Towards an Improvement of the Water Balance on Steep Slopes - Development of a Correction Algorithm of the Runoff Curve Number for Slope Angles up to 100%

Para um aperfeiçoamento do balanço hídrico em encostas íngremes – Desenvolvimento de um Algoritmo de Correção da “Curva-Número” para declividades até 100%

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YANGTZE PROJECT

Motivation
Motivação

Reliable estimations of stream flow, soil erosion or nutrients critical for model-based scenario evaluations

The crucial processes should be represented adequately for the conditions of the research region

SWAT-based study on diffuse matter inputs in the Three Gorges Region, China, with very steep slopes (average slope: 40%)

Critical question for representation of processes in SWAT:
How do HRUs in SWAT behave with slope?

Experimental Design
A estrutura do projeto experimental

- **Experimental design:**

  SWAT model with only one subbasin containing one HRU

  - different vegetation types

  - different soil types with uniform soil depth

  - two years run (1 year warmup)

  - climate data from Xiangxi catchment (China): 1116 mm/a

Parametrization:

HRU area: 5 km²

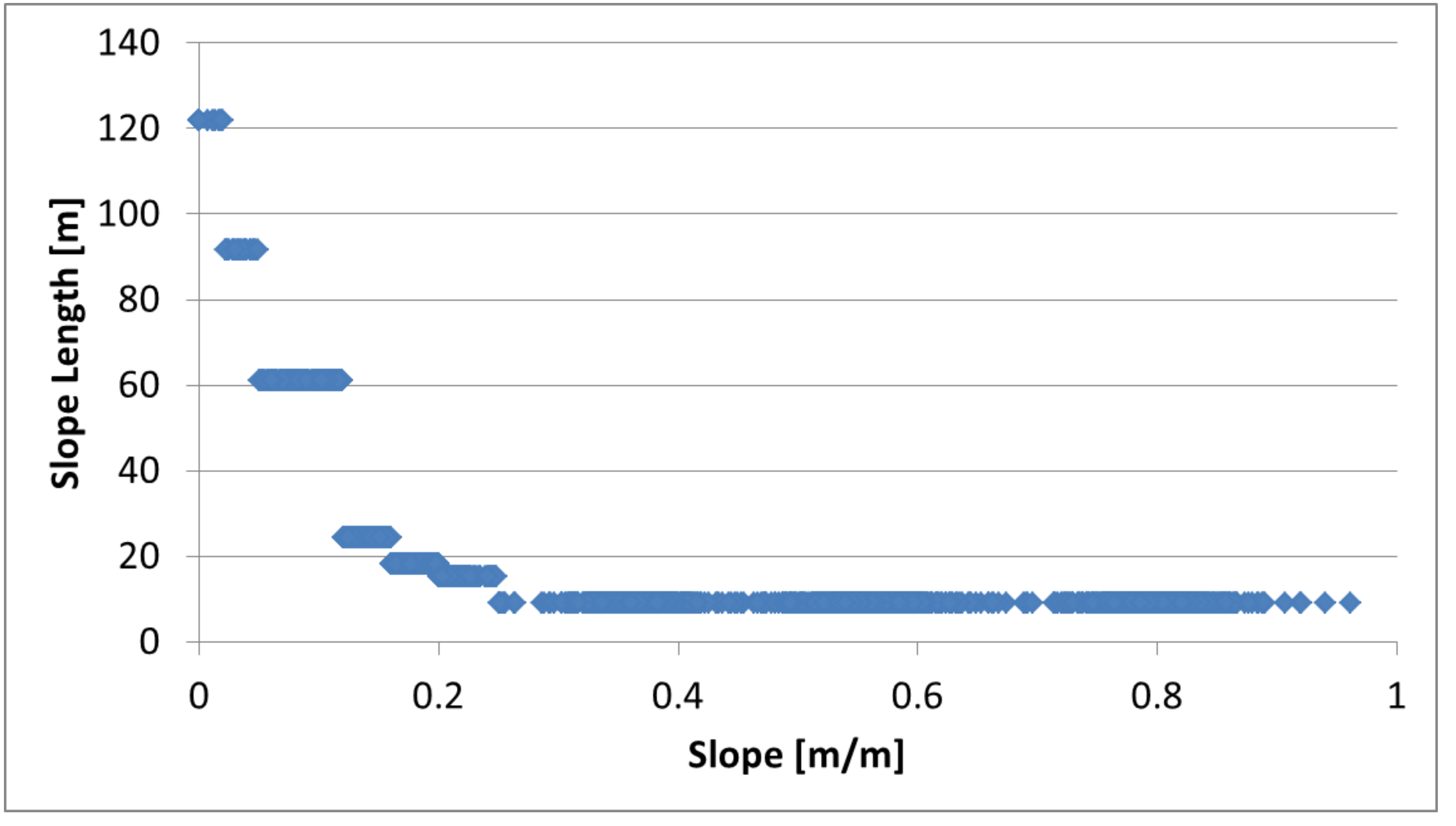
Soil Depth: 1000 mm

Slope Length: *variable*

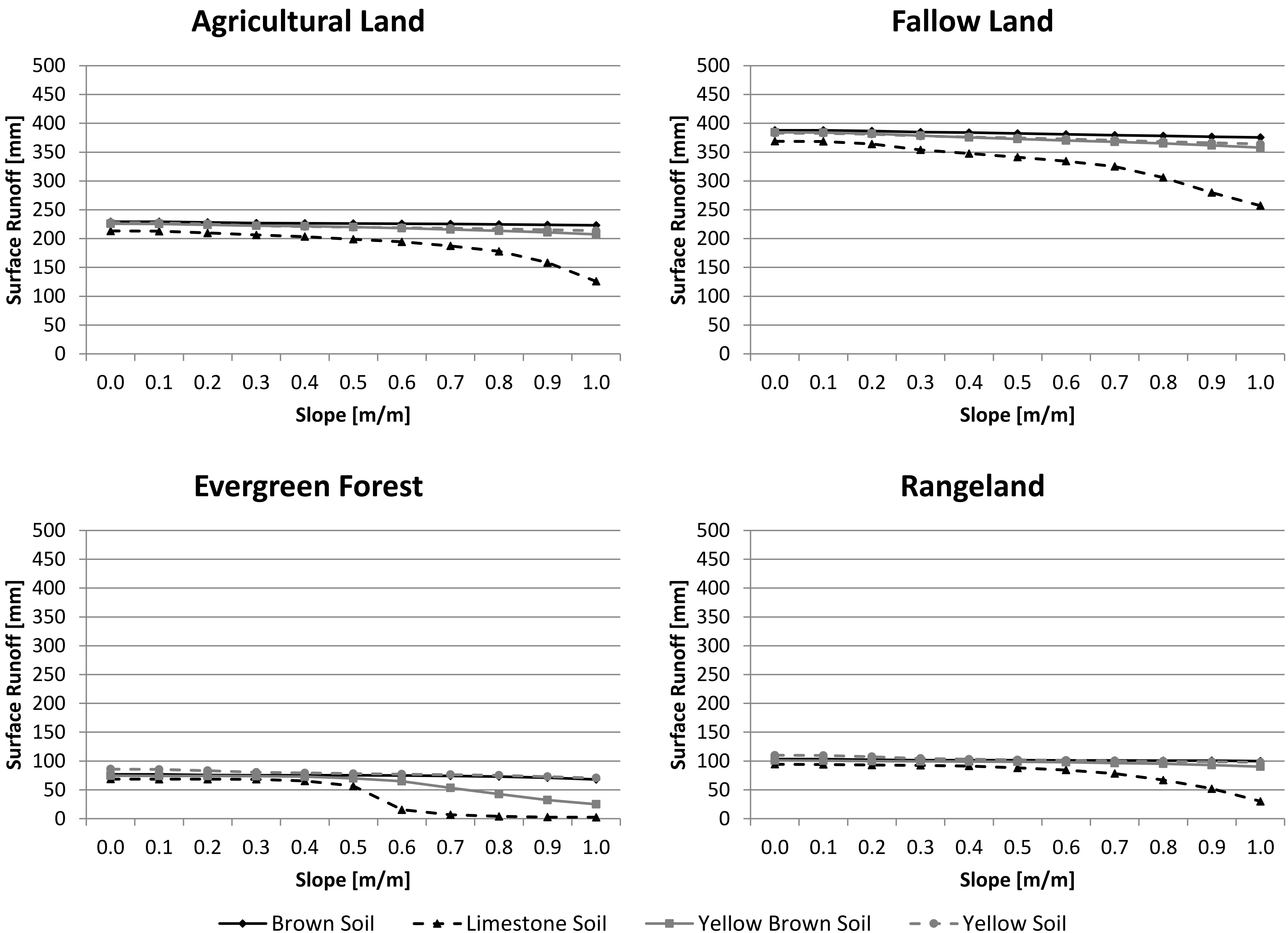
Land Use	Agricultural Land	Fallow Land	Forest	Rangeland
CN2	77	86	55	61
USLE_C	0.200	1.000	0.001	0.003
Soil	**Brown**	**Limestone**	**Yellow Brown**	**Yellow**
SOL_AWC	0.15	0.15	0.15	0.14
SOL_BD	1.00	1.20	1.43	1.40
SOL_K	26.10	26.10	26.10	8.38
Texture (S/U/C [%])	21.8/48.4/29.8	16.5/16.9/66.6	39.2/47.6/13.2	32.6/39.0/28.4
USLE_K	0.43	0.34	0.39	0.30

- HRU slope is varied > Annual output from output.hru

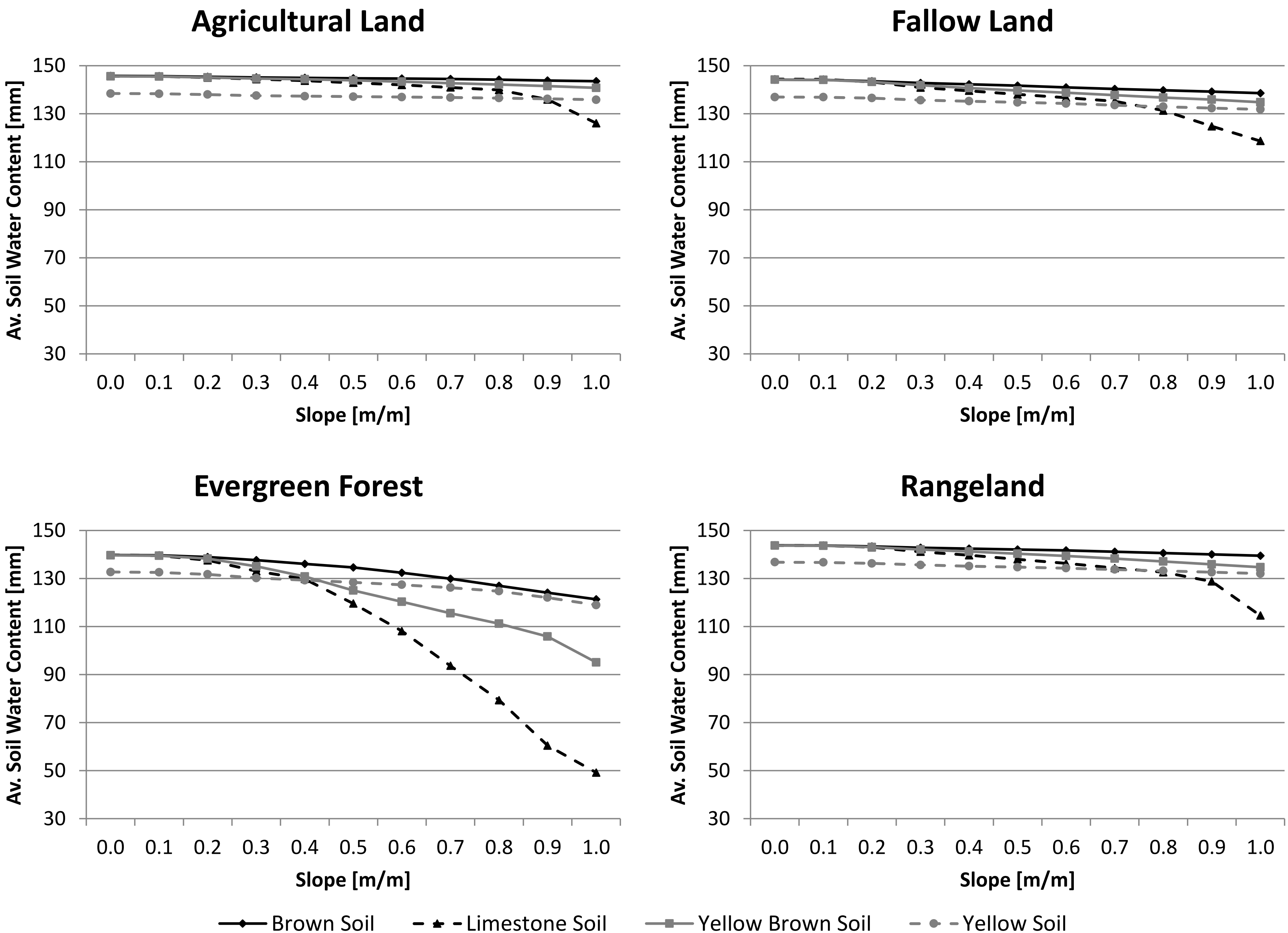
Relation between Slope and Slope Length
Relação entre declividade e comprimento da encosta



