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Analysis of Relationships Among Technology Elements (ARATE) and Its Application to Agricultural Fields

要素技術連関解析とその農学分野への応用

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要　　旨

要素技術連関解析（ARATE）は，複数の要素技術からなる複合技術の構成と，要素技術間の関係を解明する手法である。本報告では，手法の基礎的な考えかた，農業（畜産と林業を含む）技術の特性，手法の農業技術への適用実験，および実験結果に基づく手法の有用性と今後検討すべき問題が述べられている。

人間社会で実用される技術は複合技術であって，複合技術とこれを構成する要素技術とは，システムとサブシステムとの関係と同様の関係にある。すなわち，要素技術はそれぞれ特有な機能を持ち，ひとつの要素技術は互いに異なった多くの複合技術の構成要素になり得る。農業において実用される多くの技術は，複合技術の典型的な例である。

ARATE を実用するにあたっての資料としては，対象技術分野における研究の課題とその研究計画が適当である。複合技術を分析するため，その分野を構成する要素技術，技術を適用する対象と適用した結果である事物，および技術適用の条件と場所を網羅した，多観点事後組合せ方式の分類表が必要である。この分類表を典拠として，資料に記載された課題の主題分析を行い，インデクスを付与してファイルを作成する。ファイルを加工して，解析に必要な各種の数値を算出する。

本報告における実験の資料は，日本の国立農業研究機関において1979年度に新に開始された，1,532件の研究課題とその計画である。分析の典拠として，農業技術分野に関して上記の性格を備えた十進法４ケタの分類表である，農学専門事項表示コードが作成使用された。実験の結果，農業技術全体，および特定の生物を対象とし，または，特定の場所で実用される農業技術において，これらを構成する小項目（３ケタ）レベルの要素技術，その種類数，ウエイト，および要素技術間の連関の疎密をあらわす数値が得られた。

実験によって，特定の技術分野に適用した場合の，ARATEの有効性があきらかになった。しかし，他の資料の利用や，細項目レベルでの解析などの検討が必要である。ARATEは，ドキュメンテーションの一手法である。しかし，従来のドキュメンテーションが，研究者個人に必要な文献情報の提供を主な使命としていたのに対して，本手法は，技術者養成のカリキュラムの立案や，研究開発管理に必要な情報を提供することがその主な機能である。

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I. Introduction

The "*A*nalysis of *R*elationships *A*mong *T*echnology *E*lements" (ARATE) is a method of analysing research and development effectively. The purpose of ARATE is to clarify the relationship among technology elements and the structure of technology complexes, all of which consist of plural technology elements.

The author once reported that ARATE applied to all fields of science and technology and he pointed out that applications of ARATE to certain limited fields would be useful for studies and further developments of ARATE.

In the present paper the author describes the fundamental concept of ARATE, experimental results of its applications to agricultural fields (including animal industry and forestry), and discusses the usefulness of ARATE based on the experimental results, the problems needing re-examination, and its further uses.

II. Technology Complexes and Technology Elements

A. System and Subsystems

Technologies solving actural problems in our society are technology complexes consisting of plural technology elements, and the relationship between a technology complex and technology elements is that of a system and subsystems. Each subsystem has its specific functions, and a system which accomplishes a certain purpose is composed of plural subsystems. A subsystem may function not only as an element of a specific system, but also as a constituent of many other systems.

The relationship between the system and

the subsystem is similar to that between the molecule and its functional radicals in organic chemistry. For example, the structure of glutamic acid ($C_5H_9O_4N$) has a structure of

$$\begin{array}{c} COOH \\ | \\ (CH_2)_2 \\ | \\ NH_2\text{—}CH\text{—}COOH \end{array}$$

This is a structural formula which belongs to the organic chain compound. Two radicals of amino ($-NH_2$) and carboxyl ($-COOH$) are connected to one of an organic chain compound instead of two hydrogen atoms and a radical of carboxyl is connected to the other end instead of one hydrogen atom.

Glutamic acid has the construction specified in the above statement and also the characteristic biological functions of amino acid. In addition, each radical has its own characteristic function; for instance, the amino radical has the function of a base, the carboxyl radical has the function of an acid, and glutamic acid also has the functions characterized by both of these radicals. On the other hand, it is possible for each radical to be a component of various substances having another function.

In synthetic organic chemistry, it is very useful to know the function of the radical itself and the relationship between radicals in order to design compounds having preferable functions or to anticipate a method for synthesis and the function of synthesized compounds.

B. Technology Complexes in Agricultural Fields

The technology of rice production may be considered as an example of technology complexes in the argicultural fields. To produce rice, it is necessary to acquire seeds of rice plants of desirable genetic characteristics. To obtain such desirable genetic characteristics, it is essential to use breeding technology, which is based on genetic science and technology. For the satisfactory growth of rice plants, good circumstances or natural soil conditions, weather and climate are needed as well as good farm methods of irrigation, drainage, fertilization and temperature control. Here we need to utilize the various sciences and technologies of the environment, soil, climate, weather, of plant physiology, biochemistry, of fertilizers and of agricultural engineering. As rice plants grow, it is necessary to protect them from injurious pests and diseases, so we need the help of plant pathology, entomology, weed science, pesticide science, ete. For efficient harvesting and threshing, we may use agricultural machines which are developments of mechanical technology. Storage technology is indispensable. Through all the processes mentioned above, production control is necessary to minimize the input of time, manpower, and expediture for facilities, equipment, and machinery and to maximize the effective output. The scince of management and economics are needed if we wish to see rice production as an industry. Technologies of dietetics, food and cooking are essential to produce rice of high value as a raw material for food.

