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PERSPECTIVE

INTERACTIVE KNOWLEDGE LEARNING BY ARTIFICIAL INTELLIGENCE FOR SMALLHOLDERS

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ABSTRACT
Enhancement of farming management relies heavily on enhancing farmer knowledge. In the past, both the direct learning approach and the personnel extension system for improving fertilization practices of smallholders has proven insufficiently effective. Therefore, this article proposes an interactive knowledge learning approach using artificial intelligence as a promising alternative. The system consists of two parts. The first is a dialog interface that accepts information from farmers about their current farming practices. The second part is an intelligent decision system, which categorizes the information provided by farmers in two categories. The first consists of on-farm constraints, such as fertilizer resources, split application times and seasons. The second comprises knowledge-based practices by farmers, such as nutrient in- and output balance, ratios of different nutrients and the ratios of each split nutrient amount to the total nutrient input. The interactive knowledge learning approach aims to identify and rectify incorrect practices in the knowledge-based category while considering the farmer's available finance, labor, and fertilizer resources. Investigations show that the interactive knowledge learning approach can make a strong contribution to prevention of the overuse of nitrogen and phosphorus fertilizers, and mitigating agricultural non-point source pollution.

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1 INTRODUCTION

Smallholders, who operate less than 2 ha of cropland, are the majority of the farmers in the world. Almost one-third of the global population depends on production on their small farms[1]. Issues for smallholders are always related to small size of their arable land, limited crop management expertise and resources including inadequate equipment, poor education and low income. Studies have shown that unreasonable fertilization practices of smallholders in intensive production areas in China have caused not only yield and income reduction, but also serious groundwater pollution and surface water eutrophication[2]. When land, labor and finances are limited, adopting scientific and technological innovations often has the most significant impact on production efficiency and income improvement for farmers[3]. However, the lack of extension systems in developing rural areas is the primary obstacle to smallholders learning new agricultural techniques. In this article, we discuss how artificial intelligent (AI) system and information technology present opportunities to develop new extension models for smallholders, using fertilization management practices as an example.

2 DIRECT KNOWLEDGE LEARNING

In developed countries and regions, farmers with large-scale farming operations and modern agricultural machinery primarily acquire new knowledge through direct learning. In many countries, state research institutes or universities develop best management practices. Recommendation for fertilization management, soil fertility maintenance, non-point source pollution control and others are published in periodicals, brochures and on internet, and are provided to and accessed by farmers. For fertilization management, for example, fertilizer nutrient requirements of major crops with different yield classes and soil nutrient status are suggested[4–7]. With a higher professional education background, large-scale farmers can read and understand these recommendations. They are also able to calculate and convert nutrient requirements into fertilizer prescriptions, which include fertilizer and manure resources as well as amounts for each split applications or topdressings during crop growing season.

Smallholders in developing rural areas cannot fully understand and follow the recommendation for crop nutrient requirements by themselves (Fig. 1). With limited education background, they have difficulty to distinguish the differences between crop nutrient requirements and fertilizer amounts. Generally, smallholders are not capable of converting crop nutrient requirements into fertilizer prescriptions on their own. Even brochures containing fertilizer prescriptions were distributed to them, smallholder farmers often set aside the expert-recommended prescriptions and continue with their previous fertilization practices. The common reasons for this include the unavailability of fertilizer resources listed in the expert prescriptions or their high cost. Additionally, the essential labor or equipment needed for the recommended split fertilizer applications during crop growing season may not be available.

3 PERSONNEL EXTENSION SERVICES

A learning pattern reliant on personal extensions services involves direct input from technical experts from extension institutions. Studies have shown that smallholders were more like to follow the best fertilizer management practice when given direct, on-site advice by professional technicians or researchers. Farmers tend to adopt the advanced fertilization management practices, when they witness the yield or income increases from field demonstration[8,9]. For cash crops, such as vegetables, flowers, and fruits, or intercropping systems, it presents a significant challenge for extension technicians to convert nutrient recommendations into customized fertilizer prescriptions for individual smallholders.