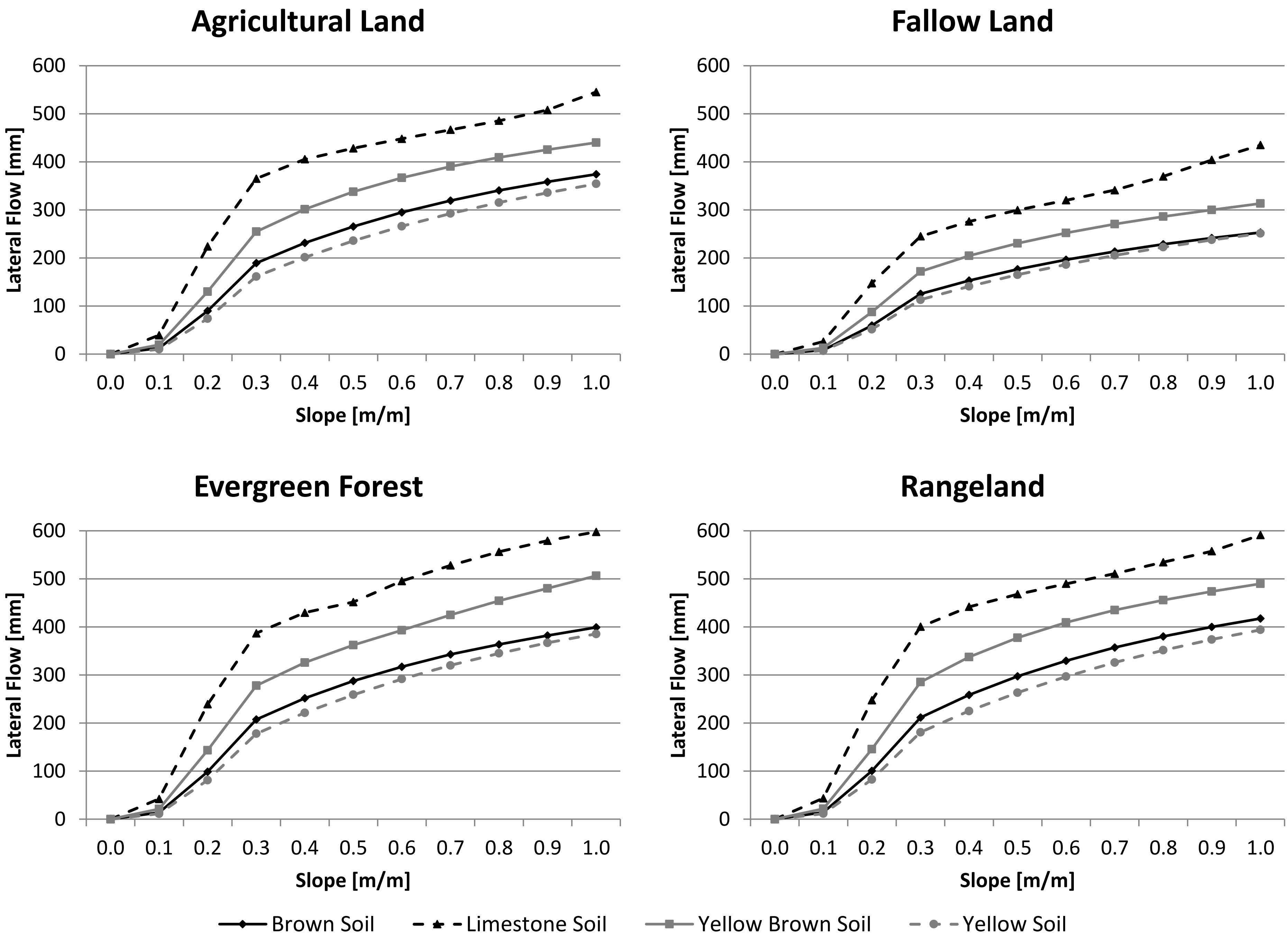
SUR_Q - Surface Runoff – Escoamento Superficial



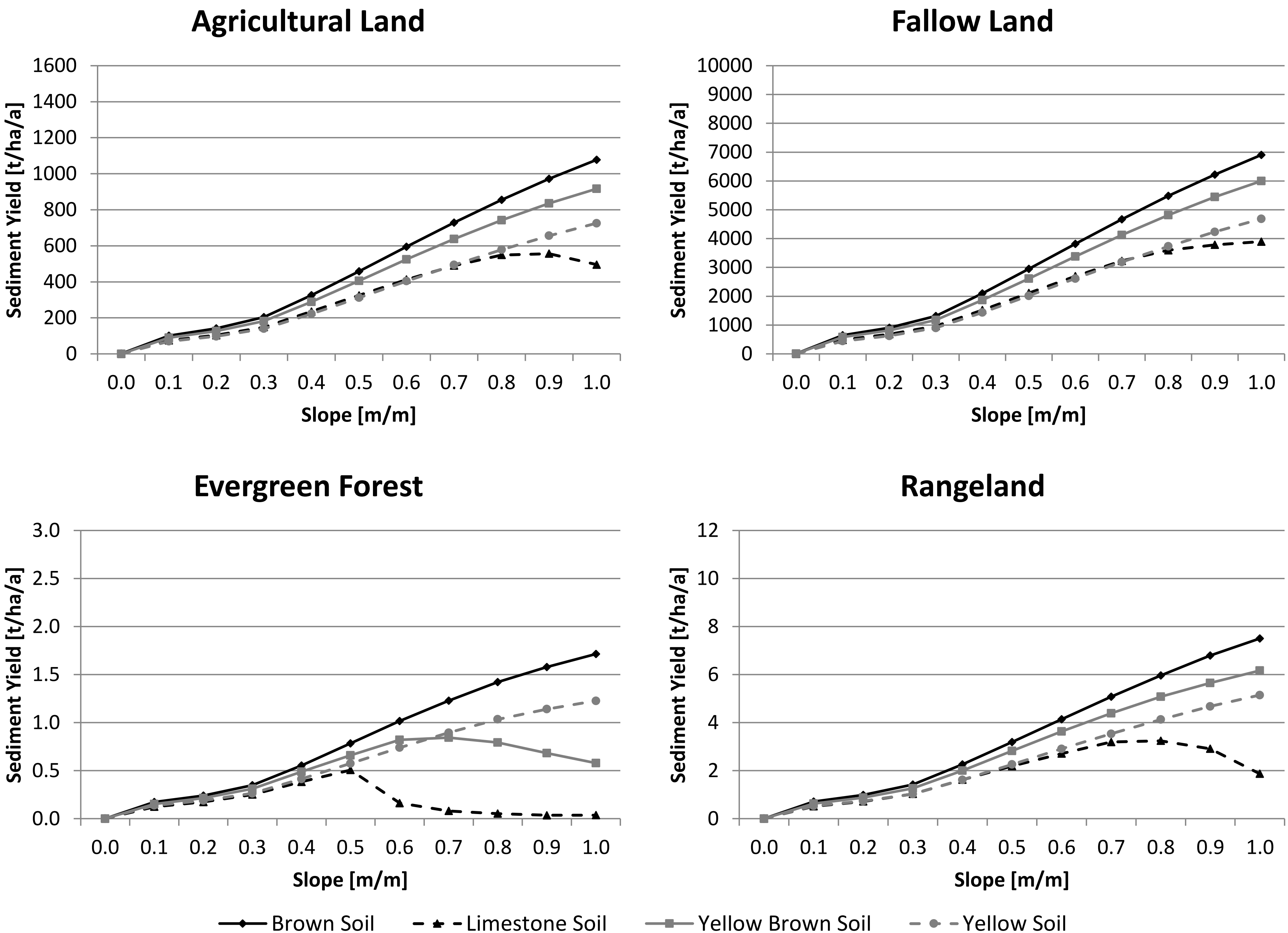
SW - Soil Water Content – Umidade do Solo



