G-2 Synthetic studies on evaluation and monitoring of desertification

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1. Introduction

Desertification affects about one fourth of the total global land area and one sixth of the global population, whereas the accurate values are not clear. United Nations Convention to Combat Desertification (UNCCD) has required establishing the objective and scientific methods for desertification monitoring and assessment. In October 2002, The Committee on Science and Technology (CST) in UNCCD has selected the 25 members of the Group of Experts who should work to provide the information on some special issues including the "Assessment of Desertification and land degradation". In Asia, the Thematic Program Network on Desertification Monitoring and Assessment (TPN1), which is one regional activity in UNCCD, has been advanced. The research project is expected to support and contribute to such international activities on desertification monitoring and assessment from the scientific standpoint.

There are various desertification expansions in Asian region. China suffers from severe desertification such as wind erosion, water erosion and salinization, mainly caused by excessive economic human activities. In Central Asia such as Kazakhstan, the main processes of desertification are degradation of soil organic matter in northern farming region and acceleration of soil salinization in southern irrigation agricultural region. Both physical factors such as availability of water resources and historical and/or socio-economic factors (disassembly of old U.S.S.R. systems) specific for the region could have caused desertification in the area. In Pakistan, the reduction of crop production by the chemical degradation such as salinization becomes tangible in the irrigation agricultural region.

For combating desertification, we should work in each affected field, whereas it is also necessary to construct methods for evaluating each desertification, such as monitoring systems using satellite images, integrated models for prospecting future situation, etc.

2. Research Objective

In the present study, we should advance the field research in various desertificated Asian regions to elucidate the desertification progress process and to extract the effective desertification indicators for establishing the evaluation system in each desertificated region (Fig.1). In addition to the regional activities, we try to develop the tools for mutual comparison and evaluation of all desertificated area, such as the evaluation systems of desertification including the integrated model and the monitoring systems using satellite images. We develop these tools in considering with various field scales, from global/regional to local/village scale, and these tools should be also verified/improved by data collected in each desertificated area.

