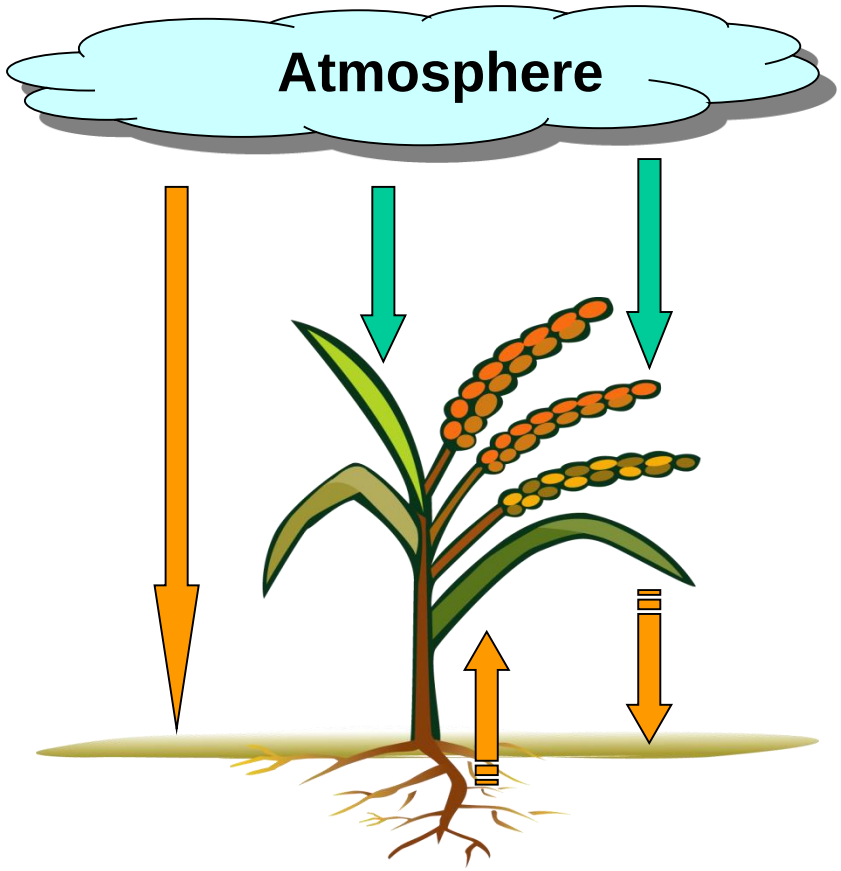
방사선환경영향평가 활용을 위한 농작물 방사성 핵종 전이 연구

최 용 호

여수 엑스포컨벤션센타, 2018년 10월 24일

➢ Transfer Pathways of RNs to Food Crops



▶ 작물체 직접오염 경로
: 침적 및 엽면흡수
- 작물체 차단/잔류
- 가식부로의 전류 (translocation)

▶ 작물체 간접오염 경로
: 지표침적 및 뿌리흡수
- 핵종의 토양-작물체 전이 (soil-to-plant transfer)
→ 전이계수(transfer factor)

▣ INTRODUCTION: Background

- The first commercial NPP of Korea began to operate in 1978 and soil-to-plant transfer factors (TFs) of radionuclides started to be measured in early 1980s.
  : 1981 for soybean & 1982 for rice

- In Korea, such measurements have been carried out almost exclusively by KAERI up to now.

- Rice is the most important staple food in Korea.
  : Per capita annual consumption is about 62 kg in 2017.
  : About 11% of the total land area is paddy field.

▣ INTRODUCTION: Definition

➢ **Definition of TF (F_v in TRS 472 of the IAEA)**

: 토양 중 농도에 대한 작물체 내 농도의 비(dimensionless)

$$TF = \frac{Plant\ concentration\ (Bq\ kg^{-1} - dry\ or\ fresh)}{Soil\ concentration\ (Bq\ kg^{-1} - dry)}$$

- 통상적 수확 시 작물체 가식부위 내 농도

- 유효토양깊이(20cm by IAEA) 내 균일 혼합 토양 농도

- 작물 수확 시로 붕괴 보정한 초기 토양 농도

▣ Overview of the Research History

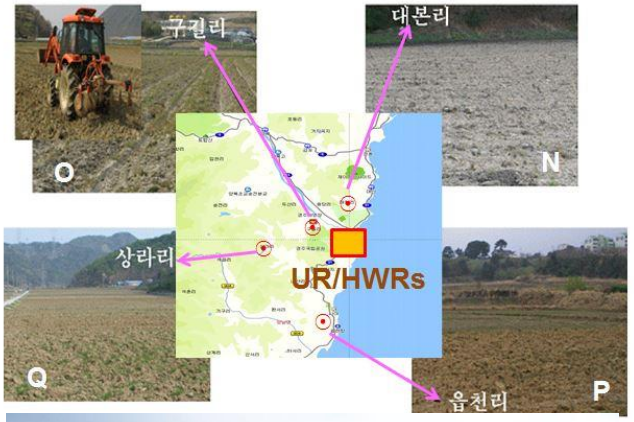
1980s : **in greenhouses built with PE film**

- TF values measured through pot experiments
- Cs, Sr, Mn, Co, Zn in up to 10 different soils for rice, soybean, vegetables and so on

