and Rambo, 2002; Dung et al., 2007). Nine plots were installed within the of Ban Tat watershed: three forest and six upland swiddening plots.

WaNuLCAS Model

WaNuLCAS simulates dynamic processes in a spatial, plot/field scale environment on a daily time step. It was developed to validate tree-soil-cop interactions in a wide range of agroforestry systems, i.e. simulation of above and below ground plant growth within a dynamic biophysical environment (Van Noordwijk and Lusiana, 1999; Van Noordwijk et al., 2004). Within the WaNuLCAS framework, two approaches are provided to calculate erosion: *ROSE* adopted from Rose and Hairsine (1988), Rose et al (1998) and *USLE* (Wischmeier and Smith, 1978). Both approaches differ in their definition of initial soil conditions:

ROSE = Cover Factor[1] * Sediment concentration in runoff[2] * Runoff event * Slope factor

USLE = Cover factor[1] * Soil Type[3] * Runoff event * Slope Factor

The *ROSE* approach enables a model calibration according to initial soil data. In contrast, the *USLE* approach provides three soil types: clay, medium and sandy as initial soil calibration information.

Scenarios for model calibration and validation:

Three different land use scenarios were selected for model validation. The scenarios are presented in a chronological order for 2000, 2001 and 2002: Crop Cycle 1 (CC_1): Upland rice – Cassava – Fallow (Weeds and *Melia azedarach*); Crop Cycle 2 (CC_2): Upland Rice – Cassava – Cassava intercropped with *Melia azedarach*; Crop Cycle 3 (CC_3): Upland Rice – Upland Rice intercropped with *Melia azedarach* – Cassava intercropped with *Melia azedarach*. In Fig.2, a combined seasonal calendar for all crop cycles is shown. The calendar presents annual and overall cropping cycle of selected scenarios CC_{1-3} as described above.

		Jan	**Feb**	**March**	**April**	**May**	**June**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
CC_{1-3}	**2000**	O	o	o	O	UR	UR	UR	UR	UR	O	o	o
CC_{1-2}	**2001**	O	C	C	C	C	C	C	C	C	C	C	C
CC_3	**2001**	O	o	o	O	URM	URM	URM	URM	URM	M	M	M
CC_1	**2002**	F	F	F	F	F	F	F	F	F	F	F	F
CC_2	**2002**	O	CM	CM	CM	CM	CM	CM	CM	CM	CM	CM	CM
CC_3	**2002**	M	CM	CM	CM	CM	CM	CM	CM	CM	CM	CM	CM

Fig. 2: Seasonal calendar of CC_{1-3} for 2000, 2001 and 2002. Cropping patterns are listed with an abbreviation: UR – upland rice, URM – Upland rice intercropped with *Melia azedarach*, C – Cassava, CM – Cassava intercropped with *Melia azedarach*, F – Fallow (*Melia azedarach* and weeds), (o) marks no crop and is defined as bare soil.

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[1] Daily calculation of leaf area index of grown crops and trees, coefficient of litter fall and crop or tree canopy coefficient factor

[2] Calibrated by an entrailment coefficient (Rose et al, 1998) (in WaNuLCAS: *E_Entrailment CoeffBarePlot*)

Statistical Analysis

A simple statistical analysis was developed to check model outputs compared to observed field data:

Goodness-of-Match / year: $(\mathrm{GOM}_{\mathrm{year}}) = \left(\frac{Pi}{Oi}\right) * 100$

Goodness-of-Match$_{\mathrm{total}}$ / crop cycle: $(\mathrm{GOM}_{\mathrm{total}}) = \left(\sum_{i=1}^{n} Pi / \sum_{i=1}^{n} Oi\right) * 100$

The *goodness- of-match* describes how close a model output run matches with observed field data, P_i is the predicted value, O_i the observed and *n* the number of samples. A value of 100 indicates a perfect one-to-one relationship, and the model was able to calculate observed field data. A value below 100 describes that the model under predicted, and above 100 over predicted observed data compared to model outputs (adapted from Loague and Green, 1991; Walker et al, 2007). Specific model analysis tools, e.g. modeling efficiency (EF) or coefficient of determination (CD) (Loague and Green, 1991; Walker et al, 2007) were not applied as a sample number of n=3 were considered too small for a statistical analysis of CD and EF.

