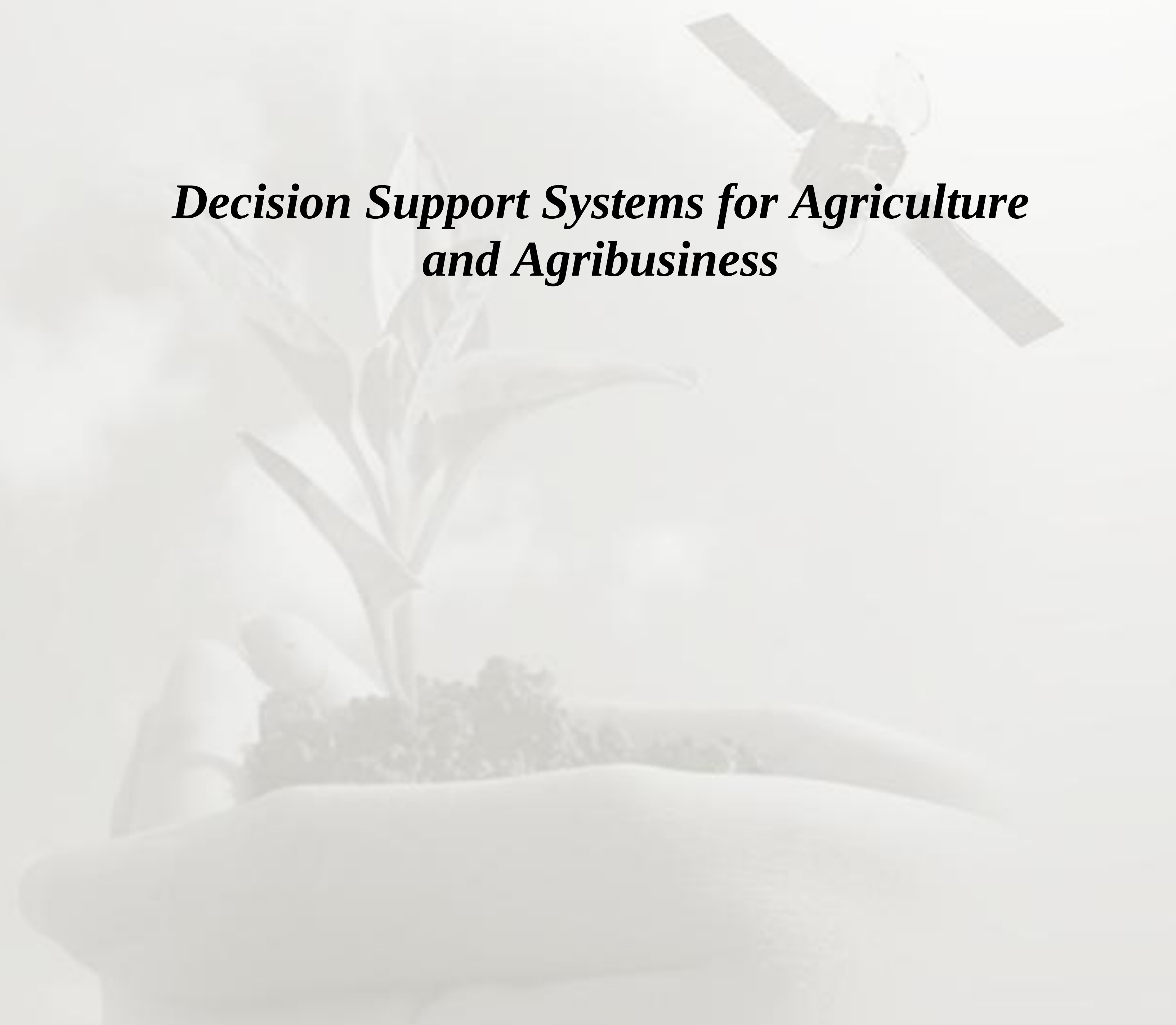
Decision Support Systems for Agriculture and Agribusiness