▣ Overview of the Research History

➢ A glass greenhouse for RI experiments built in 1993

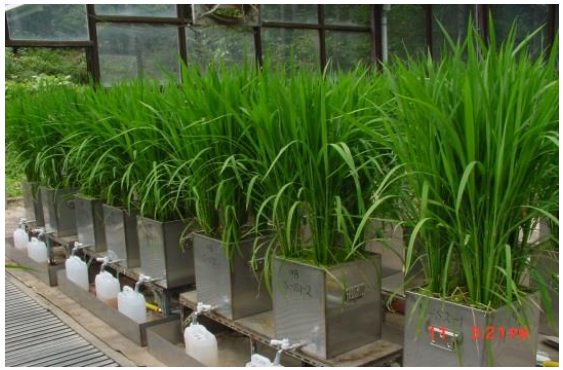
- For 2007 ~2010, TFs of Cs, Sr, I and/or Tc for rice, soybean, Chinese cabbage and radish in 2~4 soils
- Soils were collected around Gyeongju nuclear site



▣ Overview of the Research History

2007~2010 : **TF experiments in the glasshouse**

- **Plants were grown in small lysimeters or pots.**


▣ Overview of the Research History

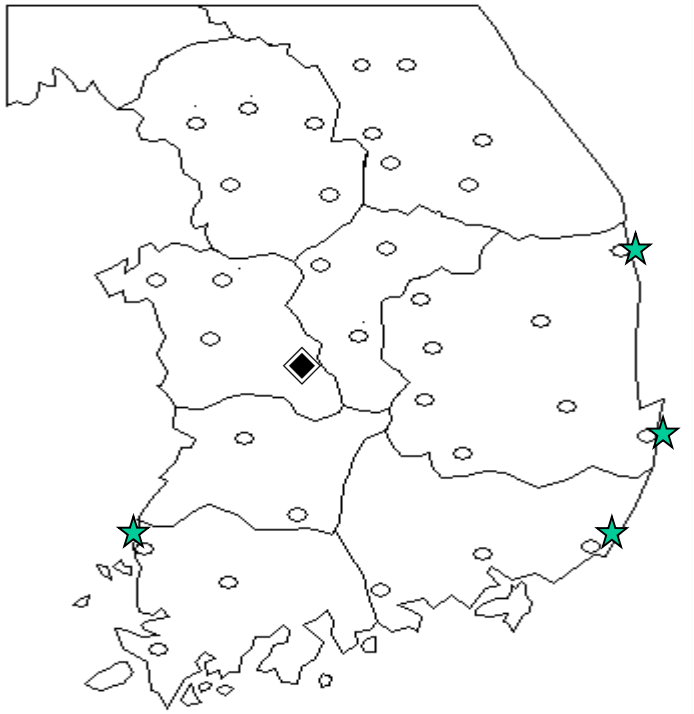
➢ **The glasshouse was renewed in 2016.**

2017~present : in the renewed greenhouse

- **TF experiments for Cs and Sr in Kori and Yeonggwang soils**
  : to investigate the effects of agrochemicals (KCl & slaked lime)
  - rice & shallot in Kori soils for 2017
  - potato and onion in YG soils for 2018, Chinese cabbage for 2019
  - rice grown in small lysimeters and others in plastic pots

▣ Overview of the Research History

1994 & ’95 : Field study for fallout ^{137}Cs



★ NPP site ◈ KAERI

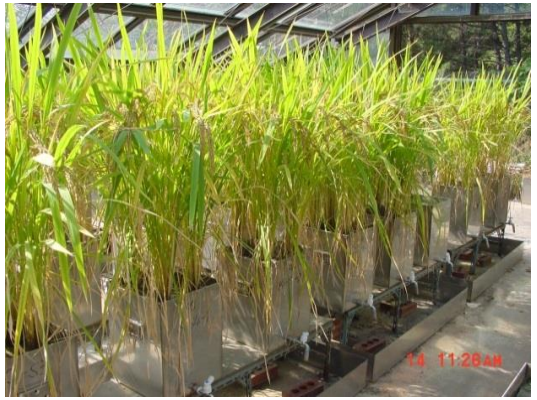
- For rice and Chinese cabbage
- plant & soil samplings in 33 areas at around harvest times
- mostly loam or sandy-loam soils of pH 4.3~6.8 and O.M. 2~4%
- 12 TF values of ^{137}Cs acquired for each plant species

▣ Materials and Methods

- Soils & RI solutions were mixed for the top 15~20 cm soil layers of the pot or lysimeters before planting.
- Pre-mixing followed by main mixing





▣ Materials and Methods

▪ Physicochemical properties of the soils

: generally characteristic of the soil weathered from granite.

(일반적 특성)

- pH : 5~6.7
- 유기물함량 : 1.0~4.0%
- 양이온치환용량 : 7~20 $cmol_+$ kg^-dry soil
- 치환성 K : 0.2~1.0 $cmol_+$ kg^-dry soil
- 치환성 Ca : 3.0~10 $cmol_+$ kg^-dry soil
- 토성(texture) : 모래나 미사 ↑, 점토 ↓ SL~L (양토 계통)

