Joint FAO/IAEA Programme

Assessment of soil erosion using nuclear techniques

E. Fulajtar

Typical soils of loess hilly lands in Western Slovakia

(Soil classification according to WRB, 1994)

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Luvi-Haplic Chernozem

Calcic Luvisol

Calcaric Regosol

O r i g i n a l s o i l s

Final stage of erosion

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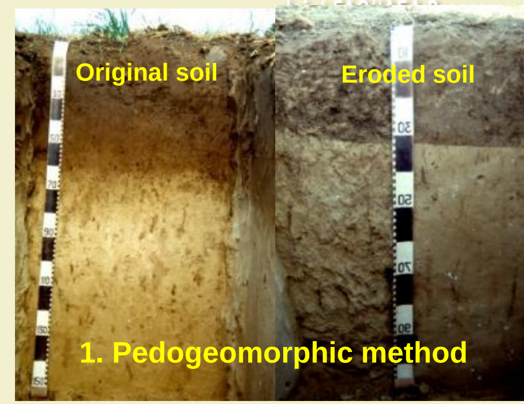
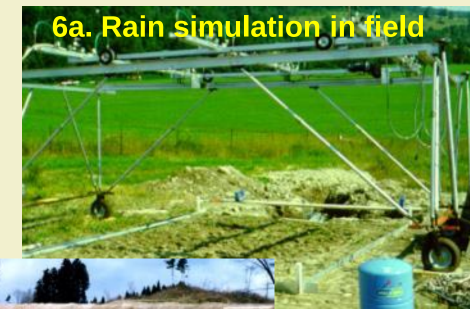
Tunnel erosion

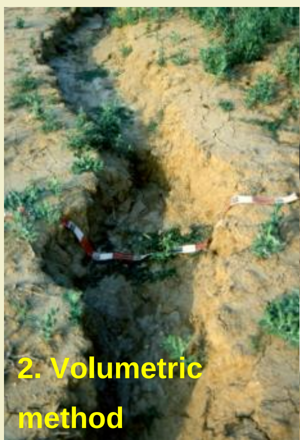
Fallout radionuclide methods used in soil erosion research

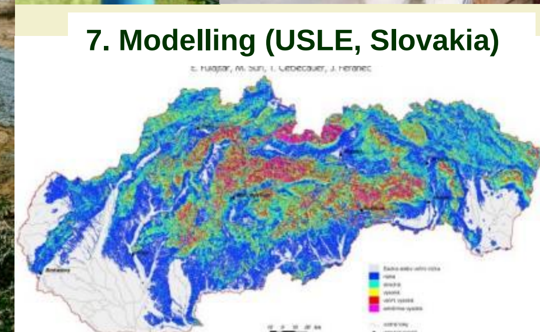
Methods for soil erosion assessment

Pedomorphic method (estimation based on the changes of soil horizonation)
Volumetric method (measuring the volume of rills and gullies).
Geodetic method (measuring the changes in soil surface as referred to stable points).
Erosion measurements at experimental plots (total collection of soil sediments)
Hydrological methods (suspended sediment load)
Rain simulation (use of artificial rainfall to create erosion: a) in field, b) in laboratory)
Erosion models (USLE, EPIC, WEPP, EUROSEM …)
Fallout radionuclide methods (^{137}Cs, ^{210}Pb, ^{7}Be)







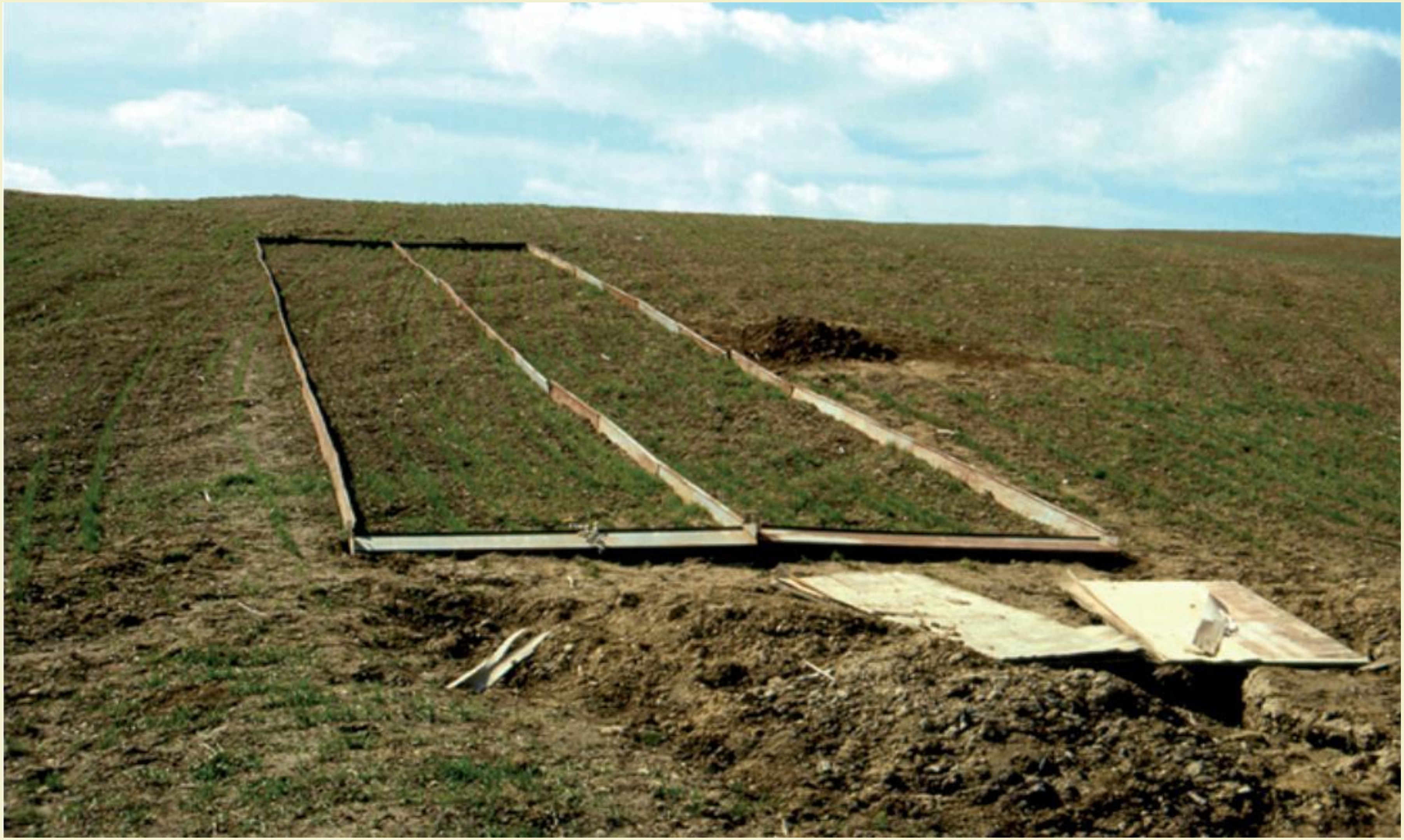


8. Fallout radionuclide methods

Direct measurement of erosion rates and sediment accumulation

- surveying methods
- erosion plots
- indirect methods (e.g. suspended sediment monitoring)
- nuclear techniques

Erosion plots



Hydrological profile with suspended sediment sampler

Erosion plots (Japan)

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Erosion pins

measure soil accumulation or loss along pins

precision low: ± 1 mm => 12 t ha^{-1}

point values

Rainfall simulation

reproduces impact of natural rain with known KE

control on experimental conditions

investigate quickly varied systems

limitation of slope length

Field rain simulator

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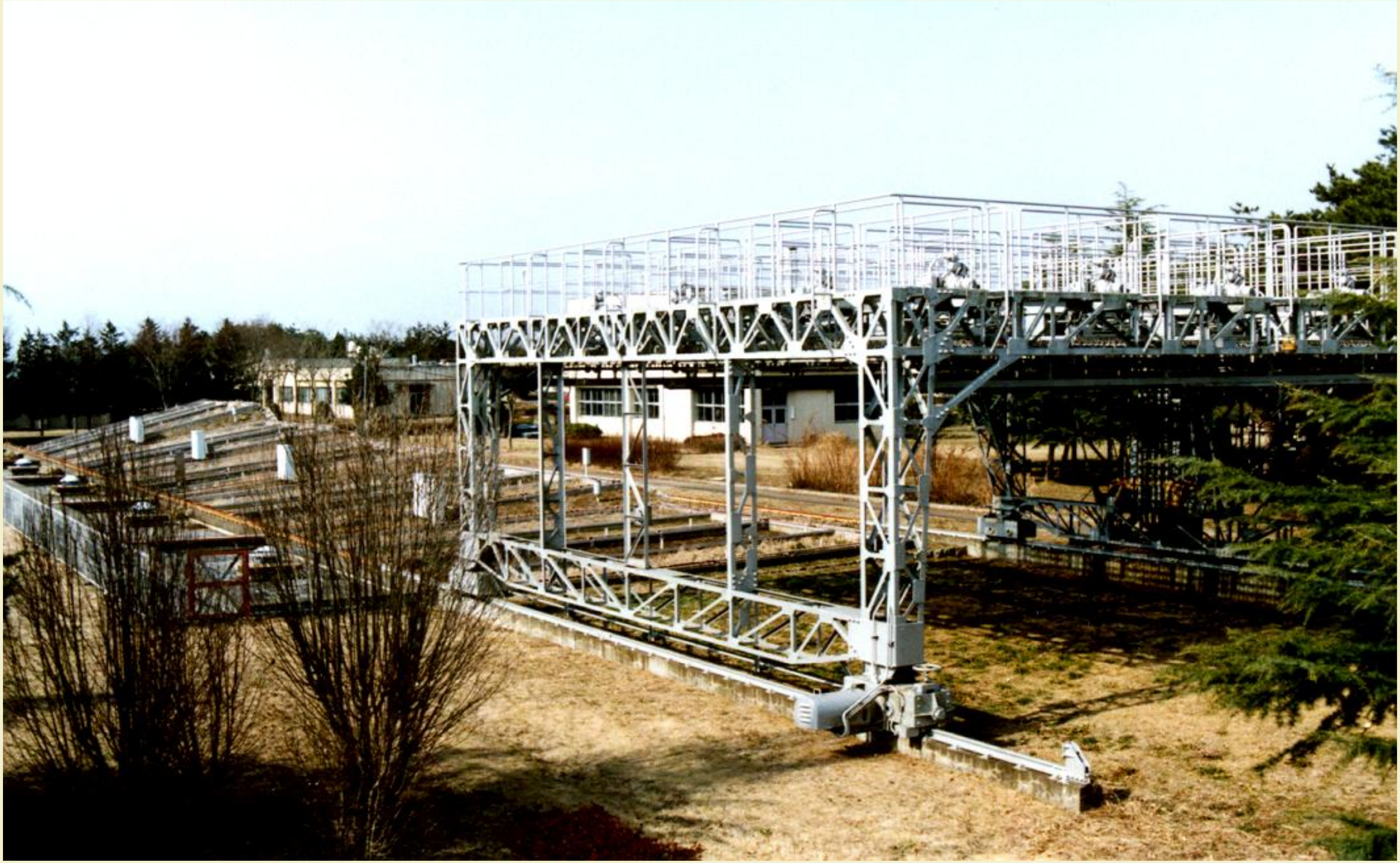


Laboratory rainfall simulator

Fallout radionuclide methods

Origin of fallout radionuclides

^{137}Cs (half-life of 30.2 years) originated from (a) atmospheric bomb tests (fallout from 1954 to mid-1980s with peak in 1963) and from (b) the Chernobyl power plant accident in 1986.

^{210}Pb (half-life of 22.8 years) has geogenic origin. It is a product of ^{222}Rn decay taking part in both soilscape and atmosphere. ^{210}Pb originating in atmosphere deposits on land surface and enriches the soil upper layer ($^{210}Pb_{ex}$)

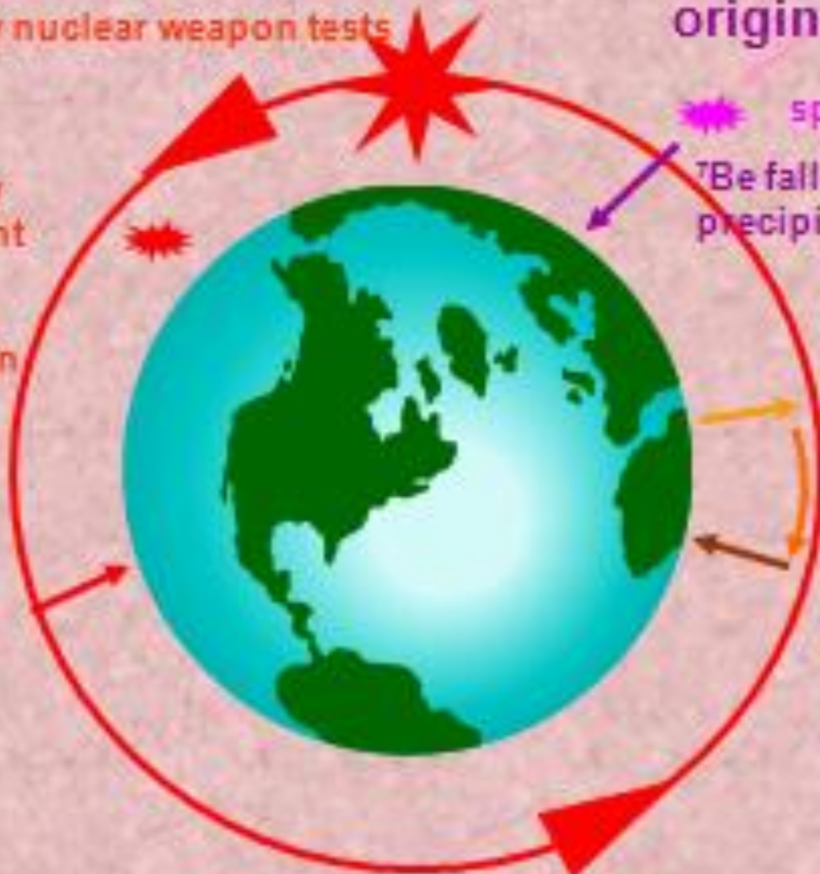
^{7}Be (half-life of 53,3 days) is a cosmogenic radionuclide produced by the bombardment of the atmosphere by cosmic rays causing spallation of O and N atoms.

Overview of Environmental Radionuclides

Radionuclide	Origin	Half-life	Emission	Energy
^{7}Be	Natural: cosmogenic	53 days	Gamma (10,3)	477 keV
^{134}Cs	Artificial: Chernobyl	250 days	Gamma (98,0)	604 keV
^{210}Pb	Natural: geogenic	22 years	Gamma (4,06)	46 keV
^{137}Cs	Artificial: Atmosferic bomb tests and Chernobyl	30 years	Gamma (85,0)	661 keV
^{239}Pu	Artificial: Atmosferic bomb tests	24000 years	Alfa	
^{90}Sr	Artificial: Atmosferic bomb tests			

Origin of fallout radionuclides (FRN)

Three radionuclides (^{137}Cs, ^{210}Pb and ^{7}Be) falling with precipitation from atmosphere (hence termed "fallout radionuclides") can be used to measure the soil erosion rates



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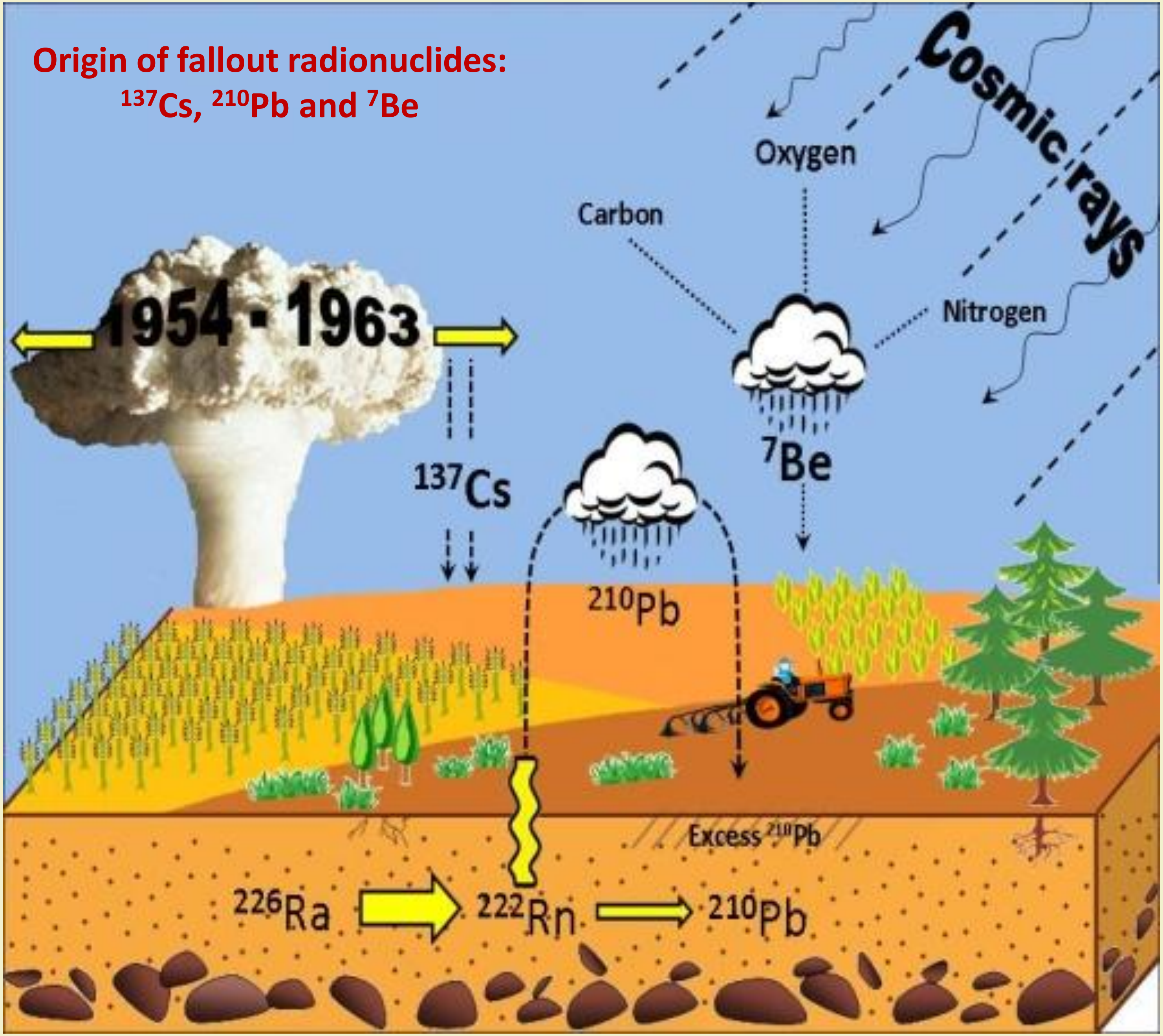
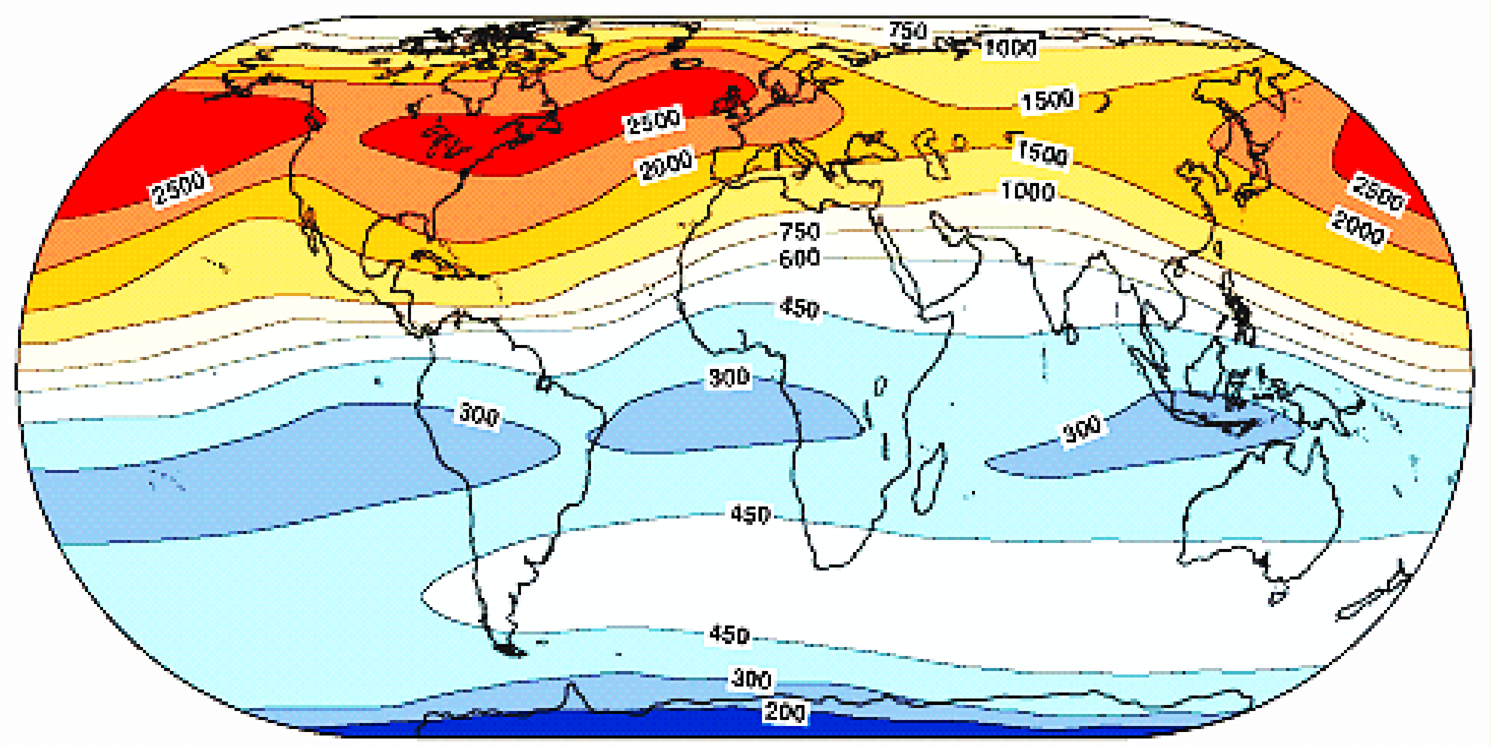
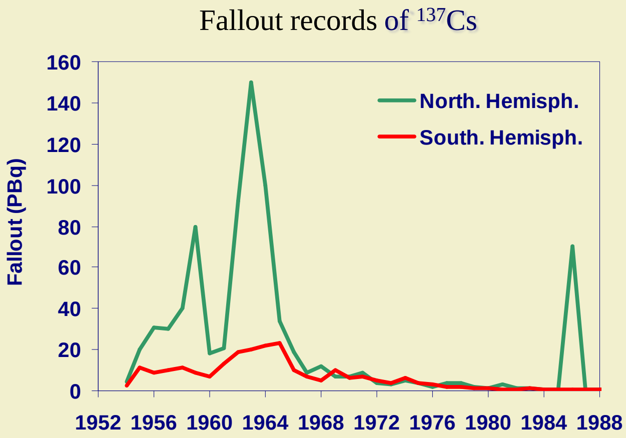
Origin of fallout radionuclides: ^{137}Cs, ^{210}Pb and ^{7}Be



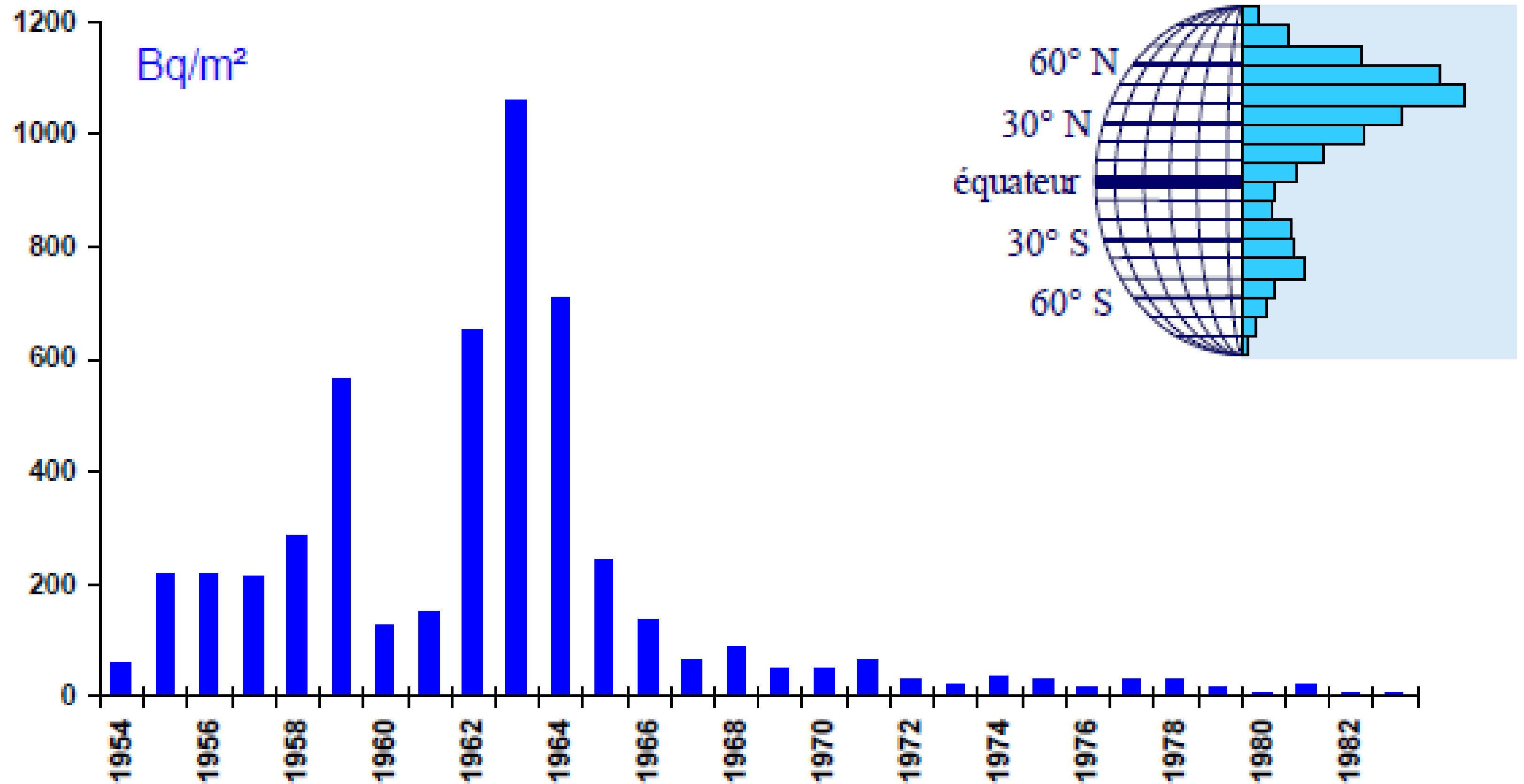
Global distribution of bomb-derived ^{137}Cs





Fallout Radionuclides: atom bomb testing

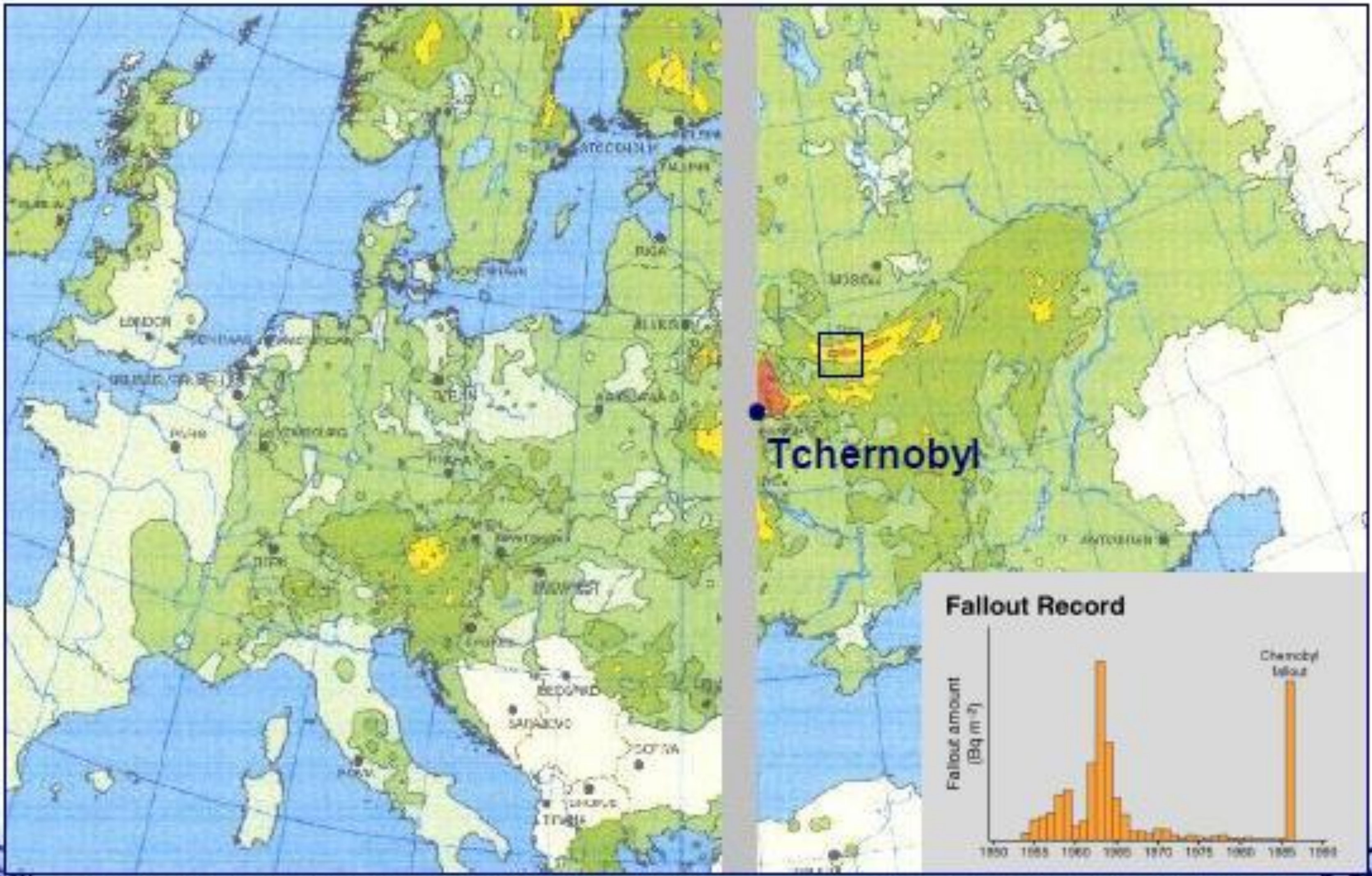
Global fallout (clear time-scale)



(Playford et al., 1990)

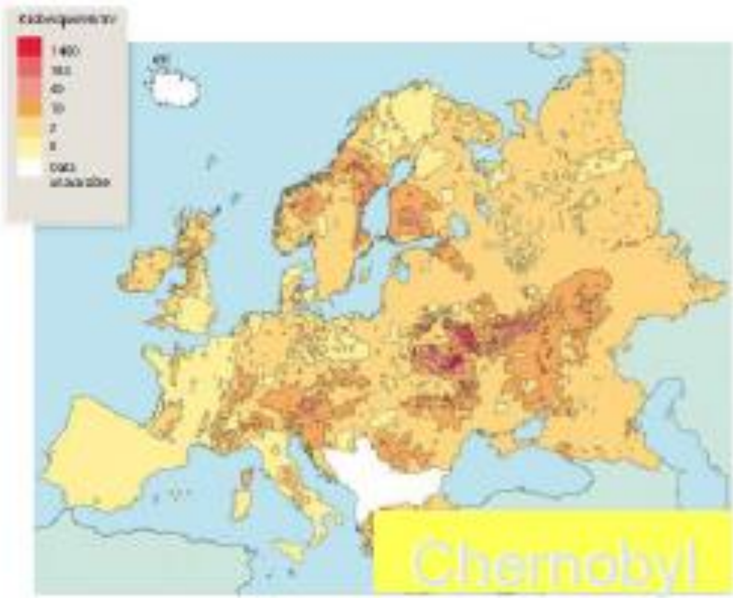
Fallout radionuclides: Chernobyl accident

Clear time-scale, regional, and spatially heterogeneous



Geographical distribution and spatial variability of radionuclide deposition

Regional scale → Local scale → Field scale



Map of caesium-137 deposits over Europe immediately after the Chernobyl accident (source: European Atlas EC/IGCE 1998 and IRSN). No data is available for the Balkans.

