IT-Mediated Development of Sustainable Agriculture Systems

Toward a Data-Driven Citizen Science

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Abstract

Sustainable farming is facing an informatization challenge on the complexity of ecosystem dynamics. We introduced collective pervasive learning using web-based database on biodiversity and farming knowledge in polyculture system. The sharing of knowledge and data is shown to be effective both in understanding the behaviour of ecosystems and the management of vegetation portfolio in relation to local environment.

Keywords

Sustainable Agriculture; Pervasive Learning, Computer-Aided Assessment, Environmental Management Systems

Introduction

Agriculture is one of the central issues in sustainability of both human society and planetary environment [Barnosky 2012]. Several international organizations are raising alert in scientific reports to prevent further biodiversity loss and convert our socioecological systems to a sustainable design (i.e., [IAASTD 2009][MEAB 2005]). The arguments mutualy emphasize the importance of small holder farmers whose contribution to local economy, nutrition diversity, and environmental protection is underexploited (i.e., [HLPE 2013]).

IT based enhancement of small scale agriculture is recently emerging, and further develppoment is needed especially for the food security in developing countries such as India and China, with a large population of small-farm holders as substantial suppliers [Balga 2013][Zhang 2013].

Small farms usually practice with locally diversified methods, depending on the ecological, geographical and social contexts. The optimization of conventional large-scale farming such as precision agriculture is not necessary enough to treat such diversity of both environment and method (i.e. Traditional small practices do not usually involve machinery). Rather, the sharing of experience, farming options, ecological database, connection to market are required for better management on site.

For that purpose, the adaptation of e-learning, web-based learning, computer-based assessment, etc, should be more effectively integrated to support the management and education surrounding local agriculture.

Web-Based Learning and Enhancement of Sustainable Agriculture

Need of Pervasive Learning in Sustainable Agriculture

Small scale farming methods are usually owned by local social network, and the exchange of information is largely limited in oral communication and on-the-job transmission. The farming knowledge and underlying logic come from the practitioner's experience, and are sometimes unclear of scientific evidence. A person's experience is too constrained by time and location compared to the complexity of ecosystems. This is a societal burden for the sane development of locally adaptive farming methods, including the adaptation ro climate change.

IT based education and sharing of information can augment human knowledge, possibly to catch up with the ecosystems dynamics. For that purpose, an integrated design of pervasive learning is necessary to maximally profit from all aspects of farming experience as information source. Single technology such as computer-aided assessment and virtual e-learning is not sufficient to support the entirety of farming practice at the speed of need. Rather, the interface to connect between IT and necessities in farming should be integratively designed. The pervasive learning for small-scale agriculture should include open-access database with various kinds of media, web-based connection such as weblog and social network service, application software and tutorials for learning and sharing, actual exchange on farming site, and so on.

Synecoculture Experiment

Synecoculture Farming Method

We applied the methodology of pervasive learning for the management of Synecoculture method in Japan. Synecoculture is a small-scale polyculture system, producing a wide variety of vegetables, herbs, fruits, etc [Funabashi 2011]. Its challenge is to intelligently manage biodiversity of the field to profit from a variety of ecosystems function such as productivity, resilience, product quality, etc. Conventional methodology that produces environmental load is avoided, such as tillage, fertilizer, chemicals and machinery. Fig.1 and 2 show the experiment site of Synecoculture. It is based on a dense polyculture of edible plants, each species competing with others to form their niche in a state of ecological optimum. In such practice, the sharing of knowledge on biodiversity and farming strategy such as vegetation portfolio become essential for the management.

FIG. 1 Overview of Synecoculture Field

Left: Photo of the field. Right: Schematic segmentation of productive surface(greens) and fruit trees(oranges)

FIG. 2 Close View of Synecoculture Field

Left: Photo of 4 ㎡ productive surface. Right: Schematic segmentation of different kinds of vegetables (13 species).

The experiment was conducted principally in three different farms in Japan, in Tokyo, Kanagawa and Mie prefecture. Other individual-based participants also enriched the database and management procedure.