As explained above, the technology of rice production uses various materials and is a purposeful compound of various fields of science and technology. In other words, the technology of rice production is a technology complex consisting of various scientific and technology elements. It is very important to clarify what technology elements are included in the technology complex of rice production, how much weight each element occupies in the complex, and how each one is related to the other elements.

To clarify a technology complex, its technology elements and the relationship between them in a specific subject field will greatly contribute to applications of the technology, to developments of new technology, and to the training of pure and applied scientists.

III. Method of the Analysis of Relationships Among Technology Elements (ARATE)

A. Sources of Information

To apply ARATE to a specific subject field, technological information covering almost the entire field must be collected in as great a quantity as possible. Such technological information should first include technological research reports published in scientific and/or technological journals. The research reports, however, have some deficiencies as sources of technonological information.

Generally speaking, technological research is carried out for the solution of specific technological problems. But the final research report is not necessarily published, even though the research has been done. Moreover, the research report does not necessarily cover the whole research; the researcher may report only a part of the research which is of academically high value, just to acquire the distinction of priority in reporting it. Moreover, the time lag between the begining of research and publication of the results is usually great. Therefore, the research report published in a scientific or technological journal may not accurately represent the situation at the time of publication.

Some technological information is presented in the name of the researcher, the title and the plan of research. A typical example of such information is available from the Science Information Exchange Service of the Smithsonian Institution. In agricultural fields, similar examples are: the *C*urrent *A*gricultural *R*esearch *I*nformation *S*ystem (CARIS) of the FAO, the Permanent Inventory of *AG*ricultural *RE*search *P*rojects in the European Communities (AGREP) by the Commission of European Community, the *C*urrent *R*esearch *I*nformation *S*ystem (CRIS) of the USDA, and the *RE*trieval System of *C*urrent *R*esearch Information in the *A*gricultural *S*ciences (RECRAS) of the Ministry of Agriculture, Forestry and Fisheries, Japan. All of the above databases handle ongoing research data, including names of researchers, titles, plans and methods of research. The data included in such databases are considered to be most suitable for the application of ARATE.

By applying ARATE, it may be possible to carry out international comparative studies in cases where international data are available and to clarify the trends of research which have prevailed in areas where data covering a long period are available.

B. Comprehension and Arrangement of Technology Elements

To apply ARATE to a certain subject field it is necessary to comprehend technology elements of each technology complex in the field. The level of the elements to be analyzed is decided in view of the purpose of the analysis. The technology elements of a certain subject field are generally not completely equivalent to the lower classification scheme of the subject field. For instance, agricultural chemistry is one of the scientific and technological fields, not a technology element but a technology complex, because it is chemistry connected with agriculture.

An example of the classification scheme for the comprehension of technological elements and a systematic arrangement of all the industrial fields is the *C*lassification of *T*echnology (CT)[1] prepared by the Japan Science Foundation. Another classification scheme developed by the same foundation is called *C*lassification of *S*cience and *T*echnology (CST)[2], which covers all fields in science and technology. The *C*lassification of *A*gricultural *S*cience and *T*echnology (CAST)[3] has been developed from CST and used as an indexer's aid for RECRAS.

In CT, technology is classified into the following four categories: technology concerning materials; technology of energy; technology of information; and technology concerning processing, transportation and storage. Technology elements in each category are developed.

CST has, in addition to the four categories of CT, the following categories: place/time/quantity/etc.; physical sciences; bio-agricultural sciences; medicine/pharmacy/etc.; and other related fields. This classification scheme consists of four-digit decimal classes and is adaptable to a multi-aspect and post-coordinated information retrieval system in the fields of science and technology.

CAST has been designed to meet the needs of RECRAS, laying stress on the bio-agricultural sciences. The concept of CAST is based on CST.

In CST and CAST, technologies, materials, conditions and places are not clearly distinguished. Therefore, they are not perfectly suitable for adoption to ARATE, although they have convenient features for analysis because of their multi-aspect and post-coordinated nature.

It is, therefore, necessary to develop for ARATE a new hierarchical classification scheme which has a multi-aspect and post-coordinated system such as CST and CAST have, covering technology elements of the fields to be analyzed, and distinguisheing objects, materials, conditions, places, etc.

C. Indexing and the File

When sources of information for ARATE are aquired, the technology elements are to be grasped and systematically processed; the contents of the technology complex shown by the sources of information are to be analyzed and indexing terms for the complex are to be decided. The indexing terms should include objects, materials, places and other conditions in addition to all technology elements which belong to the technology complex. Multiple indexing terms are to be given to one technology complex.

The logical relationship among and the weighting of technology elements express the precise contents of the technology concerned. When necessary, the name of the researchers, the research institute, the research period, research cost, etc. can be given as analytical elements.

Indexes given to each technology element are recorded in a file which should ideally be an EDP file to be processed later.

D. Processing of the File

By processing the file, it is possible to carry out various analyses of the elements of technology complexes.

1. A simple example of weighting a technology element is as follows: It is possible to know the weight of a specific technology element in a technology complex by counting the frequency of use of the element. As the indexing system has a hierarchical structure, the weight of a category in broader terms can be decided.