Development of Decision Support Systems for Agricultural Management : An overview in Japan

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***Abstract*—Improvement of farming decision making in both short term and long term is necessary for innovation of agriculture in Japan as well as other countries. Decision support systems for farmers, agricultural extension staffs and policy makers are needed for their better decision making. Therefore, we have developed several types of decision support systems for agricultural management such as FAPS-DB, FAPS, Noyaku-Navi and FVS. In this paper, an overview of the decision support systems will be illustrated with their applications. The role of each system and their connections will be also discussed from the viewpoint of time span of decision making. In addition, applicability of the systems for other countries is also considered. The FAPS-DB is a decision support system that is appreciable for overall estimation of the influence by the management strategy of the farming. The both technological data and financial data are stored in the database of this system. FAPS is a decision support system for farm planning under risk and uncertainty in agriculture based on stochastic programming. These systems are examples of long term DSS. Noyaku-Navi is a navigation system for appropriate use of agrochemical. The system is a warning system on inappropriate use of agrochemical and is an automatic recording system of agrochemical. FVS is a farming visualization system which records and plays all the information of farming operations by combinations of several kinds of sensors including GPS, RFID and camera. The system supports appropriate farming operation. These systems are examples of short term DSS.**

Keywords: management, farm planning, appropriate agrochemical use, farming visualization, short term DSS, long term DSS

I. INTRODUCTION

Agriculture has been facing economic risk as well as environmental risk. Market price fluctuation of product is an example of economic risk. Climate change is an example of environmental risk. To cope with these risks, decision support system for optimal farm planning under risk is needed. Optimal crop combinations and optimal farm size are major part of farm plan. These are classified as long term decisions making because time span of these is annual or seasonal base in general. The long tern decision making is done once year or by cropping season. The decision making has long effect in farming, e.g. more than one year or cropping season (Table 1).

On the other hand, food safety issues represent another big risk for farmers. Food safety has increasingly become a forefront of consumer concerns, industry strategies, and government policy initiatives in many countries. For example, appropriate agrochemical use is very crucial for farm operation and management. If a misapplication of agrochemicals is discovered after the application then the disposal of the agricultural products will be done. This causes serious problems to farmers. There are many decisions making in farming operation including spraying of agrochemical. Good examples of farming operation are management of machinery operation, fertilizer and water. Improvement of the farming operation and succession of skill are crucial issues for farm management. Decisions making in everyday farming is classified as short term decisions making because time span of these is daily or weekly base in general. Short term decision making is done several time in one year or by cropping season. The decision making has short effect in farming, e.g. less than one year or cropping season (Table 1).

The improvement of decision making in farming both in short term and long term is necessary for innovation of agriculture in Japan as well as other countries. Decision support systems for farmers, agricultural extension staffs and policy makers are needed for their better decision making. In this paper, an overview of the decision support systems for agricultural management will be introduced with their applications in Japan based on our researches. The technical parts of the decision support systems as well as applicability of the systems for other countries will be also discussed.

II. LONG TERM DSS : FAPS-DB AND FAPS

Risk management is a core part in farm management. The sources of risk in agriculture are numerous such as price and yield fluctuation, disease, pest, weather, policy changes and so on. The risk should be considered when making a farm plan. On the other hand, agricultural production is one of the sources of environment risk which has negative effects on agricultural production, food safety and human health. Chemical use and greenhouse gas emission caused by agricultural production are the source of such an environmental risk. Furthermore, environmental contamination and global warming are also risks which farm faces because they may damage agricultural production (Table 2).

A. Database System of agricultural technology and farm planning

A structural reform of agriculture is a big policy issue in countries that import large among of farm products. Japan is one of the good examples of such countries. Nanseki et al. (2008a) shows that the following management strategies are necessary for domestic farmers and agriculture in such a country: 1) Introduction of new crops. 2) Expansion of farm size, 3) Introduction of new technologies, 4) Introduction of new fields such as processing of farm products. To support these farm management decision making in long-run, Nanseki et al. (2003a, 2003b) have developed a decision support system, which is the first version of FAPS-DB system for PC's. The system was appreciable for overall estimation of the influence by the management strategy of the farming. The both technological and financial data are built into this system. In short, FAPS-DB is a comprehensive farm planning system (Table 3).

