

Symposium on Natural and Applied Sciences
Hosted Online from London, United Kingdom
Date: 5th October, 2026
Website: https://econferencia.com

WAYS AND MECHANISMS FOR THE EFFECTIVE USE OF INTELLECTUAL RESOURCES BASED ON DIGITAL TECHNOLOGIES AND ARTIFICIAL INTELLIGENCE

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Abstract

The article examines ways of using digital technologies and artificial-intelligence-based intellectual resources in agriculture. A four-layer digital platform architecture is developed: data collection, integration, analysis and modelling, and decision-making. The effectiveness of technological solutions under water scarcity is assessed through a model calculation, showing that smart irrigation systems can reduce water consumption per unit of output by up to 48 %. Six barriers to the adoption of digital solutions are identified and mechanisms for removing them are substantiated. The specific nature of intellectual resources in agriculture – their reproducibility and role as a new source of economies of scale – is revealed.

Keywords: Digital technologies, artificial intelligence, intellectual resources, smart farming, water saving, digital platform, agrarian sector, Karakalpakstan.

Introduction

Over recent years, the introduction of digital technologies in agriculture has become one of the priority directions of agrarian policy. However, practical results in this area remain below expectations. In our view, the main reason lies in treating technology as an end rather than as a means: sensors are installed and

software solutions are purchased, yet the specific economic task they are supposed to solve is not defined.

The concept of intellectual resources makes it possible to frame this problem on a different plane. An intellectual resource is not a technical device but the capacity of data, models and knowledge to be transformed into a management decision. A sensor is not a resource in itself; it becomes a resource when the data it collects are analysed and turned into a decision on the irrigation regime.

In the conditions of the Republic of Karakalpakstan, this issue is of particular relevance. As shown in previous studies, the sown area in the region has decreased by 7.5 percent since 2022, while rice production has fallen 2.7-fold – both processes being a direct consequence of water scarcity. There is no possibility of increasing water inflow; hence, the only way forward is to increase the output obtained from the available resource. It is precisely this task that defines the main field of application of digital technologies.

The second aspect of the problem concerns small farms. Digital technologies are usually regarded as a solution designed for large producers, since they require substantial initial investment. In Karakalpakstan, however, the bulk of agricultural output is produced by small farms. If digital transformation does not cover this segment, it will not yield a significant result at the regional level.

The aim of the study – is to substantiate ways of using digital technologies and artificial-intelligence-based intellectual resources in agriculture, to develop a mechanism for their implementation, and to assess the expected effect.

Literature review

The issue of technological renewal in the agrarian sector has been analysed from the standpoint of resource efficiency in the works of D. Tilman and co-authors. Having shown that traditional ways of increasing productivity lead to the

degradation of the resource base, the authors substantiated technological solutions as a means of escaping this contradiction [1].

J. Pretty showed that the effectiveness of technological solutions depends on social capital and knowledge-exchange systems [2]. This conclusion is especially important for digital technologies: equipment can be purchased, whereas the capacity to use it is formed through the education and advisory system.

Having studied the socio-economic conditions for adopting water-saving approaches in the lower reaches of the Amu Darya, M. Bekchanov and co-authors identified a significant gap between the technical efficiency of a technology and its practical outcome [3]. The cause of this gap lies in the institutional environment: when water is free or very cheap, no economic incentive to save it emerges.

Sources on Israel's experience provide the most thoroughly documented example of overcoming water scarcity through technological solutions. Approximately 86–90 percent of wastewater in the country is reused, accounting for nearly half of irrigation water; about 75 percent of crops are drip-irrigated [4; 5]. These indicators confirm the high level of technological potential.

The analysis of the existing literature leads to the conclusion that the technical capabilities of these technologies have been well studied, whereas the mechanism for their implementation in regional conditions and their expected economic effect have not been sufficiently substantiated. This article aims to fill this gap.

Research methodology

The study employed the methods of the systems approach, organisational modelling and scenario calculation. A layered approach was applied in designing the digital platform architecture: each layer takes the output of the layer below as its input and performs a specific function.

The scenario calculation method was used to assess the effectiveness of water saving. The calculation is of a conditional, model-based nature, in which the efficiency ranges reported in international practice were adopted as baseline parameters. The results are not intended as precise forecasts but rather for comparing the relative potential of technological solutions; field experiments under local conditions are required to refine them.