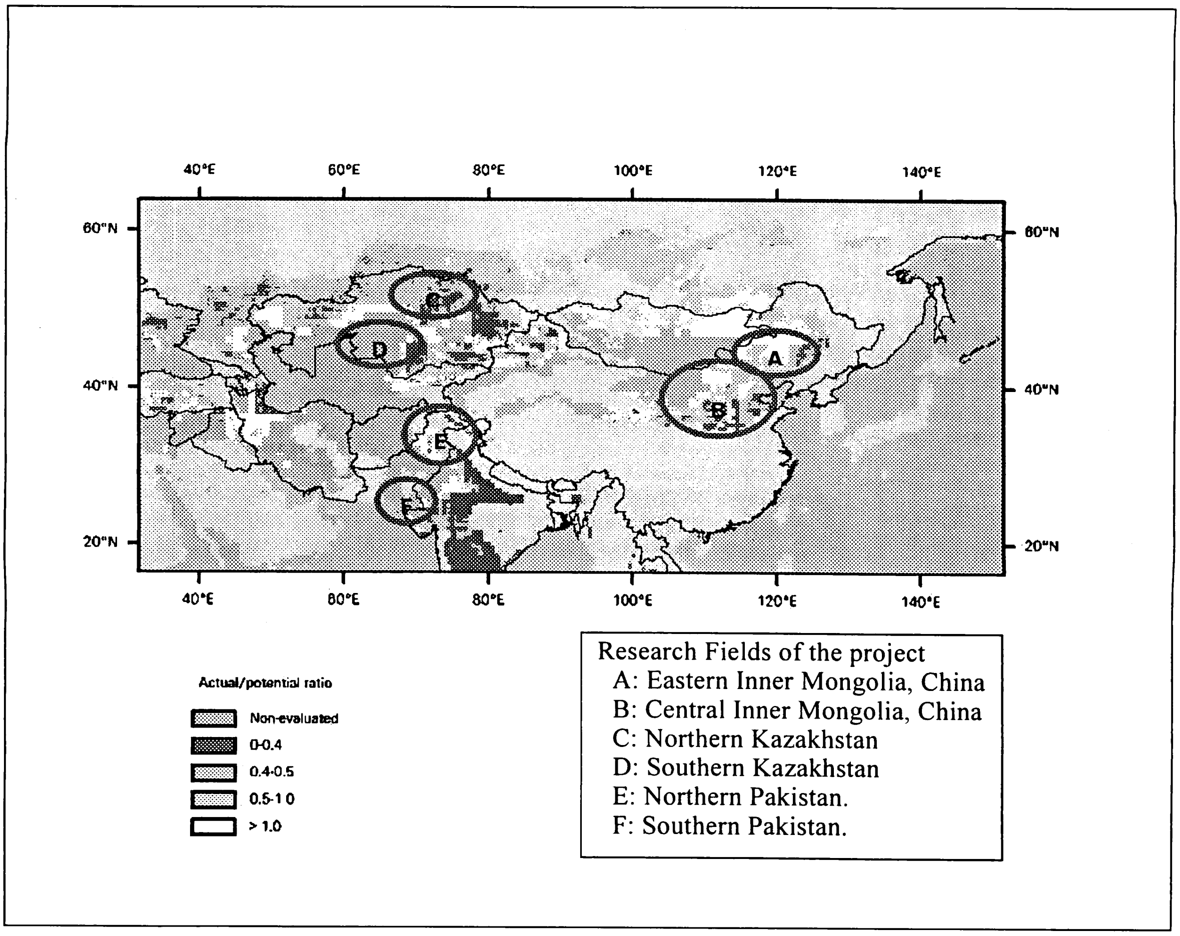

Fig.1. Research Fields of the Project. This map also shows the desertification area by using the actual NPP/potential NPP ratio from the output of our project, sub-theme 1.

3. Activities in 2001-2004

(1) Studies on monitoring and assessment of desertification

The objectives of this research are as follows: 1) to develop desertification assessment systems with various indicators for contributing National Action Programme (NAP) in national and state scale, 2) to develop methodologies for desertification monitoring and assessment in global/regional scale with using satellite images, and 3) to develop an integrated desertification model in local village scale.

1) Development of desertification assessment systems for contributing National Action Programme (NAP)

The objective is to contribute to the development of a comprehensive and systematic assessment system of desertification, including indicators such as driving forces, status, impacts, and effect of responses, through reviewing the current situation and issues of methodologies using existing literature and examination of a desertification assessment system based on administrative units.

<u>(a) Study on Current Assessment Methods of Desertification</u>

Current situation and issues of assessment methodologies of desertification are studied through literature reviews on official publications of international organizations. Through reviewing, it is found that generalized or systematic set of indicators (including indicators such as driving force, status, impact, and effect of response), practical contents of indicators, and assessment methodologies using those indicators have not been proposed to date. There is a need for the development of two different sets of indicators, one focuses on local conditions and the other can be applied universally. Reconsideration of those indicators is required from the view point of developers and users of indicators.

<u>(b) Examination of Desertification Assessment System for Administrative Units</u>

Based on the review of the current situation and issues of existing assessment methodologies, an examination was conducted to explore a desirable desertification assessment system based on administrative units, including framework of the system, selection and systematization of indicators, and concrete methods. Because policy makers are most likely to allocate resources to combat desertification to administrative units, the assessment based on these units should provide information not only status of desertification, but also relationship and balance between driving force, impact and effect of response, and to identify critical element for combating desertification.

In developing the assessment system, firstly a method of determining assessment units is examined through organizing conditions required for more detailed assessment to be able to encompass the critical issues based on characteristics of natural conditions in each administrative unit. Secondly, based on summary of desertification, framework of comprehensive assessment system of desertification is developed, including viewpoints of background information, driving forces, state, impact, and effect of responses. Based on the developed framework, selection and systematization of indicators whose main data source is general statistics. The assessment system of desertification based on administrative units is developed through examination with actual data, including level of assessment indicators and method of describing the result of assessment.

