SOIL DEGRADATION: CHALLENGE TO ACHIEVING HUMAN SECURITY

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Takashi Kosaki is Professor of Soil Science in Tokyo Metropolitan University, Japan. He obtained Doctorate degree in Agriculture from Kyoto University, Japan, and did his research with International Institute of Tropical Agriculture (IITA), Nigeria, before joining the institutions in Japan. His interest focuses on the efficient and proper use and management of soil resources in Africa, Asia, former USSR, etc. He is currently serving as Chair of Division 3, International Union of Soil Sciences (IUSS), and President of the Japanese Society of Soil Science and Plant Nutrition.

ABSTRACT

Land degradation is a threat to human security from two aspects: freedom from want (famine) and freedom from fear (environmental destruction) as pointed out by the UN Secretary General Kofi Annan in 2000 as the twin goals for the world community to advance. It is induced by natural hazards as well as human activities which include not only agriculture, grazing and logging but the construction of roads, water ways, mining operation, etc. Land degradation is the integrated deterioration of land cover, which is detected as the reduction in vegetation coverage of the land surface, the change of the type of plant communities, soil erosion and the decline in soil fertility. This paper focuses on degradation from soils point of view, i.e. soil degradation, which is one of the major topics for the soil science community to work for public awareness in the International Year of Soils 2015. Some examples of soil degradation observed in different environmental conditions are described and compared in terms of its type, causes, impact on human welfare and possible countermeasures.

Lal and Stewart (1990) classified the processes of soil degradation into the following three;

1) physical processes such as the deterioration of soil structure (slaking and the formation of surface crust), the increase in bulk density (compaction), the changes of soil water and temperature regime,
2) chemical processes such as leaching, acidification and elemental imbalances (salinization, deficiency or toxicity of a specific element, and laterite formation), and
3) biological processes such as the depletion of soil organic matter, the decrease in bio-diversity and the increase in soil-borne pathogens.

These processes are usually not independent but work together and make the problems more serious and complicated (Lal 1990). These processes are affected by natural factors as well as socio-economic, even political, factors. They can be initiated by natural causes as well as anthropogenic causes. Natural causes are soil characteristics such as an effective soil depth, clay mineralogy type and texture. Anthropogenic causes include improper management in farming systems and socio-political problems. In most of the cases of soil degradation in the world, the anthropogenic causes play more important roles than the natural ones. Followed are some examples of the analysis on the type, causes, an impact of soil degradation and possible countermeasures observed in the world.

Soil degradation associated with modernization in agricultural production system

Summer fallowing has been commonly practiced in wheat-based agricultural production systems in drylands including some parts of Russia and Central Asia in order to store water, to control weed hazard, and to accumulate mineral N through mineralization of soil organic matter. However, since summer fallowing prevents any vegetative growth by shallow tillage, it has often been reported that this practice on Chernozem soils or Ustolls had accelerated organic matter decomposition, causing the risk in lowering the sustainability of agricultural production. We found that an extensive and uniform application of summer fallowing is not beneficial to sustainable grain production in Central Asia, and thus, an alternative soil and land management technology must be developed with taking account of snow-collection-based water harvest management and its site-specific application in accordance with soils and topographical conditions (Funakawa *et al*. 2007).

Can traditional farming become a savior in degraded land in the 21st Century?

Although shifting cultivation is often claimed as a cause of soil degradation, it is still practiced for staple food production in many of the developing countries, particularly in the tropics. It is well known that the main profit of slash-and-burn is the supply of bases, P and N and that of fallowing is the recharge of soil organic carbon and nutrients. The fallowing stage has, however, been given limited information, and thus it is hardly to answer the question: How long is fallowing necessary to sustainably maintain soil productivity? Based on the monitoring and modeling in Northern Thailand in terms of carbon and nitrogen dynamics such as emission of CO_2 due to soil organic matter decomposition, litter fall, nitrogen leaching through soil profiles from farms under shifting cultivation, the followings were found. 1) Soil productivity is restored in the fallowing stage of 6 to 7 years by not only the addition of C and nutrients but also the suppression of N loss through leaching by the succession of the soil microbial community from rapid consumers of resources to stable and slow utilizers, resulting in an increase in the amount of N storage in the microbial biomass and a decrease in the rate of soil organic matter decomposition. And thus, 2) shifting cultivation system can be seen to be

well adapted to soil-ecological conditions and sustainable in northern Thailand provided the traditional style of fallowing for about 10 years is maintained (Funakawa *et al*. 2011).

Wind erosion is a major contributor to desertification, one of the soil degradation phenomena, particularly on the over-grazed/cultivated land in the Sahel region of West Africa. Topsoil, which typically contains more nutrients than subsoil, is detached and removed from arable land by wind. Thus, wind erosion affects the soil nutrient level and soil productivity. Moreover, abrasion and burial by the wind-blown sand can damage pearl millet stands, a staple cereal crop in the Sahel. Effective measures for wind erosion control have been proposed and their effects have been demonstrated. However, none of these measures have been adopted by Sahelian farmers. The main reason for non-adoption may be that developers and/or extension workers of these techniques did not give sufficient attention to their practicality for farmers. We proposed a new land management practice, called the "Fallow Band System (FBS)," which is useful for both wind erosion control and improvement of soil fertility and crop production in the Sahel. The FSB may be considered as a shifting herbaceous windbreak. This method does not impose an additional expenses and labor requirements on Sahelian farmers who are economically challenged and have limited manpower. We conducted field experiments and showed that 1) a fallow band can capture a great deal of wind-blown soil particles and coarse organic matter, leading to an effective control of wind erosion, 2) the amount of soil nutrients available for crops in a former fallow band was increased by the decomposition of trapped soil materials, and 3) the amount of soil water available for crops in a former fallow band was increased by the trapped wind-blown soil materials through improvement of rainwater infiltration into surface soil (Ikazaki *et al*. 2011).

The examples of soil degradation described above are induced by human activities, i.e. improper management of land use. Although some long term changes in local and/or global climate may affect the type and extent of soil degradation, human activities often contribute more directly and drastically to soil degradation. The types, causes and impact of soil degradation vary from one place to another, thus the possible countermeasures against soil degradation should be tested and evaluated with taking account of physical as well as socio-economic conditions in an individual situation. The application of a given set of countermeasures without detail analysis of the site in question may result in disastrous and irreversible changes in the environment and finally jeopardize human security.