Firstly even in a small village, crops, fertilizers and labor resources available to farmers can differ significantly. For example, in the Dianchi Lake watershed in China, around 100 types of vegetables, flowers, and herbs are grown by 200 smallholders within about 70 ha of cropland in a village[9]. Secondly, due to market price fluctuation of crop products, fertilizer costs and weather conditions, farmers must adjust their fertilization practices from season to season. To convince farmers trust and adopt the expert advice, the extension

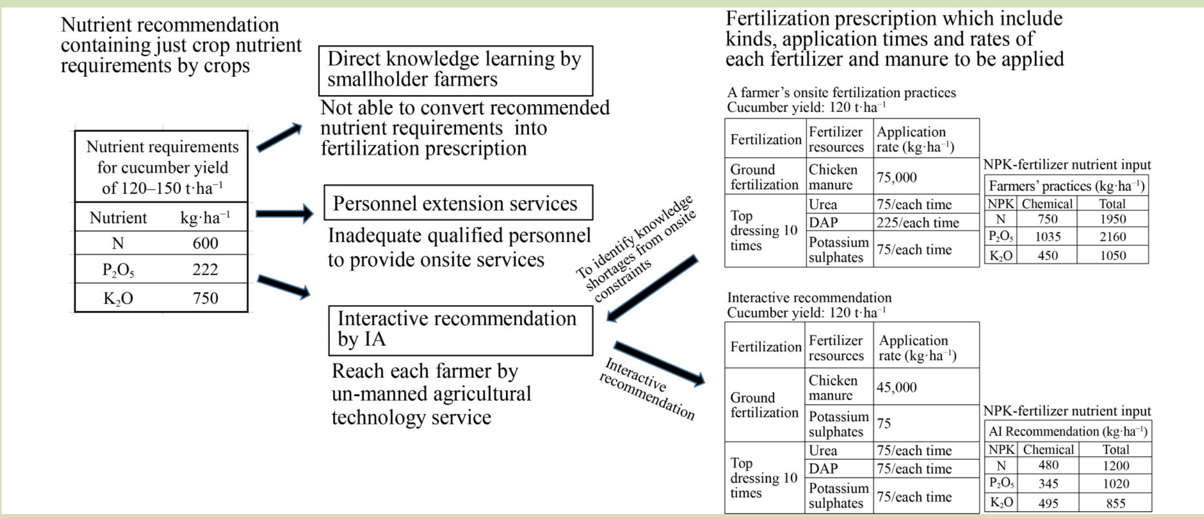

Fig. 1 Comparison of three patterns for fertilization determination.

personnel should be not only knowledgeable about nutrient management for different crops, but also highly experienced in the specific context including field on-site conditions and farmers' finance, labor and fertilizer resource constraints.

The main obstacle to effective personnel extension services is the lack of qualified extension personnel in rural areas. In many developing countries, even the extension systems have been organized and financed by states, there is often an insufficient budget and an inadequate number of qualified personnel to provide on-site technical services to farmers. In addition, in rapidly growing economies like China, it is still too expensive for smallholders to pay for commercial consulting services. Consequently, the mastery of advanced techniques by smallholders is limited and sparse. Although the best fertilization management practices and the balanced fertilization have been successfully demonstrated in China and in many developing regions since the 1980s, with considerable efforts made for dissemination through national or international programs[10,11], unreasonable and often excessive fertilization by smallholders is still common in China[12]. The challenge of providing personalized extension services to smallholders highlights the need for innovative solutions that can bridge the knowledge gap and ensure the adoption of sustainable fertilization practices.