Development of comprehensive and systematic framework and assessment system based on administrative units was carried out to cover each aspect of "Background", "Pressure", "Status", "Impacts" and "Effect of Response", using general statistics. It is suggested that this framework and method allow examination of the relationship and balance among these group in administrative unit. It is also suggested that they could be used as a tool for identifying important administrative units in combating desertification in an early stage, through relative comparison between nations or sub-nations.

On the contrary, this assessment method may have some future issues such as selection of more appropriate indicators and determination of unit level of indicators. In this study, options of unit level of indicators are examined for China (sub-theme 4) and Pakistan (sub-theme 6) in order to consider characteristics of each country, however it is necessary to conduct trials and examinations to further advancing refinement of and creating more options for the assessment system.

2) Development of methodology for monitoring regional desertification

The objective is to produce desertification map based on monitoring vegetation degradation process quantitatively by estimating regional biological productivity using satellite imageries, climate datasets and so on. Data collection and model validation were carried out by linking with sub-theme 4 (China) and sub-theme 5 (Kazakhstan).

We developed a methodology to monitor regional desertification based on vegetation degradation using unified and quantitative criteria. Using satellite images and metrological datasets of the year 2000 and 2001, we compared the actual net primary productivity (NPP) derived from CASA model and potential NPP from Chikugo model, and could identify vegetation degraded areas in Asia (Fig. 1). It is necessary to validate regional NPP model using actual NPP data collected in China and Kazakhstan.

To estimate global NPP, we used a PEM (Production Efficiency Model)-type model originally developed by Running et al. [2000]. We used the following data sets: monthly FPAR and LAI and Pathfinder AVHRR Land (PAL)-version 3 NDVI data [Nemani et al., 2003] which was modified from original PAL NDVI data; daily mean temperature, relative humidity, net solar radiation, and daily minimum temperature, NCEP/NCAR reanalysis data set from NOAA-CIRES/CDC; and vegetation type, UMD 1km Global Land Cover data from Maryland University.

We compared the 9-year-averages of the first half (1982-1990) and the second half

(1991-1999) and identified vegetation degradation areas in drylands by overlaying the vegetation degradation map on dryland map. We defined drylands after UNEP [1992] as regions where the ratio of annual precipitation (P) to mean annual potential evapotranspiration (PET) is between 0.05 and 0.65, excluding cool regions.

We judged the NPP values estimated by the model used here are generally reasonable, because the estimated global NPP (62.8 GtC/yr) is within the range of that previously reported; the estimated NPP distribution is consistent to that previously reported; and the interannual variations of global NPP are negatively correlated with global increases in atmospheric CO_2 growth rate which was independently observed.

We identified the vegetation degradation areas in drylands including the region from northeast China to the Loess Plateau, the mid-latitudes of Mongolia, the region near the border between Russia and Kazakhstan, and northwest India, as previously reported by the GLASOD soil degradation database. We also identified vegetation degradation regions such as central Kazakhstan and north of Lake Balkhash, which has not been included in the GLASOD.

As we were able to assess desertification by objective and reproducible methods and identify desertification hot spots not identified by the existing soil degradation map (GLASOD), we conclude that the new methodology proposed here for desertification assessment is valid and useful. However, this result is based on an analysis of decrease in NPP. It is desirable to analyze the reason why the NPP has been reduced for each region by more detailed spatial analysis and field survey.

3) Development of village-level integrated desertification model

The objective is to develop, try and examine three types of models including (a) biological productivity model, (b) agricultural economic model and (c) supply-demand evaluation model, and also to examine the effects of anti-desertification measures introduced by Chinese government, based on village survey data collected in Inner Mongolia, China by linking with sub-theme 4.

For biological productivity model, we applied EPIC (Erosion Productivity-Impact Calculator is now called as Environmental Policy Integrated Climate.) model developed by USDA-ARS. For agricultural economy model, we applied linear programming method. For supply-demand evaluation model, we applied a concept of "Human Carrying Capacity" represented by unit of [persons/ha]. We could set up these three types of models and apply them using data collected by sub-theme 4 in Inner Mongolia, China under three future scenarios.