Nanseki et al. (2004b, 2007a) have developed a revised web version of the system. The FAPS-DB system is a web-based system decision making support system that is significant for overall estimation of the influence by the management strategy of the farming. This system is also integrated to the market price database for vegetables and fruits, called NAPASS, through the Internet. Therefore, farming income risk caused by price fluctuation is easily evaluated. Furthermore, financial risk in terms of cash flow is also estimated at the same time.

In the web interface of the support system for farm planning, users search for the registered data of farming systems by selecting field classifications, prefectures and the names of crops. Then they input the acreage for each crop, variety, crop season, cultivation methods by selecting the corresponding data of farming systems, which is applied to the farm planning. In addition to this, by inputting wage estimates (Japanese Yen/hour), estimated farmland rent (Japanese Yen/10 a) for rice field, upland crop field, fruit farm and greenhouse cultivation, and estimated capital interest rate (%), then the system will estimate the cost of such management resources.

Furthermore, by inputting the upper limit of semimonthly farm-working hours (hour) by machines, the number of machines and facilities required in the selected farming systems can be estimated. The developed farm plan can be viewed by two methods: Internet browser and MS-Excel book format. In the present version of the system, 16 kinds of tables, such as semimonthly financial balance and cash flow, list of materials invested, list of required machinery and facilities, and also the farm work timetable are generated (http://fsdb.dc.affrc.go.jp/).

Nanseki et al. (2002, 2003b) have also developed the FAPS (farming-systems analysis and planning system). This system is a decision support system for farm planning under risk and uncertainty in agriculture (Table 3). The system is able to generate optimal farm plans according to risk preference under yield risk, market risk and weather risk based on stochastic programming. In the system, users can analyze their goals such as income and working hour goals as well as the risks faced by farmers like weather conditions and market prices based on goal programming. FAPS system is able to use output data from FAPS-DB as input data. A combination of FAPS and FAPS-DB is effective for the most advanced users.

B. Assessment of economic and environmental risk based on a farm plan

Both economic and environmental risks are crucial to manage agriculture in a sustainable perspective. This implies that assessment of economic and environmental risk of agricultural production should be integrated to farm planning. Therefore, we have developed a procedure for integrated assessment of economic and environmental risk of agricultural production. This procedure integrates several existing system such as the FAPS-DB system and the Noyaku-Navi system ((Nanseki et al., 2007b, Fig.1).

Economic risk of farming can be measured based on a farm plan as an action choice in advance as the probability distribution of income (Nanseki et. al 2009). Because of unexpected variability of price and yield, for example, farm income follows a probability distribution. Price and quantity of agricultural input (material) determine variable cost of a farm plan. Furthermore, available farm operation time is affected by unexpected weather condition change such as rain falls and droughts. Available farm operation time determines minimum number of agricultural machinery needed in a farm plan and affects value of the fixed cost consequently. When an aspiration level of income for a producer is given, a downside risk can be more specifically defined as a probability which the income falls below the aspiration level. In addition, impacts of climate change including global warming on farming can be evaluated by FAPS-DB and FAPS (Nanseki 2010).

Based on a farm plan created by FAPS-DB, economic and environmental risks are estimated. Both price and yield of each crop of a farm plan can be changed by user in the system. Because NAPASS, a nation-wide market information database for vegetables and fruits, is integrated to the FAPS-DB system with web service (Nanseki et. al .2007, 2008), it is easy to estimate income fluctuation caused by historical fluctuations of the prices.

