日本学術会議公開シンポジウム

FRONTIERS of SOIL SCIENCE: MESSAGES from the SOIL SCIENCE in ASIA.

土壌科学の最前線：アジアにおける土壌科学のメッセージ

主　催：日本学術会議土壌・肥料・植物栄養学研究連絡委員会
共　催：（社）日本土壌肥料学会、日本ペドロジー学会、日本土壌微生物学会、日本土壌動物学会
日　時：平成17年9月9日(金)13:00～17:30　於：日本学術会議講堂(東京都港区六本木7-22-34)

プログラム

（13：00～13：10）

開催にあたって：三枝正彦（土壌・肥料・植物栄養研連委員長、東北大学大学院農学研究科教授）

講演：

（13：10～13：50）

1. **Frontiers of Soil Science: Technology and the Information Age**
土壌科学の最前線：技術と情報時代
ドン・スパークス（世界土壌科学連合会長、デラウェア大学教授）

（13：50～14：20）

2. **ESAFS as the Bridge between IUSS and JSSSPN**
日本土壌肥料学会と世界土壌科学連合の架け橋としての東・東南アジア土壌科学連合
木村眞人（日本土壌肥料学会会長・東・東南アジア土壌科学連合会長、名古屋大学大学院生命農学研究科教授）

（14：20～14：50）

3. **Frontiers of Plant Pathogenic Soil Microbiology in Japan - Toward Biological Control of Soilborne Diseases -**
日本における植物病原性土壌微生物学の最前線―土壌伝染性病害の生物防除に向けて―
百町満朗（土壌・肥料・植物栄養学研連委員、岐阜大学応用生物科学部教授）

（14：50～15：20）

4. **Frontiers of Physiological Research on Soil Minerals Stresses in Japan**
土壌ミネラルストレスに関する日本における生理学的研究の最先端
松本英明（岡山大学資源生物科学研究所名誉教授）

休憩（15：20～15：30）

（15：30～16：00）

5. **Studies on Volcanic Ash Soils in Japan and International Collaboration**
日本の火山灰土研究と国際貢献　南條正巳（東北大学大学院農学研究科教授）

（16：00～16：30）

6. **Super Sustainable Functions of Paddy Soils and Multi-Functionality of Rice Paddy Field in Japan**
水田土壌の持続的な特性と水田農業がもつ多面的機能　陽　捷行（北里大学教授）

総合討論：（16：30～17：20）

（座長団）犬伏和之（土壌・肥料・植物栄養研連委員、千葉大学園芸学部教授）
山本洋子（土壌・肥料・植物栄養研連委員、岡山大学資源生物科学研究所助教授）
中西友子（土壌・肥料・植物栄養研連委員、東京大学大学院農学生命科学研究科教授）

（17：20～17：30）

閉会の辞：　東　照雄（日本ペドロジー学会会長、筑波大学大学院生命環境科学研究科教授）

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Purpose of Symposium on Frontier of Soil Science
- Messages from the Soil Science in Asia -

Masahiko Saigusa (Member for 19th Science Council of Japan,
Field Science Center, Graduate School of Agricultural Science, Tohoku Univ.)

The world population increases still rapidly and needs a large amount of the food and materials related to the life for the human race living. Consequently, it gives a big load to the global environment and courses the pollution of the atmosphere, water, and soil. According to Dr. Katsuyuki Minami, Professor for Kitazato Univ. (Minami 2004), our spaceship "Earth title" covered with green vegetation is defended by the atmosphere of 15km on the average, the soil of 18cm, the soil water of 11cm and the ozonosphere of only 3mm. However recently, the progress of ozone layer depletion in the South Pole, the increases of greenhouse gases in the atmosphere, and, in addition, the phenomenon to threaten the human race's living like decreasing of the soil water, desertification, salinization. acidification of the soil by acid rain and fertilizer, and the pollution by the heavy metal and agricultural chemicals in soil-sphere etc. are reported in all parts of the world. Therefore, many people are highly interested in these environmental problems occurred in atmosphere, hydrosphere, and soil-sphere as the global environment deteriorates further.

Among these spheres, the soil-sphere existed as a thin film of only 18cm at the surface of the earth having 12700km in the diameter, plays many important roles not only in the food production, but also in the adjustment of gas concentration between the atmosphere and the hydrosphere. Therefore, the soil environmental problems such as pollution, deterioration, erosion etc might threaten even the human race's living. Even in New Zealand, a natural rich agricultural country, soil scientist recently worries about the deterioration of their soil environment, and are challenging to restore and maintain the soil-sphere with the slogan of "SOS: Save Our Soil". It is not an exaggeration to say that the only roads of the human race living is to put this limited soil resources to practical use by introducing the latest advanced scientific knowledge and technique and to live together with other living things appropriately.

The International society of Soil Science (ISSS) that is international soil researcher's gathering started in 1924, and has been held their conference every 4 year. And, it developed into the International Union of Soil Science (IUSS) in 2002, and the organization form was changed greatly from individual participation of each soil scientist to the participation as the country unit. In our country, Science Council of Japan has been joining the IUSS in 2004 on behalf of the country. This symposium summarizes the most advanced field of soil science in Asian region which will also contribute to solve the worldwide food production and global environmental concerns like the above-mentioned and tries the world contribution aiming at the 18th World Congress of Soil Science (WCSS) held at Philadelphia USA in 2006.

土壌科学の最前線—アジアからのメッセージの開催にあたって

三枝正彦：第19期日本学術会議会員、
東北大学大学院農学研究科
附属複合生態フィールド教育研究センター

依然として急増する世界人口は、人類生存のために大量の食料と生活関連物質を必要としている。その結果、地球環境に大きな負荷を与え、大気、水、土壌の汚染を引き起こしている。北里大学教授、陽捷行博士によれば（陽 2004）緑に包まれた我々の宇宙船「地球号」は平均15ｋｍの大気と、18cmの土壌、11cmの土壌水、およびたった3mmのオゾン層によって守られているという。しかしながら、近年、南極上空ではオゾン層の破壊が進行し、また大気中には地球温暖化ガスが増加し、さらに土壌圏では土壌水の減少と砂漠化・塩類化、酸性雨による土壌の強酸性化、重金属や農薬の汚染など人類の生存を脅かす現象が世界各地で報告されている。地球環境が一段と悪化するにつれ、これら大気、水、土壌環境問題が高い関心を集めている。中でも土壌は直径12,700kmの巨大な地球の表面に平均たった18cmの薄皮として存在し、食糧生産の要であると共に、大気、水との調整役を果たしている。それゆえ、土壌の汚染、劣化、侵食は人類の生存すら脅かしかねない。近年、自然豊かな農業国であるニュージーランドさえ、このような土壌環境の悪化を懸念し、"SOS: Save Our Soil"の標語のもとに土壌の修復、保全に努めている。この限られた土壌資源を最新の先端的科学知識と技術をもって有効利用するとともに、他の生物と共生できるように適切に管理、保全することこそが人類生存の唯一の道と言っても過言でない。

国際的土壌研究者の集まりである世界土壌科学会議は1924年に発足し、4年ごとに開催されてきた。そして2002年には世界土壌科学連合に発展し、それまでの土壌科学者個人の参加から、国としての参加に組織形態を大きく変更した。我が国では2004年に日本学術会議が国を代表して世界土壌科学連合に加盟している。本シンポジウムは上述のような世界的食料生産と地球環境問題を解決するために、これらに最も関係する土壌科学のアジア地域における最先端研究を概括し、第18回世界土壌科学会議、米国フィラデルフィア大会（2006）に向けて世界貢献を試みるものである。

Frontiers in Soil Science: Technology and the Information Age

Donald L. Sparks

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Contributions in soil science research have immensely benefited humankind, including enhanced food production and the quality of our environment. This overview paper focuses on recent breakthroughs in elucidating soil biogeochemical processes in soils and other natural materials and delineates frontiers for the present decade and beyond. With the advent of state-of-the-art analytical techniques, some of which are synchrotron-based (e.g., X-ray absorption fine structure spectroscopy, XAFS) one can elucidate reaction mechanisms at small scale. The use of small scale techniques in environmental research has resulted in a new multidisciplinary field of study that soil scientists are actively involved in – molecular environmental science. This has been one of the major advances in the soil and environmental sciences over the past decade. Undoubtedly, the molecular characterization of microenvironments and interfacial reactions will become increasingly significant in understanding the interactions between chemistry, physics, and biology in natural environments.

Along with molecular scale approaches, the use of advanced computational technologies and development of multi-scale predictive models will play prominent roles in helping soil scientists address a number of research frontiers including: speciation of contaminants in heterogeneous systems; mechanisms of microbial transformations; the connection between the environment and human health; and development of effective remediation and waste management strategies.

土壌科学のフロンティア：技術と情報の時代

ドナルド　スパークス

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土壌科学分野の研究は、食糧の増産や環境問題の改善など人類にとって非常に有益となる貢献をしてきた。本講演では、土壌やその他の天然試料中の土壌生物地球化学的プロセスの解明に関する最近の飛躍的な発展に焦点をしぼり、この10年間そして今後のフロンティア研究の概観を述べる。放射光を用いた手法（たとえばX線吸収スペクトル微細構造、XAFS）など最先端の分析技術の出現により、微細なスケールにおいて反応メカニズムを解明することが可能となった。微細なスケールを対象とした技術を環境研究に応用することで、土壌科学者が積極的に関与する新しい学際的研究分野ー分子環境科学ーが生みだされた。これは土壌および環境科学におけるこの 10 年間の主要な進歩のひとつである。自然環境中の化学的、物理的、生物的な相互作用を理解するうえで、微細な環境と界面における反応を分子レベルで明らかにすることが今後さらに重要となっていくにちがいない。

分子スケールでのアプローチに加えて、最新のコンピューター技術やマルチスケール予測モデルの利用もまた、たとえば不均一系における汚染物質のスペシエーション、微生物作用による形態変化のメカニズム、環境と人間の健康との関連、効率的な環境修復と廃棄物管理方法の発展といった数多くのフロンティア研究に取り組む土壌科学者を支援するうえで、きわめて重要な役割を担うだろう。

ESAFS as a bridge between JSSSPN and IUSS

Makoto KIMURA (Nagoya University, kimuram@agr.nagoya-u.ac.jp)

1. Way to establish ESAFS

At the 13th Hamburg Congress of International Soil Science Society (ISSS) in 1986, a working group (WG) on Paddy Soils Fertility was established and Prof. Hidenori Wada (Univ. of Tokyo) was elected as the first Chairman of the WG. He made every effort to organize the first symposium at Chiang Mai, Thailand, with cooperation of the Late Dr. Samarn Panichapong, Secretary of WG and then Advisor of IBSRAM (International Board for Soil Research and Management). In December, 1988, a symposium was held with the general theme "Paddy Soil Fertility: Past, Present and Future", and attended by 180 scientists from 15 countries. The success of the symposium clearly showed that there was sheer need to enhance opportunity for exchange of information in rice research and technology among the countries with rice-based farming system as an important component of their agriculture.

During the same period of time for the preparation of the 14th ISSS Congress at Kyoto, the Japanese Society of Soil Science and Plant Nutrition (JSSSPN) examined a plan to establish a regional body to promote researches specifically related to rice cultivation in Monsoon Asia. The plan was formally resolved at the Annual Meeting of the Society in April 1990. Prior to the Kyoto Congress of ISSS, Prof. Kyuma (the then President of JSSSPN) sent by mail an appeal of JSSSPN to the national soil science societies within Monsoon Asia to set up a regional body of academic societies working in the fields of soil science, plant nutrition and fertilizer technology in relation to rice cultivation.