The effects of introducing the policy of converting slope field into forest and grassland on soil erosion were simulated in the case of small village "Ge-Zhen-Yan". While introducing the policy and converting all of 20 ha slope field into forest or grassland, it is possible to decrease soil erosion from 202 ton to 40 ton in contrast with current situation (10.6 ha slope field converted into forest and grassland). However, if the policy was not introduced and there is no slope field converted into forest and grassland, the soil erosion will rise from up to 348 ton. In addition, while introducing subsidy to converting slope into forest and grassland, only more than 2,400 Yuan per ha of the subsidy was paid to farmers, there will be a big increase in area of the converted slope field as well as a remarkable decease in soil erosion, without decrease in household income (Fig.2).

The model-simulation results imply that the policy of converting cultivated land back into forest and pasture (land conversion policy) introduced by Chinese government may have an effect to reduce soil erosion. Furthermore, the amount of subsidy currently provided to farmers (2,400 Yuan per ha) may be just enough not to reduce farmers' income with effect of reduction of soil erosion. However, the period of subsidy is restricted to eight years after conversion. Thus, there is concern that the farmers' income may be reduced after halting the subsidy for land conversion.

We also applied this model to another village in the similar way. The result is differ from "Ge-Zhen-Yan". Therefore, it should be necessary to apply this model to some more village and to analyze/verify.

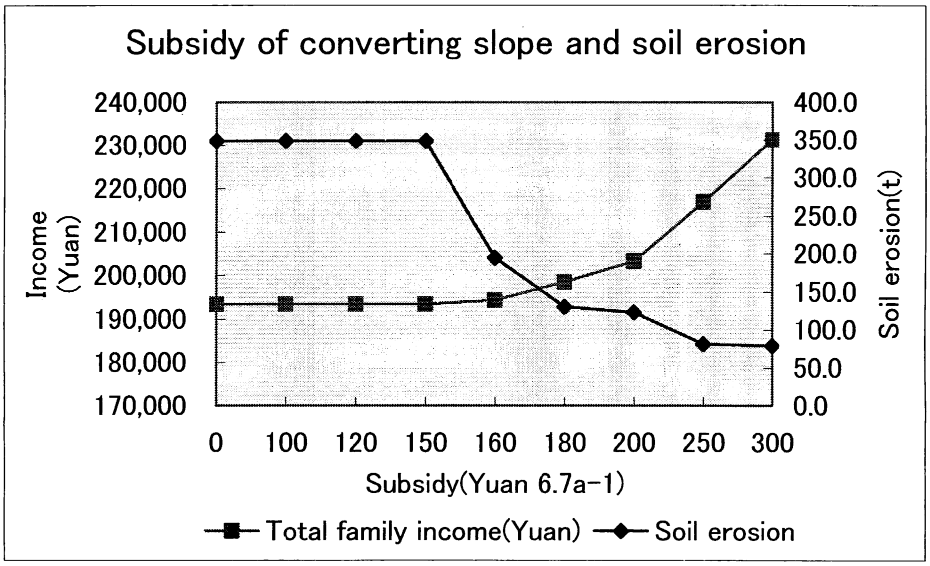

Fig.2. Subsidy of converting slope and soil erosion.

(2) Evaluation of vegetation indicators for the monitoring and assessment of desertification

To monitor and evaluate the progress of desertification in China, we aimed at presenting systematized knowledge concerning vegetation indicators of desertification in China. We collected and reviewed information concerning vegetation indicators of desertification in China, and conducted field surveys in six Chinese desertificated regions (Tengeri Desert, Ulanbuh Desert, Mu Us Sandy Land, Xilin Gol Grassland, Horqin Sandy Land and Hulunbeier Sandy Land) locating in the northern part of China.

From reviewing and field survey, we clarified how vegetation cover, biomass, species' composition, especially typical distributed species elimination/appearance, etc. changes with the progress of desertification. Based on the results of literature reviewing and field surveys including the share of available field data collected by sub-theme 4, we considered a series of succession of plant species applicable to each of six Chinese desertificated locations differing widely in meteorological and geographical conditions. We found that indicator plant species differ among these six regions, because of geographical separation and differences in climatic and soil conditions among these regions.