On the other hand, an environmental risk of farming is theoretically measured as the probability distribution of negative effects of a farm plan on health of human being and natural environment. Agrochemicals such as pesticide planned to be used in the farm plan is a major source of the risk. Another major source of risk is greenhouse gas released during manufacturing agricultural input (materials) and machinery, for example. However, relation between amount of greenhouse gas released from a farm and the negative effects on the environment are not clear and cannot be estimated in nature. Relation between value of risk score (toxicity) of agricultural technology with chemical for human (RSTh) and the negative effects are also not clear. Therefore, we estimate an amount of greenhouse gas and RSTh of a farm plan as an indicator of environmental risk.

Information of chemical active ingredients of the agrochemicals used in a farm plan created by FAPS-DB are estimated from Noyaku-Navi database. Then the risk score (toxicity) of agrochemical of the farm plan is estimated based on the information.

C. Application and discussion

In the application of the procedure (Nanseki, et. al 2010), farm income fluctuates from 1.060 to 4.154 million yen because of price fluctuation of tomato. The income fluctuation represents economic risk. Those, farming income risk caused by price fluctuation is easily evaluated. Therefore, the probability distribution of income can be estimated if the probability distribution of price of product is available. Furthermore, financial risk in terms of cash flow is also estimated at the same time. On the other hand, the amount of greenhouse gas (GHG) emissions from rice and tomato production is 14.7 ton and 3.9 ton, respectively. While the risk score of agricultural technology with chemical for human (RSTh) from rice and tomato production, is 9.00E+01 and 6.978E+04, respectively. This shows that by using these indicators, we can estimate the effects of the introduction of a new crop and/or technology on environmental risk. We can also compare farm plans from view point of environmental risk as well as economic risk.

Halberg et al. (2005) mentioned the following point. "Input–output accounting systems work best when linked to tools for production planning possibly used with the help of advisory services. This link may help to make it legitimate for advisors to address environmental issues in their contact with farmers." The procedure presented in Nanseki et al. (2009) integrates assessment of economic risk and environmental risk of farm production. The system developed is a system in which a farm planning system is linked to a kind of input–output accounting systems. The system will be evaluated by farmers and agricultural extension workers in future research in details.

An applicability of the system to Dominican Republic as an example of other countries is considered based in Nanseki et al. (2008a). The Dominican Republic-Central America-United States Free Trade Agreement (DR-CAFTA) was concluded in the Dominican Republic. It is expected that DR-CAFTA would have big impacts on rice farming and other crops in the Dominican Republic. On the other hand, vegetables, oriental vegetables, and fruits farmers would have much better access to export to USA. Therefore, a farm simulation and planning system such as FAPS-DB have to be tested and applied to adopt appropriate management decisions. Since vegetables and oriental vegetables farmers are facing the necessity of deciding which combination of crops and when to plant them, throughout the application of this system, these farmers will be able to pre-analyze and estimate quantitatively aspects such as profit, cost, required land resources, required number of machines, and cash flow for a specific planting period in every ten days (Nanseki et al., 2007a). Therefore, the application of a system such as the FAPS-DB in DR would be suitable for vegetable and oriental vegetables farmers.

III. SHORT TERM DSS : NOYAKU-NAVI AND FVS

Food contamination is one of the crucial risks for consumers. Bacillus and agrochemical are major source of food risk (Table 2). The food risk is not only hazardous to consumers, but also causes a revenue loss to farmers. In order to prevent miss applications of agrochemical, it is necessary to support appropriate decision making in agrochemicals use. This is a good example of applications of short term DSS in farming (Table 3). Therefore, Nanseki et al. (2004a, 2005a) have developed the Noyaku-Navi system.

In general, the purpose of the short term DSS is to support appropriate farming operation. This type of DSS can be also applicable to personnel training and succession of farming skill.