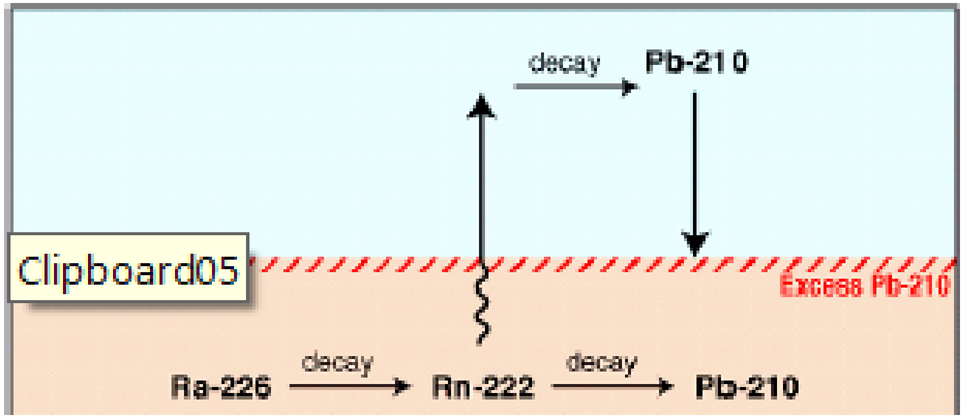
Source: European Atlas EC/IGCE 1998 and IRSN

As of April 29 2011;
Source: MEXT and DOE

Origin of ^{210}Pb and ^{7}Be

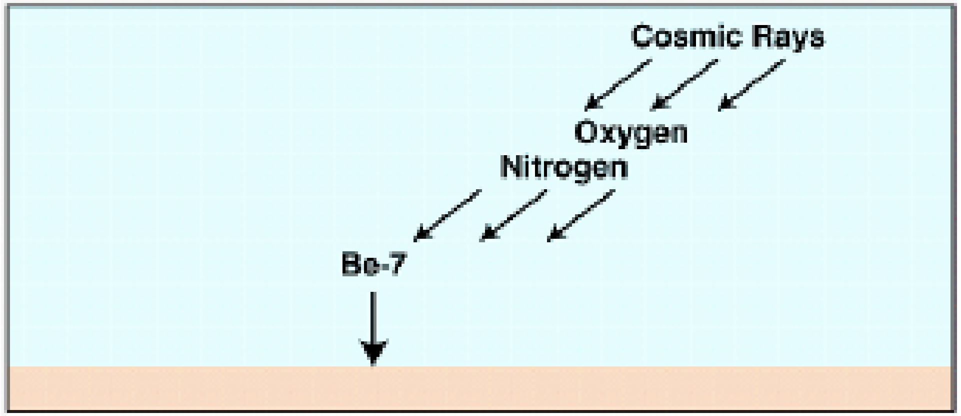
Half-life: 22.3 years

Origin: Natural geogenic



Half-life: 53.3 days

Origin: Natural cosmogenic

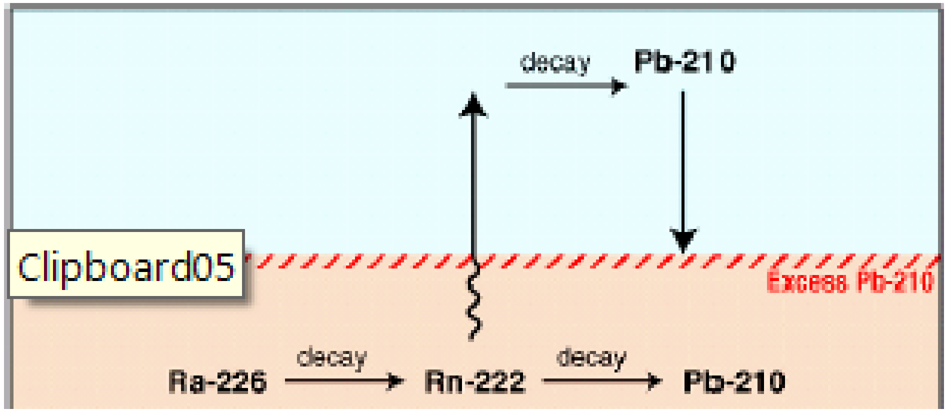


Walling, 2004

Origin of ^{210}Pb and ^{7}Be

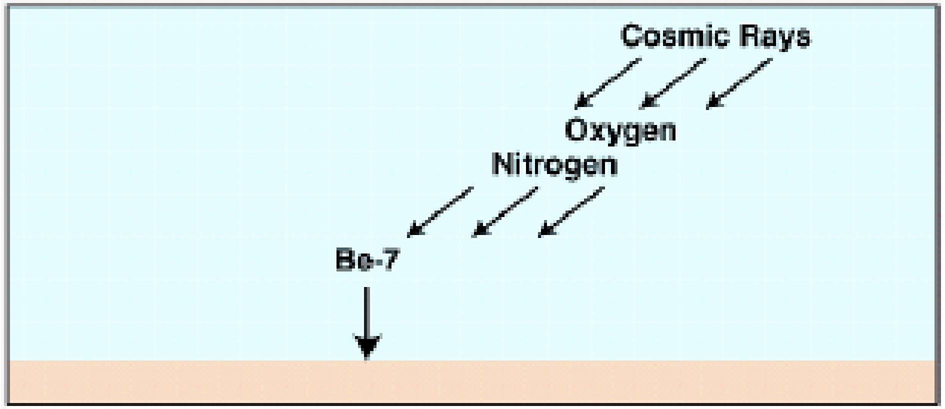
Half-life: 22.3 years

Origin: Natural geogenic



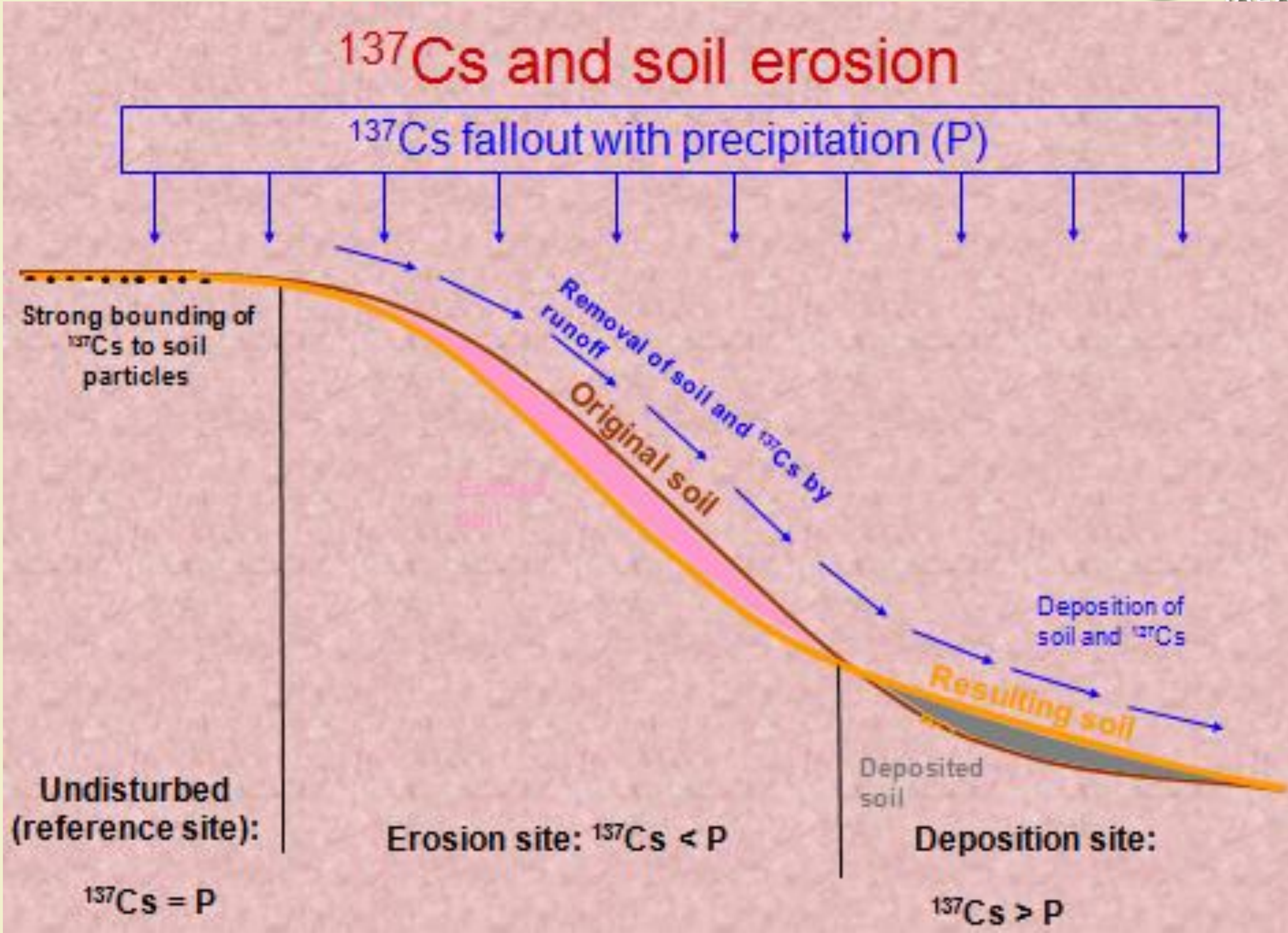
Half-life: 53.3 days

Origin: Natural cosmogenic

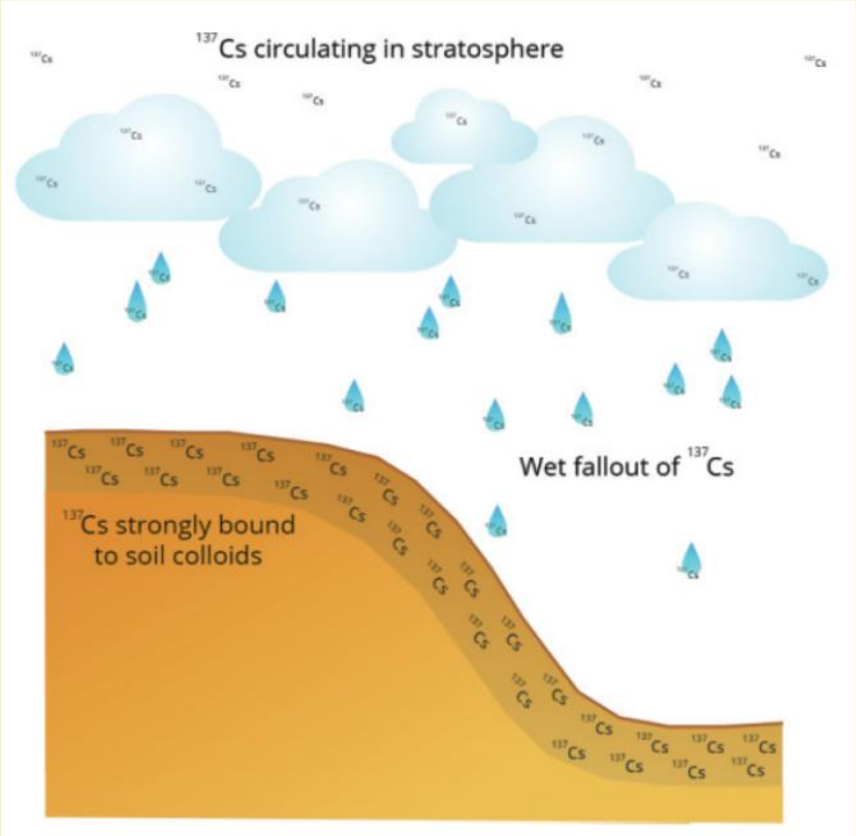


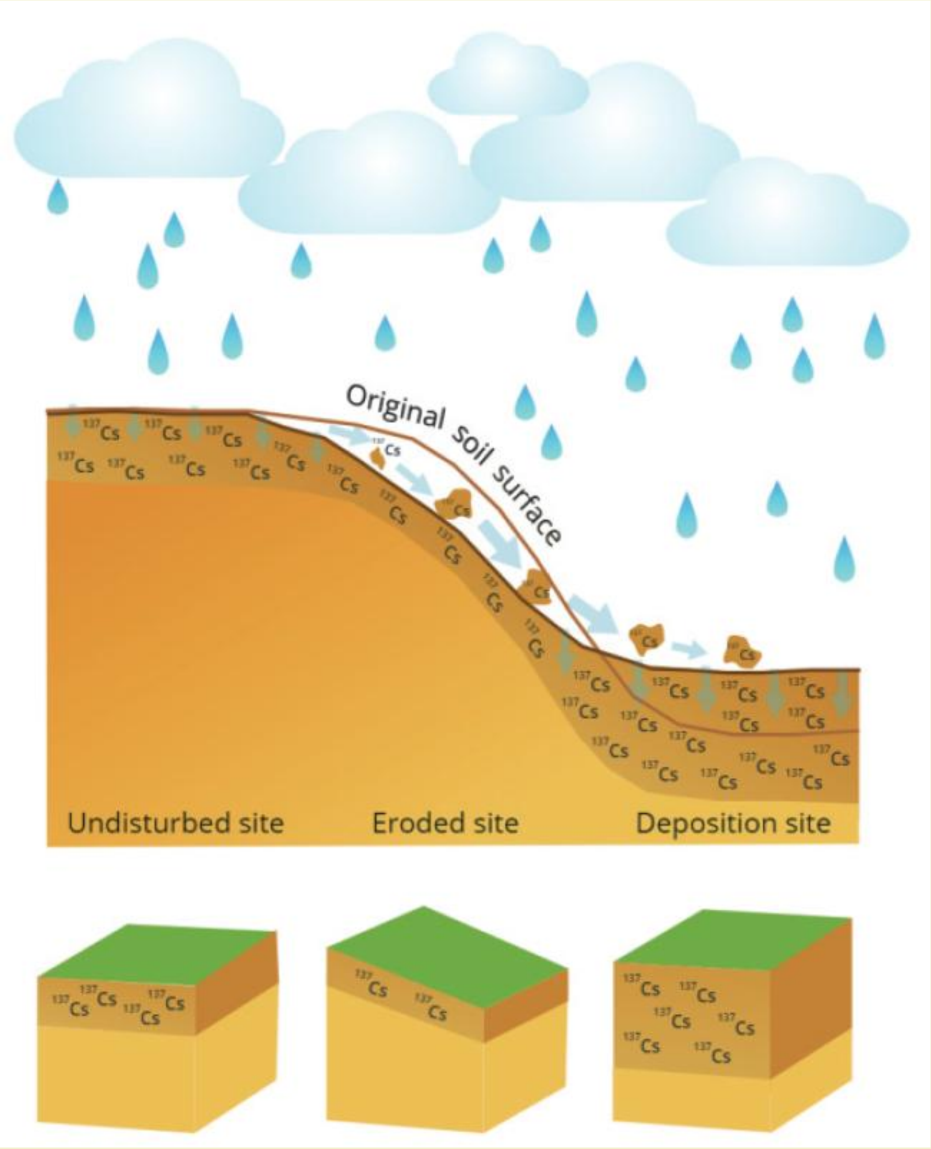
Walling, 2004

Principle of ^{137}Cs method

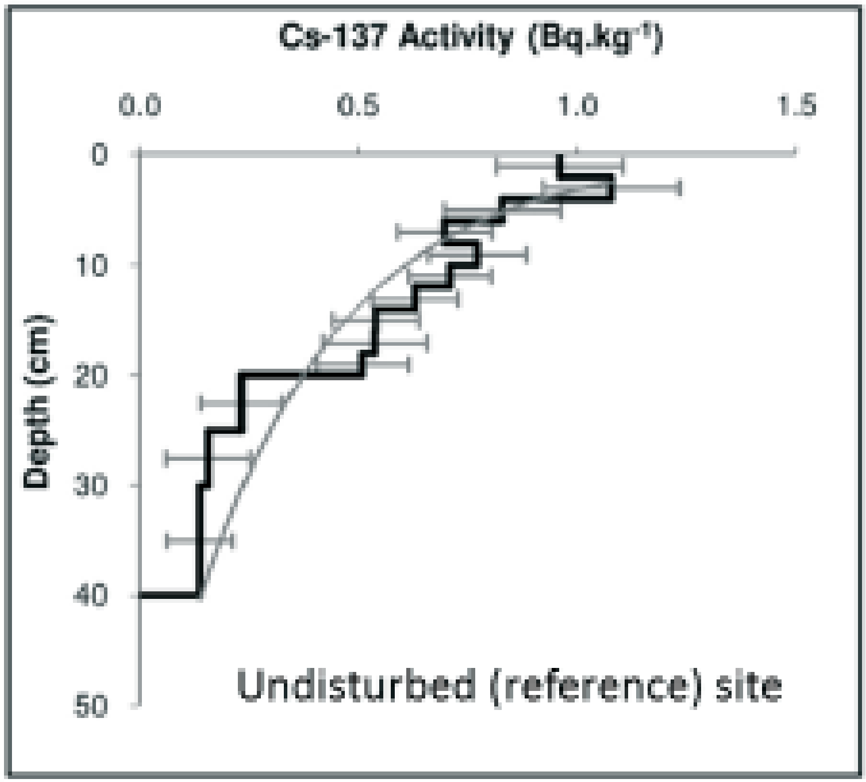


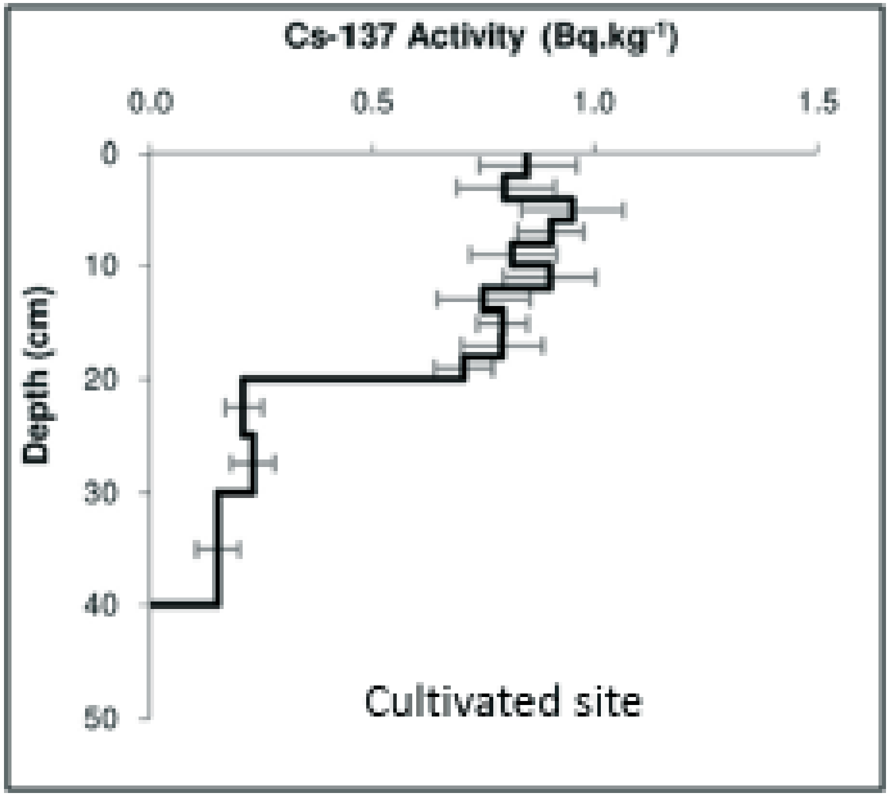
Principle of ^{137}Cs method



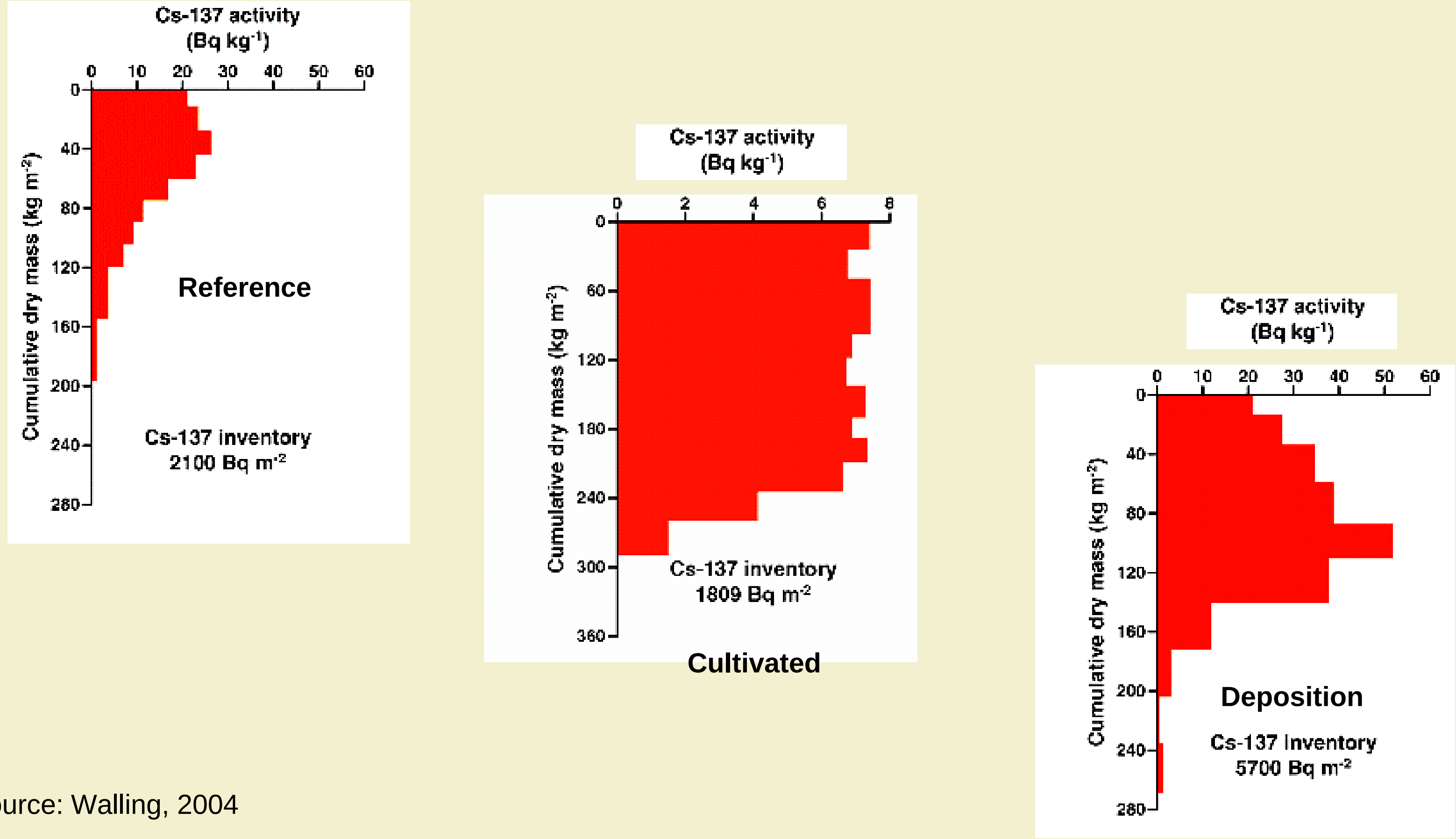


Depth distribution of ^{137}Cs method





Distribution of ^{137}Cs in soils



Source: Walling, 2004

Soil sampling for FRNs determination

Recording of site and sample information

Sampling approach

The depth incremental sampling (Bq kg^{-1})

The bulk sampling (Bq m^{-2})