Results

Calibration

The model was calibrated with climate data from 2000-2002, collected from two local weather stations (Ban Tat: 05/2000-12/2002, and Hoa Binh: 01/2000-04/2000, daily average data from 1978-1998 were used, as no data existed at the Ban Tat station for this time period). Soil data provided by CARES served to calibrate model input section *pedotransfer functions*, and furthermore *initial soil organic matter pools* according to Parton et al. (1988), Parton and Rasmussen (1994), Kirschbaum and Pau (2002). Soil input parameters were calibrated according to pedotransfer functions and similarly for all three scenarios. A dataset of *Melia azedarch* L. did not exist within WaNuLCAS *tree library*. Hence, a literature review (Hanum and van der Maesen, 1994; Vien, 2007; Chinh, N.N. 1996) was undertaken to develop such a dataset and to implement it into the model. The *ROSE* approach was chosen to validate WaNuLCAS erosion calculations in comparison with CARES field data. The *USLE* approach was not examined as detailed initial soil data provided by CARES were available and a higher accuracy of model outputs was expected by using the *Rose approach*. Preliminary model runs indicated this assumption, and therefore, *USLE* was rejected for model validations concerning soil loss outputs.

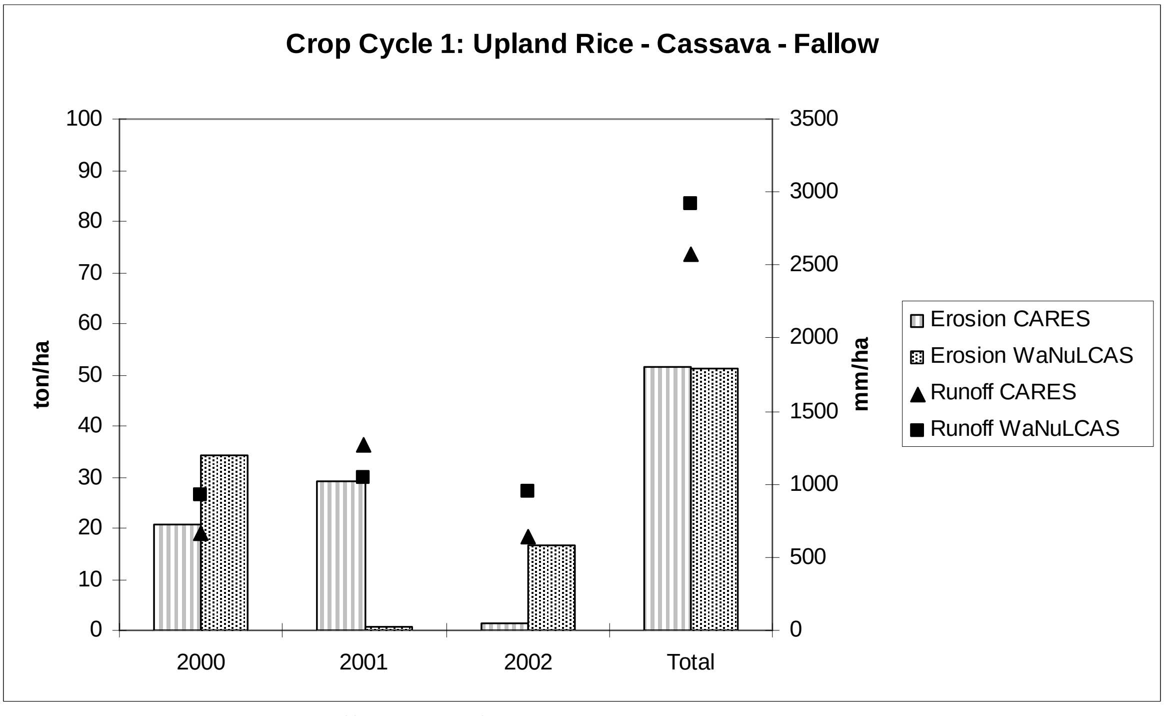

Fig.4: Erosion (ton/ha) and runoff (mm/ha) of Crop Cycle$_1$ Upland Rice, Cassava, Fallow): CARES field data *vs*. simulated WaNuLCAS model run results in 2000-2002 and in total sum.