A. System Design and Development of NoyakuNavi

The Agricultural Chemicals Regulation Law in Japan was revised in 2003 because of the use of unregistered agrochemicals by some farmers. Whoever violates the law shall receive punishment of incarceration of no more than three years, a fine of no more than one million yen, or both (Tazou, 2003). Agrochemicals refer to the broad range of pesticides, feed additives, veterinary drugs and so on. Pesticide is agrochemicals for insects, plant pathogens, weeds, molluscs, nematodes microbes, etc. Standards for pesticide use have been revised a number of times in line with expansion of their application, thus becoming more detailed and complicated. In order to prevent carelessness miss applications of agrochemicals, it is useful to develop decision support systems for appropriate agrochemicals use applying ICT on prior risk management. In order to avoid agrochemicals residues, farmers have to be guided to use agrochemicals in correct way according to the use standard and record the agrochemicals use automatically.

Nanseki et al. (2004a, 2005a) have developed a prototype of the Noyaku-Navi system which is a navigation system to support agrochemicals applications according to the Agricultural Chemicals Regulation Law. The system is a warning system on inappropriate use of agrochemical and is automatic recording system of agrochemical.

Nanseki et al. (2006, 2007b) have developed a practical version of the system based on the prototype system. The system was designed to prevent incorrect pesticide application and record automatically used agrochemicals. The system aims at guiding and supporting correct use of pesticides by farmers. The system prevents pesticides misapplication in agricultural production. The first goal of the system is to enable farmers to prevent pesticide misapplication due to carelessness. The second goal of the system is to register easily and correctly the application records through automatic recognition of the agrochemicals. This is done by using bar-codes attached to the agrochemical containers.

This system has been designed to support actual business use on farms. The first advantage of the system is multi-stage and multi-standard judgment of proper agrochemical applications. The second advantage is prejudgment of agrochemical applications. The third advantage is semi-automatic and easy recording of 5W1H historical information on agrochemical applications. In the system, both mobile phone and OCR (optical character recognition) fill-in form are available for users as data inputs.

The main functions of the system are designed according to the stages of the individual standard plan, spraying plan, purchase of agrochemicals, application of agrochemicals, harvest, collection, shipment, distribution and sales. These stages are the points of risk management needed for a proper agrochemical application in the system.

B. System Evaluation and Extension of NoyakuNavi

A first version of the system was tested and evaluated in an actual business setting in Yamagata Prefecture. From August to October, 2005 an introduction and evaluations of the system was performed at JA Tendo with 620 pear producers. The Yamagata Prefecture Government supports them actively. The OCR fill-in form that the producer had filled in, the PC registration, mobile phone registration had been judged before pear "la france" was harvested. The risk management system for agrochemical use was successfully designed and developed. Effectiveness of the multi-standard and multi-stages judgment method was confirmed. Thirty producers used a mobile phone system though all producers registered OCR system.

69% of the farmers under 50 years old want to use mobile phone system continuously in the future. On the other hand, 73 % of farmers over 51 years old do not want to use. The reason is that the farmers under 50 years old are familiar with mobile phone.

The system was applied for cherries, apples, grapes, wetland rice, tomatoes, cherry tomatoes, spinach and cucumbers as well as pear in 2006. The system was introduced into several JA in Yamagata Prefecture. The new version of system is used by more than 16000 producers in Chiba prefecture and Nagano prefecture as well as Yamagata prefecture in 2010. Thus a nationwide extension of the system is expected.

The system can be applied to foreign countries. The share of agro-products exports of China to Japan accounts for more than 25 % for over ten years. Japan is the main importing country of agricultural products from China. However, export value of agricultural products in China yearly experienced loss of nearly 20% of total exports, valued at more than 1 billion dollars. This was caused by agrochemicals misuse and residue including pesticide and veterinary drug (He 2007). In order to prevent these issues, it is necessary to introduce decision support systems for appropriate agrochemicals use by applying ICT on prior risk management in China. Therefore, applicability of the Noyaku-Navi system is considered in Nanseki et al. (2008b). Farmer who exports their product to Japan is one of the candidates as user of the Noyaku-Navi system. They face a stricter use standard and Maximum Residue limits. For these farmers, the system gives them an easy way to guide them in pesticide use and record the use. The institutional systems of agrochemicals use standards in both China and Japan have similar structure recently. And the record of agrochemicals use can be the first step of traceability system and ensure of the national food safety.