4 INTERACTIVE KNOWLEDGE LEARNING

The interactive knowledge learning approach aims to provide farmers with a service that uses an AI system to replace the fertilization recommendation based on expert advice. The system consists of two parts. The first is a user-friendly dialog interface that allows individual smallholders or their family members to enter information about their current farming practices without needing assistance from professional technicians. The second part is the intelligent decision system, which integrated with 17 model assembles of 227 analytical models designed to simulate decision-making processes by professional technicians in on-site situations (Fig. 2). Functions of the main model assembles are listed in Table 1. Through integration of assembles, unmanned interactive recommendations can be achieved. The AI system is currently computer-based using the software package Harvest Geniuses. It is intended to also develop an application system that will run on a smartphone platform.

The system is equipped with a knowledge bank for macro-, middle- and micronutrient requirements of 300 field crops over a range of yield expectations in various regions, a database for available and potential nutrient supplies of 250 organic and mineral fertilizers, and a soil GIS database for available soil nutrient contents covering throughout China[13]. After receiving information about farmer fertilizer practices via the dialog interface, the decision system identifies the information into two categories. The first consists of constraints related to on-site field conditions for each individual farmer. Factors such as fertilizer resources, split application times and seasons are heavily influenced by the availability of manures, fertilizers, finances and labor resources, as well as weather conditions. Since constraints vary for each farmer and each year, predicting them accurately off-site is not feasible. Therefore, they are

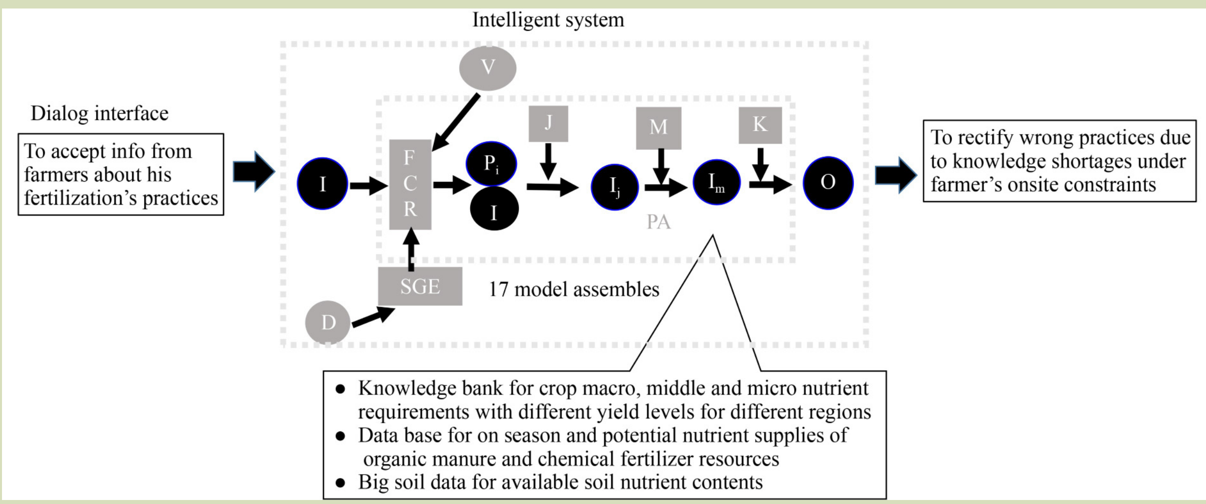

Fig. 2 The intelligent decision system integrated with 17 model assembles and the essential knowledge banks.

Table 1 Functions of the main AI system assembles

Assemble	Function
I	Farmers fertilization practice input data analyzer
C_{NPK}	Determining NPK requirements of crops
C_{mid}	Determining middle and micro nutrient requirements of crops
F	Evaluating on season and potential nutrient supplies of fertilizer resources
S_{NC}	Evaluating soil available nitrogen supply
S_{PK}	Evaluating soil available P & K-supplies
S_{pH}	Evaluating lime requirement
S_{mid}	Evaluating soil middle and micro nutrient status for the crop
S_{Last}	Evaluating nutrients left through the last crop
E	Evaluating effect of meteorological condition on fertilization
G	Evaluating effect of site specific conditions on fertilization
V	Regional parameter manager
R	Identification system (address wrong practice from knowledge depending category)
J	Rectified nutrient recommendation
M	Nutrient split application during crop growing season
K	Determining interactive fertilization prescription