2. The combination of a certain technology element with others in the same record on the file will show us whether, in a broad or narrow scope, the technology element relates with other elements, with what other elements and how closely it relates.

The analyses mentioned in the above are possible when they are carried out on the whole file of technology complexes of a specific subject field.

IV. Characteristics of Agricultural Technologies

A. Agricultural Technologies as Technology Complexes

Agricultural technologies (including technologies of forestry, animal industry and fisheries) are typical technology complexes. The central concerns of agricultural technologies are those concerning cultivation, horticulture, plant culture, animal husbandry, etc., each of which is considered a complex of many technology elements.

The objects of agricultural technologies are mainly living things and the products of living things. Biology is, therefore, an important fundamental technology element within agricultural technologies.

Agricultural technologies are closely related to society and the economy. Therefore, culture, economics, management science and other social sciences are elements belonging to agricultural technologies.

Also very important is the health of livestock and human beings. Therefore, medicine, veterinary medicine, and pharmacology enter into agricultural technologies.

Facilities, machines and equipment which are needed for agriculture have a close relation with agricultural technologies. Therefore, the technologies of machines, architecture, and civil engineering are elements of agricultural technologies.

The technology of the uses of agricultural products belongs to agricultural technologies in broader terms. In this sense, the technology of processing and storing agricultural products, food technology, lumbering, filature, paper-making, etc. are considered as elements of agricultural technologies. In addition, physics, chemistry, chemical engineering, pure and applied geology, energy technology, information technology and many other sciences and technologies are elements of agricultural technologies.

If the above concept of agricultural technologies is accepted, almost all of the sciences and technologies are technology elements contributing to agricultural technology complexes.

B. Factors Other Than Regular Technology Elements

In agricultural technology complexes, the technology elements needed differ depending upon the living objects, e.g. cattle or swine, in livestock breeding. In the case of rice plant cultivation, the technology elements to be applied depend on whether the cultivation is to be carried out in a warm or cold climate, and on upland or in paddy fields.

Therefore, the objects and purposes of research, physical and chemical conditions such as temperature, humidity, and geographic conditions are to be considered as factors of technology in agricultural technology complexes.

C. Special Features of Agricultural Research

Technological research on practical problems in agriculture is primarily research on technological complexes composed of many technology elements as explained in the foregoing.

Agricultural research has some features distinct from those in other technologies. First, the period of agricultural research is usually long. The resons for this are that the growth periods of lives are long and their growth in a year is limited. Secondly, there are many research projects adopting the same technology elements because, when living objects or places are different, the results of research become different. Thirdly, research on agricultural technologies are mostly carried out by national and prefectural / municipal research institutes in Japan. Research in universities occupies only about one-third of the total, and those by private institutes very little (Table 1).

National agricultural research institutes in Japan have very close relations with prefectural/municipal agricultural research institutes. The national institutes carry out research on basic, general and non-regional topics, or regional problems common to prefectural/municipal institutes.

The projects and outlines of research which are carried out by national and prefectural/ municipal agricultural research institutes are reported annually to the Ministry of Agriculture, Forestry and Fisheries and are published by the Ministry.

V. Experiment

A. Materials Used for the Experiment

Table 1. Researcher and Budget of Agricultural Research Organizations in Japan (April 1980)

Research Organizations	Number of Researchers	Budget (¥1,000,000)
Universities	7,491 (40.2%)	69,459 (32.8%)
National institutes	3,201 (17.2%)	42,504 (20.1%)
Municipal institutes	7,529 (40.8%)	95,746 (45.2%)
Public corporations	60 (0.3%)	550 (0.3%)
Private institutes	268 (1.4%)	3,423 (1.6%)
Total	18,569 (100%)	211,682 (100%)

Source: Bureau of Statistics, Prime Minister's Office

A total of 1,532 research projects newly begun by national agricultural research institutes in the 1979-80 fiscal year were used for the present experiment. The names of the research institutes and the numbers of research projects of each institute are shown in Table 2.

Table 2. Institutes and Number of Research Projects Analyzed in the Experiment

Institutes	Number of projects started in 1979
National Institute of Agricultural Sciences	89
Central Agricultural Experiment Station	50
National Institute of Animal Industry	43
Fruit Tree Research Station	106
Vegetable and Ornamental Crops Research Station	112
National Institute of Tea	35
National Research Institute of Agricultural Engineering	33
Hokkaido National Agricultural Experiment Station	160
Tohoku National Agricultural Experiment Station	80
Hokuriku National Agricultural Experiment Station	33
Chugoku National Agricultural Experiment Station	181
Shikoku National Agricultural Experiment Station	32
Kushu National Agricultural Experiment Station	93
National Research Institute of Agricultural Economics	37
Sericultural Experiment Station	24
National Institute of Animal Health	57
National Food Research Institute	75
Institute for Plant Virus Research	31
Tropical Agriculture Research Center	34
Institute of Agricultural Machinery	49
Forestry and Forest Products Research Institute	106
Total	1.532

B. Tools for Analysis

The *A*gricultural *S*ubject *I*ndexing *C*ode (ASIC)[4] has been developed by the author to be used as a tool for ARATE in agricultural fields. The policies of developing ASIC were as follows:

1. The structure of ASIC must have a decimal classification scheme consisting of four digits with a multi-aspect, post-coordinated and hierarchial function.
2. It must cover all the sciences and technologies of the technology elements of agricultural technologies.
3. It should have a category for factors such as place, time, physical conditions, etc., in addition to other technology elements.
4. It should provide a category for factors such as objects and/or results of the agricultural technologies.
5. Other categories for the technology elements must be provided on the basis of the concept of CAST and must be revised when needed.
6. The technology of energy and the technology of information shall be unified into one category.