Sample distribution

Single transects

Multiple transects

Regular grid

Irregular grid

Incremental depth sampling using the mechanical core sampler

Principle of ^{137}Cs method

Bulk core sampling for ^{137}Cs method

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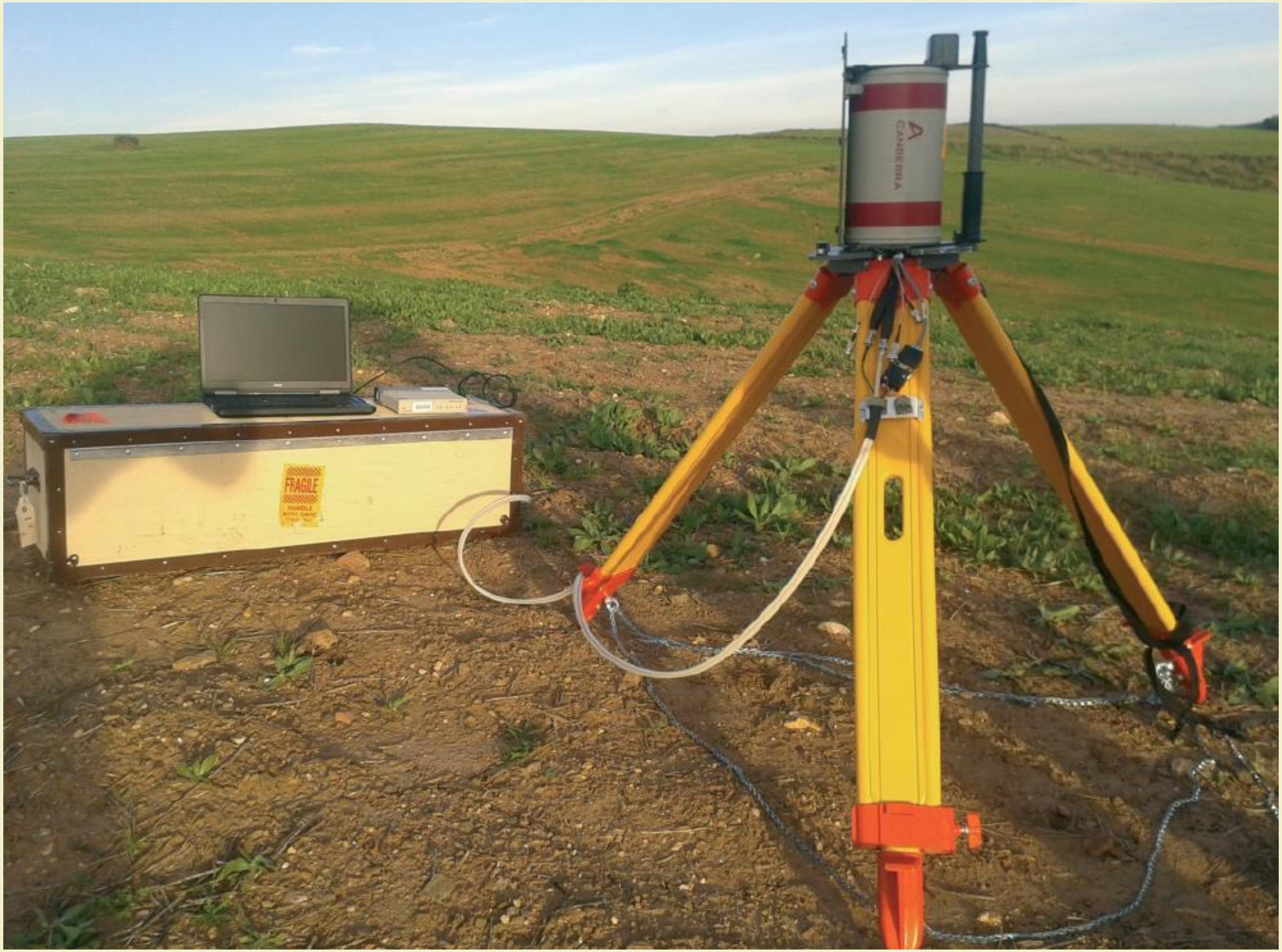
Depth incremental sampling (scraper plate)

Source: Li, 2004

In situ measurements of ^{137}Cs method using portable gamma detector



Sample preparation

Air drying, grinding and sieving

Weighting and bulk density determination

Sample measurement

Laboratory measurement using HPGe gamma spectrometry. Low background shielding

Use of appropriate software for data acquisition

Quality assurance/ quality control

Stability of detectors background

Stability of detector efficiency and calibration

Participation on inter-comparison exercises

FRNs determination

The deposited ^{137}Cs, ^{210}Pb, and ^{7}Be can be measured using the Gamma-ray spectrometry

The FRN quantity can be expressed as concentration (Bq kg^{-1}) or as total inventory or total areal activity (Bq m^{-2})

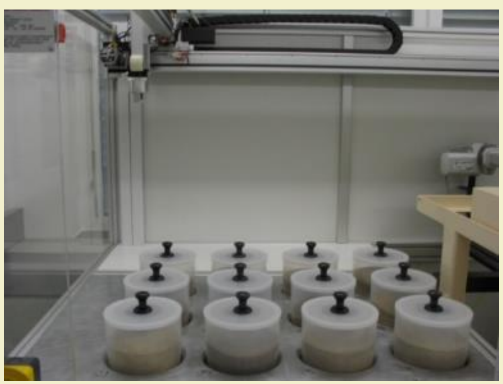
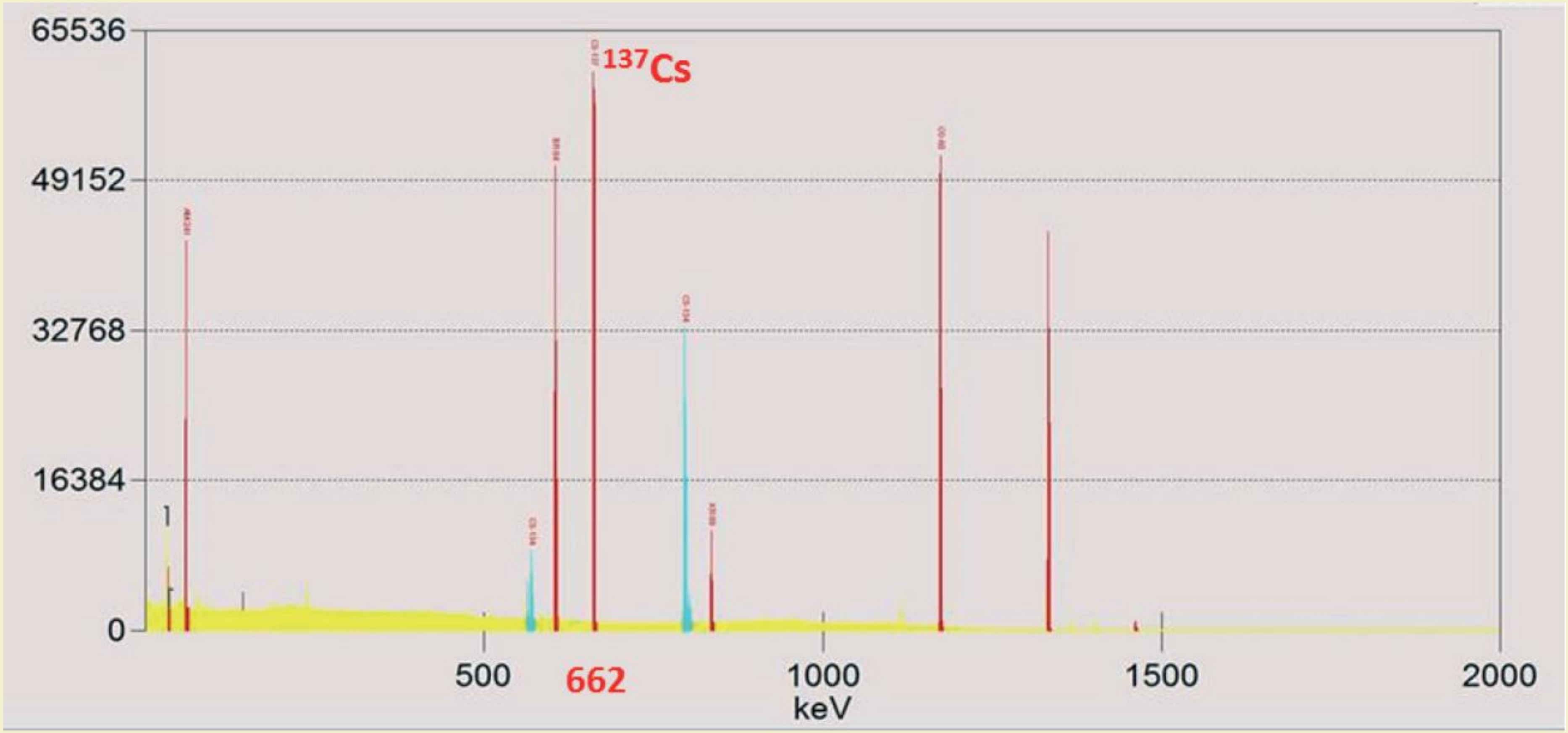


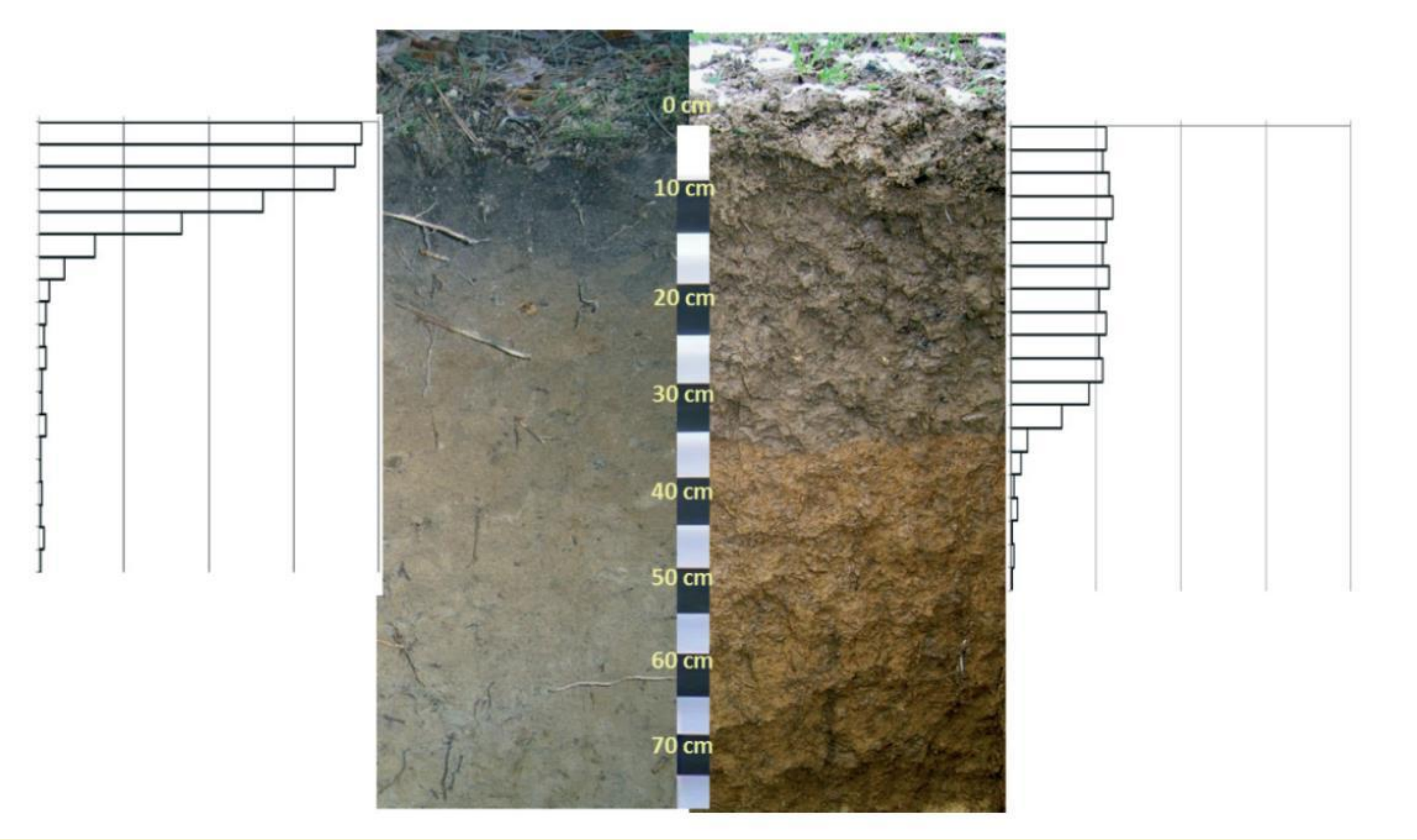
Fig 2. Gamma spectrometer, Soil Science Unit, IAEA Laboratories, Seibersdorf

Measurements of ^{137}Cs



Principle of FRN conversion models:

- Models for non-cultivated land
- Models for cultivated land



Determination of soil erosion rates with aid of conversion models

Models for cultivated sites:

- Proportional model
- Simplified mass balance model
- Standard mass balance model
- Tillage mass balance model

Models for non-cultivated sites:

- Depth distribution model
- Incremental model

MODELS INCLUDED IN THE SOFTWARE

- **Cs-137**
  - **Proportional model**
  - **MBM1, MBM2, MBM3**
  - **Profile distribution model**
  - **Diffusion and migration model**
- **Excess Pb-210**
  - **MBM2, MBM3**
  - **Profile distribution model**
  - **Diffusion and migration model**
- **Be-7**
  - **Profile distribution model**

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Conversion models (Walling et al., 2005)

Proportional Model

$$Y = \frac{Bd\left(100\frac{Ar - A}{Ar}\right)}{10TP}$$

Y - mean annual soil loss (t ha^{-1} y^{-1})
B - soil bulk density (kg m^{-3})
d - plow depth (m)
Ar - reference ^{137}Cs inventory (Bq m^{-2})
A - ^{137}Cs inventory of eroded point (Bq m^{-2})
T - time since the beginning of ^{137}Cs fallout (y)
P - particle size parameter

Model hypothesis :

- ^{137}Cs fallout is completely mixed within the cultivation layer
- Soil loss is directly proportional to the amount of ^{137}Cs removed from the soil profile since the beginning of the fallout

Advantages :

- Simple to use, needs only tillage depth and ^{137}Cs inventories

Limitations :

- Overestimates erosion if fallout is removed before being incorporated in the soil profile
- Underestimates erosion by not accounting for gradual dilution of ^{137}Cs concentration by incorporation of subsoil

Proportional model

$$Y = \frac{Bd\left(100\frac{Ar - A}{Ar}\right)}{10TP}$$

- ***Y*** - mean annual soil erosion rate (t ha-1 rok-1),
- ***B*** - soil bulk density (kg m-3),
- ***d*** - thickness of plowed horizon (m),
- ***Ar*** - reference 137Cs inventory (Bq m-2),
- ***A*** - 137Cs inventory of investigated point (Bq m-2),
- ***T*** - 137Cs fallout time (year),
- ***P*** - particle size factor for eroded point
- ***P'*** - particle size factor for accumulated point

Mass Balance Model I

$$Y = \frac{10Bd}{P}\left[1-\left(1-\frac{Ar-A}{Ar}\right)^{\frac{1}{t-1963}}\right]$$

Model hypothesis :

- ^{137}Cs fallout occurred entirely in 1963
- progressive reduction of ^{137}Cs in the soil of the plow layer due to loss by erosion and incorporation of subsoil

Advantages :

- easy to use, requires few parameters
- considers the gradual inclusion of ^{137}Cs poor soil material in the plow layer

Limitations :

- considers all fallout occurred in 1963
- does not consider potential removal of fresh fallout before incorporation in the soil

Y - mean annual soil loss (t ha^{-1} y^{-1}),
B - soil bulk density (kg m^{-3}),
d - plow depth (m),
Ar - reference ^{137}Cs inventory (Bq m^{-2}),
A - ^{137}Cs inventory of eroded point (Bq m^{-2}),
t - time of ^{137}Cs sampling (y),
P - particle size parameter

Mass Balance Model II

Model hypothesis :

- ^{137}Cs fallout variable in time
- integrates fate of FRN deposition before incorporation in soil by cultivation

Advantages :

- soil redistribution estimates more realistic than with MBm1

Limitations :

- potential difficulty to establish the value of some parameters

$$y = \frac{(1-\Gamma)I(t)d}{PA(t)} - \frac{\lambda d}{P} - \frac{dA(t)d}{A(t)dt}$$

y - mean annual soil loss (t ha^{-1} rok^{-1})
Γ - proportion of deposited ^{137}Cs removed before ploughing
I(t) - annual ^{137}Cs fallout (Bq m^{-2} rok^{-1})
d - weight of lowed layer (kg m^{-2})
P - particle size factor
A(t)- total ^{137}Cs inventory *in year t* (Bq m^{-2})
λ - decay constant for ^{137}Cs (y)
t - time since the beginning ^{137}Cs fallout (y)

Mass Balance Model 2
Parameters Required

- Local Reference Inventory
- Annual fallout input record
- Year of tillage commencement
- Proportion Factor
- Relaxation depth of Initial Distribution
- Tillage Depth
- Particle Size Correction

Profile Distribution Model

- Assumes current depth distribution established in 1963
- Assumes exponential depth distribution and uses the reduction in inventory to estimate the depth of soil loss and thus the mean annual rate of soil loss
- A relatively simple model to apply

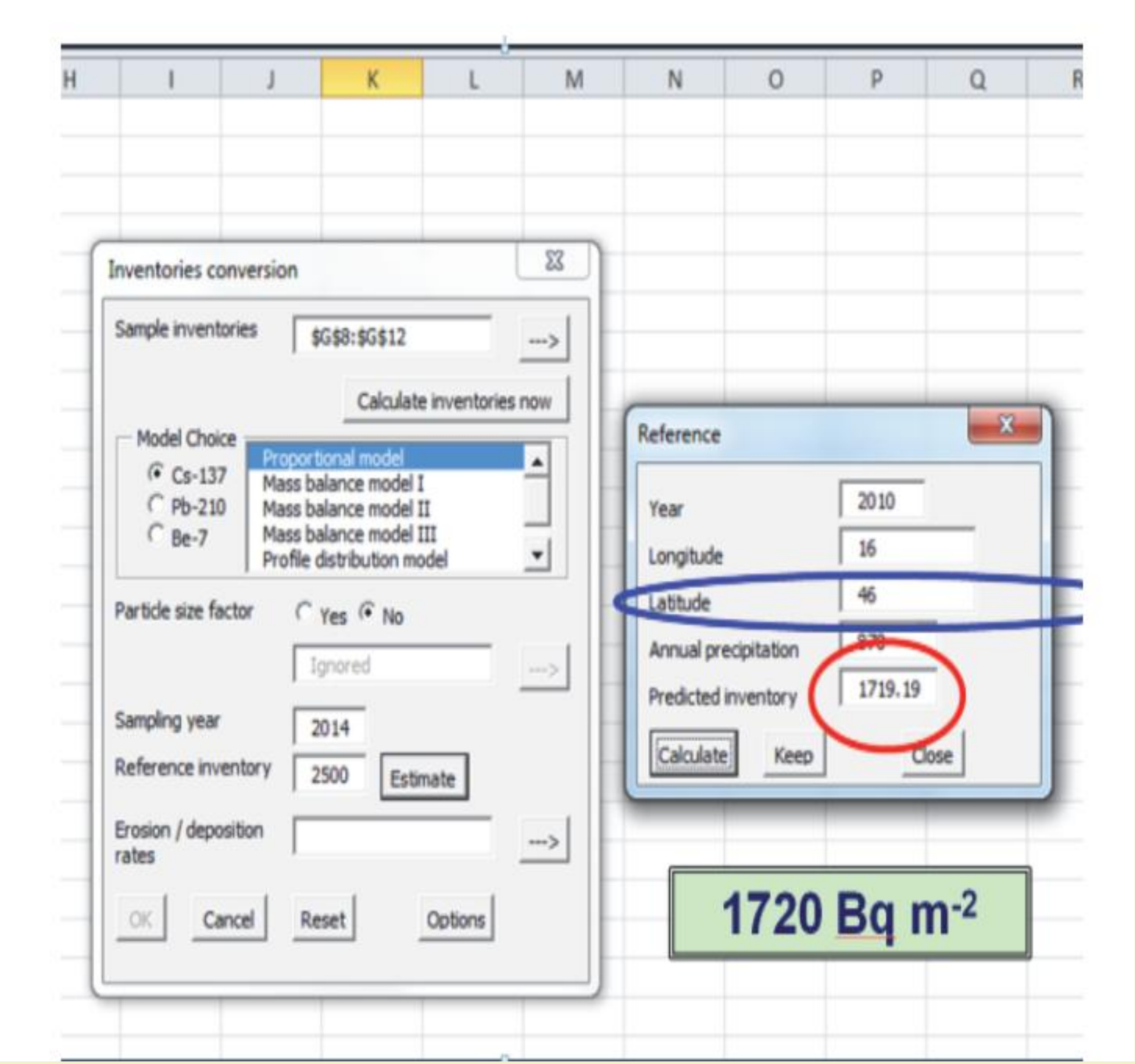
Profile Distribution Model
Parameters Required

- **Local Reference Inventory**
- **Profile shape factor – relaxation depth**

Diffusion and Migration Model Parameters Required

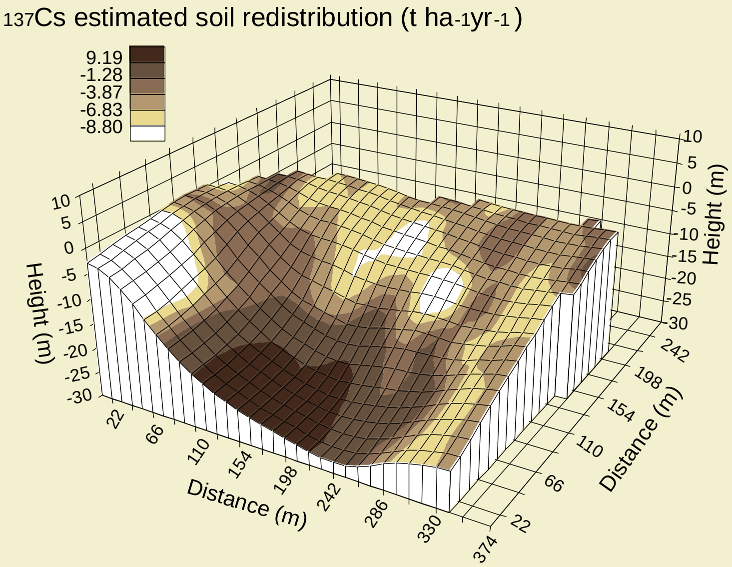
- Local Reference Inventory
- Fallout input record (synthesised)
- Diffusion and migration parameters (calculated from Cs-137 depth distribution obtained for reference site)
- Relaxation depth of Initial Distribution

Software for FRN conversion models



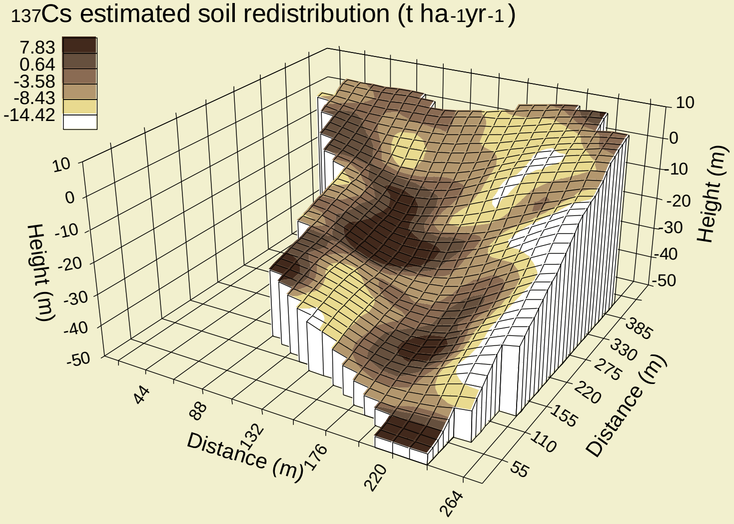
World-wide application of the ^{137}Cs technique

- Assessment of medium term rates and spatial distribution patterns of both erosion and sedimentation at the catchment scale.
- Harmonised application through two CRPs.



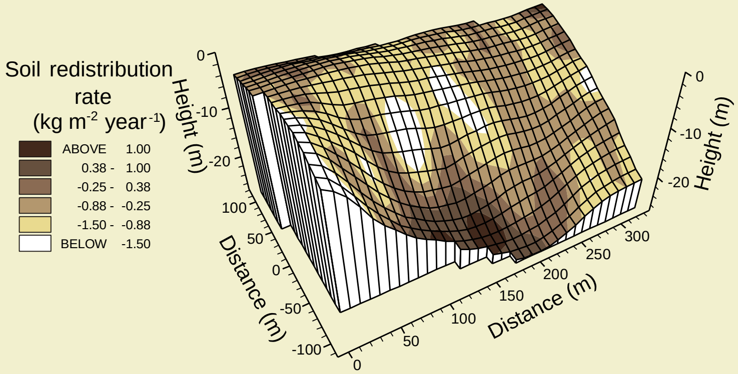
Harmonising the ^{137}Cs technique

- Assessment of medium term rates and spatial distribution patterns of both erosion and sedimentation at the catchment scale.
- Harmonised world-wide application through two CRPs



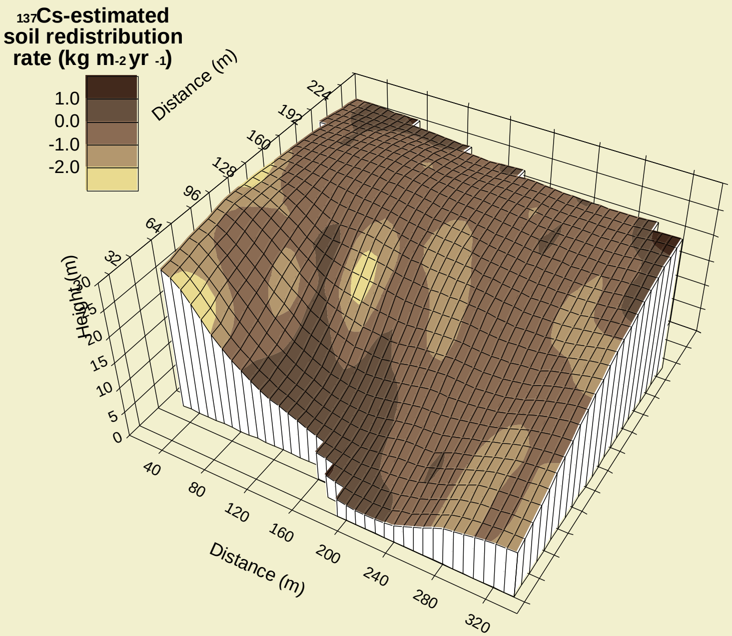
The ^{137}Cs technique

- Assessment of medium term soil erosion and deposition rates as well as spatial distribution patterns at the catchment scale.
- Harmonised worldwide application through two CRPs.