KEYWORDS
soil degradation, organic matter depletion, shifting cultivation, desertification, human security

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Ikazaki, K., Shinjo, H., Tanaka, U., Tobita, S., Funakawa, S., and Kosaki, T. 2011: "Fallow Band System," a land management practice for controlling desertification and improving crop production in the Sahel, West Africa. 1. Effectiveness in desertification control and soil fertility improvement. *Soil Science and Plant Nutrition*, 57(4), 573-586.

Lal, R. and Stewart B.A. (Eds.) 1990: *Soil Degradation*, Advances in Soil Science, vol. 11, Springer-Verlag, New York.


Soil Degradation:
Challenge to Achieving Human Security
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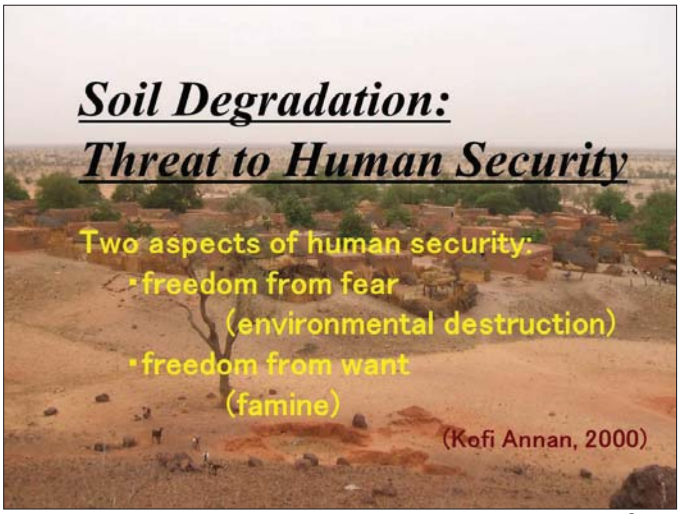
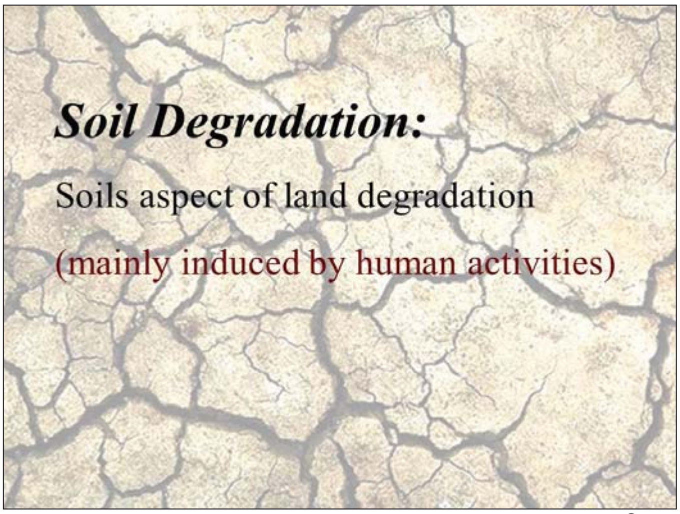

Soil Degradation:
Threat to Human Security
Two aspects of human security:
・freedom from fear
(environmental destruction)
・freedom from want
(famine)
(Kofi Annan, 2000)

2


Soil Degradation:
Soils aspect of land degradation
(mainly induced by human activities)

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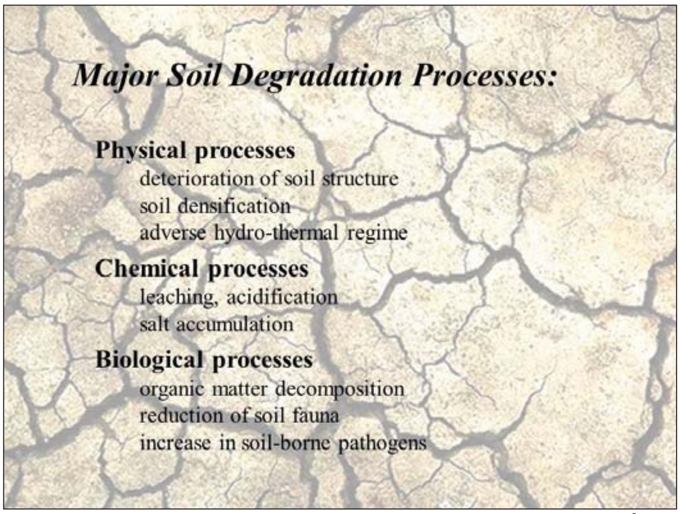
Major Soil Degradation Processes:
Physical processes
deterioration of soil structure
soil densification
adverse hydro-thermal regime
Chemical processes
leaching, acidification
salt accumulation
Biological processes
organic matter decomposition
reduction of soil fauna
increase in soil-borne pathogens

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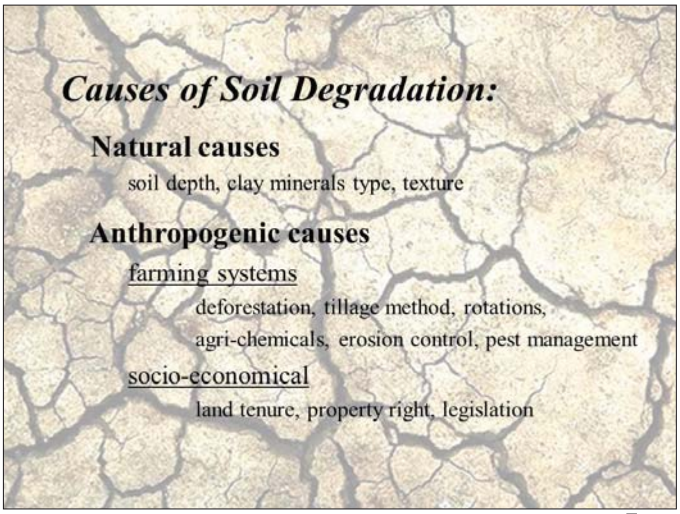
Causes of Soil Degradation:
Natural causes
soil depth, clay minerals type, texture
Anthropogenic causes
farming systems
deforestation, tillage method, rotations,
agri-chemicals, erosion control, pest management
socio-economical
land tenure, property right, legislation

5


Organic matter decline
due to
"summer fallowing"
for grain production in
Central Asia
(North Kazakhstan)