As many of the national societies expressed a positive response to the appeal, Prof. Kyuma convened the first meeting on Aug. 15, 1990 in Kyoto, during the session of the ICSS. The meeting was attended by 16 delegates from China-Mainland, China-Taiwan, India, Japan, Korea, Malaysia and Thailand.

At this meeting, Prof. Kyuma gave a brief explanation on his proposal to establish a regional body of the societies of soil science and related sciences in the countries in South, Southeast and East Asia. He reported that he had received 6 positive answers by communication from the national societies of China-Taiwan, Korea, Malaysia, Philippines, Sri Lanka and Thailand. He then confirmed the positive attitude from the delegates of China-Mainland and India who attended the meeting. Thus, altogether 9 national societies, including Japan, agreed upon to formulate a regional organization.

Naming of the regional organization in relation to the regional delineation was discussed and after some discussion "East and Southeast Asia Federation of Soil Science Societies (ESAFS)" was unanimously adopted with an understanding that this regional delineation is justified by the emphasis placed on rice-based cropping systems as an important component of agricultural production system in the region.

General Rules of the Federation were drafted during the period of the Kyoto Congress of ISSS and distributed to the delegates of the member countries and they were officially accepted. According to the Rules, the first office was held by JSSSPN for a two-year term, 1990-1992, and Prof. Kyuma became the first President.

Later, the national societies of Bangladesh, Indonesia and Vietnam became the members, so that the membership covers 12 countries within the region as of July, 2005.

(from Homepage of ESAFS)

2. Objectives of ESAFS

The Federation shall aim at promoting researches in soil and related sciences and disseminating the acquired knowledge and technology for the benefit of the member societies in the region of east and southeast Asia. By so doing the Federation shall contribute to the sustainable development of the region through harmonization of agricultural production and environmental protection.

The Federation shall also aim at promoting the effective participation of member societies and of individual soil scientists of the region in the work of the International Union of Soil Sciences.

3. ESAFS Membership

Core members shall consist of any scientific societies concerned with soil science, plant nutrition and fertilizer management and technology in any countries in east and southeast Asia where rice-based cropping system is an important component of agricultural production system.

The Federation welcomes the societies which are located outside of the region but interested in the activities of the Federation as the associate members for promoting the objectives of ESAFS together.

4. ESAFS Officers

The Officers of the Federation shall be:

1) President, 2) First and Second Past Presidents, 3) Secretary General, 4) Society Representative

The Office of the Federation shall be moved from one member society to another every two years and the President of the society which holds the Office shall be automatically appointed as the President of the Federation.

ESAFS Offices in the past

1) 1990 August – 1992 March
   Japanese Society of Soil Science and Plant Nutrition, Japan (President: Prof. Kazutake Kyuma)
2) 1992 April – 1995 September
   Soil Science Society of China, China (President: Prof. Quiguo Zhao)
3) 1995 September – 1997 November
   Malaysian Society of Soil Science, Malaysia (President: Prof. J. Shamshuddin)
4) 1997 November – 1999
   The Korean Society of Soil Science and fertilizer, Korea (President: Dr. In-Soo Yoo)
5) 1999 – 2001 May
   Soil and Fertilizer Society of Thailand, Thailand (President: Dr. Sompong Theerawong)
6) 2001 June – 2003 November
   The Chinese Society of Soil and Fertilizer Sciences, Taiwan (President: Prof. Zueng-Sang Chen)
7) 2003 November – 2005 June
   The Philippine Society of Soil Science and Technology, The Philippines (President: Dr. Rogelio N. Concepcion)
8) 2005 June – 2007 Autumn
   Japanese Society of Soil Science and Plant Nutrition (President: Prof. Makoto Kimura)

5. ESAFS Activities

A newsletter shall be published and distributed biannually by the Office of the Federation as a medium to exchange information on research news and activities among the member societies.

Symposia and workshops shall be sponsored or co-sponsored by the Federation as frequently as possible.

Member societies shall be encouraged to organize activities under the umbrella of the Federation.

ESAFS Workshops and Conferences in the past

ESAFS conferences have generally been held every two years by the then Office of the Federation. Every conference was coupled with 1 to 3 days excursion visiting interesting, informative sites for rice cultivation in the host country.

1) **The 1st ESAFS International Workshop** on "Correlation of the National Soil Classification Systems for Agro-technology Transfer" November 10-15 (1991), Osaka, Japan
2) **The 2nd ESAFS International Workshop** on "Classification and Management of Desert Soils" August 21-29 (1993), Urumqi, China
3) **The 3rd ESAFS International Conference** on "Soil Resource and Sustainable Agriculture for East and Southeast Asia (Soilsafe)" September 12-15 (1995), Kuala Lumpur, Malaysia
4) **The 4th ESAFS International Conference** on "Soil Quality Management and Agro-Ecosystem Health" November 11-14 (1997), Cheju, Korea
5) **The 5th ESAFS International Conference** on "Rice Environments and Rice Products" May 27-31 (2001), Krabi, Thailand
6) **The 6th ESAFS International Conference** on "Soil Management Technology on Low-productivity and Degraded Soils" November 24-29 (2003), Taipei, Taiwan
7) **The 7th ESAFS International Conference** on "Sustainability of Paddy Farming Systems" June 1-5 (2005), Quezon City, The Philippines

ESAFS Newsletters

The newsletters have been published twelve times. The topics of the newsletters were mainly about the activity reports of the Member Societies and the reports of ESAFS Conferences.

6. The 8th ESAFS International Conference Japan in 2007 (Tentative)

- Main Theme of Conference (Tentative)

  New Challenges of Soil Science for Harmonizing Food Production with Environments
  -Sustainable Agriculture to Take over Our Natural Resources to the Next Generation-
- Venue of Conference and Season: Tsukuba, Japan, Autumn 2007
- Excursion: Tsukuba – Nikko – Nasu – Sendai Plain – Narita
- Co-Organized by

  Japanese Society of Soil Science and Plant Nutrition (JSSSPN)
  National Institute for Agro-Environmental Sciences (NIAES)

7. Past Symposia organized by Paddy Soils Fertility WG

1) **The First International Symposium on Paddy Soil Fertility**

   6-13 December (1988), Chiang Mai, Thailand
2) **The 14th WCSS 1990 (Kyoto, Japan)**

   Fate of nitrogen in paddy fields (Chair persons; De Datta SK, Park CS & Kai H)*

Fertility and management of paddy soils (Poster session)*

* These symposium and poster session were regarded as **the Second International Symposium on Paddy Soil Fertility**

3) **The Third International Symposium on Paddy Soil Fertility** and
The First International Symposium on Paddy Soils in East and Southeastern Asia

15-19 September (1992), Nanjing, China (Co-organization with **ESAFS**)

4) **The International Conference on Soil Resource and Sustainable Agriculture for East and Southeast Asia (Soilsafe)**

12-15 September (1995), Kuala Lumpur, Malaysia (Co-organization with **ESAFS**)

5) **The 17th WCSS 2002 (Bangkok, Thailand)**

Sustainable paddy soil ecosystem: a global challenge (Chair persons; Concepcion RN & Saenjan P)

6) **The International Conference on Sustainability of Paddy Farming Systems**

June 1-5 (2005), Quezon City, The Philippines (Co-organization with **ESAFS)**

* Any symposium was not organized by WG in the 15th and 16th WCSS (at Mexico, in 1994 and at Montpellier, France, in 1998).

8. ESAFS as a bridge between JSSSPN and IUSS

The establishment of Paddy Soil Fertility WG in ISSS and the success of the first International Symposium on "Paddy Soil Fertility" by the WG in 1988 at Chiang Mai, Thailand, motivated the establishment of ESAFS as well as the timely meeting of the member societies for resolving the ESAFS establishment during the Kyoto conference of ISSS. In addition, the Third International Symposium on Paddy Soil Fertility at Nanjing, China, in 1992 that was co-organized by the WG and ESAFS took a decisive role to consolidate the ESAFS recognition among the member countries at its infancy. After the establishment of ESAFS in 1990, the ESAFS Workshops/Conferences were held basically every two years in the member countries by rotation.

On the contrary, the activity of the WG were discouraging after the Third Symposium at Nanjing in 1992. Major activities of the WG were only the joint-hosting of two ESAFS Conference at Kuala Lumpur, Malaysia (1995) and at Quezon City, the Philippines (2002) except for the WG symposium in the 17th WCSS at Bangkok, Thailand, in 2002.

Our Society has promoted the internationalization, especially to ESAFS member countries, by organizing and sponsoring several international workshops/conferences. We have many research subjects in common with ESAFS member countries such as paddy soils and Andisols, and many members of our Society have conducted many cooperative projects with ESAFS scientists with a lot of fruitful achievements. The significance of ESAFS is now far larger compared with the time of its establishment for the internationalization to Asian countries. The Paddy Soil Fertility WG in IUSS is important to take the firm position in IUSS for introducing ESAFS activities (including activities of our Society) to the world. ESAFS understands the WG well, and is its best supporter. It is requested for the Society members to take an active participation to the 18th World Congress of IUSS in Philadelphia nest July, by having a new understanding of ESAFS. It is really a very important chance for us to present our activities to the world as well as a very good opportunity for the recognition of ESAFS by the World.

日本土壌肥料学会と世界土壌科学連合の架け橋としての
東・東南アジア土壌科学連合

木村眞人（日本土壌肥料学会会長、東・東南アジア土壌科学連合会長）

1．ESAFS設立の経緯

東・東南アジア土壌科学連合（ESAFS）の設立は、1986年にドイツ・ハンブルグで開催された第13回国際土壌科学会議において、「水田土壌肥沃度」ワーキンググループ（WG）の設置が承認されたことに始まる。同WGは、1988年12月、タイ国Chiang Mai市で第1回国際シンポジウム“Paddy Soil Fertility: Past, Present and Future”を開催し、15ヶ国から180名の参加を見た。本シンポジウムの盛況は、水田土壌研究に関する情報交換の機会を、多くの研究者が待望していることを強く印象づけた。

日本土壌肥料学会は1990年4月の年次総会において、モンスーンアジア地域の稲作に関連する研究推進のために、地域連合機関設立の必要性を決議し、当時の学会長久馬一剛は、直ちに設立趣意書をモンスーンアジア各国の土壌学会に送付した。反応の多くは、趣意書に対し賛意を表するものであった。

第14回国際土壌科学会議京都大会の期間中の1990年8月15日、久馬会長は、関係国の代表者(日本を含め7ヶ国16名)を招集し、経緯、設立趣旨、各国からの反応を説明し、会議参加国を含め計9ヶ国（China, India, Japan, Korea, Malaysia, Philippines, Sri Lanka, Taiwan, Thailand）の賛成のもと、地域連合の設立が決定された。加えて、東・東南アジア各国が共通して稲作を基幹とする農業であることから、その連合の名称を「東・東南アジア土壌科学連合（ESAFS）」と正式決定するとともに、本「連合」の規約案も、京都大会中に作成・回覧され、正式に承認された。