Validation

In Figures 3-5, model output data of erosion and runoff are compared with data from Ban Tat experimental setup according to selected scenarios. The model predicted runoff (CARES in brackets) with 2922 (2576), 2712 (2709), 2120 (2880) mm/ha for CC_1, CC_2 and CC_3 in total sum for the years 2000 – 2002, respectively. By checking single years, the model overpredicted runoff in 2000 with 921 compared to 667, 675 and 675 mm/ha/year for all CARES plots respectively. In 2001, the model underpredicted runoff of scenarios CC_1 and CC_2 with 1047 mm/ha/year compared to 1264 and 1251 mm/ha/year by CARES, whereas runoff was over predicted (1154 mm/ha/year) compared to field observations of CARES for CC_3 (897 mm/ha/year). In 2002, the model overpredicted runoff of CC_1 and CC_3 (954 and 805mm/ha/year, respectively) compared to CARES observations (645 and 615 mm/ha/year, respectively). Runoff of CC_2 was underpredicted (744mm/ha/year), but was close to CARES field data (783 mm/ha/year) in 2002.

The model results of erosion[4] for the three consecutive years in total amounted to 51.3 ton/ha (CC_1), 35.6 ton/ha (CC_2) and 88.5 ton/ha (CC_3). The model results of erosion showed high variations compared to CARES on plot erosion results of 51.5 ton/ha, 47.3 ton/ha and 49.7 ton/ha for CC_1, CC_2 and CC_3 considering 2000-2002 in total sum. In 2000, WaNuLCAS overpredicted erosion for all three scenarios and amounted to 34.1 ton/ha compared to CARES observations for CC_1, CC_2 and CC_3 of 20.7, 15.9 and 15.4 ton/ha, respectively. In 2001, WaNuLCAS model underpredicted erosion in scenarios CC_1 and CC_2 with 0.6 ton/ha/year compared to CARES results of 17.9 ton/ha (CC_1) and 29.7 ton/ha (CC_2). In the same year, the model outputs of scenario CC_3 amounted 29.7 ton/ha and were almost even to CARES measurements of 29.2 ton/ha. Finally, in 2002, the model outputs differed for the selected cropping patterns and amounted CC_1: 16.6 *vs.* 1.5 ton/ha; CC_2: 0.9 *vs.* 13.5 on/ha and CC_3: 24.7 *vs.* 4.8 ton/ha compared to CARES observations.