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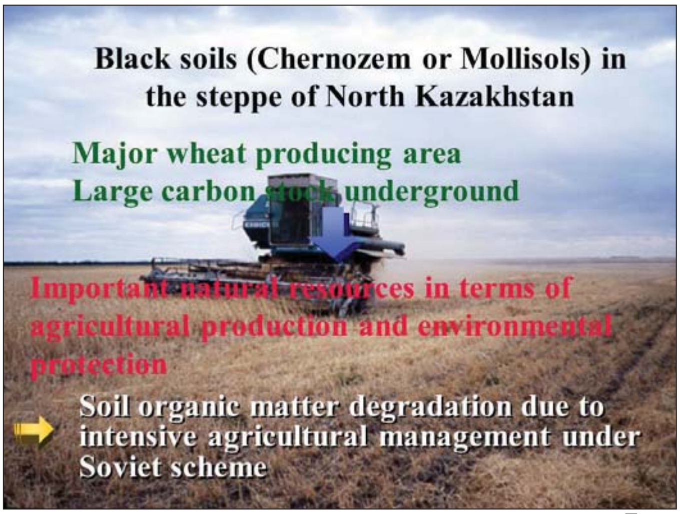
Black soils (Chernozem or Mollisols) in the steppe of North Kazakhstan
Major wheat producing area
Large carbon stock underground
Important natural resources in terms of agricultural production and environmental protection
Soil organic matter degradation due to intensive agricultural management under Soviet scheme

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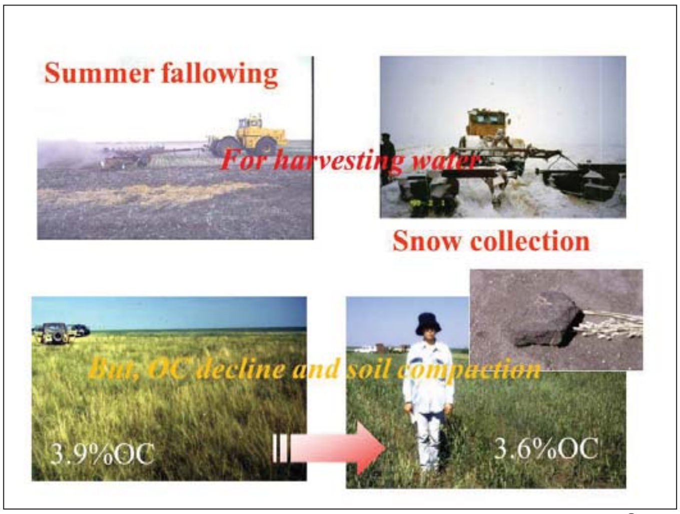
Summer fallowing
For harvesting water
Snow collection
But, OC decline and soil compaction
3.9%OC
3.6%OC

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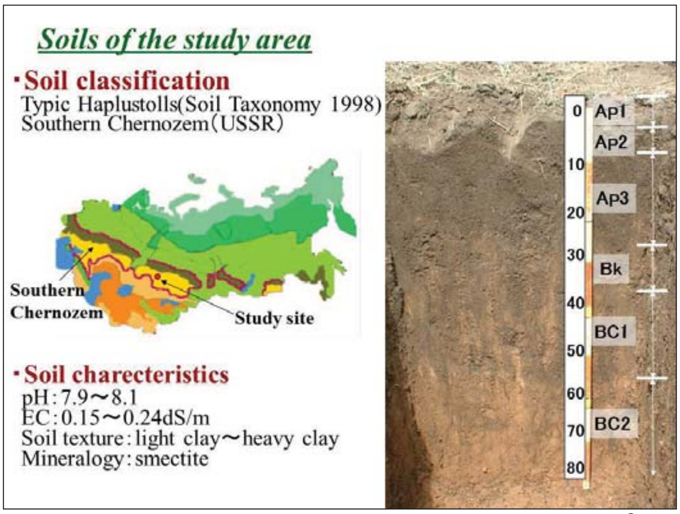
Soils of the study area
・Soil classification
Typic Haplustolls(Soil Taxonomy 1998)
Southern Chernozem(USSR)
Southern Chernozem
Study site
・Soil charecteristics
pH：7.9〜8.1
EC：0.15〜0.24dS/m
Soil texture：light clay〜heavy clay
Mineralogy：smectite
Ap1
Ap2
Ap3
Bk
BC1
BC2
0
10
20
30
40
50
60
70
80

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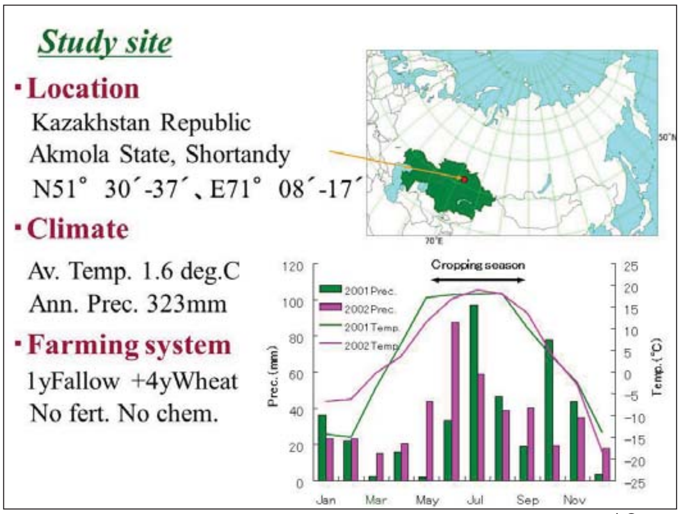
Study site
・Location
Kazakhstan Republic
Akmola State, Shortandy
N51° 30´-37´、E71° 08´-17´
・Climate
Av. Temp. 1.6 deg.C
Ann. Prec. 323mm
・Farming system
1yFallow +4yWheat
No fert. No chem.
Cropping season
2001 Prec.
2002 Prec.
2001 Temp.
2002 Temp.
Prec. (mm)
Temp. (°C)
Jan
Mar
May
Jul
Sep
Nov