: 대체로 TF 값이 보다 높을 수 있는 조건

▣ Materials and Methods

- Gamma emitters were mixed together.
  - (^{65}Zn, [^{54}Mn, ^{60}Co, {^{137}Cs]), ^{85}Sr, ^{125}I}
- Pure beta emitters were mixed individually.
  - ^{90}Sr, ^{99}Tc
- Plants were harvested at edible maturity.
  - Dried samples were analyzed for activity concentrations
    : γ-spectrometer / GM or proportional counter
- Soil concentrations ($S_{initial}$ or $S_{harvest}$)
  - determined as initial concentrations with spiking activities
  - or determined with the activities measured for soil samples collected at plant harvest

$$TF = \frac{Plant\ concentration\ (Bq\ kg^{-1} - dry\ or\ fresh)}{S_{initial,\ decay\ -\ corrected}\ or\ S_{harevst}\ (Bq\ kg^{-1} - dry)}$$

▣ Results and Discussions

- **No. of the TF values acquired for rice : by different soils**

Plant compartment	No of TF values per radio-element							
	Co	Mn	Zn	Cs [a]	Sr	I	Tc	Total
Brown rice	4	5	4	13/12	4	3	4	49
Chaff	-	-	-	3	3	-	-	6
Straw	-	-	-	3	3	3	4	13
Total	4	5	4	31	10	6	8	68

[a] 12 for fallout ^{137}Cs
: all others for fresh depositions.

▣ Results and Discussions

- **No. of the TF values acquired for upland crops**

Crop	No of TF values per radio-element [a]							
	Co	Mn	Zn	Cs [b]	Sr	I	Tc	Total
Soybean	5	5	4	6	1	2	2	25
Barley	1	1	-	1	1	-	-	4
Chinese cabbage	1	1	-	1/12	1	2	2	20
Lettuce	2	2	2	2	-	-	-	8
G. chrysanthemum	2	2	2	2	-	-	-	8
Radish	1	1	-	1	1	2	2	8
Carrot	2	2	2	2	-	-	-	8
Squash	2	2	2	2	-	-	-	8
Peanut	-	-	-	-	1	-	-	1
Sesame	-	-	-	-	1	-	-	1
Total	16	16	12	29	6	6	6	91

[a] only for the main edible part

[b] 12 for fallout ^{137}Cs

▣ Results and Discussions

- **Experimental TF values for brown rice (Tc in next)**

Soil	TF_{mix} (Bq kg^{-1}-dry plant / Bq kg^{-1}-dry soil)					
	Mn	Co	Zn	Cs	Sr	I
A	-	-	-	1.6E–01	-	-
B	-	-	-	1.0E–02	-	-
C	-	-	-	1.0E–02	-	-
D	-	-	-	4.0E–02	-	-
E	-	-	-	1.0E–02	-	-
F	2.4E–01	4.5E–03	-	2.1E–02	1.2E–01	-
G	3.2E–01	6.0E–03	2.7E+00	6.1E–02	-	-
H	2.3E–01	-	2.3E+00	1.8E–02	-	-
I	1.2E–01	2.2E–03	5.8E–01	3.0E–02	-	-
J	5.2E–01	5.9E–03	2.1E+00	1.0E–01	-	-
K	-	-	-	1.5E–01	2.5E–02	6.4E–03
L	-	-	-	2.2E–02	1.6E–02	3.4E–03
M	-	-	-	8.1E–03	1.6E–02	1.1E–03
GM	2.6E–01	4.3E–03	1.7E+00	2.9E–02	3.0E–02	2.9E–03
GM IAEA	2.6E–01	5.1E–03	1.5E+00	8.3E–03	2.3E–02	3.8E–03

▣ Results and Discussions

- **Experimental TF values of ^{99}Tc for brown rice**

Soil	TF_{mix} value of ^{99}Tc	
	Brown rice	Straw
N	1.4E–03	1.0E+00
O	2.5E–03	1.3E+00
P	5.4E–04	5.3E–01
Q	8.4E–04	6.6E–01
GM	1.1E–03	8.2E–01
IAEA	< 2.0E–04 [a]	-

[a] AM (n = 2)

- IAEA value for upland grain Tc: 1.3E+00 (AM)
- Rice value much lower than the grain value due to anaerobic conditions

▣ Results and Discussions

▪ Experimental TF values for soybean seeds

Soil	TF (Bq kg^{-1}-dry plant / Bq kg^{-1}-dry soil)						
	Mn	Co	Zn	Cs	Sr	I [b]	Tc [c]
F	4.3E–01	2.9E–01	-	8.8E–02	9.1E–01	-	-
G	2.8E+00	5.0E–01	2.3E+01	2.8E–01	-	-	-
H	2.6E–01	1.6E–01	5.9E+00	1.7E–01	-	-	-
I	2.0E–01	4.9E–02	2.3E+00	1.3E–01	-	-	-
J	1.4E+00	2.5E–01	1.1E+01	5.0E–01	-	-	-
R	-	-	-	4.6E–02	-	-	-
T1	-	-	-	-	-	9.1E–04	-
T2	-	-	-	-	-	2.8E–03	-
U1	-	-	-	-	-	-	1.6E–01
U2	-	-	-	-	-	-	2.0E–01
GM/AM	6.1E–01	2.0E–01	7.7E+00	1.5E–01	9.1E–01	1.9E–03	1.8E–01
GM IAEA [a]	2.2E–01	3.6E–02	9.1E–01	4.0E–02	1.4E+00	8.5E–03	4.3+00

[a] for leguminous vegetables (seeds and pods).

[b,c] AMs for shells are 2.4E–02 and 8.1E+00, respectively.