LAT_Q - Lateral Flow – Escoamento Lateral



SED_YLD - Sediment Yield – Produção de sedimentos

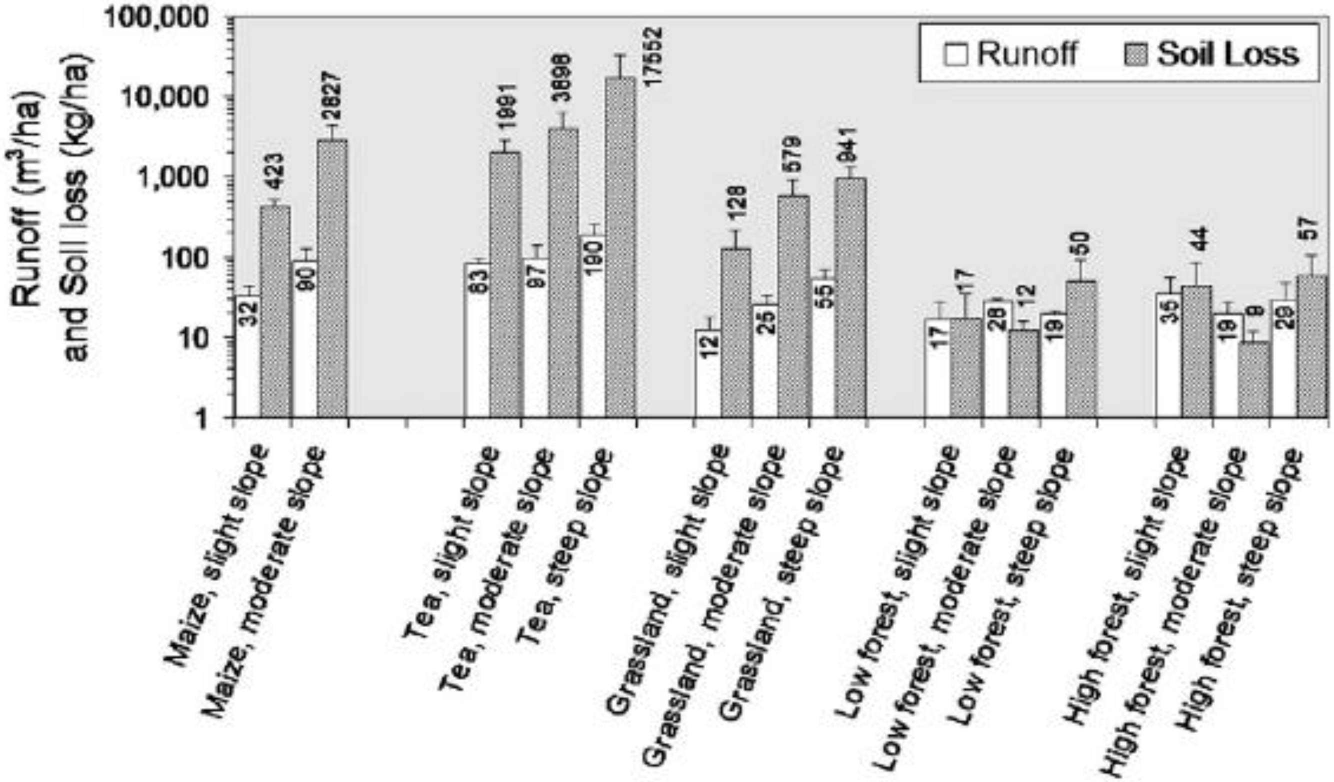


How does surface runoff behave with slope?
Como o escoamento superficial se comporta em relação à declividade?

- Surface runoff:

  Increases with increasing slope angle

  e.g. El Kateb et al., 2013



Many other studies also confirm this relation, e.g.
Chaplot & Bissonnais, 2003
Haggard et al., 2002
Barros et al., 1999

How does surface runoff behave with slope?
Como o escoamento superficial se comporta em relação à declividade?

- According to Huang et al. (2006) surface runoff increases with slope due to:

1. a reduction of the initial abstraction (Huang, 1995; Fox et al., 1997; Chaplot & Bissonnais, 2003)

2. a decrease in infiltration

3. a reduction of the recession time of overland flow (Evett & Dutt, 1985)