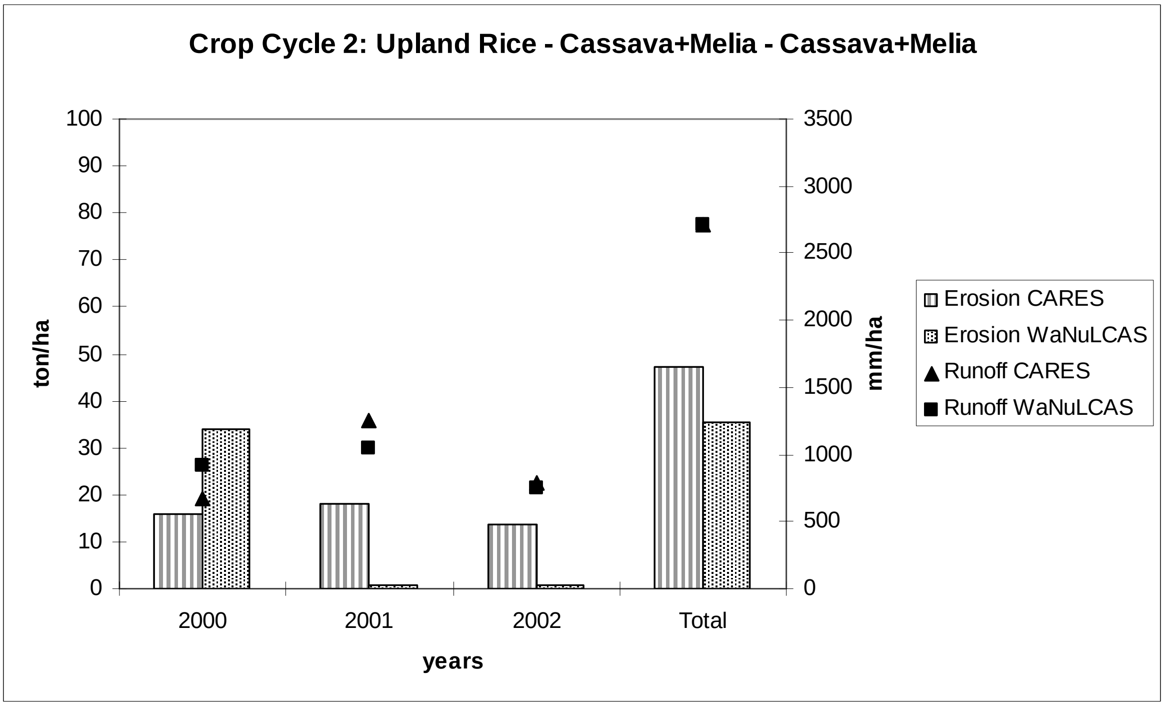

Fig.5: Results of erosion (ton/ha) and runoff (mm/ha) Crop $Cycle_2$ (Upland Rice – Cassava intercropped with *Melia azedarach* – Cassava intercropped with *Melia azedarach*): CARES field data and simulated WaNuLCAS model runs in 2000, 2001, 2002 and in total sum.

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[4] Erosion:
within this study we understand the term *erosion* as *soil loss* of a certain area, in our case soil loss of a runoff plot extrapolated to hectare.

