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DIGITAL TECHNOLOGIES IN THE GRAIN SECTOR OF UKRAINE

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DIGITAL TECHNOLOGIES IN THE GRAIN SECTOR OF UKRAINE

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Abbreviations and acronyms

ACCU	Australian Carbon Credit Unit
CAP	Common Agriculture Policy
CH4	methane
CTF	Clean Technology Fund
CO_2	carbon dioxide
CO_2 eq yr^{-1}	CO_2 equivalent per year
EAFRD	European Agricultural Fund for Rural Development
EBRD	European Bank for Reconstruction and Development
EC	European Commission
EIP-AGRI	European Innovation Partnership for Agricultural Productivity and Sustainability
ERF	Emissions Reduction Fund
EU ETS	European Union's Emissions Trading Scheme
FAO	Food and Agriculture Organization of the United Nations
GCF	Green Climate Fund
GCL	green credit line
GEF	global environment facility
GHG	greenhouse gas
GIS	geographical information system
GNSS	global navigation satellite system
GPS	global positioning system
IFI	international financial institution
IPCC	Intergovernmental Panel on Climate Change
ITC	International Trade Centre
JRC	Joint Research Centre
KE	knowledge economy
LFI	local financing institution
MDT	Ministry of Digital Transformation
MRV	monitoring, reporting and verification
N	Nitrogen
N2O	nitrous oxide
NDC	nationally determined contribution
NDVI	Normalized Difference Vegetation Index
NH3	ammonia
OECD	Organization for Economic Co-operation and Development
PATs	precision agriculture technologies
PFI	public financing institution
PPP	public-private partnership
RDP	rural development programme
ROI	return on investment
RTK	real-time kinematic positioning
SCIG	Soil Carbon Industry Group

SME	Small and medium enterprises
SSAU	State Space Agency of Ukraine
TA	technical assistance
UAH	Ukrainian Hryvnia
VRA	variable rate application
VCS	verified carbon standard

Executive summary

In 2020 Ukraine exported USD 9.4 billion worth of cereals, the freight on board (FOB) value of wheat, maize, barley, oats and other grains under the HS 10 heading, becoming the second largest exporter after the United States of America (USD 19.3 billion in 2020) (ITC, 2021). With 15 million hectares under cereals, more than half of the total sown area in Ukraine (ITC, 2021), the grain sector is a pillar of the country's agriculture that contributes up to 30 percent of its output and to global food security. The sector has undergone a major transformation in recent years with substantial investment in grain production, storage, processing, transport and exports.

To effectively discern willingness and the barriers to adopting digital technologies, interviews took place with 479 independent grain farmers, as well as 10 agricultural holdings. The location of farmers included in the sample covers approximately 15-17 percent of the area under grain crops in Ukraine. This report outlines insights from the survey and the potential for digital technologies in the grain sector and the building blocks needed to sustain them.

The area using precision agriculture technologies (PATs) in Ukraine is already an impressive 8.4 million ha, 45 percent of the area used by commercial grain farmers or agricultural enterprises. More than 50 percent of farmers currently applying PATs are interested in investing further in these technologies and to facilitate this means addressing several barriers. A rough estimate indicates there is scope to introduce PATs on 3.8 million ha. of land. According to PATs market players, Ukraine's potential, including equipment and consulting services, is estimated at USD 100 million and expected to grow to USD 1 billion in the next five years.

More than 80 percent of Ukrainian farmers with more than 500 ha (approximately 85 percent of agricultural land in Ukraine) are interested in adopting PATs. The benefits from improving productivity, lowering production costs and greenhouse gas (GHG) emissions are well documented and although many farmers do have access to relevant benchmarks and business cases, limited understanding and acceptance of the evidence on economic returns and environmental benefits, especially for medium and small farmers, hinders the adoption of PATs in Ukraine.

Remote sensing also presents an opportunity in Ukraine. A pilot satellite monitoring project on agricultural land used to increase transparency and more efficient land management indicate satellite monitoring could contribute to the development of an agricultural insurance market, with an estimated potential of USD 50 million.

Globally, food system players increasingly use distributed ledger technologies (DLTs), especially blockchain, for traceability. Blockchain still remains novel in application and is often considered a strategic investment which can trigger a degree of organizational restructuring. Furthermore, introducing blockchain often requires in-house expertise or being able to leverage external knowledge. There are quite a few interesting initiatives from the private sector on using blockchain traceability.

While there are opportunities to adopt PATs in the Ukrainian grain sector, several barriers need to be overcome for sustainable adoption. Awareness, cost and access to technical support have a huge impact on producers adopting new technologies – digital and non-digital.

In 2018 the Knowledge Economy (KE) Index produced by the European Bank for Reconstruction and Development (EBRD) acknowledged that although Ukraine performs relatively well in skills for innovation, information communication technologies (ICT) infrastructure and innovation, it scored poorly on institutions for innovation (EBRD, 2019).

The institutional environment in Ukraine does not cater for full-scale deployment of the above mentioned technologies in grain farming and trade. A lack of policies and state support programmes, including public research and advisory services specific to these technologies, hinders their full adoption. This report explores other barriers including high investment costs, challenges in calculating returns on investments (ROIs) specific to PATs, lack of human capital and the digital divide between innovators such as large agricultural holdings and smaller farms. It recommends a series of enabling measures to support uptake of these technologies, both at farm level and institutionally and sheds light on ways to finance adoption of technologies.

BARRIER 1: INVESTMENT COSTS

Investment in precision agriculture technologies is expensive and increases with the precision and resolution needed to apply them. On a 10 000 ha farm in Ukraine the cost to upgrade farm machinery and equipment to measure parameters at a 10×10 metres precision level amounts to around UAH 413 000 (USD 15 200).[1] These costs increase to nearly UAH 3 million (USD 105 000) for sharper resolution at 1×1 metre precision level. They further increase to UAH 16.5 million (USD 606 000) where the farm uses additional technologies such as autopilots, fertilizers, yield measuring equipment, real time kinematic positioning (RTK, or base stations) reaching 0.1×0.1 metre precision. Most farmers in Ukraine using PATs prefer phased implementation: soil analysis, field maps, navigation systems, fuel control systems, parallel driving or autopilot. These deliver a quick economic effect without large initial investments, provided the appropriate agricultural equipment is available.

BARRIER 2: CALCULATING RETURNS ON INVESTMENT

The challenge to calculate returns on investments and a lack of benchmarks hinder farmers from recognising the benefits of digital technologies. This report shows farmers associate digital technologies, especially PATs, with high costs and they are unsure how to assess their potential benefits.

There are few limited national systematic analytical insights and benchmarks on applying precision technologies. Cases and estimates are largely unavailable for public analysis as technology integrators conduct most of them, mainly for marketing purposes. Since many farmers are unwilling to share applied details and economic estimates, information asymmetries limit the widespread adoption of technologies.

1 Cost references apply to 2018-2019 prices. The central idea of precision farming is the pixel optimization principle and specifically, maintenance of every pixel of land within the field based on measured parameters. Pixel size is determined by technology with the lowest resolution applied to that particular field.

BARRIER 3: HUMAN CAPITAL AND TRUST

The surveys showed lack of knowledge and poor understanding of the PATs concept hinders adoption. Large farms have better access to knowledge on emerging technologies than small farms, showing the divide between large farm "innovators" and small farm "conservatives" on technology adoption is gradually increasing.[2]

This report confirms larger farms are more ready to invest in digital agriculture technologies, particularly PATs, and possess the financial literacy to quantify adoption costs and benefits. Smaller farmers' risk aversion, fear of loss and lack of confidence in applying them limits their uptake.

The lack of professional personnel and dedicated outsourcing services also restricts widespread PATs' adoption. Current expertise is based on knowledge and experiences of local practitioners, technology providers and a number of universities and public research institutions. Findings show the majority of farmers have a negative attitude towards the involvement of third party service organizations to conduct the assessment and apply precision technologies.

BARRIER 4: LACK OF INCENTIVES

Although PATs have significant potential to reduce GHG emissions, the farmers surveyed do not prioritize environmental benefits. This report estimates that variable rate application (VRA) fertilizer alone can mitigate up to 2644 thousand tonnes of CO_2 equivalent per year (CO_2eq-1), about 19 percent of current application and emission levels. Given the cost of CO_2 emissions in the European Union Emissions Trading Scheme (ETS), EUR 24.8 in 2019 on average per tonne (Nissen *et al.,* 2020), by fully realizing its potential and incentivising farmers the climate mitigation potential from precision agriculture can amount to EUR 65.6 million per year.

BARRIER 5: DIGITIZATION OF VALUE CHAINS

Contract enforcement on grain pre-harvest, post-harvest financing, or sale remain a challenge in Ukraine. This is the case even for contracts that rely on government managed central registers (Agrarian Receipts, 2021) and financial instruments such as agrarian receipts or warehouse receipts (FAO, 2012; World Bank Group, 2019; FAO, 2015). Questions of legitimacy significantly undermine trust along the grain supply chain, making it a systemic issue for further trade digitalization. It also reduces use of distributed ledger-based smart contracts that could greatly improve product traceability (for sanitary and phytosanitary purposes) and further grain movement and trading, especially for value added tax (VAT) payments and export reimbursement. As most grain trading operations in Ukraine rely on paper documents or are informal, the grain industry and market regulators need to address the reasons for this "shadow" grain market, which some official sources estimate at about 20 percent of total sales, the equivalent of USD 8 billion at 2019 farmgate prices.

2 Small farms in Ukraine are considered legal entities with an agricultural area of up to 250 hectares; larger farms are considered to be 2000 hectares or more.

State support in Ukraine partially subsidizes agricultural advisory services and capital equipment, but this has yet to focus on digitalizing grain farming. The state partially compensates the cost of agricultural advisory services, up to 90 percent, with a maximum of USD 200 000 for the entire country in 2019 (Verkhovna Rada, 2018[3]).The Ministry of Economy, Trade and Agriculture compensates farmers with 25 percent of the cost of equipment purchases, the total funding for the programme was USD 16 million (Verkhovna Rada, 2018).

BARRIER 6: STRENGTHENING COLLABORATION

The application of remote sensing data for agricultural policymaking, as well as information dissemination to market players to remove asymmetries is limited, despite the fact that Ukraine can process satellite imagery for crop identification and yield forecasts. Assessment of satellite data on crop areas, prepared by the Space Research Institute of Ukraine, in cooperation with foreign partners, found only a few remote sensing applications reached cost efficiency thresholds (International Journal of Applied Earth Observation and Geoinformation, 2014).

The lack of a dedicated remote sensing agriculture programme to cement inter-agency coordination, cooperation in acquiring and managing remote sensing data, their processing, archiving and dissemination, greatly hinders market transparency. Improved coordination between the State Space Agency of Ukraine (SSAU) and end-users of remote sensing, for real time data availability, interpreting data, and enhanced satellite imaging of crop areas, conditions and yield forecasts are a priority.

OPPORTUNITY 1: SUPPORTING KNOWLEDGE TRANSFER AND HUMAN CAPACITY DEVELOPMENT

Technology providers can benefit from involving farmers in developing technologies and tools for precision and in wider testing. Exchanging information and experiences with other farmers through participation in conferences, exhibitions and field days are the most relevant and objective sources of information about the technology. Although there are cost efficient computer simulation models and analytical decision support systems, these are not sufficiently promoted, nor readily available to farmers, technology integrators, and researchers. It is important that models to test potential benefits are easy to use and based on practical decisions made in agriculture. Introducing training and integrating PATs into new or existing educational and vocational programmes can also be the key to success. Scalable business development and technical assistance that create value could increase technology providers' responsiveness to new markets.

OPPORTUNITY 2: BUILDING PARTNERSHIPS AND IMPROVING TRUST

Building partnerships between outsourcing institutions and PATs' integrators and investing in demonstrations could increase farmers' trust in using external knowledge and support. Rather than working with consultants linked with equipment or service suppliers, the investment attractiveness of PATs could be increased by developing research and extension institutions to give farmers access to independent knowledge and expertise. If sales companies

3 The Verkhovna Rada of Ukraine, often Verkhovna Rada or just Rada, hereafter Verkhovna Rada, is the unicameral parliament of Ukraine.

and integrators developed solutions for diverse farm sizes and revenue levels, this would give visibility on independently verified ROI estimates and contribute to greater awareness and understanding by farmers of the potential costs and benefits of applying PATs.

OPPORTUNITY 3: ENHANCING REGULATORY FRAMEWORKS TO FOCUS ON DIGITALIZING

Stronger regulatory frameworks and supporting an enabling ecosystem with conducive policies and incentives to facilitate uptake of innovation together with digital technologies can yield greater benefits. For example, fertilizer application will likely increase as Ukrainian farmers close the productivity gap with their European Union peers. Combining slow or controlled release fertilizers with digital technologies can curb the upward trend of emissions from increased use, while ensuring greater productivity. Funding and focus are needed to analyse how combining technologies with alternative fertilizers compares to application and results in other countries (for instance, in the European Union). This is important to consider when advising farmers on leveraging PATs to anticipate regulatory or market access changes, such as the European Union Carbon Border Adjustment Mechanism (CBAM) (European Commission, 2021a).

OPPORTUNITY 4: ACCELERATING DIGITALIZATION OF UKRAINIAN GRAIN VALUE CHAINS

The government should invest in accelerating digitalization of the Ukrainian grain sector. The Ministry of Digital Transformation (MDT) had a budget of USD 35 million in 2021 focusing on: (i) electronic identification; (ii) e-democracy; (iii) electronic trust services; and (iv) supporting electronic document management platforms.

An efficient public-private partnership, leveraging expertise and identifying frameworks and regulations to promote digitalization of Ukrainian grain value chains, will benefit all parties. Several international companies involved in selling agricultural products have either announced plans or begun testing various blockchain transaction systems.

OPPORTUNITY 5: USE OF REMOTE SENSING TECHNOLOGIES

A huge opportunity lies in remote sensing to enhance grain market and land use transparency. Several developed countries actively use data to monitor emergencies, to obtain information on crop areas and conditions, for environmental and crop monitoring and infrastructure projects. There are substantial gains from greater transparency and efficiency in land management. These include an agricultural insurance market in Ukraine, estimated at USD 50 million (Inter-Fax Ukraine, 2019) and measuring soil health conditions and changes in carbon stocks.

OPPORTUNITY 6: INNOVATIVE FINANCING TO ACCELERATE DIGITAL TRANSFORMATION

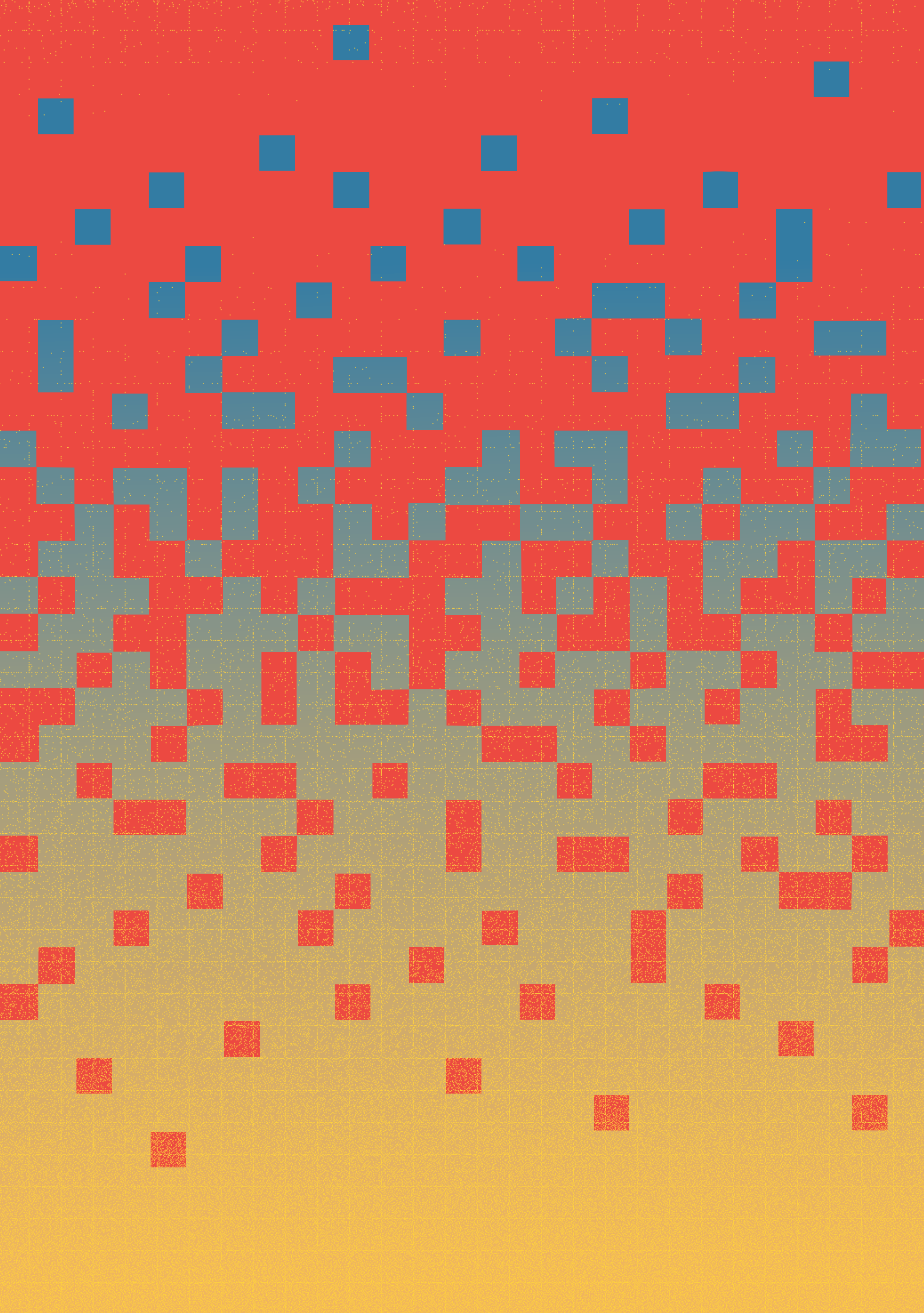
Innovative mechanisms will help overcome the challenges for farmers in obtaining finance which include high collateral and the cost of capital, as well as foreign exchange risks. While a number of digital transformation financing options exist, the focus should be on segmenting requirements for technology uptake by farm size, as field conditions, the heterogeneity of farms and the support required, will differ considerably. Although the total level of required private sector subsidization is unknown, it is likely larger farms can use their own resources to finance capital investments in digital technologies like precision agriculture. Smaller farms will likely require more support and incentives to qualify for carbon marketplaces, with the potential to compensate farmers for practices that improve soil health and reduce emissions.

OPPORTUNITY 7: LEVERAGING INTER-SECTORAL INCENTIVE MECHANISMS

Ukraine is not part of an ETS and has no voluntary carbon marketplaces. However, in preparing to join an ETS, the Ukrainian government mandated large industrial installations to monitor emissions from 2021 (OECD, 2020a). Carbon marketplaces specific to changes in agriculture offer above average prices compared to other voluntary carbon markets, since these credits are in demand and in short supply. Qualifying for a carbon marketplace can be costly and requires various steps. Green credit lines (GCLs) and international donor programmes can be used to finance adoption of technologies and the qualifications to participate in carbon markets.

GCLs can be leveraged to upskill the workforce on both large and small farms and to build an evidence base to justify investments that green funds can use to finance technology uptake. Most GCLs have focused on energy efficiency and renewable energy with few credit lines supporting adoption of digital technologies in agriculture.

The main local financing institutions (LFIs) in Ukraine (Ukreximbank, Oschadbank and Urgasbank) do not extend credit lines for adoption of technologies in the grain sector. The lack of GCLs for digitalizing agriculture is likely due to the limited evidence for their economic efficiencies and environmental benefits. With support from public financing institutions (PFIs) and international financing institutions (IFIs), LFIs can support the build-up of evidence to justify their adoption.



Chapter 1
Introduction to the Ukrainian grain sector

1.1 GRAIN MARKET DEVELOPMENT

The grain sector is a pillar of Ukraine's agriculture as it accounts for up to 30 percent of total agricultural output annually (State Statistics Services of Ukraine, 2021). The area under grain crops is about 15 million hectares, or more than half of the entire area sown (Figure 1.1) (ITC, 2021).

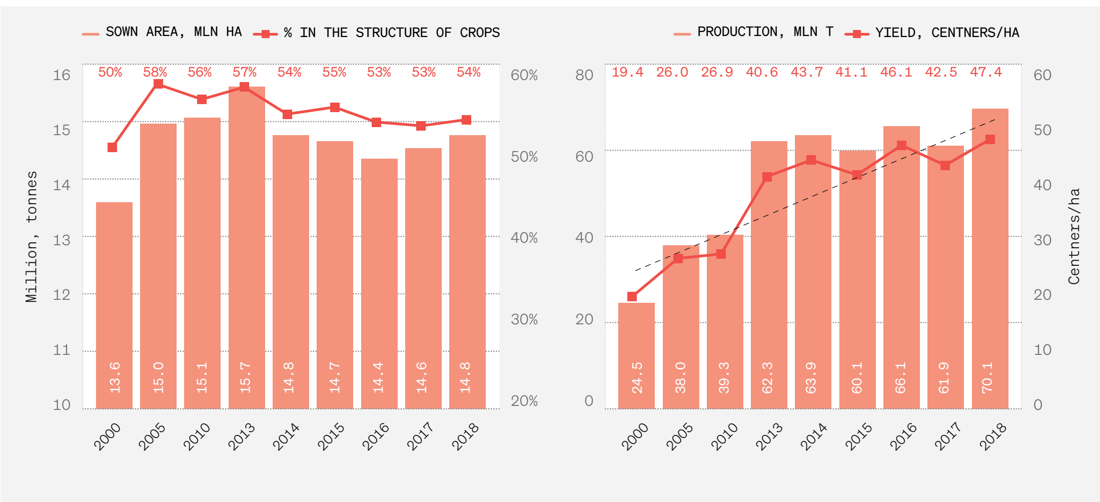


Figure 1.1
Grain production indicators

SOURCE: State Statistics Service of Ukraine, 2021. Available from: http://ukrstat.gov.ua/

Over the past decade, Ukraine has taken a leading global position in the supply of cereal crops and the sector has undergone profound transformation linked to reduced domestic feed and human consumption alongside strong export demand. In the 2018/2019 marketing year (1 July 2018-30 June 2019), net grain exports (wheat, maize and barley) reached 50 million tonnes. The total revenue from grain exports exceeded USD 7.2 billion – almost 40 percent of Ukraine's total agricultural exports. It is an outstanding result for a country that 20 years ago supplied the world market with an average of less than 5 million tonnes of grain per year (Figure 1.2) (State Statistics Service of Ukraine, 2021).

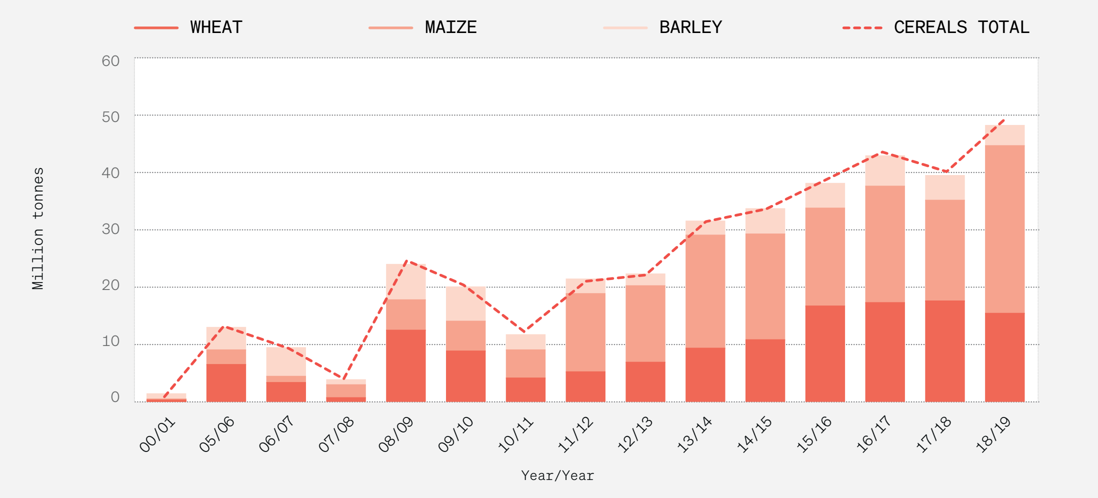


Figure 1.2
Grain exports from Ukraine in marketing years 2000/2001 – 2018/2019, million tonnes
SOURCE: State Statistics Service of Ukraine, 2021. Available from: http://ukrstat.gov.ua/

A number of other factors have also supported grain market development. The devaluation of the Ukrainian hryvnia (UAH) in 2014 improved its competitiveness and the country's natural endowments, including its rich, black topsoil, provide a favourable environment for crop production (Australian Export Grains Innovation Centre, 2016). Low supply chain and production costs[4] and proximity to key markets in the Middle East, North Africa and Europe have also given Ukraine an advantage (Australian Export Grains Innovation Centre, 2016). These factors, along with greater consolidation of farmers and investments in modernizing grain supply chains, have contributed to the steady increase in grain exports (Figure 1.2)

4 The Australian Export Grains Innovation Centre (AEGIC) estimated that in 2016 supply chain and production costs constituted 53 and 133.0 AUD/tonne, respectively in Ukraine, compared to 84.6 and 206.6 AUD/tonne in Australia.

There are no firm estimates of total investment in the grain sector. In 2010-13, EBRD and its private sector clients provided about USD 1 billion in financing to farmers and traders (EBRD, 2014). Updating agricultural machinery alone has cost USD 10 billion over the past ten years.[5] Along with investments in supply chain infrastructure they have allowed Ukraine to further capitalize on its natural advantages and low labour costs, which already support competitive grain exports. Modern farming methods are likely to further reduce the cost of production and improve yield stability. A significant factor that can further develop the grain market is the widespread use of digital technologies, transforming the current maximum yield production model into a more flexible management one, which cuts costs without reducing yields.

1.1.1 Mid-term outlook for sector development

Ukraine has no national medium or long-term grain production forecasts, nor for consumption and trade. According to the OECD-FAO Global Outlook, compared with 2018-19 estimates (68.6 and 68 million tonnes for 2018 and 2019, respectively), grain production (maize, wheat and other coarse cereals) may increase by 15 percent to 78.8 million tonnes by 2028. Using the 2018-2019 estimates (47.8 million tonnes for 2018 and 46 million tonnes for 2019), grain exports are estimated to increase by 19 percent to 56 million tonnes (see OECD and FAO, 2019).

The Ukrainian Grain Association, which represents all major grain and oilseed traders, is more optimistic and expects by 2024, production will exceed 100 million tonnes, including 80 million tonnes of grain. Given the limits to expanding acreage under cereal crops, this growth in grain will only be achieved by further crop intensification and digital technologies to increase production efficiency.

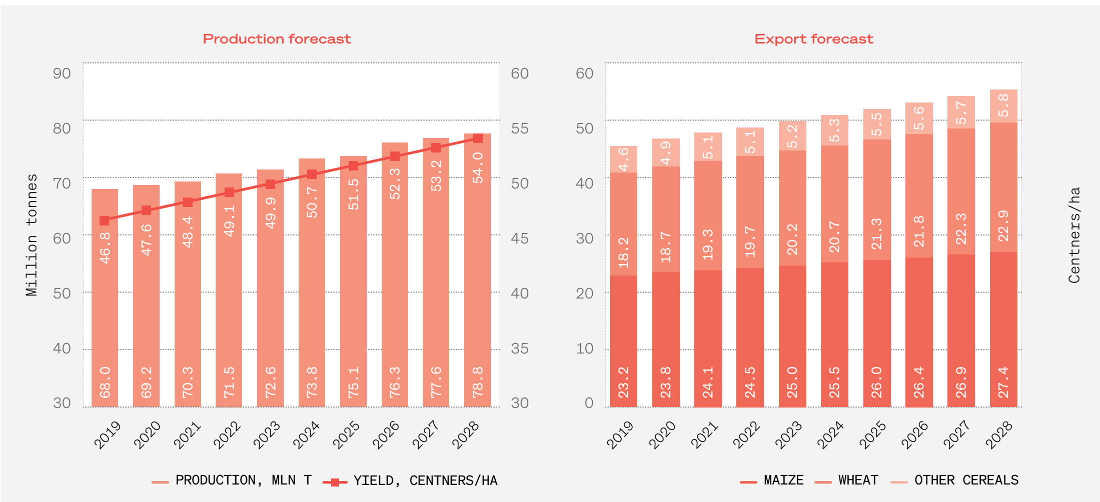


Figure 1.3

Baseline and forecasts for grain production and exports in Ukraine

SOURCE: OECD and FAO. 2019. *OECD-FAO Agricultural Outlook 2019-2028*. https://doi.org/10.1787/agr_outlook-2019-en.

5 Based on estimates made by the authors using State Statistics Service of Ukraine. 2021. Available from: http://ukrstat.gov.ua/

1.2 GRAIN FARMING STRUCTURE

In 2018 around 33 000 commercial farms (registered as legal entities/enterprises) cultivated cereals in Ukraine in addition to small commercial and household farms. Although the category of small commercial farmers, those with agricultural land up to 250 hectares being the most numerous, this accounts for only 4 percent of total grain production in Ukraine (Figure 1.4).

Figure 1.4
Grouping of grain farmers, 2018

SOURCE: Authors' calculation based on State Statistics Service of Ukraine, 2021. Available from: http://ukrstat.gov.ua/

Farmers often lease out their land to commercial operators rather than farming it themselves. Consequently, most medium to large farm operators lease rather than own the land they farm (Australian Export Grains Innovation Centre, 2016). The model of grain and oilseed production by commercial farms on rented land will likely remain even after Ukraine lifted a decade long moratorium on agricultural land sale in July 2021. The performance of agricultural holdings that join more than one commercial farm need to be considered. According to the first study on agricultural holdings, in 2007 there were 20 agricultural holdings in Ukraine, controlling about 1.7 million hectares of farmland or 11 percent of the total area used by commercial farms (agricultural enterprises) (Lapa and Lissitsa *et al.*, 2007). By 2019, according to the authors' estimates, there were more than 100 agricultural holdings in Ukraine, working about 5.6 million hectares, or almost 28 percent of the land farmed by agricultural enterprises. Between 2010 and 2018, the share of agricultural holdings increased from 10 percent to 20 percent of farmland and by 2018, the share of agricultural holdings in total agricultural output was 23 percent (UCAB, 2019).

1.3 CHALLENGES TO THE GRAIN SECTOR

The institutional environment in Ukraine is to a large extent not conducive to innovation and digitalization. This is supported by the Knowledge Economy (KE) Index produced by the European Bank for Reconstruction and Development (EBRD), used to measure the extent to which innovation and access to information drives productivity growth. The KE Index is based on four pillars (EBRD, 2019): (I) institutions for innovation (economic openness, business environment and governance); (ii) skills for innovation (general and specialized); (iii) innovation system (inputs, outputs and linkages), and (iv) information and communications technology (ICT) infrastructure (availability and sophistication). The index measures how EBRD regions and eight Organisation for Economic Co-operation and Development (OECD) comparators are fostering KE. It shows that although Ukraine performs relatively well in skills for innovation, ICT infrastructure and innovation system, it scored considerably worse on institutions for innovation (Verkhovna Rada, 2018). This score indicates the current institutional environment, through property rights, a particular judicial system and public governance, do not sufficiently support innovation-intensive industries.