Database Structure

For the management of Synecoculture, we shared on the web the database necessary for the practice: Media files such as pictures and movies for the record of biodiversity and sharing of knowledge, lists of species taxonomy classification (32,567 plant species and 30,277 insect species from open-source database), association strategy of plants, productivity results, etc.

The database was augmented by linking related taxonomical and ecological information on SQL server(FIG.3). This enables users to search related information on the recorded species and practice, as well as identifying species without a priori knowledge on taxonomical classification. This design is important to overcome the trade-off between the accessibility and complexity of ecological information, as most biodiversity database is based solely on taxonomical classification and cannot be used in real time management of farming. The dual structure between taxonomy and media files realize search response speed scalable enough to the augmentation of data.

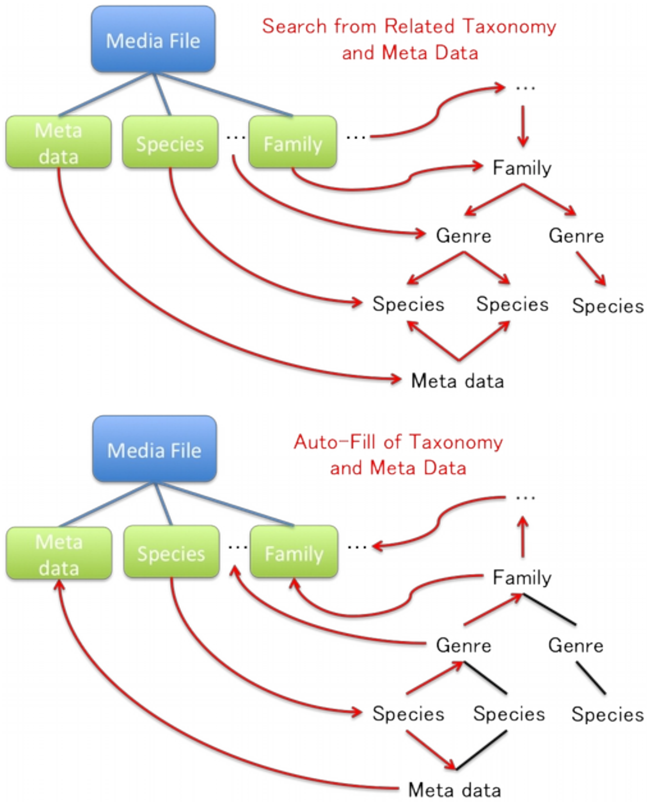

FIG. 3 Database Structure for the Support of Pervasive Learning in Synecocultue

Top: Search sequence of species name from related taxonomy and meta data. User can find species name from other information.

Bottom: Auto-filling of related taxonomical information and meta data. Registered species is automatically related with taxonomy and meta data specific to species.

Computer-Aided Assessment and Management

We have been developing the practice of Synecoculture for three years by gradually introducing the database system. Social network service and weblogs also supported distant communication and marketing. Communication with weblog played essential role in sharing knowledge with frequent Q&A exchange between farms. Especially, the sharing of information on the strategy of association of plants and the variety of harvest asynchrony in polyculture helped beginners'practice in distant region. As the database is fortified with the development of practice, more farming options were accumulated, reaching more than 300 variables playing roles in the management (FIG. 4). Such dynamic expansion of management knowledge inevitably require IT support, which in the future implies potentail application to a wider range of environmental condition.

FIG. 4 Example of Management Model Knowledge Structure

Candidates of management variables (nodes) and their dependencies in decision making (links) are depicted as a network.

With the collected database, we assessed and reconstructed the ecological network of the field(FIG. 5). The reconstruction helped to understand the functioning of each ecosystem agent in relation to the others, so that to discover the positive effect of weed and insects that are neglected in conventional method. This understanding lead to an increased knowledge on symbiotic relation between species, selective weed control, vegetation needed for pest prevention, etc. The biodiversity database attained about 20,000 field pictures with about 1,000 species recorded in three years (2010-2013). The IT supported recording of biodiversity and farming knowledge promoted a synergy between the practice, learning, and the development of the farming method. The knowledge construction coupled with the actual ecosystems' response may be further accelerated to attain sufficient speed needed for the adaptation to climate change.