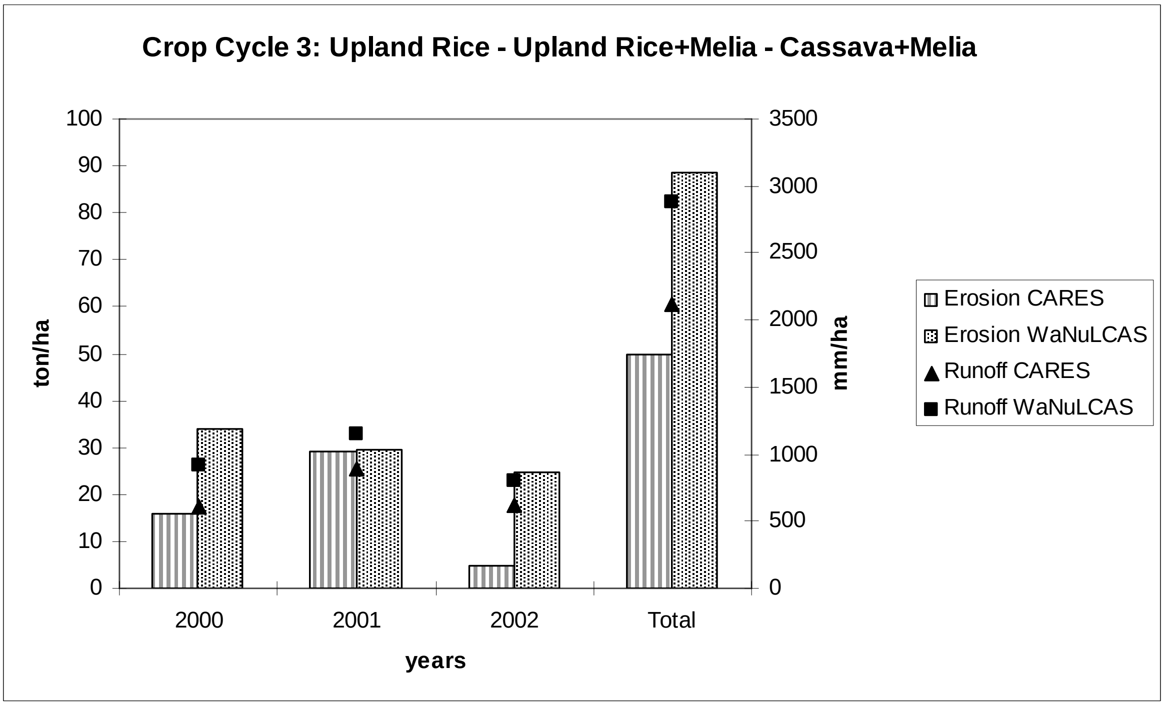

Fig.5: Results of erosion (ton/ha) and runoff (mm/ha) Crop Cycle III (Upland Rice – Upland rice intercropped with *Melia azedarach* – Cassava intercropped with *Melia azedarach*): CARES field data and simulated WaNuLCAS model runs in 2000, 2001, 2002 and in total sum.

Goodness-of-match

Runoff

Calculations of the GOM_{Year} and of GOM_{Total} are presented in Tab.1 The GOM_{Year} was calculated with 83 to 148% and GOM_{Total} with 100 – 136%. In this sense, the data indicate that the WaNuLCAS model was able to estimate runoff with 83 to 148% accuracy for a single year and with 100 – 136 % for the overall cropping cycle.

Erosion

In contrast to runoff, data of erosion GOM_{Year} and GOM_{Total} (Tab.2) showed a high variation between field data and model output. Here, GOM_{Year} showed a variation of 2 to 1107%. Thus, by considering single year erosion, the model under estimated annual erosion up to 2 % (GOM_{2001} CC_I) or over estimated erosion up to 1107% (GOM_{2002} CC_I). In general, WaNuLCAS was not able to estimate annual erosion with a similar accuracy as found for runoff patterns of similar years. Nevertheless, when considering GOM_{Total}, the accuracy of WaNuLCAS erosion predictions improved. In this context, the model was able to calculate erosion with an accuracy of 75 – 178% for the three selected scenarios.

GOM_{Year}	CC_I	CC_{II}	CC_{III}	Average
2000	138	136	151	142
2001	83	84	129	98
2002	148	95	135	125
GOM_{Total}	113	100	136	116

Tab.1: Calculation of GOM runoff per year (GOM_{Year}) and total (GOM_{Total}) in percentage

GOM_{Year}	CC_I	CC_{II}	CC_{III}	Average
2000	165	214	217	199
2001	2	3	102	36
2002	1107	7	515	543
GOM_{Total}	99	75	178	118

Tab.2: Calculation of GOM soil loss per year (GOM_{Year}) and total (GOM_{Total}) in percentage

Discussion

In general, the WaNuLCAS model calculated runoff more efficiently than erosion. Simulated runoff patterns matched closer with on plot field results and showed a lower variation compared to model outputs of erosion. A similar trend was found by Favis-Mortlock (1998), who evaluated six field-scale erosion models (GLEAMS, EPIC, CSEP, MEDRUSH, WEPP, EUROSEM) with datasets from seven sites in three countries. He concluded that long-term average results are generally best simulated, and there is evidence that relative results are more reliable than absolute model results.

The calculations of GOM_{total} for runoff showed that the model reached an accuracy of 100-136% compared to GOM_{total} of erosion with 75-178%. Nevertheless, only by comparing GOM_{total} data, one neglects the GOM_{Year} which showed a broader range of accuracy. However, the no. of runs with n=3 in this study is small, and thus detailed statistical analysis, e.g. *Modeling efficiency* and *Coefficient of determination* (Loague and green, 1991; Walker et al. 2007) were not applied. Therefore, the presented statistical analysis *goodness-of-match* can only show trends and no general patterns. Hence, it is important in future simulations to increase the number of scenarios *n* to validate WaNuLCAS outputs of erosion and runoff.

