Smart Farming – Open Multi-agent Platform and Eco-System of Smart Services for Precision Farming

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Abstract. The paper is addressing new challenges in agriculture, which are becoming nowadays critical for many countries, including climate changes, exhausted soils, aged farmers, etc. One of the new trends is associated with a step from Agriculture–4.0 focused on automation of physical processes for precision farming – to Agriculture–5.0 based on Artificial Intelligence (AI) for digitalization of domain knowledge and automation of farmer decision-making processes. A brief overview of existing IT systems for precision farming is given, key limitations are discussed and business requirements for developing AI solutions are formulated. The concept of digital eco-system of smart services for precision farming is proposed based on AI-technologies. The paper presents functionality and architecture of multi-agent platform and eco-system and identifies vitally important smart services for everyday operations of farmers. The structure and content of ontology-driven knowledge base for precision agriculture is considered, aimed at formalizing specifications of modern types of crops, agro- and bio-technologies, etc. The virtual "round table" is proposed as a generic framework for forming well-balanced recommendations for farmers with the use of ontology-based model of agricultural enterprise, which forms a specification of situation for automatic decision-making. Finally, the first case studies of the industrial prototype of the solution development are discussed.

Keywords: Precision farming · Multi-agent platform · Digital eco-system · Smart services · Multi-agent technologies · Ontology · Knowledge base · Decision making

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1 Introduction

Many countries in the world are now facing significant challenges in agriculture: climate changes, exhausted soils, aged farmers, growing demand for high-quality and safe food and ecology-clean technology of farming, low productivity and efficiency, shift to small farms, etc. One of the steps to address these challenges was Agriculture–4.0 focused on automation of physical processes, integrating in-field sensors, GPS control of machine positions, satellite image processing, etc. [1–3].

However, the growing complexity and dynamics in agriculture form the new trend of Agriculture–5.0 focused on Artificial Intelligence (AI) for automation of decision-making for farmers. New classes of AI solutions need to be supported by Knowledge Bases on products and modern agro- and bio-technologies, insects, pesticides and fertilizers, etc. It can also include a variety of AI-based technologies for adaptive planning and scheduling, pattern recognition, neuron networks and machine learning models and methods, big data and predictive analytics.

The objective of Smart Farming project is to provide open multi-agent platform and eco-system of smart services for development and application of new AI models, methods and tools for digitalization of knowledge and automation of decision-making processes in agriculture.

In this paper, we are developing the concept of open multi-agent platform and eco-system of smart services for precision farming, present the main functionality and architecture of smarts services that are now in progress, as well as results of the first case studies on solution delivery.

The expected result of developments is climate-oriented, ecologically friendly and economically efficient precision farming for worldwide applications.

2 Key Market Requirements

Food production in Russia [4] is a major export item (6%), its volume in 2017 rose to a record of \$20.7 billion (+21% compared with 2016). In 2017, grain exports from Russia also increased in this volume, and reached a record of 43 million tons. In the goods structure of grain supplies, wheat accounts for 74%, barley – 13%, corn – 12%, and other types – 1% (according to 2014 data). Russian grain is supplied to dozens of countries in the world with main consumers in North Africa and the Middle East.

However, more than 70% of Russia's agricultural lands is at risk: droughts, frosts, hail, freezing out of winter crops, strong wind and rain, waterlogged soil, etc. There is a steady increase in damage from dangerous weather phenomena: their number in Russia has increased by more than 2.5 times in the last 10 years.

In this regard, it is necessary to create climate-optimized, environmentally friendly and cost-effective crop production, which requires considerable financial investments, advanced knowledge and skills, training of specialists, etc. Another important task is reduction of losses in the chain of finished products: from purchasing and supply - to consumers (up to 25–40%).

Thus, a vitally important task is creation of smart systems to support decision-making by farmers with the following aims:

– assisting farms in introducing methods of precision farming and increasing productivity and efficiency of crop production;
– reducing costs along the whole chain of production, processing and storage of products by creating an e-market, eliminating intermediaries, etc.

To solve these problems, we propose development of methods and tools of artificial intelligence (AI), which support digitalization of knowledge and decision-making processes in daily operations of farmers at plant cultivating enterprises.

3 Overview of Existing IT Products for Precision Farming

Currently, the market has a wide range of information systems designed to solve various problems in precision farming [5–10].