In each region, micro-environment is different from location to location, then we classified indicator plants to just three categories, and we proposed useful indicator plant species related to the intensity of desertification in each six field.

We made a database on desertification indicators from data obtained literature reviewing and field survey. The results obtained from this study were expected to be useful to establish vegetation indicators of desertification in China, especially for the local people in the desertificated fields. Furthermore, response of indicator plant species to each environmental factor is also analyzed by collaboration with sub-theme 3, which were shown in next session.

(3) Evaluation of countermeasures to rehabilitate desertificated lands

In China, much effort has been devoted to combat desertification, and much empirical knowledge has accumulated in this regard. However, this information is not synthesized and lack for scientific validification. Thus, in order to establish methodologies to rehabilitate desertificated lands effectively, we collected and rearranged the present information/knowledge on rehabilitation of desertificated lands and made databases concerning with this subject. Also, we understood that experimental researches in controlled environments are fundamentally needed to clarify the ecophysiological characteristics of each plant species that should be used to rehabilitate the desertificated fields. Therefore, with environment-controlled cabinets, we examined seed germination and growth of some species that are frequently used to rehabilitate the desertificated area at Mu Us sandy land, semi-arid area in China.

We chosed Mu Us sandy land as our research site, and air seeding and seedling transplant as typical technologies for vegetation rehabilitation. Through literature analysis and environment-controlled experiments, we tried to evaluate and improve these two technologies. Many published papers, published books, yearly statistic books, unpublished reports, etc. have been collected and browsed, and a primary database including nearly 100 most important journal papers has been established.

Germination experiments under different light intensity using 9 often-used species in air seeding, germination experiments of 2 species under different temperature with/without light condition, germination experiments of 2 species under different water stress and temperature, and sand burial experiments with 3 water stress using 6 species, regeneration experiments of 3 species and seedling growth experiments of 4 species have been conducted with using several types environment-controlled growth cabinets. Results were as follows:

1) All species does not need light for seed germination, but germination of 3 species (*Agriophyllum squarrosum, Artemisia sphaerocephala, Artemisia ordosica*) was inhibited by increasing in light intensity. **2)** *Caragana intermedia* showed similar germination with various temperature, while germination of *Artemisia ordosica* inhibited high and low temperature. This inhibition was emphasized under light condition than dark. **3)** Germination of *Artemisia ordosica* was sensitive rather than *Astragalus adsurgens* to water stress, especially under high temperature (30C) and low temperature (10C). **4)** It is necessary to bury seeds with sands for germination/emergence of seedlings of many species. *Hedysarum fruticosum*, *Caragana korshinskii* and *Medicago sativa* could emerge from burial depths of 0.5-4 cm, while seedling of *Agriophyllum squarrosum*, *Artemisia sphaerocephala* and *Artemisia ordosica* could only emerge well at 0.5 cm depth of sand burial. Under the field condition, light, temperature, water stress and physical effect of sand burial seemed to affect the emergence of seedlings. **5)** *Artemisia ordosica*, *Artemisia sphaerocephala* and *Medicago sativa* showed similar responses to temperature and cutting treatments. Whole cutting of stems/twigs significantly inhibited new leaf formation and new leaf biomass accumulation, while half cutting had no significant effect. The latter treatment seemed more suitable in practice for transplantation of seedling in desertificated field. **6)** Growth of 2 species of *Artemisia* (*A. ordosica, A. sphaerocephala*) increased with increasing in water supply, whereas the seedlings of *Caragana korshinskiia*a and *Hedysarum fruticosum* has somewhat decreased by much water condition, which suggested that these species could be suitable in relative arid area (Fig. 3).