また、規約を基に、1990年から1992年の2年間、日本土壌肥料学会がESAFS事務局を務めることとなり、久馬一剛学会長が初代ESAFS会長に就任した。

その後、Bangladesh, Indonesia, Vietnamも参加し、現在ESAFSは、12ヶ国から構成されている。

2．ESAFSの目的および活動

土壌学および関連科学の研究を推進し、得られた知識と技術を東・東南アジア地域の加盟学会のために普及する。そうすることにより、連合は農業生産と環境保護の調和を通して加盟学会や個々の土壌科学者が、国際土壌学会の活動に有効に参加することを促進する。

連合の事務局は、加盟学会間での情報交換を目的にニュースレターを出版・配布するとともに、できるだけ頻繁にシンポジウムやワークショップを主催ないしは共催する。

第1回ESAFS国際ワークショップ“Correlation of the National Soil Classification Systems for Agro-technology Transfer” 1991年11月10-15日、大阪

第2回ESAFS国際ワークショップ“Classification and Management of Desert Soils” 1993年8月21-29日、中国Urumqi

第3回ESAFS国際会議“Soil Resource and Sustainable Agriculture for East and Southeast Asia (Soilsafe)” 1995年9月12-15日、Kuala Lumpur, Malaysia

第4回ESAFS国際会議“Soil Quality Management and Agro-Ecosystem Health” 1997年11月11-14日、韓国済州島

第 5 回 ESAFS 国際会議 “Rice Environments and Rice Products” 2001 年 5 月 27-31 日、Krabi, Thailand

第6回ESAFS国際会議 “Soil Management Technology on Low-productivity and Degraded Soils” 2003 年 11 月 24-29 日、台湾、台北

第7回ESAFS国際会議 “Sustainability of Paddy Farming Systems” 2005年6月1-5日、Quezon City, The Philippines

3．これまでの事務局

1990 - 1992： 日本土壌肥料学会（会長：久馬一剛教授）

1992 - 1995： Soil Science Society of China, China (Prof. Quiguo Zhao)

1995 - 1997： Malaysian Society of Soil Science, Malaysia (Prof. J. Shamshuddin)

1997 - 1999： Korean Society of Soil Science and fertilizer, Korea (Dr. In-Soo Yoo)

1999 - 2001： Soil and Fertilizer Society of Thailand, Thailand (Dr. Sompong Theerawong)

2001 - 2003： Chinese Society of Soil and Fertilizer Sciences, Taiwan (Prof. Zueng-Sang Chen)

2003 - 2005： The Philippine Society of Soil Science and Technology (Dr. Rogelio N. Concepcion)

4．第 8 回 ESAFS 国際会議（案）

メインテーマ：New Challenges of Soil Science for Harmonizing Food Production with Environments -Sustainable Agriculture to Take over Our Natural Resources to the Next Generation-

開催時期および開催場所：2007 年秋、筑波

エクスカーション：筑波－日光－那須－仙台平野－成田

主催：日本土壌肥料学会、独立行政法人農業環境技術研究所

5．日本土壌肥料学会と IUSS の架け橋としての ESAFS

ISSS に設置された「水田土壌肥沃度」WG の活動が、ESAFS の設立につながり、これまで多くの国際会議を共催してきた。ESAFS は、1990 年の設立以降、ほぼ 2 年に 1 回国際会議を開催してきたのに比べ、WG の活動は、第 3 回 “Paddy Soil Fertility” 国際シンポジウムを南京で開催して以降、ESAFS 国際会議の共催を除いては、先の第 17 回世界土壌科学会議 Bangkok 大会におけるシンポジウムのみと活動が停滞しており、その廃止が危惧されている。

現在、日本土壌肥料学会は、国際化、特に ESAFS 参加国との連携強化に務め、数々の国際シンポジウム、ワークショップを主催・共催してきた。わが国は、ESAFS 参加国と水田、黒ボク土など多くの農業基盤を共有し、日本土壌肥料学会会員の多くが、これまでに ESAFS 加盟国の研究者と数々の共同研究を実施し、多大の成果を得てきた。アジアに向かっての国際化にとって、ESAFS の存在は重要である。加えて、我が国研究者の優れた成果を、そして ESAFS 加盟国との共同研究の成果を、積極的に世界に向かって公表することも重要である。IUSS「水田土壌肥沃度」WG は、そのための最も身近な窓口であり、活動の再活性化、IUSS`における確固たる地位確立が望まれる。ESAFS は、「水田土壌肥沃度」WG の最大の理解者であり、支持基盤である。ESAFS 設立当時に比べて、その存在意義はきわめて大きい。ESAFS の存在意義を理解し、積極的に ESAFS 活動に参加するとともに、来年の世界土壌科学会議への参加が望まれる。それは、我が国の土壌肥料植物栄養分野の成果を世界に発信する場であり、ESAFS の世界的な認知にも通じる機会である。

Frontiers of Plant Pathogenic Soil Microbiology in Japan
—Toward Biological Control of Soilborne Diseases—

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Among soil microorganisms which parasitize plant species, some could cause diseases. Such microorganisms are defined as plant pathogenic soil microorganisms and are generally referred to as soilborne plant pathogens. They are divided into root-inhabiting "specialized" microorganisms which have a limited host range and soil-inhabiting "unspecialized" microorganisms which have wide host range.

There are various kinds of soilborne fungal, bacterial and viral diseases in plant. Fungal diseases are predominant among them. There is no effective control method for preventing soilborne diseases, so, they are considered as incurable diseases. In Japan, under the high growth of Japanese economy started in the end of 1950s, remarkable changes of the agricultural structure occurred and economically valuable crops, especially vegetables, flowers and fruits were started to grow under especially intensive managements. As a result, monoculture injuries mainly based on soilborne diseases became revealed. After 1970s, it became difficult to continue growing same crops in many areas known as main producing centers, which brought collapse or movement of the producing centers. Various soil disinfectants and fungicides are available to farmers, but these tend to be somewhat toxic and cause longterm pollution problems, as well as being relatively ineffective. The control of soilborne diseases of crops is an urgent problem and many researchers are now seeking methods to alleviate the damage caused by soilborne diseases by the implementation of biological control.

In Japan, main groups of soilborne diseases are almost same for 40 years since 1960s, and fungal, bacterial and viral diseases have occupied around 68%, 27% and 5%, respectively. Among bacterial diseases, *Erwinia*, *Pseudomonas* and *Ralstonia* diseases are predominant and occupy around 90% of the total bacterial diseases. Among fungal diseases, disease caused by *Plasmodiophora* that belongs to the Kingdom Protoza occupies around 12%, diseases by *Phytophthora*, *Pythium* and *Aphanomyces* that belong to the Kingdom Chlomista are 13%, and diseases by *Rhizoctonia*, *Helicobasidium/Rosellinia* (these are known to cause "monpa disease"), *Fusarium*, *Verticillium* and others that belong to the Kingdom Fungi are 7%, 24%, 24%, 7% and 13%, respectively.

The era of the research history of soilborne diseases is grossly divided into four periods; etiological research period (1854-1907), ecological research period (1908-1935), biochemical research period (1936-1973) and biological control research period (1974-present). Etiological research began with the description of *Rhizoctonia solani* in 1854 and ended with the description of *Bacterium tumefaciens* (*Agrobacterium tumefaciens*) in 1907. During the half century, descriptions of almost all the main soilborne pathogens have been completed. Since 1974, the mechanisms of natural soil suppression and of biological control have been studied intensively world wide from the aspects of physiology, ecology and molecular biology. The technology of biological control supporting the idea of "Integrated Farm System (Sustainable Agriculture)" which started from 1980s plays an important role in the "Integrated Pest Management" practices.

As for the biological control methods using antagonistic microorganisms, there are two ways. One is to multiply the microbial community existing in soil and to activate them functionally and the other is to inoculate a specific beneficial microorganism directly into soil for the purpose of suppressing the disease occurrence.

Disease suppressive soil and the phenomena of disease decline are the examples naturally occurring biological control. These are caused by the action of the community of antagonistic microorganisms existing in soil. Soil fungistasis, a phenomenon closely related with naturally occurring biological control, is also caused by the action of the community of soil microorganisms. The mechanisms of these phenomena have been studied for years by many researchers. The realistic biological control methods based on the idea of the microbial community are the amendments with organic materials, mixing with green manure crops and the utilization of compost products. The effect of disease suppression by these methods, however, is not stable, and can not be held as a universal mechanism of disease suppression.

The whole entity of the microbial community acts as a functional consortium. It means that analysis of individual microorganism or a specific antagonism does not fully explain the soil suppressiveness. Recently, attentions are being paid to study the variable functions of soil microbial community and to manage the community towards the specified direction for the purpose of suppression of soil-borne diseases. This is mainly due to the gene technology developed in the recent years in which soil microbial community could be studied using directly extracted DNA from soil. This is independent of the conventional culture-based method and could elucidate the relationship between the microbial community and the inhibitory factors for plant production such as monoculture injuries or soil-borne diseases.

It is essential to accumulate more findings and knowledge on the community evolution of soil microorganisms in order to establish consistent and reliable methods of disease control that can be applied in a wide range of conditions and situations over a long period of time. Recently, the functions of microbial community are thought to be modified purposely by additions of certain nutrients. Soil enrichment with simple sugars or amino acids may be a useful experimental approach to studying of the community evolution of soil microorganisms and the mechanism of suppression of soilborne plant diseases. To find out the realistic methods for enhancing the microbial antagonism and utilizing their functions for disease control is still kept in the researcher's dream. For its realization, further future research would be expected.

From the research of utilizing specific antagonistic microorganisms, so far many efficient biological control agents have been found. Some were even successful to be commercialized as microbial fungicides in Japan. These microbial fungicides, however, have several problems as having a narrow disease target for control, short survivability at the acting site against pathogens, difficult maintenance of their activity to suppress pathogens for long time, etc.. These constrains are thought to be the limitation and low reproduction of their biological control effect. As many introduced microorganisms are difficult to colonize in soil, new attempts have been made such as to find out the microorganisms which could be able to colonize in plant rhizosphere or rhizoplane, to utilize endophytes which live inside plants, or to artificially introduce microorganisms into plants. Plant-associated microbes give physiological and environmental advantages to their host plants. Nowadays, in Japan, biological control using endophytic fungi, actinomycetes and bacteria and their mechanisms are extensively studied. For example, Chinese cabbage seedlings grown from seeds treated with endophytic *Heteroconium chaetospira* became resistant to *Plasmodiophora brassicae* and their growth was significantly promoted. Plant growth-promoting fungi belong to genera *Penicillium*, *Trichoderma, Fusarium*, *Phoma* and sterile fungi enhanced the growth of a variety of crop plants and also induced systemic resistance against a wide range of pathogens. Tissue-cultured seedlings of rhododendron and mountain laurel that were treated with symbiotic actinomycetes, *Streptomyces galbus* and *S. padanus,* by spreading their mycelial suspensions on the surface of tissue-culture media were resistant to *Pestalotiopsis sydowiana* and *Phytophthora cinnamomi. Pseudomonas fluorescens* originally identified as an endophytic plant growth-promoting rhizobacteria enhances growth of a variety of crop plants and also induced systemic resistance against a wide range of pathogens.

Thus, objectives of the site of biological control are changing from bulk soil to rhizosphere, to rhizoplane, and even to inside roots because of the easy treatment of the antagonistic microorganisms to plants. From the research of utilizing specific antagonistic microorganisms, as the pathosystem could be narrowed down to three components; i.e., plant, pathogen and antagonistic microorganisms, the disease suppression mechanisms by introduced biological control agents could be elucidated in detail from the aspects of an antagonism and an induced resistance in plants. Utilizing specific antagonistic microorganisms, however, is effective just in a greenhouse or a vinyl house where the environment could be easily regulated, but is very difficult in a field. Many problems piled which should be solved; antagonistic microorganisms should be introduced in the whole field, introduced microorganisms usually can not colonize in a complex system as soil, high amounts of treatment is necessary, disease suppression effect is not stable, etc..