The Russian company Agro-Soft, which is the distributor of the German company Land-Data Eurosoft, is engaged in implementation of precision farming using traditional information and space technologies [5]. Products of the Russian company GEOMIR are designed to create basic e-maps of fields, determine the actual boundaries of the field, generate yield maps, and keep statistics on harvesting [6].

The Canadian company Farm-At-Hand provides systems for monitoring the progress of field work: sowing, fertilizers and plant protection products, harvesting, and others. Information on the existing agricultural equipment (model, serial number, purchase price, maintenance) is stored in a smartphone. The system provides assessment of the state of the machine park, and monitoring of all purchases [7]. The Android MachineryGuide application, developed by Afflield Ltd., a Hungarian company, is a navigation software for even and precise sowing or field spraying. The application provides a visual field management, including cases of poor visibility and collection of statistics on results of operations performed [8].

The British company Hands Free Hectare has implemented full automation of all crop growing processes: from sowing - to harvesting. Machines are managed by technical staff from the control room. Drones with on-board multispectral sensors are applied [9]. In the Online farm management system of the American company Exact Farming the following functions are implemented: recording the history of using fields and monitoring their condition (field mapping, field card, vegetation index and NDVI maps, real-time control of the situation), and basic accounting functions controlling expenses for fields [10].

It can be seen, that all these systems are collecting huge amounts of data and help farmers to visualize the situation on the fields but no one of these systems is focused on digitalization on knowledge and automation of farmers decision making.

In last period of time, a number of new studies have been recognized focused on the use of ontologies and multi-agent technology in agriculture [11–13]. The mentioned developments present the first prototypes designed mainly for research objectives and helped to prove of concepts. Some of the systems aimed to provide recommendation services but no one can provide advice-based scheduling. In any case, even these first prototypes are showcasing the key benefits of ontologies and multi-agent technology for solving complex problems in agriculture by using domain knowledge, negotiations and self-organization of agents with conflicting interests.

Analysis of these systems leads to the following conclusions:

– the created multi-agent systems are mainly the first prototypes, which require further development for large-scale practical use;
– the described industrial IT systems are “closed” for accessing internal information and connecting new services;
– all discusses industrial systems are mainly informational, aimed primarily to collect data and provide routine functions with cost accounting;
– these systems provide data, but do not contain knowledge bases which are required for decision-making support;
– there are no models, methods and decision support tools for farmers which affect adaptive re-scheduling of resources;
– it is not possible to connect other services that will support the agro-chain and allow purchases, logistics, storage, etc.;
– there is no built-in market for products and services.

At the same time, the existing global information platforms, such as those of the Moncanta company, are not only closed, but also designed for use of only their own seeds, fertilizers, chemicals, etc.

4 Digital Platform and Eco-System of Smart Services

One of the key innovations of the proposed solution is the use of ontology-driven knowledge base for digitalization and formalizing of domain-specific knowledge and automatic decision-making based on the previously developed multi-agent technology for trucks and factories, supply chains, mobile teams, etc. [14–16]. Multi-agent platform provides the conceptual framework [17] for developing Smart Services (as a kind of “Internet of Everything”) for agriculture – where agents of services play the role of autonomous “digital twins” of fields, crops, fertilizers, insects, etc.

In the presented example (Fig. 1), the Agent of Satellite2 has recognized Event1 - problematic situation on Field3 (in red). Agent of Field3 has negotiated with Agent of Drone2 and Agent of Drone3 has requested for detailed inspections. As a result of inspection, Agent of Machine1 and Agent of Machine3 are allocated and scheduled for implementing precision farming technology for Field3 – for example, to bring more fertilizers and pesticides. These agents are designed as state-full software services, which can compete and cooperate on the virtual market of the agricultural enterprise and may differ by quality of services, availability in time and prices, etc. Two different satellites or three different fertilizers can compete for one field. Each smart service here can be represented by a decision-making machine with a container of all the necessary information and can work asynchronically with all other services.