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Chapter 2
Digital technologies in the grain sector

This report focuses on three sets of technologies: precision agricultural technologies (PATs), remote sensing technologies and distributed ledger technologies (DLT), with a particular focus on blockchain. It focuses on precision agriculture, as a set of technologies to be applied to grain farming with the potential to generate economic efficiencies and environmental benefits. Remote sensing technologies can be leveraged to monitor, measure and disseminate information on crop and soil conditions and blockchain technologies can increase the transparency of grain trade and ensure traceability.

A supporting institutional environment for digital technologies in the grain sector, to make it more competitive without compromising on productivity, is largely lacking. As elaborated in Chapter 2, significant differences exist between smaller farms and larger ones, in terms of human, financial and digital capacities and willingness to innovate and adopt digital technologies. Small farmers are also likely to face greater challenges in access to finance, restricting their investing in improvements.

This report recommends a series of enabling measures to support the uptake of these technologies, at farm level, but also institutionally, shedding light on ways to support adoption of technologies financially.

2.1 AGRITECH IN UKRAINE

According to the AgTech Association in Ukraine, there were about 70 agritech start-ups at different stages of development and various phases of activity in the Ukrainian market along with various technology integrators representing leading international developers. The annual investment in Ukrainian agritech start-ups did not exceed USD 4 million in 2018 (National Investment Council of Ukraine, 2018).

National and foreign private investors and accelerators have shown a growing interest in Ukrainian agritech start-ups. In 2014, KM Core[6], a Ukrainian information technology (IT) company, invested USD 1.2 million in eFarmer,[7] a precision farming start-up. In 2016, Agrieye,[8] a producer of multispectral cameras for remote sensing and soil analysis, raised USD 150 000 from angel investors and received USD 200 000 from the Norwegian Katapult Accelerator[9] (National Investment Council of Ukraine, 2018). Kray Technologies, a developer of unmanned aerial vehicles for spraying crops with plant protection products and growth regulators, obtained a grant from the United States of America Civilian Research and Development Foundation in 2016. The company attracted a further USD 600 000 from investors, including Ukraine-based Chernovetskyi Investment Group in 2017 (National Investment Council of Ukraine, 2018). Of notable interest, is the growth of the domestic start-up ecosystem for business accelerators and venture capital companies within the agritech industry, including the AgroHub, which brings together national start-up accelerators, co-working spaces, international hubs, international and national companies, financial institutions, knowledge brokers and the media. The main objective of AgroHub is to close the gaps between start-ups and corporate companies and to harness talent and innovation (National Investment Council of Ukraine, 2018). Figure 2.1 maps out the main market players in the Ukrainian agritech industry in 2018.

Large Ukrainian agricultural holdings have increasingly shown interest in becoming involved in proprietary and joint agriculture-based technology projects. The UkrLandFarming[10] cooperates with the FarmQa[11] company based in the United States of America on soil density management. Kernel,[12] a large agricultural holding collaborates with several other domestic and foreign start-ups specializing in drone solutions. MHP,[13] the largest poultry producer, is developing a number of innovations, including the GeoInformation System project, which collects, processes and visualizes all data related to farmland management (National Investment Council of Ukraine, 2018).

6 K M Core Ukraine. 2022. [online], Kyiv. www.kmcore.com/uk
7 eFarmer. 2022. [online] Amsterdam. www.efarmer.nl
8 Agrieye. 2022. [online]. Kyiv. www.f6s.com/agrieye
9 Katapult. 2022. [online]. Oslo. https://katapult.vc/startups/accelerators
10 UkrLandFarming. 2022. [online]. Kyiv. www.ulf.com.ua/en/
11 FarmQA. 2022. [online]. Fargo, North Dakota. https://farmqa.com/
12 Kernel. 2022. [online]. Kyiv. www.kernel.ua/
13 MPH. 2022. [online]. Norwich. https://mhp.com.ua/en/pro-kompaniu

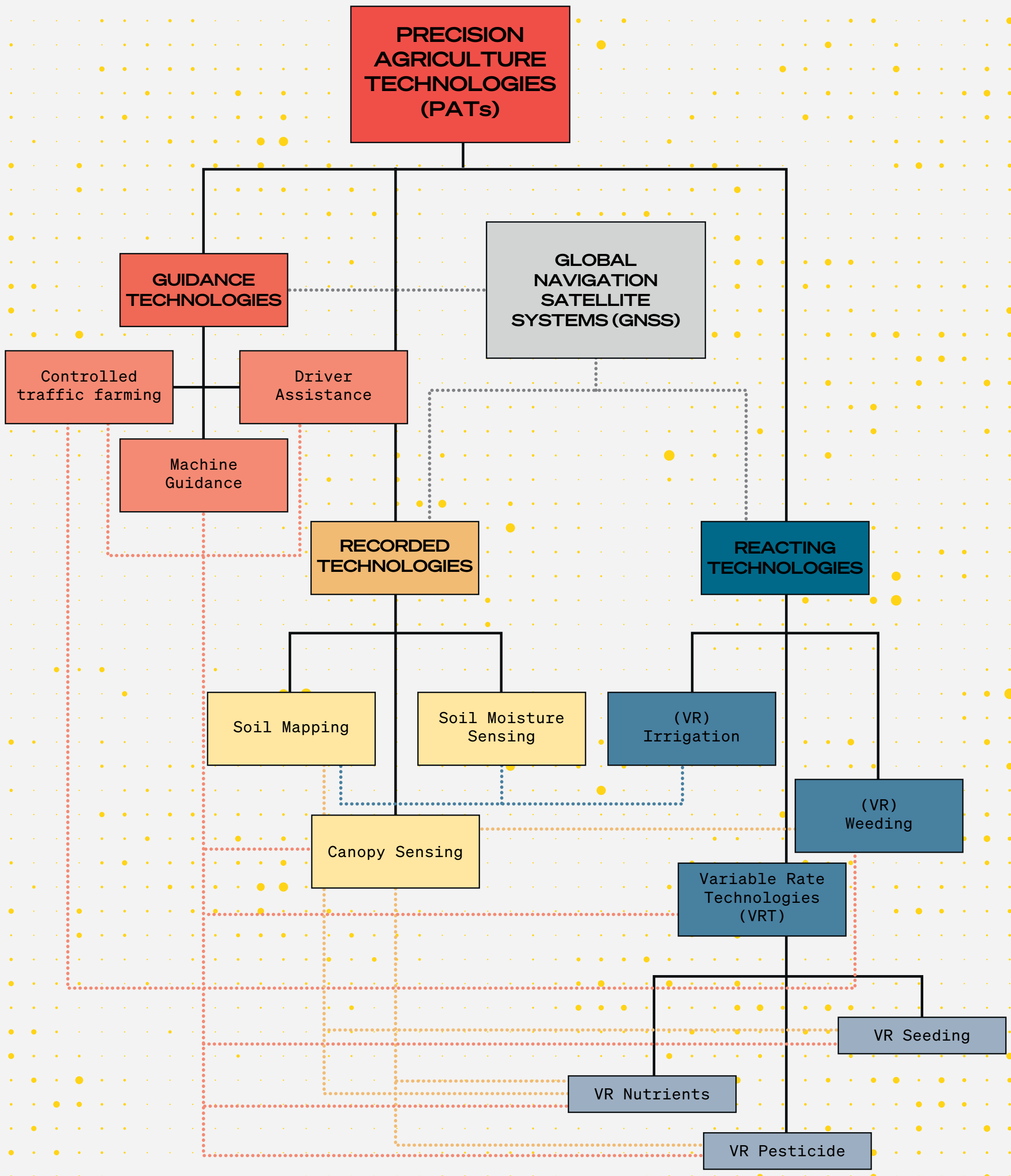
Figure 2.1
Agritech market map in Ukraine

SOURCE: AgriTech Unit. 2017. Ukrainian agritech industry guide.
http://agritech.unit.city/guide/f98ewf9fewfw/AgriTech_Industry_guide_en.pdf

2.2 PRECISION AGRICULTURE TECHNOLOGIES

The concept of precision agriculture is based on spatial inequality in the content of mineral and organic matter, soil moisture and its compaction, acidity and other variables that determine its fertility within one field. PATs are a set of data-driven geographical information system (GIS) technologies designed to maximize the use of every land parcel across a field, manage soil productivity and optimize costs. Using spatial locations, GIS integrates many different kinds of data layers including imagery, features and base maps (Soto *et al*., 2019).

Precision agriculture involves the modular use of a wide range of different equipment and technologies, with each element integrated depending on the goals and tasks set. Modularity is the fundamental difference between PATs and other innovative agricultural technologies, the use of which involves a list of equipment and guidelines. As illustrated in Figure 2.2, PATs rely on global navigation satellite systems (GNSS), which through different means, control guidance, recording and reacting technologies. The precision of technologies as well as the extent of their integration determine the effectiveness of PATs, as each level of technology is based on the previous one. Consequently, every step in precision farming integration is likely to generate additional value, requiring trials and adjustments at each implementation stage.



NOTE Solid black lines show the main precision technology types; red dotted lines indicate how guidance technologies serve other technologies; orange dotted lines are recording technologies and orange and green dotted lines show the relationship between recording and reacting technologies.

Figure 2.2

Mapping of precision agriculture technologies

SOURCE: Soto, I., Barnes, A., Balafoutis, A., Beck, B., Sanchez, B., Vangeyte, J., Fountas, S., Van der Wal, T., Eory, V. and Gomez-Barbero, M. 2019. The contribution of precision agriculture technologies to farm productivity and the mitigation of greenhouse gas emissions in the EU. Luxembourg, Publications Office of the European Union, ISBN 978-92-79-92834-5, doi:10.2760/016263, JRC112505

Technologies, such as agrochemical soil analyses, special sensors, aerial and satellite imagery of the field surface, assess field variability. Canopy maps produced using crop sensors detect the characteristics of the crop canopy, provide information on crop quality and growth and can estimate final yields. Yield mapping refers to collecting georeferenced data on crop yields and yield characteristics (such as moisture content) during harvest (Soto *et al.*, 2019). Using information from canopy and yield maps, software solutions and algorithms aggregate, analyse and visualize data to help farmers make more effective decisions about sowing, fertilizing, use of plant protection products, routes for moving equipment, etc. Software connected to precision farming equipment allows farmers to make informed management decisions to generate economic efficiencies. Software connectivity is essential to precise commercial solutions as well as variable rate application (VRA) technologies. The European Commission's Joint Research Centre (JRC) defined the functions of different VRA technologies, these are outlined in the Glossary.

Various technical advances have supported the wider application of PATS. These include improved GIS software and pixel optimizations, through technologies such as remote sensing. Pixel size is determined by the technology with the lowest resolution applied to a field. For instance, field zoning provides 250 × 250 metre resolution, basic VRA maps offer a resolution of 30 × 30 metres, while more precise VRA maps can provide 10 × 10 resolution. Drone imaging is more suitable for plant-based decision-making (Petruk, 2020) and increasingly, new satellites provide free, or affordable high quality data at field level. Novel machine-learning methods are being applied to the number and location of fields selected for crops, to reduce costs, while accurately predicting yields. These advances have led to wider availability of commercial data. Further progress in farm management systems has made it possible to integrate data from the ground and analytics help shape management decisions. Improved connectivity between farm management systems and advanced automation allows for greater field level decision-making.

2.2.1 Applied estimates on PATs' effectiveness

In Ukraine, as well as globally, there are no analytical insights to estimate the effectiveness of applying PATs nationally. This has resulted in the absence of benchmarks for farmers to evaluate potential costs and application benefits. Individual estimates of the effectiveness of technology application are largely unavailable for public analysis, as most were conducted by technology integrators. Integrator companies use these benchmarks to market their own products and services, similar to farmers using PATs. Most are not ready to share details and economic estimates, limiting the broad penetration of technologies. It is possible to overcome these information asymmetries, especially in benchmarking PATs against environmental indicators and targets.

Unlike Ukraine, the United States of America is one of the main countries driving PATs development globally with numerous analytical solutions to their application that are open to the public. For 20 years Purdue University has conducted regular surveys on PATs' integrators, one of the most comprehensive and continuous reviews of their evolution (Purdue University, 2017). The Economic Research Service of the United States Department of Agriculture (USDA-ERS) has assessed penetration levels and the economic efficiency of individual PAT technologies (USDA, 2016).

The Joint Research Centre (JRC) of the European Commission has collected cost benchmarks on various technologies outlined in Annex I: Indicative costs of precision agriculture technologies (Soto *et al.,* 2019). Through an extensive literature review, the JRC discerned various economic benchmarks from applying PATs, including the global navigation satellite system (GNSS) application reducing overlaps in fields in the Netherlands and the United Kingdom of Great Britain and Northern Ireland, leading to a 10–15 percent improvement that translates into higher farm incomes (Tullberg, 2016). Widespread adoption of controlled traffic farming (CTF) combined with auto-guidance in Denmark across wheat, rapeseed, maize and sugar beet have reduced fuel costs by 25–27 percent with 3–5 percent savings in fertilizer and pesticide use (Jensen *et al.,* 2012). The use of a real-time, automatic, site-specific weed control system compared to conventional field spraying, shows that although the costs (i.e. investment and maintenance) for the VRA technology were greater (EUR 9.56/ha vs EUR 5.20/ha), weed control costs were lower due to herbicide savings (EUR 32/ha vs EUR 68/ha in winter wheat and winter barley, EUR 69/ha vs EUR 148/ha in sugar beet and EUR 96/ha vs EUR 103/ha in maize) (Gerhards and Sokefeld, 2003).

Variable rate fertilizer/ lime application can result in savings, depending on absolute and relative prices of urea-ammonium nitrate and ammonia. Studies show greater returns on fields with high and spatially variable nutrient requirements and larger farm sizes, due to economies of scale (Raun *et al.,* 2002). In terms of variable rate planting and seeding, a study of automatic section control systems in planters among 52 fields showed that double-planted areas can reach up to 15.5 percent of the total field area. The savings from use of variable rate planters to eliminate double-planting, ranged from USD 4 to USD 26/ha depending on the farm and field type (Bongiovanni and Lowebberg-DeBoer, 2000).

Such studies, databases and analytical tools can contribute to achieving several goals: (i) improve the general level of knowledge and increase confidence in PATs; (ii) a more dynamic development of technology integrators; (iii) guide state policy efforts; and (iv) stimulate farmer competitiveness.

The information vacuum on national estimates of PATs penetration and application is a challenge not only in Ukraine. The study on global prospects for their adaptation by Harper Adams University (United Kingdom) found the following results:

- no country systematically collects official data on the level of penetration and application of PATs;
- only a few countries (United States of America, Australia and United Kingdom) conduct occasional systematic research on adoption of PATs. Alternative data sampling methods may not be representational;
- farmers and integrators usually do not disclose specific data on sales and use of technologies;
- knowledge about the level of PATS' adoption is based mainly on combining data from sporadic, scattered surveys (Harper University, 2018).

In Ukraine, farmers are sceptical of "alien" assessments of PATs' effectiveness. The level of trust in the classic tools to increase crop productivity (more productive agricultural machinery and seed varieties, effective fertilizers and plant protection products) is much higher. This is partly because most farmers consider increasing yields a key goal to realize full production potential.

Those farmers who have reached the limits of the extensive production model are the main advocates for PATs. One leading example of applying digital technologies in agriculture is the Kernel case. According to the company's own data, in 2018 it allocated USD 2.7 million, or USD 5 per hectare to innovation.

In the 2019 fiscal year, agribusiness experienced a USD 170 million in earnings before interest, taxes depreciation and amortization (EBITDA), of which USD 25 million was through use of digital systems and PATs (HB News, 2019). The company manages 550 000 ha and the economic efficiency of innovations is estimated to be USD 45 per 1 ha. The company recognizes that initially, one of the main motivations for introducing digital innovations was the need to optimize the land management and control system.

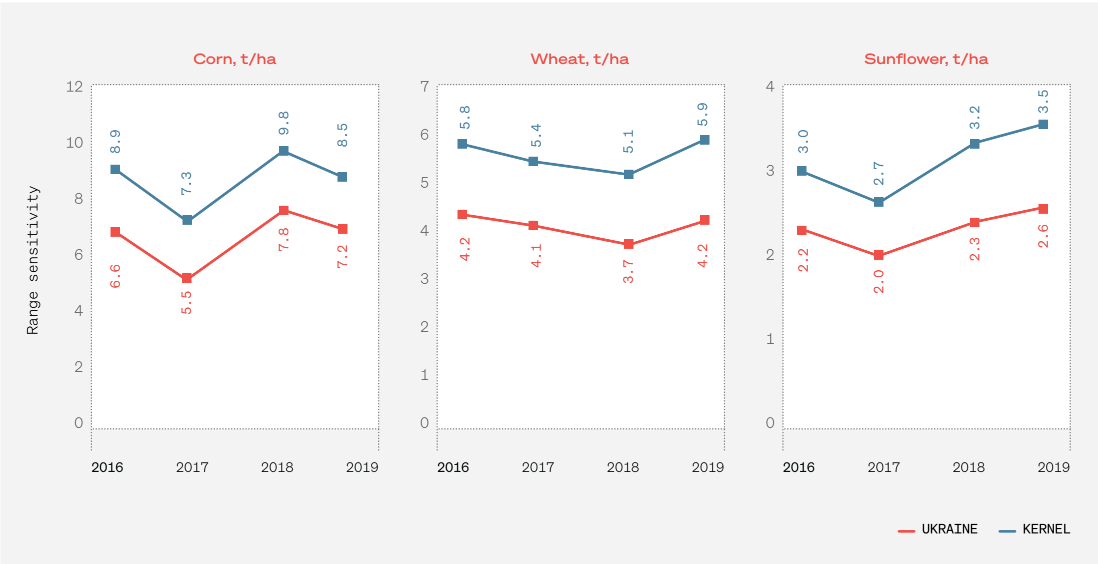


Figure 2.3
Yield comparison: Kernel vs Ukraine

SOURCE: State Statistics Service of Ukraine, 2021. http://ukrstat.gov.ua/; company data

As outlined in Box 2.1 consolidation of all the company's technological processes into a single innovative ecosystem, DigitalAgriBusiness, significantly supported digitalization efforts. The elements of the DigitalAgriBusiness ecosystem formed the basis of the new innovative platform OpenAgribusiness.

BOX 2.1

TECHNOLOGIES USED BY KERNEL

Kernel uses the following PATs technologies: high quality electronic field maps, 520 autopilots and a network of base stations of the RTK signal. The company uses a variable input rate on all sprayers and seeders. Technologies for variable application of resources are used on 30 percent of the fields. When cultivating soil, depth control sensors and nitrogen sensors regulate the rate of nitrogen application. Kernel owns a network of weather stations and an accredited agrochemical laboratory. It also operates a full range of monitoring solutions, including unmanned aerial vehicles for satellite monitoring (Figure 2.4). The entire management system is integrated into a single digital platform DigitalAgriBusiness (Figure 2.4). The company invested more than USD 3 million in developing this platform.

It claims it operates five specialized research and development (R&D) centres with 1500 test fields and 60 employees, conducting over 2000 tests annually. Each cluster is free to use up to 10 percent of acreage under its control for experiments to test new crop production techniques to raise productivity (Kernel, 2019).

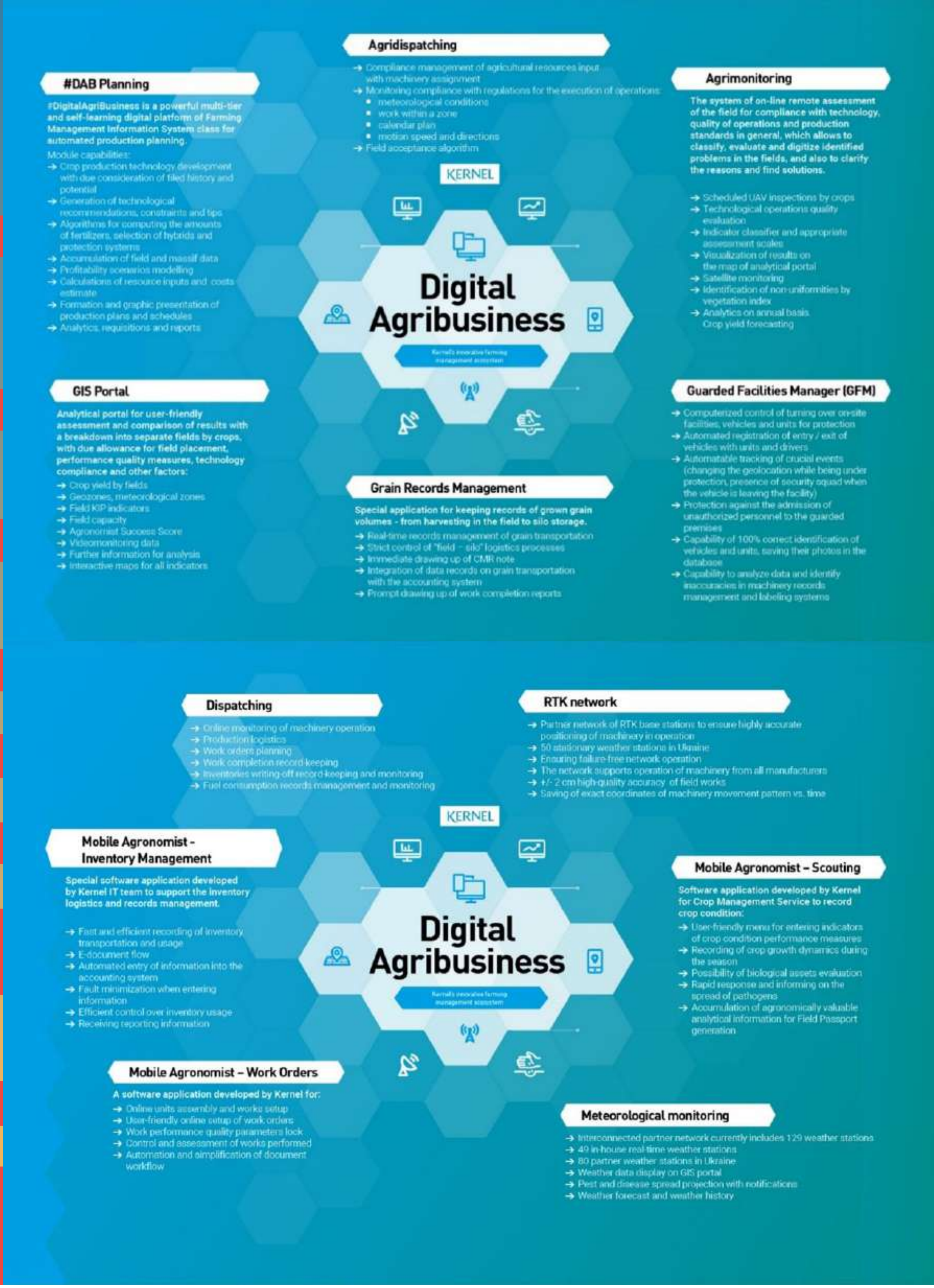


Figure 2.4

Case of technologies used by Kernel

SOURCE: Kernel Holding. 2020. Annual report for the year ended 30 June 2020. www.kernel.ua/wp-content/uploads/2020/12/FY2020_Kernel_Annual_Report.pdf

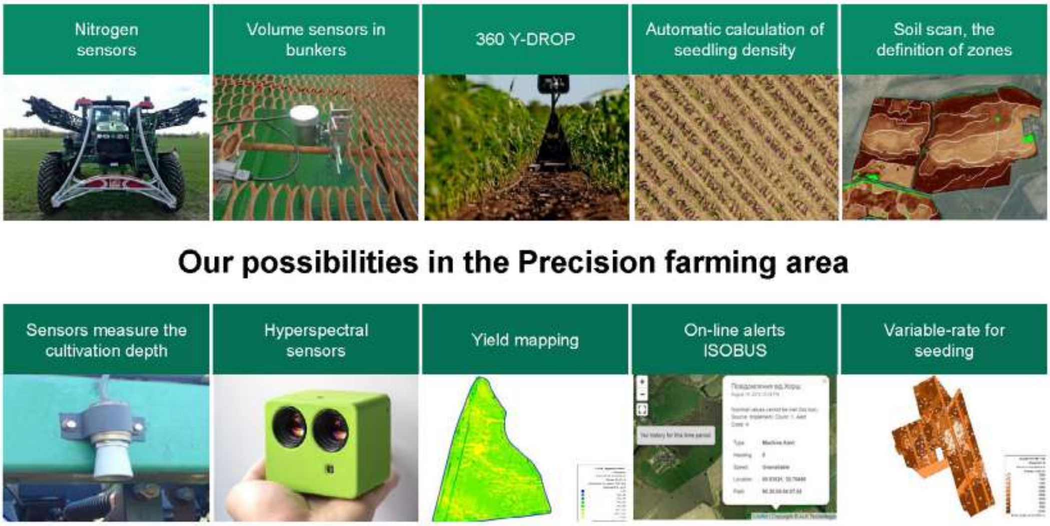


Figure 2.5

Elements of precision agriculture technologies used at Kernel

SOURCE: Kernel Holding. 2020. Annual report for the year ended 30 June 2020. www.kernel.ua/wp-content/uploads/2020/12/FY2020_Kernel_Annual_Report.pdf

CASE

AGROGENERATION – STEPS TO IMPLEMENT PATS ON AN AGRICULTURAL HOLDING

AgroGeneration is a public company listed on the New York Stock Exchange (NYSE) and Euronext in Paris, France. The Group currently operates 58 000 ha of land in one cluster in the Kharkiv region. AgroGeneration relies on a modern agricultural machinery fleet, including 45 combines, 100 tractors, 28 sprayers and 146 seeders and headers (AgroGeneration, 2020).

The need to control land use and ensure it is used optimally drove the company to rely on PATs. Annual land leases deviated by 15 percent and therefore the second objective to introduce the technology relates to increasing control of leased land movements. To achieve these objectives analogous digital solutions with an accuracy of 0.1 × 0.1 metre replaced analog control systems with a control accuracy of only 10 × 10 metres. Table 2.1, Table 2.2 and Table 2.3 outline the steps AgroGeneration has taken to increase control accuracy from 10 to 0.1 metre.

Tables 2.1, 2.2 and 2.3

The first step: control accuracy of 10 m		
Land bank	**Technical equipment**	**Digitalization of business processes**
Measure field contours	Most machinery is not suitable for precision farming	Introduce online monitoring of activities
Estimate the leased shares	Fit equipment with global positioning system (GPS) trackers with an accuracy of 5 metres	Each unit of equipment assumes one task per day
Conduct a chemical analysis of the soil	The agronomic service has autonomous meteorological stations, field control is not automated	Carry out an automatic calculation of results for each activity according to the tracker Respond promptly to processing errors and deviations from the task Drone inspection has a selective view to monitor the general condition of plants
The second step: control accuracy of 1 m		
Complete the process of maximizing cultivation of leased land	Equip machinery with a parallel driving system	Improve process of online monitoring of works and generate daily work tasks automatically
The cultivation area to coincide with the maximum possible area	Uses 30 cm correction (free of charge)	Provide each unit of equipment with a daily task (prescription card), downloaded to the on-board computer
Obtain chemical analysis of the soil systematically	Connect agronomic service weather stations to the general information system The agronomic service has survey drones	Complete automatic calculation of work results according to the on-board computer Prompt response to processing errors and deviations from the task Systematic inspection by drones to monitor the general condition of plants
The third step: control accuracy of 0.1 m		
Record field contours with an accuracy of 0.1 metre	Equip machinery with a system of precision farming and differentiated resource inputs	Improve online monitoring of works and generate daily work tasks automatically
Equip each field with sensors to monitor soil and plant conditions	Use corrective signals (correction up to 2 cm)	Provide a daily task for each unit of equipment and download it to the on-board computer
Obtain field maps	Connect agronomic service weather stations to the general information system, automating control of the fields	Automated tracking of goods and resource movements, with blockchain control
Analyse the soil in each zone	Agronomic service uses drones for mapping and for spot application of pesticides and fertilizers	Assess operative response by inspecting drones and data from field sensors for plant and soil conditions

SOURCE: AgroGeneration 2020. Steps to implement precision farming in the agricultural holding. Presentation prepared for FAO.

Figure 2.6 outlines the investment and annual costs to increase precision levels from 10 × 10 to 0.1 × 0.1 metres. Implementing PATs offers an estimated return on investment (ROI) of 32 percent, a net present value (NPV) of over USD 118 000 and an internal rate of return (IRR) of 15 percent. AgroGeneration expects to recuperate investment costs within three years. However, this business case does not take account of the full costs of digital and soil quality maps (technologies that enable field contouring), as farms over 10 000 ha had already made these investments, prior to their acquisition by AgroGeneration. This business case may not be representative of farms that have not made any PATs' investments and therefore the figures should be used indicatively.

The size of a typical farm that is part of the company is 10 000 hectares, requiring investments to modernize farming systems and replace machines with pre-installed precision farming systems: eight pieces of equipment and five trailed units.

According to company calculations, the cost of upgrading the farming system (additional modems, autopilots, base station etc.) to improve machine accuracy from 10 × 10 to 0.1 × 0.1 metres is around USD 600 000.

Expected minimum profit generated by 0.1.x 0.1 metre precision farming in comparison with 10 × 10 metre accuracy is approximately USD 20/ha.

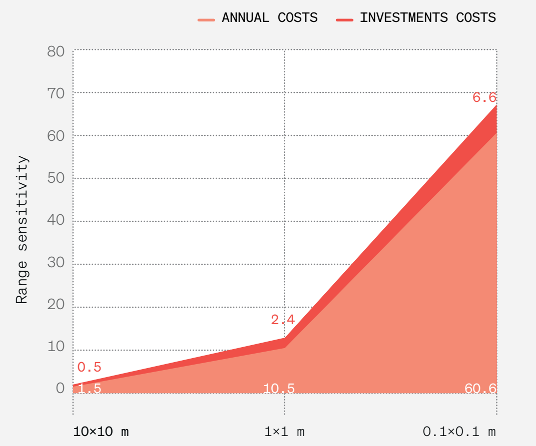


Figure 2.6
Investment and annual costs of pats depending on precision level (farm size: 10 000 ha, USD/ha)

SOURCE: AgroGeneration. 2020. Steps to implement precision farming in the agricultural holding. Presentation prepared for FAO

The AgroGeneration case is singular and it should be noted the majority of farmers participating in the survey found it difficult to provide estimates on the effectiveness of their use of PATs. One exception is a respondent managing a farm of 5500 ha who has used PATs for about four years: positioning systems, RTK, autocontrol, variable input rate, accurate field maps, soil quality mapping, weather stations and remote sensing. The total economic impact due to an increased rational use of inputs (seeds, plant protection products, mineral fertilizers and fuel) is USD 840 000 for three years or USD 51 per ha, without increasing crop productivity.

Most other positive answers estimating the economic effect of PATs are generalized conclusions on increased profitability from lower costs with an increase in overall efficiency of 20 to 30 percent.

According to Ukrainian company, AgriLab,[14] one of the integrators of innovative technologies in agriculture, farmers' savings from applying PATs can be up to USD 150 per ha. AgriLab experts have outlined the following efficiencies using individual innovative technologies:[15]

- reliable information on the quality of cultivated land and use of the right amount of fertilizer can increase efficiency by 30 percent;
- allocation of homogeneous zones in the same field can increase productivity by 20 percent;
- the technology of variable seeding rate and automatic disabling of sowing can increase yields by 12 percent compared to one sowing rate per field;
- variable rate application can generate savings from 10 to 30 percent on direct fertilizer costs.