Correction Algorithms for CN
Algoritmos de correção para CN

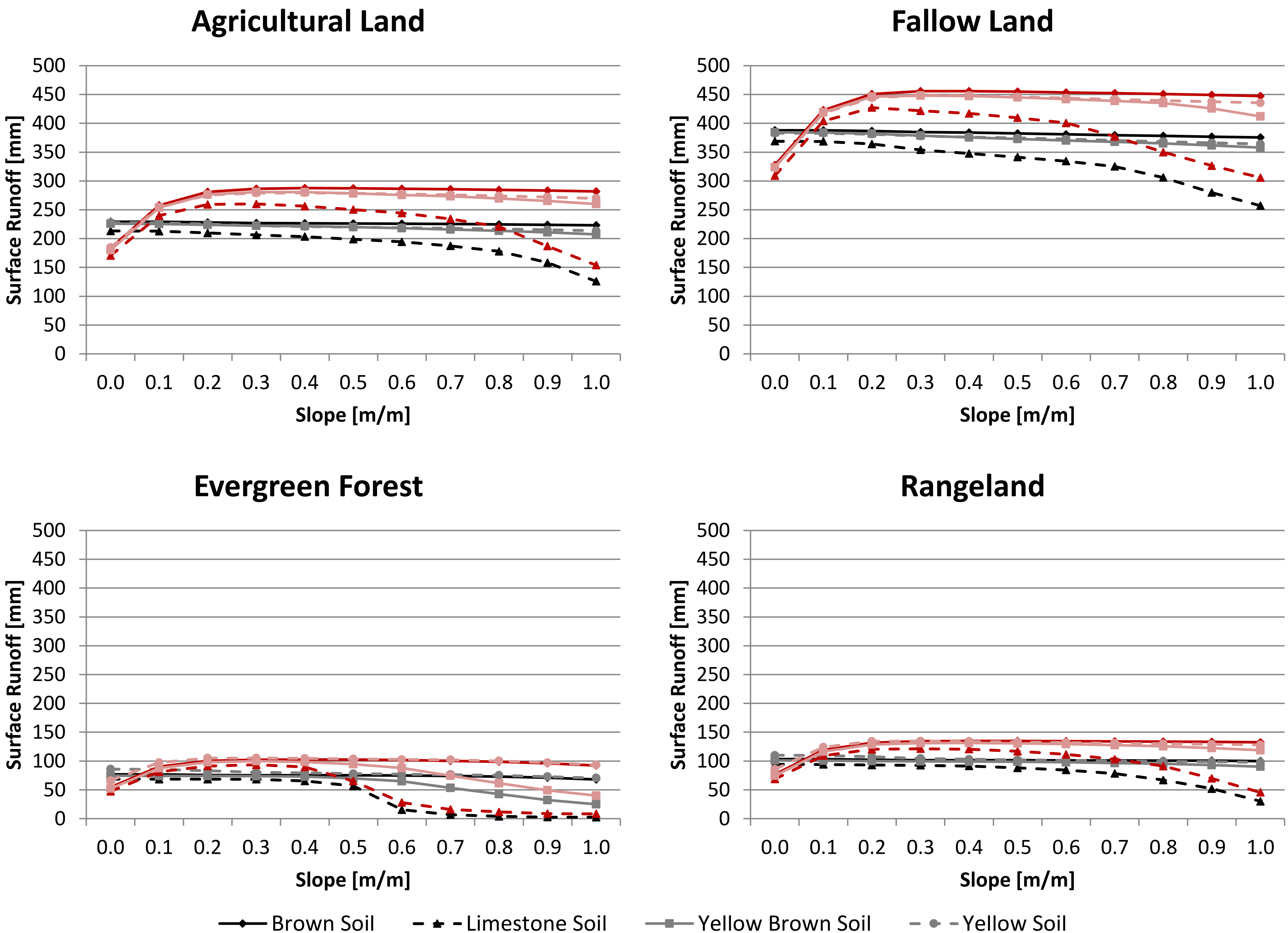
- Williams (1995):

$$CN_{2s} = \frac{(CN_3 - CN_2)}{3} \cdot [1 - 2 \cdot exp(-13.86 \cdot slp)] + CN_2$$

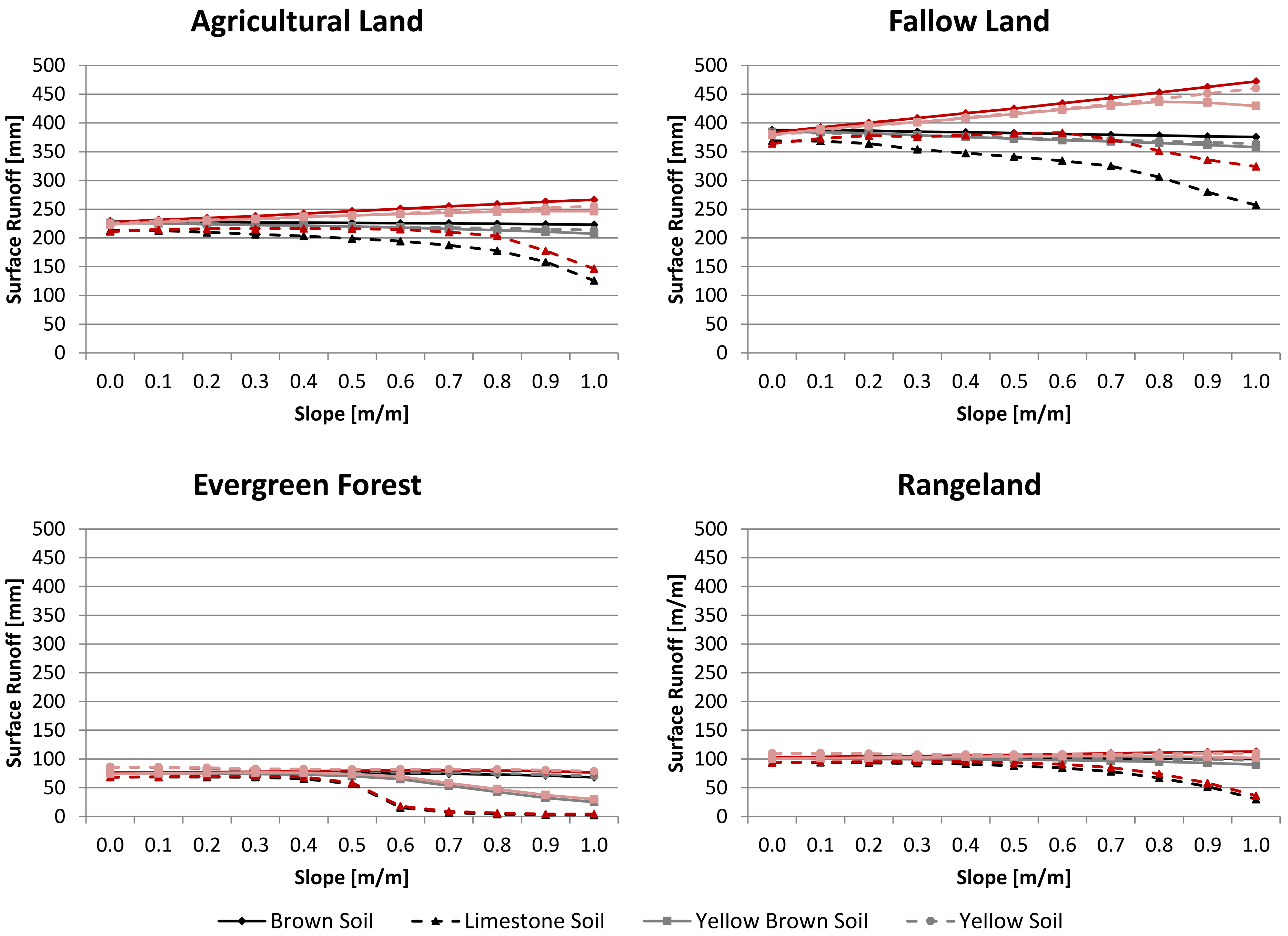
- Huang et al. (2006):

$$CN_{2s} = CN_2 \frac{322.79 + 15.63 \cdot slp}{slp + 323.52}$$

Slope Correction – Correção de declividade – Williams, 1995



Slope Correction – Correção de declividade – Huang et al., 2006



Data analysis of different studies, e.g.:

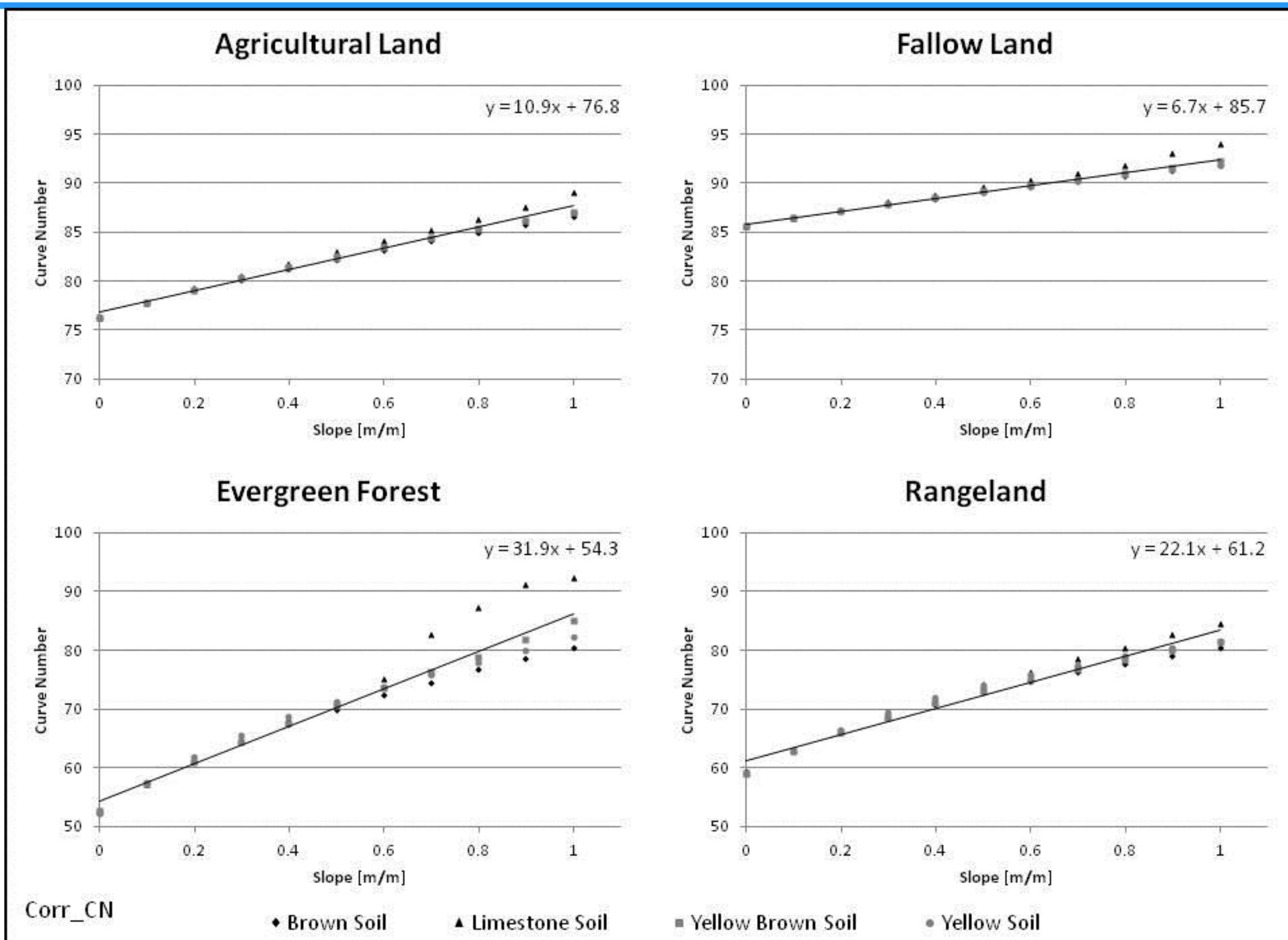
- Haggard et al., 2005
- Huang et al., 2006
- El Kateb et al., 2013

- Data analysis from these studies suggests a linear increase of surface runoff with slope by 1.5% of the annual precipitation sum per 10% slope increment on agricultural land

- With this, for the test dataset (1116 mm/a), the surface runoff increase per 10% slope increment was defined as 16.7 mm

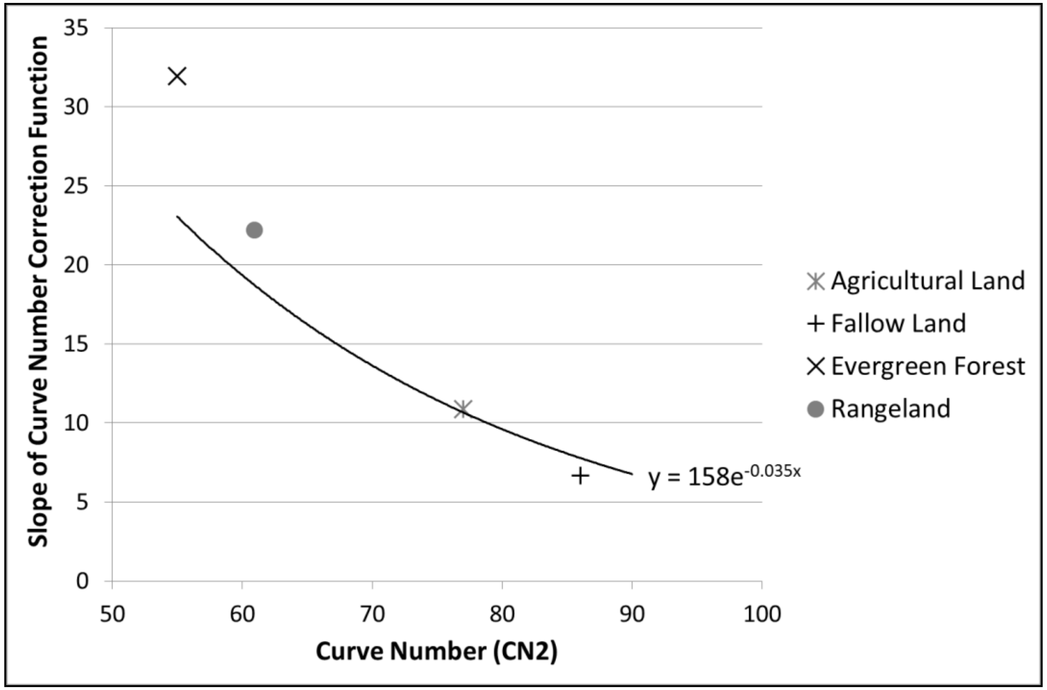
- The curve numbers to meet the desired increase rate were determined with an iterative approach using the single-HRU models