Three criteria were applied to identify implementation barriers: the nature of the barrier (technical, financial or institutional); the time required to overcome it; and who bears responsibility for overcoming it. This classification makes it possible to substantiate the sequence for removing the barriers.

The limitations of the study are stated openly. The model calculations rely not on local experimental data but on efficiency ranges reported in international practice. Local soil and climatic conditions, the state of the irrigation network and the technical preparedness of farms may significantly alter the results. In addition, the assessment of implementation barriers was carried out on the basis of expert analysis.

Analysis and results

It is advisable to begin the analysis by identifying the specific features of intellectual resources in the agrarian sector (Table 1).

Table 1 Comparative characteristics of traditional and intellectual resources

Characteristic	Traditional resources (land, water, machinery)	Intellectual resources (data, models, knowledge)
Behaviour in use	Consumed or worn out in the process of use	Not depleted by use; applied repeatedly
Cost of replication	Each additional unit requires full cost	Once created, the cost of replication is minimal
Economies of scale	Limited by production volume	Expand with the number of users
Form of ownership	Clearly defined property rights	Often a shared-use resource
Rate of obsolescence	Physical wear, 10–20 years	Technological obsolescence, 3–5 years
Accessibility for small farms	Limited: requires capital	High potential: shared use via a platform is possible

The table analysis reveals the most important property of intellectual resources: they are not depleted in the process of use, and their replication cost is minimal. This is of fundamental importance for the agrarian sector, as it creates a new source of economies of scale. Under traditional conditions, economies of scale were achieved through the consolidation of land area; under conditions of intellectual resources, they are achieved by expanding the number of users.

The practical consequence of this property is as follows: an agrotechnological model developed once – for example, an algorithm calculating the irrigation regime for a particular soil type and climatic conditions – can be applied on thousands of farms, with the cost per additional user being close to zero. This fundamentally changes small farms' access to modern technologies.

At the same time, two other properties noted in the table manifest themselves as constraints. The first is the high rate of technological obsolescence: digital solutions require renewal every 3–5 years. This necessitates planning them as current expenditure rather than as capital investment. The second is the ambiguity

of the form of ownership: the question of who owns the data and who may use them must be regulated legally.

The last row of the table – accessibility for small farms – yields the most important result in practical terms. Whereas access to traditional resources is limited by capital, access to intellectual resources can be resolved through organisational form. Hundreds of farms can use a single platform, and the cost share for each of them will be small. This creates a new mechanism for ensuring technological equality.

At the same time, this opportunity is not realised automatically. It requires an organisational intermediary link – a cooperative, a cluster or a regional advisory centre. Even if a platform is created without an intermediary link, small farms will be unable to access it: they will possess neither the technical skills nor the data-transmission channels.

The proposed architecture of the digital platform is presented in Figure 1.

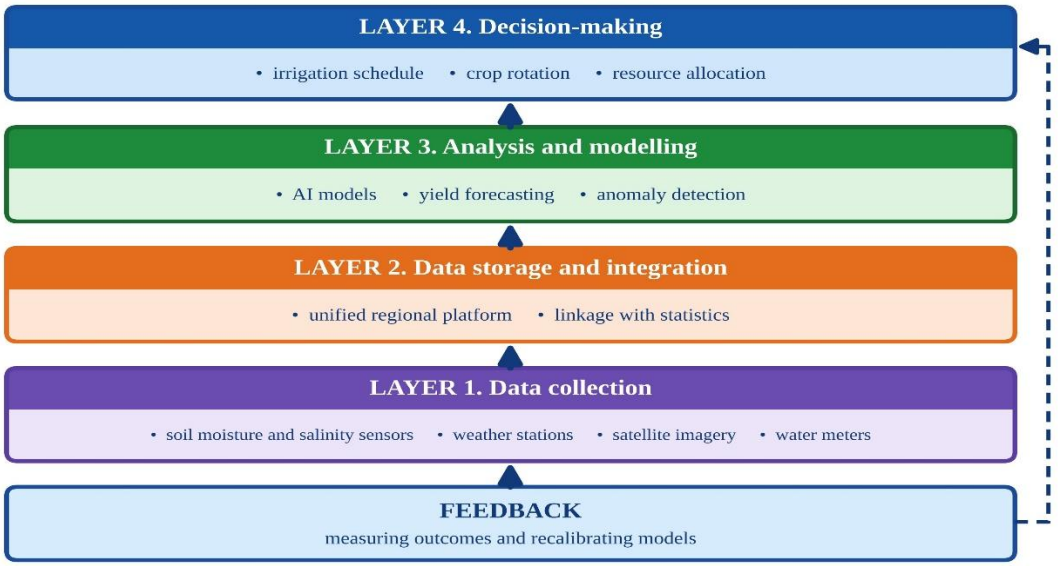


Figure 1. Layered architecture of the platform for managing intellectual resources in the agrarian sector