Measuring soil erosion and sedimentation

- The ^{137}Cs technique provides medium term soil erosion and sedimentation rates as well as their spatial distribution patterns at the catchment scale.
- Harmonised world-wide application through two CRPs



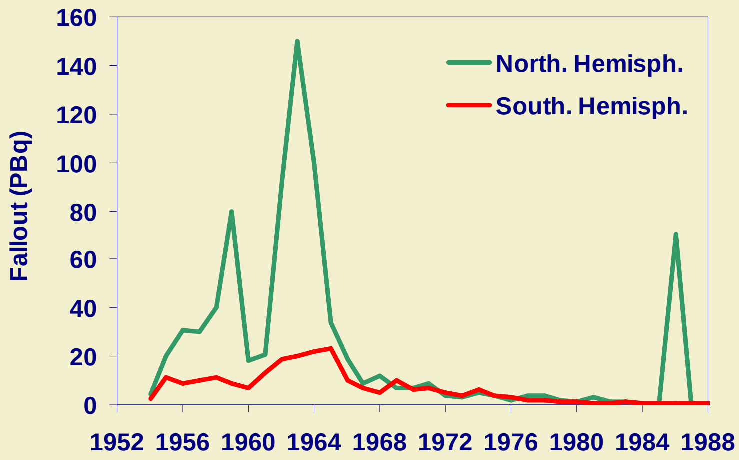
Sediment dating

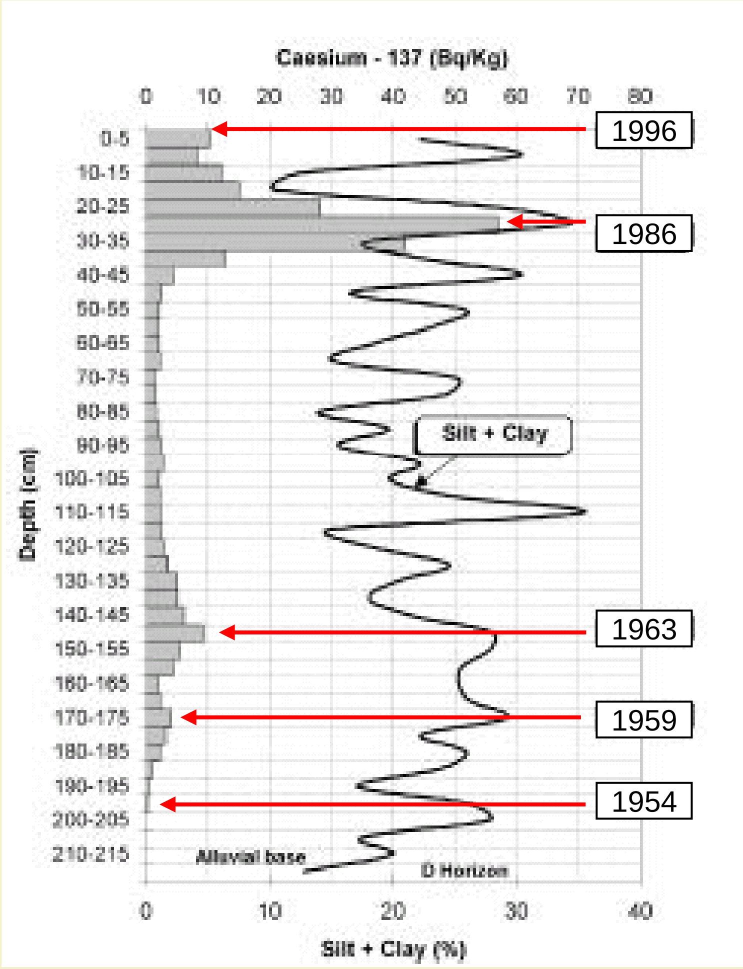
Radio-isotope content

Chemical composition

Magnetic properties

Mixing models



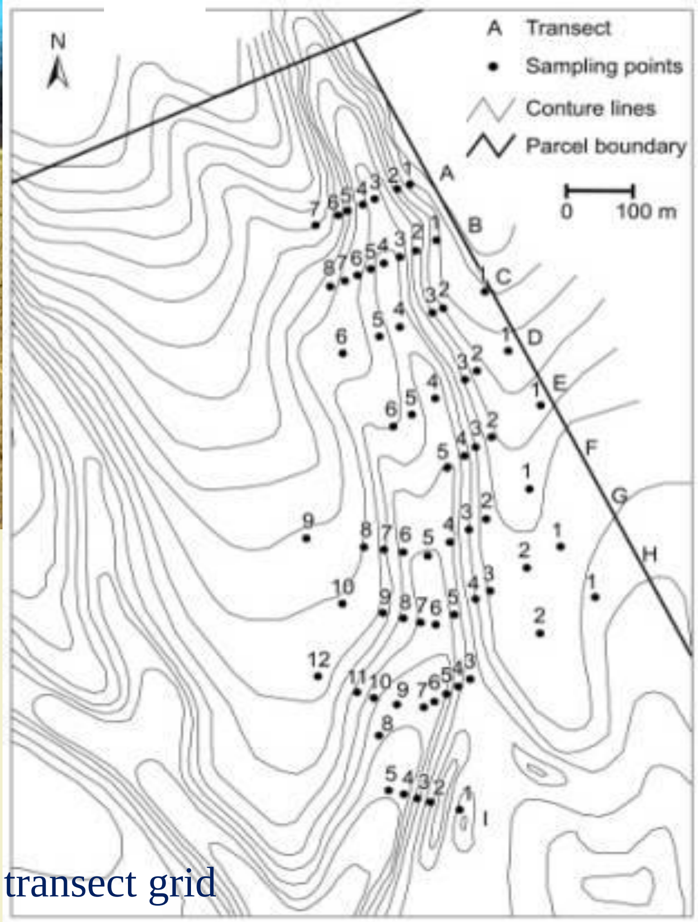


Ionita and Margineanu, 2000

Soil redistribution inventorz at plot scale at Bohunice site, Slovakia

Emil Fulajtar

Results from Bohunice site



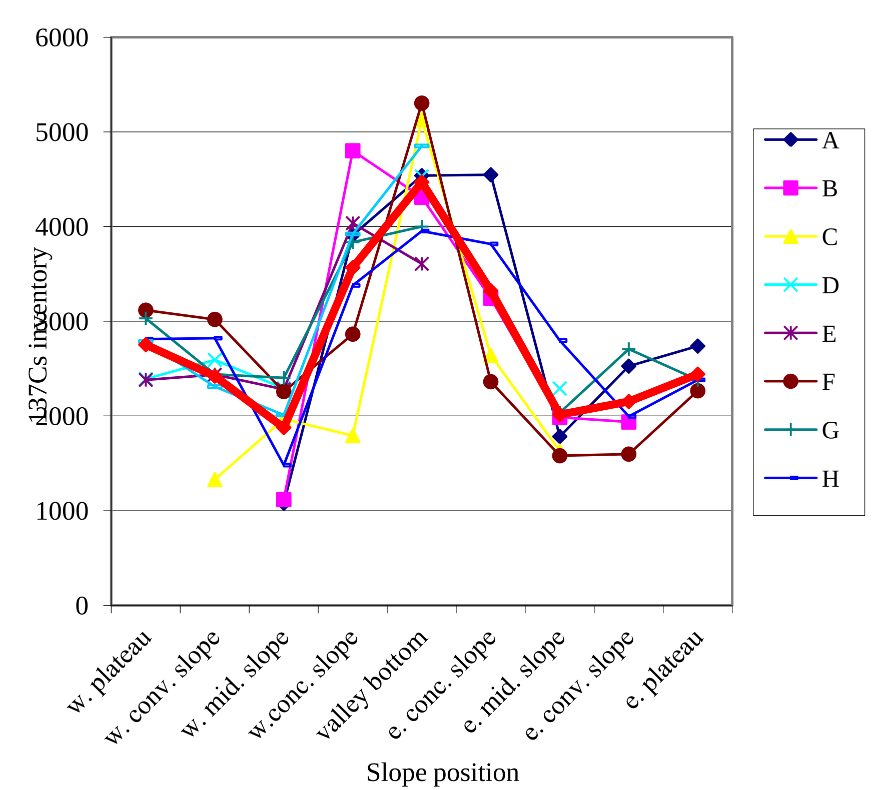
Multiple transect grid

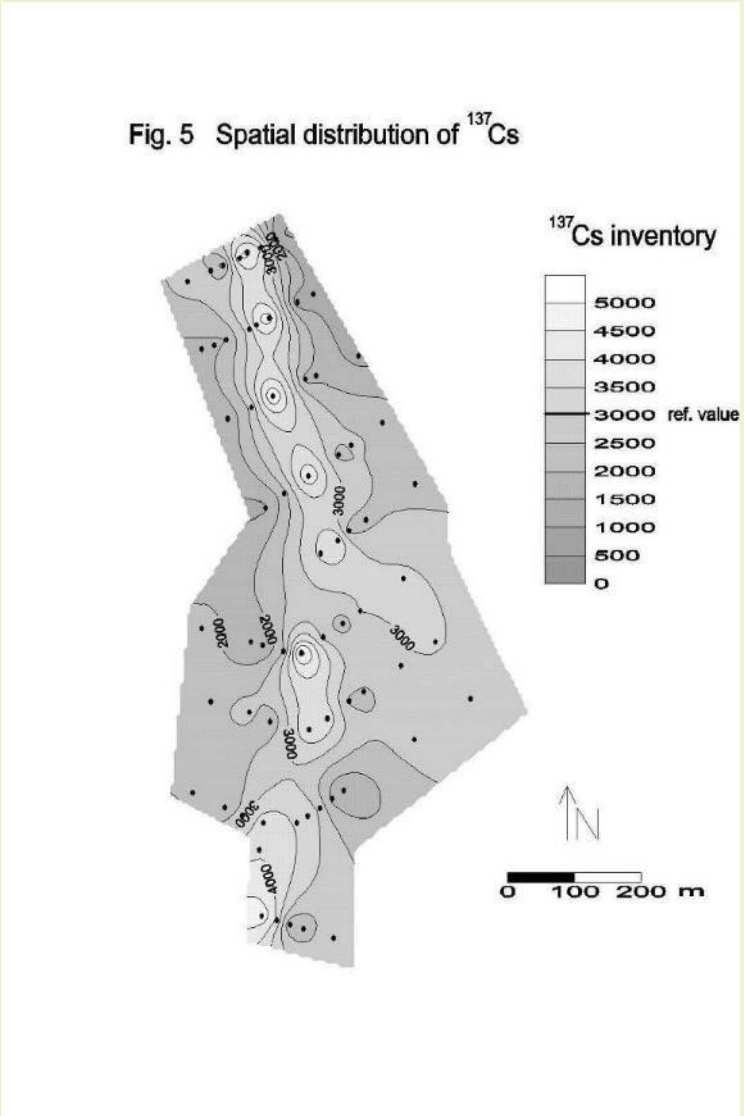
Tab. 12. Jaslovské Bohunice - Erosion and deposition rate calculated by
selected calibration models

Sample point	Position	^{137}Cs activity (Bq.kg^{-1})	Soil erosion - deposition (t.ha^{-1}.year^{-1})		
			Proportional model	Mass ballance model I	Mass ballance model II
Transect A					
A1	ESS	2455,7	- 20,67	- 28,88	- 9,01
A2	VB	4615,7	58,08	88,96	24,18
A3	WCcS	3932,0	33,15	50,77	15,98
A4	WSS	2038,8	- 35,89	- 54,59	- 17,56
A5	WCvS	2069,9	- 34,75	- 52,50	- 16,84
A6	WP	2989,8	- 1,11	- 3,30	- 0,90
Transect B					
B1	VB	4490,7	53,52	70,32	22,75
B2	WSS	2898,0	- 4,56	- 5,88	- 1,80
B3	WCvS	2762,4	- 9,50	- 12,55	- 3,85
B4	WP	2687,9	- 12,13	- 14,50	- 8,20
Transect C					
C 1	ECvS	1078	-64,34	-127,06	-94,23
C 2	ESS	3910	29,34	59,26	42,21
C 3	VB	4539	50,15	101,28	72,14
C 4	WCcS	4548	50,45	101,88	72,57
C 5	WSS	1783	-41,02	-65,51	-41,90
C 6	WCvS	2526	-16,44	-22,40	-12,81
C 7	MP	2738	-9,43	-12,36	-6,90
C 8	ESTV	2182	-27,82	-40,57	-24,31
C 9	TVB	2836	-6,19	-7,97	-4,41
C 10	WSTV	3063	1,32	2,24	1,45
C 11	WP	2979	-1,46	-1,83	-1,00
Transect D					
D 1	ECvS	1538	-49,12	-83,68	-56,07
D 2	ESS	1117	-63,05	-122,75	-90,19
D 3	ECcS	4801	58,82	110,33	75,38
D 4	VB	4310	42,57	79,86	54,56
D 5	WCcS	3244	7,31	13,71	9,37
D 6	WSS	3226	6,72	12,60	8,61
D 7	WCvS	1936	-35,96	-55,36	-34,48
D 8	MR	1910	-36,82	-57,03	-35,67
D 9	ESTV	1409	-53,39	-94,42	-64,97
D 10	TVB	3150	4,20	7,40	4,88
D 11	WSTV	1733	-42,67	-69,01	-44,54
D 12	WP	2630	-13,00	-17,37	-9,82
Transect E					
E1	ECvS	1328	-56,07	-101,66	-71,19
E 2	ESS	2967	-1,85	-2,34	-1,28
E 3	ESS	1797	-40,56	-64,55	-41,18
E 4	VB	2502	-17,23	-23,58	-13,53
E 5	WSS	2641	-12,64	-16,85	-9,51
E 7	ESTV	2744	-9,23	-12,09	-6,74
E 8	TVB	3666	21,27	34,61	21,82
E 9	WSTV	3059	1,19	1,94	1,22
E 10	WP	3812	26,10	42,47	26,77
Transect F					
F1	EP	2391	-20,91	-29,22	-17,01
F2	ECvS	2593	-14,22	-19,14	-10,86
F3	ESS	2292	-24,18	-34,47	-20,34
F4	VB	4532	49,92	70,14	39,95
F5**	WSS	2290	-24,10	-34,46	-20,20
F6**	MR	1424	-52,96	-93,09	-63,86
F7	ESTV	2117	-29,97	-44,31	-26,82
F9	WSTV	2081	-31,16	-46,43	-28,26
F10	WP	1931	-36,12	-55,68	-34,71
Transect G					
G1	EP	2381	- 23,39	- 33,14	- 10,39
G2	ECvS	2436	- 21,39	- 29,98	- 9,37
G3	ESS	2281	- 27,04	- 39,08	- 12,33
G4	ECcS	4036	36,95	52,93	20,14
G5	VB	3608	21,32	30,54	11,62
Transect K					
K1	EP	3117	3,11	4,91	3,02
K2	ECvS	3020	-0,09	-0,12	-0,07
K3	ESS	2259	-25,27	-36,27	-21,50
K4	ECcS	2864	-5,26	-6,75	-3,72
K5	VB	5304	75,45	106,96	61,31
K 6	WCcS	2362	-21,87	-30,74	-17,96
K 7	WSS	1580	-47,73	-80,38	-53,41
K 8	WCvS	1597	-47,17	-79,06	-52,36
K 9	WP	2266	-25,04	-35,89	-21,25

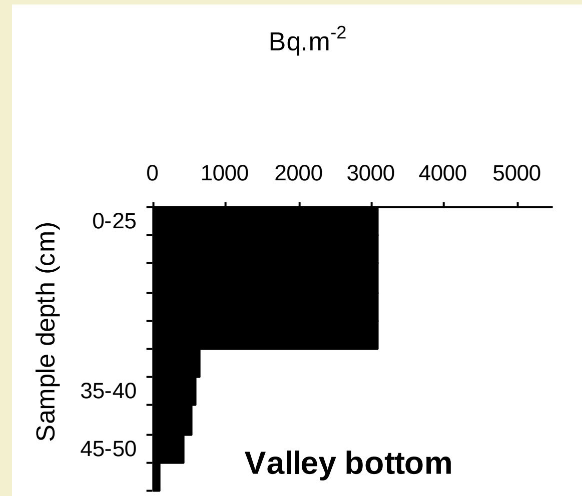
Transect H					
H1	EP	3031	0,26	0,38	0,22
H2	ECvPP	2945	-2,58	-3,27	-1,79
H3	ECvS	2440	-19,29	-26,70	-15,44
H4	ESS	2402	-20,54	-28,65	-16,65
H5	ECcS	3835	26,86	37,33	21,13
H6	VB	4000	32,32	44,92	25,42
H 8	WSS	2034	-32,72	-49,26	-30,20
H 9	WCvS	2707	-10,45	-13,78	-7,72
H 10	WP	2380	-21,27	-29,79	-17,37
Transect I					
I1	EP	2812	-6,98	-9,04	-5,00
I2	ECvPP	2823	-6,62	-8,55	-4,73
I3	ECvS	1481	-51,01	-88,31	-59,86
I4	ESS	1848	-38,87	-61,10	-38,63
I5	ESS	2853	-5,62	-7,23	-3,99
I6	ECcS	3380	11,81	19,09	11,95
I7	VB	3416	13,00	21,02	13,16
I8	VB	3954	30,80	49,80	31,17
I 9	WCcS	3817	26,27	42,47	26,58
I 10	WSS	2797	-7,48	-9,70	-5,38
I 11	WCvS	1995	-34,01	-51,65	-31,86
I 12	WP	2381	-21,24	-29,74	-17,34
Transect L					
L1	EP	2786	- 8,63	- 11,35	- 3,48
L2	ECvS	2310	- 25,99	- 37,34	- 11,76
L3	ESS	2011	- 36,91	- 56,58	- 18,22
L4	ECcS	3922	32,92	48,90	15,67
L5	VB	4852	66,71	98,95	30,88

Fig.3 137Cs distribution along transects



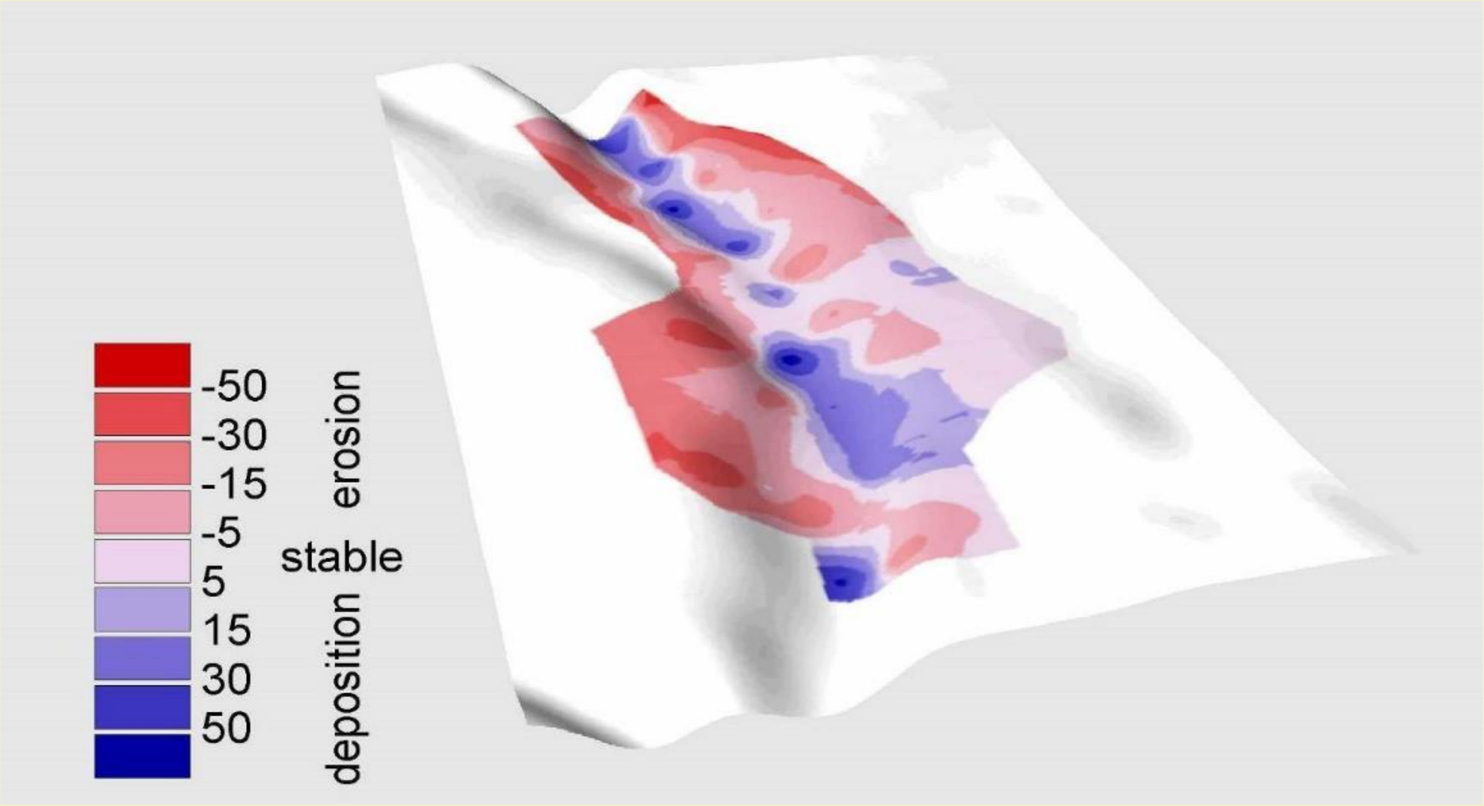


^{137}Cs spatial distribution

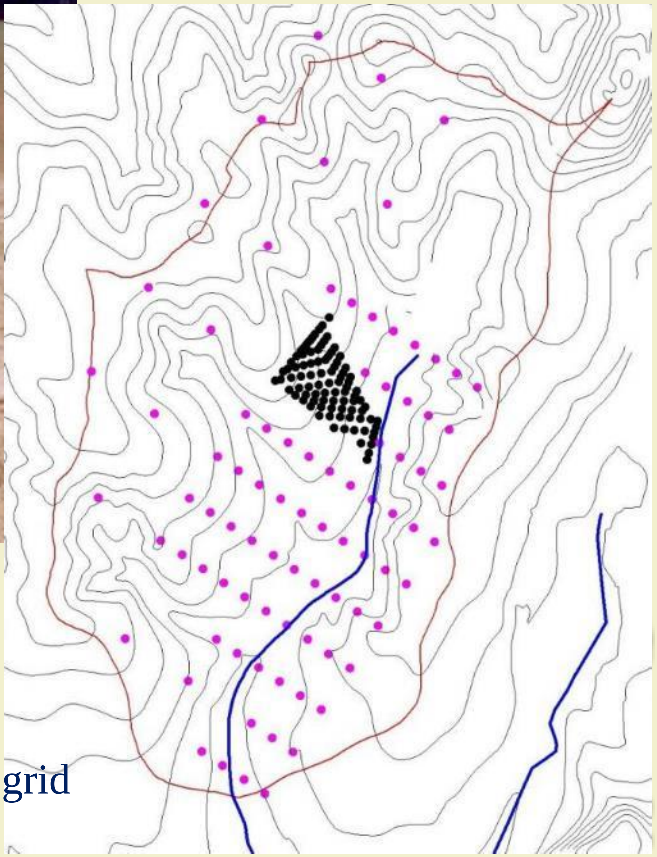


^{137}Cs depth distribution at depositional sink area

Spatial pattern of erosion/deposition processes (1:10 000), Jaslovské Bohunice, soil erosion rates (t ha^{-1} y^{-1}) calculated by mass balance model



Results from Mochovce site

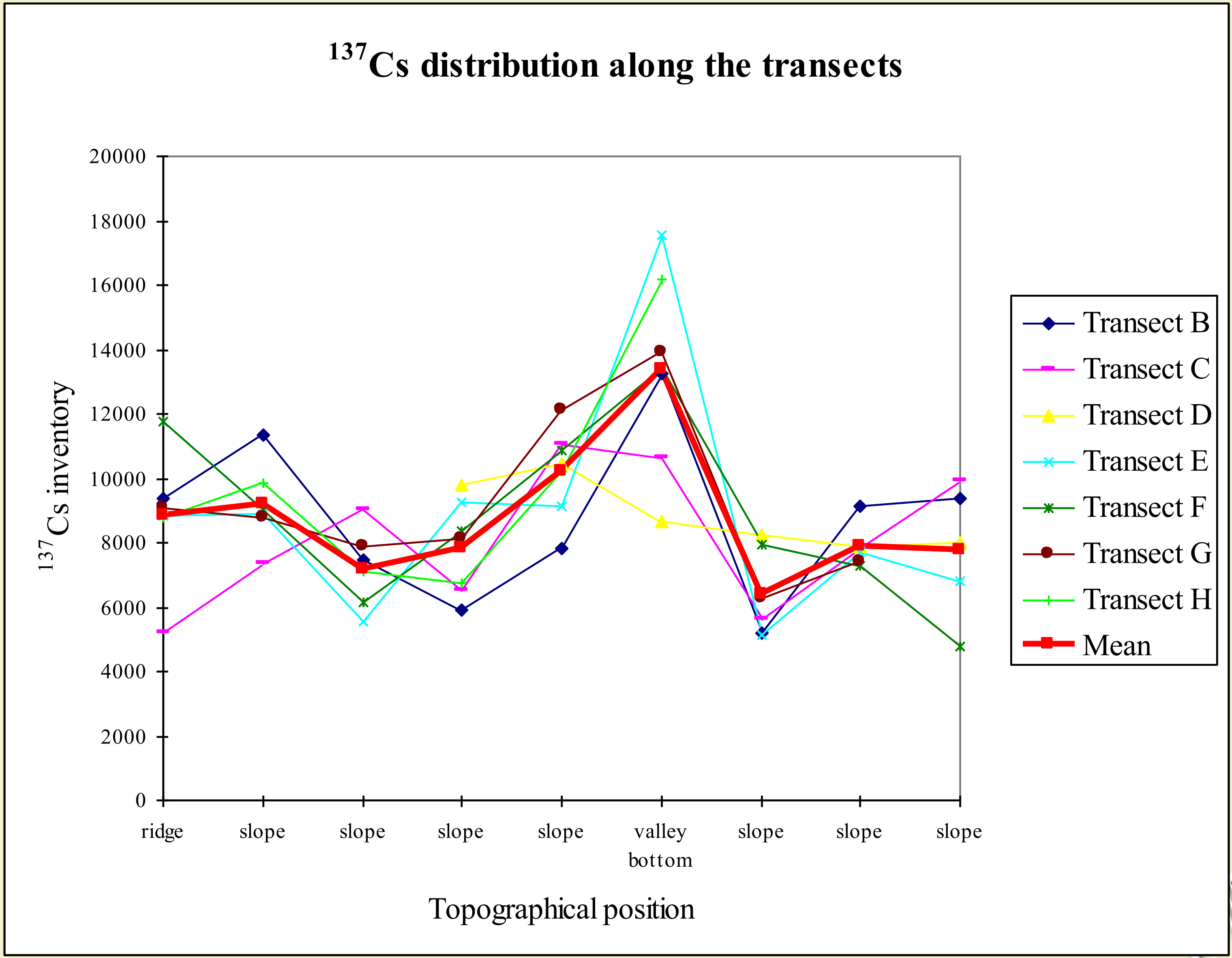


Multiple transect grid

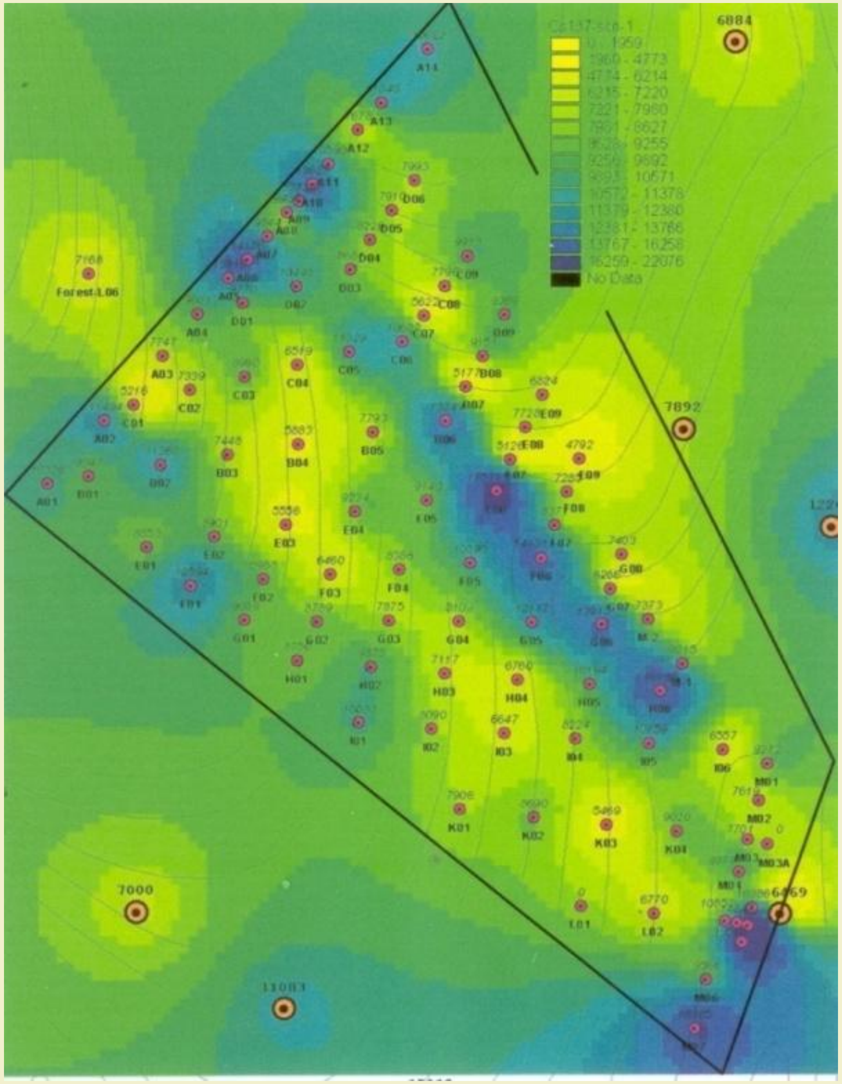
Total ^{137}Cs inventories and soil erosion/deposition rates calculated by conversion models