According to AgriLab estimates, profitability increases range from 10 percent (using one element) to 50 percent (integrated implementation). Another technology integrator, SmartFarming, reports PATs will provide at least USD 100 additional income per ha for each agricultural producer per year (AGGeek, 2019). Based on the above estimates, the potential for increased profits for the grain and oilseed sector of Ukraine from adopting precision technologies could reach USD 2.4 billion per year.[16]

In general, expert estimates of the potential effectiveness of PATs and actual results of applied cases are quite close and Ukrainian estimates generally correlate with the results of the ARMS survey, farm profits and adoption of precision agriculture. According to this research, American farmers using PATs had a profitability of USD 45–86 higher than farmers who did not use PATs (USDA, 2016).

While estimates of the potential benefits of using PATs are confirmed, the amount of investment needed is specific to every case. In Ukraine, the development level of farms is extremely varied, starting from the fleet of agricultural machinery and level of technology integration to the organization of business processes and management accounting. In each case, introducing PATs should entail an assessment and examination of the entire production chain. This includes identifying inefficient areas of activity and only after that can recommendations on technological and managerial solutions be tailored to the conditions of a particular farmer.

Given these variations, any assessment of the investments to implement technical specifications will be subjective. According to various experts, the cost of implementing PATs in an enterprise that manages 10 000 hectares of land can vary from USD 480 000 to USD 720 000 with the payback period ranging between 5–7 years.[17] Most farmers who implement PATs prefer phased implementation: soil analysis, field maps, navigation systems, fuel control systems, parallel driving or autopilot. These measures provide a quick economic effect and do not require large initial investments, provided the appropriate agricultural equipment is available.

14 AgriLab. 2022. [online]. Priluki. www.agrilab.ua/ru/tochne-zemlerobstvo-po-amerykansky/

15 Analyses and estimates provided by Ukrainian company AgriLab

16 This calculation assumes a profitability increase equivalent to USD 100 per ha. Since the grain and oilseed sector comprises 23.5-24.5 million ha, the additional profit per year can be estimated at 24.0 million ha * USD 100 = USD 2.4 billion.

17 Consolidated estimates from interviews with farmers and PATs’ integrators

2.2.2 Potential impacts of PATs on the environment

Agriculture directly and indirectly contributes to GHG emissions and therefore climate change. According to the Intergovernmental Panel on Climate Change (IPCC), food systems, including agriculture and land use, storage, transport, packaging, processing, retail and consumption accounted for an estimated 21 to 37 percent gigatonnes of CO_2 equivalent emissions per year (GtCO2eq-1) (10.8–19.1 $GtCO_2eq\ yr^{-1}$) of total anthropogenic GHG emissions during 2007–16. This includes emissions of 9–14 percent from crop and livestock activities (4.8–7.6 2 $GtCO_2$ eq yr^{-1}) within the farm gate and 5–14 percent from land use and land use change, including deforestation and peatland degradation (2.4–7.4 $GtCO_2eq\ yr^{-1}$).[18] More specifically, agriculture, forestry and other land Use (AFOLU) activities accounted for around 13 percent of carbon dioxide (CO_2), 44 percent of methane (CH4) and 81 percent of nitrous oxide (N2O) emissions from human activities, globally during 2007–16 (IPCC, 2019).

Crop production emits CO_2 and N2O, while experts estimate that the anthropogenic impact of N_2O is 298 times stronger than CO_2.[19] CO_2 emissions result from the use of energy in agrotechnological operations (the use of fuel in agricultural machinery), as well as carbon stock changes in the soil due to land use. Nitrous oxide emissions occur as a result of the microbial transformation of nitrogen (N) from use of organic and synthetic fertilizers.

New practices to reduce GHG emissions in agriculture should correlate with increasing productivity, as addressing increased demand for food and ensuring food security will require greater productivity. Increased grain productivity, without compromising on climate change impacts, is gaining critical importance.

The application of PATs can support the above goals. A different approach to managing soil productivity and cost optimization can generate a positive impact on farmers' productivity and economic efficiency. Optimizing input amounts (fertilizers, plant protection products and fuel), can also contribute to reducing GHG emissions.

Due to the diversity of precision technologies, application of PATs can vary greatly in reducing GHG emissions. In a European Union study an expert group proposed a classification table for PATs' potential to reduce GHG emissions (Table 2.4) (Soto *et al.,* 2019).

18 Consolidated estimates from interviews with farmers and PATs integrators
19 Authors' estimates based on FAOStat Data (www.fao.org/faostat/en/#data)

Table 2.4
PATs' ranking by potential greenhouse gas emission reduction

Technology rank	Technology	Rank in potential reduction of GHG emissions
1	Variable rate fertilizer application	5
2	Variable rate irrigation	3
3	Controlled traffic farming	2
4	Machine guidance	2
5	Variable rate pesticide application	2
6	Variable rate seeding/ planting	1
7	Precision physical weeding	1

NOTE: The scale of importance of the GHG reduction potential (Likert scale indicated by the authors) is: 5, very high potential; 4, high potential; 3, moderate potential; 2, small potential; 1, low potential.

SOURCE: Soto, I., Barnes, A., Balafoutis, A., Beck, B., Sanchez, B., Vangeyte, J., Fountas, S., Van der Wal, T., Eory, V. and Gomez-Barbero, M. 2019. The contribution of precision agriculture technologies to farm productivity and the mitigation of greenhouse gas emissions in the EU. Luxembourg, Publications Office of the European Union, ISBN 978-92-79-92834-5, doi: 10.2760/016263, JRC112505.

Variable fertilizer application technology can significantly reduce GHG emissions, especially so for nitrogen, because although all inorganic fertilizers contribute to GHG emissions by emitting carbon dioxide during production and transportation, global warming from N-based fertilizers is much higher because it also contributes to nitric oxide emissions.

Variable irrigation systems assume second place in reducing GHG emissions because, first, they reduce the amount of irrigation water and therefore the energy costs to pump and transport it. Second, an optimal irrigation schedule can prevent excessive soil moisture, which increases N_2O emissions.

Controlled traffic farming and machine guidance optimize the use of machinery only with a corresponding reduction in costs and fuel use, which can be converted into reduced emissions.

Variable pesticide application can reduce GHG emissions due to fewer plant protection products used in fields and from their industrial production. In the case of variable rate pesticide application, the environmental impact is significant from the point of view of fewer chemicals that adversely affect natural resources: water, air and soil.

The results of a European study (Soto *et al.*, 2019) revealed positive impacts from the use of PATs in reducing emissions. Based on the Miterra-Europe model[20] in 2015, applying PATs could abate up to 1.5 percent of total GHG emissions in European Union agriculture with greater impact in countries where crop production predominates.

20 MITERRA-EUROPE is a deterministic and static model which calculates N and phosphorus (P) balances, emissions of NH_3, N_2O, NOx and methane (CH_4) into the atmosphere and leaching of N to groundwater and surface waters. The model assessed the effects and interactions of policies and measures in agriculture on those fluxes, including structural measures.

In Ukraine, the largest source of GHG gases is the energy sector, accounting for about 73 percent in 2017. The share of agriculture is about 13 percent of total emissions. According to FAO estimates, about 55 percent of GHG agriculture emissions relate to the impact on soils from agricultural activities: mineralization of organic matter as a result of mechanical effects on soils, plant debris, nitrogen fertilizers (FAO, 2019a).

Even though the volume of GHG emissions in agriculture in Ukraine remained relatively the same over ten years, the structure of emissions has changed. There was a decrease in the livestock sector (enteric fermentation), with a steady rise from crop production, primarily from increased use of synthetic fertilizers. According to FAO estimates, about 30 percent of agriculture GHG (55 percent) were affected by N_2O emissions from anthropogenic nitrogen releases to soils. The remaining agriculture emissions are from crop residues (16 percent) and cultivation of organic soils (9 percent), see Figure 2.7 (FAO, 2019a).

According to research and scientific assessments, further penetration and development of PATs in Ukraine could reduce GHG emissions. In 2017, it was estimated technologies that reduce inputs, particularly fertilizers, can cut emissions by 3.0–9.1 percent. Climate change mitigation potential ranged from 881 000 to 2 644 000 tonnes of CO_2 equivalent per year (CO_2eq-1) in 2017 (Table 2.5). These estimates assume PATs can reduce nitrogen use by 10–30 percent.

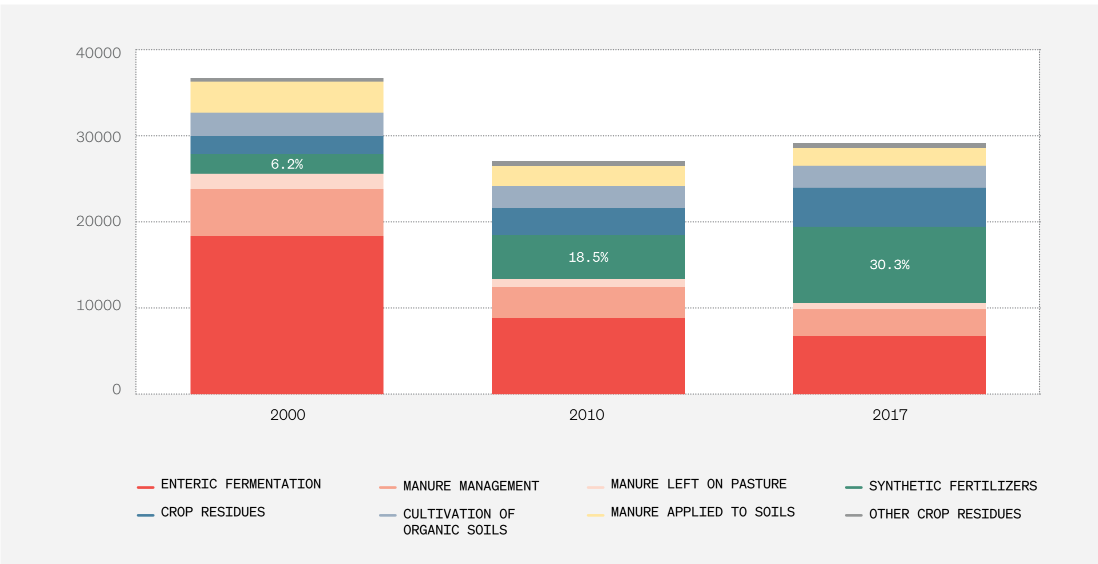


Figure 2.7
Dynamics of greenhouse gas emissions in agriculture of Ukraine, kt CO_2-eq

SOURCE: FAO, 2019a. FAOStat Data. Ministry of Ecology and Natural Resources of Ukraine. Annual National Inventory Report. Ukraine's greenhouse gas inventory 1990-2017

Table 2.5
Assessment of climate mitigation potential in Ukraine – best case scenario

Description	2014	2015	2016	2017
Synthetic fertilizer emissionS, kt CO_2eq	6591	6358	7729	8813
Mineral nitrogen fertilizers applied, thousand tonnes	1021	985	1197	1365
Estimated ratio	6454	6454	6455	6455
The range of reduction in the volume of mineral nitrogen fertilizers	10-30%	10-30%	10-30%	10-30%
Climate mitigation potential range in Ukraine, thousand tonnes of CO_2eq	659–1977	636–1907	773–2319	881–2644

SOURCE: FAO. 2019a. FAOStat Data. Ministry of Ecology and Natural Resources of Ukraine. Annual National Inventory Report. Ukraine's greenhouse gas inventory 1990-2017; State Statistics Service of Ukraine. 2021. http://ukrstat.gov.ua/; authors' calculations

Given the cost of CO_2 emissions in the European Union ETS (EUR 24.8 in 2019 on average per tonne), the climate mitigation potential from PATs in Ukrainian crop farming (using the 2017 potential range of 881–2644 CO_2eq) is estimated at EUR 21.8–65.6 million per year (Nissen *et al*., 2020).

In 2019 the Ministry of Economic Development, Trade and Agriculture issued optimistic economic growth projections (EBRD, SWUK and IEF, 2021). Gross domestic product (GDP) growth could result in higher GHG emissions as farmers are likely to apply more fertilizer to increase production and maximize soil use. Such projections drove sensitivity analyses to better understand how economic growth can affect GHG emissions. With support from the EBRD and the Government of Sweden, the Institute for Economics and Forecasting at the National Academy of Science of Ukraine (NASU) used these analyses to revise the nationally determined contributions (NDCs) of Ukraine (EBRD, SWUK and IEF, 2021). The report noted that the use of slow or controlled release fertilizers can increase the nitrogen consumed by plants, therefore reducing the need to apply large amounts of fertilizers. Combining controlled release fertilizers with PATs can curb the upward trend in fertilizer application to reduce emissions, without limiting productivity growth.

A recent European Court of Auditors review of the European Union Common Agricultural Policy (CAP) highlights the challenges in reducing fertilizer emissions (European Court of Auditors, 2021). Decreasing GHG emissions has been one of the main CAP objectives since 2014 and between 2014 and 2020, the European Union spent over EUR 103 billion on key climate change actions, 26 percent of the CAP budget. The review results demonstrate that GHG emissions from agriculture fell by 25 percent between 1990 and 2010, due to a decline in fertilizer use and the number of livestock. However, since 2010 the CAP has not further reduced livestock and fertilizer emissions usage. This is partly due to increased demand for livestock products since 2014 and greater fertilizer use (chemical and manure) in some countries: Bulgaria, Czech Republic, Hungary, Romania and Slovakia. The CAP did not increase the carbon content stored in soils and plants. These results occurred despite CAP support for reducing emissions from manure storage, along with biogas solutions using manure as feedstock at different levels across European countries. The CAP has seldom supported effective climate change mitigation related to chemical fertilizer (forage legumes, variable rate application and nitrification inhibitors). The review findings reveal that despite investment and support, without compromising on productivity growth, reducing emissions from fertilizer use is challenging. Therefore, in estimating PATs' potential to reduce emissions in Ukraine, European Union experiences are highly relevant.

For most farmers in Ukraine the environment is not a major consideration in implementing PATs and in the survey received the lowest rating: 2.3 out of 5. Future regulatory changes, such as the Carbon Border Adjustment Mechanism (CBAM) which seeks to prevent GHG leakages and level the playing field between European and foreign emitters (Marcu, Mehling and Cosbey, 2020), may change farmers' approach to the issue. This new carbon tariff will impact mostly on industry in the short and medium term, but will have impacts on agribusiness in the longer term. Cement, iron, steel and petroleum are likely to be most affected, followed by chemicals, fertilizers, industrial gases, aluminium and paper. To remain competitive, farmers and agricultural commodity exporters should consider future regulatory changes, and apply digital technologies to measure and reduce emissions.

APPLYING DIGITAL TECHNOLOGIES TO REDUCE GHG EMISSIONS – THE CASE OF KERNEL

In Ukraine, Kernel claims it has invested in reducing GHG emissions through technology. In the company's business model, farming generates most direct emissions (scope 1 and 2), with fertilizer application driving scope 1 emissions (Table 2.6). In 2020 farming produced 94 percent of Kernel's direct GHG emissions and N_2O made up 83 percent of emissions (Kernel, 2020). CO_2 emissions were mainly from machinery burning fuels and transporting grain (14 percent of scope 1 emissions). The company claims it has reduced N_2O emissions by 10–15 percent through differentiated fertilizer application. To address CO_2 emissions, Kernel has cut fuel consumption and improved machinery mileage, by modernizing its fleet and route optimization and states it has improved GHG emission reporting quality. The GHG Protocol Principles guided previous disclosures but in 2020, the company reported its emissions were in full compliance with the GHG Protocol (Kernel, 2020). The company also adhered to the Standards of the Global Reporting Initiative (GRI) in reporting sustainability information (Kernel, 2020).[21] An increased area from 391 harvested hectares in 2016 to 513 hectares in 2020 combined with greater scope to disclose N_2O emissions from soils under management (fertilizer use and biogenic emissions caused by changes in organic carbon stocks in soil), has contributed to greater N_2O emissions. Due to a lack of data on fertilizer use in previous years (Kernel began estimating GHG emissions in 2018), volumes were estimated using average fertilizer application rates for each crop, discounted by 10 percent to reflect different agricultural practices (Kernel, 2020). Despite this, Kernel states it has reduced emission intensity per tonne of grain by 3 percent between 2016 and 2020.

21 Kernel uses a financial control consolidation approach to calculate emissions based on fuel consumed and conversion factors from the GHG Protocol (GHG Emissions from Stationary Combustion). It also uses the IPCC Fouth Assessment Report rates for global warming potential calculations, reporting emissions from agricultural soils in the financial year when the products were harvested, while using data on mineral and organic fertilizers applied during the growth period of the previous financial year.

Table 2.6
Assessment of greenhouse gas emissions by Kernel

	2016	2017	2018	2019	2020
Acreage harvested, thousand ha	391	385	569	529	513
Gross direct (Scope 1) GHG emissions, thousand tonnes CO_2eq	662	748	922	981	955
By gas type					
CO_2	129	174	200	192	174
CH_4	34	32	33	25	22
N_2O	498	542	688	764	759
By division					
Oilseed processing	4	14	3	3	9
Infrastructure and trading	29	63	70	59	44
Farming	627	670	847	918	900
Other	1	1	2	1	1
By source					
Fuel-sourced	138	184	211	203	186
Cattle farming	38	35	37	28	25
Fertilizer application	486	529	673	750	744
Gross indirect (Scope 2) GHG emissions, thousand tonnes CO_2eq	73	83	94	90	96
GHG emissions intensity ratio, kg CO_2-eq					
Per tonne of sunflower seeds processed	147	139	134	131	128
Per tonne of grain grown	375	419	343	386	365

SOURCE: Kernel Holding. 2020. Annual report for the year ended 30 June 2020. www.kernel.ua/wp-content/uploads/2020/12/FY2020_Kernel_Annual_Report.pdf

The launch of the Kernel DigitalAgriBusiness platform has enabled not only more accurate profitability simulation scenarios, but supports efforts to reduce GHG gas emissions. Figure 2.8 demonstrates some of the ways in which Kernel uses the platform to manage its emissions (Kernel, 2020).

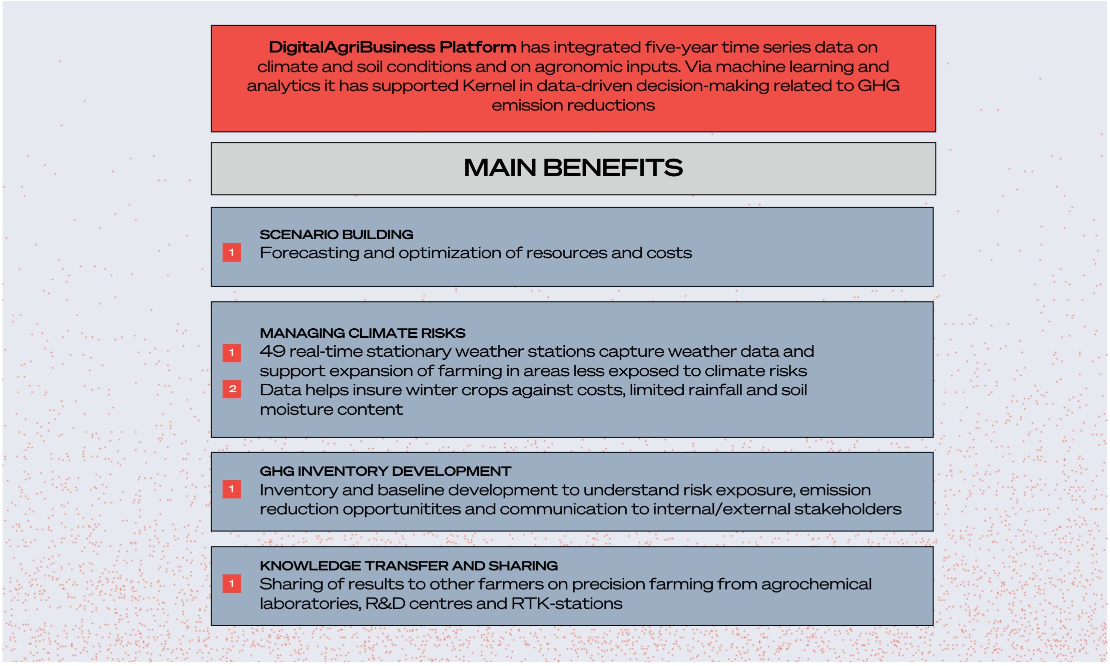


Figure 2.8

Using the digital agribusiness platform to manage GHG emissions

SOURCE: Kernel Holding. 2020. Annual report for the year ended 30 June 2020. www.kernel.ua/wp-content/uploads/2020/12/FY2020_Kernel_Annual_Report.pdf

Figure 2.9 highlights the number of hectares managed under precision technologies, which is increasing on a year-on-year (YoY) basis; sharing results is increasingly important for benchmarking.

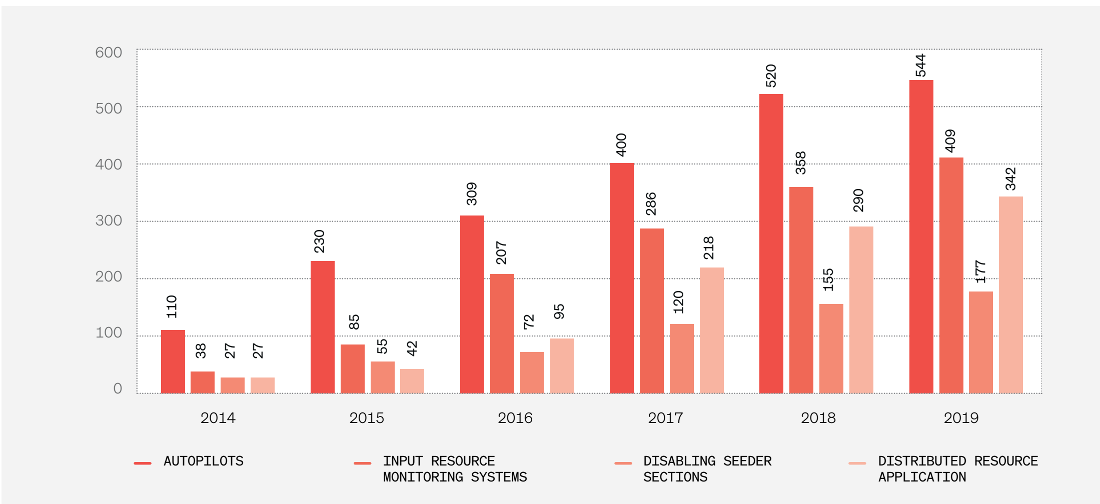


Figure 2.9

Kernel: PATs implementation, ‘000 HA

SOURCE: Kernel Holding. 2020. Annual report for the year ended 30 June 2020. www.kernel.ua/wp-content/uploads/2020/12/FY2020_Kernel_Annual_Report.pdf

CASE OF GREENSEEKER APPLICATION

The careless use of fertilizers can lead to accumulation of nitrates in the soil and pollution of groundwater, a significant problem in Ukraine where 30 percent of the population live in rural areas. According to official data, 78 percent of villages do not have a central water supply but take drinking water from wells that are 2–5 metres deep, filled with groundwater. Rural residents thus consume residues of fertilizers, nitrates and other pathogens.

Technologies are essential to supply the plant with the precise amount of nitrogen it can absorb. Calculating fertilizer application based solely on an agrochemical soil analysis does not consider the possibly stressed status of the plant as a result of nitrogen deficiency, often caused by insufficient moisture or sulphur. Their presence in the soil does not guarantee this in the plant so it is advisable to check nitrogen supply in the plant itself.

Differentiated nitrogen fertilizer application systems, biomass mapping and application based on real-time crop measurements can solve such problems. Sensors can collect data to measure the normalized difference vegetation index (NDVI) of plants, using these with other agronomic data to determine a plant's need for nitrogen. They can also provide information on crop conditions, potential productivity, crop resistance to lodging, pests and diseases.

The GreenSeeker N-sensor is an example of this technology which monitors changes in crop growth. A spreader or sprayer with a computer can differentiate application of nitrogen fertilizer in real time as the spreader passes over the crops. The algorithm and parameters of the differentiated norm based NDVI can be entered directly into the field and changes to the norms made "on the fly", eliminating delays between evaluating crops and fertilizing.

Evaluation of the GreenSeeker N-sensor application took place on farms producing winter wheat at the plant-nutrient level (AgriLand, 2021). The agronomist's recommended application rates are 150 kg /ha of ammonium nitrate while the actual variable application using GreenSeeker is on average 121.3 kg /ha, a saving of 19.2 percent in fertilizer (Figure 2.10).

After fertilizing the wheat crop, electronic biomass maps clearly show the intensity of plant colour in the plants, as well as a map of nitrogen application rates. The gradation of nitrogen application displays the spreader's operating trend, inversely proportional to the biomass map, taking into account recommendations for this phase of plant development and this variety.

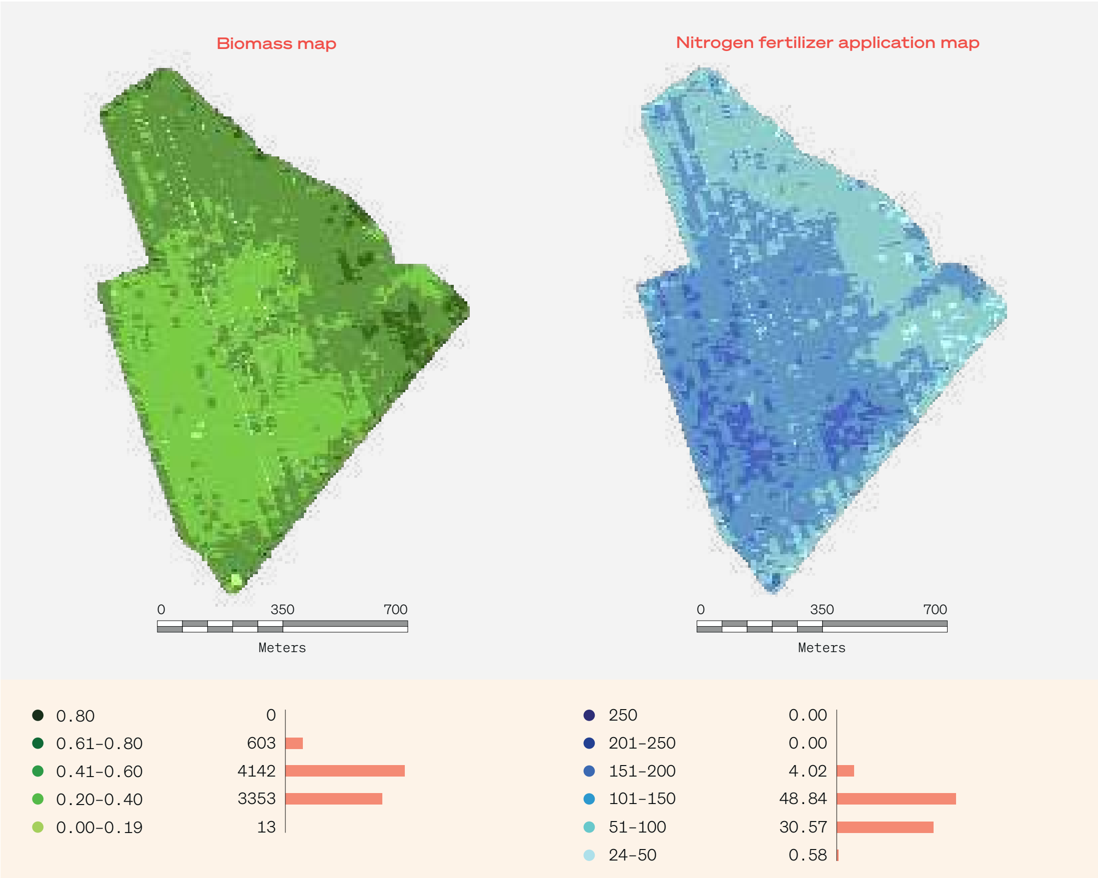


Figure 2.10
GreenSeeker application maps

SOURCE: AgriLand. 2021. Results of work n-sensor GreenSeeker. http://agriland.ua/en/results-of-work-n-sensor-greenseeker

The spreader applies the minimum value of nitrogen fertilizers (in some cases 0 kg) to one-third of the field. The plants in these areas are well developed and do not require a lot of nitrogen for normal vegetation. In several areas, there was a significant nitrogen deficiency, which, if applied evenly, could not be covered. The sensor determined the optimal amount of nitrogen in different parts of the field and gave instructions to the spreader.

As a result, there were fertilizer savings per one ha of 30 kg with total savings of 74.9 tonnes, the equivalent of USD 20 800 (Table 2.7 and Table 2.8).

On average the positive economic effect of variable nitrogen fertilizer using the GreenSeeker N-sensor for crops in different cases was about 20–35 kg fertilizer savings per ha or in the range of USD 5–9.[22] With appropriate implementation, an investment in the GreenSeeker N-sensor can pay for itself in one year on 2000 ha of grain crops.

22 Analysis does not assume an increase in yields, but demonstrates the potential to reduce fertilizer use while maintaining the same yield levels.

Table 2.7
Technology application assessment

	Farm #1	Farm #2
Farm area, ha	2180	572
Oblast	Vinnytska	Chernihivska
Crop	Winter wheat	Winter wheat
Stage	Topdressing nitrogen	Topdressing nitrogen
Fertilizer	Ammonium nitrate	Ammonium nitrate
Agronomist's recommendation (traditional technology), kg/ha	150 (51.6 kg N)	150 (51.6 kg N)
Total recommended use of fertilizers at farm level with traditional technology, tonnes*	327	85.8
Variable application (PATs), kg / ha	123.8 (42.5 kg N**)	118.8 (40.4 kg N)
Total use of fertilizers at farm level with variable application (PATs), tonnes	269.88	67.95
Fertilizer saving at farm level, tonnes	57.12	17.85
Fertilizer saving	17.5%	20.8%

NOTE: *Fertilizer amount is converted into tonnes and multiplied by the total farm area.
**123.8 kg of fertilizer comprises 42.5 kg of active nitrogen ingredients.

SOURCE: AgriLand. 2021. Results of work n-sensor GreenSeeker.
http://agriland.ua/en/results-of-work-n-sensor-greenseeker

Table 2.8
Comparison of actual harvesting results

	Farm #1	Farm #2
Farm area, ha	2180	572
Oblast (Region)	Vinnytska	Chernihivska
Productivity, 100 kg/ha		
Traditional technology	47-51	50
GreenSeeker	63	50
The protein content		
Traditional technology	18-21%	27%
GreenSeeker	25.5%	31%
Gluten, %		
Traditional technology	12.6-13.5%	13%
GreenSeeker	15.9%	15%
Grain class		
Traditional technology	class 2-3	class 2
GreenSeeker	class 1	class 1

SOURCE: AgriLand. 2021. Results of work n-sensor GreenSeeker.
http://agriland.ua/en/results-of-work-n-sensor-greenseeker

2.2.3 State regulation of precision agriculture technologies

In Ukraine there is no application or dissemination of PATs as a separate innovation area. Annex II summarises the framework documents and regulations on innovative agricultural development, although these priority areas and goals are purely declarative.

Precision farming was first introduced in 2018 through the Concept for the development of the digital economy and society of Ukraine for 2018–2020 whereby in 2019 the government proposed a resolution on agriculture digitalization with all measures, funding programmes etc. (Verkhovna Rada, 2018). However, there was a change in government and state policy to stimulate PATs may focus on expanding state support programmes.