10


Water dynamics

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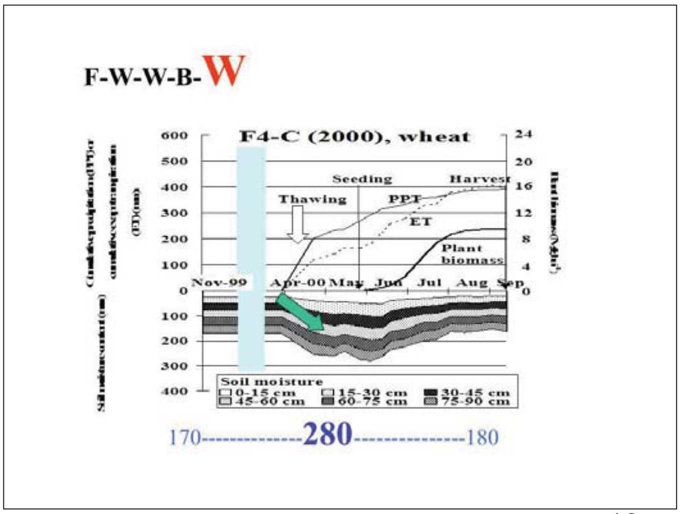
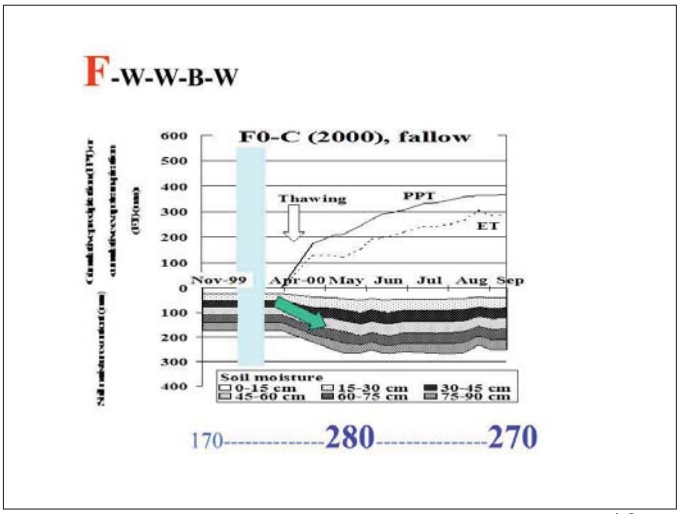

F-W-W-B-W
F4-C (2000), wheat
Thawing
Seeding
Harvest
PPT
ET
Plant biomass
Nov-99
Apr-00
May
Jun
Jul
Aug
Sep
Soil moisture
0-15 cm
15-30 cm
30-45 cm
45-60 cm
60-75 cm
75-90 cm
170
280
180

12



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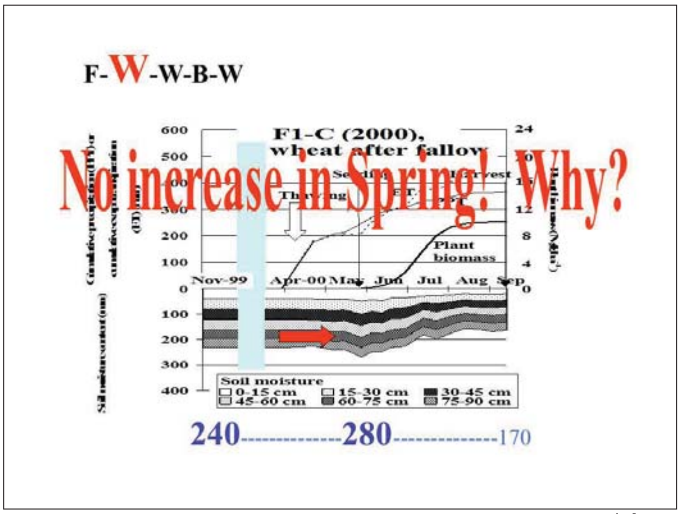

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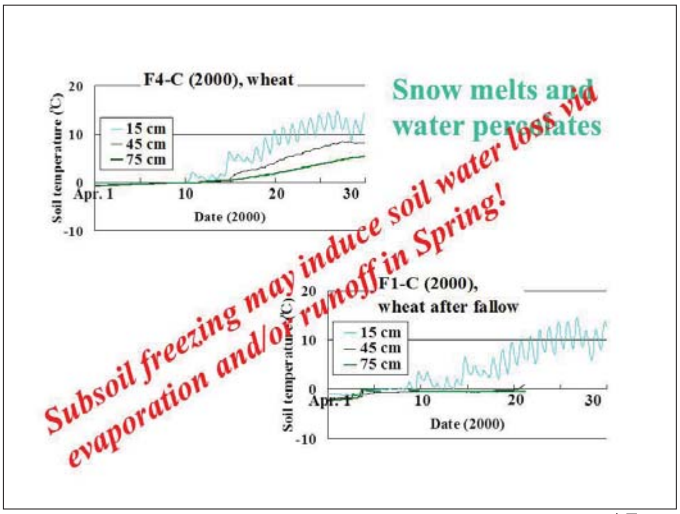

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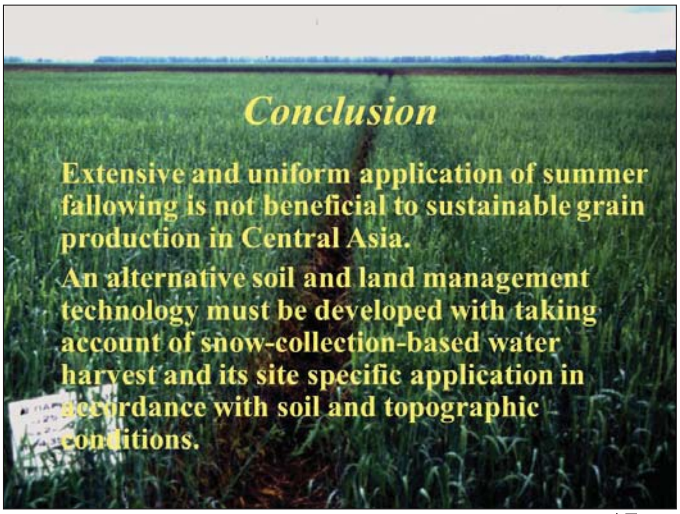