It is necessary for ARATE to provide the categories mentioned in 3. and 4. separately from the technology element categories. The category mentioned in 3. is generally speaking, almost the same as Class 0 of CAST. In CAST, the categories of techlology elements and objects are mixed in the classification, and form a separate category.

The outline of ASIC, the divitions and details of its classes 0 and 1, and sample sections of classes corresponding to technology elements are shown in Tables 3, 4, and 5, respectively.

C. Indexing and the File

Using ASIC, the subject analysis of each research project was made and indexing codes were given to the project. The subsections of Classes 0 and 1 and the sections of Classes 2-8 were used as indexing codes. The number of indexing codes which may be given to a research project is unlimited. Some examples of the results in indexing are shown in Table 6. An example of the description of a project and the indexing codes given to the project

Table 3. Outline of Agricultural Subject Indexing Codes (ASIC)

Class	Number of Divisions	Number of Sections	Number of Subsections
0 Place, Time, Condition	10	59	291(291)
1 Substances and Living Things	9	56	389(389)
2 Biological sciences	3	21(10)	153
3 Biological technology	7	39(26)	217
5 Social sciences	8	28(18)	107
6 Physical sciences	8	47(16)	131
7 Physical technology	7	39(21)	118
8 Energy and information technology	8	48(17)	109
Total	60	337(108))	1,515(680)

( ): Number of sections or subsections used in the experiment.

Table 4. Classes 0 and 1 of ASIC

Divisions	Details (examples)
01 Land, Climate	082 Seasons
02 Water areas	0820 Seasons (general)
03 Space	0821 Spring
04 Marine areas	0822 Summer
05 Farm	0823 Autumn
06 Political geography (excluding Japan)	0824 Winter
07 Political geography (Japan)	0825 Rainy season
08 Time, Quantity, Quality	0826 Dry season
09 Phase, Physical condition	0829 Seasons (others)
11 Substances	
12 Natural resources	161 Fertilizer, Pesticide, Feed
13 Microbes, Plants (taxonomical)	1610 Fertilizer, Pesticide, Feed (general)
14 Animals (taxonomical)	1611 Fertilizer, Growth regulator
15 Organisms (habitat, use, harm)	1612 Soil condition
16 Substances (for use)	1613 Pesticide
17 Food	1614 Feed
18 Parts, Machinery, Plants	1619 Fertilizer, Pesticide, Feed (others)

Table 5. Technology Elements in ASIC (Sections)

2010 Biology, Palaeontology	3110 Soil
2110 Cytology	3120 Plant culture
2120 Embryology	3123 Plant breeding
2140 Genetics	3140 Agricultural engineering
2150 Physiology, Biochemistry, Biophysics	3150 Fertilization, Watering
2160 Organ physiology	3160 Plant pathology
2170 Ecololy	3170 Plant protection
2181 Cell and tissue culture	3180 Silviculture
2184 Biometrics, Biostatistics	3190 Microbe culture
2186 Electron microscopy	3240 Sericulture, Apiculture

3250	Insect diseases and protection
3260	Poikilothermic animal keeping
3410	Animal husbandry
3420	Capture, protection of natural animals
3500	Animal diseases (general)
3510	Animal diseases (symptoms)
3530	Tumor, Cyst, Polyp
3540	Nutrition disorders, Metabolic diseases
3550	Wounds, Poisoning, Immunological diseases
3590	Diseases (others)
3610	Diagnosis
3620	Preventive, Treatment
3710	Hygiene
3720	Public health, Disasters
3730	Pharmacies
5110	Rural development
5120	Rural sociology
5210	Food habitats
5230	Living
5240	Leisure
5310	Public nuisance and prevention
5320	Natural disasters, Prevention
5420	Fire service
5440	Safety
5510	Economics
5520	Management
5530	Production control
5540	Quality of production control
5550	Standards
5560	Inspection, Calibration
5610	Law, Regulation
5620	Administration
5630	Sociology and welfare
6130	Statistics, Probability
6300	Physics
6400	Chemistry (general)
6410	Physical chemistry
6416	Photochemistry
6417	Radiochemistry
6420	Analytical chemistry
6430	Inorganic chemistry
6440	Organic chemistry
6450	Polymer chemistry
6460	Natural organic chemistry
6610	Geoscience
6700	Meteorology, Climatology (general)
6710	Weather
6730	Radiation, Temperature
6770	Climate
7010	Material processing (general)
7050	Information technology (general)
7100	Probes and gathering of natural resources
7200	Chemical processing (general)
7221	Chemical processing (use of catalyzer)
7222	Chemical processing (use of organisms)
7310	Physical effects of products (for use)
7320	Chemical effects of products (for use)
7330	Physico-chemical effects of products (for use)
7340	Biological effects of products (for human use)
7350	Biological effects of products (for animal use)
7360	Biological effects of products (for plant use)
7370	Biological effects of products (for microbe use)
7400	Waste processing
7610	Effects of mechanical processing
7630	Mechanical formation
7640	Mechanical combination
7670	Mechanical unit processing (others)
7680	Construction
7701	Transportation
7705	Storage
8010	Energy technology (general)
8110	Mechanical energy (natural)
8120	Heat energy (natural)
8130	Waste energy
8200	Energy processing (general)
8201	Energy conversion
8290	Waste energy processing
8301	Energy transmission
8350	Energy storage
8410	Heat (final form for use)
8440	Light energy (final form for use)
8450	Atomic energy (final form for use)
8700	Information processing
8750	Control
8760	Measurement
8770	Electronic data processing, System engineering
8800	Documentation, Communication

are presented in Figure 1.[5)]

After indexing, a set of the code numbers and all indexes given to the project are stored in the EDP file.