C. Developemnt of FVS

The Noyaku-Navi system also semi-automatically registers details of the location where judgments are made and agrochemicals are used (5W1H) including images of pests made by a camera-equipped GPS mobile phone. On the other hand, FVS, farming visualization system, enables farmer full-automatic recording of 5W1H information of whole farming operation. FVS is designed to record and replay all the information of farming operations by combinations of several kinds of sensors including GPS, RFID, camera and microphone (Fig. 2). The system is applicable to support appropriate farming operation. Non-skill operator is able to learn farming skill based on recorded visual and audio data of skilled operator. The data of GPS gives exact location where operation is done. The data of RFID gives exact information of materials touched by skilled operator.

IV. Concluding Remarks

In this paper, an overview of the decision support systems was illustrated with their applications. The role of each system and their connections were also discussed from view point of time span of decision making. Firstly, FAPS-DB and FAPS were reviewed as example of long term DSS. We reviewed a procedure for integrated assessment of economic and environmental risk of agricultural production by the FAPS-DB system. Income fluctuation can be estimated as an indicator of economic risk. The amount of greenhouse gas emissions and risk score of agrochemical of a farm plan can be estimated as two of the major indicators of environmental risk. The integrated assessment of economic and environmental risk of agricultural production is able to draw characteristics of specific crop and farming systems. This information is useful for long term decision of policy maker, agricultural extension staff as well as for farmers.

Secondly, we reviewed Noyaku-Navi and FVS as short term DSS. Noyaku-Navi is designed to support appropriate agrochemical use and to reduce risk of miss-application of agrichemical. The system enables farmer semi-automatic and easy recording of 5W1H historical information on agrochemical applications. Although the OCR-based system is being widely adopted, the mobile phone-based system will increasingly take over in the future. FVS enables automatic recording of all the information of farming operations by combinations of several kinds of sensors including GPS, RFID and camera. The system supports appropriate farming operation and it can be useful for personal training to learn skill of farming.

In this paper, based on the time span in decision making, decision making systems are classified as long term DSS and short tern DSS. More applied studies of these systems in the world will be a future research topic.

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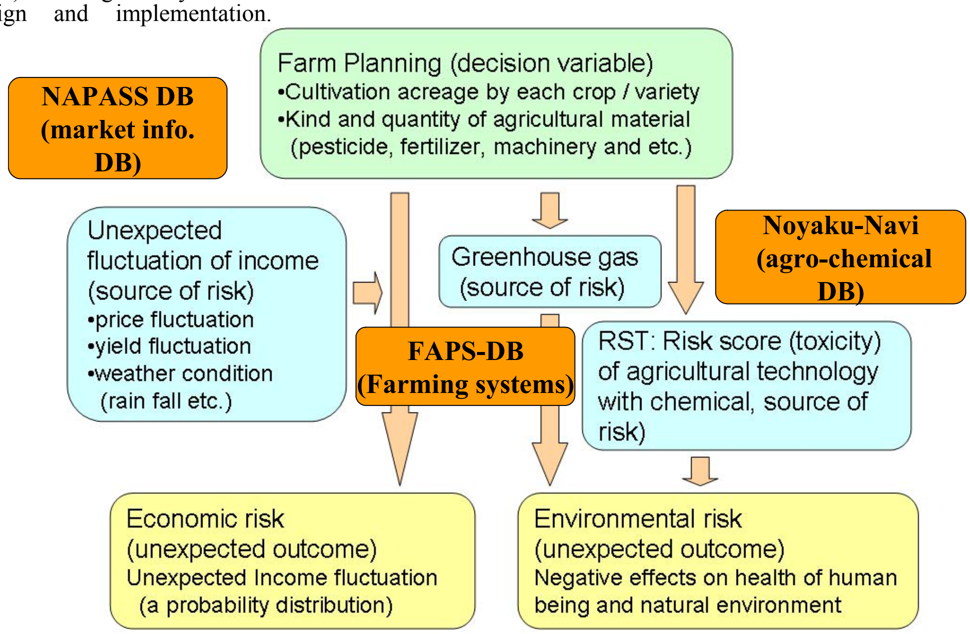