One has to be aware that crop yield calibration was simplified for the purpose of this study. As the focus in this study was set on erosion and runoff patterns, plant growth input parameters were neglected for a detailed calibration. When the model was able to grow crops and trees according to the seasonal calendar a further calibration was not executed. As such, model output data of crop yield and biomass production did not match with CARES field data. Furthermore, intercropping of *Melia azedarach* influenced the crop biomass and yield production of a certain model run. Nevertheless, the intercropping of *Melia azedarach* did not show remarkable differences in erosion and runoff patterns compared to model runs without intercropping *Melia azedarach.*

In general, WaNuLCAS crop growth is calibrated in the model section *crop management*. Every crop is defined by a dataset provided in the section *crop library*. Beside different growth parameters, a specific *crop cover efficiency* factor is listed and defines how good a certain crop or tree is able to protect soil from erosion. The *ROSE* equation takes this parameter into account using a *canopy factor*. This canopy factor is calculated by two crop and tree growth parameters, i.e. *leaf area index* and *crop cover efficiency* factor. Hence, the model assumes “full cover” if the plant growth reaches a certain threshold value during a model run. Therefore, erosion is minimized by a full canopy and ground cover provided through growing crops and trees. In general, it was found that after about three to four weeks within a certain model run, the crop growth canopy factor reached full cover status. In this sense, WaNuLCAS overestimates the canopy factor in a later stage of crop growth cycle. Rainfall events occurring in this cropping stage cannot influence erosion patterns. The equation is overruled by the full cover assumption provided by the canopy factor. Therefore, by comparing WaNuLCAS model outputs of erosion among each other, it was shown that depending on the selected scenarios model behavior differed significantly. As stated above, the reason is “timing of soil coverage” provided by a certain scenario throughout the year. A scenario with long annual crop growth periods, e.g. CC_1 and CC_2 results in smaller erosion amounts in total sum then a scenario with a shorter growth period as found in CC_3. Hence, the erosion amounts of WaNuLCAS differed throughout the selected scenarios and years respectively.

Beside daily WaNuLCAS assumptions within a model run, input parameters *E_EntrailmentCoeffBarePlot* (entrailment coefficient of a bare plot (ECB), *S_RelSurfInfiltrInit*, (the initial infiltration capacity of the defined plot) (IS) and *S_SurfInfiltrperKSAT* (initial infiltration capacity per K_{SAT} of the defined model setup) (ISI) are major factors influencing model performance regarding erosion and runoff. It is emphasized to find a good balance between these input parameters when using WaNuLCAS for a validation of erosion and runoff.

Conclusion

WaNuLCAS 3.2 can serve as useful tool to validate relationships of runoff and erosion within a selected setup of parameters. The model proved its applicability to estimate runoff and erosion with the *ROSE* equation. Nevertheless, it is suggested to improve WaNuLCAS model structure. The model assumes full ground and canopy cover by crops after about four weeks, depending on selected crop type and cropping cycle. If rainfall events occur in a later part of a crop growth cycle, the model does not take it into account for estimating erosion and runoff, as full plant coverage is assumed by the model. Hence, it is suggested to develop an algorithm which overrules the full canopy factor in this stage of cropping cycle to enable the model to calculate erosion and runoff depending on the daily rainfall amounts. Furthermore, a second algorithm is needed which enable an erosion event when several rainfall events sum up over a defined threshold level within a certain time period.

It is not clear, if the WaNuLCAS model structure can be improved in the stated way. The suggestions require more knowledge of event-based erosion and runoff model applications. Detailed knowledge of other erosion and runoff model applications are needed to compare approaches by soil physical and model perspectives. Further studies on WaNuLCAS erosion and runoff model behavior are needed to reach a higher level of reliability and confidence in the model performance of erosion and runoff.

Acknowledgements

I like to thank my family and friends for supporting me during my studies and for helpful comments concerning work and projects.