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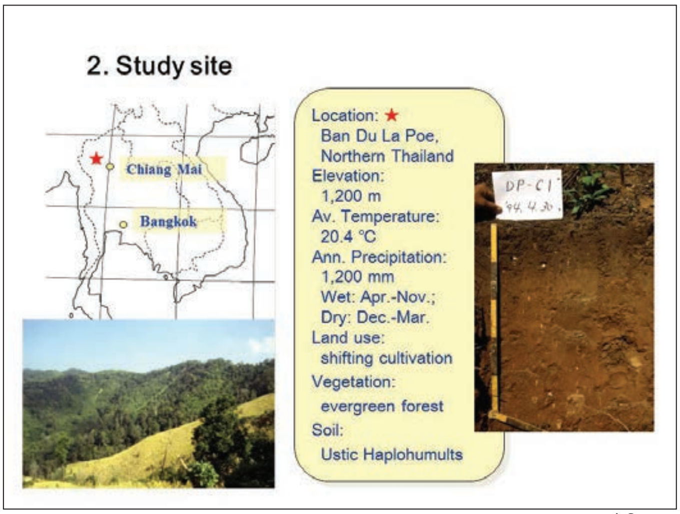

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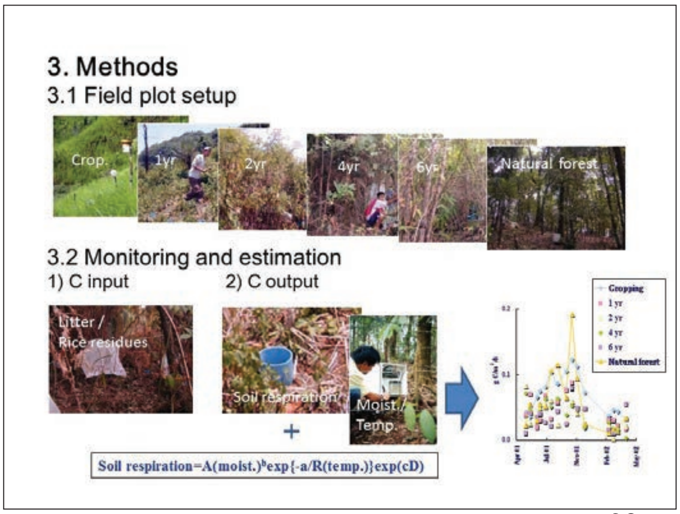

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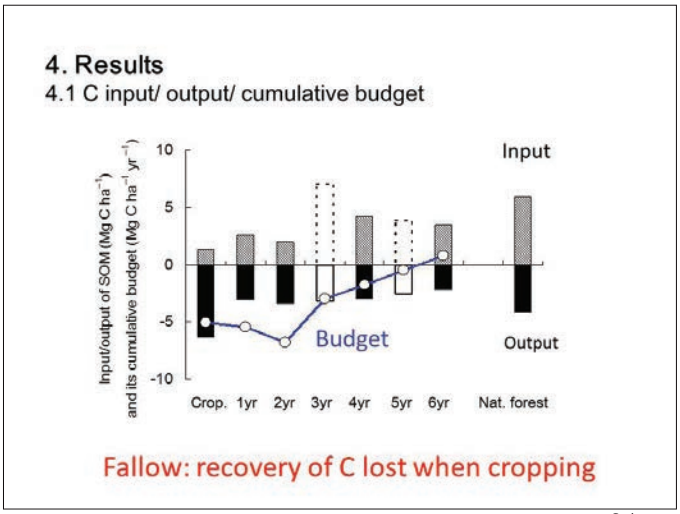

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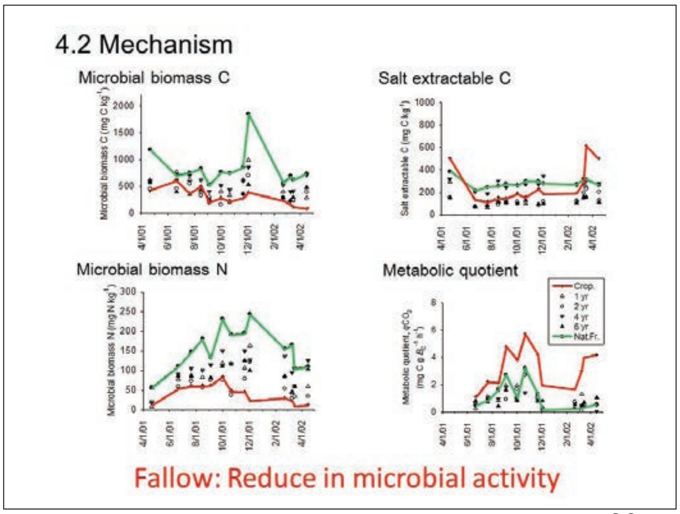

22

5. Conclusions

1) Soil carbon lost in the cropping stage is restored by the litter input in the fallowing stage of 6 to 7 years.

Mechanism includes

2) addition of C and nutrients and
the suppression of C and N loss
by (presumably)
the succession of the soil microbial community
from rapid consumers
to stable and slow utilizers of SOC

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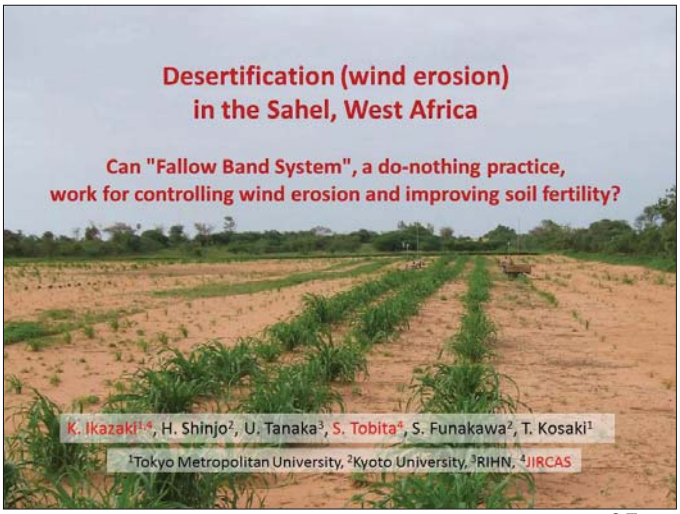