These programmes compensate up to 90 percent of the cost of agricultural advisory services, with a 2019 budget of USD 200 000. The Ministry of Economy, Trade and Agriculture develops and administers state support for agriculture sector, including compensation of 25 percent of the cost of agricultural machinery and equipment with programme funding of USD 16 million. These subsidies do not support capital investments in digitalization but agribusiness associations have lobbied for partial compensation for services such as monitoring fields, land accounting and precision farming technologies. However, the lack of a policy on digitalizing agriculture and a regulatory framework on precision technologies, have largely blocked state programmes to support adoption of precision technologies.

As mentioned, lack of knowledge resulting in a limited understanding of the PATs concept hinders precision technologies. The limited evidence on their economic returns and environmental benefits for the Ukrainian grain sector, could also impede the government from embracing such policies and allocating funding as it has no incentives to promote precision technologies among farmers. Although government incentives could support technologies in the grain sector, as discussed in Chapter 2.2.4, the absence of government support has not deterred their uptake. Greater involvement of technology integrators, business development services (BDS) and consulting services to quantify economic and environmental returns, could contribute to further technology penetration, especially for small and medium-size farmers.

2.2.4 Survey on precision agriculture technologies

Survey methodology

The research used telephone surveys targeting a sample of respondents based on the number of agricultural enterprises in Ukraine, about 40 000 (Figure 2.11), farmers managing 2000 to 5000 ha being the largest (Figure 2.11).

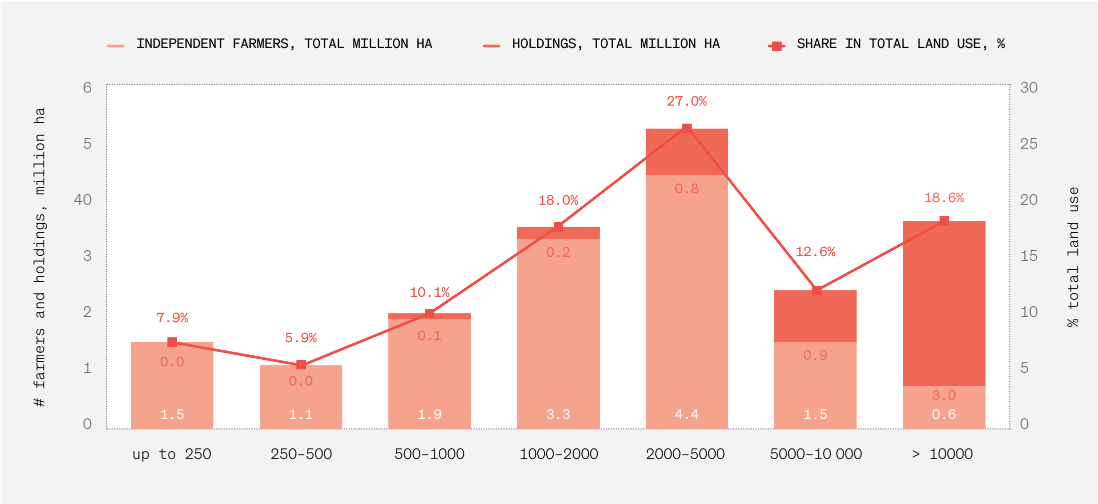


Figure 2.11
Distribution of farmers by size (agricultural enterprises)

SOURCE: Authors' calculations based on State Statistics Service of Ukraine. 2021. http://ukrstat.gov.ua/

To calculate the sample, the survey used a 95 percent confidence level. The sample distribution by region reflected the number of farmers, the total sown area and the area under grain crops and oilseeds along with a grouping of farmers according to land size. The sample was randomly generated in accordance with established selection criteria. The sample excluded a number of regions where the sown area for grain and sunflower crops was less than 3 percent of the total sown area. Interviews took place with 479 independent farmers and ten agricultural holdings. The area of farms in the sample covers approximately 15–17 percent of the sown area under grain crops (Table 2.9).

Table 2.9
Sample distribution by category and region

Oblast	Number of respondents							
	up to 250 ha	250–500 ha	500–1000 ha	1000–2000 ha	2000–5000 ha	5000–10 000 ha	beyond 10 000 ha	Total
Vinnytska	9	2	11	3	2			27
Dnipropetrovska	18	5	9	14	13	7	1	59
Donetska			3		2			5
Zhytomyrska	26	5	2	8	1	1		42
Zaporizka	10	2	7	4	3			26
Kyivska	13	1	6	4		2		24
Kirovohradska	11	1	3	5	2	3		22
Mykolaivska	9	7	1	5	6	1	1	28
Odeska	6	3	5	4	4			22
Poltavska	6	12	6	8	4	4	1	36
Sumska	19	7	10	1		4		37
Kharkivska	3	2	4	4	4	1		17
Khersonska	10	3	2	3	1			19
Cherkaska	2	8	3	5	2	4		20
Chernihivska	31	7	14	7	2	4		61
Total	**173**	**65**	**86**	**75**	**46**	**31**	**3**	**479**

SOURCE: APK-Inform. 2022. [online]. Dnipro. www.APK-Inform.com

The questions in this survey were adapted from a similar study on PATs penetration in the European Union, developed by the European Environment Agency (EEA), Copa Cogeca, the European Association of Farmers of Agricultural Machinery and other partners (European Commission, 2019a).

Survey results

The main part of the telephone survey focused on independent small and medium-size farmers not directly affiliated with agricultural holdings with a land range of 40 000–500 000 ha (Table 2.10). Farmers managing 250 ha comprise the largest share, while those managing between 1000 and 5000 ha make up 26 percent (Table 2.10).

Table 2.10
Land area used by enterprises

Group	Number of respondents	Group share, %
up to 250 ha	173	36
250–500 ha	65	13.5
500–1000 ha	86	18
1000–2000 ha	75	15.5
2000–5000 ha	46	10
5000–10 000 ha	31	6
beyond 10 000 ha	3	1
Total	**479**	**100**

SOURCE: FAO Survey conducted for this report

Categorization of respondents by revenue

Compared to other survey questions, answers on farmers' revenue are the most limited as half the respondents refused to answer the question on their annual revenues, even at the range level while the number of positive answers decreases as enterprise size increases. For land use area of 2000–5000 ha, only 24 percent of respondents gave an estimate of their annual revenue (Table 2.11).

Table 2.11
Estimated number of respondents by annual revenue

Groups, USD	under 250 ha	250–500 ha	500–1000 ha	1000–2000 ha	2000–5000 ha	5000–10 000 ha	beyond 10 000	Total
Up to 0.1 million	118	13	22	11	-	1		**165**
0.1–0.6 million	6	20	8	3	4	6		**47**
0.6–1.15 million		1	6	6	3	1		**17**
1.15–4.0 million				1	4	1		**6**
Over 4 million				1		1		**2**
Not willing to disclose	49	31	50	53	35	21	3	**242**
Total	**173**	**65**	**86**	**75**	**46**	**31**	**3**	**479**

SOURCE: FAO Survey conducted for this report

PERCEPTION OF TECHNOLOGIES

Attitude towards PATs

The survey results show most farmers have basic awareness with 80 percent of respondents saying they know something about PATs. Small farmers with a land area up to 500 ha are least acquainted with them. Out of all the respondents, 20 percent said they were not familiar with PATs, while 52 percent said they are familiar with them, but do not use them (Figure 2.12).

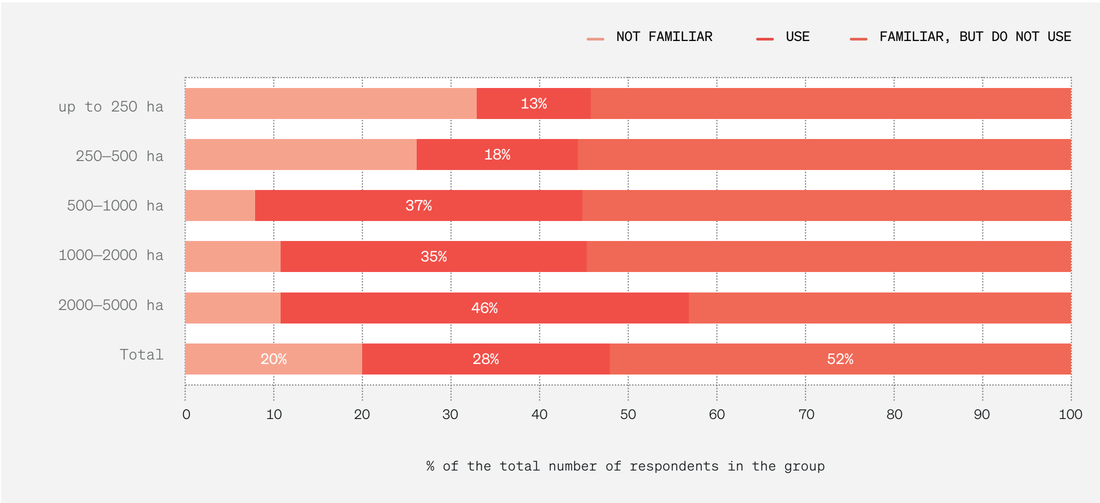


Figure 2.12
Familiarity with PATs by farm size

SOURCE: FAO Survey conducted for this report

Based on the representative sample, in Ukraine, PATs may be used on more than 8.4 million ha, or about 45 percent of the area of agricultural enterprises. In the group of farms with revenues of USD 0.1 million to USD 0.6 million per year, 17 percent said they were unfamiliar with PATs, reaching 35 percent for smaller farms, whose annual revenues are up to USD 0.1 million (Table 2.12). Among respondents who did not provide information on their financial results, level of PATs awareness was more than 84 percent, while 35 percent said they use PATs in their business.

Among agricultural holdings, the degree of penetration of PATs is much higher: 70 percent of agriculture holdings use PATs, while 30 percent use some elements in their production, by no means a fully fledged application. In general, the understanding of precision agriculture differs significantly depending on the size of the enterprise.

Table 2.12
Familiarity with PATs by company revenue

Group, USD	Familiar, but do not use	Use	Not familiar
	% of the total number of respondents in the group		
Up to 0.1 million	52	13	35
0.1–0.6 million	53	30	17
0.6–1.15 million	59	35	6
1.15–4.0 million	33	67	0
Above 4 million	50	50	0
Not willing to say	49	35	16
Total	**52%**	**28%**	**20%**

SOURCE: FAO Survey conducted for this report

Information sources on the technology

According to the survey, the most significant sources of PATs information are specialized conferences/ exhibitions and the internet with the greatest frequency of mentions compared with other channels: 49 percent and 43 percent, respectively. The least significant source of information is state agencies at 15 percent (Figure 2.13).

The other frequently mentioned information channel among those familiar with the technology, is exchange of experiences with other farmers, making positive feedback from other farmers one of the main motivating factors for using the technology. This is valid for all groups of farmers and agricultural holdings.

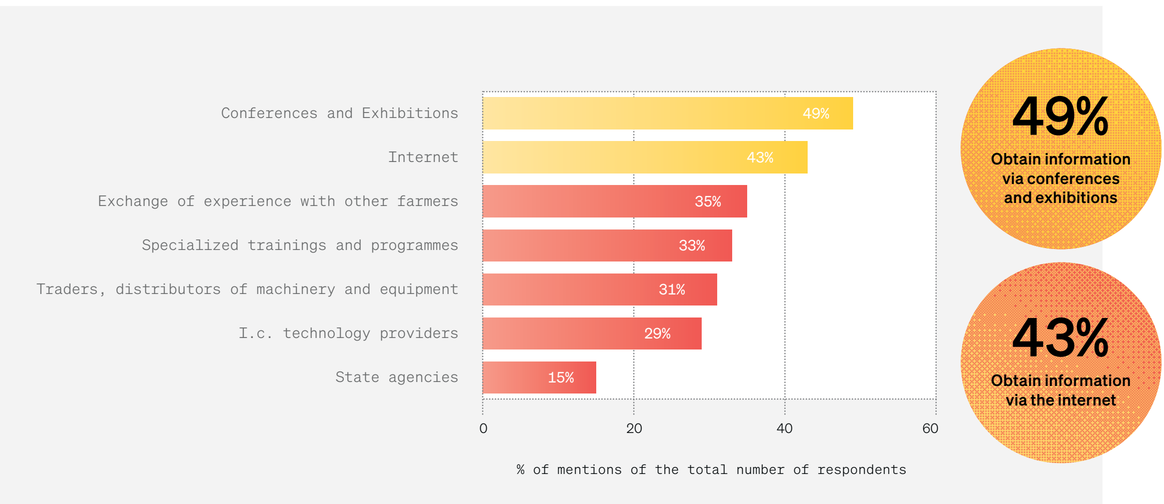


Figure 2.13
Sources of information on PATs

SOURCE: FAO Survey conducted for this report

Assessment of barriers to technology implementation

The biggest deterrent to technology implementation is the high initial cost, ranked on average at 4.0 points (Figure 2.14). The larger the respondent's lands, the more high costs are critical to them.

The second barrier was uncertainty about implementing the technology (3.4 points) although the greater the size of the enterprise, the less significant this is. The larger the farm size, the more farmers are aware of the potential from using the technology.

Staffing is another barrier to technology penetration. For respondents with over 5000 ha, the significance of this problem was rated at 4.3 points (as in Figure 2.14), in part associated with the complexity of the number of operations and applied technologies in large farms.

Another significant barrier, for larger enterprises, relates to the lack of land, rated at 3.6–3.8 points. The barriers to implementing PATs are ranked in the following order: high initial cost; problems of equipment compatibility and insufficient digital infrastructure; lack of land; and the limited number of trained management and technical staff at all levels. Implementation uncertainty and lack of knowledge about the technology are the least constraining factors for agricultural holdings.

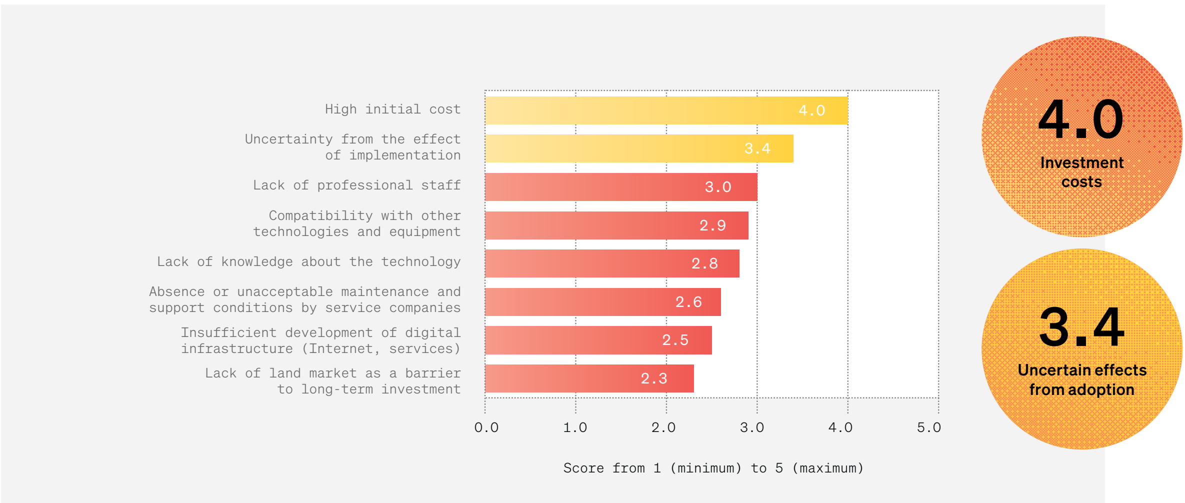


Figure 2.14
Barriers for investing and implementing PATs

SOURCE: FAO Survey conducted for this report

Being averse to experimenting with new technologies, cost of implementation and uncertain return on investments were the main hindrances to adopting PATs among grain producers, while farm size was another major factor for those with less than 250 ha.

Interest in investing in the technology

The potential interest of respondents to invest in PATs is limited. Among those who do not use PATs, only 18 percent showed interest in investing in the technology (Figure 2.15).

A factor is the high proportion of small entities (up to 250 ha) in the sample, for whom the benefits of the technology are the least tangible. The survey results confirm a correlation: the larger the land use, the greater potential interest in investing in the technology in the future. Starting from 1000 ha, every third respondent plans to invest in PATs. All agricultural holdings taking part in the panel interview would consider investing in PATs. The area of agricultural land with new PATs investments is estimated to be 3.8 million ha,[23] based on expression of interest which may not directly translate into actual investments, especially for farms under 250 ha.

Taking this and the connectivity of PATs elements the share of respondents using them can be reduced from 28 percent (Table 2.12) to 15–17 percent, mainly relating to farmers with holdings up to 500 ha. The area where PATs are being introduced can be recalculated as 6.8–7.0 million ha.

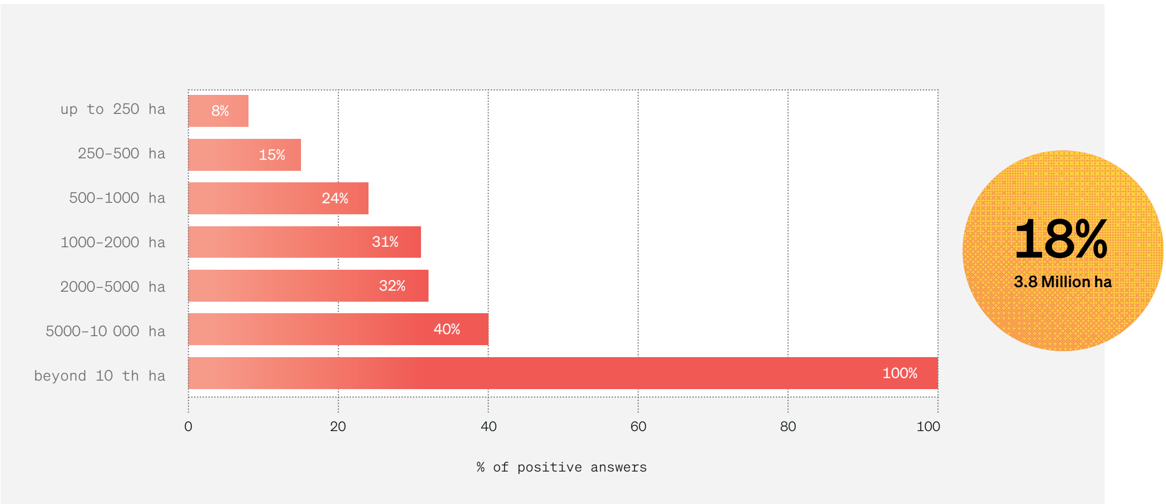


Figure 2.15
Investment plans for the adoption of PATs
SOURCE: FAO Survey conducted for this report

23 Calculation based on land area in the group of respondents who do not use PATs, weighted by the proportion of positive responses. PATs are not applied on a total of 21.1 million ha and 18 percent of the respondents expressed interest in investing in precision technologies, equating to a potential application area of 3.8 million ha.

APPLICATION OF PATS

Motivation for implementing the technology

The main motivation for investing in precision agriculture was production and economic efficiency followed closely by increased profitability and productivity, as well as reduced labour costs and fewer material and technical resources (Table 2.13).

Table 2.13
Main reasons for technology adoption (average response score)

Groups	up to 250 ha	250–500 ha	500–1000 ha	1000–2000 ha	2000–5000 ha	5000–10 000 ha	Total
Labour cost reduction	2.9	3.6	3.6	3.2	3.8	4.1	3.5
Profitability increase	3.1	3.7	3.3	2.5	3.7	3.6	3.3
Input cost reduction	2.8	3.2	3.5	3.3	3.6	3.3	3.3
Yield increase	2.8	3.6	3.1	2.6	3.0	3.1	3.0
Improving the production chain control system	2.1	2.8	2.9	2.2	1.9	3.3	2.5
Environmental aspect	2.0	2.7	2.8	1.7	2.0	2.8	2.3

SOURCE: FAO Survey conducted for this report

The lowest motivations for investment relate to positive environmental impacts and expected improvements in control of the production chain. During interviews, farmers using PATs did mention significant improvements in field ecological conditions due to more careful use of resources and improved soil treatment.

Better administrative and production control was a strong motivating factor for larger farmers. Sensors allow precise monitoring of input use and can detect theft of these, the most significant factor for large farmers with more than 2000 ha.

Duration of technology application

Application of the technology for most respondents using PATs is in its initial stage, 58 percent have used it for less than five years (Table 2.14) while the distribution of respondents by duration of use is uniform.

Table 2.14

Experience in PAT technology use depending on farm size (percentage of respondents)

Group, %	up to 250 ha	250–500 ha	500–1000 ha	1000–2000 ha	2000–5000 ha	5000–10 000 ha	Over 10 000 ha	Total
Starting to use	17	8	9	12	5		50	10%
Experience of 1–5 years	48	67	63	62	52	63		58%
Experience of 5–10 years	26	17	22	15	29	38	50	24%
More than 10 years	9	8	6	12	14			8%

SOURCE: FAO Survey conducted for this report

Area of technology application

In terms area of use, about 60 percent of respondents declared 100 percent technology coverage of their land. For those with land area over 1000 ha, this was 50 percent of respondents.

Since they are multicomponent it was not possible to assess the application area of individual PATs. The response to this question is highly subjective since technology use is determined by respondents' understanding of it. Widespread use of precision positioning systems, GPS and RTK (FarmingUK, 2021), by one entity with an autocontrol system can be considered 100 percent penetration. For another, basic implementation assessment begins with accurate electronic field maps and analyzing soil quality as the basis for further application of the technology, to realize its full potential.

Application of the technology

For respondents, PATs related to sowing, fertilizing and plant protection are the most sought after, to reduce input and production costs. Operations in monitoring, analysis and forecasting are considered the least needed areas of technology, less than 18 percent of respondents use such tools (Table 2.15).

Table 2.15

Use of PATs in specific field operations (percentage of respondents)

Groups	up to 250 ha, %	250–500 ha, %	500–1000 ha, %	1000–2000 ha, %	2000–5000 ha, %	5000–10 000 ha, %	Total
Sowing	65	33	75	81	81	88	73%
Fertilizer application	70	58	66	65	76	75	69%
Introduction of pesticides/ plant protection	65	42	69	54	81	56	64%
Soil treatment	61	33	59	50	71	44	55%
Harvesting	17	8	19	19	38	31	23%
Monitoring, analysis and forecasting	13	17	13	15	29	25	18%
Irrigation	4	8	3	12	10	6	7%

SOURCE: FAO Survey conducted for this report

Application of individual elements of PATs

Analysis of the elements of the technology based on the survey results may indicate varied understanding of it. PATs is based on managing the productivity of each plot in a field, using digital field maps. Among enterprises with a land area up to 500 ha, only 11 percent of respondents used such maps (Table 2.16) but the larger the farm, the more frequently they are mentioned.

Slightly more than 25 percent of respondents, mainly those with land up to 500 hectares, used variable resource application (fertilizers, seeds and plant protection products) but without using electronic field maps nor auxiliary autocontrol systems.

Table 2.16

Use of PAT components by farm size (percentage of respondents)

Groups	up to 250 ha, %	250–500 ha, %	500–1000 ha, %	1000–2000 ha, %	2000–5000 ha, %	5000–10 000 ha, %	Total
Precision positioning systems (GPS, RTK)	51	53	71	77	86	91	78%
Auxiliary auto control systems	20	25	55	69	71	86	61%
Digital field maps	9	17	59	67	73	89	59%
Variable rate seeding	48	33	75	54	43	63	56%
Variable rate fertilizer application	43	33	59	50	52	63	52%
Variable rate pesticide application	26	42	59	42	52	81	51%
Analysis and mapping of soil quality	13	15	16	23	43	56	28%
Differential tillage	26	8	22	27	38	19	25%
Yield mapping	4		9	12	14	25	11%

SOURCE: FAO Survey conducted for this report

A significant number of respondents who use PATs on their farms, may not be using it at the moment. Analysis of technologies used by most respondents with up to 2000 ha indicates low understanding of the concept of PATs.

The most sought technologies are precise driving (direction indicators, autosteering and autopilots), automatic disabling of application equipment, as well as the simplest to implement. Panel interviews indicate farmers often perceive driving technologies as VRA enabling .

The most commonly used technologies are precision positioning systems, digital field maps, soil quality analysis, autocontrol and VRA. Four out of ten companies use VRA, the other three are piloting it and the remaining three are preparing phased application of PATs by conducting audits.

Many large agrarian companies admit PATs has given them the impetus to transform their entire agricultural production and management systems. For a number of large companies, such as Kernel, MHP, and HarvEast, PATs are indispensable elements of their management systems.

Application of auxiliary precision farming elements

Monitoring and analysis are among the main elements of PATs but are not widely used. This confirms the observations that a significant number of respondents do not understand PATs. Slightly more than 11 percent of surveyed enterprises use remote sensing, but 19 percent use monitoring and yield forecasting tools (Table 2.17).

Table 2.17
Use of auxiliary elements of precision farming (percentage of respondents)

Groups	up to 250 ha, %	250–500 ha, %	500–1000 ha, %	1000–2000 ha, %	2000–5000 ha, %	5000–10 000 ha, %	Total
Remote sensing			13	8	19	25	11%
Yield monitoring and forecasting	3	-	16	23	24	38	19%
Auxiliary sensors, weather stations	4	17	22	19	24	38	21%
Specialized software applications	5	8	19	1	24	19	17%
Control and analysis centres				4	5	6	3%

SOURCE: FAO Survey conducted for this report

Remote sensing tools

As noted, only 11 percent of respondents use remote sensing elements while 60 percent rely on satellite images and 80 percent use aerial photographs for remote sensing.

Involving service companies in analysis and development of recommendations

PATs generate significant amounts of information which require sophisticated analysis and respondents were asked about their attitude to outsourcing this work to third party service organizations (Table 2.18).

About 77 percent gave a negative answer concerning possible interest in such services, relying instead on their own expertise. Six percent of respondents use service support at implementation stage but only 17 percent do so on a regular basis. Interestingly, respondents stated lack of professional staff as a significant barrier to implement PATs: rated 3.0 as a barrier to implementation.

Table 2.18

Use of third party services by farm size (percentage of respondents)

	Group, %	up to 250 ha	250–500 ha	500–1000 ha	1000–2000 ha	2000–5000 ha	5000–10 000 ha	Over 10 000 ha	Total
NO	Own expertise suffices	83	75	75	77	52	56		70%
NO	Such service is absent	9	8	3	4				4%
NO	Not ready to provide information			6		5	6		3%
YES	Use on a regular basis	9		16	15	29	25	100	17%
YES	Used only at implementation stage		17		4	14	13		6%

SOURCE: FAO Survey conducted for this report

Farmers implement innovations through pilot projects and respondents noted some of the declared parameters from the use of technologies (not only precision farming) are either not achieved or do not deliver the expected results.

EFFECTS OF TECHNOLOGY IMPLEMENTATION

Perceived benefits

As previous survey results show, the main motivation for using PATs is cost efficiencies and respondents' expectations are mostly justified – 37 percent confirmed that the "application of PATs makes me more technologically effective" (Table 2.19).

About 22 percent of answers related to the objective that “data collection systems give me more information about the productivity of my farm”. Respondents rated “assistance in making better decisions” or “new ways of management” significantly lower: 16 percent and 17 percent, respectively.

Table 2.19

Main objectives for PAT introduction by farm size (percentage of respondents, each limited by the maximum of two objectives)

Groups	up to 250 ha, %	250–500 ha, %	500–1000 ha, %	1000–2000 ha, %	2000–5000 ha, %	5000–10 000 ha, %	Over 10 000 ha, %	Total
Application of PATs makes me more efficient	39	31	37	35	40	33	33	37%
Data collection systems give me more information about the productivity of my farm	18	13	24	28	21	17	33	22%
Intelligent software and collected data help me make better decisions	15	13	13	15	21	19	0	16%
Application of the technology allows me to create new ways of management and control on the farm	15	25	21	15	10	22	0	17%
Cannot answer	12	19	6	8	7	8	33	9%

SOURCE: FAO Survey conducted for this report

Analysis of expected benefits

The results showed production efficiency indicators from use of PATs met farmers' expectations. Reducing the cost of inputs and labour received the highest score, 4.5 while yield increase was the third major advantage, scoring 4.4 (Figure 2.16).

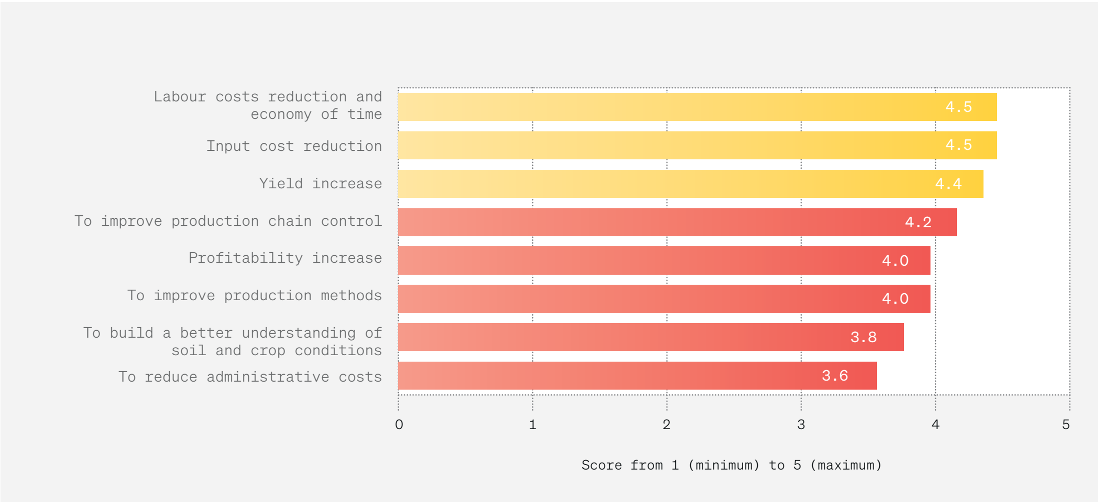


Figure 2.16
Main benefits from using PATs

SOURCE: FAO Survey conducted for this report

The economic justification of PATs is to increase profitability for farmers through maximum productivity (yield) and reducing the cost of inputs. Despite respondents' fairly high scores in these areas, their assessment of the benefits from increased profitability turned out to be lower: only 4.0, suggesting expectations on the economic effectiveness of the technology are overrated.

There were similar responses from those with agricultural holdings. Despite positive ratings on the use of PATs in general, overall economic effect (increase in profitability) was also rated 4.0.

Experience of using the technology

The majority of respondents assigned a high score for level of satisfaction in using PATs with an average of 4.2 out of 5 (Figure 2.17).