The discussed concept of smart services is in match with the definition of digital eco-systems [18]: “A digital ecosystem is a distributed, adaptive, open socio-technical system with properties of self-organization, scalability and sustainability inspired from

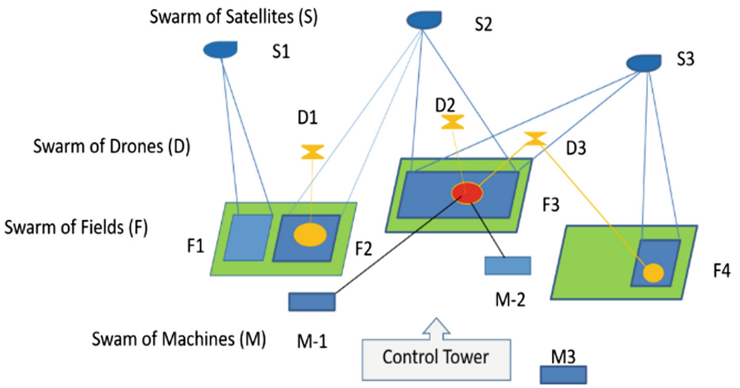

Fig. 1. The concept of multi-agent precision farming. (Color figure online)

natural ecosystems. Digital ecosystem models are informed by knowledge of natural ecosystems, especially for aspects related to competition and collaboration among diverse entities".

With the use of multi-agent platform, the digital eco-system for precision farming can be organized not as a traditional fully centralized, hierarchical, monolithic and deterministic solution, but as an open cloud-based environment available for any authorized third party developers: buyers of crops, providers of pesticides and fertilizers, universities, consulting and hi-tech companies, start-ups, associations of farmers, etc. The benefits of decentralized organization of decision-making systems are discussed in [15].

The developed eco-system will contain the following parts:

1. **Open Digital Platform for Eco-System support** – cloud-based software environment, in which software services are organized as "agents" – autonomous software objects, which are able to react to events, perform planning and control execution of plans but also coordinate their decisions by protocols of negotiations. The main parts of the platform will be memory storage for secure saving of big data and applying real-time analytics and forecasting, sessions of negotiations, enterprise service bus, etc.
2. **Knowledge Base on Precision Farming** – contains useful information on modern technologies of precision farming, specifics of soil, types of crops, required machines, fertilizers, insects, illnesses and receipts of treatment, pesticides, etc. The domain knowledge will be formalized with the use of agricultural ontologies based on semantic networks [19] for automatic decision-making processes by software agents and farmers, which can help specify the problem and find well-balanced solutions for farmers.
3. **Smart Fields, Smart Crops, Smart Fertilizers, Smart Soil, Smart Pesticides, etc**. – a number of software agents organized as smart services, which will monitor the state of their "owners", make plans and generate recommendations, negotiate results with other services and users.

4. **Service of "Round Table"** – agents of smart services are organized in a virtual "Round Table" for coordinated decision-making support and consulting for farmers. New unpredictable events trigger affected agents, which need to reach a new consensus by re-balancing their plans and coming to a conclusion on what to do in a new situation, consulting from the Knowledge Base of precision farming. Agents of services can compete and cooperate, suggesting different reactions for use of bio-technologies, fertilizers, pesticides, etc.
5. **Smart Agent of Farmer in Mobile Phone** – work as the farmer's agent (assistant) helping to provide adequate reaction to events, making planning and adaptive re-planning of agricultural operations, reminding about important stages of crop cultivation, advising on problems with the use of tablets or mobiles.

The objective of the digital platform and eco-system of smart services is to help farmers and agricultural enterprises improve everyday operations through recognition of problem situations and adaptive management of their resources, making next steps towards digitalization of their knowledge and all operations and direct communication with customers, providers of fertilizers and pesticides, machines, etc.

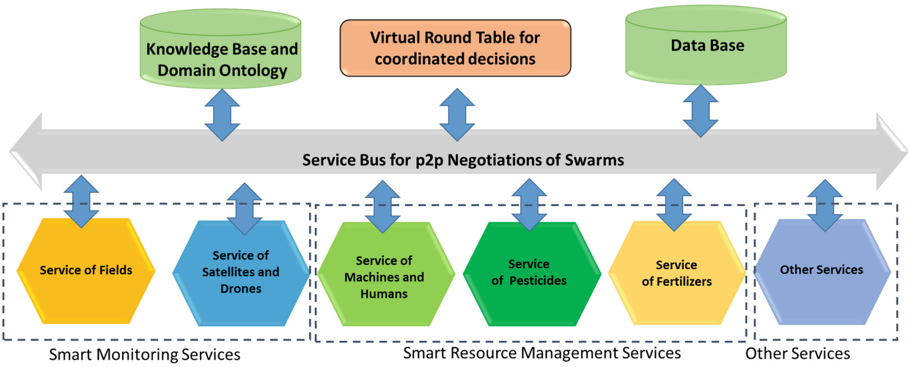

Fig. 2. Digital platform and eco-system of smart services.