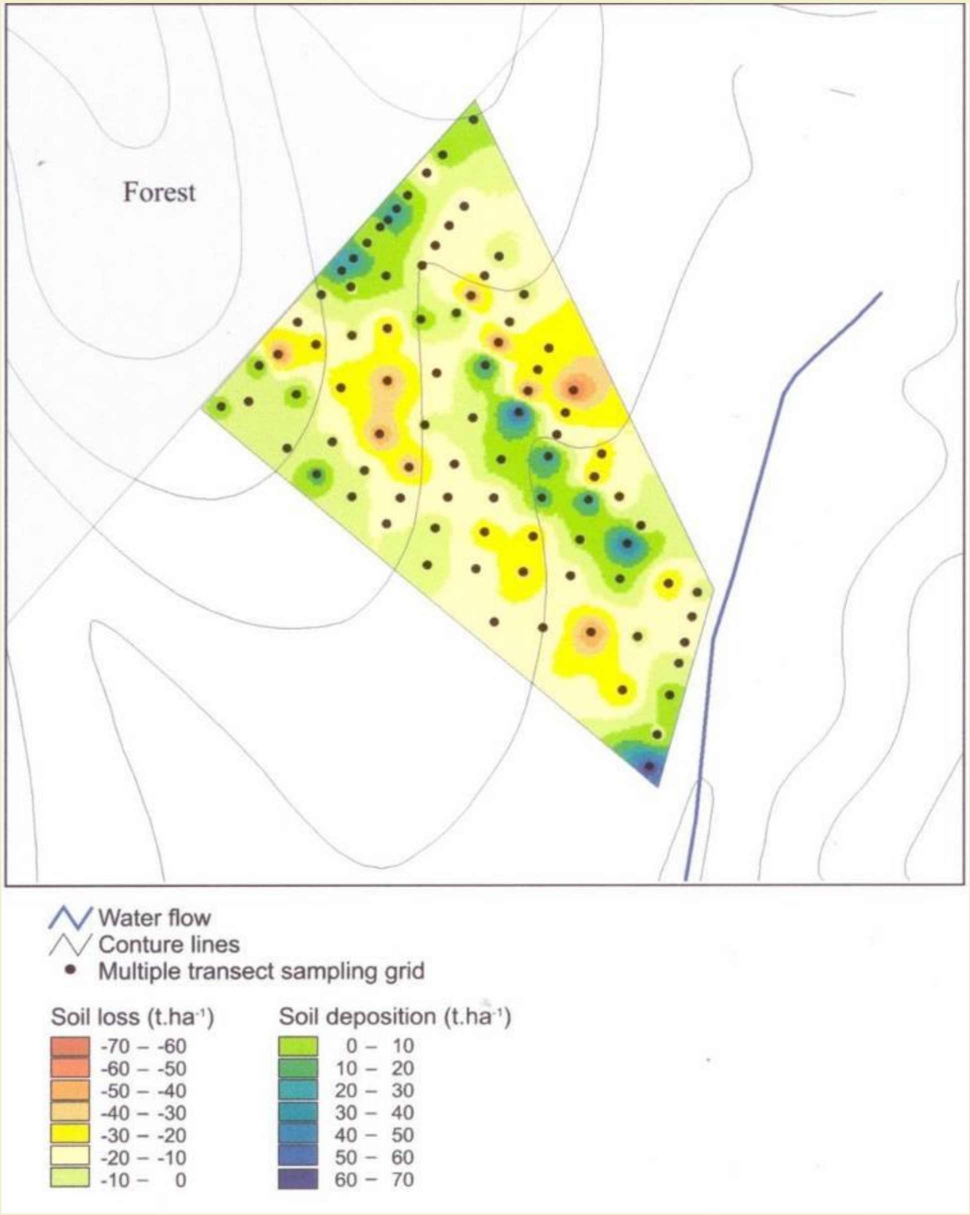
Sample profile	Sample depth (cm)	Slope position	^{137}Cs inventory (Bq.m^{-2})	Soil redistribution		
				Proportional model	Mass balance model I	Mass balance model II
				t.ha^{-1}		
Transect A						
A1	0 - 40	ridge	10326	3,3	5,1	3,0
A2	0 - 40	slope	11404	14,4	21,8	12,9
A3	0 - 40	slope	7747	-23,0	-32,7	-19,0
A4	0 - 35	slope	9801	-2,0	-2,6	-1,4
A5	0 - 35	slope	13810	39,0	55,2	31,1
A6	0 - 35	slope	14186	42,8	60,6	34,2
A7	0 - 40	slope	9844	-1,6	-2,0	-1,1
A8	0 - 40	slope	9486	-5,3	-6,8	-3,7
A9	0 - 40	valley	13734	38,2	53,0	29,6
A10	0 - 40	slope	13627	37,1	51,5	28,7
A11	0 - 35	slope	10590	6,0	8,4	4,7
A12	0 - 35	slope	7678	-23,8	-33,8	-19,7
A13	0 - 35	slope	11040	10,6	15,0	8,4
A14	0 - 35	ridge	10662	6,8	9,5	5,4
Transect B						
B1	0 - 40	ridge	9347	-6,7	-8,7	-4,7
B2	0 - 40	slope	11360	13,9	18,1	9,7
B3	0 - 40	slope	7448	-26,1	-37,7	-22,2
B4	0 - 40	slope	5883	-42,1	-67,7	-43,0
B5	0 - 40	slope	7793	-22,6	-32,0	-18,5
B6	0 - 50	valley	13249	33,2	50,3	29,7
B7	0 - 35	slope	5177	-49,3	-83,9	-55,6
B8	0 - 35	slope	9151	-8,7	-11,4	-6,3
B9	0 - 40	ridge	9369	-6,5	-8,4	-4,6

Sample profile	Sample depth (cm)	Slope position	^{137}Cs inventory (Bq.m^{-2})	Soil redistribution		
				Proportional model	Mass balance model I	Mass balance model II
				t.ha^{-1}		
Transect C						
C1	0 - 40	slope	5216	-48,9	-82,9	-54,8
C2	0 - 35	slope	7339	-27,2	-39,6	-23,4
C3	0 - 35	slope	8990	-10,3	-13,7	-7,6
C4	0 - 35	slope	6519	-35,6	-54,7	-33,6
C5	0 - 35	slope	11029	10,5	16,7	10,1
C6	0 - 50	valley	10607	6,2	9,8	6,0
C7	0 - 35	slope	5622	-44,8	-73,4	-47,4
C8	0 - 35	slope	7796	-22,5	-31,9	-18,5
C9	0 - 40	ridge	9913	-0,9	-1,1	-0,6
Transect D						
D1	0 - 35	ridge	9770	-2,4	-3,0	-1,6
D2	0 - 35	slope	10448	4,6	5,8	3,1
D3	0 - 50	valley	8681	-13,5	-18,2	-10,1
D4	0 - 40	slope	8226	-18,1	-25,0	-14,2
D5	0 - 35	slope	7910	-21,4	-30,0	-17,3
D6	0 - 40	slope	7993	-20,5	-28,7	-16,5
Transect E						
E1	0 - 40	ridge	8853	-11,7	-15,6	-8,7
E2	0 - 35	slope	8901	-11,2	-14,9	-8,3
E3	0 - 35	slope	5556	-45,5	-74,9	-48,5
E4	0 - 35	slope	9234	-7,8	-10,2	-5,6
E5	0 - 35	slope	9140	-8,8	-11,6	-6,4
E6	0 - 50	valley	17571	77,4	117,0	69,4
E7	0 - 35	slope	5126	-49,9	-85,1	-56,6
E8	0 - 35	slope	7728	-23,2	-33,0	-19,2
E9	0 - 40	ridge	6824	-32,5	-48,9	-29,6


^{137}Cs distribution along the transects
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
^{137}Cs inventory
ridge
slope
slope
slope
slope
valley bottom
slope
slope
slope
Topographical position
Transect B
Transect C
Transect D
Transect E
Transect F
Transect G
Transect H
Mean

^{137}Cs spatial distribution





Spatial distribution of soil erosion and deposition at Mochovce site, Slovakia

The erosion rates at the steepest central parts of the slopes are between 17 and 63 t ha^{-1} y^{-1} with an average of 39 t ha^{-1} y^{-1} (Mass Balance Model II).

The deposition rates in the valley bottom range from 3 to 69 t ha^{-1} y^{-1} with an average of 32 t ha^{-1} y^{-1}.

Comparison of soil erosion rates obtained by ^{137}Cs method at Jaslovské Bohunice and Mochovce sites

Site and Authors	Site scale	Process	Period	Slope length	Slope inclination	Vegetation	Mean erosion rate		Range of rates	Number of data
							original units	t ha^{-1}	t ha^{-1}	
Jaslovské Bohunice Fulajtár (2003)	cca 40 ha	overall on-site soil redistribution	1954-1998	80 m	4-8^{o}	ArL	26.1 t ha^{-1}	**26,1**	**11,4-54,4**	70 points
Mochovce	cca 50 ha	overall off-site sediment transport	1954-1998	100 m	4-12^{o}	F+ArL	39.0 t ha^{-1}	**39,0**	**17,0-63,0**	88 points

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Soil erosion rates measured at experimental plots

Site and Authors	Method	Plot size	Process	Period	Slope length	Slope inclination	Vegetation	Mean erosion rate		Data range	Number of data
								Original units	t ha^{-1}	t ha^{-1}	
Čečejovce Stašík et al (1983)	total collection	25x2 m (50m^2)	sheet and initial rill erosion	1981-82 (growing seasons)	25 m	6-7^o	OR, WW	485 (g.m^{-2})	**4,85**	**2.9-6.8**	2
Stakčín, Ubľa Chomaničová (1988)	total collection	10x5 (50m^2)	sheet and initial rill erosion	1986-88 (growing seasons)	10m	6-10^o	WW, WR, SM, P	294 (g.m^{-2})	**2,94**	**0-8,7**	8
Osikov, Kočín, Gbely, Smolinské, Rišňovce Fulajtár, Janský (2001)	total collection	20x2 m	sheet and initial rill erosion	1994-96 (whole years)	20 m	4-6^o	SB, SF, GM, WW, ShB	925 (g.m^{-2})	**9,25**	**0-75**	12
						8-10^o	WW, ShB, WR, SB, GM, SF, AL, OR	1.384 (g.m^{-2})	**13,8**	**0-75**	34
Lukáčovce, Turá Lúka Gajdová et al (1999)	tipping buckets	100x10 m (1000m^2)	sheet and mature rill erosion	1997-99 (whole years)	100 m	4-12^o	WW, WR, SB, OR, GM	42.4 (kg.ha^{-1})	**0,04**	**0-0.32**	10

Compound Specific Stable Isotope Analyses (CSSI)

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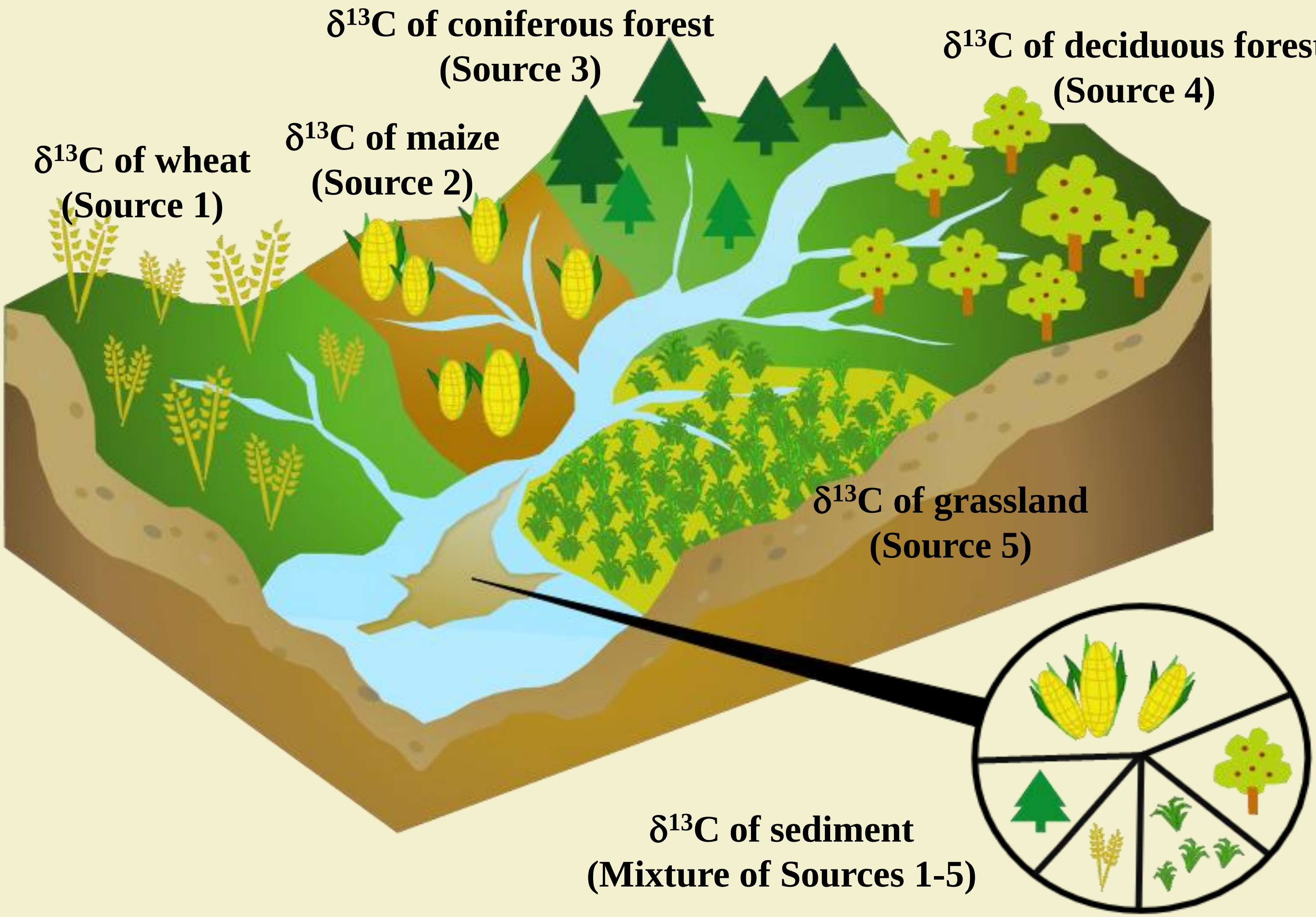

Assessment of long term impact of soil erosion under the large scale mechanized agriculture using remote sensing

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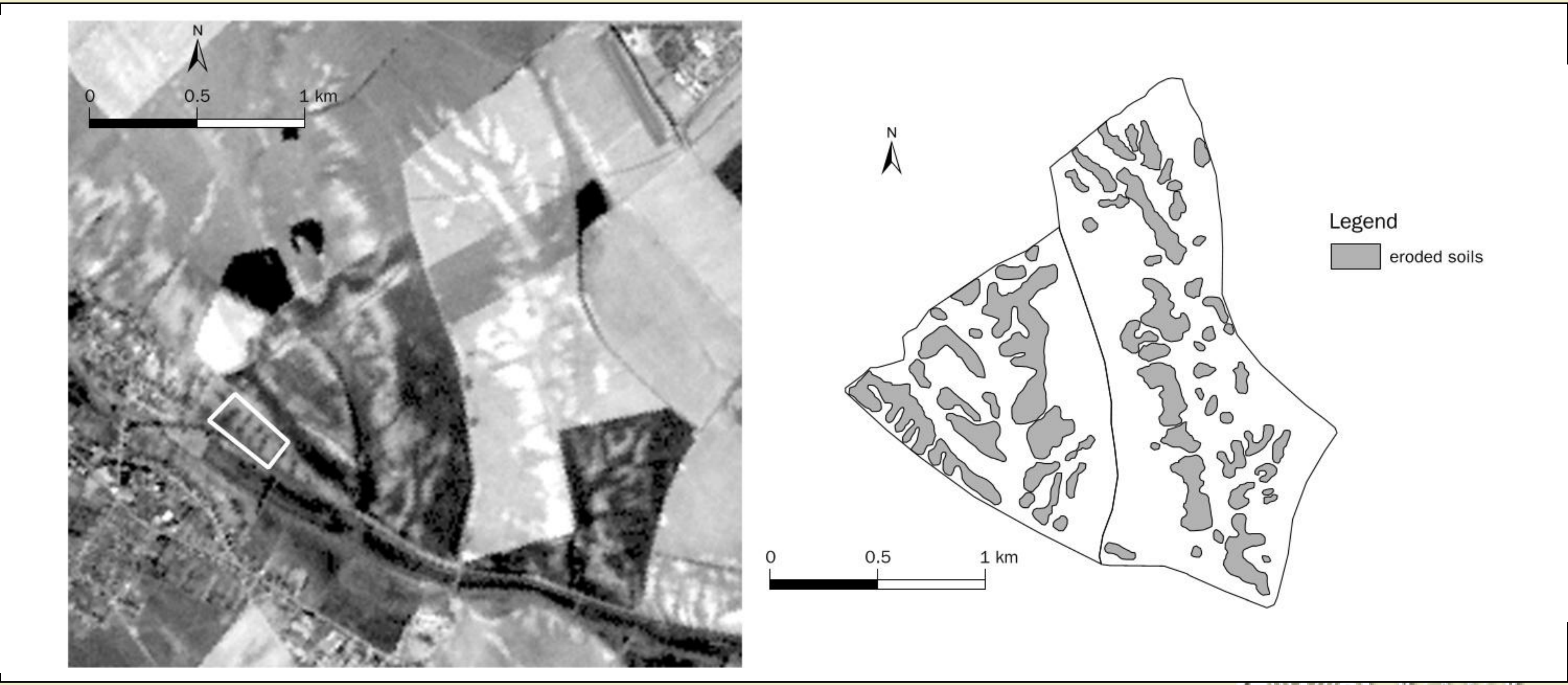
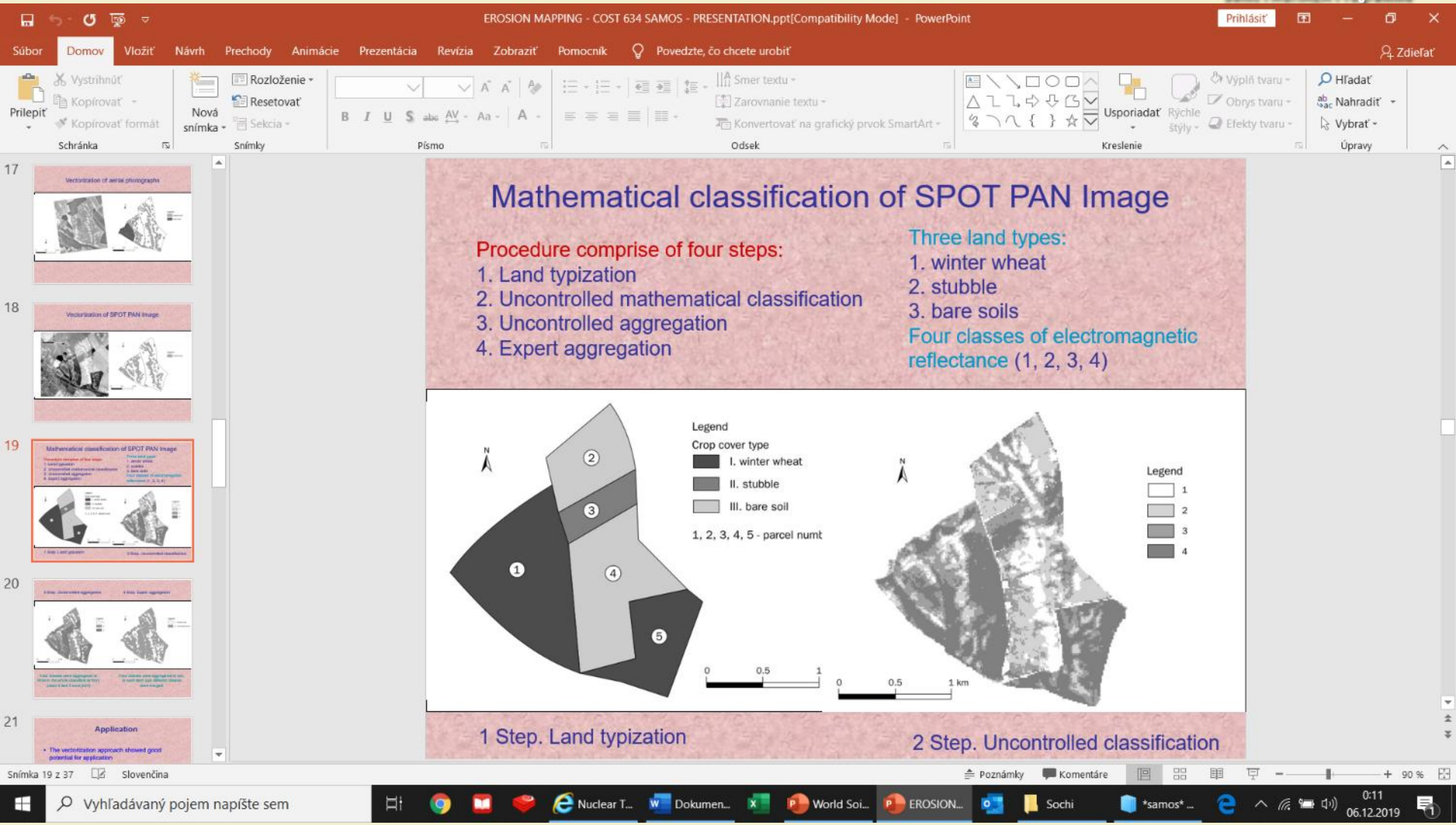
Data from individual transect sites

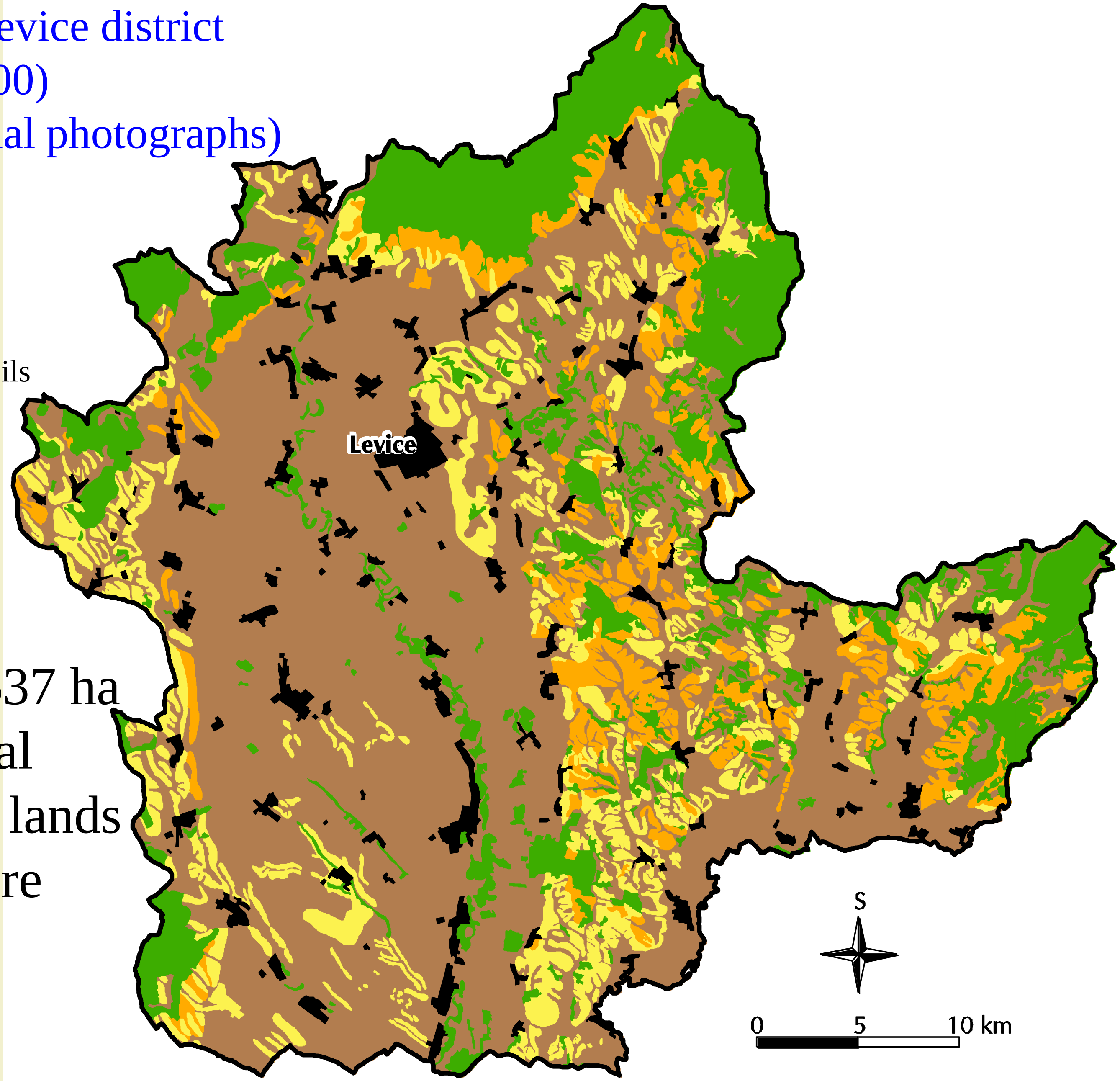



EROSION MAPPING - COST 634 SAMOS - PRESENTATION.ppt[Compatibility Mode] - PowerPoint
Mathematical classification of SPOT PAN Image
Procedure comprise of four steps:
1. Land typization
2. Uncontrolled mathematical classification
3. Uncontrolled aggregation
4. Expert aggregation
Three land types:
1. winter wheat
2. stubble
3. bare soils
Four classes of electromagnetic reflectance (1, 2, 3, 4)
Legend
Crop cover type
I. winter wheat
II. stubble
III. bare soil
1, 2, 3, 4, 5 - parcel numt
N
0 0.5 1
Legend
1
2
3
4
N
0 0.5 1 km
1 Step. Land typization
2 Step. Uncontrolled classification
Snímka 19 z 37
Slovenčina

Eroded soils of Levice district
(1:50 000)
(vectorization of aerial photographs)

Explanation:

- Agricultural land
- Moderately eroded soils
- Strongly eroded soils
- Forests
- Urban areas



Approximately 4 637 ha (31% of agricultural land) in loess hilly lands of Levice district are strongly eroded.

Achievements of the technical cooperation in Africa: Example of TC project in Uganda (UGA5037)


2017/04/05

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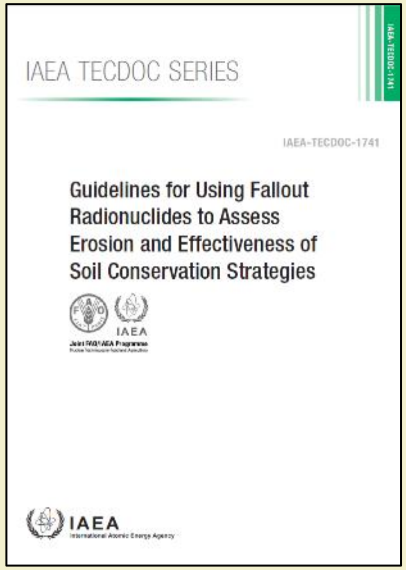
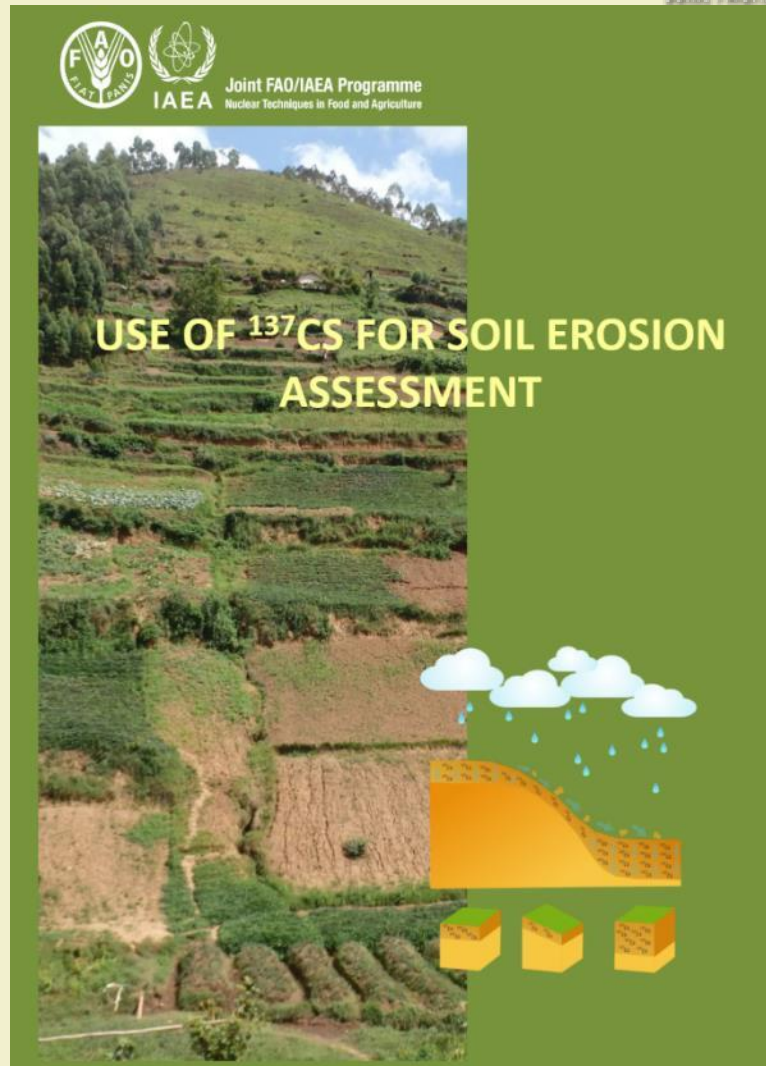
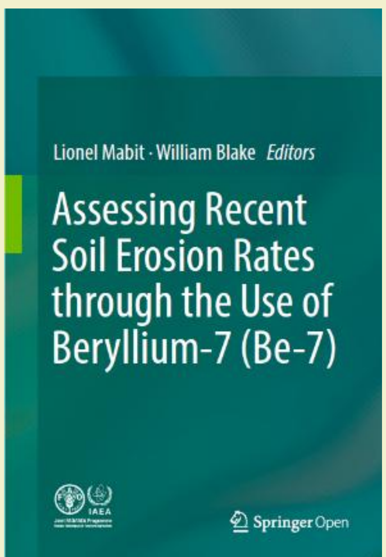
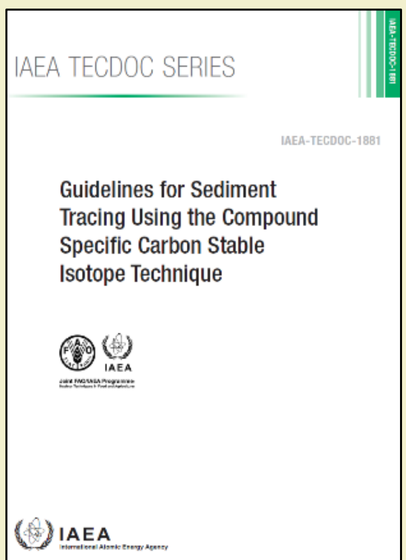
Methodological handbooks









Success stories: awareness rising articles on web site

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Combatting Soil Erosion to Help Achieve Zero Hunger and Clean Water: IAEA Commemorates World Soil Day

Joanne Liou, IAEA Office of Public Information and Communication

DEC
5
2019

Isotopes were used to determine soil erosion rates of experimental plots with no-tillage (front) and conventional tillage (back) land management in Zimbabwe. (Photo: E. Fulajtar/IAEA)

Over 45 billion tons of soil are lost to erosion every year. Farmers in several countries have succeeded in slowing down erosion with the help of nuclear techniques. Here are their stories from Zimbabwe, Argentina and Sri Lanka.