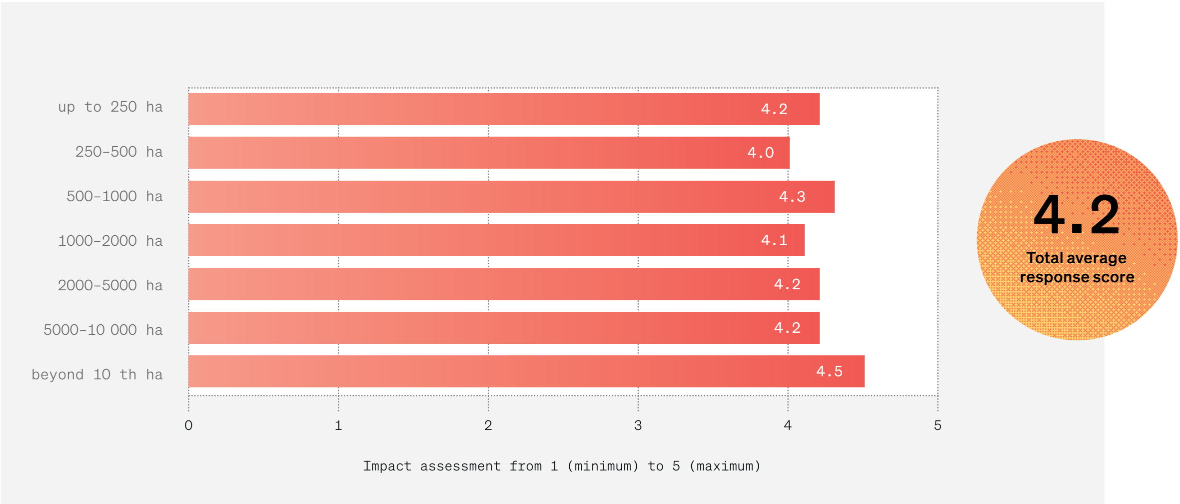


Figure 2.17
Rating experience of technology use

SOURCE: FAO Survey conducted for this report

Challenges in technology application

High initial capital expenditure costs are the main barrier to PATs' adoption (Figure 2.18) as well as high operating costs (maintenance and advisory services): 4.2 out of 5.0. Other challenges include inadequate staff qualifications, equipment compatibility and lack of technical support and system maintenance (3.9 and 3.8).

Regarding the effectiveness of technology application, farmers already using PATs had fewer difficulties: 2.7, correlating with answers on their benefits. However, farmers may not fully understand the modularity of PATs which may influence responses on benefits.

Assessing the effectiveness of PATs can often be based on the respondent's perception of the technology, without economic modelling to support it. Most respondents admitted they did not assess the economic effect of introducing elements of PATs based on cost benefit analyses.

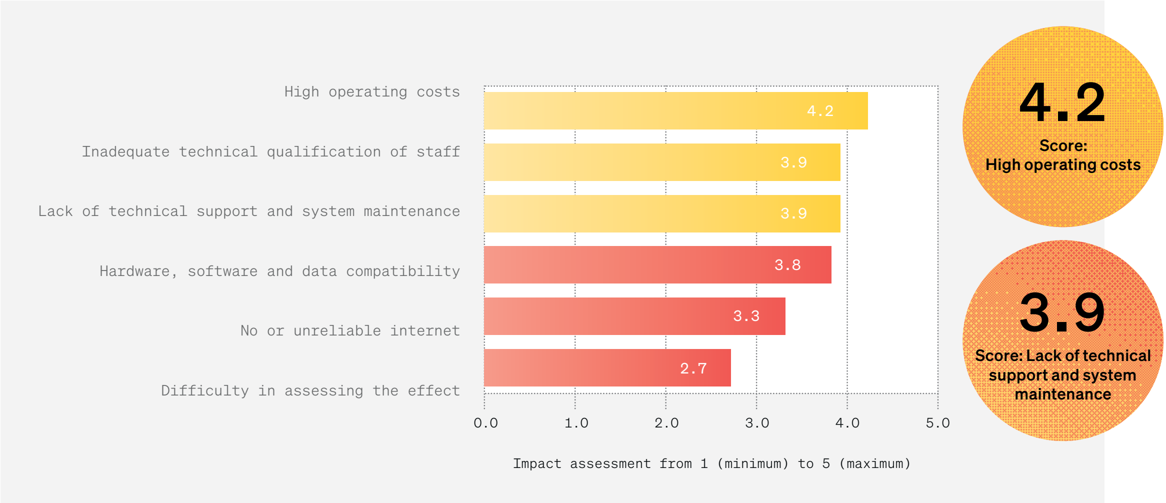


Figure 2.18
Main difficulties in introducing and applying the technology

SOURCE: FAO Survey conducted for this report

Technology investment plans

The results demonstrate that 51 percent of PATs' users are inclined to further invest in the technology (Figure 2.19) with a clear correlation of positive responses with the holding size, starting from 2000 ha. The low rate in the group of up to 250 ha, 34 percent, is explained by heavy initial investments, which do not meet expectations in the short term.

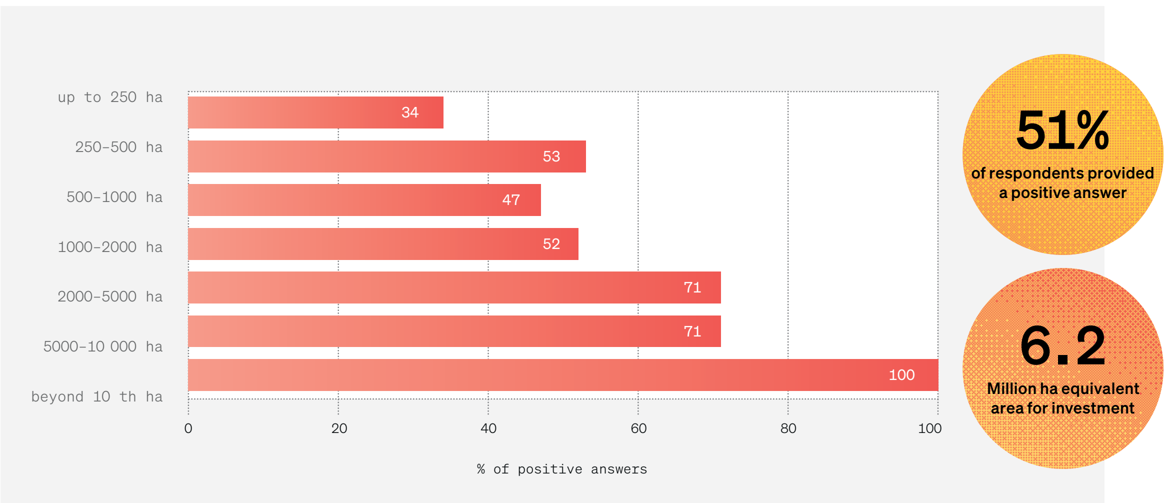


Figure 2.19
Investment plans in PATs

SOURCE: FAO Survey conducted for this report

INCENTIVES STIMULATING PATS' DEVELOPMENT

Incentives for technology development

Traditional methods of agricultural production in Ukraine are still proving their effectiveness. Therefore, further development of PATs depends directly on market demand and understanding the needs of potential clients, their characteristics and expectations.

The survey shows the main constraint on a more active application of PATs is the high cost. A major incentive could be a 10 percent cost reduction, as well as government implementation programmes (3.7) (Figure 2.20)

A third important incentive for farmers is confidence in achieving final results, respondents rating 3.4 for "Confidence that my costs will be reduced" and 3.1 for "Confidence that productivity will increase". This suggests propensity to invest is correlated to understanding the benefits of precision agriculture.

These conclusions differ significantly for farms over 5000 hectares, as well as agricultural holdings which are likely to be using the technology and have an idea of its effectiveness. Incentives are therefore more closely related to better services and data protection. The opposite situation is the case for farms up to 250 ha, which declared a low rating for almost all incentives, ranging from 2.0 to 3.0.

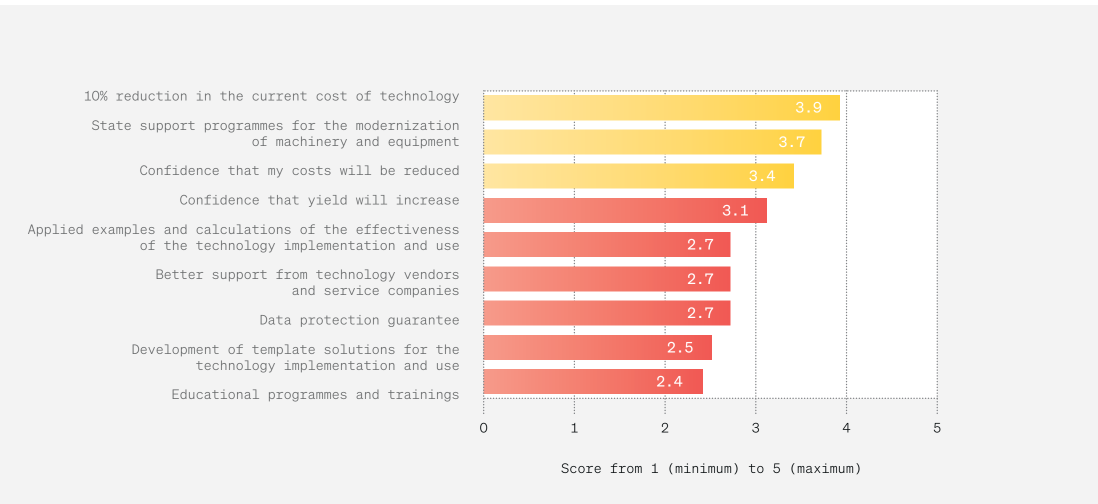


Figure 2.20
Incentives for uptake or expanding the use of PATs

SOURCE: FAO Survey conducted for this report

CHALLENGES HINDERING ADOPTION AND RECOMMENDATIONS TO STIMULATE UPTAKE

1 There is a lack of knowledge and understanding of the technology as a whole and its potential benefits

Farmers in Ukraine are open to innovative technologies – 56 percent of respondents follow innovation trends but small land users (up to 250 ha) have the least interest in innovation – only 38 percent.

More than 80 percent of farmers are aware of PATs and 28 percent of them use the technology. At the same time, a deeper analysis of respondents' answers may indicate limited understanding of the technology so that the percentage of respondents who use PATs can be reduced to 15–17 percent. A lack of knowledge and evidence of the effectiveness of PATs may discourage further investment, leading to general scepticism so that PATs continue to be the niche of the "innovators" with a widening gap between "innovators", mainly large farms and "conservatives", primarily small farmers.

Recommendations: Solutions based on easy-to-use tools are necessary with investment in awareness and knowledge sharing, to enhance farmers' financial and digital literacy, so they can determine the costs and benefits of precision farming. Involving them in developing technologies and tools for precision farming can expand their knowledge and contribute to easier implementation of PATs and transfer knowledge and technology between farmers. Sharing experiences between farmers, including participation in conferences and exhibitions, is considered the most relevant and objective source of technology information.

2 Challenges in estimating returns on investment

According to the survey, a high initial investment is the main deterrent to technology penetration. In estimating ROIs, all farmers said the high initial cost is a significant barrier.

The second greatest deterrent is the uncertainty about the effects of technology but the bigger the enterprise the less significant this factor as larger farmers are more aware of the potential of the technology. It is difficult for farmers with small facilities to identify the potential benefits of PATs' investments in equipment, data sensors and software. The benefits are not always obvious, since it is not always easy to estimate the ROI and other benefits, such as environmental impacts, are difficult to quantify and likely to be neglected. Farmers can monetize emission reductions through these technologies, thus qualifying for carbon marketplaces; see Chapter 3. In addition, there are concerns that their use can lead to other difficulties and new technical problems as many small farmers believe PATs are not applicable to them. Most farmers need a clear assessment of the potential benefits of precision farming before they are introduced.

Recommendations: It is necessary to create demonstration fields to display the benefits of using PATs. Computer simulation models and analytical decision support systems may already exist, but they may not be promoted, nor readily available to farmers, technology integrators and researchers. The models for testing potential benefits must be easy to use and based on practical decisions made in agriculture. Adapting the technology to demand may increase costs, but it is important that precision technologies are to a certain degree segmented to different farm sizes, the desired technology hierarchy and precision levels. Farmers can then obtain a more accurate picture of costs and benefits. Introducing the technology should occur in stages, gradually increasing the level of complexity, to avoid large investments at the start. Integrating PATs into educational programmes, awareness building and training can be the key to success. This should include the private sector so farmers can gradually adopt technologies, challenging the common perception of precision farming as a high cost, complex set of tools, more suited to large farmers.

3 Technology integrators, outsourcing and skilled staff shortage

PATs require specialized skills and prompt and high quality analysis at implementation and application stages. The majority of respondents, 77 percent, have a negative attitude to third party service organizations carrying out this work, as they said they had sufficient skills themselves to uses PATs, a claim which appears unlikely.

According to the panel interviews, market participants noted high quality outsourcing services for PATs are inadequate. One of the reasons is the reluctance of Ukrainian farmers to pay for such services, primarily because they are sceptical about their quality.

The lack of specialized staff is also a barrier to further technology penetration, its significance for decisions on PATs' investments being rated in the survey at 4.0.

Technology application in Ukraine being fairly recent, there are already a number of farmers with a negative experience of applying PATs, arising from their own lack of knowledge and with technology integrators that offer solutions which are unrelated to the actual needs of farmers. Many technology integrators market and sell PATs, without considering customer value aspects. Sales companies propose technology elements but often do not outline possibilities for interconnections between those technologies, without which an effective result is practically impossible. If sales companies and integrators develop and customize solutions to various farm sizes and revenue levels, this will give more visibility to ROIs and help farmers understand better the costs and potential benefits of PATs The second constraining factor is a shortage of skilled staff. PATs involve a new range of skills: data scientists for data analysis; IT engineers to develop algorithms; a digital operator for drone control and GIS analysis and so on. Development of PATs knowledge and skills in Ukraine lags behind their development globally.

Recommendations: It is necessary for the private sector to present solutions adapted to the market and the needs of farmers. Outsourcing institutions can make PATs a more attractive prospect as a way to support farmers applying them. They can also offer farmers independent knowledge and experience as opposed to working with technology companies whose aim is to sell their products along with support. PATs integrators should use BDS and incubator services to adapt business and marketing models to market demand. Given the Ukrainian business environment, independent consulting institutions may not deliver the desired effects. Alternatively, PATs integrators could adapt business models to agricultural enterprises that use appropriate technologies with relevant educational and vocational programmes.

2.3 REMOTE SENSING TECHNOLOGIES

2.3.1 Application of remote sensing technologies in agriculture

Agriculture is one of the most promising areas to apply remote sensing, especially in crop production and land control. Multispectral and hyperspectral aerial and satellite imagery create Normalized Difference Vegetation Index (NDVI) maps, which can distinguish soil from grass or forest, detect plants under stress and differentiate between crops and crop stages (FAO, 2018a). The main areas of remote sensing application are the following:

- identify land information, areas and land boundaries;
- land control regarding soil characteristics, erosion indicators and ecological conditions;
- assess and forecast crop conditions, development and productivity;
- monitor soil cultivation practices and agrotechnological operations;
- monitor and verify state support and subsidy distribution;
- use of geodata for digital credit scoring;
- measure carbon stocks in the soil.

Spatial and temporal variations at field level render it challenging to measure carbon changes in the soil. Variations can include diverse management practices (tillage, application of fertilizers and irrigation), soil types, crop biomass, variegated climates, seasonality and different crop lifecycles. There is an absence of reliable databases for aggregated data on GHG emissions and soil carbon stock changes (Bispo *et al.*, 2017). Rapid, accurate and cost-effective technologies, such as remote sensing and field based infrared spectroscopic measurements, could enable frequent, large-scale monitoring of soil carbon data. Remote sensing collects management activity data including tillage practices, crop types and productivity levels, to be used as inputs for data simulations and for collecting more accurate local data (Paustian, 2020). Combining direct plot measurements and modelling can help determine the efficacy of land management practices in soil carbon sequestration (Smith *et al.*, 2020).

Satellites can also provide detailed data at scale to drive systems and models in monitoring carbon stocks and exchange with more efficient data sampling in optimizing nitrogen application and irrigation. National Aeronautics and Space Administration (NASA) Harvest is launching a Sustainable and Regenerative Agriculture initiative to respond to industry's need for scientific carbon neutrality efforts (Nasa Harvest, 2020). The costs of designing and implementing soil carbon sequestration systems vary considerably and depend on farm size, topographic conditions, spatial variability and minimum detectable changes as well as whether individual or composite samples are analysed together. Sampling costs can range from USD 2–3/ha (Karky and Kutsch, 2010) to USD 17–28/ha (Mudge *et al.*, 2020). Euroconsult estimates the global remote sensing data and services market is worth USD 4 billion with agriculture comprising 35–27 percent and is expected to grow to USD 8.5 billion by 2026 (Euroconsult, 2021). Most of this is in the United States of America, the European Union ranks second. For further information on policy and application of remote sensing, please refer to Annex III: Policy development and application of remote sensing in the United States of America and the European Union.

Globally, public-private partnerships (PPPs) can prove to be key to unlock and collect ground data. NASA Harvest launched an initiative in partnership with Swiss Re, to collect global yield and data of major crops across production and export countries. The partnership relies on the Green Chlorophyll Vegetation Index (GCVI), a satellite derived metric to distinguish between fields with different yields. In 2018 the partnership accounted for a variation greater than 70 percent in wheat yields, saving up to 20 percent of the costs of collecting crop cuts, reducing them by 50 percent in Ukraine (NASA Harvest, 2020). GEOGLAM Crop Monitor provides monthly information on global crop conditions with 40 contributing partners, the first instance the international community came together to produce crop assessments. Global forecasts have a 3–5 percent margin of error and can be executed two months prior to harvest, while national forecasts have a 3–8 percent error margin and can take place 1.5–2 months before harvesting. The error margin for subnational forecasts is 8–14 percent, implemented 1.5–2 months before harvest (Nasa Harvest, 2020). PPPs and global initiatives support cost-efficient efforts to produce accurate ground data, not only for yield forecasting, but to provide the data to measure the effects of sustainable regenerative agricultural practices.

2.3.2 Remote sensing in Ukraine

The main organization responsible for all space-related activities in Ukraine, including remote sensing, is the State Space Agency of Ukraine (SSAU) which implements the National Scientific and Technical Space Programme. One of its tasks is earth remote sensing from outer space. This includes monitoring a range of conditions, including: snow melting, quantity of precipitation, dust storms, drought, maps of agricultural crops freezing, monitoring spring and general flood emergencies, fire outbreaks, geophysical phenomena and technological explosions (State Space Agency of Ukraine, 2018). Remote sensing is therefore not limited to monitoring agricultural conditions and as a result there is no separate funding for remote sensing in agriculture. UAH 130.4 million (USD 4.6 million) funded the activities of the Programme in 2018 with UAH 76.8 million (USD 2.7 million) approved for remote sensing from outer space (State Space Agency of Ukraine, 2018).

Ukrainian law defines remote sensing of the Earth as obtaining data about the planet's surface by aerial photography or observation and measurement from space. One of the law's goals is to collect country-level information from space (Verkovna Rada, 2021) but it does not cover remote sensing activity to regulate the space information market in Ukraine. A 2013 government regulation on remote sensing of the Earth has yet to be adopted (Verkhovna Rada, 2020).

Other regulatory legal acts reflect remote sensing such as the SSAU 2015 decree on its strategy to meet the public need for space information systems (Verkhovna Rada, 2015).[24] Among the challenges to be addressed is the insufficient regulation of "remote sensing technologies for the implementation of state tasks for monitoring emergencies in the agricultural sector, subsurface use, eco-monitoring, land and forest management, national security and defence." Legislative steps should enhance coordination between the SSAU and remote sensing users, including agricultural holding managers and farmers. The space strategy to 2022 should also make available real-time data on agricultural conditions for all private and public users with support in interpreting and managing data.

24 Authors' analyses of legislation

At state level, there has been little use of remote sensing for agriculture managerial decisions with just a few collaborative initiatives such as the Memorandum between the Ministry of Agrarian Policy and the SSAU, of 5 June 2015. This supports best SSAU practices and methods for yield forecasts, assessing the quality of agriculture practices and identifying illegal crops. This provides free monthly maps indicating moisture content, snow cover, vegetation, damage to vegetation cover etc.

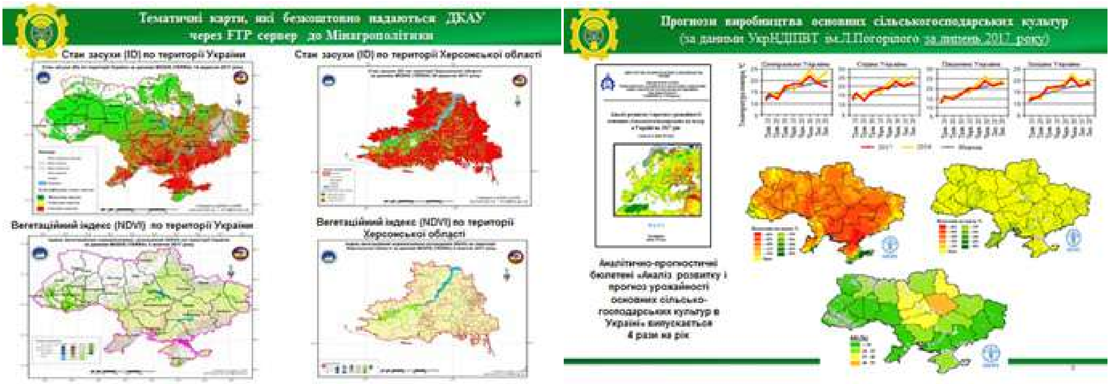


Figure 2.21

Complimentary thematic maps granted by the State Space Agency of Ukraine to the Ministry of Agrarian Policy through FTP server

SOURCE: Ministry of Agrarian Policy of Ukraine. 2019. Quarterly bulletin of: Analysis of development and forecast of productivity of the main agricultural crops in Ukraine.

The Ministry of Agrarian Policy also publishes a quarterly bulletin: Analysis of development and forecast of productivity of the main agricultural crops in Ukraine developed by the Ukrainian Research Institute for Forecasting and Testing of Machinery and Technology for Agricultural Production after L. Pohorelov (Ministry of Agricultural Policy and Food of Ukraine, 2019).

These maps rely on open source data from international organizations such as FAO, so these examples illustrate the limited use of satellite monitoring for managerial decision-making in agriculture at state level. Donor organizations funded a number of pilot projects in space remote sensing technologies such as European Union and World Bank support for a satellite project to monitor agricultural land use. A North American-Ukrainian company, EOS, ran the project with the help of remote sensing space technology. It analysed the land cover of Earth's surface using space monitoring data, to create a map of agricultural crops, determine the exact boundaries of fields and highlight the main types of coverage from 2016 to 2018 (Earth Observing System, 2019). It also identified inconsistencies in cadastral data and data on the lack of crop rotations.

The assessment of using satellite data for crop area estimation jointly prepared by the Space Research Institute of Ukraine of the SSAU and National Academy of Sciences of Ukraine, with foreign partners, found that only MODIS and Landsat-5/TM were cost-effective while AWiFS, LISS-III, and RapidEye images were not.

As well as increasing transparency and efficiency of land management, satellite monitoring could help develop the agricultural insurance market, estimated to be USD 50 million (Interfax-Ukraine, 2019). Realising the potential of state management decisions requires remote sensing regulation, as well as a state strategy on its application.

The private sector already has considerable experience in remote sensing in particular:

- measuring boundaries, use of land plots, field history;
- monitoring the condition of sown areas, estimation of losses from negative natural factors, yield forecasting;
- controlling agricultural activities.

Both small farmers and large vertically integrated enterprises use satellite monitoring. The following operators provide remote control services in Ukraine:

- Cropio (Syngenta, 2021): monitoring of cultivated areas, autodocumentation, forecasting and planning agricultural operations;
- ArpoOnline (Agro Online, 2021): developer of advanced solutions in agricultural enterprise management, including satellite monitoring;
- Geosys (Geosys, 2021): international company specializing in field precision farming and information technology; provides a full range of services to monitor vegetation of crops, risk management, creating fertilizer maps;
- Earth Observing System (EOS) (Earth Observing System, 2021): provides a comprehensive analysis of aerospace images; in 2018, won a tender for satellite monitoring of crops and land use within the World Bank and European Union programme: Support for transparent land management in Ukraine.

2.3.3 Opportunities and recommendations to support adoption of remote sensing technologies

Agriculture is one of the most promising areas for remote sensing to assess crops, land control and crop productivity, monitor management practices, verify state support and subsidy distribution and for carbon stock measurement. The United States of America and the European Union have used remote sensing for multiple purposes and have developed legislative frameworks to support this.

In Ukraine, the SSAU is responsible for all space-related activities including remote sensing. However, this is not limited to monitoring agriculture and as a result, there is no separate funding programme for remote sensing in agriculture. Legislation is necessary for coordination between the SSAU and end-users of remote sensing, for real-time data availability and interpreting data and satellite images.

The 2015 Memorandum between the Ministry of Agrarian Policy and the SSAU in 2015 produced maps of various agricultural conditions. However, remote sensing and satellite monitoring have not been used extensively for state decision-making on agriculture. Other opportunities relate to combining direct measurement (remote sensing) and modelling to monitor soil carbon stock changes and determine the efficacy of different land management practices to enhance soil carbon sequestration.

2.4 DISTRIBUTED LEDGER TECHNOLOGIES

2.4.1 Introduction and application of distributed ledger technologies

Distributed ledger technologies and more specifically, blockchain comprise a digital database that uses cryptography to link and secure transactions and data entries. It disintermediates data processing and storage within a peer-to-peer network of computers to validate and store transaction history and information (FAO, 2018b).

The technology was developed as the basis for the Bitcoin payment network. Over the last ten years, blockchain has evolved beyond cryptocurrency and according to the Rising Blockchain Journal, blockchain is applied in 24 industries: government services, financial markets, medicine, logistics, insurance (Tabernakulov and Kuifmann, 2019). The International Data Corporation (IDC) states global expenditure on blockchain solutions in 2019 outside cryptocurrencies reached USD 2.7 billion and by 2023 may exceed USD 15.9 billion (IDC, 2021).

Globally, despite a number of pilot projects, blockchain technology is still considered in its early stages with very few practical or large-scale projects. This is largely due to regulatory uncertainty, lack of trust, operational difficulties, inability to scale and audit/compliance concerns (PwC, 2018). Private companies have run more blockchain projects over the past few years (McKinsey, 2018).

Implementing blockchain in business requires extensive knowledge, such as security, law and organizational and business process structuring. Companies using blockchain often have to change their structure, as traditional processes may not comply with its basic principles. According to a survey by The Gartner (May, 2018), 14 percent of companies implementing blockchain had to make fundamental changes in their business models (Yushchenko, 2018) and almost 20 percent of these noted a critical lack of specialists in this field.

The growing corporate interest in blockchain has driven changes to the technology to develop and change, originally developed as an autonomous system, with extremely limited interaction with the outside world. For the purposes of state or corporate use, integration into existing information systems is fundamental. For both corporate and public sectors, blockchain can provide a reliable and trusted environment to store and disseminate data that do not require multilevel verification or complex access control procedures. Blockchain can be reduced to three system areas:

1. **Cryptocurrencies** Cryptocurrencies remain the main driver of the blockchain industry and most of the promising innovative solutions are produced by independent cryptocurrency developers.

2. **Smart contracts** These are the second most popular funded area for blockchain. Legally, the essence of a smart contract is fulfilling an agreement between two or more parties according to predefined conditions (computer algorithm). It works without the direct participation of the parties through transactions or other actions that are performed using software tools.

3. **Digital registers** The inability to change data in blockchain makes this technology extremely attractive for use in any registers, both public and commercial. Transferring information from state registers to blockchain technology can significantly accelerate all internal processes and minimize the risks of distorting information or replacing documents.

Among these blockchain system areas, smart contracts offer cost reductions in investment and retail banking, as well as the insurance industry. In investment banking, smart contracts can shorten settlement cycles of syndicated loans from 20 to 6–10 days in the United States of America and Europe. In retail banking, smart contracts could save consumers USD 480–960 per loan and banks could annually save USD 3–11 billion in the United States of America and European markets (Capgemini Consulting, 2016). Smart contracts in the motor insurance industry could potentially generate USD 21 billion in annual savings through reduced overheads in claims handling (Capgemini Consulting, 2016).

Implementing a smart contract is largely determined by the presence of established rules in the location where the contract is applied. Where chaos and uncertainty prevail, smart contracts can serve as a basis to restructure operations and systems. Prior to implementing smart contracts it is important to break down the costs and prioritize those that are costly. Not all contracts need to be converted into smart ones and for some the benefits of automating processes may not be sufficient to justify investment. Internal contracts with underlying trust or where disputes can be resolved more easily, should not have priority over those with external parties. Low frequency, but more complex contracts that take longer to execute should probably also take precedence (Global Trade, 2020).

2.4.2 Application of distributed ledger technologies in Ukraine

Overview of national blockchain operators

According to a survey by the Blockchain Association of Ukraine (BAU) there are about 100 companies and projects in the blockchain industry. Most companies were formed in the wake of the rise in cryptocurrency value in 2017. In 2017–18, companies with Ukrainian origin created 25 cryptocurrencies with the funds raised through ICO (initial coin offering) amounting to more than the equivalent of USD 99 million. In Ukraine cryptocurrency mining volume exceeds USD 100 million per year (BRDO, 2018).

Out of 58 blockchain companies surveyed by the BAU in 2019, 78 percent are focused on Ukrainian and global markets, 16 percent are in foreign markets but only one company operates solely in Ukraine. The survey confirmed 60 percent of the industry players consider systemic development of blockchain as necessary, while 48 percent indicated the need for financial support and investments (BAU, 2019). Bitfury, one of the pioneers in the global blockchain industry, has Ukrainian roots and is considered the first to implement the transfer of the state register to blockchain, with the project of converting the land cadaster of Georgia to blockchain. In 2017, the company introduced its own Exonum blockchain platform for deploying private blockchains, which could become a competitor to Hyperledger Fabric and R3 Corda. For a more detailed overview of the blockchain operators in Ukraine, see Annex IV.

Government regulation

Blockchain as a digital register in public services is one of the most promising areas of technology application although there are no international standards to regulate it nor in Ukraine. Throughout the development of cryptocurrencies, the Parliament of Ukraine introduced a number of draft laws aimed at addressing legal challenges to the cryptocurrency market, and expectedly, were unsuccessful. However, in May 2020 the Ministry of Digital Transformation (MDT) launched a public consultation about the draft law on virtual assets. It sets out to define: (i) the legal status of virtual assets; (ii) issuance rules; (iii) the relevant regulator and scope of its powers; and (iv) liability for breach of conduct of business rules (Hlotov, 2020). The draft law defines MDT as the key governmental policymaking and regulatory body.

In countries planning to develop blockchain technology, there is a regulatory framework in several interrelated areas: crowdfunding regulation, digital assets, electronic notaries and smart contracts. Although there is progress in defining virtual assets, legislation in Ukraine does not define a smart contract or its requirements. As a result, most possibilities for blockchain technology remain outside the legislative framework, including smart contracts, an important enabling condition for blockchain. There is regulation of electronic contracts and according to the Civil Code of Ukraine, an electronic agreement is equivalent to a written agreement and if possible, should be reproduced in visual form.

Smart contracts are drawn up in a programming language, a format not amenable to human perception and therefore, in accordance with current legislation, a smart contract cannot be recognized as an electronic contract.

With a budget of USD 35 million in 2021, the MDT planned to focus on: (i) electronic identification; (ii) e-democracy; (iii) electronic trust services; and (iv) electronic document management platforms (Ministry and Committee for Digital Transformation of Ukraine, 2021). The last two areas may support implementation of blockchain. Despite progress in defining virtual assets through the MDT draft law, no legal framework exists to deploy blockchain in the areas of state registers, smart contracts or crowdfunding.

Despite the lack of legislation the public sector has initiated several pilot blockchain projects: the seized property auction system (SETAM), the Geocadastre and the Property Rights to Real Estate Register.