▣ Results and Discussions

▪ Experimental TF values for leafy vegetables

Plant type	Soil	TF (Bq kg^{-1}-dry plant / Bq kg^{-1}-dry soil)						
		Mn	Co	Zn	Sr	Cs	I	Tc
Chinese Cabbage	S [a]	2.4E+00	2.1E–01	-	2.5E+01	1.4E+00	-	-
	T3	-	-	-	-	-	1.5E–01	-
	T4	-	-	-	-	-	3.4E–02	-
	U3	-	-	-	-	-	-	1.4E+02
	U4	-	-	-	-	-	-	1.2E+02
Lettuce	G [a]	3.4E+01	8.4E–01	4.3E+01	-	6.3E-01	-	-
	H [a]	1.5E+00	8.4E–02	5.5E+00	-	5.3E-01	-	-
G. chrysan-themum	G [a]	1.9E+01	4.4E–01	2.1E+01	-	1.5E+00	-	-
	H [a]	2.0E+00	1.0E–01	4.8E+00	-	1.0E+00	-	-
GM/AM		5.4E+00	2.3E–01	1.2E+01	2.5E+01	9.2E-01	9.3E–02	1.3E+02
GM IAEA (leaves)		4.1E–01	1.7E–01	2.4E+00	7.6E–01	6.0E–02	6.5E–03	1.8E+02

[a] assuming the dry-to-fresh weight ratio is 0.08.

▣ Results and Discussions

▪ Experimental TF values for root vegetables (roots)

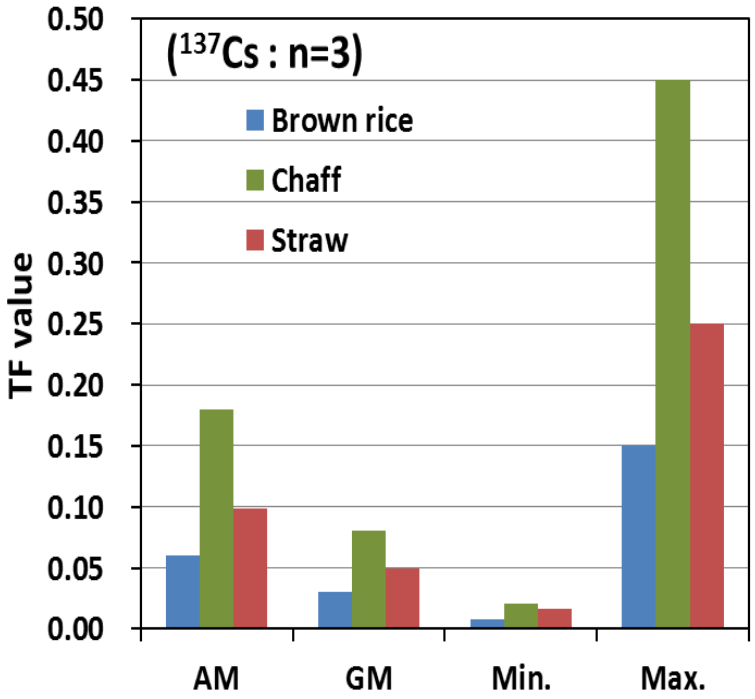
Plant type	Soil	TF (Bq kg^{-1}-dry plant / Bq kg^{-1}-dry soil)						
		Mn	Co	Zn	Sr	Cs	I	Tc
Radish	S [a]	3.1E–01	9.8E–02	-	4.7E+00	5.2E-01	-	-
	T3	-	-	-	-	-	4.3E–01	-
	T4	-	-	-	-	-	5.9E–02	-
	U3	-	-	-	-	-	-	1.1E+01
	U4	-	-	-	-	-	-	1.3E+01
Carrot	G [b]	4.0E+00	3.9E–01	1.5E+01	-	2.2E-01	-	-
	H [b]	3.9E–01	5.6E–02	4.5E+00	-	1.2E-01	-	-
GM/AM		7.9E–01	1.3E–01	9.8E+00	4.7E+00	2.4E-01	2.4E–01	1.2E+01
GM/AM IAEA		4.2E–01	1.1E–01	1.9E+00	7.2E–01	4.2E–02	7.7E–03	4.6E+01