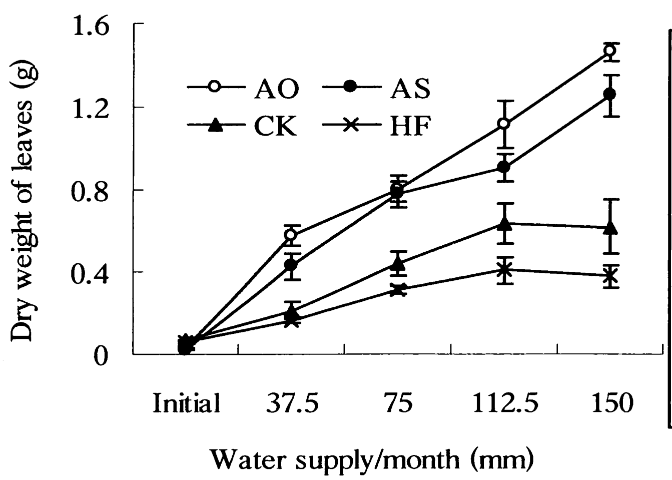

Fig.3. Dry weight of leaves under different watering regimes. (mean± SE)
Artemisia ordosica (AO)
Artemisia sphaerocephala (AS)
Caragana korshinskii (CK)
Hedysarum fruticosum (HF)

The information of eco-physiological characteristics of each plant species obtained in our study is fundamental and useful for considering the time and the place (environment) of desertification rehabilitation by air seeding and transplanting.

(4) Study on development of the index for evaluation of environmental resources changes with desertification in China

China suffers from severe desertification such as natural wind and water erosion and salinization, caused mainly by excessive economic activities. Therefore, it is necessary to develop the index for evaluating the environmental resource changes with desertification and also to study on the desertification process.

The purpose of this study were, 1) to survey natural conditions in the monitoring sites in the middle and the eastern part of Inner Mongolia, and to select indicators of soil and vegetation for desertification and restoration, 2) to develop techniques to assess surface erosion from the concentrations of radioactive nuclide fallout in soil, and 3) to clarify the quantitative effects of change in household decision caused by changes of social-economic conditions on land degradation.

1) Selection of indicators of soil and vegetation for desertification and restoration

We conducted field surveys on vegetation and soil including soil property and the accumulation of radioactive nuclides in the monitoring sites in the middle part of Inner Mongolia. We also conducted the monitoring survey on vegetation and soil property change in the eastern part of Inner Mongolia.

Based on the results of the field survey and existing database we suggested that the occurrence and the relative dominance of *Artemisia* species and annual Chenopodiaceae as indicators of vegetation degradation, especially in sandy lands. We also found that that soil particle size and organic carbon content were most important indicators for evaluating the degree of soil degradation.

There was significant relationship between vegetation and soil indicators, which suggested that it is possible to make a general evaluation of desertification and restoration at a somewhat big area by using integrated vegetation-soil indicators.

2) Development of techniques to assess surface erosion by radioactive nuclide fallout in soil

We marked off areas of grassland as test areas in which we controlled grazing and investigated the relationship between the concentration of fallout ^{210}Pb radioactivity in the soil, the topographical conditions, and the grazing pressure.

We compared the grazing zones and found the low ^{210}Pb radioactivity concentrations in the place with higher grazing density and with greater vegetation degradation by grazing.

The method of estimating the extent of erosion by using fallout of ^{210}Pb in the soil as an indicator should be useful for assessing desertification, and might be promising for applications such as judging the risk of desertification and confirming the effectiveness of afforestation and other remedial countermeasures.

3) Quantitative effects of change in household decision caused by change of social economic conditions on land degradation

By using agricultural economic model developed in sub-theme 1, we simulate the quantitative effects of change in household decision caused by changes of social-economic conditions on land degradation.

The effects of introducing "the policy of converting slope field into forest and grassland" on soil erosion were simulated. In addition, introducing the subsidy to converting slope into forest and grassland has also estimated by using this model (See sub-theme 1).

Not poverty, but practices to reduce poverty posed negative impacts on rangeland conservation. Restriction of number of herds per capita or grazing pressure might be considered as alternative policy measures to promote simultaneously rangeland conservation and poverty alleviation.