Although Ukraine holds a leading position in the world grain market (in 2018/2019 it supplied 50 million tonnes of grain), in organizing and structuring business processes, the Ukrainian grain market is still underdeveloped. The Ministry of Agrarian Policy estimates “shadow” grain turnover at 20 percent of the total volume. According to market operators, these estimates are optimistic and the real “shadow” grain sales are likely to be higher. Secondly, despite global trends in digitalization, the majority of trade and non-trading operations between entities in Ukraine are mainly on paper but often not formalized, significantly reducing scope for using smart contracts. Enforcing contracts in Ukraine remains a challenge even those that rely on government central registers for agrarian receipts, pre and post-harvest financing or warehouse receipts. Out of 4907 agrarian receipts in August 2020, about 30 contracts were contested in court often with claims over the legitimacy of receipts, signatures or even notarial writs that enforce execution of claims (Ministry of Economy, Trade and Agriculture, 2021).

Trade finance blockchain solutions

TradeLens (IBM and Maersk) is one of the largest blockchain platforms in logistics, covering more than 100 organizations within its ecosystem (Figure 2.22) (TradeLens, 2021). In addition to advantages for all ecosystem participants in cost reduction and accelerating cargo flows, the blockchain platform focuses on promoting and adopting common industry standards.

Figure 2.22
Map of trade ports and terminal network in tradelens ecosystem

SOURCE: TradeLens, 2021. Ecosystem. www.tradelens.com/ecosystem

NOTE: Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties. Final boundary between the Sudan and South Sudan has not yet been determined.

In 2020 the Customs Service of Ukraine joined the TradeLens blockchain platform in a test to track the logistics and documentation of containers, arriving in Ukraine.

Potential benefits of joining TradeLens blockchain platform (State Customs Service of Ukraine, 2021) are:

- the ability to track the logistics of each container online in real time; all ecosystem participants can access information and are free to share it;
- reduced container transportation risks; the State Customs Service can analyse information about transport of goods from the moment the order appears; this will increase the transparency, efficiency and security of container logistics;
- low risk cargos can clear customs through ports faster; the block chain platform can also signal goods that require careful verification;
- increased transparency of customs clearance for maritime cargo.

Other blockchain trade finance platforms that have moved beyond proof of concept and pilot stages include Komgo, We.trade, Marco Polo and Contour.

Application of blockchain in agriculture and grain trading

Over the past few years, a number of agribusinesses have announced plans or tested various blockchain solutions to guarantee traceability of agricultural commodities and products. In 2018 the Barilla Group collaborated with IBM to develop a pilot project using blockchain to guarantee the origin and quality of products and raw materials, from the field to the end consumer (Forbes, 2019). The project first applied to fresh Italian basil and expanded to other agricultural commodities, including cereals, tomatoes and milk. Other notable examples for using blockchain to support traceability include Carrefour Italy, the first retail company operating in Italy to utilize blockchain for product traceability, starting with poultry products and then citrus (BNT Bitnews Today, 2018). The Red Orange Consortium of Sicily developed a blockchain tool to prevent food fraud and enable consumers to check production field, date of harvest, storage methods and distribution of citrus products, through a smartphone scan (Forbes, 2019).

BOX 2.2

NGO FAIRFOOD – INCREASING SUPPLY CHAIN TRANSPARENCY

NGO Fairfood (Fairfood, 2021) uses processes supported by blockchain in improving smallholders' income in several value chains such as coffee, coconut, tomato, shrimp, pineapple, vanilla and cane sugar. Nestlé, in collaboration with OpenSC, is piloting supply chain transparency through an innovative blockchain platform that allows consumers to track their food right back to the farm. The initial pilot programme will trace milk from farms and producers in New Zealand to Nestlé factories and warehouses in the Middle East (Nestlé, 2019).

BlockApps, a blockchain platform provider, has partnered with Bayer AG, a German multinational pharmaceutical and life sciences company, to launch the TraceHarvest Network in 2020.[25] It is an Ethereum-based blockchain solution to track and trace the lifecycle of agricultural products. TraceHarvest was developed in collaboration with the Crop Science Division at Bayer and will enable farmers, grain manufacturers, distributors and processors to selectively share and review data within a single, secure platform (Bayer AG, 2020). To date the solution has only been piloted on higher value crops, where traceability costs will likely be absorbed by consumers willing to pay premiums. However, it is unclear how costs will be covered if the solution were extended to commodities sold in bulk.

25 TraceHarvest. 2022. [online]. https://blockapps.net/traceharvest/

Louis Dreyfus Co., Shandong Bohi Industry Co,. ING, Société Générale and ABN Amro took part in the commodity sale of soybeans in 2018. The sales agreement, letter of credit and certificates were digitized on the Easy Trading Connect blockchain platform, using ethereum blockchain as the basic architecture of the platform, saving a lot of time at all stages of verification, fivefold according to Louis Dreyfus, Head of Sales and an example of the successful implementation of a smart contract. It demonstrates implementation of an algorithm to automate several simple operations in a distributed computing network and guarantees invariability and compliance with the contract terms.

BOX 2.3

THE BUILDING BLOCKS OF COVANTIS

In 2018, ADM, Bunge, Cargill and Louis Dreyfus (ABCD) collaborated to improve trade using new technologies such as blockchain and artificial intelligence and digitize global sales of agricultural products. With regulatory approval and the addition of COFCO and Glencore Agriculture they formed a consortium, Covantis SA. In 2021 the platform went live with 30 entities, including six founding members and now includes almost 18 companies, major traders in agricultural commodities (Covantis, 2021a). The platform will initially cover bulk shipments of commodities such as corn and soybeans from Brazil to global destinations. The consortium aims to increase the reliability, efficiency and transparency of global trade operations by replacing paper contracts, bills and payments. Covantis chose ConsenSys, an ethereum blockchain technology company, as its lead technology partner to develop digital solutions.

Covantis will focus on in bulk commodity exporters and importers. Through blockchain, it seeks to increase efficiencies, decrease risk and working capital, as well as retain in-house expertise. Blockchain can support contract fulfilment, which can be complex. Delays or the non-fulfilment of contracts can be costly (a one-day delay can cost up to USD 20 000–30 000) and cause long-term reputational damage to future relations and tendering processes (Covantis, 2021b). Figure 2.23 outlines the value proposition of Covantis and the various key performance indicators (KPIs) which it will encourage participating members to use in benchmarking performance.

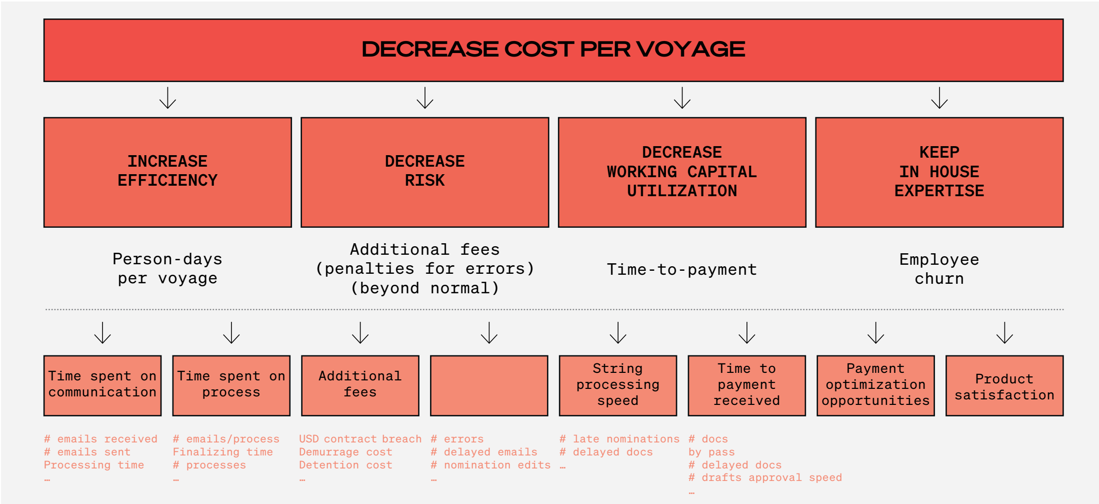


Figure 2.23

The value proposition of Covantis

SOURCE: Covantis, 2021c. Covantis – global post-trade network for the agri industry. Presentation prepared for FAO

Table 2.20

Market share, percentage of top ten exporters of grains (bulk shipments) in Ukraine: 2018/2019 and 2017/2018

Company	2018/2019 %	2017/2018 %
Kernel	11,7	8,6
Nibulon	9,8	9,2
Cofco	8,9	8,1
Cargill	7,6	7,1
ADM	7,6	8,7
Bunge	6,3	8,6
Louis Dreyfus	6,0	8,2
Glencore	5,1	6,0
Agroprosperis	4,1	3,8
Black Sea Commodities	3,4	4,1
Covantis	41,5	46,7

NOTE: Summary information for the 2019/2020 marketing year is not yet available

SOURCE: Authors’ research

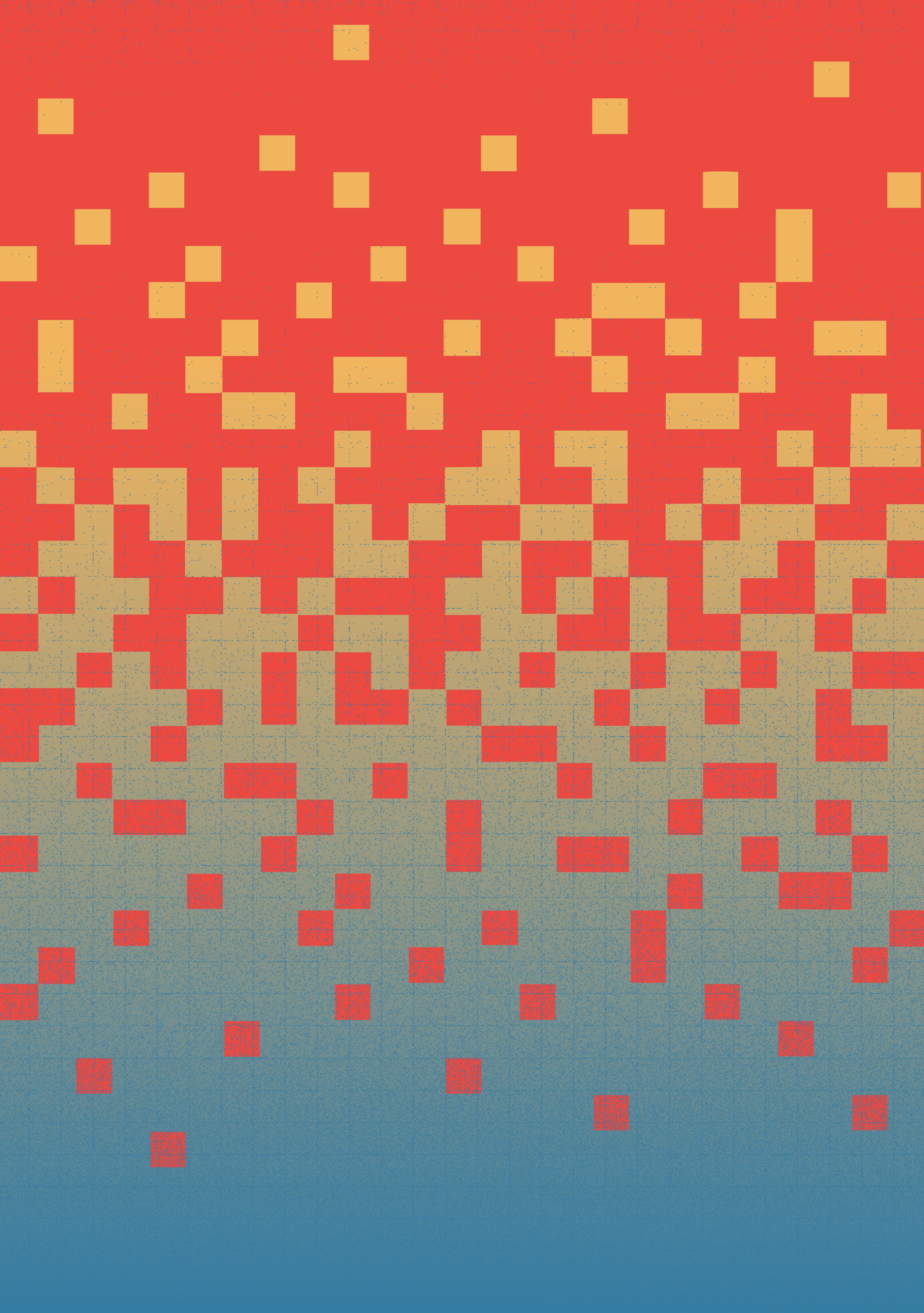
The Chief Executive Officer of Covantis, Petya Sechanova, states the platform will cater for smaller participants (Ledger Insights, 2020) and initially focus on exporters, freight on board (FOB) sellers and charterers. Through later releases, the consortium will include on board cost, insurance and freight and cost and freight (Cif/Cfr) buyers as well as agents and service providers in supervision, inspection and fumigations. Large producers and FOB exporters in Ukraine are unaware of the Covantis implementation plan. Given that Covantis exporters comprise 41 percent of the market share, including FOB exporters who are not part of the consortium, eventual market entry will need to closely be monitored. The consortium has rapidly expanded its client base and in early 2021, Covantis had advanced discussions with 20 firms, of which 16 are in the process of joining (Covantis, 2021b). Founding members will maintain separate legal and financial status from more recent members. The consortium also has a vested interest to include as many companies as possible, as successful deployment depends on broad participation of trade actors. Entry costs take the form of an annual subscription fee, determined by: (i) the market where the actor operates; (ii) the service provided; and (iii) the volume of trade (Covantis, 2021b). Costs of entry vary and depend on each grain contract, as companies have different approaches and diverse resources for contract fulfilment.

2.4.3 Opportunities and recommendations to support adoption of distributed ledger technologies

There are hardly any smart contracts based on blockchain in the Ukrainian grain market. Self-executing contracts lack a trustworthy data ecosystem as well as a regulatory framework hindering adoption, further exacerbated by an underlying culture of mistrust in trade and production relations between entities.

In terms of state application, the transfer of the register of warehouse documents for grain to blockchain may be a priority. This technology will increase transparency in the relationship between the depositor and the subject for grain storage. This transfer allows use of smart contracts to minimize warehouse paperwork not linked to actual grain deliveries.

The Covantis consortium will pilot its blockchain solution for wheat and maize exports from Ukraine to all key locations although it is not yet clear how its operations, governed by Swiss law, will comply with national regulations and documentation requirements.



Chapter 3
Accelerating the adoption of digital technologies through financing options

3.1 MARKET LIMITATIONS

Globally, banks judge investment in agriculture as risky, due to low profitability, variable output and cash flow uncertainties from seasonality, weather, pests and long production cycles (Lundblad and Rissanen, 2018). In Ukraine, macro-economic pressures, geopolitical tensions with the Russian Federation and falling commodity prices have led to high foreign exchange risks and economic contractions (OECD, 2018). This is reflected in the financial markets, as credit risks and non-performing loans have in recent years increased. Although the number of bankruptcies has fallen since 2015, corporate lending remains subdued, corporate lending remains subdued, with banks over-capitalized, negatively affecting investor confidence and reducing capital flows for investment, including digital innovations and green agriculture technologies. Recent trends indicate small and medium enterprises (SMEs) are taking out more loans, accounting for 33 percent of business lending in 2018 (OECD, 2020b).

Farmers often face credit challenges to finance digital technologies

The survey results confirm initial investment is the main deterrent to technology adoption for farmers, particularly since they have limited access to credit. Farmers in Ukraine have several ways to finance capital expenditure: bank loans; venture and growth capital; forward contracts; pre-crop financing by input suppliers; leasing schemes; hire purchase; invoice discounting and other advances from equipment providers. But access can be challenging and varies significantly depending on farm size.

For bank loans, the high cost of capital, short terms and unrealistic collateral requirements limit borrowers from developing bankable projects (OECD, 2018). Input suppliers, producers, retailers and exporters often rely on bank loans, however volatile, high interest rates and a poor credit history restricts access to bank loans (OECD, 2015). This is even more the case for smaller producers, whose financial status stops them investing in up to date equipment and other improvements. A survey by the European Business Association in 2018 found that of 133 SMEs in Ukraine, 52 percent indicated credit is expensive and only 19 percent found it accessible (European Business Association, 2019).

Farmers are often heavily indebted to suppliers and since the government does not guarantee agricultural borrowing, banks are not inclined to offer long-term loans (European Business Association, 2019). Most credit is seasonal (6–10 months) and commonly reserved for buying inputs. Commercial interest rates are around 21 percent (August 2019) for the agriculture sector, almost 2 percent higher than the average cost of capital at 18.4 percent). Interest rates in foreign currency for investment in agriculture in August 2019 were around 7 percent, almost 2 percent higher than average rates of 5.2 percent (National Bank of Ukraine, 2021). Figure 3.1 and Figure 3.2 outline the cost of capital in local and foreign currencies across different sectors. Volatile foreign exchange rates further limit the ability of farmers to repay loans in foreign currencies while banks can demand up to 200 percent collateral, depending on the level of risk and creditworthiness (OECD, 2015).

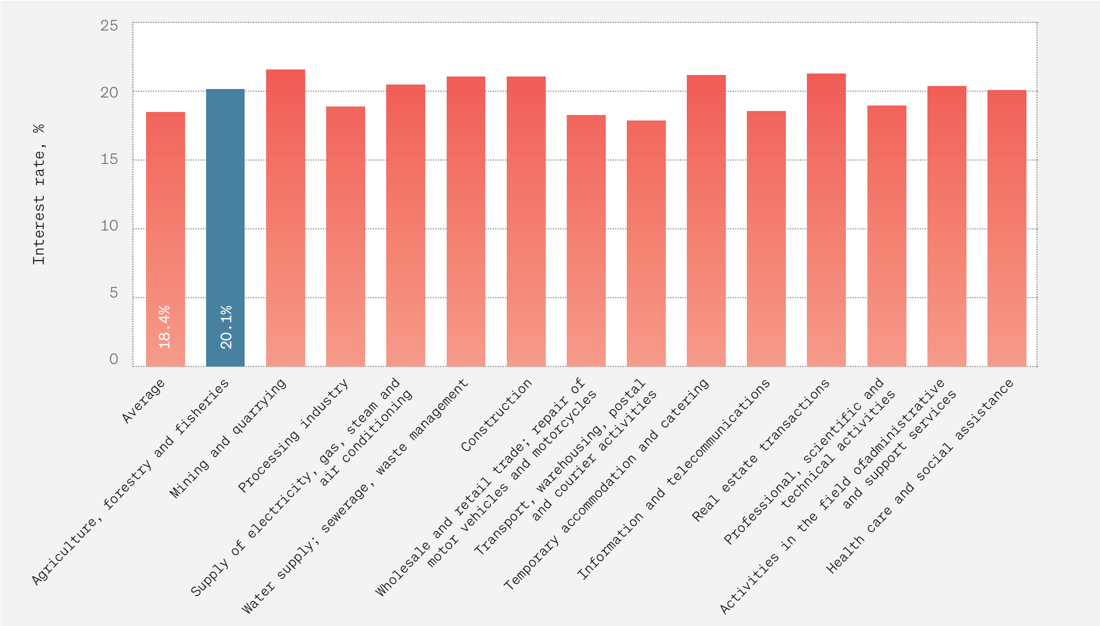


Figure 3.1
Ukraine: average weighted interest rate on new credit by sector of economy in UAH, percentage per year, August 2019

SOURCE: National Bank of Ukraine, 2021. Financial sector statistics. https://bank.gov.ua/ua/statistic/sector-financial/data-sector-financial#2fs [Cited 12 May 2021].

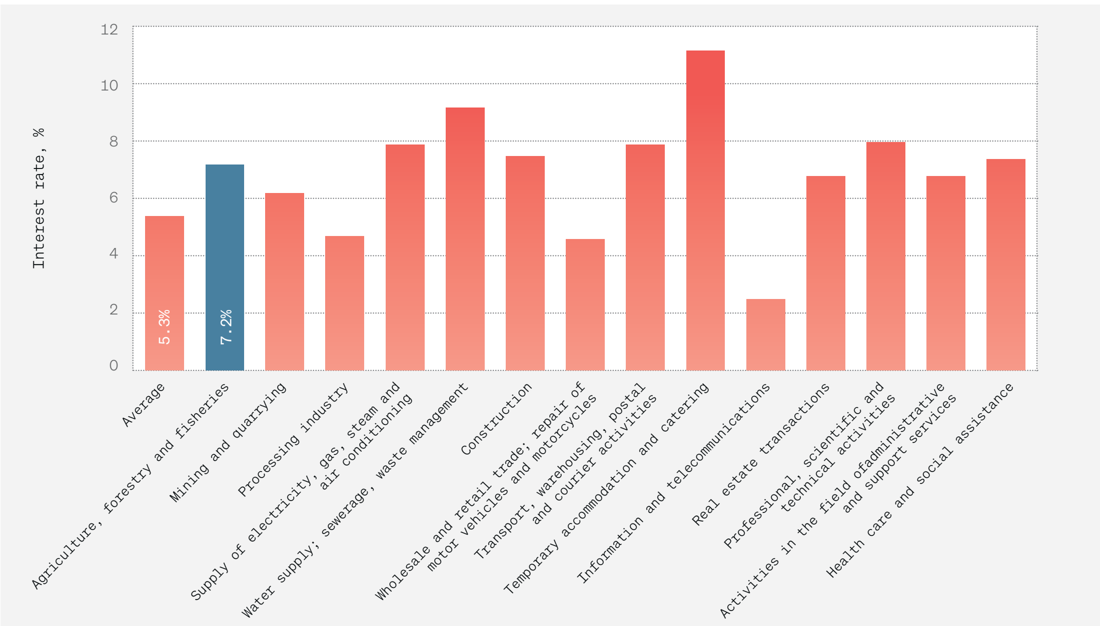


Figure 3.2
Ukraine: average weighted interest rate on new credit by sector of economy in USD, percentage per year, August 2019

SOURCE: National Bank of Ukraine, 2021. Financial sector statistics. https://bank.gov.ua/ua/statistic/sector-financial/data-sector-financial#2fs

Farm size matters

The capacity to adopt digital technologies depends on farm size. Larger farms can usually work different fields that experience diverse conditions, making them more robust to agricultural risks. They have lower volatility and more stable cash flows, making it easier to draw down finance than smaller farms. Smaller farms do not always have the same resilience against agricultural risks as larger ones and since farmers are dependent on the performance of their farms, some may be more risk averse. Smaller farms may be unable to use the technology in full and therefore feel PATs are less attractive. Larger farms may also be able to pilot the technology in certain areas of the field, whereas smaller farms cannot afford to set aside large parcels of cultivated land for piloting purposes.

Thus many smaller farms see technologies such as PATs as more relevant to larger farms, being better equipped to estimate benefits and absorb potential risks. Smallholder farmers may fear a loss in adopting technologies, as greater complexity may impact margins. Many farmers also lack confidence being accustomed to their own production practices, without the knowledge to apply novel technologies. Larger farms can also invest in skilled labour and specialized agronomists. Neither large agricultural enterprises nor small farms are incentivized financially by the market nor the government, to invest in technologies that reduce emissions.

3.2 FINANCING OPTIONS FOR ADOPTION OF DIGITAL TECHNOLOGIES

The European Union recognises the economic and environmental potential of digitalizing agriculture

To decide whether to include precision agriculture in future agricultural and climate instruments the European Commission in 2019 analysed the roles that technologies play in reducing GHG emissions and increasing farm productivity. The Commission proposed a series of legislative instruments to frame and enhance precision farming, supporting the creation of a European Agricultural Fund for Rural Development (EAFRD) (Soto *et al.,* 2019). These offer farmers incentives to adopt environmentally friendly techniques and invest in physical assets towards farm modernization and intensification, supporting wider adoption of PATs and related technologies. The EAFRD is the funding instrument of the Common Agriculture Policy (CAP) and is also part of the European Structural Investment Funds (ESIF). Under the EAFRD, European Union countries develop, submit and implement rural development programmes (RDPs) to address country-specific challenges. At least 30 percent of funding for each RDP must be for measures relating to the environment and climate change. Much of it comes via grants and annual payments to farmers who switch to more environmentally acceptable practices (European Commission, 2021b).

During 2014–20, EUR 161.2 billion was allocated under the European Union Rural Development Policy. EAFRD comprises EUR 99.6 billion, while national and regional public co-financing makes up EUR 50.9 billion, with EUR 10.7 billion from voluntary national financing (European Commission, 2017a).

The EAFRD financed a number of projects on piloting and adopting precision technologies, summarized in Annex V: Precision farming projects supported by the EAFRD. Support per project ranges from EUR 18 000 to 348 000 with most funding capital investments. There was also some funding for projects to develop human capacity, through farmer advisory services and training on the use of equipment.

Key lessons in supporting precision agriculture projects include: (i) regulations for EAFRD financing are at times inflexible for entrepreneurs, requiring five year projects; (ii) long-term relationships between farmers and research institutions can incentivize farmers to assume risks and costs, as they provide inputs and methodologies for piloting (European Commission, 2017b); (iii) significant challenges exist in integrating diverse data sources into application maps (European Commission, 2018); (iv) farmers and end-users of precision technology should participate in their design, to foster ownership; and (v) precision technologies can lead farmers and stakeholders to rethink their production models of commodities that were viewed as harmful to the environment, i.e. rice (European Commission, 2018).

As elaborated in 2.2.2 Potential impacts of PATs on the environment, reducing GHG emissions through the CAP is challenging. Results demonstrate that between 2014 and 2020, the CAP did not succeed in reducing emissions from fertilizer usage and livestock (European Court of Auditors, 2021), mainly due to increased demand for livestock products since 2014 and greater fertilizer use, both chemical and manure, in a number of countries. CAP measures did not lead to an increase in the carbon stored in soils and plants. The findings reveal that despite high levels of investment and support, reducing emissions from fertilizer use, without compromising on productivity growth, is challenging (European Court of Auditors, 2021).

The European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI), formed in 2012, integrated different European Union funding streams for agricultural innovation projects, including the European Rural Development policy and Horizon 2020, its research and innovation programme.

Horizon 2020 is the largest European Union funding framework for science and innovation and from 2014 to 2020 provided EUR 80 billion (European Commission, 2021c). Since 2012, EIP-AGRI has channelled funding to over 200 projects supporting precision technologies, nine agriculture projects promoting the use of blockchains and 50 remote sensing projects (European Union, 2021).

Recently, the European Union made further legislative changes to the CAP from 2021 to 2027. One includes building stronger agricultural knowledge and innovations systems (AKIS) to boost innovation and disseminate results more widely (European Commission, 2020b) with a main pillar being support for the digital transition in agriculture.

Horizon Europe supersedes Horizon 2020 with a budget of EUR 95 billion for 2021–27 (Horizon Europe, 2020) and 35 percent going to achieve climate objectives (Horizon Europe, 2020). The programme identified six mission areas, of which two relate to agriculture: soil health and food and adaptation to climate change (Horizon EU, 2019).

Scope for financing digital technologies in the grain sector in Ukraine

Survey responses confirm the main drivers for the private sector to introduce precision technologies are reduced labour and input costs and increased yields and profitability. Companies and agricultural holdings are incentivized to make capital investments to reduce costs and potentially increase profits. However, the precise level of subsidization required by the private sector to fully finance adopting PATs is unknown. Large agricultural holdings are already using resource efficiencies for PATs capital investments and it is assumed some can increase these investments.

The areas where these technologies are being implemented cover more than 8.4 million ha and 51 percent of respondents already using PATs plan to invest in developing the technology, corresponding to 6.2 million ha. For farms over 2000 ha, this increases to above 71 percent, while only 34 percent of respondents with farms below 250 ha have expressed such interest. On farms not using PATs only 18 percent are willing to invest in the technology, equivalent to 3.8 million ha. The share decreases to 8 percent for farms under 250 ha and increases to 40 percent for those above 5000 ha. Larger farms are more willing to use their own resources to invest in PATs but farms below 1000 ha will need external incentives to do so.

Currently more than 100 agricultural holdings manage 5.6 million hectares, or almost 28 percent of the total land under cultivation. Most have the capacity to further pilot PATs innovations and improve precision levels. Large holdings, such as Kernel, are also investing in start-ups to further develop the technology in Ukraine. Larger farms may still need support to develop a skilled labour force to accurately configure, apply and understand precision technologies, in-house or outsourced. Smaller entities will need external support to upskill their workforce. International donor programmes, green credit lines (GCLs) and green funds and grants can play a critical role here. Smaller farms will also need support for capital investments in PATs. Ukraine could leverage its membership of Horizon Europe to digitalize the grain sector.

In 2015 Ukraine became a member of the Horizon 2020 Programme (OECD, 2020b), giving participants the same status as their European counterparts and allowing them to shape the programme. It does not specifically support agriculture projects, but rather innovative institutions and SMEs at start-up stage or about to enter new markets. The programme focuses on giving SMEs access to loans, partial financing, guarantees and counter-guarantees.

Thirteen Ukrainian enterprises have obtained EUR 2 550 000 through Horizon 2020 (OECD, 2020b). Although the programme does not support adoption of digital technologies in Ukrainian agriculture, the EIP-AGRI has financed various blockchain, PATs and remote sensing projects across Europe. The Ministry of Education and Science is negotiating with the European Commission on conditions for Ukraine joining Horizon Europe (Lviv Polytechnic, 2021). Over EUR 33 billion (35 percent of the total EUR 95 billion) will be dedicated to addressing climate change across Europe, opening an opportunity for Horizon Europe funds to help digitalize the grain sector in Ukraine.

Leveraging green credit lines to finance digital innovations and technologies
GCLs can fulfil the twofold objective of realizing green projects, giving the opportunity for LFIs to expand the local green lending market, once the credit line has closed. GCLs offer reduced interest rates and longer loans more aligned to longer loan repayment schedules, better matched to the lifecycle of green investment projects. GCLs offer incentive grants on fulfilment of specific outcomes and can deliver technical assistance (TA) financed by the public or international financial institutions (IFIs). Technical assistance can include evaluation of green investment opportunities, monitoring of operations and marketing and communication to stimulate demand for green financing through new or existing credit lines. Annex VI: Advantages of green credit lines summarizes how GCLs can address common challenges that local markets face in financing green investment projects (I4CE, 2017).

The most notable providers of GCLs include the European Investment Bank (EIB), the Inter-American Development Bank (IDB), Kreditanstalt für Wiederaufbau (KfW), the International Bank for Reconstruction and Development (IBRD), the European Bank for Reconstruction and Development (EBRD), Agence Française de Développement (AFD), the International Finance Corporation (IFC) and the Japan International Cooperation Agency (JICA). In 2017, the IBRD, KfW and JICA had outstanding GCLs worth EUR 1 billion each, whereas IDB, EIB, EBRD and AFD had active GCL portfolios of EUR 2 billion, respectively (I4CE, 2017). Annex VII: Green credit line projects provides an overview of GCLs that invest in agriculture technologies to mitigate the effects of climate change.

A large number of GCLs comprise targeted investments within the energy sector, promoting energy efficiency and renewable energy sources but there are few credit lines with the objective of measuring and reducing GHG emissions in agriculture. Even fewer investments are made to advance trade and post-trade efficiencies, such as smart contracts.

Local banks have experience with energy efficiency credit lines, but not in extending credit for digital technologies in agriculture
Ukrainian LFIs have primarily used GCLs to finance investments within the energy sector and adopt energy efficient solutions. As Table 3.1 illustrates, from 2007 to 2014, ten LFIs relied on GCLs for these investments (OECD, 2018).