All over the world, the Earth's fine soil particles are losing ground to erosion. As 95 percent of food is cultivated in soil, the health and availability of Earth's living surface impacts the quality and quantity of the food we produce. "Agricultural landscapes lose valuable soil mainly through soil redistribution processes," said Emmanuel Chikwari, Head of the Chemistry and Soil Research Institute in Zimbabwe. "Once the soil resource is lost, it cannot be replaced for generations."

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Nuclear Techniques Help Reveal High Rate of Soil Erosion in Benin

Emil Fulajtar, IAEA Department of Nuclear Sciences and Applications
Joanne Liou, IAEA Office of Public Information and Communication

NOV 12 2019

Soil erosion is a major problem for Benin's farmers. Nuclear techniques help scientists find its exact causes, so that they can tackle erosion. (Photo: E. Fulajtar/IAEA)

Harmless traces from nuclear testing more than half a century ago are helping researchers assess soil erosion rates. In Africa, about 65 percent of the continent's farm land is affected by erosion-induced losses of topsoil and soil nutrients, according to the Food and Agriculture Organization of the United Nations (FAO). Benin is among those countries severely impacted by soil erosion, which poses a major problem for economic development since agriculture represents approximately 35 percent of the country's GDP and 80 percent of its export income. A recent study applied a nuclear technique to assess rates of soil erosion and support land conservation in Benin.

"Evidence shows that over 90% of soils in Benin have a high level of degradation," said Pascal Houngnandan, Director of the Laboratory of Soil Microbiology and Microbial Ecology at the Faculty of Agricultural Sciences,

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World Day to Combat Desertification: Using Nuclear Technology to Strengthen Soil and Water Conservation Strategies

JUN
17
2014

Soils are critical for all life-they act as a water filter and growing medium, supply nutrients for plant growth and contribute to biodiversity. Yet, despite the universal importance of healthy soil, we continue to lose approximately 5 to 7 million hectares each year through soil degradation - 24 billion tons of this non-renewable resource have been lost over the last century from the world's arable land. Today, land and soil degradation affect approximately 1.5 billion people, and not just in arid or dry environments.

June 17 is World Day to Combat Desertification, and this year's theme is 'Land Belongs to the Future - Let's Climate Proof'. The International Atomic Energy Agency (IAEA), through its technical cooperation programme and the Joint FAO/IAEA Division, is helping Member States to address this goal by

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On solid ground: IAEA celebrates World Soil Day

DEC
7
2015

More than 50% of the Earth's land is moderately or severely affected by soil degradation. Without sustainable practices, this trend will unfortunately continue, jeopardizing biodiversity, threatening global food prices, and endangering more than 2.6 billion small-scale farmers whose livelihoods depend on healthy soil. Although the challenge is great-both in size and complexity-the UN celebration of World Soil Day on 4 December reminds us that we have the tools to confront, and eventually resolve, the challenge.

Whereas it may take 1,000 years for a single centimetre of healthy soil to form, that same plot of land can be degraded or destroyed in moments. This is the central message of World Soil Day-arable land is fragile and limited, which means that our land-use must be respectful and sustainable. Through its technical cooperation (TC) programme, the IAEA works closely with its

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Erosion in Moroccan Watersheds Can Be Reduced up to 60 Percent Through the Use of Isotopic Techniques

Nancy Hart, International Development Correspondent

OCT
11
2016

(Photo: Champa Dissanayake/Sri Lanka AEB)

The erosion that plagues Morocco's hillsides affects more than the agricultural fields that are losing soil. The eroding soil that sweeps down the hillsides eventually ends up as sediment in water reservoirs, leaving them with less water storage capacity. The Joint FAO/IAEA Division, working with Morocco's nuclear institution and other partners, adapted and introduced a package of isotopic techniques to identify the most erosion-prone areas. Having this information allowed for development and introduction of

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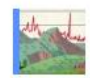
Studying Erosion with the Help of Radionuclides

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World Soil Day: Madagascar Combats Soil Erosion with Tradition and Nuclear Science

Nicole Jawerth, IAEA Office of Public Information and Communication

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An age-old agricultural method is helping to combat soil degradation and protect a source of food and income for more than 75% of the population in Madagascar. Through a study using isotopic techniques on the mountainous island, scientists working with the IAEA, in cooperation with the Food and Agriculture Organization of the United Nations (FAO), found that traditional terrace farming can reduce soil erosion and run-off in the country by up to 40% when compared to unprotected agricultural fields.

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World Soil Day: Caring for the Planet Starts from the Ground and Nuclear Techniques can Help

Nicole Jawerth, IAEA Office of Public Information and Communication

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Erosion threatens soil resources worldwide. Nuclear science offers ways to study and protect this finite, non-renewable resource. (Photo: M. Benmansour/CNESTEN)

Have you ever thought about soil? Thought about this vast limited resource where your food grows? This finite, non-renewable resource is under threat worldwide. Intensive agricultural practices, pollution and climate change threaten its health and the life-sustaining support it offers people and the planet.

But soil has an ally: nuclear science.

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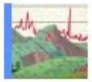
Studying Erosion with the Help of Radionuclides

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How to Win a Fight Against Soil Erosion: Nuclear Science Helps Farmers in Morocco

Nicole Jawerth, IAEA Office of Public Information and Communication

FEB 26 2018

Farmer El Haj Abdeslam's son drives a tractor to help with the farm work while scientists take soil samples from the fields. (Photo: R. Moussadek/INRA)

Farmer El Haj Abdeslam and his three helpers spent years fighting soil erosion that swept away their crops' fertile ground, taking their incomes with it. Now Abdeslam and many Moroccan farmers like him are saving their soil and their source of food and money using soil-conservation methods selected with the help of nuclear science.

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- Isotope Techniques Trace Erosion Source to Sri Lanka's Terraced Tea Plantations
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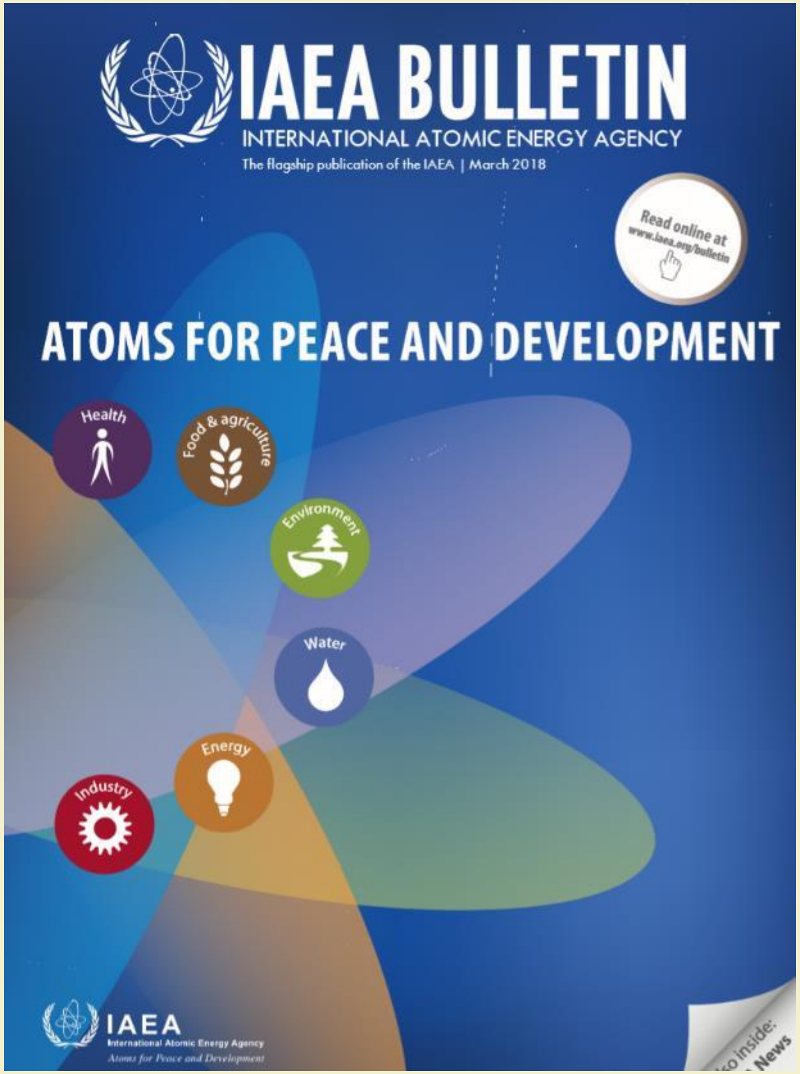

How to win the fight against soil erosion: saving fertile land and preserving water quality with the help of nuclear techniques

By Nicole Jawerth and Miklos Gaspar

Erosion eats away at fertile land, threatening food production and farmers' income alike. The top layer of the soil, which is the first to go, is the most nutritious. Often this nutritious soil ends up in rivers and lakes where it encourages algae to grow, causing the amount of oxygen in the water to decrease. This in turn compromises water quality and harms fish populations.

Nuclear techniques can help scientists and farmers find erosion hot spots and identify the right soil conservation technique to save both farmland and fresh water sources (see The Science box on page 17). The IAEA, in cooperation with the Food and Agriculture Organization of the United Nations (FAO), provides support to 70 countries on erosion research. This article profiles two of them: Morocco, where the focus is on saving agricultural land, and Myanmar, where they are fighting off an algae boom in the country's second largest lake.

Saving farmland in Morocco

Farmer El Haj Abdeslam's son drives a tractor to help with the farm work while scientists take soil samples from the fields.
(Photo: R. Moussadek/INRA)

Farmer El Haj Abdeslam and his three helpers spent years fighting soil erosion that swept away their crops' fertile ground, taking their incomes with it.

"Year after year, soil erosion was making the quality of my land worse and that made my farm less productive," said Abdeslam, whose 5-hectare chickpea and cereal farm feeds his family of seven and is his sole source of income. "Since the scientists helped me conserve my soil, my farm has been producing 20 to 30% more with less input, and my income has gone up."

The scientists used fallout radionuclides and compound-specific stable isotope techniques (see The Science box on page 17) to pinpoint erosion-prone areas and evaluate the effectiveness of various conservation methods. The technique was introduced in response to Morocco's more than 100 million tonnes of soil losses each year.

"Once we knew where the erosion hotspots were, we tested several soil-conservation methods using nuclear techniques to see how we could improve the situation. We adapted and combined different conservation methods

14 | IAEA Bulletin, March 2018

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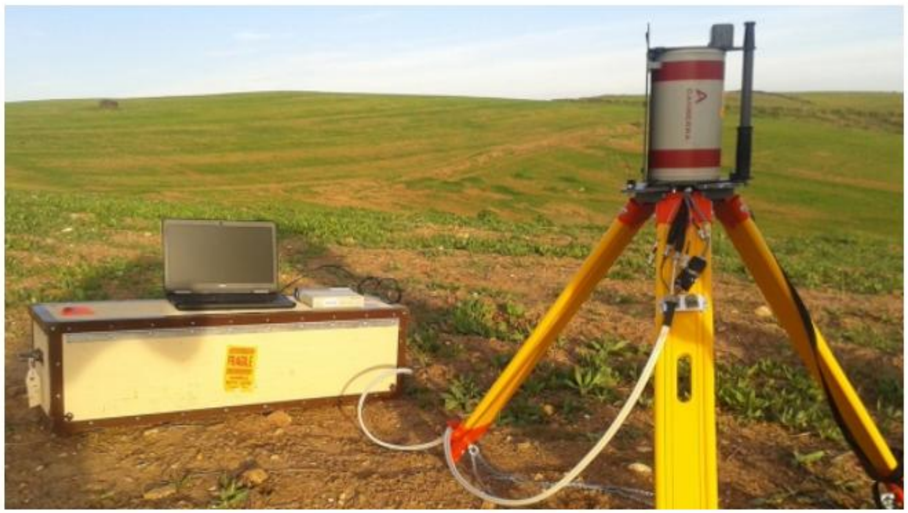
Egypt and Senegal Receive Gamma Detectors to Help Combat Soil Erosion

Matt Fisher, IAEA Office of Public Information and Communication

NOV 9 2018



A portable gamma detector provided to the National Centre of Energy, Sciences and Nuclear Techniques in Morocco (CNESTEN). (Photo: CNESTEN)

Experts in Egypt and Senegal will be better able to fight soil erosion thanks to two gamma spectroscopy detectors which have just been delivered through the IAEA's technical cooperation programme. The detectors will be used for soil erosion assessment in areas that have experienced severe land degradation, a phenomenon that jeopardizes agriculture in many regions of the world, including in arid and semi-arid lands in Africa.

Related Stories

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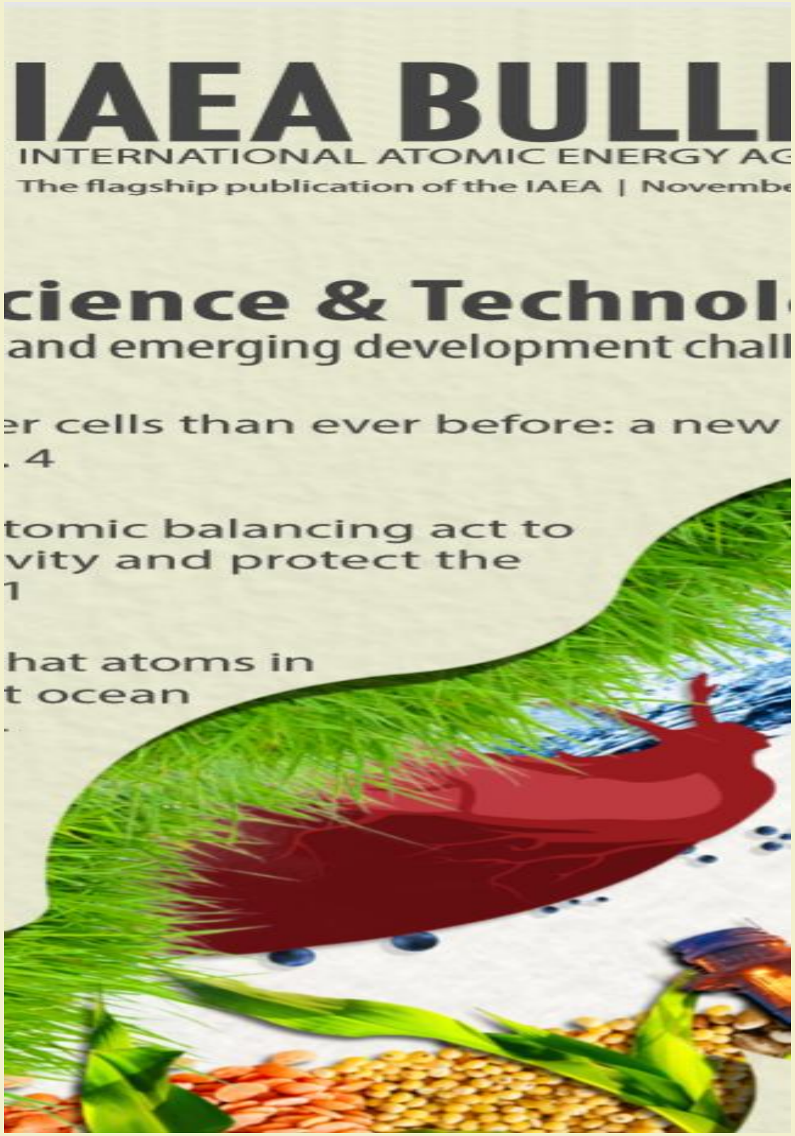
- World Soil Day: Caring for the Planet Starts from the Ground and Nuclear Techniques can Help
- Viet Nam Tackles Soil Erosion With Nuclear Techniques

Related Resources

- Studying Erosion with the Help of Radionuclides
- Soil Erosion Control
- Land and water management
- Guidelines for Using Fallout Radionuclides to Assess Erosion and Effectiveness of Soil Conservation Strategies
- Impact of Soil Conservation Measures on Erosion Control and Soil Quality

Nuclear Techniques in Food and Agriculture

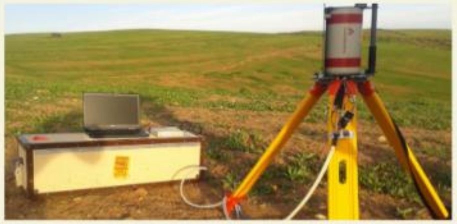


The neutron activation analysis e-learning tool was reviewed at a workshop in September 2018 at the IAEA Headquarters in Vienna.

"The tool is intended to be a living book that can be constantly updated and extended as this field evolves to include different laboratory protocols and research areas," Barradas said. The launch of the first revision is planned for early 2019.

— *By Luciana Viegas*

Egypt and Senegal receive gamma detectors to help combat soil erosion



Experts in Egypt and Senegal will be better able to fight soil erosion thanks to two gamma spectroscopy detectors which were delivered in November 2018 through the IAEA's technical cooperation programme. The detectors will be used for soil erosion assessment in areas that have experienced severe land degradation, a phenomenon that jeopardizes agriculture in many regions of the world, including in arid and semi-arid lands in Africa.

Egypt and Senegal are both suffering from severe land degradation, with soil productivity in most of the northeast Nile Delta in Egypt, for instance, having decreased by more than 45% in the last 35 years, according to recent studies. Land degradation is the result of several factors, including overexploitation of land, unsustainable agricultural practices and extreme weather events, which have occurred more frequently in the last few decades. Soil erosion — a major type of land degradation caused by both human and environmental factors — can lead to the complete loss of the fertile topsoil, leaving the affected land unfit for agriculture.

Agriculture is an important economic sector in most African countries, accounting for approximately 12% of Egypt's gross domestic product (GDP) and 17% of Senegal's GDP. Low-input farming from subsistence farms run by families represents a significant component of this sector. It accounts for a high proportion of jobs, and provides livelihoods to subsistence farmers and their families. As this type of farming typically takes place on arid and semi-arid land with marginal agricultural potential, such as drylands and mountains, it is particularly susceptible to soil erosion.

The IAEA, in cooperation with the Food and Agriculture Organization of the United Nations (FAO), has been assisting countries for more than 20 years in combating land degradation by supporting the use of isotopic techniques to assess soil erosion.

Fallout radionuclide tracers, such as caesium-137 (Cs-137), have been used extensively in assessing soil erosion and sedimentation. This radionuclide is present in the atmosphere from where it falls to the ground in precipitation and accumulates in the uppermost soil layer. During erosion, the topsoil is washed away, which can be measured as decreased levels of Cs-137. At the same time, where the eroded soil settles, increased levels of Cs-137 are seen.

The erosion assessment using Cs-137 has many advantages compared to traditional methods, said Emil Fulajtar, a soil scientist in the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture. This method provides long-term mean erosion rates, while conventional methods provide mostly short-term data. Using this nuclear technique, there is therefore no need for long and resource-demanding monitoring programmes: soil redistribution can be assessed in a single sampling campaign. It also helps to determine the spatial distribution of erosion, which is essential input for soil conservation programmes aimed at sustainable land management and thereby food security.

The provision of gamma spectrometers, which are used to carry out the Cs-137 measurements, is part of an ongoing initiative by the Joint FAO/IAEA Division to help African countries enhance their capacity to control soil erosion; this also includes the training of scientists on the use of the Cs-137 method and the establishment of gamma spectroscopy capacities across the continent. Another three table-top gamma detectors — for Madagascar, Algeria and Zimbabwe — and three portable gamma detectors — for Morocco, Tunisia and Madagascar — have already been delivered.

"We will use the gamma detectors for the 'fingerprinting' of sedimentation in the Nile River to trace the origin of contamination from different sources, such as drainage from industrial and agricultural bodies located on the riverbank," said Mohamed Kassab, a lecturer at the Egyptian Atomic Energy Authority's Nuclear Research Centre. "We also plan to help other countries in Africa to build capacity in gamma measurements and analytical services."

— *By Matt Fisher*

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Success stories: awareness rising articles in IAEA fact sheets

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COUNTRY IMPACTS
MOROCCO

Reducing soil erosion in Morocco

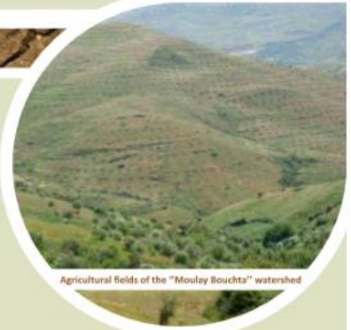
THE CHALLENGE

Soil erosion is the mainland degradation process in Morocco, which is affecting up to 40% of its land area. About two million hectares of Moroccan agricultural lands are affected by water erosion[1]. On average soil erosion ranges from 5 to 20 t/ha/year, but exceeds these magnitudes in northern and north-western agricultural basins. For example, in the pre-Rif hills, soil erosion is exceeding 50 t/ha/year[1,2].

Out of a total area of 20 million ha of watershed in Morocco, 50% is estimated to be subjected to very high erosion risks with a yearly soil loss of around 100 million tons[1,2]. This annual soil loss leads to a reduction of 75 million m^3 of downstream dam water storage capacity. Each year about 0.5% of the country's reservoir storage capacity is lost. This water loss is equivalent to an annual water volume permitting the irrigation of 10,000 ha of arable lands[2].

In Morocco, reducing soil erosion and land degradation is a national priority for improving soil quality and protecting downstream water quality and quantity.

THE PROJECT


Agricultural fields of the "Moulay Bouchta" watershed

Through IAEA Technical Cooperation and research projects and with the technical support of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, the Centre National de L'Energie, des Sciences et des Techniques Nucléaires (CNESTEN) in partnership with the Institut National de Recherche Agronomique (INRA), Ecole Nationale Forestière d'Ingénieur (ENFI), the Centre de Recherche Forestière (CRF) and the Institut Agronomique et Vétérinaire Hassan II (IAV) quantified soil erosion rates and assessed the effectiveness of no tillage soil conservation practices.

Under no tillage management soil loss was reduced from 14 to 10 t/ha/year in the south east of Rabat (Marchouch site) and from 38 to 23 t/ha/year in the Tetouan region[3].

In addition, using a combination of fallout radionuclides (FRNs) and compound-specific stable isotope (CSSI) techniques (see below), the CNESTEN estimated soil loss of 23 t/ha/year in the Moulay Bouchta watershed and identified that around 90% of the sediment in the downstream Talembout water reservoir originated from the surrounding agricultural areas indicating the effectiveness of forest plantations in protecting soil resources against erosion. Sedimentation rates were established for the downstream reservoir at 60 t/ha/year[4].

THE TECHNOLOGY

Fallout radionuclides (FRNs) such as anthropogenic caesium-137 (^{137}Cs), geogenic lead-210 (^{210}Pb), and cosmogenic beryllium-7 (^{7}Be), are strongly bound to fine soils particles. Therefore, these radioisotopes are very conservative soil tracers, which can assist in establishing soil erosion and sedimentation rates and evaluating the efficiency of soil conservation measures to control soil erosion and associated excess of sedimentation.

Compound-specific stable isotope (CSSI) techniques are based on the measurement of carbon-13 (^{13}C) natural abundance signatures of specific organic compounds (natural fatty acid biomarkers) in the soil. By linking fingerprints

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MADAGASCAR

Return to traditional terracing improves farm production in Madagascar

In Madagascar, where farming has moved toward modern intensive agricultural practices in recent decades, a study has demonstrated that the country's farmers would be much better off if they returned to the traditional terrace farming of their ancestors. Using isotopic techniques to study erosion patterns of the island country's mountainous regions, where more than 30 percent of the agricultural area is already degraded, the Joint FAO/IAEA Division found that terracing systems could reduce soil erosion by 40 percent.

Astronauts once reported that Madagascar looked as if it were bleeding to death. Today, looking at a satellite view of the country makes it easy to see what they meant. The image shows reddish rivers and reservoirs – not filled with blood but with the country's red ferralitic soil that is eroding down the island's steep slopes, leaving agricultural land barren and adding sediment and its polluting nutrients of nitrogen, phosphorus and potassium to water systems.

Due to deforestation and improper farming practices, Madagascar, one of the world's poorest countries, loses more topsoil per hectare each year than just about any other country in the world. The soil itself is not particularly fertile and now it has to deal also with the impacts of climate change, such as drought, floods and unpredictable rainfall that further break down the soil structure and makes it more likely to erode.

In order to help Madagascar's farmers with conservation practices, scientists at the Institut National des Sciences et Techniques Nucléaires (INSTN-Madagascar) in the capital, Antananarivo, worked with Joint FAO/IAEA Division experts to address the problem and identify the country's most erosion-prone areas. The Joint FAO/IAEA Division assists countries in quantifying soil erosion rates and assessing the effectiveness of their soil conservation practices. In the case of Madagascar,

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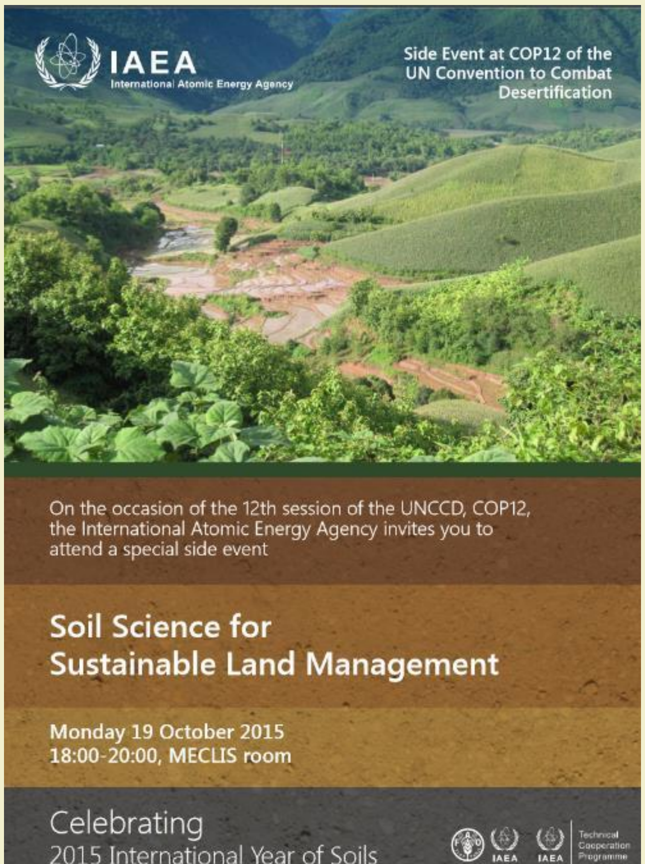
Presentations on meetings and conferences

Side Event at COP12 of the UN Convention to Combat Desertification (TC and Joint FAO/IAEA Division)
https://www.iaea.org/sites/default/files/documents/tc/COP_12_Flyer_.pdf



Organisation of a special IAEA event
at the 12th session of the Conference of the Parties (COP) to the UN Convention to Combat Desertification (UNCCD)
Ankara, Turkey, 19 October 2015

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IAEA emphasizes link between nuclear techniques and soil sustainability at COP12 side event

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UNCCD COP12 2015 ANKARA TURKEY

For the world's 2.6 billion small-scale and subsistence farmers, healthy soils can be the difference between stability and poverty, a full plate and an empty stomach, life and death. But despite the universal value of healthy soils, human economic activity continues to cause land erosion and soil degradation, placing approximately 5 to 7 million hectares in danger each year. Against this backdrop of threatened soils, and as climate change further complicates the challenge, the IAEA has organized a side-event to highlight the benefits of soil science for sustainable land management, to be held on the margins of the 12th session of the UNCCD Conference of the Parties

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Linkage of UNCCD and RAF 5063

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United Nations

ICCD/COP(12)/17

Convention to Combat Desertification

UNCCD

Distr.: General
16 July 2015

Original: English

Conference of the Parties
Twelfth session
Ankara, Turkey, 12–23 October 2015
Item 3 (b) of the provisional agenda
Effective implementation of the Convention at national, subregional and regional level
Leveraging of synergies among the Rio conventions, including land-based adaptation to climate change and related advice from the Science-Policy Interface

Leveraging of synergies among the Rio conventions

Note by the secretariat

Summary

Decision 9/COP.11 calls for a review and assessment of the progress made by the secretariat of the United Nations Convention to Combat Desertification (UNCCD) in promoting and strengthening relationships with other relevant conventions and international organizations, institutions and agencies. This document provides a summary of a select number of such activities and highlights their efficacy in promoting and strengthening these relationships.