As a result of the first developments, the following list of the most important smart services has been identified (Fig. 2):

– *Data Base on Farmers Fields* – supports full list of farmer fields with digital information on the history of all operations, boundaries and 3D-model of the profile of landscape, bio-chemical characteristics of soil, weather conditions, accumulated water and minerals, fertilizers and pesticides;
– *Smart Strategic Planning for Crop Rotation* – provides adaptive strategic planning of crop rotation for the new season, starting with sowing of crops and finishing with harvest of crops under conditions of weather forecast, available resources, etc.;
– *Smart Monitoring* – takes hyper-spectrum images of fields by satellites and drones and will try to recognize types of problems, including non-seeding, insect attacks, etc.;

- *Smart Operational Scheduler* – provides adaptive resource allocation, scheduling, optimization and control in real time, including machines and workers, mobile teams of agronomists and trucks, pesticides and fertilizers;
- *Smart Finance* – will compute planned and actual farmer budgets:
- *Smart Maintenance* – planning of machine repairing.

Agent of farmer could be connected with Institutions of Agriculture and Associations of farmers for individual consultancy and observing results and plans. It can also directly communicate with other farmers, receive consulting from them and to share knowledge and best practices across the community of farmers.

5 Virtual Round Table of Agents Representing Smart Services

A digital eco-system of smart services is created to work with the ontological model of each plant-growing enterprise, integrating data on the fields, their processing history, planted crops, available machinery, state of warehouses, etc.

The main idea of the digital eco-system is to enable services to compete for the customer and cooperate, i.e. complement each other. Users have the opportunity to choose configuration of services and pay for it by subscription. Each smart service is represented by an autonomously operating software agent, capable of reading and recording data in the ontological enterprise model and interacting with agents of other services through the common enterprise bus. As a result of analysis of requirements and business processes of the plant-growing enterprise, the following set of agent types has been developed (Table 1).

The virtual “round table” is a set of regulations for coordinated decision-making by service agents in the event of problem situations that simulates the work of farm specialists.

Design of the eco-system of smart services includes the following components in order to implement the concept of a virtual “round table”:

- Knowledge base for forming and making coordinated decisions;
- Digital platform for launching services and their communication, including data transfer bus;
- The Moderator Agent managing the course of negotiations, from setting a problem situation - to fixing the result of negotiations;
- Agents of smart services that can read scene data or record their results, as well as interact with each other according to protocols;
- Task panel, where smart services record tasks for solving and choose tasks for themselves;
- The scene with the formalized model of the problem situation, together with the developed action plan and the expected result;
- Business radars to assess the decisions made;
- Agent negotiation log that helps audit the decisions made.

Table 1. Agent classes at the "round table"

Agent type	Functions and goals
Field Agent	Determines the choice of the most appropriate crop for achieving field efficiency, taking into account preceding crops, soil types, relief and other factors
Crop Agent	Determines the choice of the most appropriate field for the plant variety and then - the order of operations for cultivation and control of process technical maps. The crop agent also generates tasks for agents of machinery, brigades, and monitoring
Plant protection product (PPP) Agent	Determines the type of plant protection products to be applied in the field. Plans technological operations for PPP application. Minimizes the amount of applied pesticides
Fertilizer Agent	Plans tasks from agronomist by types, order and timing of fertilizer application. Minimizes the amount of applied fertilizer in accordance with the technical process
Monitoring Agent	Determines the choice of satellites or drones for processing requests and possible delivery times for images, provides data on field surveys, determines field indices, identifies inhomogeneities in the fields
Agent of Pests (Insects) or Diseases	Based on the identified inhomogeneities in the fields and related parameters (weather conditions, calendar of disease development, proximity to a forest area, etc.), the agent tries to determine the most likely pests or possible plant diseases, determines the possible PPP type for treatment or insect control
Agronomist Agent (AA)	Plans crop rotation and determines crops for sowing in fields, controls the state of fields, determines technological operations for each field and plant
Brigade Agent	Forms, coordinates and monitors plan implementation for crop processing (plan for shift-daily tasks)
Machinery Agent	Generates the field processing plan, sets maintenance requirements, selects machine operators and machinery by specialization type, minimizes downtime
Machine Operator Agent	Plans working hours, and employment calendar as agreed with the Agronomist Agent
Staff Agent (Moderator)	Moderates the "round table", controls indicators set by the agronomist and supports the process of plan coordination by agents

Service agents solve their tasks based on their own target functions and functions of bonuses and fines, which reflect the degree of achieving the specified indicators in the virtual system market. Each agent, having reached certain values of indicators, receives or gives virtual currency. The system can impose fines on the agent and offer it some bonuses, as well as lend to the agent, allocating funds to it in order to improve its condition. The virtual "round table" (VRT) of service agents is created in the event of any problem situation arising from a significant deviation from the expected result. In the course of work, VRT can be replenished with agents of those services that are affected by the changes. Description of the situation in the form of a scene is available to all agents of VRT. Under control of the moderator agent, each agent analyzes the situation and makes its own proposal, which is recorded in the scene.