defined as constraints with high uncertainty. The second category consists of knowledge that depends on farmer practice, such as nutrient in- and outputs by fertilization and crop harvest, ratios of different nutrients, ratios of each split nutrient amount to the total nutrient input during whole crop growing season. The goal of interactive knowledge learning approach is to identify and correct erroneous practices within the knowledge-dependent category while respecting the constraints imposed by farm resources including finances, labor and fertilizers. By adjusting and regulating application rates of manure and fertilizer resources for each split application, the AI system is able to provide tailored recommendations for individual farmers under the constraints of their specific on-site constraints.

For cases where farmers apply excessively high or low amounts of fertilizer nutrients, the AI-generated recommendations are not a one-time modification, but rather a gradual correction that ultimately approaches the expert-recommended amount in order to reduce the risk of yield reduction. As shown in Fig. 1, for cucumber yields of 120–150 $t \cdot ha^{-1}$, NPK fertilizer nutrient requirements recommended by research institution are 600 kg N, 225 kg P_2O_5 and 750 kg K_2O per hectare. The NPK nutrient input under current farmer practices was 1950 kg N, 2160 kg P_2O_5, and 1050 kg K_2O, respectively. The rectified recommendation by AI system in the first cropping year was 1200 kg N, 1020 kg P_2O_5, and 855 kg K_2O. This gradual correction over several years helps reduce the risk of yield reduction and improves farmer acceptance of the recommendations. The interactive knowledge learning approach offers a promising alternative to traditional extension services, enabling smallholders to access tailored fertilization recommendations that can lead to more sustainable and efficient agricultural practices.

Investigation involving around 3000 farmers from various provinces in China revealed that this interactive knowledge learning approach was preferred by farmers over a direct learning approach. This preference was particularly evident for cash crops or intercropping system with multiple vegetable and grain crops, the acceptance rate reached nearly 98%, while the direct leaning approach was lower than 2% among smallholders[14]. Field trials conducted in cropland with intensive fertilizer application in China showed that yield and income increased by 10%–30% using the interactive approach, compared to farmers normal practices, while fertilizer nitrogen and phosphorus inputs deceased by 20% for grains and 38% for cash crops[14]. In the heavily eutrophicated watersheds of China, cash crops are typically grown on more than 30% cropland[12]. The interactive learning approach, highly valued by cash-crop smallholders, can be crucial to preventing the overuse of nitrogen and phosphorus fertilizers, and alleviating agricultural non-point source pollution.

Fig. 3 Interactive knowledge learning approach can supply onsite recommendation to each smallholder farmer

The main advantage of an interactive knowledge learning approach is that it can be an effective substitute for personnel extension system through its use of a knowledge learning robot. To provide each farmer with on-site field recommendations, a countrywide extension system needs a vast number of qualified personnel and a correspondingly high budget allocation. The interactive knowledge learning approach supported by cloud computing can reach every farmer and village with access to internet and the mobile phone network. Through system development and knowledge bank updates by state research institutions, every smallholders in a country could directly receive and share the benefits from the state funded research projects (Fig. 3).

5 CONCLUSIONS

Enhancement of farming practices relies heavily on improving the knowledge available to and used by farmers. In the past, both the direct learning approach and the personnel extension system have proven insufficiently effective for smallholders. The important limitations in developing countries include the poor education smallholders preventing them learning directly from written materials, low financial resources and a deficiency of extension personnel in rural areas. This disconnect between extensive agricultural research achievements and their application in the field remains an ongoing issue. However, with this new approach, any smallholder with access to the internet or a mobile phone can easily obtain understandable and acceptable interactive recommendations tailored to their own economic, labor and resource context. As three-quarters of global poverty is currently directly or indirectly associated with smallholders, their learning is critical for reducing world hunger, poverty, and environmental pollution. The interactive knowledge learning approach offers a promising alternative to the established extension methods for providing agricultural advice.

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