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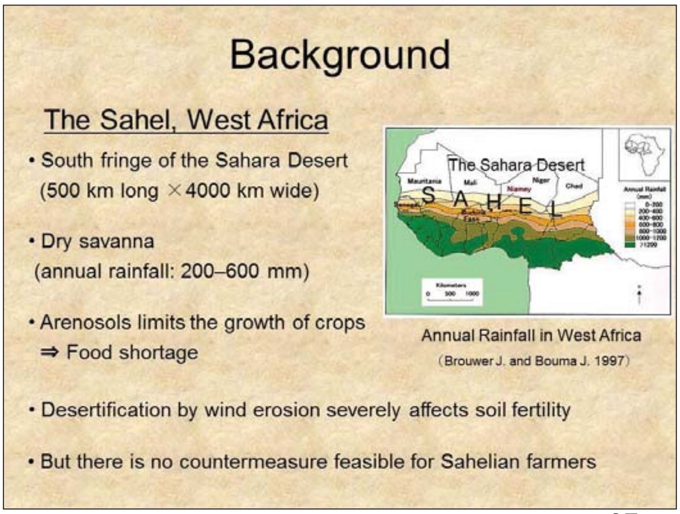

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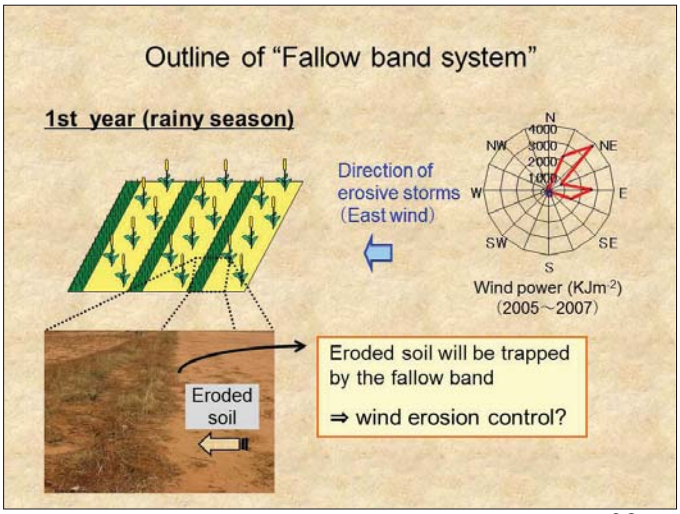

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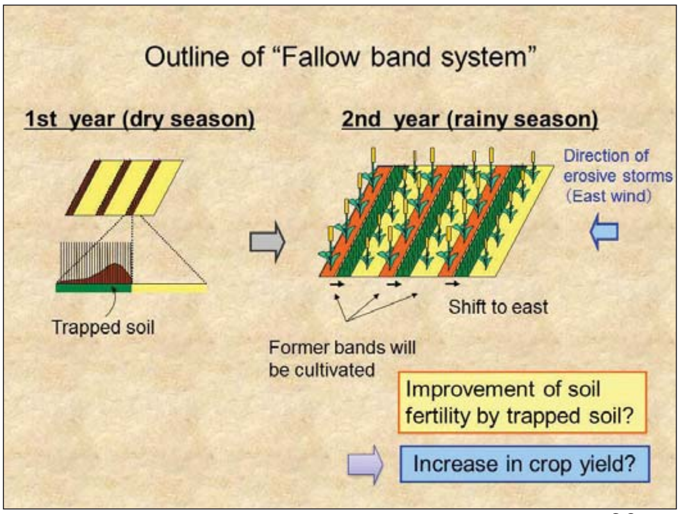

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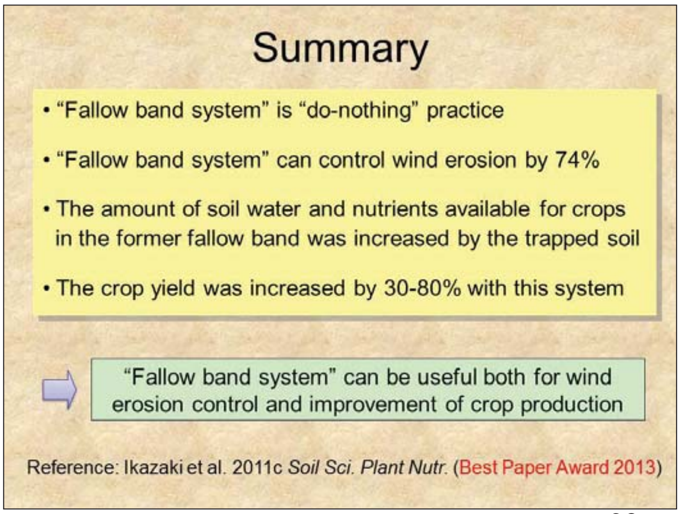

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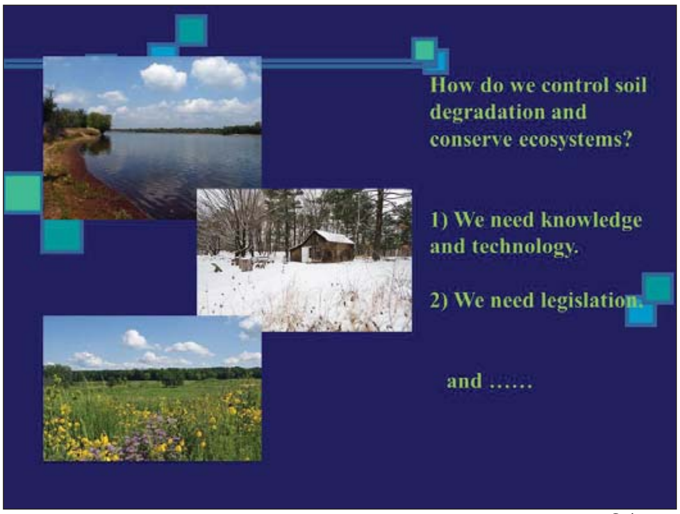
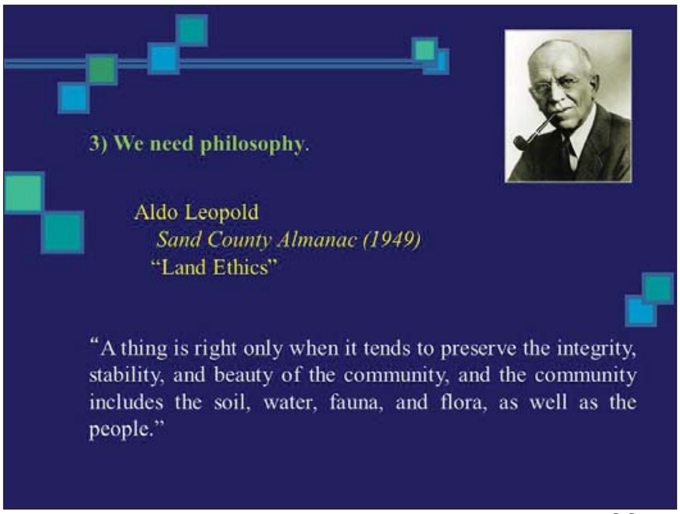

How do we control soil degradation and conserve ecosystems?
1) We need knowledge and technology.
2) We need legislation.
and ……

31


3) We need philosophy.
Aldo Leopold
Sand County Almanac (1949)
"Land Ethics"
"A thing is right only when it tends to preserve the integrity, stability, and beauty of the community, and the community includes the soil, water, fauna, and flora, as well as the people."