For this event, the next participant is activated according to the specified rules. Solution proposed by the agent and presented in the scene is analyzed by other agents, and the process is either continued with control transferred to the next agent, or a conflict occurs, understood as a contradiction between the goals, preferences and limitations of agents, for example, going beyond the season budget. In this case, the agent-moderator stops the process, identifies the agent that made the greatest contribution to the result, and asks it to "adjust" the proposal, for example, finding a different fertilizer that would be close in quality but cheaper. If there is a new solution and the conflict is resolved, the process continues. As a result, direct negotiations between agents provide conflict resolution by mutual concessions based on satisfaction functions and functions of bonuses and fines. Concessions can be made both by individual agents, and agents of the enterprise as a whole, when concessions of several individual agents give a general increase in the target function of the whole system. After resolution of one local conflict, new conflicts may emerge - such "movement" at VRT continues until all conflicts are resolved or, if there are no more options to solve the problem, control is transferred to the user of the corresponding agent. As a result, the problem solution that is coordinated with all agents and users is formed at the virtual "round table".

One of the possible agent interaction protocols of the virtual "round table" is shown in Fig. 3. The main idea of the method is to find an agent that provides a minimum value but requires maximum investments, and improve its position in a step-by-step way.

The proposed model of the virtual "round table" makes it possible to create and apply various AI methods and tools for elaborating and making coordinated solutions using tools of resource planning, big data analytics, forecasting, etc.

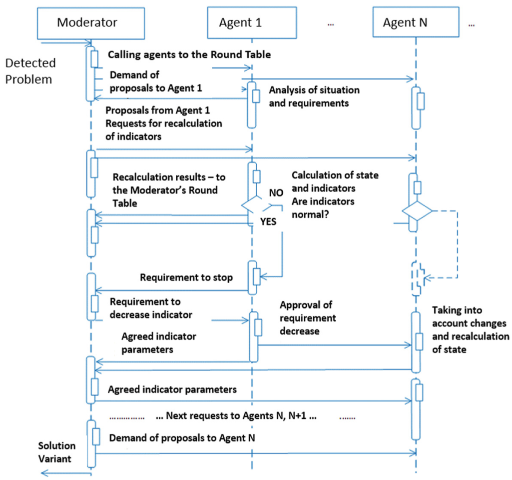

Fig. 3. Protocol of the virtual "round table".

6 Ontology-Driven Knowledge Base for Precision Farming

Benefits of using ontologies as a tool for knowledge digitalization and formalization in computer-readable format are well-known [20]. Agents receive from ontology the necessary domain knowledge and rules for decision making. The main reason of using ontologies in the considered solution is to digitalize and formalize required knowledge for automatic decision-making and separating domain knowledge from the source code of the solution [19]. The detailed overview of existing ontologies for agriculture can be found in [21]. The issue is that all these ontologies are not fully applicable for modelling of agricultural enterprise with the use of available resources – but it is critical for planning and scheduling.

The developed ontology of precision farming for wheat production is more focused on specifying the following main classes of concepts and relations:

- characteristics of climate zone and related sorts of crops;
- sorts of wheat and some other crops usually combined with wheat;
- types of precision farming technologies (No-Till for saving water, etc.);
- types of pesticides and fertilizers;
- types of illnesses and diseases, plant treatment;
- types of insects and their damages; when they appear, how to protect plants;
- sorts of soil, balance of minerals, agro-chemical attributes;
- classes of machines and technical tools and equipment;
- classes of farmers and their competencies;
- classes of spare parts, required fuel, other materials.

A fragment of the developed ontology for precision farming is given in Fig. 4, which defines the concept of “Task” – as the most important for scheduling tasks dynamically. With the use of ontology it becomes possible to create ontological model of the enterprise and specify available resources, problem situations, plans and schedules for everyday operations based on the formally defined concept of “Task”.