Table 3.1

Ukraine local financing institutions that have used green climate lines

Local financial institution	EBRD	IFC	EIB	IBRD	KfW	NEFCO / Nordic Investment Bank	Green for Growth Fund	Global Climate Partnership Fund
Ukreximbank	■		■	■		■		■
MGB Megabank	■						■	
Raiffeisen Bank Aval	■							
Credit Europe		■						
Oschadbank			■					
Prominvestbank			■					
Forumbank			■					
Unicredit			■					
Procredit		■			■			
Bank Lviv						■		

SOURCE: OECD. 2018. Access to private finance for green investments: energy efficiency and renewable energy financing in Ukraine, green finance and investment. Paris, OECD Publishing. https://doi.org/10.1787/9789264303928-en

Ukreximbank is the largest intermediary recipient of IFI energy-efficiency finance in the region. The state-owned bank has received more than EUR 500 million through six credit lines from five IFIs and other financing bodies (OECD, 2018). Ukreximbank possesses the necessary capacity to use GCLs effectively. Other banks, including Oschadbank and Urgasbank, have shown similar capabilities.

Despite this capacity, LFIs have not extended credit lines for digital technologies in the grain sector, likely due to the lack of evidence to justify economic and environmental returns from the grain sector in Ukraine. Among the evidence gaps are a lack of feasibility studies on the economic viability and capital investments to monitor GHG emission changes and generation of co-benefits. PATs require investments in VRA systems and biomass mapping to collect data on crop conditions, productivity and nitrogen. Field-level spatial, temporal and management practice variations render it difficult to measure carbon stock level changes in soil. Investments in remote sensing could allow the collection of these data on a large scale, however, it is unclear whether LFIs are willing to extend the financing required. With support from PFIs, IFIs and green funds, the LFIs will likely be more inclined to provide credit lines for feasibility studies and ultimately, for the adoption of technologies to monitor, measure and reduce GHG emissions. Besides supporting smaller farmers (under 1 000 ha) in technology capital investments, GCLs should also focus on providing TA and upskilling the workforce of both large and small farming enterprises.

Other non-banking financing options can be leveraged to support the adoption of digital technologies

Non-banking options include financial and insurance companies, credit unions, pension funds and pawnshops. In 2018 their assets were over UAH 187 billion (USD 6874 million). The venture capital market has increased, with 115 deals in 2018 compared to 89 in 2017 (OECD, 2020b). Equity investments have also increased and are now over USD 126 million.

There are various government support programmes, including: State Invention Incentive Fund, National Research Foundation and Ukrainian Start-up Fund (OECD, 2020b). These may be attractive to small and medium sized farmers, who cannot obtain commercial financing. As noted, state support covers up to 90 percent of the cost of agricultural advisory services, with a programme budget in 2019 of USD 200,000. The Ministry of Economy, Trade and Agriculture compensates farmers for 25 percent of the cost of equipment under a programme worth USD 16 million (Verkhovna Rada, 2018). Up to now these subsidies have not covered capital investments in digitalization. The lack of priority for digitalizing agriculture and absence of a regulatory framework have largely blocked state support for precision technologies.

Green funds and grants

The best known green funds, the Green Climate Fund (GCF) and the Global Environment Facility (GEF have provided only limited support to projects on the uptake of PATs, blockchain and remote sensing technologies. The GEF has mainly focused on resource efficient, renewable and low carbon technologies in agriculture, building up institutional and farmer capacities, raising awareness and private sector partnerships.

In 2017 the GCF and the Climate Technology Centre and Network (CTCN) partnered up to develop and transfer energy efficient, low carbon and climate resilient technologies. This included feasibility assessments, collecting key data and the correct systems to support renewable energy sources, climate resilient agriculture technologies, climate information and early warning systems. A major focus was to increase data accessibility from satellites and capture reliable data to inform climate change assessments. USD 890 000 have been committed to this in Ghana, Myanmar and Tonga (GCF, 2021).

Although these funds have not directly supported PATs projects, remote sensing and blockchain, there is a greater focus on the successful uptake of digital technologies, helping to convince not only local financiers, but farmers of their economic and environmental benefits for the grain sector. GEF and GCF should seriously consider financing digital innovations that promote efficiencies and reduce emissions. To scale up activities and de-risk delivery of capital flows, GCF has set up the private sector facility to promote private investment through low interest and long-term loans, lines of credit, equity investments and risk mitigators such as guarantees, first loss protection and grant based capacity building. Up to 2021, the GCF funded 35 private sector projects with USD 3 billion, with a total value of USD 12.5 billion (GCF, 2021).

The Clean Technology Fund (CTF), the Global Environment Facility (GEF) and the GCF, as well as European Union blending facilities and operations funded by bilateral agencies all contribute to climate finance availability. The CTF has received USD 5.4 billion since 2008 from donors and deploys finance through multilateral development banks. GEF's replenishment for 2018-22 was USD 4.1 billion and the GCF received pledges of USD 9.9 billion in its 2020-23 replenishment. Other grants include the EBRD Green Innovation Vouchers Scheme initiated in 2018 and funded by Austria's Delivering Resource Efficiency Investments (DRIVE) programme in Serbia. A total of EUR 150 000 was extended to 11 companies to increase their innovation capacity in green technologies, precision agriculture and resource efficiency (Development Aid, 2018). The maximum voucher amount was EUR 20 000 for SMEs to work with local research and development institutions to implement and scale up innovative solutions. Similar grant and voucher schemes can develop the evidence base to adopt digital technologies in the grain sector in Ukraine.

Ukrainian farmers will need support to fulfil requirements of verifying and certifying environmental benefits to participate in carbon marketplaces

Voluntary carbon markets allow actors to buy carbon credits to offset their emissions and function outside the compliance markets. They are not usually backed by any government or mandatory targets but based on organizations certifying emission reductions have environmental integrity. In 2018 the volume of voluntary carbon market transactions reached a seven-year high with 98.4 tCO_2eq valued over USD 295 million, an increase of 52 percent in volume and 48.5 percent in value since 2016 (Forest Trends' Ecosystem Marketplace, 2019). In contrast, regional, national, and international carbon reduction regimes create and regulate compliance markets, such as the Kyoto Protocol and the European Union's Emissions Trading Scheme (EU ETS). The latter is the first and largest emission trading scheme, covering about 40 percent of the European Union's GHG emissions, capping the amount of certain GHG gases that can be emitted (European Commission, 2020b). Companies can receive, buy and trade emissions allowances and the limited number of allowances ensures these retain value. Annually, a company must surrender enough allowances to cover all its emissions or be subject to fines. The ETS mainly covers power generation, heavy industry and aviation, excluding agriculture. This is mainly because agriculture's emission profile is different from other sectors, as it includes methane and nitrous oxide, creating significant measurement problems. A project approach where the authority compiles a list of farming practices as valid reduction measures for the ETS system might hold promise (Matthews, 2014).

The average ETS carbon credit price in 2019 was EUR 25 tCO_2eq, largely due to the market stability reserve (MSR) to address a supply and demand imbalance in allowances. The economic slowdown from COVID-19 caused the price to drop by almost 40 percent to a near two-year low just above EUR 15/tonne CO_2 for the first quarter of 2020 (World Bank, 2020). The absence of limitations on issuing carbon credits results in lower prices on the voluntary carbon market. These vary significantly across sectors with different issuing standards. Table 3.2 presents the average weighted prices by project type and Table 3.3 compares average prices by standard issuer.

Carbon voluntary marketplaces, which focus on compensating farmers for adopting sustainable farming are rare enough but can maintain high carbon credit prices as these are valuable and in high demand. Some include the Nori and Indigo carbon marketplaces in the United States of America and in Australia the Soil Carbon Industry Group (SCIG) and AgriProve. For Nori and Indigo AG, the above average carbon market pricing is because credits from practice changes are valuable as they are new benefits to soil carbon and emission reductions beyond business as usual practices. These credits are a rarity and are priced at approximately USD 15 per credit (Indigo, 2021). Indigo AG estimates growers can generate 0.3–1 credits per acre in the first year, increasing over time (Indigo, 2021). Nori estimates growers who plant cover crops or switch to minimum tillage can remove between 0.2 and 1.5 tonnes of CO_2 per acre per year (Nori, 2020). SCIG and AgriProve work with the Emissions Reduction Fund (ERF), a voluntary standard from the Australian Government. Projects can earn Australian Carbon Credit Units (ACCUs) issued by the Clean Energy Regulator (CER) and registered to carbon projects under the ERF, where one ACCU is equivalent to one tonne of CO2eq. In August 2020, ACCUs had a spot value of AUD 15.90 per credit (Australian Government Clean Energy Regulator, 2020a). AgriProve estimates that a 1 percent increase in soil organic carbon in the top 30 centimetres of soil can deliver 124 carbon credits per hectare (AgriProve, 2020a).

Table 3.2
Transacted voluntary carbon offset weighted average price by project category, 2017-19

	Average price per year, USD		
Type of project	2017	2018	2019
Forestry and land use	3.4	3.2	4.3
Renewable energy	1.9	1.7	1.4
Waste disposal	2.0	2.2	2.5
Household devices	5.0	4.8	3.8
Chemical processes/ industrial manufacturing	1.9	3.1	1.9
Energy efficiency/ fuel switching	**2.1**	**2.8**	**3.9**
Transportation	2.9	1.7	1.7

SOURCE: Forest Trends' Ecosystem Marketplace, 2020. Voluntary carbon and the post-pandemic recovery. State of voluntary carbon markets report, Special Climate Week NYC 2020 Installment. Washington DC, Forest Trends Association

Table 3.3

Comparison of major voluntary standards average prices

Standard	Average price
Gold standard	USD 4.6 (2016)
Verified carbon standard (VCS)	USD 2.7 (2018)
Climate, community and biodiversity standard (CCBA)	USD 2.5 (2018)
Woodland carbon CO_2de	STG 7–20 (2019)*
Climate action reserve	USD 3 (2016)
CDM-UNFCCC	**USD 1.4 (2016)**

NOTE: *In the United Kingdom, companies pay between STG 7–20 /tC02 for pending issuance units (carbon credits). As only a small number of verified woodland carbon units have been sold, it is not known if the price for these differs. Woodland Carbon Code. 2022. [online]. https://woodlandcarboncode.org.uk/buy-carbon/how-to-buy#price

SOURCE: Forest Trends' Ecosystem Marketplace, 2020. Voluntary carbon and the post-pandemic recovery. State of voluntary carbon markets report, Special Climate Week NYC 2020 Installment. Washington DC, Forest Trends Association

BOX 3.1

QUALIFYING FOR A CARBON MARKETPLACE PROVIDES A NUMBER OF BENEFITS TO FARMERS

These advantages include: (i) farmers can develop a saleable asset in a carbon credit; (ii) support in setting targets for carbon removals, lower input costs; improved soil health; better return on investments, and (iii) possible price premiums for production changes (Australian Government Clean Energy Regulator, 2020a). Currently, Nori and Indigo carbon credits are sold at approximately USD 15 per credit.

Verra recently released a verified carbon standard (VCS) methodology for improved agricultural management (IALM), developed in collaboration with Indigo AG and TerraCarbon LLC (Verra, 2020). IALM incentivizes land management practices that reduce emissions, enhance storage of organic carbon and contribute to increased soil health and agricultural resilience. It incorporates direct measurements of soil organic carbon stocks and biogeochemical models such as DNDC and COMET-Farm that rely on previous management practice, soil, and weather data to quantify changes in soil organic carbon stocks and GHG fluxes (Verra, 2020). In contrast to carbon marketplaces, which are limited to certain geographical areas, this methodology is applicable to any project developer throughout Verra's global VCS Programme.

Ukrainian farmers will need support from LFIs, research institutions, global and domestic funds and if possible, government subsidy programmes to comply with international certification, verification and carbon marketplace requirements. Large agricultural holdings are to a greater extent better positioned to raise the capital to qualify for carbon marketplaces. But smaller farms will likely need GCLs to cover the costs of participating in carbon markets.

Despite the challenges in quantifying benefits, digital technologies can improve access to financing and generate efficiencies, as well as having positive environmental impacts.

Although challenges exist in accurately estimating ROIs and environmental benefits of adopting digital technologies, various sources advocate their adoption. Digital finance solutions can help farmers access credit. Technological advances in farm sensors, satellite imagery and drones combined with precision farming, can enable better risk management and increase the profitability of farms, while helping them establish their digital footprint. Financial and non-financial players can use this farm-level data to determine creditworthiness, as well as inform new financial products targeting farmers, including solutions related to payments, savings and insurance. For instance, satellite images are decreasing the need for frequent remote field visits, saving time and transaction costs for agribusinesses, banks, and insurance companies (IDH and CGAP, 2020). Digital payments can reduce the costs of delivering loans and repayment schedules. While digital technology can simplify communication, information sharing and financial transactions, expanding digital solutions to farmers often requires new skills and expertise in mobile and online platforms, digital design, data capture, data management and analytics (IFC and Mastercard Foundation, 2018). Multiple players are often involved, including mobile network operators, third party technology and financial technology service providers (Fintechs). Motivations to enter the financial services market may include launching new technology solutions to meet a perceived market gap not served by traditional financial institutions (IFC and Mastercard Foundation, 2018).

Specific to precision agriculture, Lundblad and Rissanen found that PATs can significantly reduce farmers' income volatility and increase productivity, two factors that should lead to greater creditworthiness (Lundblad and Rissanen, 2018). PATs can also generate improved data exchange between financiers and farmers and a better understanding of how farmers can service their loans. This can reduce information asymmetry, adverse selection and moral hazard and lead to better credit screening. Information sharing can aid banks checking collateral to assess the risk more accurately. Financiers can monitor farmers' activities to determine their long-term financial stability.

PATs and related technologies can allow farmers to generate benchmarks to improve the terms for other farmers. One precondition is that farmers should share data and financiers should offer incentives for farmers to do so (Lundblad and Rissanen, 2018). Remote sensing and satellites can collect field-level data to accurately price risk and associated premiums. Blockchain can improve traceability purposes and smart contracts can mitigate trade risks further down the supply chain. All of these technologies can help farmers tap into agricultural insurance markets and in theory protect their assets against risks and encourage more productive investments.

As noted, PATs can increase productivity, efficiency and reduce GHG emissions. In Ukraine VRA alone could mitigate up to 2644 thousand tonnes of CO_2-eq-1, assuming fertilizer is reduced by 20–30 percent. Using GreenSeeker for variable nitrogen application can generate on average over 19 percent in fertilizer savings. Fields with inferior soil may need more nitrogen for certain areas to level out and achieve yield targets, possibly leading to increased emissions which should be closely monitored. Economic growth projections can also lead to increased application so controlled release fertilizers with digital technologies could curb this upward trend while maintaining productivity.

Remote sensing technologies can provide a cost effective alternative to collecting data to measure carbon changes in soil. Using blockchains for smart contracts can mitigate risks of lost revenue downstream that is required for investments in technologies that directly reduce emissions.

Given market conditions in Ukraine, uptake of digital technologies in the grain sector will take some time. Digital technologies such as PATs should incentivize LFIs to provide credit lines to farmers willing to adopt similar technologies. With farmers' reluctance to invest due to limited evidence and low prioritization of environmental benefits, uptake of digital technologies to reduce emissions will take a long time.

3.3 STRATEGIC RECOMMENDATIONS AND THE WAY FORWARD

Farmers find it difficult to source finance due to high collateral requirements and cost of capital, as well as foreign exchange risks. Loans are also usually seasonal and for inputs. Farm size can matter, as larger farms can take more risks, leading to lower volatility and more stable cash flows. Smaller farms are usually less resilient to agricultural risks and less able to use technology while larger ones can pilot the technology in certain areas of the field. They can invest in skilled labour and have the financial literacy to quantify costs and benefits of technology.

Despite these challenges, precision technologies can reduce income volatility and increase productivity, leading to creditworthiness. Remote sensing and blockchain can help farmers access insurance markets, to protect their assets against risks and encourage more productive investments. Variable rate application alone can mitigate up to 2644 CO_2eq yr^1 and GreenSeeker can generate on average, over 19 percent in fertilizer savings.

Funding CAP instruments such as the EAFRD and EID-AGRI should be an inspiration to support technologies on different farms. Ukraine's participation in the Horizon Europe programme could also be used to finance digital technologies in the grain sector. Large farms and holdings are better able to employ resource efficiencies to fund PATs but smaller farmers (>1 000 ha) will likely need external support from GCLs which can also help upskill their workforce required to apply these technologies.

Although GCLs can support green investment projects where local conditions may limit them, few support technologies to reduce GHG emissions, nor have LFIs in Ukraine extended credit to them for agriculture due to limited evidence of efficiencies and environmental benefits. With support from PFIs and IFIs, LFIs can build up such an evidence base.

Global green funds and grants are developing the enabling conditions that contribute to the adoption of digital technologies in agriculture but should strongly consider directly financing them.

Participating in a carbon market compensates farmers for applying regenerative practices that improve soil health and reduce emissions, including PATs. Ukraine is not part of an ETS and has no voluntary carbon marketplaces . However, in preparation for joining an ETS, the Ukrainian Government instructed large industrial installations to monitor emissions from 2021 (OECD, 2020a). Voluntary carbon credit prices are on average lower than those from compliance-based markets and vary greatly across sectors and standards issuing them. However, carbon marketplaces specific to practice-based changes in agriculture, offer above average prices, since these credit types are in demand and in short supply. Qualifying for a carbon marketplace can be costly and requires various steps. Larger farms are better positioned to attract and raise the required capital to qualify for carbon marketplaces. However, smaller farms will require support to cover necessary costs of participating in carbon markets.



NEW HOLLAND
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Chapter 4
Conclusions

4.1 PRECISION AGRICULTURE TECHNOLOGIES

PATs survey responses confirm a limited understanding in Ukraine and that the innovation gap between large farms and smaller ones is increasing. Currently, sector-specific conferences and exhibitions are considered the most objective source of information about the technology.

Initial investment in PATs is the main deterrent to technology penetration. Uncertainty regarding the implementation of PATs and its benefits is the second most significant barrier but it decreases with farm size. Smaller farms are discouraged by the complexities in adopting PATs and farms of all sizes neglect potential environmental benefits as these are difficult to quantify and not internalized.

The majority of respondents do not view the involvement of third party service organizations in the analysis and implementation of PATs positively. Many farmers believe the outsourcing market for implementing PATs is immature and are reluctant to pay for advice services, claiming there is a shortage of specialized staff.

Recommendations for further development

Private sector

- Private companies, technology service providers and integrators should adapt their business and marketing models to consider disclosing ROI or other efficiency indicators. They may need to adjust their customer value propositions and promote the benefits of applying PATs. Farmers need capacity development on how to market these benefits, especially environmental ones, in order to obtain price premiums.
- For medium and small-scale farmers participation in open field days and demonstration fields would help them better understand potential costs and benefits of PATs.

Financial institutions and funds

- Digital finance solutions can help farmers improve access to credit and mobile network operators while third party technology providers and fintechs can reduce information asymmetries and improve credit risk scoring.
- GCLs, TA and other credits lines can directly support: (i) cost benefit analyses customized to farm sizes and conditions, where focus should be on quantifying environmental benefits; and (ii) capital investments to adopt VRA technologies (canopy and yield maps and guidance technologies).
- Through TA, relevant training programmes applicable to different farm sizes and contexts should be developed.
- Farmers and agricultural holdings should be supported to qualify for carbon markets and GCLs can be used to directly finance investments related to MRV.

Public sector

- The Ministry of Agrarian Policy and Food of Ukraine and related agencies could benefit from the efficient collection, centralization, sharing and analysis of agriculture-specific data to support adoption of digital technologies.
- The public sector should introduce PATs through educational and vocational programmes and subsidize the search for adequate human resources to support this.
- The government should offer incentives to outsourcing institutions and especially PATs integrators for agricultural enterprises that directly use the technologies.
- The government should promote high quality national offsetting based on international standards; develop and align de-carbonization strategies and targets to NDCs and clearly communicate these. Appropriate ministries should support governance in MRV and application of standards to offset and reduce emissions.

International organizations and technical agencies

- International organizations and technical agencies have a role in promoting access to data and improving the digital literacy of adopters and business development service providers.
- Technical agencies should support standardization of tools and methods of MRV through dialogue and discussion on best practices.
- International organizations and technical agencies should develop and deploy interventions to improve human capital to address skill gaps in agriculture, as well as supporting farmers to adopt, benefit and sustain gains from digital technologies.

4.2 DISTRIBUTED LEDGER TECHNOLOGIES

Considering Ukraine's leading position as a grain producer and exporter and the significance of the grain "shadow" market, there is an opportunity to leverage blockchain to establish smart contracts to automate and increase the reliability of contractual relationships. However, prior to implementing them, market participants will have to upgrade their electronic document management systems.

In terms of public sector operations, digitizing warehouse documents may be a priority. This can increase transparency in the relationship between the depositor and the body responsible for grain storage. Phased in implementation of smart contracts technology with blockchain would seem more likely within a single group of companies or well known counterparties. Deploying blockchain in such an environment will encourage other players to cooperate, thereby improving the culture, currently based on large scale mistrust.

The Covantis consortium will pilot its blockchain solution for wheat and maize exports from Ukraine to all key locations. It is not clear how the operations of this consortium, governed by Swiss law, will comply with national regulations and documentation requirements. Additional members of the consortium will retain a separate legal and financial status from the founding members. Given that Covantis will constitute more than 40 percent of the grain market share, inclusion of producers and exporters currently not part of the consortium, will have to be closely monitored. It is in the interest of Covantis to include all relevant actors, as their participation will determine contract effectiveness.

Recommendations for further development

Private sector

- Companies aiming to implement smart contract systems, should consider upgrading electronic document management systems.
- The private sector should support and create accepted frameworks, data governance (ownership, sharing, privacy and storage) systems and processes so different data management systems can work together.
- Companies in the grain sector should build or join an existing consortium, as this can serve as a forum to discuss and handle emerging regulatory and technical challenges.

Public sector

- The public sector should strengthen capacity to handle regulatory uncertainties, build sandbox models to experiment with promising emerging technologies and identify the regulatory, policy and governance aspects needed to scale up.
- The Government of Ukraine should pass the required regulation to support digitalization of agricultural value chains, with focus on smart contracts to improve the efficiency and transparency of grain trading.
- The government should also digitalize the register of grain warehouse documents.
- Government departments should promote the central role that smart contracts can play in reducing shadow market value and volume.
- The government should monitor the competitiveness and inclusiveness of existing consortiums and ensure these do not exclude smaller or new market players.

International organizations and technical agencies

- Technical agencies should share best practices in applying blockchain solutions in grain trading.
- International organizations and technical agencies should engage in dialogue to build partnership between governments and the private sector to deploy and support blockchain solutions in commodity trading.

4.3 REMOTE SENSING TECHNOLOGIES

In Ukraine, the SSAU is responsible for policy regarding all space related activities, including remote sensing. Currently, there is no separate policy or funding support programme for remote sensing in agriculture. Legislation is needed to enhance coordination between the SSAU and the end users of remote sensing, particularly ensuring real-time data availability on interpreting and enhancing data and satellite imagery.

Remote sensing and satellite monitoring have not been used extensively in agriculture decision-making at state level. Donor funded programmes and the private sector have piloted remote sensing in agriculture to develop an agricultural insurance market. Legislation and funding can promote wider use of remote sensing in agriculture.

Recommendations for further development

Public sector

- The Government of Ukraine should improve data governance mechanisms to facilitate collection, storage, sharing and building value from trustworthy satellite data.
- Government departments should promote open data initiatives and incentives to support innovation and sharing solutions between various actors.
- The government should also ensure that SSAU works with all users to provide data integrity.
- Agencies should focus on demonstrations and building capacity on the wider use of remote sensing in agriculture – measuring soil carbon stocks and developing the agricultural insurance market.

International organizations and technical agencies

- Share best practices for remote sensing in agriculture.
- Engage in dialogue and partnership building initiatives between governments and the private sector with technical agencies that specialize in remote sensing in agriculture.

4.4 FINANCING OPTIONS FOR SUPPORTING THE ADOPTION OF DIGITAL TECHNOLOGIES IN THE AGRICULTURE AND GRAIN SECTORS

Larger farms are more inclined to experiment and adopt digital technologies as they have stronger financial and digital literacy, can invest in skilled labour and quantify the costs and benefits of technology adoption. Smaller farms are more risk averse and lack capacity and capital for new technologies.

Precision technologies can reduce costs of production and increase productivity, two factors which should lead to a creditworthiness improvement. This is especially relevant and applicable for larger holdings. VRA alone has the potential to mitigate up to 2644 thousand tonnes of CO_2 eq yr^{-1} and generate on average, 19.2 percent in fertilizer savings. Precision agriculture technologies could be environmentally and economically beneficial, raising productivity while reducing fertilizer use, supporting better use of water and targeting pesticide spraying.

Remote sensing, in combination with other digital solutions such as smart contracts, can help farmers purchase agricultural insurance, to protect their assets against risks and encourage more productive investments. From a creditworthiness perspective, precision technologies should incentivize LFIs in Ukraine to extend credit lines. However, given market limitations, farmer scepticism and low priority of environmental benefits, uptake will likely take a long time.

Larger farms can to a greater extent leverage their own resource efficiencies for PATs' capital investments, whereas smaller farmers will likely require support. Potential funding options include GCLs, international donor programmes and green funds and grants. GCLs can be used to upskill the workforce but few of them support adoption digital technologies in agriculture. LCIs in Ukraine rarely extend credit lines to implement grain technologies, likely due to the limited evidence of efficiencies and environmental benefits. With support from PFIs and IFIs, LFIs can support producing evidence to justify the adoption of technologies. Global green funds should consider engaging in directly financing technology adoption. Ukraine's continuous participation in the Horizon Europe 2020 programme could also be used to finance adoption of digital technologies in the grain sector.

Participating in a carbon market compensates farmers for applying regenerative practices that improve soil health and reduce emissions. Ukraine is not part of an ETS and there are no voluntary carbon marketplaces however the government is taking steps to participate in an ETS. Qualifying for a carbon marketplace can be costly and requires various steps, smaller farms will require support to meet the costs.

Recommendations for further development

Private sector

- Companies directly working with farmers need to segment requirements for technology uptake by farm size, field conditions and heterogeneity.
- Companies need to also push for greater digitization of agriculture value chains, data sharing frameworks and connecting mechanisms.
- Private sector actors should engage in public-private partnerships and private-private partnerships to extend reach, reduce costs and sustain initiatives.

Public sector

- The public sector should leverage EAFRD and EID-AGRI programmes to encourage uptake of digital technologies in the grain sector.
- The government should focus on fostering a multistakeholder partnership that can leverage cross-sectoral developments in moving ahead with digitization of agriculture value chains.
- Focus should be on building connected frameworks, shared data platforms and investing in building human capital for digitalization.
- The government could potentially use participation in Horizon Europe as a source of funding for adoption of technologies in the grain sector.

Financial institutions and funds

- Financial and non-financial players should leverage data from digital technologies to determine creditworthiness to introduce and customize financial products for farmers.
- Financial institutions should promote GCLs to support development of an evidence base detailing potential costs and advantages of technology uptake.
- Green funds should directly sponsor technology uptake in agriculture.
- Use of GCLs to support farmers qualifying for carbon marketplaces should be encouraged.


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Annexes

Annex I
Indicative costs of precision agriculture technologies

PAT Type	Description	Source	Price range for PAT (C)
Machine Guidance			
Guidance systems (GPS)	Guidance systems refer to the systems that are used for the tractor guidance. Lighbar guidance is an entry level guidance system that indicated to the tractor driver how to steer the tractor for following the most effective route during field operations. Mechanical steering is a system that aids to steering the tractor. Autopilot is a system that has the abiity to fully control the steering system of the tractor without having any help by the tractor driver. There are different levels of accuracy according to the GPS equipment used such as WAAS (30cm), Radio Beacon (10cm), RTK (3cm).	Groover (2009)	Lightbar Guidance System – 30cm accuracy **EUR 1735** Lightbar Guidance System – 10cm accuracy **EUR 4500** Mechanical Steering Systems – 10cm accuracy **EUR 5800** Auto Pilor Systems – 3cm accuracy **EUR 36 640**
		Price (2011)	Lightbar **EUR 1830** WAAS (Wide Area Augmentation System) **EUR 5500** Omnistar **EUR 7330** Radio Beacon **EUR 11 910** **RTK** (Real Time Kinematik) **EUR 19 240**
VRA Seeding			
VRA seed drill (with GPS)	VRA seed drills are seed drills that have the ability to apply seeds in different densities. They use a field computer that computes the seed doses that must be applied by site specific needs (through sensor or map based prescription maps), by a GPS unit that understands the tractor position on the field, by a microcontroller that receives information from the field computer and adjusts the seed doses accordingly and sometimes by sensor(s) that instantly measure the organic matter for applying seeds.	Farm Industry News (2007)	**EUR 16 490–93 420**
VRA seed drill kit	VRA seed drill kit is a group of components that is implemented in a conventional seed drill for enabling it in precision agriculture. The key components of the system are microcontrollers for controlling the seed doses, a field computer that sends data to the microcontroller based on prescription maps and a GPS unit for the tractor.	Farm Industry News (2013)	**EUR 12 500–25 500**

VRA Fertilization			
VRA spreaders (with GPS)	VRA spreaders have the ability to apply fertilizers in different doses to the site specific needs. These systems are consisted by field computer that computes the doses that must be applied by site specific needs (through sensor or map based prescription maps), by a GPS unit that understands the tractor position on the field, by a microcontroller that receives information from the field computer and adjusts the fertilizer doses accordingly and sometimes by sensor(s) that instantly measures the crop needs for fertilizers.	Cochran *et al.* (2004)	**EUR 16 030–35 720**
VRA spreader kit	VRA spreader kit is a group of components that is implemented in a conventional spreader for enabling itin precision agriculture. The key components of the system are microcontrollers for controlling the fertilizer doses, a field computer that sends data to the microcontroller based on prescription maps and a GPS unit for the tractor.	The Daugherty Companies (2015)	**EUR 4580 –9160**
VRA Spraying			
VRA sprayer	VRA sprayers have the ability to apply different doses of spraying products. VRA sprayers can be boom sprayersor orchard sprayers according to the crop type. These systems are consisted by field computer that computes the doses that must be applied by site specific needs (through sensor or map based prescriptionmaps), by a GPS unit that understands the tractor position on the field, by a microcontroller that receives information from the field computer and adjusts the fertilizer doses accordingly and sometimes by sensor(s) that instantly measures the crop needs for spraying doses.	Farmers Classified	**EUR 30 000–100 000**
		Silvan	**EUR 53 100**
		Gerhards and Sökefeld (2003) (The cost includes together the VRA sprayer, the weed detection system and the direct injection system)	**EUR 10 700**
VRA sprayer kit	VRA sprayer kit is a group of components that is implemented in a conventional sprayer for enabling it inprecision agriculture. The key components of the system are microcontrollers for controlling the spraying doses, a field computer that sends data to the microcontrollerbased on prescription maps and a GPS unit for the tractor.	TeeJet	**EUR 9160–27 470**
		Downey *et al.* (2011)	**EUR 13 740**
VRA Irrigation			
VRA irrigation equipment adoption	VRA irrigation equipment is the equipment that is needed for applying variable rate irrigation. This equipment consists of sensors that detect crop water needs such as weather station, soil moisture sensors and actuators for applying accurate water doses such as solenoid valves.	HydroSense	**< EUR 40/ha**
		Kim *et al.* (2008)	**EUR 915**

PATs Services			
On the go soil sensing	On the go soil sensing is a mapping service that collects soil samples for measuring soil parameters according to precision agriculture methods. Also, non-destructive methods for estimating these parameters can be used. Aim of this service is to produce prescription maps for variable rate fertilization and variable rate seeding in order to achieve the highest economic profit by managing in field variability.	Hurst *et al.* (2015)	**EUR 6.5/ha**
EO crop scouting and services	Earth Observation based crop scouting services offer added value services to farmers by exploiting satellite data. These data are used for assessing crop status, providing yield estimation, delineating management zones and as a result producing prescription maps for variable rate applications (seeding, fertilization, spraying).	Space-tec (2012)	**EUR 6-10/ha**
UAV crop scouting and services	UAV based crop scouting services offer added value services to farmers by exploiting high resolution datacollected from drones. These data are used for assessing crop status, providing yield estimation, delineating management zones and as a result producing prescription maps for variable rate applications (seeding, fertilization, spraying).	Wilkes (2015)	**EUR 10-25/ha**

SOURCE: Soto, I., Barnes, A., Balafoutis, A., Beck, B., Sanchez, B., Vangeyte, J., Fountas, S., Van der Wal, T., Eory, V. & Gomez-Barbero, M. 2019. The contribution of precision agriculture technologies to farm productivity and the mitigation of greenhouse gas emissions in the EU. Luxembourg, Publications Office of the European Union, ISBN 978-92-79-92834-5, doi:10.2760/016263, JRC112505.