32


2015
International
Year of Soils

33

Chair Koyama: I'd like to introduce the second keynote speaker, Professor Takashi Kosaki. As President Iwanaga already explained, he is the Professor in Tokyo Metropolitan University. Currently, he is the President of Japanese Society of Soil Science and Plant Nutrition. At the same time, he is serving as the Chair of Division 3 of IUSS, the International Union of Soil Sciences.

That means he's really the representative of soil scientists in Japan. So, he is the most suitable person to deliver keynote speech in this symposium which is commemorating the Year of Soil in 2015. As he is working in Tokyo Metropolitan University, which is located in very urban area, his interest is very broad, covering the relation between the human beings and environment.

Today, he provides the very theoretical and comprehensive knowledge on soil science and environment in general. Could you start your presentation, Professor Kosaki? Floor is yours.

Dr. Takashi Kosaki: Thank you very much, Mr. Chairman. Good morning, ladies and gentlemen. I am very happy and honored to be given a chance to talk in this symposium organized by JIRCAS today. The topic today is soil degradation. And that is a big challenge to achieving the human security.

Soil degradation is now threatening human security. What is human security? During the cold war time in 1960s to 1990s, security was a matter of nation. But after the collapse of the Soviet Union, the support from each a nation was partially cut off and thus we and our community should now take care of us by empowerment of the people and social networking. That is a human security issue and which was firstly pointed out by the former UN Secretary General, Kofi Annan. He mentioned two aspects of human security. Those are the freedom from fear and the freedom from want. The soil degradation takes away freedom from fear through the environmental destruction as well as the freedom from want through the famine. The soil degradation is a big challenge to achieving human security.

Land degradation includes many aspects and soil degradation is one of those aspects and very closely related to the human activities.

We can name three major soil degradation processes. Those are the physical, chemical and biological processes. The physical degradation process includes the deterioration of soil structure, soil densification and adverse hydro-thermal regime. The chemical processes include leaching, acidification and salt accumulation. Biological degradation processes include organic matter decomposition and the reduction of soil fauna and increase in soil-borne pathogens and such. This is why the solution is not very much simple. Maybe all those processes are taking place, not only alone but mixed together.

What triggers off the soil degradation? There are two causes: natural and anthropogenic. Natural causes include soil depth and clay minerals type or the texture and such. Anthropogenic may be farming systems, such as deforestation and tillage method, rotations, agri-chemicals, erosion control or pest management and such and such. The socio-economical causes are also anthropogenic as well and include land tenure system, property right, and legislation and such.

Now I would like to show you some of the examples of soil degradation together with possible countermeasures in the world. The first example is the organic matter decline due to "summer fallowing" for grain production in Central Asia.

In Central Asia, particularly in Northern part of Kazakhstan, the Chernozem or the Mollisols are commonly distributed and has been actively used for wheat and other crop production, since the Soviet time. These soils, as you know, store a huge amount of soil organic matter as well as the mineral nutrients and thus they are very important in sustaining our life in agricultural aspect. They are also important in environmental aspect because of the working as a sink or a source of carbon dioxide gas. But some studies have been reporting that soil organic matter degradation due to intensive agriculture in those areas.

Due to marginal conditions for crop growth in terms of soil moisture in this region, some water harvesting techniques have been commonly practiced, such as the summer fallowing and snow collection. After 30-40 years of cultivation, the organic matter decreased and soil compaction appeared and they may inducesoil degradation and crop yield decline.

This is the soil of the study area. They are Typic Haplustolls or the Southern Chernozem. The local soil scientists love to call the soil with the latter. They have thick A horizons, some carbonate accumulations in B and C horizons, and below we can see some gypsum accumulation horizons. They have neutral to slightly alkaline reactions with quite heavy texture.

Our study site is Shortandy near Astana, the new capital of Kazakhstan. It is under the continental climate with warm summer and cold winter with precipitation around 350 millimeters per annum. Their common rotation system includes 4 years wheat planting with 1 year fallow. As you know, in fallow period, the land is ploughed several times, making the soil surface bare to avoid moisture loss through evapotranspiration by the wheat.

This is how they keep the land in the fallow period, making the land bare, with ploughing, with huge horse powered tractors like this. So, let me start how fallowing affects the water dynamics.

I would like to show you the changes of soil moisture in the soil of the surface down to 90 centimeters from winter through growing season till the harvest time. Vertical axis issoil moisture content in millimeters. In ordinary farm planted with wheat, the soil moisture increases when the snow starts to thaw and reaches maximum of 280 millimeters at the time of planting and gradually decreases as plant grows and reaches the minimum of 180 millimeters in the beginning of winter.

In case of fallow, previously planted with wheat, moisture increases with snow thawing and reaches maximum to 280 millimeters and is moist till the end of growing season. So, this moisture of 270 millimeters is carried over to the next growing season.

What about the season after fallowing? In the beginning of spring, the soil contains 240 millimeters of moisture and starts to gain some moisture from snow thawing and reaches 280 at the time of planting then decreases till the end of the growing season. Is summer fallowing in the previous year beneficial to the plant this year or not? We do not see much increase in moisture in spring time. As you remember that ordinary farm showed 100 millimeters increase in spring time. Why not here, but only 40 millimeters increase?

Please have a look at the soil temperature. In ordinary farm, temperature goes up from mid-April and in the soil of 15 centimeters from the surface goes fastest and then 45 centimeters, then 75 centimeters, a bit more slowly. What about the plot after fallowing? Fifteen centimeters show soil temperature increase, but no increase in 45 centimeters and 75 centimeters. It means subsoil is frozen. What happens if soil is frozen when snow melting? The melted snow may not be percolating into soil, but lost via evaporation and/or surface runoff.