[a,b] assuming the dry-to-fresh weight ratios are 0.09 and 0.14, respectively

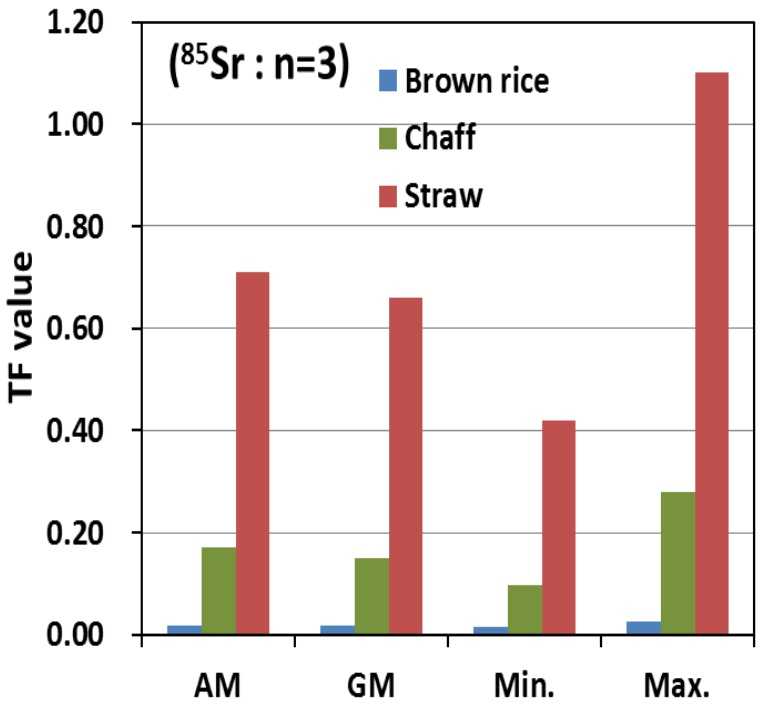
▣ Results and Discussions

- **Transfer to different parts of the rice (Gyeongju soils)**

- ^{137}Cs TF



- ^{85}Sr TF



(Ref. STE 412/413, 248-256, 2011)

- **^{125}I TF and ^{99}Tc TF : Straw >> Brown rice**

  : by factors of about 70~500 and 600~1000, respectively.

▣ Results and Discussions

▪ Correlations between soil properties and TF values

^{137}Cs TF for brown rice

- r values in greenhouse experiments : no statistically significant

pH	O.M.	CEC	Ex. K	Ex. Ca	Sand	Silt	Clay
−0.4077	0.4017	−0.3036	−0.3989	−0.1501	0.0359	0.0023	−0.1046

Note) N=13, r (절대값) ≥ 0.5529 → significant at p = 0.05

- r values in field studies : no statistically significant

pH	O.M.	CEC	Sand	Silt	Clay
−0.2069	−0.2750	−0.4257	0.0346	−0.1892	0.4278

Note) N=12, r (절대값) ≥ 0.5760 → significant at p = 0.05

▣ Results and Discussions

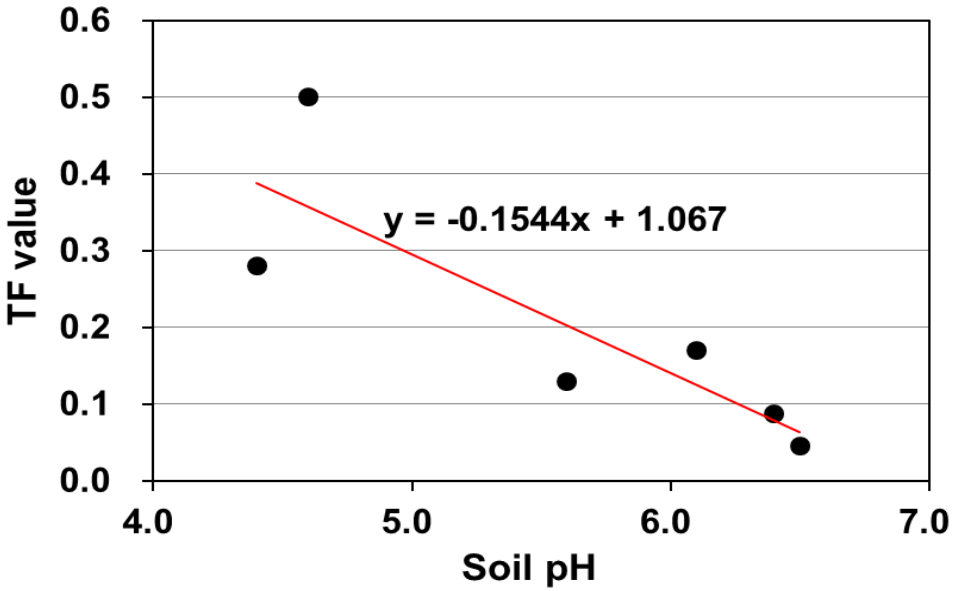
▪ Correlations between soil properties and TF values

^{137}Cs TF for soybean seeds

- r values in GH experiments : statistically significant for pH

pH [a]	O.M. [a]	CEC [a]	Ex. K [a]	Ex. Ca [a]	Sand [b]	Silt [b]	Clay [b]
−0.8444	0.0848	0.3508	−0.5405	−0.5846	−0.7375	0.8547	0.2650

[a] N=6, r (절대값) ≥ 0.8114
→ significant at p = 0.05
[b] N=5, r (절대값) ≥ 0.8783
→ significant at p = 0.05