In many instances, biological control against soilborne diseases involves the modification of the soil rhizosphere in favor of the plant and the beneficial microorganism. The impact of these changes to the microenvironments around the rhizosphere needs to be well understood in order to avoid irreparable disorders in the soil systems. Similarly, there are possibilities to overdose the recommended application rates by ambitious end users/farmers interested in significant and tangible disease suppression equivalent to those previously achieved through chemical controls. The holistic impact to these possible malpractices may take a long time to be fully understood and appreciated. Biological control has had good reception by the consumers compared to genetically modified produce. However there is need to continuously review the end user packaging, formulations, and recommendations based on the continuous risk assessment data on the use of various developed biological control systems.

When moving ahead with the "Integrated Farm System", the significance of biological control is further compounded. The research of utilizing specific antagonistic microorganisms follows the exploitation of the microbial fungicides which could be used in actual agricultural production fields. Such microbial fungicides, however, are restricted to use inside a closed system as mentioned above. To receive much recognition of biological control as a general technology of disease suppression by the agricultural producers, it is necessary to compile many successful examples of biological control and to establish biological control methods using soil microbial community in fields.

日本における植物病原性土壌微生物学の最前線
－土壌伝染性病害の生物防除に向けて－

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植物病原性土壌微生物とは主に植物寄生性の土壌微生物のうち植物に病気を起こすものが対象となる。また、連作による作物の生育、収量の低下を引き起こす不定性病原菌のような一般には病原菌とみなされていない土壌微生物も含まれる。これらは根系に生息する「分化寄生菌(寄生性が分化し宿主範囲が限られているもの)」と土壌に生息する「未分化寄生菌(宿主範囲が広く腐生能力の高いもの)」に分けられる。

重要な土壌伝染性病害(以下、土壌病害)には、各種の菌類病、細菌病およびウイルス病がある。なかでも菌類病がその大半を占めている。土壌病害を防ぐ有効な方法はなく、そのため土壌病害は難防除病害と位置づけられている。日本では1950年代後半に始まった高度経済成長の中で、農業形態は急速な変貌を遂げ、経済性の高い作物の専作化を行うようになり、その結果、土壌病害を主要因とする連作障害が顕在化してきた。1970年代以降には、多くの主要な野菜産地において土壌病害が原因で同じ作物を生産できなくなるいわゆる“産地崩壊”や産地を移動せざるを得ない“産地移動”が生じている。

土壌病害の研究の歴史を時代別に見てみると大きく、病因学的研究(1854～1907)、生態学的研究(1908～1935)、生化学的研究(1936～1973)、生物防除学的研究(1974～現在)に分けることが出来る。土壌伝染性病害の病因学的研究は1854年の *Rhizoctonia solani* の記載に始まり、1907年の *Agrobacterium tumefaciens* が記載されるまでの半世紀の間にほぼ主要な病原菌の記載は終わっている。1974年以降は生物防除学的研究の時代であり、自然で見られる発病抑止機構の解析や生物防除機構の解析が生理・生態学と分子生物学の両面から盛んに行われている。1980年代から始まった環境保全型農業を支える技術として微生物を利用する生物防除は総合的有害生物管理の中で重要な位置を占めており、世界的なレベルで生物防除研究が盛んである。

拮抗微生物を用いた土壌病害の生物防除への取り組みには、もともと土壌に定住していた拮抗微生物コミュニティーの増殖や活性を増強させて病害の発生を抑制しようとするものと、有用な拮抗微生物を直接的に土壌に導入して病害を防除しようとする、大きく二通りがある。

自然に生じた生物防除の例として知られている発病抑止土壌や土壌病害の発病衰退現象はいずれもそこに定住している拮抗微生物コミュニティーによって生じたものであり、微生物コミュニティーが病害抑制に成功した例である。また、自然に生じる生物防除に深く関わっているとされる土壌静菌作用も、そこに定住している微生物コミュニティーにより生じたものである。こうした現象の解析は、多くの研究者によって何年もかけて研究されてきた。微生物コミュニティーの考え方に基づいた現実的な生物防除法として、有機物の施用、緑肥作物の鋤き込み及びコンポストの利用等が行われている

が、それらの病害抑制結果は必ずしも一定しておらず、そのため、現在はまだこれらの病害抑制のメカニズムを普遍的なものとして捉えることができないでいる。複合系である微生物コミュニティーでは土壌の微生物相全体が機能を持ったコンソーシアムとして作用するため、個々の微生物やある特定の拮抗作用を解析しても、土壌の抑止性を解明できないことになる。最近、多様化した土壌微生物コミュニティーの機能を解析し、コミュニティーを特定の方向に制御することで土壌病害を防除しようとする試みが再び着目されている。これは、近年発達した遺伝子技術の成果に負うところが大きい。すなわち、培養に依存せずに土壌中から直接抽出したDNAを用いて土壌微生物相を解析することで連作障害や土壌病害等の生産性阻害要因と微生物相との関連を解明しようとするものである。自然で生じている生物防除の現象を見つけ出し、そのメカニズムを解析して、微生物拮抗を強め実際の防除に役立てる方策を見出すことは、まだ研究者の夢の域を出ていないのが現状だが、今後の研究成果を期待したい。

特定の拮抗微生物を利用する生物防除の取り組みからは、生物防除効果の高い有望な生物防除エージェントが見出されており、日本においてもこれまでに微生物殺菌剤として各種の微生物が資材化に成功してきている。しかしながら、防除対象の病害が限られてしまうことや、拮抗菌が病原菌と作用する部位で長期にわたって生存しない、または、生存していても病原菌を抑制するだけの活性を維持できない等の問題がある。このことが生物防除効果を限定し、その再現性を低くする原因とされる。また、導入した拮抗微生物は土壌への定着が困難なことから、植物の根圏あるいは根面に定着できる菌の探索や、あるいは、植物体内に生活している内生菌を利用するか、人為的に拮抗微生物を植物に共生させようという試みも行われている。現在は特に内生糸状菌、内生細菌、内生放線菌等の内生菌を用いた生物防除とそれらの機構解析が精力的に研究されている。このように、拮抗微生物の資材化を目的とした研究対象は、土壌全体→植物の根圏土壌→根面→根内、と次第に微生物の処理しやすい場面に移行してきている。また、特定の拮抗微生物を利用する生物防除の研究では、系を宿主・病原菌・導入微生物の3者に絞り込むことができるため、導入した拮抗微生物による病害抑制のメカニズムが病原菌に対する拮抗作用と宿主への抵抗性誘導の両面から詳細に調べられている。しかしながら、特定の拮抗微生物の利用は環境が制御できる温室やビニールハウスなどでは可能だが、一方、圃場を用いる場面では極めて難しい。微生物を土壌全体に処理せざるを得ないこと、複合系の中への投入であり定着の問題が生じること、処理量が莫大となること、効果が不安定であること等、解決しなくてはならない問題が山積している。

環境保全型農業を推し進める上で生物防除研究の重要性が増している。特定の拮抗微生物を利用する生物防除の研究の流れは、前述したように実際の農業生産場面で使用される微生物殺菌剤の開発にまで発展してきた。しかし、その利用は今のところ閉鎖系の施設内に限られている。生物防除が一般的な技術として生産者に認められるためには、特定の拮抗微生物を利用した生物防除の成功例を数多く築きあげるとともに、土壌微生物コミュニティーを利用した生物防除技術が圃場レベルでも総合的有害生物管理の中で重要な位置を占める技術になることを示す必要があろう。

Frontiers of physiological research on soil minerals stresses in Japan

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It is estimated that approximately 70% of the soils are problem soils containing acid, alkaline, heavy metal-contaminated and salinity soil etc. in the world. Acid soils are the largest problem soil. Attention has been paid to improving the agricultural production in acid soil because of increasing environmental problems and the anticipated population growth in the world in the future. Currently approximately 12% of the land in crop production is acidic, however, the extent of acid soil is increasing world-wide. The evidence is comprehensive from south Sweden, where the pH of virtually all forest and other semi-natural(uncultivated) soil has decreased by 0.5 to 1.0 units or more over a period of only 3 or 4 decades(Tyler 1989). World population is projected to increase from 5.3 billion in 1990 to 6.3 billion in 2000, 8.5 billion in 2025, and 10.6 billion in 2050. Such increased population pressures will magnify the demand for more food from the limited cultivated land (Baligar and Fageria 1997). Borlaug and Dowswell(1993) state that to meet this food demand, cereal production needs to be doubled from about 2 billion tons in 1999 to 4 billion tons in 2025. Therefore the effort should be paid to utilize the various problem soils for food productions. Japanese soils are basically characterized by acid soil because the origin of soil is volcanic. So far Japanese scientists have being contributed to the understanding on the nature of acid soil and the mechanism of plant injuries by Al which is the major factor causing the reduction of productivity in acid soil. Furthermore the tolerance mechanism has been analyzed dramatically in past few decades. The plant genome initiative and developments in molecular biology and genetic engineering of crop plants are opening up vast opportunities to impose crop productivity. Recent developments in molecular biology have resulted in the isolation and characterization of several genes that are expressed in the planst grown in specific problem soil. The manipulation and pyramiding of these desirable genes could significantly improve the productivity of crop in the problem soils. The cooperation of both plant and soil scientists is getting more and more important to overcome the problems under soil mineral stresses. In this article, I would like to introduce some pioneer researchs regarding the physiological and molecular approach including transgenic plants expressing the tolerance genes for Al, ion-deficient and phosphate-deficient stress.

General characteristics of acid soil

Acid soils occupy approximately 30% or 3950 billion ha of the world's ice free land area. Only 4.5% (179 million ha) of the acid soil area is used for arable crops. The main factor in producing acid soils is the thousands and even millions of years of leaching by rain water, which is both a good solvent and is slightly acidic. The water adds protons (H^+ ions) while removing the more soluble nutrients and gradually dissolving most primary and secondary minerals. Under the most intensive weathering this ultimately results in soils that consist of little except oxides and hydroxides of iron and Al plus some kaolinite and qualtz and produces soils which are acidic to great depth (Baligar et al. 1998). Only 10.6% of the total area of the world is cultivated

(1406 million ha) and about 24.2% (3190 million ha)is considered cultivable or is potentially arable land(von Uexkull and Mutert 1995). Most of this area (about 2500 million ha) is composed of acid soils, of which about 1700 million ha are located in the humid tropics mainly as Oxisols and Ultidols. In Asia, the highest regional share of acid soils is found in Southeast Asia and the Pacific(excluding Australia and New Zealand) whose 63%(315 million ha) of the regional land area is comprised of acid soils with Ultisols accounting for 57.6%(181 million ha) of the region's acid soils. Eastern and Southern Asia use the highest proportion (77 million ha) of arable and permanently-cropped acid soils due to population pressure and extensive area used for plantation crops. Poor crop growth in acid soils can be correlated directly with Al saturation. Also the poor fertility of acid soils is due to usually the combination of Al toxicity, manganese toxicity, iron toxicity (reduced soil conditions only), phosphorus deficiency, magnesium deficiency and potassium deficiency.