Ideal curve number values for the Slope Correction Algorithm
Valores ideais da CN para o Algoritmo de Correção da Declividade



Development of a CN correction algorithm for slopes up to 100%
Desenvolvimento de algoritmo de correção da CN para declividades até 100%

- To adjust the rate of CN correction for different land uses, the initial CN was used
- With the adjustment of the correction function, also the lower surface runoff increase rates for forest and shrubland could be implemented



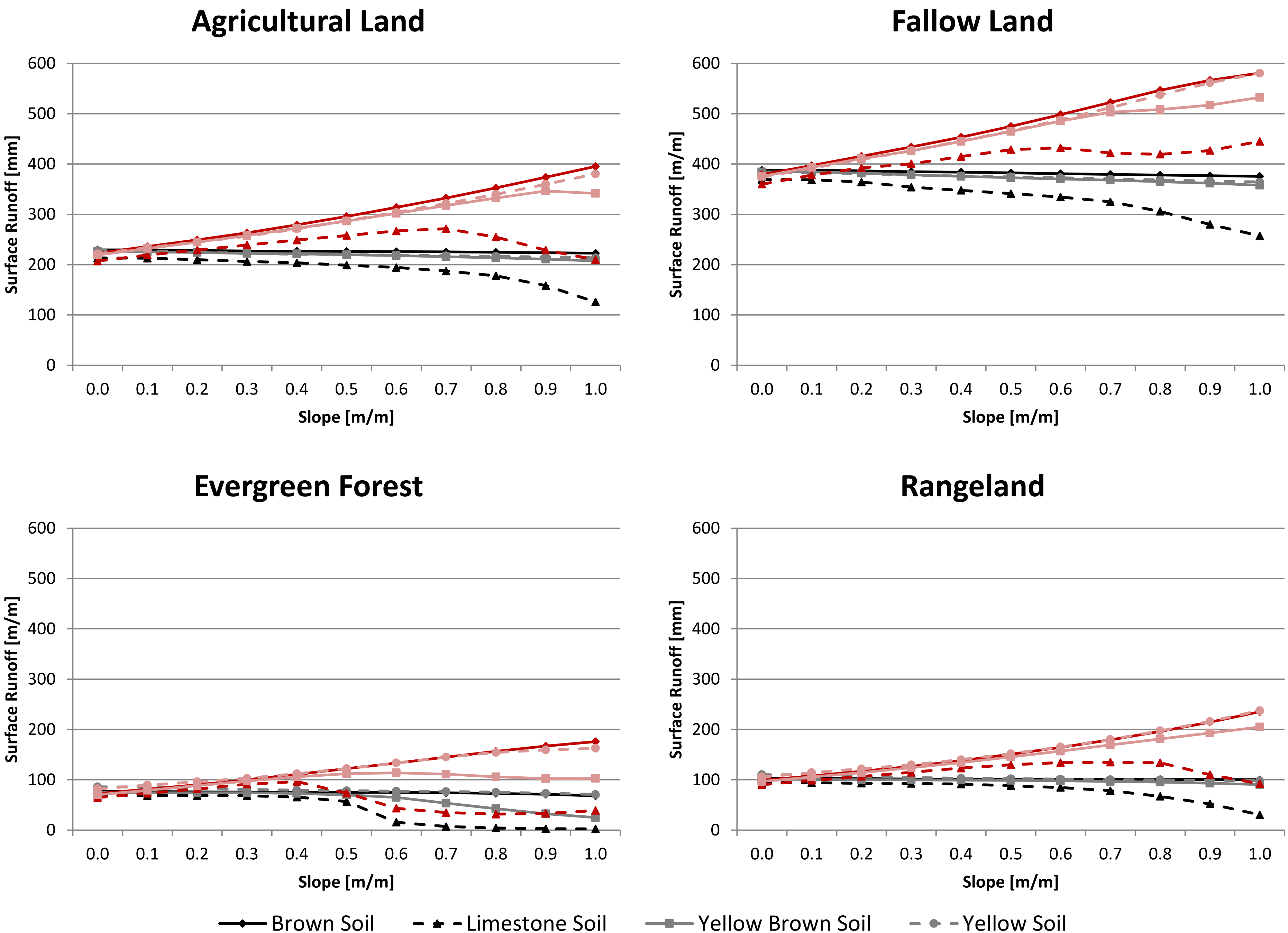
- With this the CN correction equation can be written as:

$$CN_{korr} = a \cdot slp + CN2 \cdot (1 - 0.05 \cdot a)$$

with

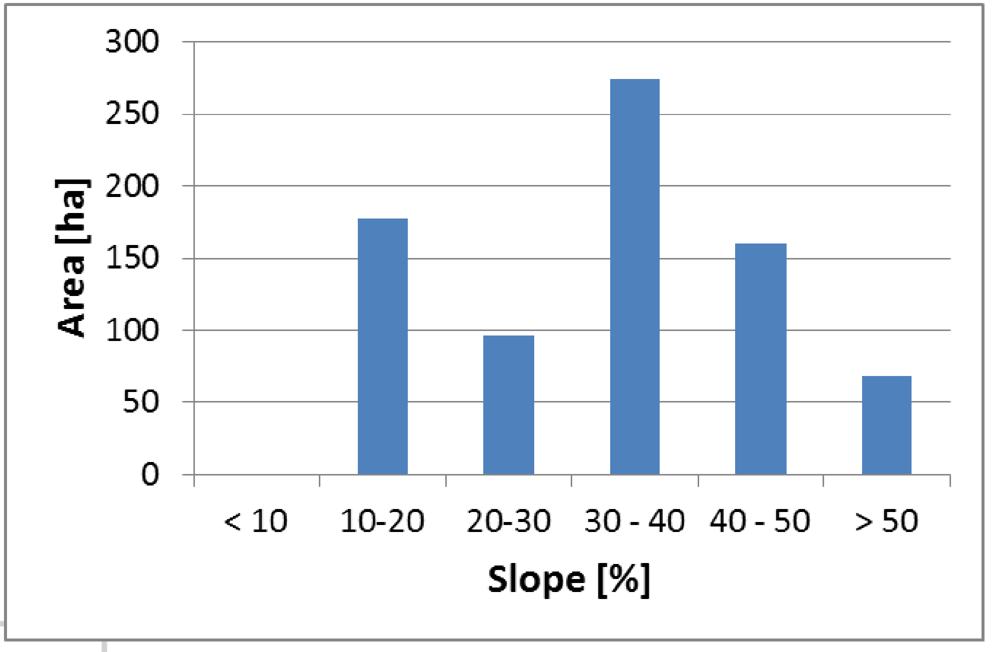
$$a = 158 \cdot exp(-0.035 \cdot CN2)$$

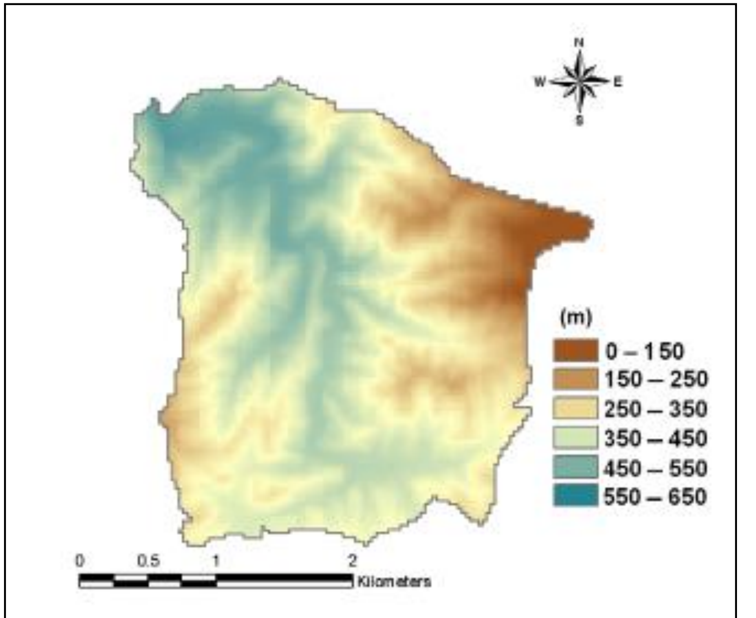
New CN Slope Correction Algorithm – Novo Algoritmo de Correção da Declividade da CN



Test of the New CN Correction Algorithm
Teste do Novo Algoritmo de Correção da CN

- Steep-sloping watershed in the northwest of South Korea
- Area: 7.8 km²
- Mainly forested (~70%)
- Annual Precipitation: 1210 mm





(a) DEM

Source: Joh et al., 2011

Test of the New CN Correction Algorithm
Teste do Novo Algoritmo de Correção da CN

Method:

- Implementation of the different slope correction algorithms in the source code of SWAT
- Separate calibration of streamflow for every slope correction algorithm
- No calibration of the curve number (CN2)

Test of the New CN Correction Algorithm
Teste do Novo Algoritmo de Correção da CN

Evaluation statistics (2004-2006):

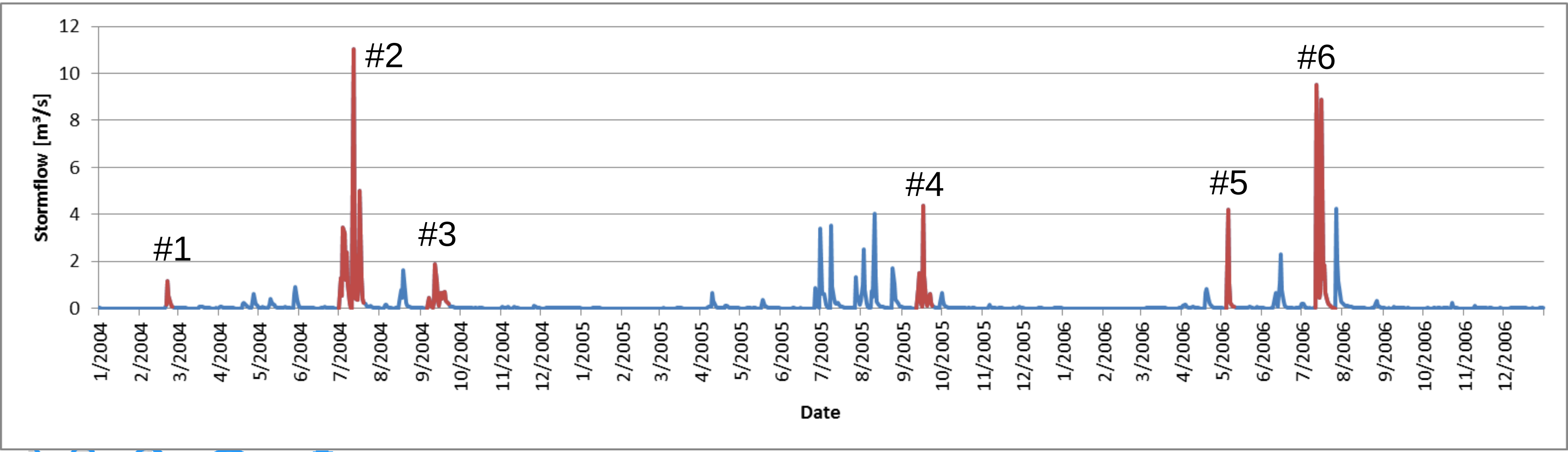
Statistical Parameter	unmodified	Williams, 1995	Huang et al., 2006	New Algorithm
R^2	0.935	0.934	0.936	0.935
NSE	0.803	0.827	0.821	0.842
RSR	0.444	0.416	0.423	0.398
PBIAS	16.28	22.85	19.66	11.18

Test of the New CN Correction Algorithm
Teste do Novo Algoritmo de Correção da CN

- Event-based validation:

  Application of a baseflow filter (Arnold & Allen, 1999)

RMSE	Event #1	Event #2	Event #3	Event #4	Event #5	Event #6
unmodified	0.0644	0.7072	0.1411	***0.1491***	0.1432	0.7267
Williams, 1995	0.0606	0.4011	0.1755	0.1990	0.1505	0.6734
Huang et al., 2006	0.0833	0.6769	0.1978	0.1519	0.1452	0.7027
New Algorithm	***0.0490***	***0.3765***	***0.1184***	0.1511	***0.1082***	***0.6120***



Conclusion
Conclusão

- A new approach for the correction of the curve number for slopes up to 100% was developed
- The newly developed slope correction for the curve number yields solid results for a steep-sloping Korean watershed
- Additional tests of the algorithm in other mountainous catchments towards its general applicability necessary
- Further improvement and validation of the algorithm can be supported by field experiments
- The water balance on steep slopes in SWAT behaves not always plausibly
- The development of this algorithm is a step towards better representation of landscape processes in SWAT

Thank you for your attention!

Muito obrigado por sua atenção!

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