▣ Results and Discussions

▪ Correlations between soil properties and TF values

^{137}Cs TF for Chinese cabbage

- r values in field studies : no statistically significant

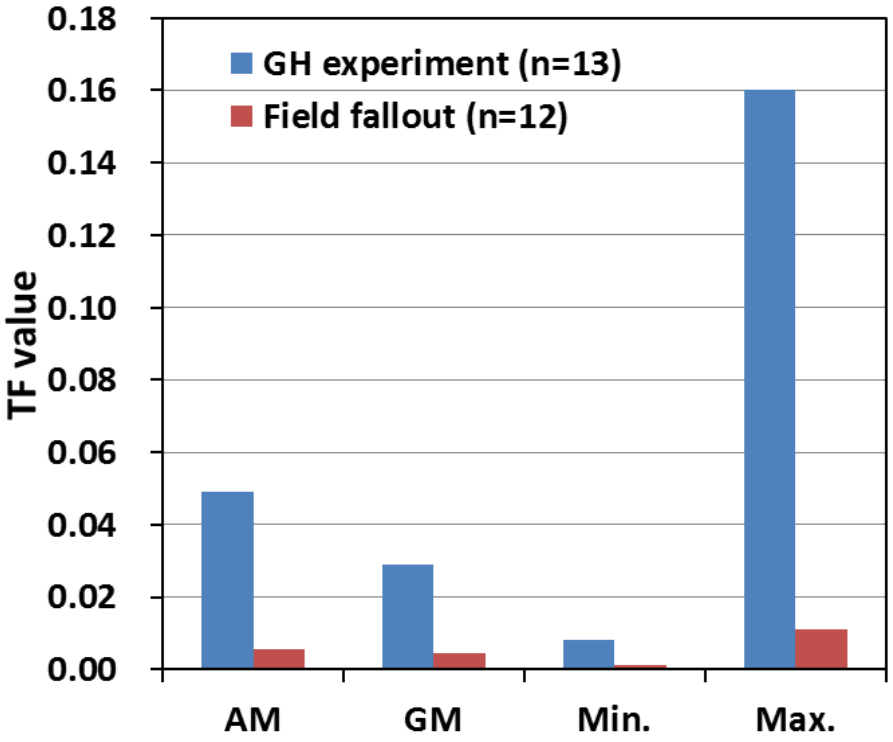
pH	O.M.	CEC	Sand	Silt	Clay
0.1188	−0.4248	−0.3276	-0.0038	0.0509	-0.1361

Note) N=12, r (절대값) ≥ 0.5760 → significant at p = 0.05

▣ Results and Discussions

▪ Experiments vs. field fallout study

- ^{137}Cs TF for brown rice



- ^{137}Cs TF for Ch. cabbage →

Experiment (SV)	1.4E+00
Field (min.~max.)	8.5E−03~2.1E−01

Note) SV : Single value

- In the experiments, freshly deposited radionuclides
- In the field study, aged for decades

: Irreversible fixation by ageing

: Much lower TF values than in the experiment

☐ Usage of TF (F_{iv})

- **Estimation of root-uptake concentration at edible maturity (C_{iv})**

  - For normal operation

$$C_{iv} = d_i\left[\frac{\{1 - exp(-\lambda_i T_b)\}}{P\lambda_i}\right]F_{iv}$$

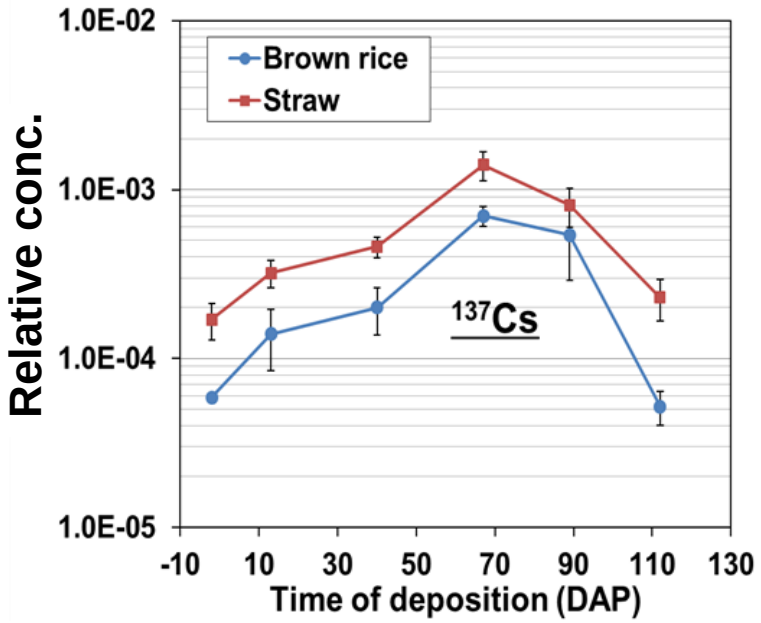
  : Pre- or post-operational, long build-up time

  - For acute release : root-uptake rate constant (R_{iv}, d^{-1})

$$R_{iv} = \frac{F_{iv}}{T_e} \quad \text{or} \quad R_{iv} = \frac{F_{iv}\Delta B_{1d}}{B_{tot}}$$

: 총흡수량은 흡수기간 또는 흡수기간 동안의 생체량 증가에 비례한다고 가정

→ very much different from what was shown in the figure.



□ Usage of TF

- 고리 5,6호기 환경특성평가(1988) 및 ODCM TF 자료

작물종/토양 [a]	작물형 (ODCM)	TF value			
		Mn	Co	Sr	Cs
쌀/F	-	2.4E-01	4.5E-03	1.7E-01	2.1E-02
콩/F	-	4.3E-01	2.9E-01	9.1E-01	8.8E-02
보리/F	-	6.8E-01	8.6E-03	4.3E-01	5.5E-02
-	Crop	2.6E-01	1.9E-02	2.2E-01	2.6E-02
배추/S	-	1.9E-01	1.7E-02	2.0E+00	1.1E-01
무/S	-	2.8E-02	8.8E-03	4.2E-01	4.7E-02
	Kimchi	1.2E-01	1.3E-02	1.4E+00	8.4E-02
-	Veget.	3.0E-02	1.0E-03	7.0E-01	2.0E-02
-	Fruits	2.9E-02	1.8E-03	2.0E-01	2.0E-03

[a] Appendix 참조

- ODCM TF values need to be updated.