Al toxicity

Al, the most abundant metal in the earth's crust, has been implicated as early as 1918 as a cause of root-growth retardation in barley and rye plants grown on acid soils (Hatrwell and Pember 1918). Today, Al is recognized as serious global problem for crop productivity. The primary target of Al toxicity is the root apex. Al affect a number of different cellular functions although the foremost effects of Al toxicity is still not clear. Exposure to Al causes stunting of the primary root and inhibition of lateral root formation. Affected root tips are stubby due to inhibition of cell elongation and cell division. The restricted root system is impaired in nutrient and water uptake, making the plant more susceptible to drought stress.

Al tolerance mechanism

Several strategies have been pursued to manage acid soils. The primary method has been the application of large amounts of lime, to raise soil pH and cause conversion of toxic Al^{3+} to less toxic forms, and application of phosphorus (P). However, these soil amendments are not practical in many locations such as highly erosive slopes nor are they economical where large areas require amendment or where transportation costs are prohibitive. In addition, liming does not remedy soil acidity below the plow layer. Therefore interest in solution of Al toxicity has being directed to the more physiological research, that is, development of Al-tolerant crop cultivars with deep root penetration is of paramount importance. Gross estimates indicate that billions of dollars could be saved in the purchase of lime or potential crop production increases as a result of new stress resistant plant varieties (National Academy of Sciences 1976). However, we should not forget that the progress of recent physiological research on Al stress is due to the excellent and pioneer research on the chemical characteristic of acid soil by Japanese soil chemist. Daikuhara (1910) found excellent method for the determination of soil acidity caused by Al with KCl extraction. Many recent studies provided the strong evidence that Al-tolerant genotypes of wheat, soybean, corn etc. exclude Al from root tips by exudation of organic acids from root tip that chelate toxic Al rendering less toxic(Exclusion mechanism). In wheat, activation of malate efflux occur in 5 min after exposure of root tips to Al. Recently novel gene encoding Al activated malate transporter(*ALMT1*) was detected by cooperative research of Japan(Research group of Dr. Matsumoto, Okayama University) and CSIRO, Australia(Sasaki et al. 2004, Delhaize et al.2004). Electrophysiological evidence with *Xenopus* oocytes and transgenic barley and tobacco cells expressing *ALMT1* demonstrate that

ALMT1 encoding Al-activated malate transporter on plasma membrane is capable of conferring Al tolerance to plant cells.

Phosphate deficient stress in acid soils

Since phosphorus (P) is a severely limiting and nonrenewable resources, improvement of the ability of P acquisition is an important goal in sustainable agriculture (Kihara et al 2003). Large fraction of applied P to acid soils is fixed by amorphous hydrated oxides of Fe and Al. The fixed Al-P is less available for plants. Plants have range of strategies to improve P acquisition from soils when derived of P such as high –affinity Pi-transport systems, the exudation of organic anions including citrate and malate and the efflux of acid phosphatase. The research group of Dr. Koyama, Gifu University, succeeded to get the transformants which can grow better in the medium with Al-P by increase of the biosynthesis of citrate (Koyama et al 2000, Kihara et al. 2003). The strategy used was the introduction of the gene encoding mitochondrial citrate synthetase of *Daucus carota* mutant cell lines (IPG) into *Arabidopsis thaliana.* They also found that NADP-specific isocitrate dehydrogenase (NADP-ICDH) is repressed in mutant cell line which can grow with insoluble phosphate (IPG: insoluble phosphate grower).

Iron deficient stress in alkaline soil

Iron deficiency in cultivated plant is a world wide problem in calcareous alkaline soil, which accounts for 20-30% of the cultivated soil in the world. There is sufficient Fe in this soil, but it is sparingly soluble in soil water under aerobic soil conditions at pH above 7. The pioneering work of Takagi (1976) who discovered mugineic acid, paved the way the establishment of two Fe-acquisition systems in the plant kingdom, strategy 1 and 2. In strategy 2, so- called mugineic acid families (MAs) are released from the roots and bind with sparingly soluble Fe(III) in the soil medium, converting it soluble Fe(III)-MAs. So far intensive works on strategy 2 have been carried out by the research group of Dr. Mori, Tokyo University. They investigated the biosynthetic pathway of MAs and purified the all enzymes connected to the pathway (Higuchi et al 1999, Takahashi et al.2001). Furthermore they cloned the all genes requisite for the synthesis of MAs. MA is synthesized and secreted from the root of graminaceous plants under Fe deficiency. Nicotianamine aminotransferase(NAAT) is the critical enzyme in the biosynthesis of MAs. Takahashi et al. (2001) succeeded to prepare the transgenic rice overexpressing NAAT gene from barley and found the increase in NAAT activity and synthesized DMA (deoxymugineic acid) in transformants. When control and transformant rice were grown in alkaline soil, the latter grew much better than the former.

Towards the future

To fulfill the requirement of foods, the increase in the utilization of fertilizer, pesticide and development of new arable land have being played an important role until recently. However this kind of effort is no more effective as before and finding the other effort is needed for future development of crop production. One important strategy is to use the problem soils which comprise 70% of the soil in the world. There are many stresses factors for the growth of plants in problem soils and cooperative research in agricultural science, especially in soil science and plant nutrition is getting more and more important. Under the scope of this line, Japanese Society of Soil Science and Plant Nutrition organized several international symposia in a past decade. XIII Plant Nutrition Colloquium 1997, Tokyo., Aluminum Toxicity and Tolerance 1997,2000,2004 Kurashiki., 2nd

Silicon in Agriculture, 2002, Tsuruoka., XII Iron Nutrition and Interactions in Plants 2004, Tokyo.,16th Environmental Biogeochemistry 2003, Oirase., 6th Plant-Soil Interactions at low pH 2004, Sendai. In 2006, WCSS (18th World Congress of Soil Science) will be held in Philadelphia, USA from July 9 to15. We shall organize one symposium (3.3P) entitled "Plant Responses and Adaptation to Ionic Stresses" which will be partially supported by Japanese Government. This symposium will stress approaches for amelioration of soil problems to improve the crop production. The presentation of the paper will be strongly welcomed. Please visit www.18wcss.org. or contact me or Dr. Yamamoto (yoko@rib.okayama-u.ac.jp).

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土壌ミネラルストレスに関する日本における生理学的研究の最先端

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世界の土壌の約70%は問題土壌といわれ酸性、アルカリ、重金属汚染、塩類集積土壌等が含まれる。最大のものは酸性土壌でしかも地域により過去、数十年でpH が0.5から1.0低下し酸性土壌は拡大している（Tyler 1984）。一方で世界人口は増加が続き2000年の63億から2025年には85億になると予想されている（Baligar and Fageria 1997）ので穀類の生産も1999年の20億トンから2025年には40億トンが必要とされる（Borlaug and Dowswell 1993）。日本の土壌は基本的に火山灰土壌で酸性土壌でありわが国の土壌学、植物栄養学における研究者は酸性土壌の化学特性、Al 毒性や耐性機構について国際的な貢献をなしてきた。特にAl耐性機構について過去10年で飛躍的な成果を収め、その基盤に生理学、分子生物学、遺伝子工学などの果たした役割は大きい。世界の陸地の10.6%が農業に供され24.2% が農業に利用可能と考えられている（von Uexkull and Mutert 1995）。その大部分（25億ヘクタール(ha)）は酸性土壌を含み、そのうち17億haは熱帯湿潤地域に主としてOxisolsやUltisolsとして存在する。酸性土壌は雨水中のH^+と塩基との交換による長年の土壌の風化作用の結果と考えられている。アジアでは東南アジア、オーストラリア、ニュージーランドを除く太平洋地域に存在する。東南アジアでは酸性土壌の占める割合がもっとも高く7700万ha存在しAl毒性、リン、カリ欠乏、マンガン過剰などが認められる。

Al毒性　:酸性土壌におけるオオムギの生育阻害がAl　毒性よることが始めて報告されたのは約90年前である（Hartwell and Pember 1918）。Alは酸性土壌における傷害の主因とされ根の伸長阻害や細胞分裂阻害などが引き起こされるがその原因はまだはっきりとは解明されていない。

Al耐性　:酸性土壌ストレスの克服にはいくつかの戦略がとられてきた。石灰を投与して土壌pHを高めることやリン酸を投与するなどである。石灰の大量投与は技術的、資源的、輸送の面など問題がある。近年、土壌の改良より低コストであると考えられる植物の改良を目指した研究が活発になされるようになった。生理学的、遺伝子工学的な研究の基盤には土壌化学者による酸性土壌の性質にかんするこれまでの地道な研究が基盤になっている。古く1910年に大工原によりその本質はアルミニウムによるとする酸性土壌の酸度の測定に関するわが国の優れた研究は世界の酸性土壌の研究に新しい方向性を与えた。彼はKClを用いて抽出する方法を提唱し広く受け入れられている。最近Al耐性

遺伝子（*ALMT1*）がコムギ根端より発見され、この遺伝子は根の原形質膜に存在しAlによって活性化を受けるリンゴ酸輸送体をコードしており根がAlに接触するとリンゴ酸を分泌して根圏に存在する毒性Al^{3+}とキレート結合し無毒化する。*ALMT1*を導入したオオムギやタバコ細胞はAlによりリンゴ酸を分泌しAlを含む水耕液中や酸性土壌でよく生育した(Sasaki et al. 2004, Delhaize et al. 2004)。

アルカリ土壌における鉄欠乏ストレス　：世界中の農耕地の20-30%を占めるpH7.0以上のアルカリ土壌では鉄欠乏をきたす。イネ科の植物はアルカリ土壌で不溶性の鉄を利用するためムギネ酸（MAsを）分泌し不溶性の鉄をFe(III)-MAsとして可溶化して利用する能力がある（Takagi 1976）（戦略II)。東京大学の森敏らの研究グループは本機構を分子生物学、遺伝子工学的な立場から研究しMAsの生合成に必要な酵素、nicotianamine aminotransferase (NAAT)をコードする遺伝子の単離に成功しオオムギの*NAAT*を鉄欠乏に感受性のイネに導入しイネの鉄欠乏に対して耐性を与えることに成功した（Higuchi et al. 1999, Takahashi et al. 2001）。

酸性土壌におけるリン酸欠乏ストレス　：土壌中の可給態リン酸含量は低く作物のリン酸獲得能に関する研究は多い。岐阜大学の小山らのグループは酸性土壌ではAl-Pとして存在する難溶性のPの利用について研究しリン欠乏（Al-Pとして与えられた）下でも生育できるニンジンの突然変異体（IPG）のミトコンドリアに存在するクエン酸合成酵素の遺伝子をarabidopsisに導入しAl-Pの利用性を高めることに成功した（Koyama et al.2000）。またクエン酸をイソクエン酸に代謝するイソクエン酸脱水素酵素の抑制により突然変異体（IPG）の不溶性リン酸利用効率が高い理由の一端を明らかにした（Kihara et al.2003）。