D. Processing of the File and Its Results

1. Frequencies of technology elements appearing in each class of ASIC

The percentages of frequencies of indexes

Table 6. Examples of the Results of Indexing

	Number of project	Average number of indexes per project	Number of varieties of indexes used
All projects	1,532	3.2	92
Ricie plant	151	3.3	52
Wheat and barley	74	3.0	35
Cattle	103	3.0	45
Swine	23	3.6	25
Virus	69	3.5	28
Eumycetes	52	4.0	36
Upland fields	79	2.8	30
Paddy fields	102	3,1	31

used for all the projects or for specific living things or places were computed and are shown in Table 7.

2. Frequencies of technology elements

The frequencies of technology elements in cluding indexes of all the projects and some specific living things or places were computed, and the upper ten technology elements, their frequencies (%) and the totals of the upper ten frequencies (%) are shown in Table 8.

3. Numbers of the related technology elements

The projects which include certain specific technology elements were selected from the file of all the projects and a subfile of them was made. Then the number of the "related technology elements" (or the technology elements other than the specific technology elements) in the subfile were computed. The relationship between the frequencies of all technology elements and the numbers of the related technology elements are presented in Figure 2.

Title of Project: Development of sclerotium of *Rhizoctonia Solani* on the rice plant

Outline: The sources of infection of sheeth blight on the rice plant is sclerotium of *Rhizoctonia Solani.* The amount of wintering sclerotium infleuences the percentage of contraction and damage to the plant. Therefore, if we can control the development of sclerotium, we must have a strong protective device against the desease. The present research intends to clarify major substantial factors to begin the development of sclerotium and to examin developmental differences among the varieties of the rice plant.

Indexes:

1341: Rice plant
2010: Biology, Palaeontology
2120: Embryology
2140: Genetics
2150: Physiology, Biochemistry, Biophysics
3106: Plant pathology
3170: Plant protection

Figure 1. Example of the description of a project and indexes taken from it.

4. Relativity of technology elements

The numbers of the projects which include any pair of technology elements were computed on all technology elements. The relativity (R) of two technology elements is presented

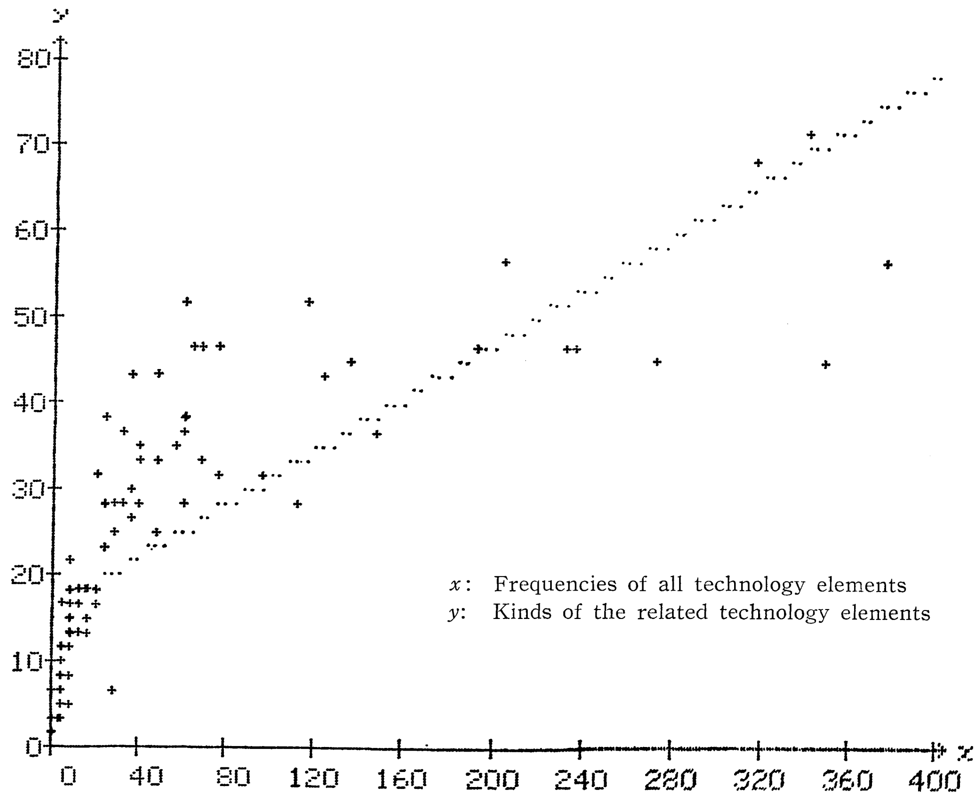
Table 7. Frequency of Indexes in Each Class. (%)