Yes, we can see such losing water and water erosion is taking place. Summer fallowing may induce the loss of water and soil organic matter from snow melting.

So in conclusions here, extensive and uniform application of summer fallowing is not beneficial to sustainable grain production in Central Asia. An alternative soil and land management technology must be developed with taking account of snow-collection-based water harvest and its site specific application in accordance with soil and topographic conditions.

The Next example is in monsoon Asia, Thailand. “Shifting cultivation” is still practiced widely, particularly in the tropics, and often claimed as one of the major causes of land degradation. But on the other hand, we know it is a traditional system for staple food production since long time ago. The objectives of this study are to understand the role of fallowing in terms of mechanism of recovery of soil organic carbon and other nutrients and how long necessary for sustaining this system.

Our study site was in the Northern Thailand and close to Chiang Mai. They have clear wet and dry seasons. The soils are mostly Ustic Haplohumults.

We established six experimental plots: cropping plot, it is planted with upland rice; the first year under fallow, herbaceous plants start to grow; the second year fallow, they grow taller; the forth year fallow, the herbaceous plants are replaced with tree species; the sixth year fallow, the trees are going to be densely grown; then the natural forest. In each plot, we monitored and estimated the carbon input and output. For carbon input we measured litter fall and for carbon output we measured soil respiration. We monitored soil moisture and temperature every hour, and applied Arrhenius-type prediction equation and estimated carbon output throughout the year.

The results are like this. The cropping phase shows the highest carbon output. During the fallow phase, carbon input is gradually increasing. For the third year when herbaceous plants are replaced by the trees, we estimated carbon input with assumption that all leaves and stems of herbaceous plants together with half of tree litters are incorporated into soil. That is why the input is quite high here. Blue line shows cumulative budget curve of carobon and we can see that the soil carbon is restored after 6 years fallowing.

Next I'd like to show you what is happening during the fallowing stages. The red line shows cropping phase and green line shows the forest. So microbial biomass carbon and nitrogen show maxima in the end of the rainy season and decline in the dry season and forest holds much higher carbon and nitrogen stock in the microbes. A further interesting thing is that in the dry season the microbes are mostly dead in the cropping stage but survive in the forest and the fallow stages. They keep carbon and nitrogen in their body with suppressing their activity, which is shown as their very low metabolic quotient.

So conclusions. Soil carbon lost in cropping stage is restored by the litter input in the fallowing stage of 6 to 7 years. And the mechanism includes the addition of carbon and nutrients, and the suppression of carbon and nitrogen loss by presumably the succession of the soil microbial community from rapid consumers to stable and slow utilizers of soil organic carbon. That means shifting cultivation is sustainable.

But can we keep this system for long period? If they refuse to do so, can we say not to do so in your own place? Is there any alternative? We are now studying the alternatives, such as the agroforestry and mulching, and more intensive use of the lowland, if possible.

The last example is the wind erosion in West Africa. Let me talk about "Fallow Band System." This is, to put it strongly, "do-nothing practice" for wind erosion control and improvement of soil fertility in the Sahel. This is a joint research project with JIRCAS and the chief contributor, Dr. Ikazaki, was one of my staff members in the university and now is a member of JIRCAS.

This is how the wind storm is approaching.

I'd like to start with the introduction of the Sahel. The Sahel region of West Africa is located at the south fringe of the Sahara Desert. The climate is dry savanna with annual rainfall between 200 and 600 millimeters. As a stable food, pearl millet is grown without fertilizers. In the Sahel, the low soil fertility due to very sandy soils, that is Arenosols, limits the growth of crops and this is one of the reasons of serious food shortage there. In addition, the desertification by wind erosion severely affects soil fertility, but there is no countermeasure feasible for Sahelian local farmers.

In the first year, the 5-meter wide herbaceous fallow bands are arranged in cultivated field at right angle to the direction of erosive wind, East wind, in the rainy season. The fallow band can be easily created by skipping usual seeding and weeding, by doing nothing, and thus the additional labor and expenses will not be imposed on the Sahelian farmers. The crops are cultivated in the rest of the field with conventional method. The fallow bands are maintained also in the next dry season so that they are expected to trap wind-blown materials and control wind erosion in the field.

In the next rainy season, new fallow bands are established aside from the former bands towards the direction of the wind and crops are cultivated on the former fallow bands as well as in other areas of the field. In the former fallow bands, we can expect the improvement of soil fertility by trapped soil and thus better crop production.

I'd like to finish with the brief summary. The first, the "fallow band" is "do-nothing" practice; and the second, "fallow band" can control the wind erosion by 74%; the third, the amount of soil water and nutrients available for crops in former fallow band was increased by trapped soil and the crop yield was increased by 30% to 80% with this system. Therefore, we conclude the "fallow band" can be useful, both for wind erosion control and improvement of the crop production.

I have shown you some of the examples of soil degradation. How do we control soil degradation and conserve the ecosystems? Firstly, we need knowledge and technology to cope with; and secondly, we need the control by law.

But is that enough? I think that we need the philosophy. We need something like the spirit with which we are willing to do soil conservation. Aldo Leopold, the father of environmental ethics, proposed the "Land Ethics." He mentions, "A thing is right only when it tends to preserve the integrity, stability, and beauty of the community, and the community includes the soil, water, fauna, and flora, as well as the people." It is really necessary to share this idea with all those who are now facing the soil degradation today as well as those who are not facing today but may be facing tomorrow.

Well, I am very sure many of you or all of you have already known next year is the International Year of Soils. We soil scientists are all ready for working with your people. We are planning to organize symposia or exhibitions, conferences and photo contest, and many other events throughout the year and everywhere in the world. So, please join us in those events and those for combating soil degradation as well, it is now the high time to do so.

Thank you very much for your attention.

Chair Koyama: Thank you very much, Professor Kosaki. We learned the essence of soil degradation and conservation through very interesting research examples, especially the importance to know the relationship between the human activity and natural conditions.

Today, we had two keynote speeches and personally I was really impressed from the enthusiasms from the speakers, but differently. One is from farmer's point of view, showing how to solve the real problem in the field. The second one is from scientist's point of view, explaining how to connect the scientific knowledge to the field. Both interests are needed for today's symposium. I think we learned a lot.

Please join me to give a big applause to the excellent two keynote speeches. Thank you very much. Thank you.