将来に向けて：これまで農学者、農業従事者は必要な食料を供給するため肥料、農薬の大量使用また農耕地の拡大によって対応してきた。しかしこれらの戦略による食料増産に限界がみられ今後は不良土壌の有効利用が望まれる。そのため不良土壌におけるさまざまなストレス因子を克服するため農学者、特に土壌、植物栄養学の研究者の共同研究がさまざまな角度から強く求められている。このような背景のもとわが国の土壌、植物栄養の研究者は過去10年以内に多くの国際シンポジウムを開催しこれらの領域における国際貢献をはたしてきた(英文の項を参照されたい)。2006年には18th WCSS（国際土壌会議）がアメリカのPhiladelphia　で6月9-15日に開催される。本会議に日本の植物栄養研究者からの働きかけが強く求められ学術会議の支援も期待されシンポジウム（３．３Ｐ）”イオンストレスに対する植物の応答と適応“を開催する。我が国の研究者の積極的な参加がもとめられている。（www.18wcss.org）また国内連絡先はhmatsumo@rib.okayama-u.ac.jpないしyoko@rib.okayama-u.ac.jpです。

Studies on Volcanic Ash Soils in Japan and International Collaboration

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1. Outlining properties of volcanic ash soils

The Japanese Islands are the places where 4 plates, that are Pacific, North American, Eurasia and Philippine Sea plates, meet. There are about 80 active volcanoes now in Japan. Medium and small-scale eruptions frequently occur somewhere in Japan. Volcanic ash soils cover about one-sixth of Japanese land surface. Volcanic ash soils are mainly distributed in southern and eastern parts of Hokkaido, eastern part of Tohoku, the whole Kanto, Chubu, around the Mt. Daisen in Chugoku, and central and south Kyushu districts. The word "volcanic ash soils" can be used for any soil derived from volcanic ash. Kurobokudo is a more restrictive name for a black and fluffy soil, and is the major soil derived from volcanic ash on the uplands in Japan. Kurobokudo, Andisols, Andosols and Ando soils are the names used for the volcanic ash soils rich in active Al and Fe and have the similar definition as mentioned below.

a. Morphological properties

The matured Ando soils show a unique set of morphological, mineralogical, chemical and physical properties. A thick, humus-rich, dark-colored A horizon overlain by a brown Bw horizon is a typical profile of these soils. The black A horizon is formed under grass vegetation dominated by C4 plants and the grass vegetation was maintained by intensive human activities like setting fire to the fields. On the other hand, the dark brown A horizon is formed under forest vegetation. Thick multi-sequum profiles locate near large volcanoes as a result of repeated huge eruptions with long dormant periods. Fresh deposits of air-borne ash or lahar are sandy layers of vitrandic Entisols or volcanogenous regosols.

b. Mineralogical properties

Noncrystalline or poorly-crystalline minerals such as allophane, imogolite, ferrihydrite and opalline silica are the characteristic secondary minerals in these soils. Allophane has a very small hollow spherical structure with a diameter of 3 to 5 nm. Imogolite has very thin tubular structure with inner and outer diameter of 1 and 2 nm, respectively. The typical allophane in the soils show elemental composition close to $SiO_2 \cdot Al_2O_3 \cdot nH_2O$ similar to that of imogolite. Opalline silica shows thin ellipsoidal shape, consists mostly of silica, and is often found in the A horizon of young Ando soils.

c. Chemical properties

Ando soils show unique chemical properties such as high phosphate sorption capacity, variable charge and so on due to abundant noncrystalline secondary minerals and highly humified humus complexed with Al. Phosphate is sorbed by active Al contained in allophane, imogolite and Al complexed with humus and by active Fe of ferrihydrite. A series of reactions are accompanied by the phosphate sorption such as a decrease in the amount of positive charge of the soil, release of hydroxide ion, silicate ion and soluble organic matter from the soil and an increase in negative charge of the soil. The variable charge means the amount of positive and negative charges dependent on pH and indifferent electrolyte concentration. The site of positive charge is formulated as a protonated hydroxo-ligand bound to active Al and Fe. The negative charge arises from dissociation of hydroxyl group bound to the active Al and Fe. The negative variable charges show high preference to multivalent cations, including heavy metals.

d. Physical properties

The noncrystalline and poorly crystalline secondary minerals and humus also affect the physical properties of Ando soils. Allophane, imogolite, ferriydrite and humus form stable and highly aggregated structures that have abundant micro, meso and macro pores. These highly porous structures hold a large amount of hygroscopic and plant-available water. The porous structure also leads to high hydraulic conductivity of these soils. The highly porous structure lower the bulk density of these soils. Possibly due to the high stability of porous aggregates, these soils show high liquid and plastic limits. Allophane and imogolite hardly disperse at neutral pH range due to their zero point of charge in this pH range. Abundant humus further stabilize the aggregated structure. Water holding capacity, dispersibility of noncrystalline clays, liquid and plastic limits of these soils are irreversively reduced with drying.

e. Classification

These properties of volcanic ash soils are reflected in the criteria of soil classification systems. High phosphate sorption capacity is used to define the Kuroboku soil group in the classification of Japanese cultivated soils. The Kuroboku soil group corresponds to Andisols in the Soil Taxonomy (ST) of the United States Department of Agriculture, and Andosols of the World Reference Base for Soil Resources (WRB). Abundant oxalate-extractable Al and Fe, low bulk density and high phosphate retention are used to define matured Andisols and WRB-Andosols. Volcanic glass content is also used to characterize young Andisols and WRB- Andosols. Subdivision into allophonic and nonallophanic ones according to the predominance of allophane-imogolite or Al-humus complex is included at least partly in all the classification systems of the Kuroboku soil group, Andisols and Andosols

f. Genesis

Ando soils are mostly formed on uplands under humid climates. Volcanic glass, commonly rich in Si, is dissolved forming Al-rich colloidal materials that are allophane, imogolite and Al-humus complex and Fe-rich ferrihydrite. Rapid dissolution of volcanic glass and removal of Si and basic cations needs humid climate and location on uplands with good drainage. Inceptisols are formed under semi-dry climates and in the poorly drained areas possibly due to slower removal of Si. Spodosols are possibly formed under humid and cold climate due to formation of soluble chelating organic materials in the overlying organic layer.

g. Utilization

Ando soils in Japan were previously problem soils due to phosphorus deficiency, high Al toxicity of nonallophanic Ando soils, Cu and Zn deficiency and so on. These chemical problems are now amended and the Ando soils are used as excellent upland fields having good physical properties such as high air and water permeability, and high water holding capacity. Root crops such as horse raddish, chinese yam, burdock, are especially suitable for Ando soils as well as many other upland crops. In the tropical countries, Ando soils are relatively graded better than in Japan possibly due to high temperature enhancing phosphorus release, nitrogen mineralization and plant growth.

2. Studies on volcanic ash soils in Japan

It is almost a century since Seki's early work on volcanogenous loam was published. Several monographs on volcanic ash soils were published in English in the latter half of the 20th century. In 1964, "Volcanic Ash Soils in Japan" was compiled by the Ministry of Agriculture and Forestry, Japanese Government. The book includes ten chapters that are distribution of volcanic ash soils, land use, soil minerals, physical properties, soil erosion, chemical properties, microbiological properties, classification, valuation on productivity of volcanic ash soils, and development of soil productivity. By that time, variable charge properties and high phosphate sorption capacity of Ando soils were recognized and imogolite was discovered by Yoshinaga and Aomine in 1962. Humic acid type in Ando soils was found to resemble that of Tsuernozems by Kumada. In 1986, "Ando Soils in Japan" was edited by K. Wada. This book includes detailed soil characterization data of 26 soil profiles covering south to north of important sites in Japan. By that time, opalline silica was reported by Shoji and Masui in 1969 in the A horizon of young Andisols. Then, unique shape of allophane particles was described by Kitagawa in 1971 and was confirmed by Henmi and Wada in 1976. In 1993, a comprehensive book "Volcanic Ash Soils – genesis, properties and utilization was published by Shoji, Nanzyo and Dahlgren integrating the developments made by International Committee on the Classification of Andisols (ICOMAND) and other research works from all over the world as well as those from Japan. By this time, the Andisol order was established in ST as the eleventh soil order in 1990.

Moreover, many valuable review papers and special issues on Ando soils were published as follows: Amorphous clay constituents of soils (Wada and Harward, 1974), Physical properties of allophane soils (Maeda, Takenaka and Warkentin, 1977), The distinctive properties of Andosols (Wada, 1985), Allophane and imogolite (Wada, 1989), Clay mineralogy and chemistry of soils formed in volcanic material in diverse climatic regions (Mizota and Reeuwijk, 1989), Volcanic ashes and their soils (Matsumoto, 2002), and The nature, properties and management of volcanic soils (Dahlgren, Saigusa and Ugolini, 2004).

3. International collaboration

Many collaborative works between Japan and overseas countries have been done to develop sciences on volcanic ash soils. The name "Ando soils" was introduced in 1947 during reconnaissance soil survey in Japan by American soil scientists. In 1964, FAO soil correlation meeting on volcanic ash soils was held in Tokyo. During this meeting, the attendants visited 8 pedons in Hokkaido, Kanto and Kyushu districts, and definition of Ando soils were discussed based on their properties. Two seminars on amorphous materials in soils were held at Kyushu University and Oregon State University in 1969 and 1976, respectively, for the direct exchange of information and cooperative studies. In 1978, ICOMAND was established after the Andisol proposal by G.D. Smith. Many workshops and meetings were held during the ICOMAND activities for more than 10 years. The 9th International Soil Classification Workshop was held in Kanto, Tohoku and Hokkaido districts, Japan, in 1987. The tour guide describing geological and climatic information, morphology of soil profiles and characterization data of 23 pedons were delivered at the meeting and the proceedings were published in 1988. The number of attendants were about 120 from Japan and 40 from 16 overseas countries. The central concept of Andisols was revised from the exchange complex dominated by amorphous materials to abundant active Al and Fe including humus-Al complex during the ICOMAND activities. Collaborative works were also done in Indonesia and Philippines under the projects of the former Tropical Agricultural Research Center, and Japan International Cooperative Agency, the Japanese Government.

Many Japanese researchers visited USA, New Zealand, European counties etc., to attend meetings and to study Ando soils in overseas countries. The meeting on soils with variable charge was held in New Zealand in 1980. A series of meetings were held between 1998 and 2004 as the European Cooperation in the field of science and technical research (COST) action titled Soil Resources of European Volcanic Systems (COST-622). The Field Science Center, Tohoku University held an meeting on New Perspectives of Volcanic Ash Soils in the Integrated Ecosystems in 2004 having 6 speakers from overseas countries in the Circum Pacific Volcanic Zone. The titles of symposium related to Andosols in the recent World Congresses of Soil Science are "Physical, chemical and mineralogical characteristics of Ando soils" at Kyoto in 1990, "Indurated volcanic soils: use and management" at Acapulco in 1994, "Crystal chemistry of trace elements and evolution in soils of short range ordered minerals" at Montpellier in 1998 and "Poorly ordered nanoparticulate materials in soils" and "Andisols and related soils" at Philadelphia in 2006.

4. Perspectives

Human impacts on soils and environments are gradually increasing now. Goals of soil science are to elucidate material cycles quantitatively on the earth surface, to control the cycles for environmental conservation and sustainable crop production, to keep the soil quality high and so on. High buffering capacities of Ando soils in many reactions appear useful to ameliorate some environmental problems. International collaboration will contribute to these studies because the properties of Ando soils are dependent on climates and human activities. Both integration of developments in the different scientific fields and new fact finding are also important.