Object / Class	All project	Rice plant	Wheat and barley	Cattle	Swine	Upland fields	Paddy fields	Virus	Eumy-cetes
Biological sciences	27.5	24.6	14.8	43.5	47.5	18.0	17.9	55.5	42.8
Biological technology	36.6	49.8	55.3	32.9	30.5	55.3	56.2	38.2	43.3
Social sciences	15.9	11.8	16.1	12.3	3.7	15.8	16.3	1.7	2.4
Physical sciences	7.7	5.1	1.3	2.6	1.2	4.5	4.5	2.1	3.8
Physical technology	10.2	6.7	12.1	8.1	15.9	5.0	3.2	2.5	7.2
Energy and information technology	2.2	2.0	0.4	0.6	1.2	1.4	1.9	0	0.5

Table 8. Weights of Some Main Technology Elements

Ranking	All projects	Rice plant	Wheat and barley	Cattle	Swine	Virus	Eumycetes	Upland fields	Paddy fields
1	Ecology (7.56)	Plant pathology (11.17)	Palant culture (13.90)	Animal husbandry (16.77)	Organ physiology (18.07)	Plant pathology (17.14)	Plant pathology (18.26)	Soil (17.93)	Fertilization, Watering (9.58)
2	Plant pathology (7.00)	Plant culture (9.34)	Plant breeding (12.55)	Physiology, Biochemistry, Biophysics (16.45)	Animal disease (general) (12.04)	Physology, Biochemistry, Biophysics (13.46)	Ecology (12.98)	Ecology (10.76)	Soil (8.94)
3	Production control (6.90)	Ecology (8.53)	Production control (11.21)	Organ physiology (10.33)	Physiology, Biochemistry, Biophysics (10.84)	Ecology (7.34)	Microbe culture (9.13)	Production control (8.96)	Plant culture (8.94)
4	Physiology, Biochemistry, Biophysics (6.41)	Plant protection (8.33)	Plant pathology (8.96)	Ecology (9.93)	Animal husbandry (9.63)	Cell and tissue culture (6.53)	Biology, Palaeontology (8.65)	Plant pathology (8.52)	Plant pathology (8.94)
5	Plant culture (5.46)	Plant breeding (7.52)	Plant protection (8.52)	Animal disease (general) (5.16)	Ecology (6.02)	Organ Physiology (65.3)	Plant protection (7.21)	Plant protection (7.17)	Production cohtrol (8.62)
6	Plant protection (4.73)	Fertilization, Watering (7.52)	Ecology (4.93)	Production control (4.19)	Biological effects of products (for animail use) (4.81)	Infectious diseases (6.12)	Embryology (5.76)	Fertilization, Watering (7.17)	Ecology (7.66)
7	Soil (4.65)	Production control (7.52)	Soil (4.93)	Management (3.54)	Biology, Palaeontology (3.61)	Cytology (5.30)	Physiology, Biochemistry, Biophysics (4.80)	Agricultural engineering (6.27)	Plant breeding (7.34)
8	Embryology (4.10)	Physiology, Biochemistry, Biophysics (5.48)	Fertilization, Wartering (4.48)	Biological effects of products (for animal use) (3.22)	Diagnosis (3.61)	Plant protection (4.89)	Genetics (3.84)	Plant culture (5.82)	Plant protection (7.02)
9	Plant breeding (3.90)	Soil (4.67)	Physiology, Biochemistry, Biophysics (3.13)	Embryology (2.90)	Waste processing (3.61)	Electron microscopy (4.08)	Cytology (3.36)	Management (3.58)	Agricultural engineering (5.43)
10	Fertilization, Watering (2.99)	Gegetics (3.04)	Chemical processing (general) (3.13)	Diagnosis (2.90)	Biometrics, Biostatistics (2.40)	Biology, Palaeontology (3.26)	Electron microscopy (2.40)	Physiology, Biochemistry, Biophysics (3.58)	Management (3.83)
Total	(53.7)	(73.12)	(75,74)	(74.49)	(74.64)	(74.65)	(76.39)	(79.76)	(76.30)

( ): Weight in percentage



Regression formula: $y=15.5859+0.1576x$

Figure 2. Relationship between frequencies of technology elements and the kinds of related technology elements

by the following formula,

$$R \equiv F_{A \cdot B}/(F_A+F_B-F_{A \cdot B}),$$

provided that

F_A : Frequency of technology element A,
F_B : Frequency of technology element B, and
$F_{A \cdot B}$: Frequency of co-occurrence of A and B.

The value of R is in the range of $0 \leqslant R \leqslant 1$.

The upper 20 frequencies of co-ocurrences of a pair of technology elements and the value of relativities are given in Table 9. The upper 22 major technology elements of all the projects are listed by rank, and the other related technology elements co-occurring with them and the values of the relativities (which are larger than 0.1) are shown in Table 10.