Introducing sedentary beef livestock technologies might generate a big increase of household income while keeping grazing pressure at a reasonable level. However if credit supporting is not available for poor farmers, this cannot generate a significant increase in household income. Therefore, sedentary beef cattle technologies introduced with providing credit supporting to poor livestock farmers may generate several times income increase while keeping restriction of grazing pressure at a reasonable level.

Above results imply that rural development practices to improve access to new technologies and credit service may contribute simultaneously to poverty alleviation and environmental conservation. Environmental conservation regulation and rural development policy should be combined in environmental degraded areas in developing countries.

(5) Study on the elucidation of desertification process and the evaluation of desertification in Central Asia

Two major processes of desertification in Central Asia, *i.e.* degradation of soil organic matter (SOM) in northern steppe of Kazakhstan and soil salinization in irrigated field in the southern part of Kazakhstan, were investigated. Since both the natural and socio-economic conditions specific for post Soviet countries can contribute to the processes of desertification in the area, we should clarify not only each process but also their interactions. Our main results are as follows:

1)The overall budget of SOM in three years (2001 to 2003), which was caliculated based on the amount of crop residue input and decomposition rate of SOM, was greatly affected by land use, such as inclusion of fallow during the period. Decomposition rate of SOM was the highest on the plateau, followed by northern and then southern slopes (Fig. 4).

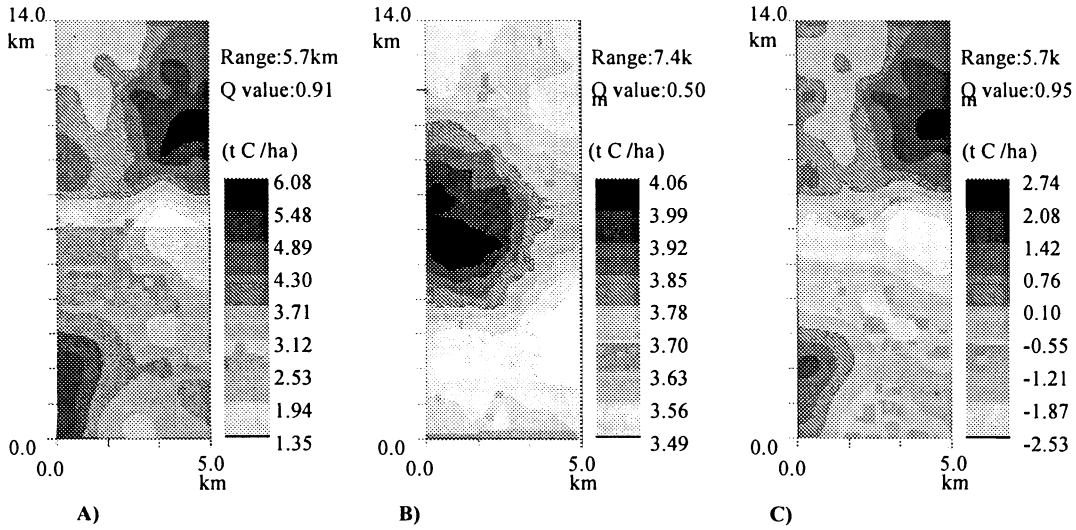

Fig.4. Spatial variability of A) total carbon input as plant residue, B) total CO_2 emission, and C) carbon budget

2) According to the field survey in the irrigated field of Shagan and Shamenov farms, Kzylorda State in southern part, the main factors that can affect on acceleration of soil salinization were relative elevation and soil texture. Hence, in both the areas, it is important to establish appropriate land use systems including site-specific managements in the whole farm level in order to mitigate the risk of desertification.

3) The socio-economic study revealed that the integration of cereal production by business companies often contributed to decrease the desertification through intensification of farm and land managements, whereas, in some cases, low benefit and more extensive land managements could accelerate the desertification.