日本の火山灰土研究と国際貢献

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1．火山灰土の主な特徴

わが国は４枚のプレートが出会う地球上の活動的な場所である．中小規模の火山活動は国内のどこかで絶えず起こる．火山灰土は国土の１／６を占め，北海道の東部と南部，東北地方東部，関東地方，中部地方，大山周辺，および九州中南部に多く分布する．火山灰土は火山灰由来の土壌すべてに使われるが，黒ボク土は黒くホクホクしたものに限られる．黒ボク土，Andisol，Andosol，Ando soil はほぼ同義に使われる．

ａ．断面形態

成熟した黒ボク土は一連の特徴的な断面形態，鉱物組成，化学性，物理性を示す．
表層は暗色で腐植に富み，その下は褐色 B 層という断面構成が一般的である．黒色 A 層は草原植生下で生成し，暗褐色 A 層は森林植生下で生成する傾向がある．大きな火山の近くでは埋没 A 層-B 層の繰り返し積層が認められる。新鮮な降灰，ラハール堆積物は未熟土である．

ｂ．鉱物学的性質

アロフェン，イモゴライト，オパーリンシリカやフェリハイドライトなどの非晶質ー低結晶質二次鉱物が黒ボク土を特徴づける主な鉱物である．アロフェンは Al/Si 原子比が２のものが多く，オパーリンシリカは若い火山灰土の A 層に多く含まれる．

ｃ．化学的性質

高いリン酸保持量および変異荷電などが特徴的である．これらの特徴は上記非晶質ー低結晶質鉱物と A 層では多量に含まれる腐植-Al 複合体による．リン酸イオンとの反応には，非晶質成分の組成によるが，正電荷の減少，水酸化物イオン，ケイ酸や水溶性有機物の放出，負電荷の増加などが伴う．変異負電荷部位は多価陽イオンに親和性が高い．

ｄ．物理的性質

非晶質ー低結晶質鉱物と腐植-Al 複合体は物理的性質に対する影響も大きい．これらの成分が作り出す安定で多孔質な凝集構造により，固相率，容積重が小さく，微細ー粗孔隙が多く，通気性，透水性，保水性が高い．中性領域で分散性が低く，乾燥により，保水性，分散性，液性限界，塑性限界などが不可逆的に減少する．

ｅ．分類

以上の特性は火山灰土の土壌分類基準にも使われている．わが国の農耕地土壌分類における黒ボク土，合衆国の土壌分類におけるアンディソル，世界土壌照合基準のアンドソルには共通部分がある．また，アロフェン質および非アロフェン質の細分も使われている．

f．生成

黒ボク土は湿潤気候下の台地・丘陵地によく発達する．その生成過程では一般的にケイ素に富む火山ガラスが溶解してアルミニウムに富むアロフェン，イモゴライト，腐植-Al 複合体が形成する．火山ガラスの速い溶解とケイ素および塩基の溶脱には良好な排水が必要である．排水不良条件または半乾燥気候下ではインセプティソル等になる．

g．利用

わが国の黒ボク土は過去においてはリンや微量要素などの欠乏，非アロフェン質黒ボク土におけるAl 過剰などにより化学性はよくなかったが，その後の改良と良好な物理性が奏功し優れた畑土壌となっている．

2．わが国における火山灰土の研究

関の初期の火山灰土研究以降，約一世紀が経過しつつある．その中で２０世紀後半に火山灰土に関する英文の単行本が３冊出された。1964 年の「Volcanic Ash Soils in Japan」、1986 年の「Ando Soils in Japan」、1993 年の「Volcanic Ash Soils – Genesis, Properties and Utilization」である。これらにはそれぞれの時期までの火山灰土に関する研究の進歩がまとめられている。さらに 1970 年代以降、７つ以上の英文総説・雑誌の火山灰土に関する特集号が組まれている。

3．国際共同研究

これまでに火山灰土研究に関する多くの国際共同研究と国際会議が持たれ、その都度わが国の多くの研究者が努力してきた。「Ando soils」という用語は 1947 年の米国土壌学者によるわが国の土壌調査中に作られた。1964 年には火山灰土の国際対比に関する会議がわが国で開かれた。1969 年と 1976 年には土壌中の非晶質物質に関するセミナーが九州大学とオレゴン州立大学でそれぞれ持たれた。1978 年にアンディソル分類に関する国際委員会が発足し、1987 年にはわが国でもワークショップが持たれた。その他にも国内外で多くの国際会議や共同研究が行われてきた。

4．今後の展望

人間活動の環境影響は次第に増大している。土壌研究の役割には地表を覆う土壌中における物質循環を定量的に解明し、環境保全や持続的作物生産、土壌機能維持に生かすことなどがある。黒ボク土は多くの側面で緩衝機能が強く、これらの課題解決に貢献することが期待される。黒ボク土の性質は気象条件や人為の影響を受けやすく、国際対比もその進展に重要で、さらに他分野における進歩との融合や新事実の発見なども貴重ある。

SUPERIOR SUSTAINABLE FUNCTIONS OF PADDY SOILS AND MULTI-FUNCTIONALITY OF RICE PADDY FIELDS IN JAPAN

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Introduction

Human activities are closely related to the changes in the Earth's environment. The cycle of materials on a global scale has been transformed as a result of the clearing of forests for increasing the arable land area, expansion of the livestock industry, changes in the chemical composition of the atmosphere by the combustion of fossil fuels, discharge of wastes, cutting through mountains for mining deposits and distribution of heavy metals on the Earth. Mankind is now modifying the original environment of the Earth.

The biosphere of the Earth is suffering from environmental disruption including global warming, depletion of the ozone layer, deforestation, marine pollution, acid rain, deforestation, water pollution, soil erosion, pollution with metals, reduction of biological diversity, pollution through nuclear wastes, pollution through livestock and human wastes and depletion of underground water.

Agricultural activities themselves, through the increase of food production, affect the environment. Nitrous oxide derived from the application of nitrogen fertilizers and from livestock wastes and methane produced from flooded rice fields and ruminant livestock affect the atmosphere and cause global warming and destruction of the ozone layer.

However, the beneficial effect of agriculture on the environment should not be overlooked. The Committee for Agriculture of the OECD suggests that agriculture is a major custodian of the environment and is endowed with multiple functions to conserve the environment. Sustainable agriculture is proposed as one way to solve the conflicting problems. However, this concept is controversial and complicated in its definition and in the application of practices to attain sustainability.

As an example, it is suggested that paddy field farming in delta areas covered with alluvial soils rich in nutrients or in fertile lowlands, valleys, terraced lands with volcanic ash and other soils is a most suitable system to promote sustainable agriculture and preserve the agro-ecosystems, provided that the availability of water resources is not a limiting factor. Under such conditions, moderate yields of rice can be continuously obtained by using relatively low input due to the superior functions of paddy fields associated with submergence, including nitrogen fixation by algae, phosphorus dissolution and availability to crop under reductive conditions, increased soil pH under reductive conditions, potassium and silica availability by hydrolysis, enhancement of microorganism activity, buffer action from micro-climate change, nutrient enrichment from irrigation water, prevention of weed growth, nitrous oxide (N_2O) and NOx absorption from the atmosphere, and absence of growth injury in spite of cropping for 1,000 and 2,000 years.

In addition, the role of paddy fields in the control of soil erosion and runoff, preservation of soil fertility, cycling of nutrients, reservoir function, etc. should be emphasized.

How can we maintain and increase food production and control the above load on the environment? I report here the role of rice paddy fields in the promotion of sustainable agriculture and conservation of the environment.

First, the superior functions of rice paddy soils as a natural industry with a history of more than one thousand years of food production are presented. Further, modern science has developed superior mechanisms for the use of rice paddy soils. Then, multiple functions of paddy fields for environmental conservation are presented.

Superior Sustainable Functions of Rice Paddy Fields

Modern science has confirmed the superior function of rice paddies. To maintain high yields and to secure continuous harvests every year on arable land, we have to add large quantities of chemical fertilizers. When such large amounts of fertilizers are applied to arable land, salt damage occurs in both soils and plants. However, in rice paddy fields, there are no such problems because paddy soils are flooded during the hot summer season. As a result, the soil in rice paddies shows the following superior characteristics (Minami, 1998).

1. Nitrogen fixation by algae

Algae occur when paddies are filled with water. Algae absorb the ammonium nitrogen derived from soil, and fix it in the paddies as organic nitrogen. As a result, discharge of nitrogen in water can be prevented. In addition, some algae can fix the nitrogen in the air.

2. Effective use of nitrogen through the application of lime

Since quick lime and slaked lime are alkaline, when used in rice paddies, the pH levels of water temporarily reach a value of about 9. As a result, humus in the soil is dissolved making it easier for microorganisms to break it down, and thus, in turn the supply of ammonium nitrogen increases.

3. Phosphorus solubilization under reduction conditions

Phosphorus is an essential element for crops. In rice paddy soils, phosphates occur in the form of ferric phosphates. When reduced, the iron in ferric phosphates changes from ferric iron to ferrous iron. As a result, the solubility of ferric phosphates is significantly increased, and iron is dissolved in the water and absorbed by the roots of rice. In addition, when reduction causes the pH level to increase, the ferric phosphates become even more soluble.

4. Increase of soil pH under reduction conditions

Since the soil in rice paddies is constantly covered with water, when it is dried, the pH level becomes acidic. When it is covered with water, iron and carbon gas increase the pH level. This is why the acidity of the soil is not a problem.

5. Potassium and silica solubilization by hydrolysis

Rice absorbs silicic acid to such a degree that it is referred to as a silicic acid plant. Even if potash and silicic acid are not supplied as fertilizer, rice will grow normally. This is because the elements in the soil undergo hydrolysis.

6. Activity of microorganisms

The soil of rice paddies is highly fertile because algae in the water produce organic matter, and are constantly supplying that organic matter to the soil. After the algae die, the nutrients assume an inorganic form and are supplied to rice in later stages, or in the following year. Photosynthetic bacteria decompose hydrogen sulfide and organic acids that are harmful to rice. Aerobic and anaerobic microorganisms interact at an appropriate level, and the microorganisms are used by the ecosystems.

7. Nutrient enrichment from irrigated water

Irrigated water from upstream contains magnesium, calcium, silica, potassium, nitrogen and other nutrients, as well as clay particles, all of which supply nutrition to rice paddy soil. In recent years, however, there has been an excess of these nutrients which is harmful to rice.

8. Buffer action against micro-climatic change

By covering rice paddies with water, a certain alleviating effect on sudden changes in temperature that occur seasonally or at night is observed.

9. Ability to withstand continuous cropping

Problems arising from continuous cropping are related to microorganisms such as molds that require oxygen and nematodes. Since rice paddies are covered with water, the amount of oxygen is insufficient for these organisms to thrive, so that continuous cropping for even thousands of years is possible.

10. Ability to control weeds and pests

As the aerobic conditions are needed for the growing of weeds and pests, the rice paddy fields are favorable than those in upland fields.

Multi-Functionality of Rice Paddy Fields in Japan

Living organisms exert an "environment-forming effect". Although living organisms are affected by their ambient environment, they, in turn, affect and create a unique environment.

In areas in which agriculture and forestry activities are conducted, the effects of the atmosphere, soil, water, plants and animal create such a unique environment. These effects exert environmental preservation functions when they are beneficial for nature and human beings. This is how we define environmental preservation functions of agricultural ecosystems in this paper.

Many agricultural scholars have suggested that mining and industry destroy nature, but that agriculture protects it. However, it is clear from the book entitled "Topsoil and Civilization" by V. G. Carter and T. Dale (1955) that agriculture has also destroyed nature. The fall of Mesopotamian civilization resulted from the accumulation of salt in the soil that led to desertification. Starting with Europe, there are many other such examples around the world.