Special thanks to Dr. Tran Duc Vien, Dr. Nguyen Van Dung and Dr. Nguyen Thanh Lam and Tran Trung Kien of CARES, Centre of Agricultural Research and Ecological Studies, Hanoi Agricultural University, Vietnam. Further thanks to my supervisors Prof. George Cadisch, Dr. Thomas Hilger and Dr. Gerd Dercon Institute of Plantproduction and Agroecology in the Tropics and Subtropics, University of Hohenheim, Stuttgart, Germany and all members of Institute of Plantproduction and Agroecology in the Tropics and Subtropics, University of Hohenheim, and all members of the Uplands Program. Finally, I like to thank the DFG, Deutsche Forschungsgemeinschaft for funding this study.

References

Chinh, N.N. (ed.) (1996): Vietnam Forest Trees, Forest Inventory and Planning Institute, Agricultural Publishing House, Hanoi, Vietnam

Dung, N.V., Vien, T.D., Lam, N.T., Tuong, T.M., Cadisch, G. (2007): Analysis of the sustainability within the composite swiddening agroecosystem: 1. Nutrient balances of swidden fields with different cropping cycles, unpublished article

Favis-Mortlock, D.T. (1998): Validation of Field-Scale Soil Erosion Models using Common Datasets, in: Boardman, J., Favis-Mortlock, D. (eds.): Modeling Soil Erosion by Water, NATO ASI series, Series I: Global Environmental Change, Vol. 55, Springer-Verlag, Berlin Heidelberg New York

Hannon B., Ruth M. (1994): Dynamic Modeling. Springer-Verlag, New York. 248 pp.

Hanum, I.F., van der Maesen, L.J.G.(eds.) (1997): PROSEA - Plant Resources of Southeast Asia No.11: Auxiliary Plants, Backhuys Publishers, Leiden, NL

Kirschbaum, M.U.F., Paul, K.I. (2002): Modeling C and N dynamics in forest soils with a modified version of the CENTURY model, Soil and Biochemistry 34: 341-354

Loague, K., Green R.E. (1991): Statistical and graphical methods for evaluating solute transport models: Overview and application, Journal of Contaminant Hydrology 7: 51-73, Elsevier B.V. Amsterdam

Parton, W.J., Rasmussen, P.E. (1998): Long-term effects of crop management in wheat-fallow: II. CENTURY model simulations, Soil Science Society of America 58: 530-556

Rykiel, E.J. (1996): Testing ecological models: the meaning of validation, Ecological Modelling 90: 229-244

STELLA (1994): STELLA II technical documentation. High Performance Systems Inc., Hanover, USA

Van Noordwijk, M., Luisana, B., Khasanh, N. (2004): WaNuLCAS 3.1, Background on a model of water, nutrient and light capture in agroforestry systems. International Centre for Research in Agroforestry (ICRAF), Bogor Indonesia

Van Noordwijk, M., Luisana, B. (1999): WaNuLCAS, a model of water, nutrient and light capture in agroforestry systems, Agrforestry Systems 43: 217-242

Vien, T.D. (2007): Indigenous Fallow Management with *Melia azedarach* Linn. in Northern Vietnam, unpublished article

Vien, T.D., Dung, N.V., Dung, P.T., Lam, N.T. (2004): A Nutrient Balance Analysis of the Sustainability of a Composite Swiddening Agroecosystem in Vietnam's Northern Mountain Region, Southeast Asian Studies 41, No.4

Vien,T.D., Rambo, A.T (eds.) (2002): A Methodology for studying the nutrient balance of a composite swiddeing agroecosystem in Vietnam's Northern Mountain Region, CARES Working Paper No.1, CARES, Centre for Agricultural research and Ecological Studies, Department of Agroecology and Environmental Science, Hanoi Agricultural University, Gia Lam, Hanoi, Vietnam

Walker, A.P., Mutuo, P. K., Van Noordwijk, M., Albrecht, A., Cadisch, G. (2007): Modeling of planted legume fallows in Western Kenya using WaNuLCAS. (I) Model calibration and validation, Agroforesty Systems 70: 197-209

Wischmeier, W.H. and Smith, D.D. (1978): Predicting rainfall erosion losses: A guide to conservation planning. U.S. Department of Agriculture, Agricultural Handbook No. 537.