(6) Study on the elucidation of the desertification process and the development of desertification indicators in Pakistan

The objectives of our study are 1) extracting scientific factors causing desertification mainly salt accumulation, 2) analyzing various factors including historical, religious and social ones that accelerate desertification and 3) evaluating applicability of EPIC (Erosion Productivity-Impact Calculator or Environmental Policy

Integrated Climate) model to salt affected area in order to estimate plant production in a community-scale or a farm-scale.

1) Concerning natural scientific factors, data were collected in four monitoring sites along with Indus basin. Pakistan counterparts also participated to collect field data. Major cause of salinization seemed to be the geological origin and quality of irrigation water. However, the extent of the pressure would be different from area to area. Our reconnaissance soil survey obtained the different status of soil quality between upper stream and down stream area. The former was damaged by high pH, and the latter was damaged by salt and sodium accumulation.

2) From present literature and information survey, three main factors caused salt accumulation were suggested. One reason was the separation of irrigation systems in accordance with the Independence from India in 1947. India-Pakistan Water Right regulated Pakistan to use only two main canals out of 5 canals, which led water shortage and hardly stable water supply. Therefore, Pakistani farmers became used to 'inadequate' irrigation way, and they irrigate water as much as possible when they have a chance to obtain irrigation water. As alternatives for water shortage, tube wells were utilized, and now 33% of total irrigation water is supplied by tube wells, however their water quality was poor, especially in Sind province. Second reason is seepage of water from canals. And the third reason is that fine texture soil on the plain is vulnerable to salinization.

3) Applicability of EPIC model to salt affected soils was confirmed. Simulation results with detailed soil data set from Sargodha have not yet supported that EPIC model visibly responded to soil attributions related to salinization, i.e. pH, dissolved Na ion, SAR (sodium adsorption ratio). We also determined variability of EPIC model with data set from Kazakhstan provided by sub-theme 5. Simulation results showed the same trend, which we obtained in Sargodha. Consequently, it is essential to build add-on component, which can identify a trend of salinization.

We applied two major soil classification systems, Soil Taxonomy and WRB, into soil profiles in Sargodha. From landuse and salinity viewpoint, WRB delineated two mapping units clearly. However, EPIC simulation results of crop biomass and evapotanspiration of each mapping unit didn't show difference.

We analyzed algorithm of EPIC subroutines, and recognized a scalability of customization for salinization. There was a severe constraint to obtain migration of EPIC model, which was developed with FORTRAN, to Windows based GUI. Collaboration with professional computer programmers was essential to develop software. We are also grateful to have an opportunity, through this project, to exchange opinion with USDA-ARS EPIC Team to deepen our knowledge about EPIC model. There are many off-spring models form EPIC, however, few in focusing on salinization.

4. General Discussion

United Nations Convention to Combat Desertification (UNCCD) has refered, "Desertification is the degradation of land in arid, semi-arid, and dry sub-humid areas. It is caused primarily by human activities and climatic variations." Also, "Combating desertification is essential to ensuring the long-term productivity of inhabited drylands." Therefore, "Biological Productivity" such as NPP should be the most important indicator for assessing the desertification, especially, in global/regional scale by using a satellite images.

In another point of view, "Indicator Plant Species" must be actual index for local people who could easily recognize the sign of desertification in the field.

"Integrated Desertification Model" combined "Plant Productivity Model (EPIC Model)" with "Agricultural Economic Model" and "Supply-Demand Evaluation Model" should be useful for evaluating/estimating not only future desertification degree but also the effects of countermeasure for desertification.

Some of our group members conducted the researches at different desertification area such as China, Kazakhstan and Pakistan, while some of us developed evaluation methods by using data collected in some research field not only by themselves but also by other members. Also developing methods was checked/verified at some other desertificated fields. Information changing and data sharing by some groups in our project were one of the most important way to progress the present "Synthetic Study".

Our research activities could contribute the activities of the Committee on Science and Technology (CST) in UNCCD and also the "Thematic Program Network on Desertification Monitoring and Assessment (TPN1)", which is one Asian regional activity in UNCCD. However, for certifying these assessment methods, we need to conduct more researches in various scales, from local village scale to global/regional scale, to support and contribute to such international activities on desertification monitoring and assessment from the scientific standpoint.