Such phenomena gave rise to the concept of protection of nature in Europe and United States. Because Japan's land is so naturally resilient, we have not recognized the importance of protecting nature. Regarding rice paddy agriculture, however, the wisdom of our ancestors has helped us, as I have explained earlier. Rice paddy agriculture has enabled to overcome the disadvantages of Japan's natural conditions, and allowed us to produce food while preserving the natural environment. In addition, our ancestors developed agricultural technology by maintaining a harmony with the grasslands and farms in mountainous and woodland areas, and flat lands with rice paddies, hence utilizing the toposequence in nature.

The Japan's Ministry of Agriculture, Forestry and Fisheries has implemented many projects to quantitatively assess the multiple functions of agricultural and forestry ecosystems and to develop a management technology to maintain and improve these functions. As a result of these projects, it was confirmed that agricultural and forestry ecosystems exert various beneficial functions.

1. Water

Water conservation function: In this function, soil and rice plants absorb water and replenish water resources, such as underground water. This function can be quantitatively assessed through annual rainfall, land inclination, land use, soil permeability, water permeability of the surface layer, water-holding capacity of the surface layer, and underground water level data.

Flood prevention function: Water is temporarily stored in paddies and reservoirs to prevent floods. This function can be quantitatively assessed based on surface layer geology, land inclination, topography, land use, soil and annual rainfall data. One example shows that rice paddies are about four times more effective than mountainous or woodland areas in the prevention of floods and about 15 times superior to urban areas.

Water quality improvement function: Microorganisms in rice paddy soils and in irrigation and drainage canals help to clean water polluted with nitrogen and phosphorus. This function can be assessed based on denitrification potential, vegetation absorption, regional categorization, surface soil layer, toposequence, river and water movement vector data.

2. Soil

Landslide prevention function: This function prevents landslides in the case of terraced rice paddies and crops planted on inclined fields. This function can be quantitatively assessed based on valley spacing, inclination, soil layer depth, tree age, tree type and farmland type data.

Soil erosion prevention function: This function prevents landslides in the case of terraced rice paddies and crops planted on inclined fields. This function can be quantitatively assessed based on rainfall, land inclination, land use, soil type, and soil particle size data.

3. Atmosphere

Air quality conservation function: By this function harmful gases in the air are absorbed, leading to purification of the air. Convection and diffusion cause harmful gases in the air, such as nitrogen and sulfur, to be absorbed by agricultural and forestry ecosystems. Rice paddies even have the ability to absorb nitrous oxide in the air which is related to global warming and destruction of the ozone layer. Quantitative assessments will be conducted in the future.

4. Biota

Biodegradation of organic wastes: In this function livestock manure, urban garbage and sewage are decomposed. This function can be quantitatively assessed based on average annual temperature, annual rainfall, soil texture, inclination, and land use data.

Conservation of biotic communities: This function enables to preserve living organism resources such as insects, small animals and birds. Rice paddy agriculture called "secondary nature" preserves various types of plant life, and the living organisms which are dependent on it. Quantitative assessments are currently being conducted.

5. Human being

Health and recreation functions: Paddy fields as well as forests, grasslands and farmlands exert health and recreation functions for visitors. These functions are assessed on data such as convenience, scenery, history, cultural importance, and existence of water.

Amenity: The term amenity covers several functions. Therefore, each agricultural or forest area should concentrate on the preservation of specific functions. By categorizing the structure of agricultural and forest areas, and assessing the various functions of each category, the relative importance of the functions in each category should be determined. These functions can be assessed based on data from geological categories, land use categories, vegetation, and questionnaires.

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水田土壌の持続的な特性と水田農業がもつ多面的機能

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はじめに

世界の人口は、いまでは 64 億人を突破した。このままいけば、人間の活動によって地球の自然循環機能が圧しつぶされる事態も起こりかねない。失われつつある土壌・水資源、温暖化しつつある大気、破壊されつつあるオゾン層がそのことを証明している。この地球生命圏がひん死の危機に直面する前に、われわれは彼女（ガイア）に負わせてきた重荷を軽くしなければならない。

21 世紀は、食料をますます増産することが大切になる。しかし同時に、食料生産が環境破壊を引き起こすことが絶対あってはならない。この一見相矛盾する問題に立ち向かうのが、これからの農業に課せられた課題といってよい。でも、農業と環境の調和は、いきなり地球規模や国単位で考えられるものではない。わたしたちの身近な農村で、農業と環境の調和が維持できれば、その積み重ねとして、地球や国でも農業と環境の調和が成り立つのである。ひとつの大陸の農業と環境が調和されれば、地球生命圏の保全にもつながる。そして結局は、地域の自然を生かした地域の農業と暮らしをつくることが、地球環境を守ることにもつながっていく。

これからの農業は、自然のしくみや農業のもつ多面的機能を活用した、新しい科学の上につくりあげられなければならない。わたしたちの身近にある資源を十分に活用して、自然と人間が共生できる 21 世紀型農業を一刻も早くつくりあげることが、いま求められている。その一つの例として、古来綿々として続いてきたわが国の水田農業がある。ここでは、その水田の土壌がもつ持続的な特性と、水田農業がもつ多面的機能を紹介する。

水田土壌の持続的な特徴

複雑な地形と気象をもつ日本列島に分布する土壌は、世界にもまれな特徴をもつことになった。国土面積の 15%にすぎない耕地に、多くの種類の土壌が複雑に分布し、そのうえ傾斜が多く，起伏に富む地形や、降雨が集中する地域の土壌は、土壌浸食と養分流出を受けやすい。

この自然の欠点を封じるため、わたしたちの祖先は昔から山麓に畑を、沖積に水田を配してきた。この祖先の知恵が日本農業の基盤になっている。山麓から流れ出る土や養分は、沖積の水田に蓄えられ、1000 年以上の持続的なイネの生産を可能にしてきた。

科学の進歩によって、この水田土壌のすぐれたはたらきが明らかになってきた。

植物の三大必須元素とされる養分はチッソ、リン酸、カリウムである。水田土壌では、いながらにしてこの三元素を獲得できる。山からの水が養分や養分を含んだ土を運んでくれるとともに、水を張

る水田では藻類が育ち、これが空中のチッソを固定し土壌にチッソを残してくれます。また水をはることで、土の中にあるリン酸やカリウムがとけだし、イネに吸収されやすくなる。

水をためることで、気象変動がイネにおよぼす影響をやわらげる。また水には雑草や病害虫の発生をおさえる力もある。毎年イネをつくりつづけても、水があるため、特定の病原菌がふえることもなく、1000年も2000年もの連作に耐えられる。

これだけのすぐれたメカニズムをもつ農業形態は、ほかにはみつけることができないであろう。その稲作が、日本の農業の中心なのである。

わが国の水田農業がもつ多面的機能

もともと自然環境にあわせて発達してきた農業は、環境を保全するはたらきをもっている。というのも、作物もふくめ、生物には環境形成作用という働きがあるからだ。生物は周囲の環境から影響を受け、逆に環境にも影響をあたえながら生きている。環境からモノを取りこんで成長する一方、環境にはたらきかけて独特の環境をつくりだしているのだ。これを生物の「環境形成作用」という。

たとえば植物の光合成がそうだ。植物は、大気から二酸化炭素を吸収し、そのお返に酸素を大気に放出する。また、植物の根は土の養分を吸収するために有機酸などを土壌に放出するが、それが微生物をふやしたりして豊かな土壌をつくるはたらきをしている。斜面の植物が、土壌がなければ生きながらえていけないので、流亡しないよう根でしっかりと土壌を保持しているのも、その証である。

農林業が行われている場所では、大気・土壌・水・植物・動物、そしてさらに人間の力が相互に関係しあって、特有の環境が形づくられている。それぞれの環境をいかし、少しでも豊かな農業を営もうとする人間の力が、生物の環境形成作用に追加され、農業は地域、地域に独自の環境をつくりだしてきた。

地域の自然と人間が共同して田畑がつくられ、農作物が育つ。だから農業のありようは、地域や田んぼの１枚１枚でちがってくるものだ。農業のもつ環境形成作用が、自然や人間にとって望ましい方向にはたらくとき、この機能は「環境保全機能」となる。これがいくつかあるので、この機能を合わせて多面的機能と呼ぶ。それらの機能を整理する。

１．水

われわれは、農業や農村から多くの恵みを得ている。いちばん大切な食べもののほかに、農業には環境を保全する多様なはたらきがある。その中からまず、水をめぐる機能について紹介する。

洪水防止機能：水田は、ダムやため池のように雨水を一時的に貯留して、河川への急激な水の流出を緩和してくれる。そのため、洪水被害を軽減・防止する機能がある。また、畑地でも土壌にあるすき間に一時的に水を貯留して、河川流出を緩和してくれる。

渇水緩和機能・水涵養機能：田畑の水を一時的に貯留することは、雨が降らないときの渇水をやわらげる機能にもなる。また、農林地は灌漑水や降雨を吸収し、これを地下に徐々に浸透させることによって地下水を涵養する。水田は灌漑期に長い間水を張るから、地下への浸透量がほかの土地利用にくらべて多いため、地下水を貯めておく能力が大きいことになる。

水質浄化機能：汚染された水が水田にはいると、田面を流れているあいだに汚染物質の一部は、大気に揮散したり、土壌に沈殿したり吸着されたりする。その結果、この水が水田から流出するときは、流入したときよりもきれいになっている。このはたらきを水質浄化機能と呼ぶ。

2．土

つぎに土をめぐる機能である。

土壌浸食防止機能：土壌浸食とは、水または風によって表土が流れたり飛ばされたりする現象である。水を張ることによって、集中豪雨があっても浸食をほとんど受けない。畑では、土壌が作物や草におおわれていれば浸食を受けにくいが、畑に作物がなにもない裸地状態になっている場合や、排水のためのしくみが不備で雨がふると泥水が流れでるような傾斜地などでは、浸食の被害が大きくなる。

土砂崩壊防止機能：急峻な山地、谷地、崖地では、集中的な豪雨で土砂崩壊が起こる。このような地域でも、水田があれば土砂崩壊が防止される。棚田は土砂崩壊を防ぎ、そのうえ、洪水や渇水をやわらげてくれる、地域の貴重な財産なのだ。

3．大気など

最後に大気についての機能である。

大気浄化機能：作物をふくめて植物は、葉面にある気孔を介して大気中の二酸化炭素を取りこみ、光合成で糖を合成して酸素を放出する。このガス交換のときに、大気中のイオウやチッソなどの汚染ガスも気孔から植物体内に取りこみ、自らのからだつくりに役立てる。これを大気浄化機能と呼ぶ。微生物を多く含む土壌にも大気浄化機能がある。

気候緩和機能：作物・植物や水面からは水分が蒸発散し、葉や水は熱を吸収する。これにより暑さをやわらげてくれる。これを気候緩和機能と呼ぶ。とくに水田は、このはたらきが大きい。

生物相保全機能：カブトムシの幼虫は腐った植物を食べ、成長する。堆肥がつくられ、よく手入れされた炭焼き用の雑木林がある農村は、カブトムシのかっこうの繁殖地だ。水田や水路はトンボやドジョウなど、さまざまな生きものの生息地だ。農村地域では、多種多様な生物が保全されている。ムギ畑に巣をつくり育つヒバリは、作物の害虫を食べてくれる。多種多様な生物がいることによって、農作物に被害をあたえる病害虫の発生などもおさえられている。