Figure 1. Assessment of economic and environmental risk based on farm plan

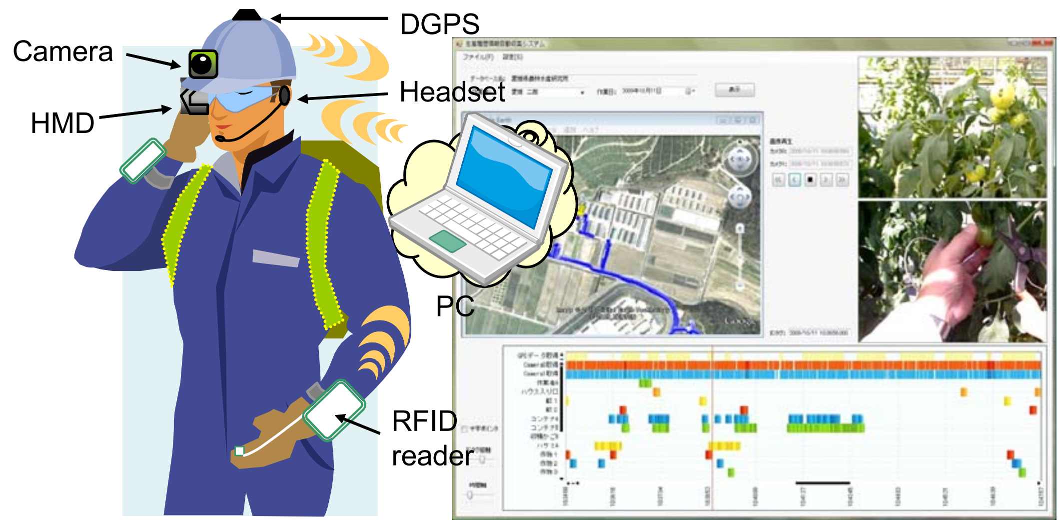

Figure 2 Image of FVS: Farming visualization system

Table 1 Long term and short term decision making

Type of decision making	Characteristics of decision making	Examples of decision making
Long term decision making	Decision making is done once one year or cropping season. The decision making has long effect in farming (e.g. more than one year or cropping season)	Optimal farm planning. e.g. farm size, crop conbinations, crop pattern, marketing channel and etc.
Short term decision making	Decision making is done several time in one year or cropping season. The decision making has short effect in farming (e.g. less than one year or cropping season)	Appropriate agrochemical use and other farming operation. e.g. machinery operation, fertilizer management, water management and etc.

Table 2 Economic, enviromental and food risk

Type of risk	Characteristics of risk	Example of source of risk
Economic risk which farm faces	Farm income fluctuation and loss of revenue	Price fluctuation, yiels fluctuation and quality fluctuation by pest, disease and weather condition. Unexpected rain fall which delays farming operation, illegal or miss-application of agrochemical, inappropriate management of crop, water and soil
Environmental risk which farm faces	Environmental contamination Global warming (climate change)	Contamination of soil and water Changes of yield, quality, cropping pattern and crops which can be grown
Environmental risk caused by farm	Environmental contamination Global warming (climate change)	Agromaterial use in farmin. Agrcochimecal, fertilizer, machinary, equiptment and etc.
Food risk caused by farm	Food contamination	Bacillus, agrochemical and etc.

Table 3 Decision making field and Decision support systems

Decision making field	Type of DSS	Related risk
Comprehensive farm planning	Long term DSS: FAPS-DB	Economic risk, Environmental risk
Optimal farm planning under risk	Long term DSS: FAPS	Economic risk
Appropriate agrochemical use	Short term DSS: NoyakuNavi	Economic risk, Food risk
Appropriate farming operation, Personnel training and succession of farming skill	Short term DSS: FVS	Economic risk, Food risk, Environmental risk