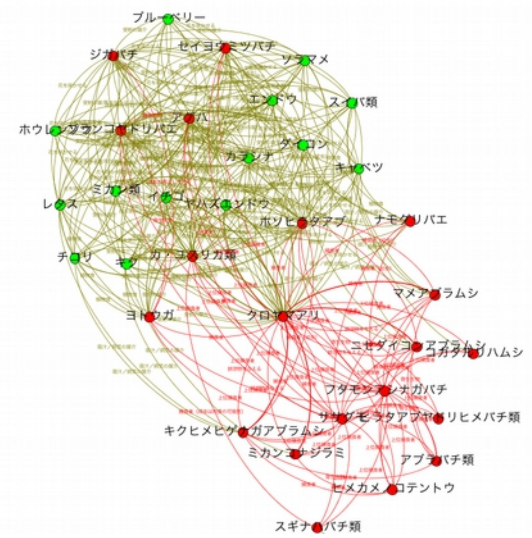

FIG. 5 Example of Reconstructed Ecological Network between Plants and Insects in Synecoculture Field

Green nodes: Plants, Red nodes: Insectes, Arrows: Interactions based on literatures

The marketing on weblog opened access to a wide range of potential consumer all over Japan(average 5,000 access per day on http://ameblo.jp/muu8/), and doubled the income per surface of an experimental farm compared to the adjuscent organic practice.

Database-driven Enhancement of Biodiversity

Synecoculture has various potential other than producing food. The contribution to local biodiversity is one of the positive effect that the culture can provide. The database and organization of pervasive learning can encapsulate wider range of activity surrounding agriculture, including ecological leveraging of local environment. To further investigate the validity of IT supported practice in ecosystems management, we experimented the enhancement of biodiversity in Rhopalocera species. An ensemble of literature on local vegetation, historical Rhopalocera observation records, information on the interaction between species and actual vegetation data of the farms were assembled on the database to give prediction on the possible Rhopalocera visit during the year 2012. With the use of database, we further introduced edible plants to maximally attract Rhopalocera whose habitats are observed in the region. The results showed high accuracy of prediction and effectiveness of vegetation control over the induction of insect fauna (FIG. 6). This result suggests the validity of data-driven citizen science framework on the enhancement of biodiversity in a systematic way.

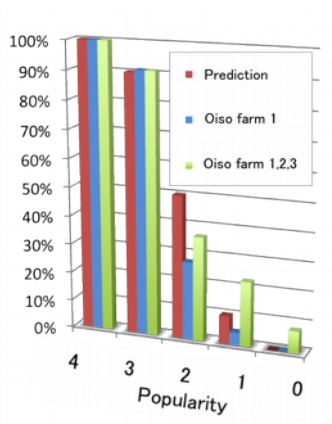

FIG. 6 Top: Examples of 27 Rhopalocera species recorded in Synecoculture Fields. Bottom: Prediction and result of Rhopalocera visit in Synecoculture Fields. Popularity ranks(0 - 4) and prediction rate(red bar) were defined using local ecological records and actual vegetation data. The results(blue and green bars) are the percentage of the accuracy of prediction in each subset of fields.

Conclusions

We developed an integrative framework for the collective development of small-scale sustainable agriculture with the use of database and web-based communication tools. The emerged design converges to a variation of pervasive learning, including mental, physical, and virtual aspects of communication and practice. We investigated the validity of this approach in the actual management and development of Synecoculture method, as well as the enhancement of biodiversity in local environment. The results were shown effective in data acquisition, sharing, assessment, knowledge discovery and propagation of farming options based on the functioning of biodiversity in the field.

The IT based enhancement of small farmers with environmental concern will further lead to a generation of citizen science in ecosystems management (http://unitwin-cs.org/), which is expected to mediate the emergence of boundary organizations important for the local governance to attain sustainability goals [Ehrlich 2012].

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ACKNOWLEDGMENT

The author acknowledges Takashi Otsuka for the development of Synecoculture concept, Hidemori Yazaki and Kousaku Ohta for the database management. The database was developed in collaboration with YUKAI engeneering inc. Other citizen-based Synecoculture practitioners invalubaly contributed to this work.

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