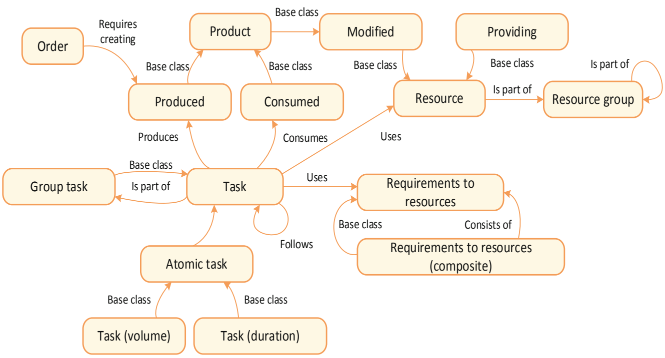

Fig. 4. Basic ontology of planning.

The proposed model of the virtual "round table" makes it possible to create and apply various AI methods and tools for elaborating and making coordinated solutions in resource planning, big data analytics, forecasting, etc.

7 Example of Work

Let us briefly consider an example of decision-making at the virtual "round table" in the created eco-system of smart services:

- The Satellite Agent identifies that one of the fields of the enterprise is problematic, with a new inhomogeneity.
- The Field Agent initiates task formulation to determine causes of the problem and develop action plans for its countering.
- The Drone Agent offers its service, preliminarily planning shooting.
- The agronomist receives the offer he can agree to. Next, drones with a hyperspectral camera perform remote survey of the problem area. The result is recorded in the Field Database - a data repository about the field.
- New images area initiate the task of recognizing the problem type.
- Plant Disease and Pest Agents are activated, which compete in their inputs.
- Let the pests be determined as the most likely reason of the problem situation.
- The Agronomist Agent schedules the agronomist's visit to the field for making decisions on the spot.
- When the agronomist visits the field, he discovers that the cause of the problem situation is different - under-feeding of plants.
- When the agronomist enters this information into the system, the Fertilizer Agent starts planning fertilization, taking into account available fertilizers.
- Agents of Machinery and Machine Operators reschedule their work.
- Machine operators receive new daily tasks on their tablets.
- The Field Agent records the event of finding the causes of the problem and working out measures of influence.
- The Field Agent sets the field for further monitoring and control in order to track changes and confirm the result.

Decisions on operational adjustment of field visits plans, made on the basis of remote analysis of crop condition from satellites or UAVs, are transmitted to the agronomist through a mobile application (Fig. 5), which allows him to view the field map in real time, as well as up-to-date information about fields and performed work, obtained from the knowledge base. The agronomist can also make marks and track changes via the event feed. The application has a client-server architecture, can work offline, locally saving the changes made, and upload them to the knowledge base when connecting to the network. Similar mobile applications are available for foremen and machine operators.

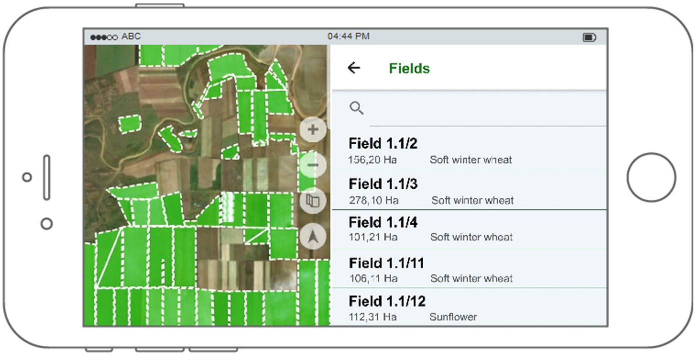

Fig. 5. Prototype of agronomist's mobile application.

8 Conclusion

The first prototype of Smart Farming platform and eco-system was developed and applied for one of the best wheat producers in Russia – Peschanokopskaya Agro Group (Rostov region) which includes three farming enterprises with about 30 000 Ha in total configured in 350 mosaic fields. The smart services for planning can help farmers develop plans for seasonal crop rotation and share limited resources across farm fields. As a result, efficiency of all operations has increased by up to 10% within the last 2 years. Productivity achieved in 2016 was 59,6 centner per Ha and in 2017 the growth was up to 64 centner per Ha, which is the best result for Rostov region.

The key innovations of the proposed platform and eco-system are based on the use of knowledge base and multi-agent technology for solving complex problems of adaptive resource management.

The next step in solution development will be to establish Smart Market-Place where key participants of agriculture industry can directly sell their products and services with the use of smart contacts, crypto-currency and block-chain technology.

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