☐ Usage of TF

- **Determination of reference soil concentration (Ref_{iv}, Bq kg^{-1}-dry)**

$$Ref_{iv} = \frac{L_{iv}}{F_{iv}}$$

: L_{iv} = food activity limit (Bq kg^{-1})

(500 → 100 Bq kg^{-1} for RCs at Fukushima)

Ex) Rice L_{iv} 500 Bq kg^{-1} → Ref_{iv} 5,000 Bq kg^{-1} for paddy soil

- F_{iv} = 0.1

: based on monitoring data (1959-2000) (JER 140, 59-64)

- realistic or conservative ? reasonably conservative

: RCs TF in 2011, Fukushima : 0.0013~0.17 (7 paddy fields, Fujimura et al. (2014) in JER 140, 59-64)

: KAERI exp. TFs 0.008~0.16

- Rice L_{iv} 100 Bq kg^{-1} → Ref_{iv} 1,000 Bq kg^{-1} for paddy soil?

□ Usage of TF

- **Looking for the possibility of soil phytoremediation**

- P = 200kg m^{-2}, B_{tot} = 2 kg-dry m^{-2}, TF = 100 for 100% removal

- max. TF for rice straw (dry) : Cs 0.25, Sr 1.1 / KAERI-3 soils

- max. TF for maize straw (dry) : Cs 0.49, Sr 3.0 / IAEA

- TF for Chinese cabbage (dry) : Cs 1.4, Sr 25 / KAERI-SL

- max. TF for leafy vegetable (dry leaf) : Cs 0.98, Sr 7.8 / IAEA

- Possible candidate radionuclide : Tc & Cl in upland soils

- TF of Tc for dry plant

: 0.22 (soybean seed) ~ 162 (leaf) / KAERI-2 soils

: maize straw, max. 37 / IAEA

: leafy vegetable, 4.5~3400 / IAEA

- TF of Cl rather similar to Tc

□ Considerations for the use of TF data

- whether based on fresh plant or dry plant ?
- for which part – edible, other part or whole plant ?
- whether based on initial or at-harvest soil concentration ?
  - sometimes based on the average concentration (Tc, Cl / IAEA)
  - • initial soil concentration decay-corrected to harvest time
- whether data before or after processing (PF up to 2~3) ?
  - (brown+white) rice / IAEA
- how long the build-up time in soil ?
  - DB : fallout, various settling periods / pre- or post- ?
  - little data for continuous depositions over a long time
- which value to be used – AM+nSD, $GM \times GSD^n$, Maximum, or ?
- whether the soil ploughed or not ?

◆ Model, object and data in accordance with one another !

▣ Concluding Remarks

- In Korea, some amount of soil-to-plant TF data has been produced by KAERI. The TF values varied considerably with radionuclides, soils, plant species and parts.
- Much of the data was adopted in the IAEA TRS-472 and TECDOC-1616 through the EMRAS program (2003-2007). Recently produced Korean data and new data to come may help to strengthen the transfer DB of the IAEA.
- The TF data is applicable to both normal and accidental situations. In order to enhance the reliability of the radiological assessment for Korean terrestrial food chains, further studies should be performed for many other exposure conditions (soil, plant, time).
- In spite of the decades-long study, we are still hungry for data. Production of domestic data and international cooperation for data exchange need to be continued.


Thank you for your attention !!

▣ Appendix

▪ Physicochemical properties of the soils

: generally characteristic of the soil weathered from granite.

- in pot experiments for rice TF

Soil code	pH	OM (%)	Exch. cation (cmol/kg)		CEC (cmol/kg)	Sand (%)	Silt (%)	Clay (%)	Tex-ture	Test nuclide
			K	Ca						
A	5.8	1.5	0.13	6.8	7.1	39.3	46.7	14.0	L	^{137}Cs
B	8.8	0.6	0.99	3.6	8.4	24.8	64.6	10.6	SiL	^{137}Cs
C	7.7	2.1	0.29	17.2	12.2	48.8	38.6	12.6	L	^{137}Cs
D	5.5	1.8	0.21	5.3	10.9	6.0	64.2	29.8	SiCL	^{137}Cs
E	6.0	2.1	0.41	4.3	9.0	60.5	31.7	7.8	SL	^{137}Cs
F	6.4	0.4	0.36	4.5	7.5	78.9	16.4	4.7	SL	^{137}Cs,^{90}Sr,^{54}Mn,^{60}Co
G	4.4	0.9	0.16	1.8	6.7	71.4	20.6	8.0	SL	^{137}Cs,^{54}Mn,^{60}Co,^{65}Zn
H	6.1	0.7	0.18	3.3	4.7	81.9	15.3	2.8	LS	^{137}Cs,^{54}Mn,^{60}Co,^{65}Zn
I	5.6	0.9	0.16	3.9	5.4	71.9	20.9	7.2	SL	^{137}Cs,^{54}Mn,^{60}Co,^{65}Zn
J	4.6	2.4	0.11	3.2	7.2	67.3	26.7	6.0	SL	^{137}Cs,^{54}Mn,^{60}Co,^{65}Zn