Annex II
Framework documents and regulations promoting innovation in the agriculture sector in Ukraine

1 **The national report, Sustainable Development Goals of Ukraine, presents the results of adaptation of 17 global Sustainable Development Goals taking taking account of national specifics and Goal 2: Overcoming hunger, agricultural development.**

a. Objective 2.2: to double the productivity of agriculture, primarily through the use of innovative technologies;
b. Objective 2.3: to ensure the creation of sustainable food production systems that contribute to the conservation of ecosystems and improve the quality of land and soil, primarily through innovative technologies.

2 **Resolution of the Cabinet of Ministers of Ukraine No. 980 covered medium-term priority areas of innovation activity at industry level for 2017-2021, section IV, technological renewal and development of the agricultural sector:**

- the creation of energy-saving and resource-saving technologies for growing crops with elements of precision farming;
- technological update of soil diagnostics;
- introduction of technology to monitor agricultural resources using satellite imagery of the earth's surface.

3 **Resolution of the Cabinet of Ministers of Ukraine No. 67-p, Concept for the development of the digital economy of Ukraine for 2018-2020:**

- “Principles of digitalization [...] Principle 2. Digitalization should be aimed at creating benefits in various areas of everyday life. This principle provides for improving the quality of health and education services, creating new jobs, developing entrepreneurship, agriculture, transport, protecting the environment and managing natural resources, improving culture, helping to overcome poverty, prevent disasters, and ensure public safety".
- “In order to develop agriculture, it is important to introduce digital farming, a fundamentally new management strategy based on the use of digital technologies. The development of the agrarian sector associated with the use of geographic information systems, global positioning, on-board computers and smart equipment, as well as managerial and executive processes that can differentiate processing methods, fertilizing, plant protection products”.

- “Digitalization of the agricultural sector will have a positive impact on the digitalization of rural infrastructure, in particular in terms of connecting villages to high speed Internet. The low level of economic development in rural areas of Ukraine leads to the migration of rural youth to cities, high unemployment and low incomes for the rural population, the destruction of social and engineering infrastructure and so on. That is why agro-industrial business is interested in using information technologies, both on the field and in workers’ homes, in order to improve the quality and living conditions in rural areas, to achieve the highest social standards”.
- "Digitalization of agriculture and farming is an instrument of a large-scale rural digitalization programme, connecting rural areas to digital infrastructure, bridging the digital divide and the socio-economic revival of rural areas."

Annex III
Policy development and application of remote sensing in the United States of America and the European Union

The United States of America has vast experience in the development and application of remote sensing in agriculture. The basis for success is an advanced legislative framework.

- Policy Act (1992). Land Remote Sensing Policy Act of 1992, 15 U.S.C. 5601 *et seq.*[27] legislatively reinforces the importance of remote sensing for national security and in other areas, while directly defining the Landsat Federal Government Programme. It establishes that paid services in remote sensing can be provided exclusively by private companies.
- Public Law 111-314 (laws relating to national and commercial space programmes as title 51, United States Code, National and Commercial Space Programmes 18 December 2010).[28] It directly recommends the use of remote sensing in agriculture at the federal level, as well as the maximum involvement of private companies in such activities.

At the state level, remote sensing is the main tool in the development of a cropland data layer (CDL), developed by the National Agricultural Statistics Service in cooperation with the Department of Agriculture (USDA).[29] The CDL system plays a significant role in informing government agencies on an independent assessment of sown areas, the state of crops and forecasting of crop capacity. It monitors 114 crop cultures throughout the growing season. The Foreign Agricultural Service (FAS), a division of the USDA, also uses satellite information to monitor and forecast production indicators in countries around the world.[30]

27 United Nations Office for Outer Space Affairs. 2022. [online]. Vienna. www.unoosa.org/oosa/oosadoc/data/resolutions/1986/general_assembly_41st_session/res_4165.html
28 United States Government. 2002. [online]. Washington DC. National and Commercial Space Programs. www.govinfo.gov/content/pkg/PLAW-111publ314/pdf/PLAW-111publ314.pdf
29 United States Department of Agriculture. 2022a. VegScape – Vegetation Condition Explorer. [online]. https://nassgeodata.gmu.edu/VegScape/
30 United States Department of Agriculture, 2022b. Foreign Agricultural Service. World Agricultural Production. [online]. Washington DC. www.fas.usda.gov/data/world-agricultural-production

The European Union. Initially remote sensing in the European Union was a tool to predict and monitor sown areas and yields, supported by monitoring agriculture with a remote sensing (MARS) system, created in 1988. MARS newsletters are available at no cost to a wide audience.[31] Since 1993, this has contributed to an integrated administration and control system (IACS), for effective control over allocation of agricultural subsidies and payments under the Common Agricultural Policy (CAP). Its key components are remote sensing control tools (CwRS) and a digital land parcel identification system (LPIS).[32]

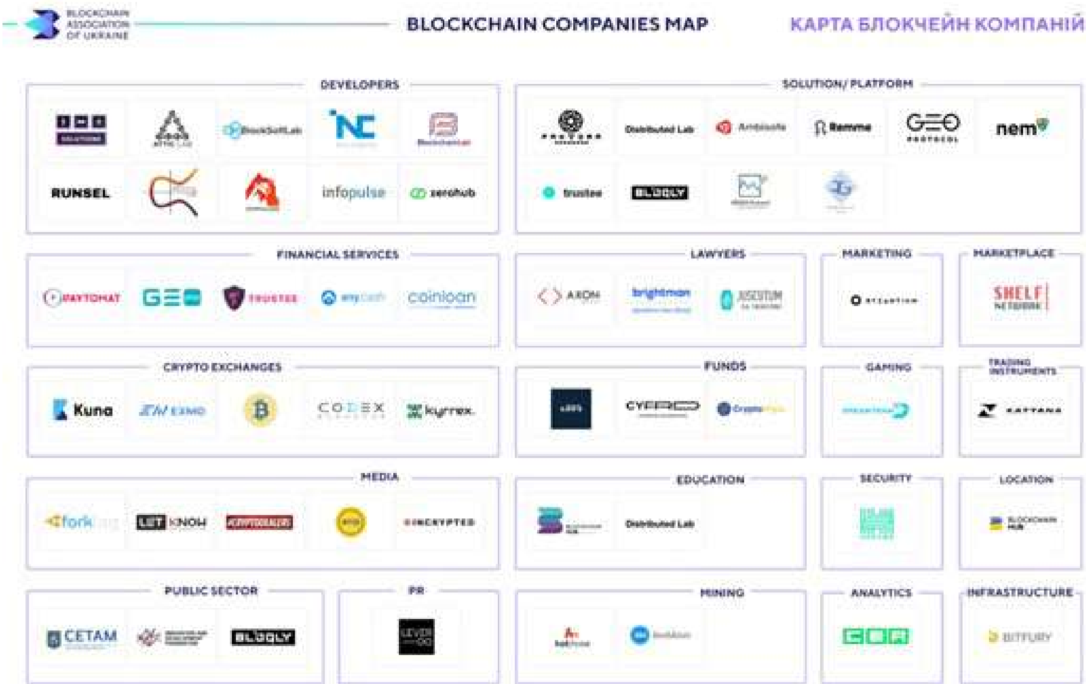
In addition to making subsidies more efficient, this system has made significant savings in administration costs. It is estimated an inspector's visit to a site costs around EUR 1800, while verification of remote sensing is around EUR 60–70.[33] Remote sensing in European Union agriculture is based on an extensive legislative framework that regulates the use, financing, acquisition of satellite images, monitoring of agricultural land, management and control rules, etc.

31 https://ec.europa.eu/jrc/en/mars/bulletins

32 European Commission. 2022. EU Science Hub. Remote sensing to support the CAP. [online]. Brussels. https://ec.europa.eu/jrc/en/science-update/remote-sensing-cap

33 Northern Ireland Assembly. 2022. Contextual overview of the use of remote sensing data within CAP eligibility inspection and control. [online]. Belfast. http://www.niassembly.gov.uk/globalassets/documents/raise/publications/2015/dard/3115.pdf

Annex IV
Overview of blockchain operators in Ukraine



SOURCE: Blockchain Association of Ukraine, 2019. Overview of the blockchain Industry in Ukraine. https://bau.ai/wp-content/uploads/2019/05/Overview-of-the-blockchain-industry-in-Ukraine.pdf

Annex V
Precision farming projects supported by the European Agricultural Fund for Rural Development

Project	Country	Duration	Promoter	Project financing, EUR: Total	EAFRD	Private	Regional	Description	Results
Regadio de Precisão - Precision Irrigation	Portugal	2017 - 2020	TERRAPRO	464 000	348 000	116 000	N/A	Development of agronomic tools to measure irrigation requirements. Funding of 70 percent of equipment costs (soil moisture probes, meteorological stations, technology for pivots), human resources and dissemination of results.	Enables farmers to irrigate and fertilize their fields more efficiently on the basis of information and tailored advice on the soil characteristics and water reserves in the soil.
Investing in a site specific precision sprayer	Netherlands	2016 - 2017	Farm Katerberg	150 000	18 000	132 000	N/A	Wim Katerberg farms 300 hectares and applied for RDP support to acquire a new sprayer machine that would allow him to conduct precision farming.	Cost savings and a reduced impact on the environment. For example, in potato cultivation two litres of pesticides per hectare are required with conventional agriculture, but the new site specific sprayer needs only 1.3 litres.
APPVID – Grapevine diseases management	Spain	2016 - 2018	Asociación de Bodegas de Rioja Alavesa	266 088	171 408	51 827	42 852	Develop a collaborative system of precision viticulture. Small growers will have a real time online tool to help them manage diseases. The remote sensors and mobile app will provide detailed information about vineyard health, facilitating planning of phytosanitary treatments.	Expected results: Improved farm profitability, reduced environmental impact due to more accurate phytosanitary treatments and improvement of grape quality.
Acquiring machinery for research trials and precision farming	Bulgaria	2007 - 2013	Hristo Hristov	200 386	46 401	142 385	11 600	A medium size farm specializes in the production of grain crops. Support from measure M121 of the Bulgarian RDP was used to purchase a tractor, GPS kit, computerized device for precision seeding and fertilizing, a plough and other items. Training was carried out on how to use the new equipment.	This requires 3–7 percent fewer seeds, fertilizers, plant protection products are needed. There is less waste and fewer losses due to mechanical failures and more reliable field tests. The income from the trial parcels increased due to faster seedling turnover and improved yields.
Efficient irrigation system in a fig orchard	Portugal	2016 - 2018	Sociedade Agrícola e Turística Quinta da Mó de Cima, SA	376 931	96 117	262 852	16 962	The project financed the application of precision technologies on a fig farm. The new system consists of soil moisture content probes and a meteorological station for reading the temperature, recording the dew points and indicating the appropriate harvest time for the 40 ha.	This system reduced the amount of fruit below commercial quality from 20 percent to 10 percent. Production will increase from 22 to 31 tonnes per ha. The figs are bigger raising the average selling price from EUR 1.3 to EUR 1.5 per kg.
GIS-ELA - Geo Information Systems for the Austrian Agriculture	Austira	2014 - 2020	Chamber of Agri-culture Lower-Austria (LKNÖ)	525 180	240 643	50 018	234 518	Only 6 percent of Austrian farmers are using data and GNSS/GPS-based precision farming. The project evaluates the potential of precision farming technologies for Austria by assisting farmers to use the app maps with free software and low level technical equipment in close cooperation with the pilot farms	The pilot farms employ a large range of technical equipment but high level technical equipment does not correlate to farm size. None of the eight farms had used app maps before, but two are using precision farming based on GPS-steering. A big challenge is how to integrate different data sources to create the map.
Modernization of a rice growing farm in Portugal	Portugal	2014 - 2020	Orivárzea Orizicultores Do Ribatejo S.A	326 555	93 449	201 955	31 149	Orivárzea is an association of rice producers. Before receiving RDP support, Orivárzea used inadequate irrigation infrastructure that was over 30 years old. Investments included intregrating a network of sensors with remote transmission to monitor the level and quality of water from a distance, allowing for a more rational management of water to meet the needs of the plants.	Investment in the pumping system has increased water catchment efficiency, i.e. with less energy consumption. New pipelines maintain the same low, but sufficient water level across all the rice beds. In terms of its efficiency, costs for water, energy, pesticides, fertilizers and labour decreased while yields increased.

SOURCE: Authors' research

Annex VI
Advantages of green credit lines

Barrier category	Barrier	How green credit lines can help address the barrier
General investment environment barriers	Economic barriers due to weak climate and environmental policy	Targeted policy dialogue in recipient countries may help support the implementation of policies improving the enabling environment for green investments
	Financial barriers related to real and perceived risks, and the financial structure of green investments	Provision of concessional funds, longer tenors and grace periods as well as the use of complementary risk-management mechanisms may help better match green investments needs
	Legal barriers	N/A
Demand-side barriers	Low awareness: lack of understanding of climate investment opportunities	TA to end-borrowers, for example, in the form of energy auditsor providing information on financing options may help increase the interest in pursuing green investment opportunities
	Prevailing business practices: preference for near-term benefits instead of long-term savings and revenue streams	Incentive payments structured as ex-post grants that reimburse parts of the investment financed by the GCL may help motivate end-borrowers to develop green projects
	Lack of in-house capacity to develop sound investment proposals for LFIs	TA to end-borrowers may support them in drafting business plans and loan applications and accompany green investment projects along their lifecycle
Supply-side barriers	Lack of access to long-term capital in LFIs	Provision of concessional funds, longer tenors and grace periods
	Lack of access to long-term capital in LFIs	TA to LFIs, for example, in the form of market studies or portfolio assessments, as well as institutional capacity building may boost the development of green lending in LFIs and ensure long-term sustainability of green lending practices.
	Unsuitable lending practices	Concessional funding with longer tenors and grace periods may allow LFIs to provide end-borrowers with products better matching the time horizons of economic benefits (revenues and savings) of green investment projects
	Lack of risk management mechanisms	Complementary instruments such as guarantees or insurance may help reduce real and perceived risks of engaging in green lending for LFIs
	High up-front costs and risks for developing new business lines in green lending	TA to LFIs can support them in designing, testing and deploying new financial products, while concessionality can offset the additional transaction costs

SOURCE: I4CE (Institute for Climate Economics). 2017. Using credit lines to foster green lending: opportunities and challenges. https://www.cbd.int/financial/2017docs/ice-creditlines2017.pdf

Annex VII
Green credit line projects

Project name	Country	Start/ end date	IFI/PFI	LFI/Company	Project financing, USD million: Total cost	Project financing, USD million: PFI/IFI loan	Project objectives
Kernel Grain Working Capital	Ukraine	4 September 2019	European Bank for Reconstruction and Development	Kernel Group	300	80	• Expand access and use of open digital solutions for precision agriculture which will benefit Kernel Group and partner farmers in their daily operations • Enhance connectivity of silos by facilitating access to Kernel's logistics or other logistics solutions
Agricultural Modernisation and Innovation	Ukraine	23 November 2017	European Investment Bank - InnovFin	Astarta-Kyiv	87	43	• Investments to enlarge/update grain and sugar capacity to improve trade/export logistics and mitigate impact of climate change on yield variation and post-harvest losses • Develop agribusiness management software to optimize entire value chain
Agricover SME	Romania	14 February 2019	International Finance Corporation	Agricover Credit IFN SA	10	10	Provide longer tenor investment loans to agribusinesses/ SMEs for climate-smart equipment upgrades to increase energy and water efficiency targeting farming
Central Fin Agri	Sri Lanka	11 May 2018 – 2023	International Finance Corporation	Central Finance Company PLC (CF)	20	20	Provide longer-tenor funding to 10 000 MSMEs to support technology investments, climate-smart agriculture solutions and women-owned enterprises
NDB Agri Loan	Sri Lanka	16 May 2018 – 2023	International Finance Corporation	National Development Bank PLC (NDB)	50	50	• Work with participating financial institutions to build capacity for agrivalue chain financing and to disseminate knowledge on climate smart agricultural practices to improve yields and income levels of farmers/small agribusinesses • Capacity development of participating financial institutions on agrivalue chain financing and development of related products
Agrobanco	Peru	18 November 2015	Agence Française de Développement	Agrobanco	58.7	58.7	• Develop and strengthen the green investment portfolio • Improve Agrobanco's environmental and social performance • Reduce costs related to the most innovative investments with a technical assistance programme to improve the definition and identification of eligible green projects.
Kazagro Climate Loan for SMEs and Midcaps and MSMEs	Kazakhstan	21 July 2017	European Investment Bank	Kazagro National Management Holding JSC	100	100	Financing projects contributing to climate change adaptation, such as resource efficiency (e.g. water efficiency, irrigation), protection of soil erosion schemes (buffer zones, river bank fencing), improved logistics and grain elevators, afforestation of degraded land, and possibly climate mitigation (e.g. biomass energy projects)
NEPF Farming Ukraine	Ukraine	26 February 2014	European Bank for Reconstruction and Development	New Europe Property Fund L.P (NEPF)	120	40	Funds will be used to replenish the enterprises' working capital and support their export operations with grain for the next three seasons. It also assumes a significant reduction in carbon dioxide emissions and the improvement of energy efficiency at the enterprises involved

SOURCE: Authors' research

Annex VIII
Requirements set by the Nori carbon marketplace

1. **Farms have in the last ten years adopted one or more of the following regenerative practices:**
   - cover cropping;
   - reduced tillage;
   - increased crop diversity;
   - increased crop rotations;
   - switches from synthetic to organic matter additions such as manure or compost.

2. **Data.** Farms must be able to provide at least three years of pre-switch operating data to support their claim for new practice adoption. For further details on data requirements please refer to Annex V: Data requirements – eligibility criteria for Nori carbon marketplace. Additionally, Nori has partnered with COMET-Farm, a GHG accounting tool that models how much carbon has been removed by comparing sustainable practices to previous farming methods. To ensure the accuracy of modelling efforts, COMET-Farm will require as much historical data on past practices as possible, going back as far as 2000.

3. **Farms must be willing to sign a ten year project registration contract.**

4. **Willingness/ability to pay verification costs between USD 3000–5000.**

SOURCES: Nori. 2021. Pilot croplands methodology. [online]. V.1.1. https://nori.com/resources/croplands-methodology; Nori. 2020. Nori data policies and requirements for croplands methodology. [online]. https://docs.google.com/document/d/1fLSoI5XIIRRfkK6ceWXXvXxVfW8dB_u8i_gIDBu6jOk/preview#heading=h.zarxrol0v6yt

Planting and harvest

- Crop (or cover crop) type
- Date planted
- Date harvested or killed
- Yield
- Only grain, fruit, or tuber harvested?
    - If not, what percentage of post-harvest residue was removed?
- For orchards,
    - Did you prune?
    - Did you clear or renew?

Tillage

- Tillage type
- Tillage date

Fertilizers (synthetic)

- Fertilizer type
- Fertilizer date
- Fertilizer rate (kg per acre)
- Did you use a slow release or nitrification inhibitor product?
- Application method

Manure or compost

- Manure type
- Manure date
- Manure rate (tonnes dry matter per acre)
- Manure N content
- Manure C:N ratio

Irrigation

- Irrigation date
- Irrigation volume (inches per acre)
- We can take this as a start and end date with frequency or total amount of water and divide it evenly over the period the crop was in the ground.

Liming

- Liming type
- Liming date
- Liming amount

Did you do any burning?

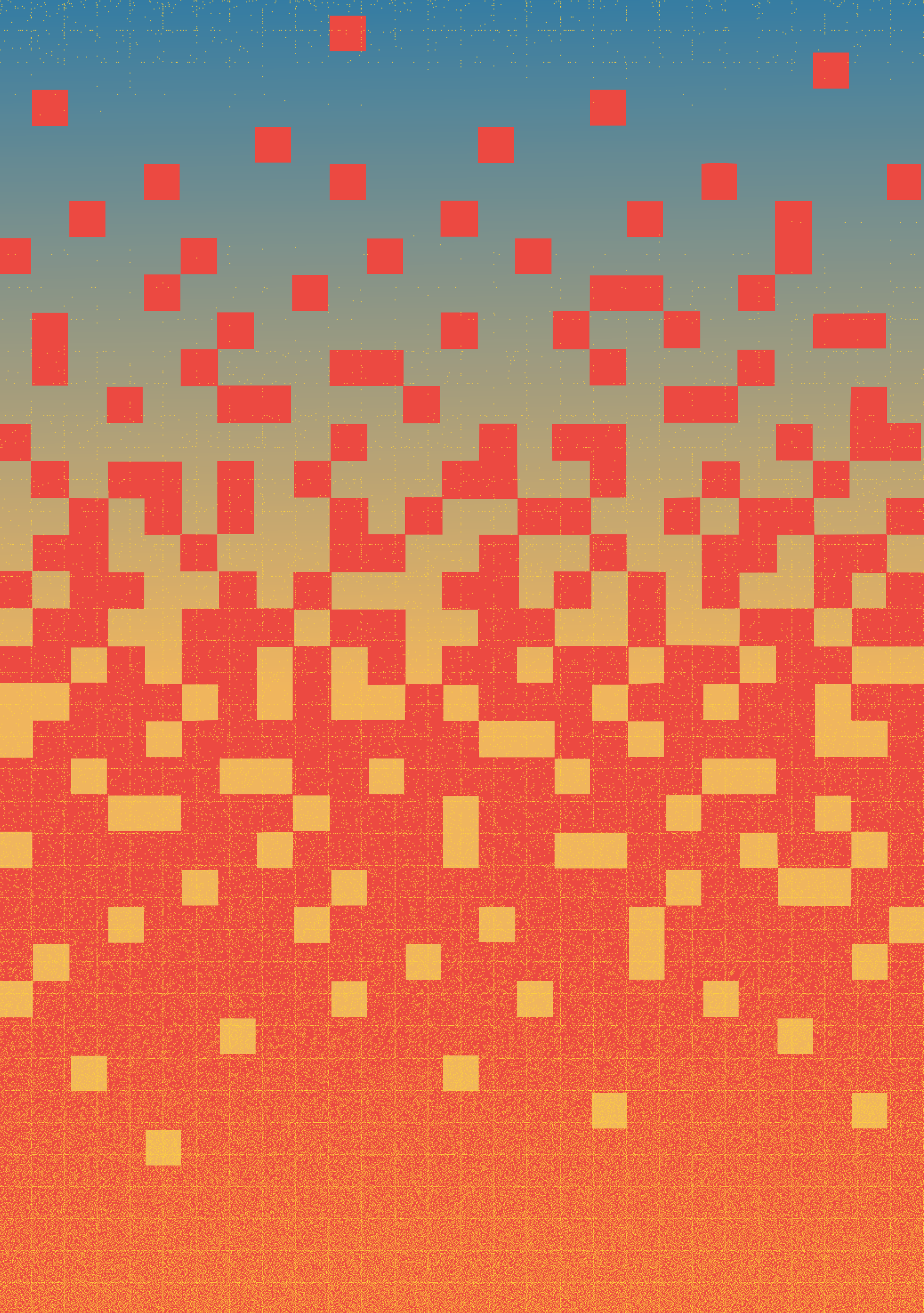
- No
- Yes, before planting
- Yes, after planting

Glossary

Term	Definition
Agricultural holding or agroholding	Group of separate legal entities (mostly operating as limited liability companies) that rent agricultural land mostly for crop production, independent farmers, and or processing organizations that are owned by the same beneficiary/ies and operate under the management of a parent (holding) company.
Auxiliary auto-control systems	Systems that can control the steering system of a tractor without any guidance from the driver, as well as the supporting electrical auxiliary components related to security, comfort, lighting and information systems.
Blockchain	Digital database that uses cryptography to link and secure transactions and data entries. It involves data processing and data storage within a peer-to-peer distributed network of computers (distributed ledger technologies) used to validate and store transaction history and information (FAO, 2018).
Canopy maps	Maps produced using crop sensors that detect the characteristics of the crop canopy and its area, provide information on the crop growth level and quality, and possibly assist in predicting the final crop yield (Soto, *et al.*, 2019).
Carbon dioxide equivalent (CO_2eq)	Amount of carbon dioxide (CO_2) emission that would cause the same integrated radiative forcing, over a given time horizon, as an emitted amount of a greenhouse gas (GHG) or a mixture of GHGs (IPCC, 2014).
Carbon voluntary market	Voluntary markets for emissions reductions cover those buyers and sellers of Verified Emission Reductions (VERs), which seek to manage their emission exposure for non-regulatory purposes. Such credits are not eligible in Emissions Trading Schemes (ETS) (such as the EU ETS) due to a potential lack of transparency and control exercised compared to government controlled compliance systems (European Commission, 2015).
Compliance carbon markets	Trading system through which countries may buy or sell units of greenhouse-gas emissions in an effort to meet their national limits on emissions, either under the Kyoto Protocol or under other agreements, such as that among member states of the European Union (OECD, 2013).
Controlled traffic farming (CTF)	System that confines all machinery loads to the least possible area of permanent traffic lanes and which has the potential to reduce soil compaction (Soto, *et al.*, 2019).
Cryptocurrency	Any form of currency that only exists digitally and that usually is not issued or regulated by a central authority, but instead relies on a decentralized system to record transactions and manage the issuance of new units. Cryptocurrency relies on cryptography to prevent counterfeiting and fraudulent transactions (Merriam Webster, 2021a).
Geographical Information System (GIS)	Computer system that allows the capture, storage, query, analysis and display of geospatial data. It provides computerized mapping and geospatial analyses for a better understanding and modelling of real-world occurrences. By using geospatial locations, GIS integrates many different kinds of data layers including imagery, features and base maps (Alcaras, Parente and Vallario, 2020).
Global Navigation Satellite System (GNSS)	Constellation of satellites providing signals from space that transmit positioning and timing data to GNSS receivers. The receivers then use this data to determine location (European Union Agency for the Space Programme, 2021).

Global Positioning System (GPS)	Navigational system using satellite signals to determine the location of a radio receiver on or above the earth's surface (Merriam Webster, 2021b). In the context of precision agriculture technologies (PATs), GPS or guidance systems refer to the systems that are used for tractor guidance.
Greenhouse gases (GHGs)	Atmospheric gases responsible for causing global warming and climate change. The major GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_20). Less prevalent, but very powerful, GHGs are hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6) (United States of America Environmental Protection Agency, 2019).
Green credit line	Intermediation tool aimed at fostering green lending. Under a GCL, funds are typically extended by a public financial institution (PFI) to participating local financial institutions (LFIs), that in turn on-lend them to developers of eligible green projects. GCLs may include special financial conditions, such as reduced interest rates, longer tenors, increased grace periods or incentive payments. GCLs may also include technical assistance (TA), which is usually funded by a PFI and aims at building capacity of local banks to provide loans to green investment projects and/or capacity of end-borrowers to structure investment proposals (I4CE, 2017).
Precision agriculture technologies (PATS)	Set of data-driven GIS-based technologies designed to maximize the use of every land parcel across a field and enable field works in targeted areas.
Real-time kinematic positioning (RTK)	Differential GNSS technique originated in the mid-1990s that provides a high-precision positioning in the vicinity of a base station. An RTK set-up consists of a base station (a receiver at a fixed, known location), one or several rover users (receivers that move and of which position data is required) and a communication channel with which the base broadcasts information to the users in real time (Soto, *et al*., 2019).
Remote sensing	Sensing and analyzing of the Earth's surface from space by using the properties of electromagnetic waves emitted, reflected or scattered for better management of natural resources, land use and environmental protection" (United Nations Office for Outer Space Affairs, 1986).
Smart contract	Agreement between two or more parties according to predefined conditions (computer algorithm). A smart contract works without the direct participation of the parties through transactions or other actions that can be performed using software tools.
Tillage	Mechanical manipulation of the soil for the purpose of crop production, affecting significantly soil characteristics such as soil water conservation, soil temperature, infiltration and evapotranspiration processes (Busair, *et al.,* 2015).

Variable rate application (VRA)	Enable changes to the application rate to match the actual need for fertilizer, plant protection chemicals, lime, seeds, etc. in a precise location within a field. Application rates are guided by an electronic map or readings from sensors and a control system calculates the input needs of the soil or plants and transfers the information to a controller, which delivers the input to the location (Soto, *et al.*, 2019). More specifically, it includes: • Variable rate fertilizer application: allows fertilization at designated variable rates and placement to be aligned to specific crop needs in a location within the field. Inorganic fertilizer is spread either as liquid or as solid granules, while manure is spread either as slurry or as solid manure. • Variable rate irrigation application: customizes water application based on the crop's needs, based on mapped topography information, soil data maps, prior yield data and information about the crop's status. This can, for example, be achieved by pulsing sprinklers or boom sections on and off and/or controlling the system speed to modify the application depth along the length of the irrigator. VRI uses GPS technology and the control systems which can be easily retrofitted onto uniform sprinkler systems. • Variable rate seeding/ planting application: alters the rate of planting and seeding during application. This is often accomplished by disconnecting the seeding/ planting system from the ground drive wheel, which normally keeps the planting/seeding rate constant when the speed of the tractor varies. By driving the planting/seeding system with an independent engine, gear box or hydraulic drive, the rate can be adjusted to local soil potentials. • Variable-rate pesticide application: modifies the rate of application to match the actual or potential field pest stress and it also prevents the application of pesticide where it is not needed. • Precision physical weeding: the method of weed control through burning, mechanical weed control with knives, discs, hoes or harrows with minimum crop damage and no chemical herbicide use.
Yield mapping	Process of collecting georeferenced data on crop yields and yield characteristics (such as moisture content) during the time that the crop is harvested.



Comprising 30 percent of agricultural output and with an area of 15 million hectares, the grain sector is a pillar of Ukraine's agriculture. In 2020 Ukraine exported USD 9.4 billion worth of cereals, the second largest exporter after the United States of America, making Ukraine a major contributor to global food security. Using extensive interviews, the report assesses the extent to which Ukrainian farmers have adopted digital technologies, the many barriers to them doing so and the considerable opportunities these technologies present, while offering sharp insights into their potential contribution and how best to sustain them. The report also considers the level of interest larger farmers have in adopting precision agriculture technologies, and their benefits in terms of improved productivity, lower costs and reduced greenhouse gas emissions, despite the relatively high initial investment required. It concludes with a list of recommended actions, calling on four groups to embrace digital technologies and thus develop and transform Ukraine's grain sector: the private sector, financial institutions, the public sector and international organizations. This publication is part of the Country Investment Highlights series under the FAO Investment Centre's Knowledge for Investment (K4I) programme.

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