VI. Discussion

A. Present Experimental Results

Some remarkable points of the present experimental results are discussed in the following:

1. Scope of technology elements

The numbers of varieties of indexes used for all projects, or some specific projects concerning living things and places are shown in Table 6. The number of technology elements used for indexing all the agricultural technologies was 92, covering 85% of all technology elements. The numbers of varieties of indexes used for the rice plant and cattle were 52 and 45, respectively, indicating that they require

Table 9. Frequencies of Co-occurrence and Relativeties of Pairs of Main Technology Elements

Pair of Technology Elements		Frequency of Co-occurrence	Relativity
Plant pathology	Plant protection	194	0.5025
Ecology	Plant pathology	159	0.2834
Plant culture	Production control	119	0.2418
Ecology	Plant protection	96	0.1875
Embryology	Ecology	95	0.1970
Physiology, Biochemistry, Biophysics	Ecology	93	0.1365
Genetics	Plant breeding	68	0.2593
Plant breeding	Plant pathology	68	0.1433
Soil	Fertilization, Watering	67	0.2514
Plant breeding	Plant protection	67	0.1860
Embryology	Silviculture	65	0.0253
Rural sociology	Management	65	0.4515
Ecology	Soil	57	0.1042
Embryology	Physiology, Biochemistry, Biophysics	52	0.1110
Physiology, Biochemistry, Biophysics	Organ physiology	51	0.1338
Plant breeding	Production control	51	0.1338
Plant culture	Plant pathology	46	0.0806
Physiology, Biochemistry, Biophysics	Production control	45	0.0733
Physiology, Biochemistry, Biophysics	Plant pathology	43	0.0693
Physiology, Biochemistry, Biophysics	Animal husbandry	42	0.1052
Ecology	Production control	42	0.0623

comparatively wide varieties of technology elements. On the contrary, projects concerning swine and the virus did not require many varieties of technology elements.

2. Weights of technology elements

a. Class level

The weights of technology elements included in all projects are presented by the percentages of the frequency of the technology elements. On the class level they are shown in Table 7. The highest weight of technology elements included in all projects was observed in the class of Biological Technology (36.5%), followed by the class of Biological Sciences (27.5%). The class of Social Sciences (including Economics, Management Science, Sociology, etc.) (15.9%), and Physical Technology (10.2%), followed in succession. The present status of agricultural research is well presented by these data.

Concerning some specific living things and places, the distribution of weights of technology elements differs considerably.

First, in cases of cattle, swine, virus, and eumycetes, weights in Biological Sciences were very high. It is assumed that Biological Sciences, such as the physiology of livestock, taxonomy, identification, genetics, etc. of microorganisms, are important in these research projects.

In the cases of virus and eumycetes, the weight of Biological Technology is high, presumably because these microbes are closely related to diseases in useful plants and animals.

Table 10. Main Technology Elements and Their Related Technology Elements ($R>0.1$)

Ranking	Technology Element	Related Technology Elements
1	Ecology	Plant pathology (0.2834), Embriology (0.1970), Plant protection (0.1875), Physiology, Biochemistry, Biophysics (0.1365), Soil (0.1042), Radiation, Temperature (0.1040)
2	Plant pathology	Plant protection (0.5025), Ecology (0.2834), Plant breeding (0.1433), Embryology (0.1342)
3	Production control	Plant culture (0.2418), Plant breeding (0.1055)
4	Physiology, Biochemistry, Biophysics	Ecology (0.1365), Organ physiology (0.1338), Embryology (0.1110), Animal husbandry (0.1052)
5	Plant culture	Production control (0.2418), Effects of mechanical processing (0.1157), Fertilization, Watering (0.1058)
6	Plant protection	Plant pathology (0.5025), Ecology (0.1875), Plant breeding (0.1860), Genetics (0.1008)
7	Soil	Fertilization, Watering (0.2514), Econogy (0.1042)
8	Embryology	Ecology (0.1970), Plant pathology (0.1342), Physiology, Biochemistry, Biophysics (0.1110), Radiation, Temperature (0.1045), Genetics (0.1003)
9	Plant breeding	Genetics (0.2595), Plant protection (0.1860), Plant pathology (0.1443), Production control (0.1055)
10	Fertilization, Watering	Soil (0.2154), Plant culture (0.1058)
11	Genetics	Plant breeding (0.2529), Plant protection (0.1008), Embryology (0.1003)
12	Animal husbandry	Management (0.1079), Physiology, Biochemistry, Biophysics (0.1052)
13	Organ physiology	Infectious diseases (0.1879), Biological effects of products (for animal use) (0.1377), Physiology, Biochemistry, Biophysics (0.1338)
14	Management	Rural sociology (0.4545), Economics (0.1971), Sociology and welfare (0.1475), Animal husbandry (0.1079)
15	Rural sociology	Management (0.4545), Sociology and welfare (0.4545), Economics (0.1846)
16	Effects of mechanical processing	Plant culture (0.1157)
17	Biological effects of products (for animal use)	Infectious diseases (0.1714), Organ physiology (0.1377)
18	Chemical processing (general)	Storage (0.1057), Waste processing (0.1022)
19	Agricultural engineering	Geoscience (0.1855)
20	Analytical chemistry	Polymer chemistry (0.1686)
21	Radiation, Temperature	Heat energy (natural) (0.1212), Embryology (0.1045), Ecology (0.1040)
22	Cytology	Electron microscopy (0.1408), Cell and tissue culture (0.1126)

(   ): Relativity

In the cases of rice plant, wheat and barley, upland and paddy fields, Biological Technology shows a heavy weight because plant culture is of primary importance.

A high value of the weight of the class of Physical Technology in the case of swine may be explained by the fact that Waste Processing in swine breeding and Processing of pork are of importance at the present time in Japan.

b. Level of sections

The weights of technology elements on the level of Sections of ASIC have been computed (see Table 8).