^{60}Co : no data

▣ Appendix

- Gyeongju soils in small-lysimeter experiments for rice TF

Soil code	pH	OM (%)	Exch. cat. (cmol/kg)		CEC (cmol/kg)	Sand (%)	Silt (%)	Clay (%)	Tex-ture	Test nuclide
			K	Ca						
K	5.5	4.4	0.41	6.1	8.2	46.2	43.6	10.2	L	^{137}Cs,^{85}Sr,^{125}I
L	5.4	3.3	0.79	14.9	16.3	10.6	69.5	19.9	SiL	^{137}Cs,^{85}Sr,^{125}I
M	5.6	2.4	0.63	6.2	12.8	21.5	50.3	28.2	CL	^{137}Cs,^{85}Sr,^{125}I
N	5.5	3.7	0.29	4.5	14.5	-	-	11.0	L	^{99}Tc
O	5.1	4.2	0.48	10.9	27.7	-	-	15.4	SiL	^{99}Tc
P	5.6	3.0	0.49	6.1	17.0	-	-	26.9	L	^{99}Tc
Q	5.1	4.9	0.94	20.4	43.5	-	-	25.2	L	^{99}Tc

: also characteristic of the soil weathered from granite.

▣ Appendix

- Soils in pot experiments for upland crop TFs

Soil	Test crop	pH	OM (%)	Exch. cation (cmol/kg)		CEC (cmol/kg)	Sand (%)	Silt (%)	Clay (%)	Tex-ture	Test radionuclide
				K	Ca						
F	S,B,P,M	6.4	0.4	0.36	4.5	7.5	78.9	16.4	4.7	SL	Cs,*Sr*,Mn,Co
G	S,L,C,Q,G	4.4	0.9	0.16	1.8	6.7	71.4	20.6	8.0	SL	Cs,Mn,Co,Zn
H	S,L,C,Q,G	6.1	0.7	0.18	3.3	4.7	81.9	15.3	2.8	LS	Cs,Mn,Co,Zn
I	S	5.6	0.9	0.16	3.9	5.4	71.9	20.9	7.2	SL	Cs,Mn,Co,Zn
J	S	4.6	2.4	0.11	3.2	7.2	67.3	26.7	6.0	SL	Cs,Mn,Co,Zn
R	S	6.5	3.6	1.7	9.4	-	-	-	-	-	^{137}Cs
S	H,R	6.0	-	-	-	-	-	-	-	SL	Cs,*Sr*,Mn,Co
T1	S	7.0	7.0	1.8	18.2	22.5	-	-	-	SiL	^{125}I
T2	S	5.5	4.7	1.2	8.6	16.4	-	-	-	L	^{125}I
T3	H,R	5.0	2.3	0.5	3.0	12.5	-	-	-	SiL	^{125}I
T4	H,R	6.8	3.1	1.2	15.6	23.3	-	-	-	SiL	^{125}I
U1	S	6.7	5.2	2.3	12.6	24.1	-	-	-	SiL	^{99}Tc
U2	S	6.1	5.6	2.4	7.3	22.1	-	-	-	SL	^{99}Tc
U3	H,R	4.7	2.3	1.2	1.9	15.9	-	-	-	CL	^{99}Tc
U4	H,R	7.2	2.6	1.8	13.6	30.2	-	-	-	CL	^{99}Tc

▣ Appendix

- Soils for 12 rice TF values of fallout ^{137}Cs

Soil code	pH	OM (%)	CEC (cmol/kg)	Sand (%)	Silt (%)	Clay (%)	Texture
FR-1	5.5	3.74	11.4	58.6	27.4	14.0	SL
FR-2	5.8	3.24	10.2	65.0	21.0	14.0	SL
FR-3	5.5	1.69	12.8	52.9	30.1	17.0	SL
FR-4	5.6	2.24	7.5	39.3	40.7	20.0	L
FR-5	5.7	6.55	14.6	47.9	38.1	14.0	SL
FR-6	5.5	1.94	9.5	50.3	29.6	20.1	L
FR-7	4.9	3.12	7.3	60.2	22.3	17.5	SL
FR-8	5.8	2.14	8.6	59.7	19.9	20.4	SCL
FR-9	4.3	2.07	14.7	23.0	51.1	25.9	SiL
FR-10	5.0	1.95	6.5	65.6	17.1	17.3	L
FR-11	5.6	2.52	9.1	43.5	40.1	16.4	L
FR-12	6.4	1.83	9.3	42.0	36.7	21.3	L

: also characteristic of the soil weathered from granite.

▣ Appendix

- Soils for 12 Chinese cabbage TF values of fallout ^{137}Cs

Soil code	pH	OM (%)	CEC (cmol/kg)	Sand (%)	Silt (%)	Clay (%)	Texture
FC-1	5.4	3.52	9.9	69.2	22.8	8.0	SL
FC-2	5.9	3.67	12.5	67.5	23.5	9.0	SL
FC-3	6.2	2.88	7.5	67.6	23.4	9.0	SL
FC-4	6.1	1.96	9.9	65.3	25.7	9.0	SL
FC-5	5.5	1.66	8.7	68.9	17.1	14.0	SL
FC-6	5.1	2.36	11.3	61.8	20.8	17.4	SL
FC-7	6.4	2.71	8.9	73.8	13.4	12.8	LS
FC-8	6.8	4.79	14.1	72.9	11.9	15.2	SL
FC-9	5.9	2.21	9.8	72.2	15.6	12.2	SL
FC-10	4.2	2.41	9.7	63.4	22.3	14.3	SL
FC-11	5.8	3.17	14.0	31.3	53.3	15.4	SiL
FC-12	5.6	3.00	9.8	52.3	28.2	19.5	SL

: also characteristic of the soil weathered from granite.