The review and assessment includes the various initiatives undertaken with: (1) the other Rio conventions and the Global Environment Facility with regard to the development of common indicators and other synergies in reporting processes and capacity-building; (2) other entities such as the Food and Agriculture Organization of the United Nations, UN-Water, the World Meteorological Organization and the International Atomic Energy Agency on the issues of water, drought, forests and soil management; and (3) other organizations and institutions such as the Convention on Wetlands of International Importance especially as Waterfowl Habitat (the Ramsar Convention), the International Union for Conservation of Nature and the International Organization on Migration on UNCCD related collaboration.

Finally, following a brief conclusion, the document outlines recommendations for future work priorities for promoting and strengthening these relationships.

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Nuclear Techniques in Food and Agriculture

Effectiveness of soil conservation strategies on erosion in Morocco

M. Benmansour [1], L. Mabit [2], R. Moussadek [3], M. Yassin [4], A. Nouira [1], A. Zouagui [1], R. Mrabet [3], H. Iaaich [3], S. Hajib [4]

(1) Centre National de l'Energie, des Sciences et des Techniques Nucléaires (CNESTEN), Rabat, Morocco
(2) IAEA Joint FAO/IAEA Division, Soil and Water Management and Crop Nutrition Laboratory, Seibersdorf, Austria
(3) Institut National de la Recherche Agronomique (INRA), Rabat, Morocco
(4) Centre National de la Recherche Forestière (CRF), Haut Commissariat aux Eaux et Fôrets et à la Lutte contre la Désertification (HCEFLCD), Rabat, Morocco

INTRODUCTION

❑ For Morocco, reducing soil erosion and land degradation is a national priority for improving soil quality and protecting downstream water quality and quantity

❑ Reliable datasets on the magnitude of erosion and the effectiveness of soil conservation practices are required for decision makers

❑ The aim of this work is to illustrate the role of fallout radionuclides (i.e. ^{137}Cs and ^{7}Be) for supporting soil conservation strategies through case studies in three Moroccan sites: **Marchouch**, **Harchane** (Fig.1) and **Oued Mellah** (Fig.2) located in Rabat (1), Tétouan (2) and Chaouia-Ouardigha (3) regions respectively (Fig.3)

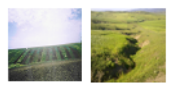


Fig.1: Marchouch and Harchane sites
(soil conservation practice = no-till technique)

Fig.2: Fields of Oued Mellah Watershed
(soil conservation practice = Atriplex and cereal with fruit plantations)

Fig.3: Locations of the study sites
(1: Marchouch ; 2: Harchane ; 3: Oued Mellah watershed)

MATERIAL AND METHODS

❑ In the Rabat and Tétouan regions, with semi-arid and Mediterranean climates respectively, the no-till technique was tested as soil conservation practice and compared to conventional tillage
❑ In the Chaouia-Ouardigha region (semi-arid climate) the efficiency of conservation practices based on Atriplex plantations and cereal & fruit plantations was assessed within the framework of the management of "Oued Mellah" watershed

❑ Methods used: (i) **Fallout ^{137}Cs** for retrospective assessment of long term [50-60 yr] soil redistribution rates and (ii) **fallout ^{7}Be** [half-life of 53 days] for documenting short term soil erosion

❑ Reference sites were investigated near the study areas. In the agricultural studied fields, the soil sampling strategy was based on a transect approach

❑ ^{137}Cs and ^{7}Be were measured by gamma spectrometry using a "p type" high purity germanium (HPGe) detector with high resolution and 30% efficiency

❑ Estimates of erosion/deposition rates from ^{137}Cs and ^{7}Be data set have been produced using conversion models (i.e. Mass Balance Model II and the Profile Diffusion Model)

RESULTS AND DISCUSSIONS

❑ Long term soil erosion rates of the three regions evaluated by the ^{137}Cs method, ranged from 8 to 58 t ha^{-1} yr^{-1}

❑ The net soil erosion rates appeared to be related to the rainfall, slope and the past land use (Tab.1)

❑ The ^{7}Be results indicated that soil loss has been reduced significantly under no-till as compared to conventional tillage in Rabat and Tétouan regions. Indeed, soil erosion rates were lowered by 50% for the Marchouch site (Fig.4) and by 40% for the Harchane site (Fig.4)

❑ For the Oued Mellah watershed, the results highlighted that high density Atriplex plantations have reduced soil loss by approximately 57 to 80% compared to Atriplex plantations with low density while for the site under fruit plantations and cereals, soil erosion has been decreased by 58% compared to bare soils (Fig.5)

Region	Site	Mean annual rainfall (mm)	Slope	Past land use	Net soil erosion rate (t ha^{-1} yr^{-1})
Rabat	[illegible]	[illegible]	17%	Conventional tillage with cereal/legumes	[illegible]
Tetouan	[illegible]	[illegible]	10%	Conventional tillage with cereals/legumes	[illegible]
	[illegible]	[illegible]	10%	Conventional tillage with cereals/legumes	[illegible]
Chaouia-Ouardigha	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
"Oued Mellah" Watershed	[illegible]	[illegible]	[illegible]	Bare soil	[illegible]
	[illegible]	[illegible]	[illegible]	Cereals	[illegible]
	[illegible]	[illegible]	27%	Degraded forest	[illegible]

Tab.1: Long-term soil erosion rates using ^{137}Cs associated with different study fields

Fig. 4 : Short term soil erosion rates in Marchouch and Harchane sites (Conventional Tillage versus No-Till)

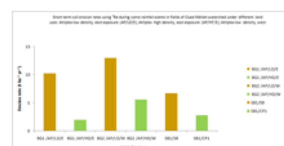


Fig. 5 : Short term soil erosion rates within the Oued Mellah Watershed

CONCLUSIONS

❑ This Moroccan study demonstrated the potential of the ^{137}Cs and ^{7}Be techniques to estimate long- and short-term soil erosion rates and to assess the effectiveness of soil conservation strategies

❑ Isotopic techniques are increasingly applied in agricultural fields and watersheds in Morocco for providing useful and reliable information to decision makers

Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

Assessing the effectiveness of conservation agriculture practices with Caesium-137 radionuclide techniques in semi-arid areas of Zimbabwe

Chikwari. E [1], Mhaka. L [1], Gwandu. T [1], Chipangura. T[1], Shumba. A [1], Manyanga. A [1], Matsenyengwa. S [2], Mabit. L [3], Rabesiranana. N [4]

(1) Chemistry & Soil Research Institute, Department of Research and Specialist Services, Harare, Zimbabwe
(2) Institute of Agricultural Engineering, Department of Agricultural Mechanization, Harare, Zimbabwe
(3) Soil & Water Management and Crop Nutrition Laboratory, FAO/IAEA, Vienna, Austria
(4) Institute of National Sciences and Nuclear Techniques (INSTN), Antananarivo, Madagascar

INTRODUCTION

❑ Soil formation in Zimbabwe is very low (e.g. 0.5 t/ha/yr), whereas rates of soil erosion are much higher.

❑ It has been estimated that in some agricultural areas, the cultivation of maize may only be possible for another 15 years before soils become too shallow to allow any cultivation

Sheet and rill erosion on sandy soils degrade soils, however with appropriate tillage systems and residue cover, soil erosion mitigation is possible !

❑ The study's objectives were:

(i) To test for the first time the use of fallout radionuclide based techniques (i.e. ^{137}Cs) for estimating soil erosion magnitudes under Zimbabwean agro-environmental conditions

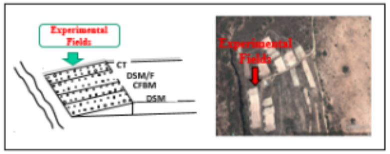
(ii) To assess the effectiveness of conservation agriculture practices in controlling soil erosion using the ^{137}Cs technique

MATERIALS AND METHODS

❑ The study site is located in the Makoholi research station situated 260 km south of Harare (Zimbabwe)

❑ Semi-arid climate, the soils include coarse loamy sands (gleyic lixisols)

❑ Since 1988, the conservation agriculture (CA) practices include (i) direct seeding with mulch (DSM), (ii) CA basins with mulch (CFBF), and (iii) 18 years direct seeding, left fallow for seven years (DSM/F)



❑ For each study plot and the reference site, 10 core samples were collected along equidistant downslope transects and analysed for ^{137}Cs content

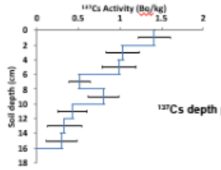
❑ Based on the ^{137}Cs data set, the conversion Mass Balance Model 2 (MBM 2) was used to derive soil redistribution rates

❑ A full sediment budget has then been produced for the plots investigated

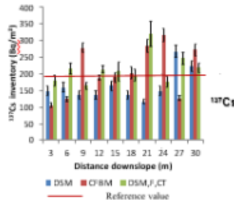
RESULTS AND DISCUSSIONS

❑ The ^{137}Cs inventory at the reference site was 214 Bq/m² (CV =19%; n=10)

❑ The mean ^{137}Cs inventories for DSM, CFBM basins and DSM/F were 194, 190 and 214 Bq/m² respectively



^{137}Cs depth profile for the reference site



^{137}Cs inventories for 3 CA practices

Gross & net erosion rates, sediment delivery ratios at the study site

Farming Practices	Gross Erosion rate (t/ha/yr)	Net Erosion Rate (t/ha/yr)	Sediment Delivery Ratio
Direct Seeding + Mulch (DSM)	7.5	3.8	50%
Conservation Farming Basins + Mulch (CFBF)	7.3	4.6	63%
DSM/Fallow (DSM/F)	2.6	0	2%

CONCLUSIONS

❑ Despite low ^{137}Cs soil content, the ^{137}Cs technique has been successfully tested for assessing field-scale variations in soil loss and soil redistribution

❑ This study highlights that soil erosion can be significantly reduced by using proper soil conservation strategy

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Terraced agriculture protects soil from erosion: Case studies in Madagascar

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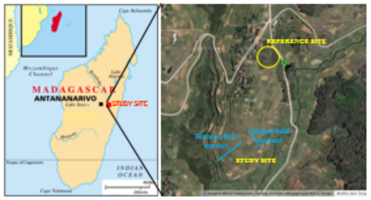
OBJECTIVES

- To produce Malagasy data on soil erosion/sedimentation rates under various agricultural practices
- To assess soil conservation efficiency of traditional agricultural practice

STUDY SITE AND METHODS

STUDY SITE

- Two adjacent cultivated fields (i.e. sloped field & terraced field), located 40 km east of Antananarivo, in Madagascar highlands
- One reference site selected close to the 2 study sites



Sloped field

Terraced field

SAMPLING AND LABORATORY WORK

- Motorized soil corer was used for soil sampling
- Soil samples collected (n = 50)

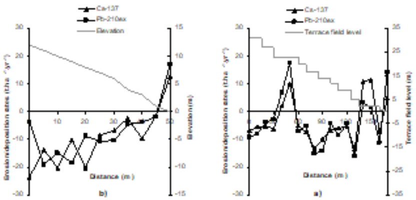
Reference site: 18 bulk + 1 profile
Sloped field: 11 bulk + 1 profile
Terraced field: 18 bulk + 1 profile

- ^{137}Cs and $^{210}Pb_{ex}$ activities were measured simultaneously by gamma spectrometry system with high resolution, low background N-type HPGe detector
- Soil redistribution rates determined by Mass Balance Models (MBMs)

RESULTS AND DISCUSSIONS

INVENTORY

- *Reference site*: ^{137}Cs and $^{210}Pb_{ex}$ inventories are 216 Bq.m^{-2} ± 20% (Mean ± Coefficient of Variation) and 3078 Bq.m^{-2} ± 13%, respectively
- *Sloped field*: ^{137}Cs and $^{210}Pb_{ex}$ inventories vary from 110 Bq.m^{-2} to 280 Bq.m^{-2} and from 2026 Bq.m^{-2} to 4110 Bq.m^{-2}, respectively
- *Terraced field*: ^{137}Cs and $^{210}Pb_{ex}$ inventories vary from 145 Bq.m^{-2} to 280 Bq.m^{-2} and from 2141 Bq.m^{-2} to 4253 Bq.m^{-2}, respectively



Soil redistribution	Sloped field		Terraced field	
	^{137}Cs	$^{210}Pb_{ex}$	^{137}Cs	$^{210}Pb_{ex}$
Mean erosion (t.ha^{-1}.yr^{-1})	9.1	7.9	7.7	8.5
Gross erosion (t.ha^{-1}.yr^{-1})	8.2	7.2	5.5	6.2
Net erosion (t.ha^{-1}.yr^{-1})	7.4	5.9	3.4	3.8
Sediment delivery ratio (%)	89	82	61	61
Eroding area (%)	91	91	72	72

SOIL EROSION RATES

- For the sloped field - using the ^{137}Cs and $^{210}Pb_{ex}$ methods - net soil erosion rates are 7.4 t.ha^{-1}.yr^{-1} and 5.9 t.ha^{-1}.yr^{-1}, respectively
- For the terraced field, net soil erosion rates are 3.4 t.ha^{-1}.yr^{-1} and 3.8 t.ha^{-1}.yr^{-1}, respectively

CONCLUSIONS

- Timeframe discrimination shows that erosion phenomenon has increased in the last 50 years (from ^{137}Cs data) compared to the last 100 years (from $^{210}Pb_{ex}$ data)
- However, results highlight that terraced agricultural practice reduces soil erosion magnitude and therefore, provides an efficient solution to protect soil resources of the Malagasy highlands

Joint FAO/IAEA Programme
Nuclear Techniques in Food and Agriculture

Test of a new stable isotopic fingerprinting technique (i.e. Compound Specific Stable Isotope) in a sub-catchment to establish agricultural soil source contribution to deposited sediment

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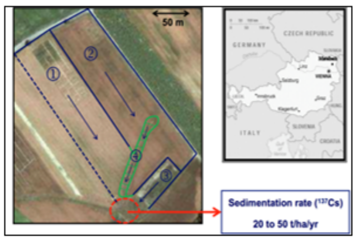
1. Background & Objectives of the study

- The aims of this study performed in Austria were:
  - ✓ *To test the compound-specific stable isotope (CSSI) approach to distinguish the different sediment sources which contribute to the sedimentation area;*
  - ✓ *To distinguish the best fatty acids (FAs) indicators according to the land use of the sources & the sedimentation area;*
  - ✓ *To assess the contribution of each connected source to the sedimentation area.*
- In the Mistelbach watershed, **one sediment mixture** and **four contributing sources** [three agricultural fields (*S1*, *S2*, *S3*) & one grassed waterway (*S4*)] were investigated.



- $\delta^{13}C$ of four fatty acids (FAs) (i.e. $\delta^{13}C_{16:0}$ $\delta^{13}C_{18:0}$ $\delta^{13}C_{22:0}$ $\delta^{13}C_{24:0}$) and $\delta^{13}C$ of the soil bulk carbon has been measured in the sources & the mixture.

Table 1. *Bulk organic carbon information of the sources & the sediment mixture*

Bulk soil	Source 1	Source 2	Source 3	Source 4	Mixture
$\delta^{13}C$ organic carbon (‰)	-25.05	-24.16	-14.89	-18.65	-17.32
Organic carbon (% C_{org})	1.36	1.70	2.53	3.82	3.19

Table 2. *$\delta^{13}C$ signatures of the FAs present in the sources & the sediment mixture*

FAs (in $\delta^{13}C$ ‰)	Source 1	Source 2	Source 3	Source 4	Mixture
Myristic acid ($C_{14:0}$)	NA	NA	-26.33	NA	-37.37
Palmitic acid ($C_{16:0}$)	-21.84	-26.26	-22.85	-26.88	-27.70
Palmitoleic acid ($C_{16:1}$)	NA	NA	NA	-27.72	-29.26
Stearic acid ($C_{18:0}$)	-24.36	-27.8	-22.92	-25.73	-29.75
Oleic acid ($C_{18:1}$)	-26.02	NA	-22.66	-30.23	-29.78
Linoleic acid ($C_{18:2}$)	-23.52	-26.29	-22.49	-38.96	-26.67
Arachidic acid ($C_{20:0}$)	NA	NA	-27.74	-32.7	-34.54
Behenic acid ($C_{22:0}$)	-32.44	-33.39	-30.73	-34.90	-33.23
Lignoceric acid ($C_{24:0}$)	-30.09	-31.44	-28.89	-32.24	-32.99

2. Selection of the best isotopic tracers

- Principal Component Analysis to establish correlation among FAs & sources
- Based on PCA results, one-way analysis of variance is used to exclude tracers which have no significant difference

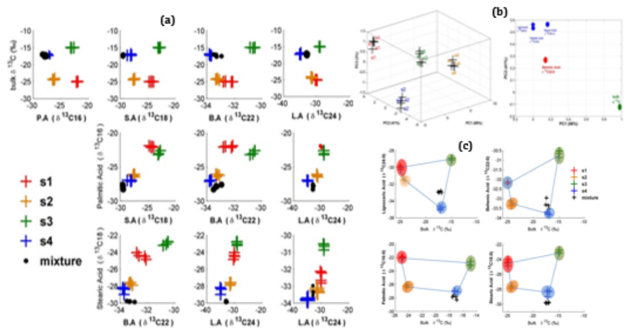


Fig.2. *Determination process for the best suitable FAs: (a) visualization of all possible combination, (b) projection on principal component axis of sources & tracers, (c) mixing polygons of selected FAs contributing to the mixture*

3. Apportioning source contribution

- Sources contribution to the mixture using 4 mixing models (i.e. IsoSource, SIAR*, SIMMR*, MixSIAR*)
- (*) Bayesian approach of source apportioning is given by equation (1)

$$y_i \sim N\left(\sum_{k=1}^{k} p_k S_k, \sigma^2\right) \qquad (1)$$

$s_k \sim N(\mu_{sk}, \sigma^2_{sk})$; $\sigma \sim u(0,n)$
Y_i is the isotope value, **s** are the source values, **p** are the soil proportions and σ the standard deviation.
The goal is to estimate the **p** and its uncertainty.

- The output from each mixing model was expressed **as isotopic proportions.**
- These isotopic proportions were converted to soil proportions based on the bulk $\%C_{org}$ (*Table 1*) using the linear conversion equation (2) from **Gibbs (2008)**:

$$S_n(\%) = \frac{I_n/C_n\%}{\sum_1^n I_n/C_n\%} \qquad (2)$$

I_n is the mean feasible isotopic proportion of source soil n in the mixture estimated using an isotopic mixing model and $C_n\%$ is the $\%C_{org}$ in the source soil.

4. Results & Discussions

Fig. 3. *Probability distribution function of the soil proportion of each source to the mixture at the highest credible interval (i.e. 97.25%) for the three mixing models i.e. SIAR, SIMMRS, MixSIAR*

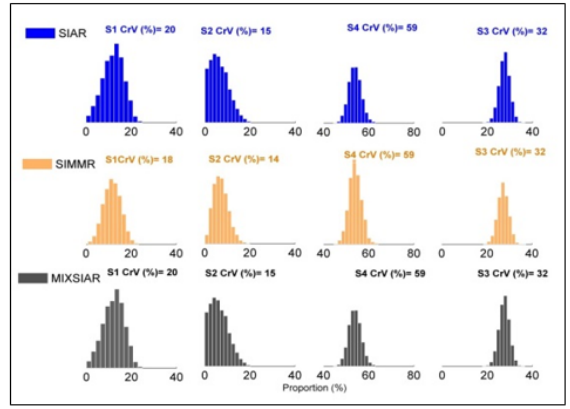


Table 3. *Comparison of the mean soil proportion of the sources with their respective standard error using IsoSource, SIAR, MixSIAR, SIMMR*

	IsoSource	SIAR		MixSIAR		SIMMR	
SOURCES	Proportion (%)	Proportion (%)	se	Proportion (%)	se	Proportion (%)	se
SOURCE 1	4.28	12.10	±0.08	12.10	±0.08	11.70	±0.07
SOURCE 2	15.43	6.40	±0.07	6.40	±0.07	7.10	±0.06
SOURCE 3	26.47	27.60	±0.04	27.60	±0.04	27.20	±0.04
SOURCE 4	53.81	53.90	±0.05	53.90	±0.05	54.00	±0.05

Fig. 4. *Past historical land use & crop rotation of Mistelbach watershed*
NB: (*) C4 plants

	Source 1	Source 2	Source 3	Source 4
1990	spring barley	sunflower	sunflower	sunflower
1991	sunflower	winter wheat	winter wheat	winter wheat
1992	winter wheat	winter wheat	winter wheat	winter wheat
1993	sugar beet	sugar beet	sugar beet	sugar beet
1994	spring barley	spring barley	maize (*)	maize (*)
1995	sunflower	sunflower	winter wheat	winter wheat
1996	winter wheat	winter wheat	sugar beet	sugar beet
1997	spring barley	sugar beet	spring barley	spring barley
1998	pea	spring barley	sunflower	sunflower
1999	winter wheat	rapeseed	winter wheat	winter wheat
2000	sugar beet	winter wheat	maize (*)	maize (*)
2001	spring barley	pea	winter wheat	winter wheat
2002	sunflower	rapeseed	maize (*)	maize (*)

	Source 1	Source 2	Source 3	Source 4
2003	winter wheat	maize (*)	winter wheat	grassed waterway
2004	sugar beet	winter wheat	sunflower	grassed waterway
2005	spring barley	sugar beet	winter wheat	grassed waterway
2006	rapeseed	pea	maize (*)	grassed waterway
2007	winter wheat	winter wheat	winter wheat	grassed waterway
2008	winter barley	sugar beet	maize (*)	grassed waterway
2009	sugar beet	sunflower	winter wheat	grassed waterway
2010	spring barley	winter wheat	maize (*)	grassed waterway
2011	winter wheat	winter wheat	winter wheat	grassed waterway
2012	sunflower	sugar beet	sunflower	grassed waterway

5. Conclusion

- An alternative statistical approach for selecting the best suitable FAs as soil/sediment fingerprints has been tested & validated
- All mixing models highlight that S4 is the main contribution to the sediment mixture
- This study demonstrates the complementarity of FRNs and CSSI techniques

Managing agricultural water and land degradation

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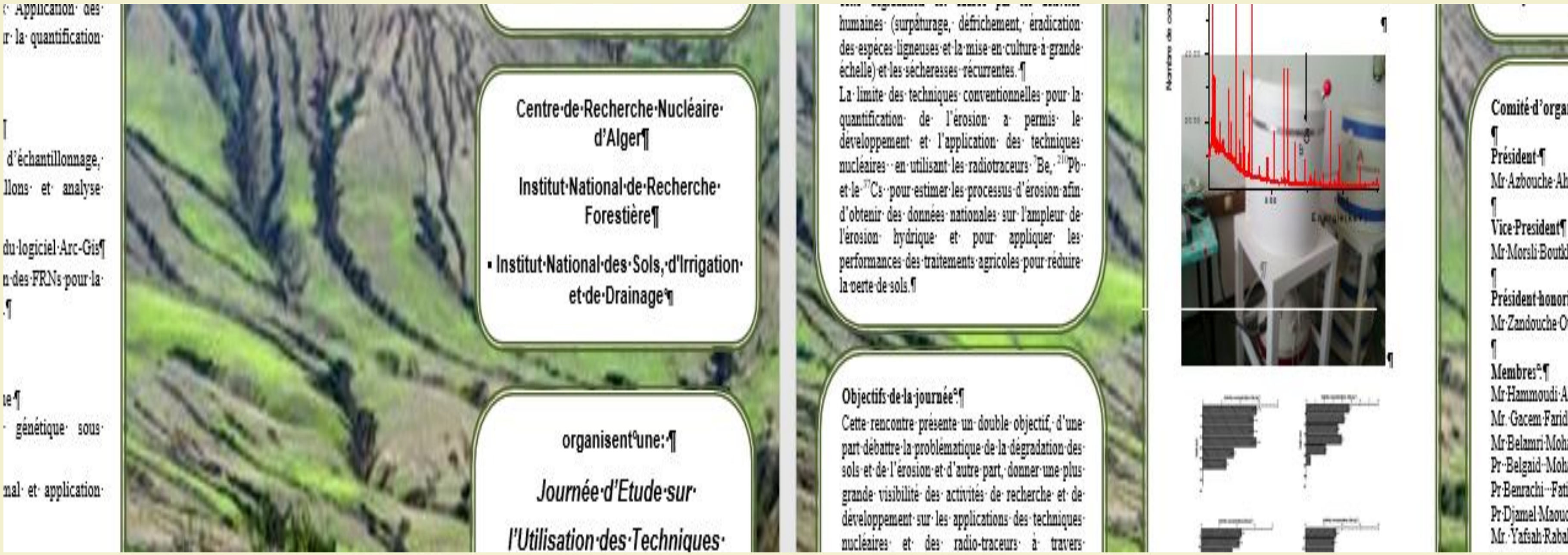
... Application des ...
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... nal et application ...

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organisent une :

Journée d'Etude sur l'Utilisation des Techniques

... humaines (surpâturage, défrichement, éradication des espèces ligneuses et la mise en culture à grande échelle) et les sécheresses récurrentes.

La limite des techniques conventionnelles pour la quantification de l'érosion a permis le développement et l'application des techniques nucléaires en utilisant les radiotraceurs ^{7}Be, ^{210}Pb et le ^{137}Cs pour estimer les processus d'érosion afin d'obtenir des données nationales sur l'ampleur de l'érosion hydrique et pour appliquer les performances des traitements agricoles pour réduire la perte de sols.

Objectifs de la journée :

Cette rencontre présente un double objectif, d'une part débattre la problématique de la dégradation des sols et de l'érosion et d'autre part, donner une plus grande visibilité des activités de recherche et de développement sur les applications des techniques nucléaires et des radio-traceurs à travers ...