In the case of all research projects Ecology showed the highest value. Plant and animal culture is the basis of agriculture, for which Ecology is the most important factor. The second highest weight was of Plant Pathology, because one of the important roles of agricultural technology is the healthy cultivation of useful plants. The third highest value was given to Production Control, showing that one of the main objectives of agriculture is concerned with the production of useful plants and animals.

Cumulative sums of the upper ten weights of technology elements of some specific plants and animals and some specific places were more than 70%. The order and ratio of technology elements included in each case were specifically different. Let us pay special attention of the appearance of technology elements other than those appearing in all research projects. Instead of Embryology in the case of all the projects, Genetics appears in the case of the rice plant, and Chemical Processing in wheat and barley. The former shows that Genetics is of importance as a basis of breeding choice varieties, and the latter suggests that Chemical Processing is important for wheat and barley as food. The weights in both cases are about 3%.

In upland and paddy fields, Agricultural Engineering and Management were evident. The sum of the weights was 9.85% and 9.25%, respectively. Agricultural Engineering is a technology element to consolidate fields and Management is concerned with the basic problem of agriculture.

In the cases of cattle and swine, Organ Physiology, Animal Disease, Diagnosis, and Biological Effects of Products, which are related to Animal Husbandry and Animal Health, came out in the upper ranks.

In the case of swine, it is worth noting that Waste Processing appears with a frequency of 3.61%. This indicates that this is one of the important problems of swine management in the suburban area.

A total of weights of the technology elements which did not appear in the upper ten ranks in the case of all projects was 41.9% in the case of cattle, and 75.8% in the of swine. It shows that the livestock technology is unique among agricultural technologies.

In the case of virus, Cell and Tissue Culture, Cytology, Electron Microscopy, Biology and Palaeontology appeared, and the sum of their weights was 19.2%. In case of eumycetes, the sum of the weights of the same technology elements reached 27.4%. Organ Physiology and Infectious Diseases which appeared in the case of virus are technology elements concerning animal diseases.

c. Relationships among technology elements

(1) Frequencies or weights and scope of relationship

Figure 2 shows that the technology elements with heavier weights in the agricultural technologies have relations with other technology elements. The correlation coefficient between the weight of a technology element and the number of varieties of other technology elements with which the technology element is related is 0.7726 ($t=11.98$).

From the data of Table 9, some observations may be made about a pair of technology elements with the highest frequencies: Production Control shows the widest scope of relations with other technology elements, because agriculture is one of the productive industries; Physiology, Biochemistry and Biophysics follow Production Control, because they are the bases of the life sciences and relate with biological technology. Other basic technology elements also have wide scopes of relations with other technology elements.

(2) Frequency of co-occurrence

All of the pairs of technology elements shown in Table 9 appear frequently in the file and are ranked within the upper fifteen, except Silviculture. The greatest frequency was observed in the Plant Pathology and Plant Protection pair. Plant Pathology is the basic study of pests and diseases of plants and Plant Protection is aimed at finding methods and devices of protecting plants from pests and diseases.

(3) Relativity

The relativity is an index showing the degree of close relation between a pair of technology elements. The index (R) is not influenced by the frequencies of each technology element in the file, as explained in V.D.4.

The greatest relativity was found in the Plant Pathology and Plant Protection pair; their close relations have already been explained.

The technology elements with heavier weights and those closely related with them ($R>0.1$) could be foreseen from the common sense of agriculture.

B. Future Improvements

1. Sources of information

In the present experiment, ongoing research projects in agricultural sciences and technologies carried out in a single year in Japan were analyzed. The author believes the effectiveness of ARATE has, in general, been proved.

However, it is necessary to experiment using different sources of information from the present experiment to improve ARATE, to compare technologies in different countries, and to examine trends of technological change.

2. Tool for analysis

ASIC, which was used as an analytical tool for the present experiment, was basically appropriate to the present agricultural technology in Japan. Future examinations will, however, be required of its details, and a different subject field would require a different tool for analysis appropriate to it.

In the present experment, the analysis was carried out to the level of the sections of ASIC. It is necessary in future to analyze down to the subsection level. In future it is necessary to develop a tool of device for analysis based on a new viewpoint and to clarify the relationships among more than three technology elements.

3. Uses of ARATE

Examples of major uses of ARATE are discussed in the following:

a. Planning curricula for training technologists

In college education and/or on-the-job training of corporation personnel, the trainees must learn what the technology elements have heavier weight and/or wider scope of relativity in the technology in which they are expected to work.

Using ARATE one can find the technology elements which have high weights and/or which relate to many other technology elements. The results will supply useful information for planning curricula for training technologists.

b. Management of R and D

R and D is aimed at finding new combinations of already known scientific and/or technological elements and to solve new problems. Frequencies of co-occurrence and relativities of technology elements found by ARATE show what pairs of technology elements have never, or rarely, or frequently been combined in the past. In other words, it will suggest whether a newly planned project will be stereotyped and its R and D will be easy, or whether it will be original and its R and D will carried out with difficulty. It will be useful in planning completely original projects which would be based on a new combination of technology elements. It will supply the management of R and D with useful information.

Documentation of technology has hitherto supplied the researcher and technologist with information necessary for their R and D. ARATE is one of methods of documentation, but information gained by ARATE is useful mainly to R and D management. ARATE is, in this sense, of different use from documentation methods in the past.

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