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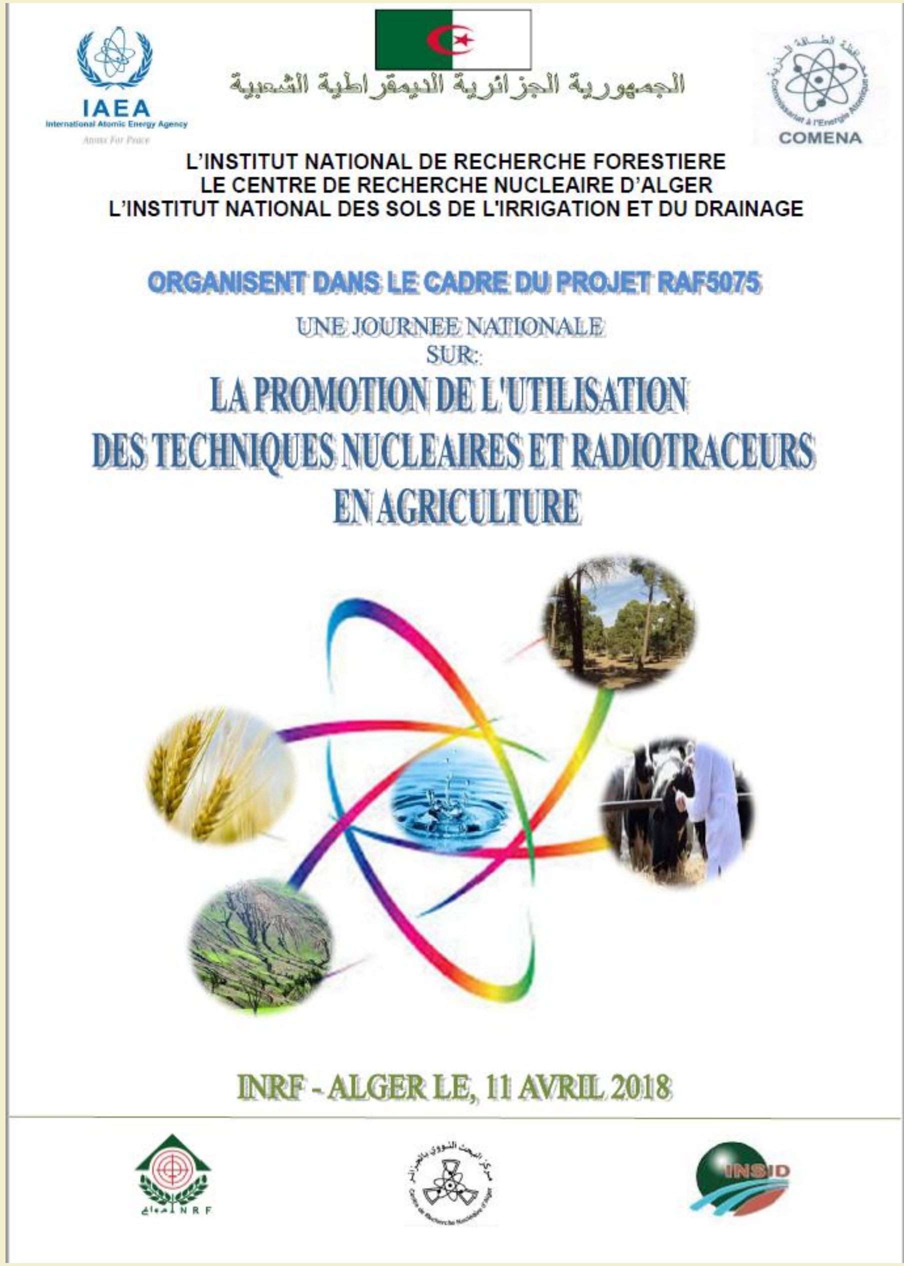
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EFFECT OF TILLAGE AND MULCHING ON SOIL WATER EROSION IN LINSINLIN WATERSHED, CENTRE OF BENIN

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Isohypse tillage

Mulching

water erosion

Watershed

Djidja

ABSTRACT

Soils degradation in Benin is most commonly reported thread for the agricultural production and this situation became more crucial in the Centre of Benin. This study has been carried out to evaluate the contribution of farmer's soil conservation practices to combat soil erosion in the agricultural watershed of Linsinlin. A field experiment was conducted on loamy-sand soil using Fisher Block design under researcher management. The factors which testified during study were tillage and mulching. The "Runoff plot" system was installed to collect erosion data. Three rainfall episodes viz, June 15, 19 and 27, 2016 with 52, 27 and 57 mm of water were used for the data collection. Rain distribution was measured for each rainy episode using a rain gauge. These three rainy episodes constitute a repetition

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ASSESSMENT OF THE LEVEL OF SOIL DEGRADATION IN THREE WATERSHEDS AFFECTED BY INTENSIVE FARMING PRACTICES IN BENIN

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ABSTRACT

Soil degradation is a serious problem for people living in watersheds of Benin. This degradation is mainly due to poor farming practices and because of this poor management annual maize production reduced critically. This study was aimed to estimate the state of physical and chemical soil degradation of three watersheds of southern Benin. One reference site representing sacred forest was also chosen for comparing the results of watershed. Soil cores were also collected from these selected sites. Physical and chemical parameters were determined from the collected soil samples. Results of study revealed that the watershed soil is more compact and lower in nutrients than the soil of reference sites. The bulk soil density was significantly higher in Gović and Lokogba watersheds compared to their reference site. As a result of intensive farming and water erosion, root biomass of the soil has significantly decreased from 86 to 82% in Gović, 69 to 67% in Lokogba and 75 to 70% in Linsinlin. The total soil nitrogen of watershed declined significantly, from 33 to 24% in Gović, 32 to 30% in Lokogba and 38 to 25% in Linsinlin. Available soil phosphorus decreased from 10.93 ppm to 7.11 ppm in the Lokogba watershed. The soil phosphorus of Linsinlin watershed was reported highest from 5.5 ppm to 8.00 ppm compared to the reference site. The soil organic matter of watershed declined from 38 to 37% in Gović and 68 to 66% in Lokogba. Lokogba watershed is the most degraded one compared to three watersheds studied.

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ELSEVIER

Assessment of soil redistribution rates by ^{137}Cs and $^{210}Pb_{ex}$ in a typical Malagasy agricultural field

CrossMark

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ABSTRACT

Soil degradation processes affect more than one-third of the Malagasy territory and are considered as the major environmental threat impacting the natural resources of the island. This innovative study reports about a pioneer test and use of radio-isotopic techniques (i.e. Cs-137 and Pb-210ex) under Madagascar agroclimatic condition to evaluate soil erosion magnitude. This preliminary investigation has been conducted in a small agricultural field situated in the eastern central highland of Madagascar, 40 km East from Antananarivo. Both anthropogenic Cs-137 and geogenic Pb-210 soil tracers provided similar results highlighting soil erosion rates reaching locally 18 t ha^{-1} yr^{-1}, a level almost two times higher than the sustainable soil loss rate under Madagascar agroclimatic condition. The sediment delivery ratio established with both radiotracers was above 80% indicating that most of the mobilized sediment exits the field.

Assessing soil erosion rate through fallout radionuclides in Madagascar is a first step towards an efficient land and water resource management policy to optimise the effectiveness of future agricultural soil conservation practices.

1. Introduction

Soil degradation induced by human activity is a major concern in Madagascar. Its severity is very high for 21.9 percent of the area (130 081 km^2), high for 48.2 percent (286 007 km^2), moderate for 24.5 percent (145 153 km^2) and low for only 4.6 percent (27 094 km^2) (FAO, 2004). To summarise, more than 30% of the island's total soil area, covering 184 338 km^2, is degraded.

Soil erosion, the most common form of soil degradation, is present in all its aspects: rill and sheet erosions, landslides, gully erosion and its most emblematic form, the "*lavaka*".

Soil erosion and sedimentation cause not only on-site degradation of non-renewable natural resources, but also off-site problems such as downstream sediment deposition in agricultural fields, floodplains and water streams. These impacting problems on soil fertility and crop productivity in agricultural land, on water

well documented (e.g. Pimentel, 2006; UNEP, 1992; Walling, 2000). Due to their impact on the sustainability of agricultural production, there is a clear need to acquire quantitative data on the extent, magnitude and actual rates of erosion/sedimentation as well as on their economic and environmental consequences.

From the mid-1950s, research activities on soil erosion and soil protection have been conducted intensively in Madagascar, resulting in more than 4200 scientific articles and technical documents (Chabalier, 2006). Studies were performed mainly using Wischmeier erosion plots, for 6 climatic zones in 20 sites, and at the catchment level in 11 sites. Experiments involved quantification of erosion extent, determination of Wischmeier equation parameters for local conditions, investigation on vegetation covering and agricultural practice effects (Chabalier, 2006). Most of the studies lasted 2–7 years. Long term experiments were rare because of logistic difficulties and maintenance cost.

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ELSEVIER

Assessment of soil erosion and deposition rates in a Moroccan agricultural field using fallout ^{137}Cs and $^{210}Pb_{ex}$

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RUSLE 2

ABSTRACT

In Morocco land degradation – mainly caused by soil erosion – is one of the most serious agro-environmental threats encountered. However, only limited data are available on the actual magnitude of soil erosion. The study site investigated was an agricultural field located in Marchouch (6°42′ W, 33° 47′ N) at 68 km south east from Rabat.

This work demonstrates the potential of the combined use of ^{137}Cs, $^{210}Pb_{ex}$ as radioisotopic soil tracers to estimate mid and long term erosion and deposition rates under Mediterranean agricultural areas.

The net soil erosion rates obtained were comparable, 14.3 t ha^{-1} yr^{-1} and 12.1 ha^{-1} yr^{-1} for ^{137}Cs and $^{210}Pb_{ex}$ respectively, resulting in a similar sediment delivery ratio of about 92%. Soil redistribution patterns of the study field were established using a simple spatialisation approach. The resulting maps generated by the use of both radionuclides were similar, indicating that the soil erosion processes has not changed significantly over the last 100 years. Over the previous 10 year period, the additional results provided by the test of the prediction model RUSLE 2 provided results of the same order of magnitude.

Based on the ^{137}Cs dataset established, the contribution of the tillage erosion impact has been evaluated with the Mass Balance Model 3 and compared to the result obtained with the Mass Balance Model 2. The findings highlighted that water erosion is the leading process in this Moroccan cultivated field, tillage erosion under the experimental condition being the main translocation process within the site without a significant and major impact on the net erosion.

1. Introduction

With only 19% of its land arable, Morocco faces major environmental challenges and pressure on soil and water resources. This is true for many developing countries in Africa experiencing economic growth which is the consequence of urbanisation, limited funds available for natural resource management and a nascent legal and regulatory framework for environmental protection. Due to the intensification of agricultural practices leading to unsustainable farming practices (e.g. inappropriate tillage practices, straw exportation, overgrazing) and specific bio-climatic conditions (e.g. recurring and severe droughts), more than 15 million hectares of the Moroccan agricultural land is under

on-site impact of erosion on the agricultural Moroccan landscape is the reduction of soil fertility, the main off-site impact being dominated by an increase of siltation processes in water reservoirs. It was estimated that out of 22.7 million hectares potentially exploitable in the Northern part of Morocco, 77% are exposed to very high erosion risks (Belkheri, 1988). The Global Assessment of Human Induced Soil Degradation (GLASOD) survey carried out during the 1980's by the United Nations Environment Programme (UNEP) and the International Soil Reference and Information Centre (ISRIC) established that the severity of human induced degradation has been classified as severe and very severe for more than 20% of the Moroccan territory (FAO, 2005).

In fact, around 100 million tons yr^{-1} of soil is lost and the

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SPECIAL ISSUE ARTICLE

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Promoting the use of isotopic techniques to combat soil erosion: An overview of the key role played by the SWMCN Subprogramme of the Joint FAO/IAEA Division over the last 20 years

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Abstract

The International Atomic Energy Agency (IAEA), through the Joint Division with the Food and Agriculture Organization (FAO) of the United Nations, assists its Member States in applying nuclear techniques to alleviate challenges in food safety, food security and sustainable agricultural development. The Soil and Water Management & Crop Nutrition (SWMCN) Subprogramme, within the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, has made significant contributions to the development of isotopic techniques for the assessment of soil degradation and the development of efficient soil and land conservation approaches. These techniques include fallout radionuclides such as ^{137}Cs, ^{210}Pb$_{ex}$, ^{7}Be, and $^{239+240}$Pu as well as ^{13}C stable isotope and compound-specific stable isotope analyses. These methodologies were developed and/or refined through the work of researchers from developed and developing countries who were selected to work within the frame of IAEA's Coordinated Research Projects (CRPs). Internal research activities implemented in the Joint FAO/IAEA's SWMCN Laboratory in Seibersdorf supported the work accomplished in the CRPs.

The methodologies thus developed have been subsequently disseminated to developing countries by IAEA's Technical Cooperation Programme to assist Member States to adopt climate-smart agriculture and reduce soil degradation that poses a threat to food security and the environment. This review paper provides an overview of the activities conducted in the frame of CRPs for combating soil erosion over the last 20 years and highlights the major achievements. Examples of the success and the impact obtained in Morocco, Madagascar, and Vietnam in using these isotopic techniques are presented.

KEYWORDS
climate change, fallout radionuclides, soil degradation, soil tracers, stable isotopes

8.1 | Assessing the effectiveness of terraced agriculture in Madagascar's agricultural highlands through the use of FRNs

Soil degradation—mostly due to soil erosion—is of national concern in Madagascar. According to the FAO, around one third of the island's total soil area is degraded (Nachtergaele et al., 2011). To establish effective conservation strategies, trustworthy rates of soil erosion/sedimentation under different Malagasy land uses are required.

In partnership with the "Institut National des Sciences et Techniques Nucléaires" (INSTN—Madagascar) based in Antananarivo, the SWMCN Subprogramme investigated soil erosion problems in order to strengthen the resilience and ability of the Malagasy smallholder farmers to ensure food security. Thus, for the first time, fallout ^{137}Cs and ^{210}Pb$_{ex}$ methods were tested effectively in Madagascar with the objective of investigating the effects of traditional agricultural practices utilized on hillslopes (Rabesiranana et al., 2016).

Soil erosion rates of an unprotected agricultural field and a terraced field were quantified in an experimental study area located in the eastern central highlands, 40 km east of Antananarivo (Photo 1).

As reported by Rabesiranana et al. (2016), this pioneer use of FRNs (i.e., ^{137}Cs and ^{210}Pb$_{ex}$) demonstrated that, in promoting the use of traditional terrace systems, soil erosion can be reduced by up to 40%. This Malagasy study also highlighted that traditional terracing could significantly limit the transfer of sediment and therefore the downstream potential off-site impact of the agro-ecosystems in allowing a better soil redistribution within the agricultural fields.

8.2 | FRN techniques contribute to the improvement of soil conservation in Moroccan agro-ecosystems

In Morocco, reducing on-site and off-site impacts associated with soil erosion and land degradation is a major concern for improving soil quality and protecting downstream water quality and quantity. Soil erosion is the main land degradation process in Morocco and affects at least 13% of its land area (Nachtergaele et al., 2011).

In partnership with the SWMCN Subprogramme, the Centre National de l'Énergie des Sciences et Techniques Nucléaires (CNESTEN) and its local Moroccan partners investigated soil degradation using FRN techniques (i.e., ^{137}Cs and ^{7}Be) to contribute directly to agricultural decision making at the national level.

Photo 1. INSTN – Madagascar team performing soil sampling prior to ^{137}Cs and ^{210}Pb$_{ex}$ determination by gamma spectroscopy for assessing soil erosion magnitude (© Naivo Rabesiranana, INSTN–Madagascar)

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Special cooperation

Exploitation of the results of TCPs for cooperation with international organizations and education institutions

Cooperation with International Institute for Applied Systems Analysis (IIASA) and University Colleague of London (UCL)

Working with IIASA's Resources and Environment Group.

Objectives: To test the use of soil erosion data based on FRN for validation of erosion model EPIC (USLE, RUSLE, MUSLE, MUSS) for erosion prediction at regional level

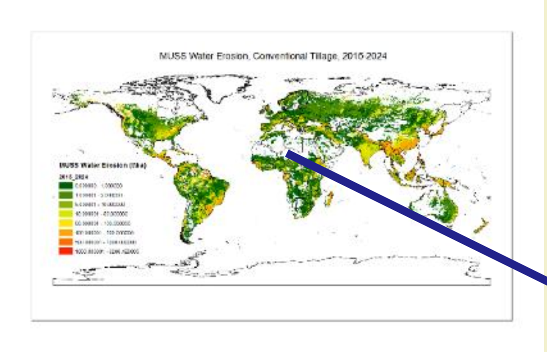
Steps undertaken:

- Participating on the IIASA Workshop (Laxemburg, October 24th, 2017)
  - Presenting information on the NAFA activities related to soil erosion
  - Discussing the work plan for cooperation
- Investigation of published data on soil erosion rates derived from FRN from tropical and arid regions (South China, South Asia, Australia, Africa and Latin America)
- Building the database, processing of metadata and data preparation for model validation

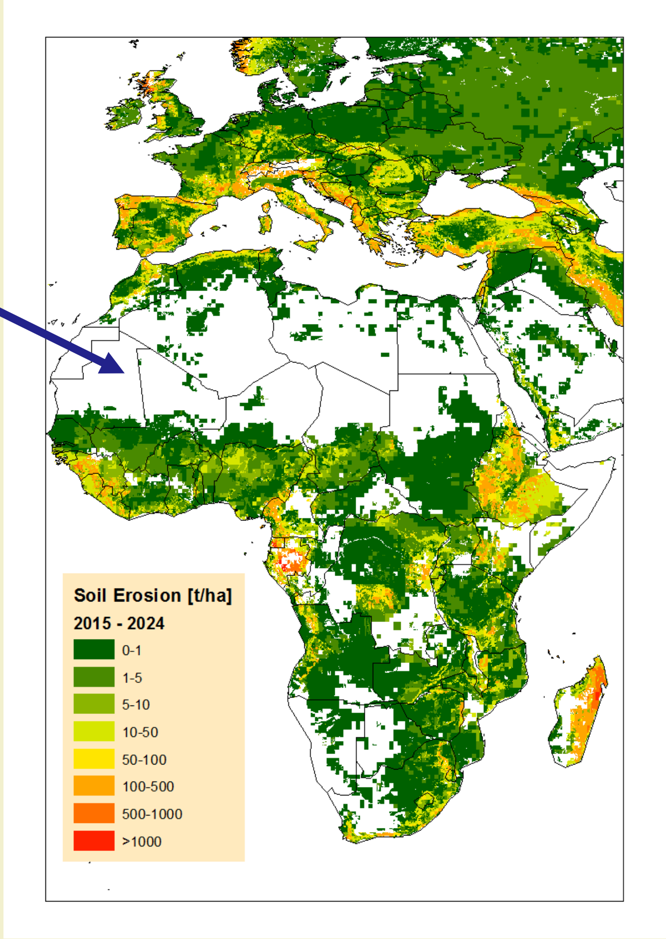
IIASA Workshop 'Joint Land Potential and Modeling Soil Erosion with EPIC in Humid and sub Humid Tropical Regions, October 24th, 2017

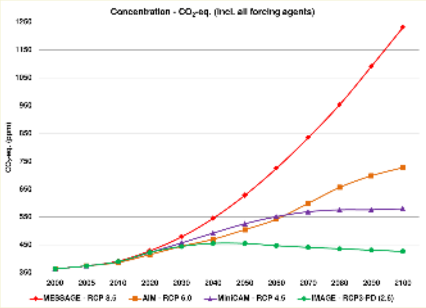
Presentations on NAFA Activities:

- **Fulajtar, E.: Principles of fallout radionuclide methods (FRN) for soil erosion assessment with focus to Cs-137 method**
- **Fulajtar, E.: Soil erosion rates on tropical and sub-tropical regions estimated by FRN methods collected by IAEA and collaborating partners**
- **Fulajtar, E.: IAEA activities at the field of soil erosion and possible cooperation with IIASA**



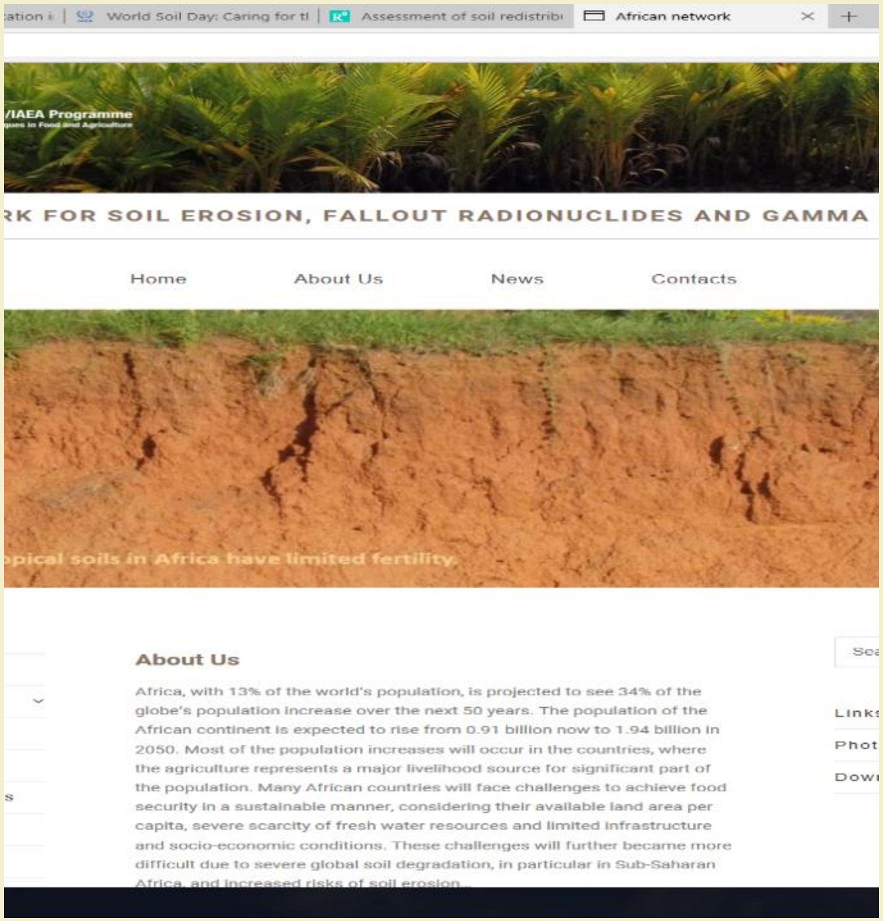
Carr, D., Skalsky, R., Balkovic, J. Example of erosion modelling at global scale using EPIC - *MUSS* (Modified Universal Soil [Loss Equation] Small [Watershed]) equation.

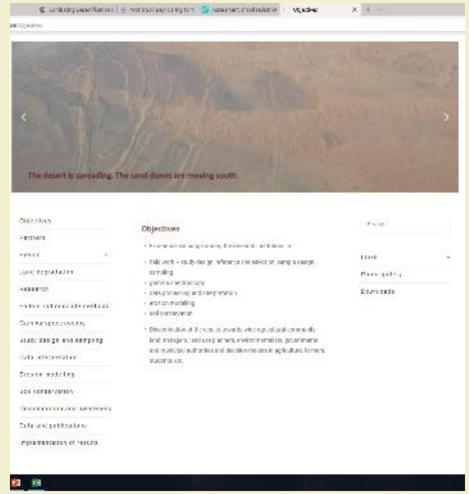


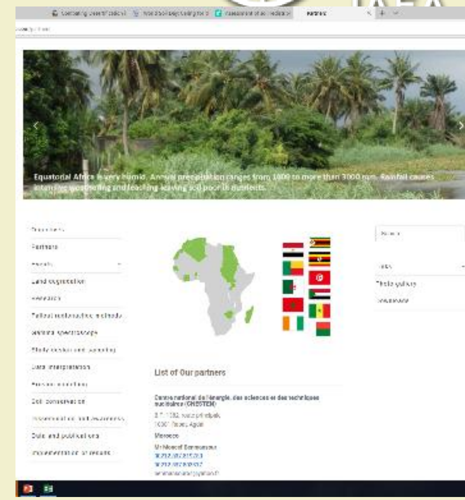


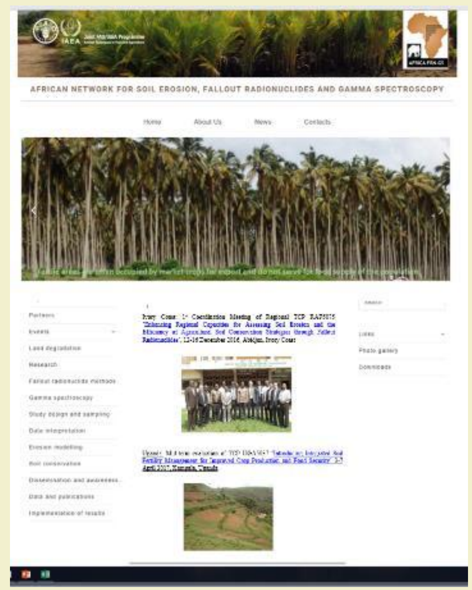
African Network for Soil Erosion, Fallout Radionuclides and Gamma Spectrometry

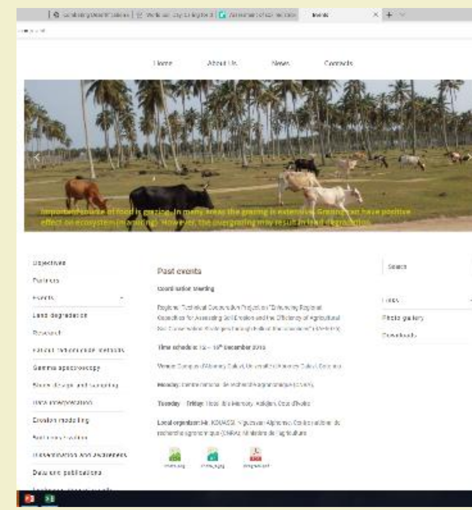
https://atanasovs.000webhostapp.com











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Establishing Regional Network in Africa (11 countries):

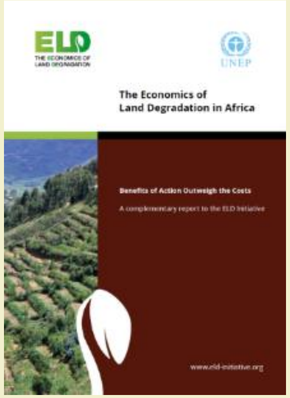
African Network for Soil Erosion, Fallout Radionuclides and Gamma Spectrometry

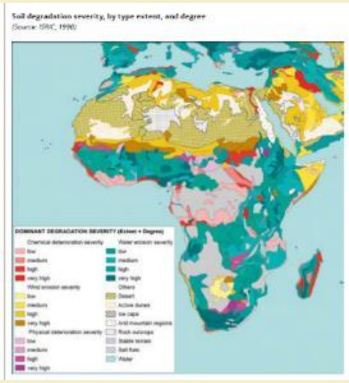
Objectives:

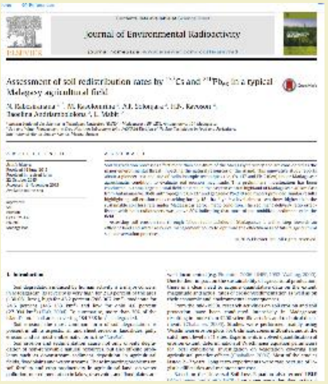
- Exchange of experience in gamma spectroscopy laboratory works and maintenance of equipment
- Exchange of experience in field work (sampling strategy, design and sample collection)
- Exchange of experience in data processing, interpretation, geostatistics and modelling
- Building information base on erosion spatial and temporal distribution in Africa

Steps undertaken:

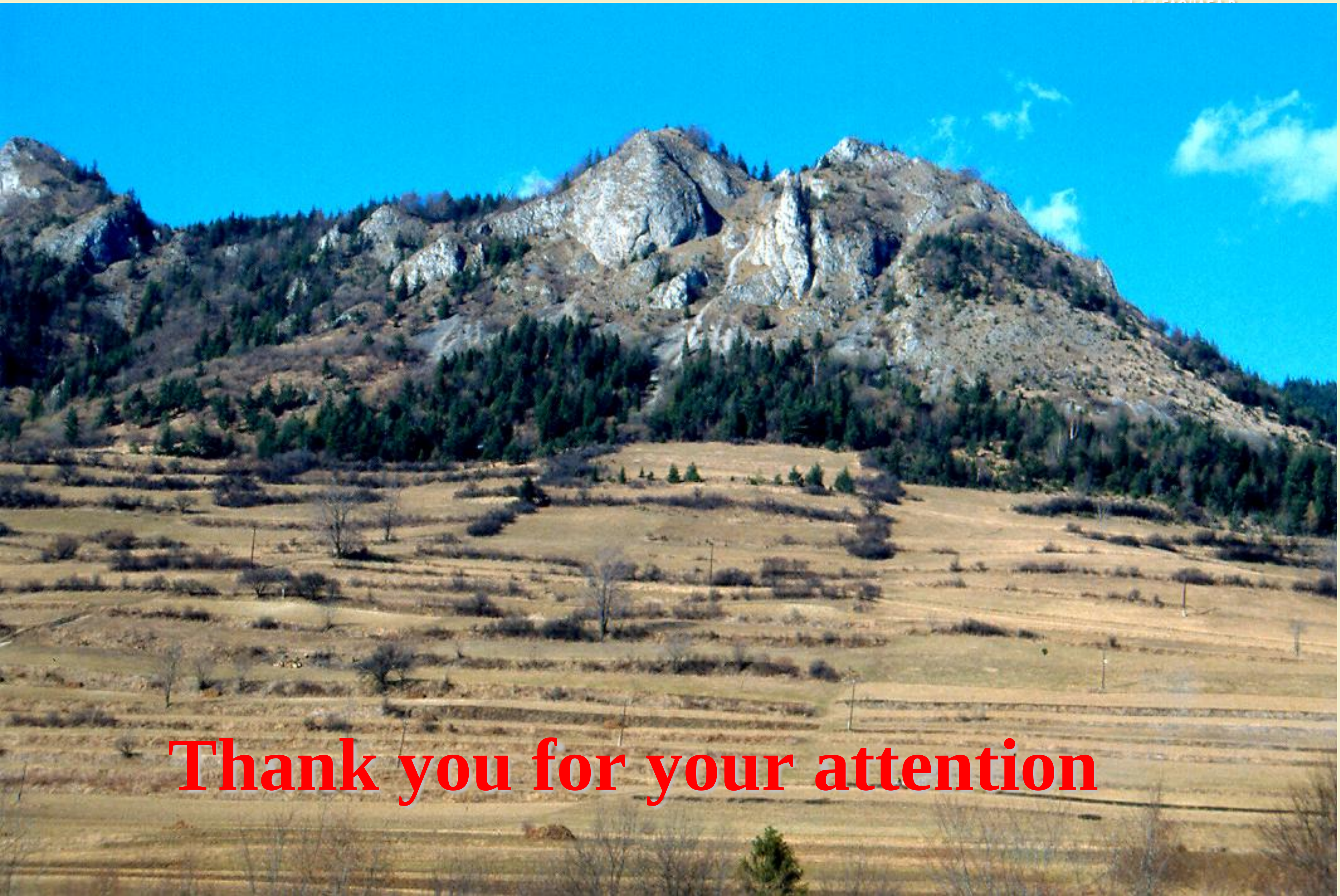
- Establishing the network through the communication with member states
- Establishing website https://atanasovs.000webhostapp.com
- Starting to build database on soil erosion and initiating information exchange
- Communication towards the Land degradation group of UNEP






Journal of Environmental Radioactivity

Assessment of soil redistribution rates by ^{137}Cs and $^{210}Pb_{ex}$ in a typical Malagasy agricultural field


Thank you for your attention