The first layer of the architecture is devoted to data collection. It includes sensors measuring soil moisture and salinity levels, meteorological stations, satellite imagery and water meters. An important feature of this layer is the diversity of sources: reliance on a single source reduces data reliability, whereas cross-checking several sources makes it possible to detect errors.

The second layer concerns data storage and integration. The importance of this layer is often underestimated, although it is precisely this layer that turns out to be the weakest link of the system. Data coming from different sources differ in format, units of measurement and collection frequency; analysing them without bringing them into a single system is impossible. In addition, the platform's linkage with official statistics must be ensured – otherwise two parallel data systems will emerge.

The third layer – analysis and modelling – is precisely the area in which artificial intelligence tools are applied. Three main tasks are performed here: yield forecasting, anomaly detection (disease, salinity hotspots, faults in the irrigation system) and solving optimisation problems. Each of these tasks requires a different type of model; therefore, the platform should rely not on a single universal model but on a set of models.

The fourth layer is devoted to decision-making and delivers the final product of the system. An important methodological point: at this layer, the system does not make the decision but provides a basis for it. Responsibility for the final decision remains with the human – this is particularly important in the agrarian sector, where non-formalised knowledge of local conditions plays a major role.

The feedback link at the bottom of the diagram turns the entire system into a closed loop. It measures the outcome of the decision taken and provides information for recalibrating the models. Without this link, the platform becomes a system that is configured once and loses its accuracy over time.

An important feature of the architecture is the independence of the layers from one another. Each layer receives the output of the layer below in a standard format, while its internal structure does not affect the other layers. This makes it possible to build the system step by step and to replace individual components: for example, updating the analytical model does not require changing the sensor network.

This principle is of decisive practical importance, since the rate of technological obsolescence of digital solutions is high. An integral, non-separable system requires complete replacement, which is costly. In a layered architecture, by contrast, an obsolete component is updated separately.

The resource requirements and implementation complexity of the platform layers are presented in Table 2.

Table 2 Characteristics of the digital platform layers and conditions for their implementation

Layer	Main components	Resource requirement	Implementation period
1. Data collection	Sensors, weather stations, satellite imagery, water meters	High: purchase and installation of equipment	2-3 years (phased)
2. Integration	Unified database, standardisation of formats, linkage with statistics	Medium: software and methodological work	1-2 years
3. Analysis and modelling	Forecasting models, anomaly detection, optimisation algorithms	Medium: specialists and computing power	2-3 years
4. Decision-making	Recommendation interface, mobile application for farms, advisory service	Low to medium: interface and training	1-2 years
Feedback	Measuring outcomes, recalibrating models	Low: an add-on to the existing system	Continuous

The table analysis raises the question of the implementation sequence. Logically, it seems natural to start with the first layer, yet it has the highest resource requirement. In practical terms, the expedient solution is to start with the second and fourth layers: consolidating the existing statistical and reporting data into a single database and, on that basis, creating a simple recommendation system for farms.

The advantage of such a sequence is that it delivers quick and inexpensive results and builds users' trust in the platform. Expansion of the sensor network is then carried out at the next stage, in the priority areas identified. Acting in the reverse order – first installing an extensive sensor network – creates the risk that data will be accumulated but remain unused.

A separate comment is needed on the third layer. Artificial intelligence models require an array of historical data in order to function. Newly installed sensors accumulate such an array over several years. For this reason, at the initial stage the models rely not on local data but on existing statistics and foreign experience, and only later are they adapted to local conditions.

A specific recommendation can be made regarding the fourth layer: the interface for farms should be as simple as possible. International experience shows that systems with complex interfaces have low levels of use, even if they are technically far more powerful. The optimal option is a message in the form of a few specific recommendations (for example, irrigation date and rate) delivered via mobile phone.

The relative water-saving effectiveness of technological solutions was assessed on the basis of a model calculation (Figure 2 and Table 3).



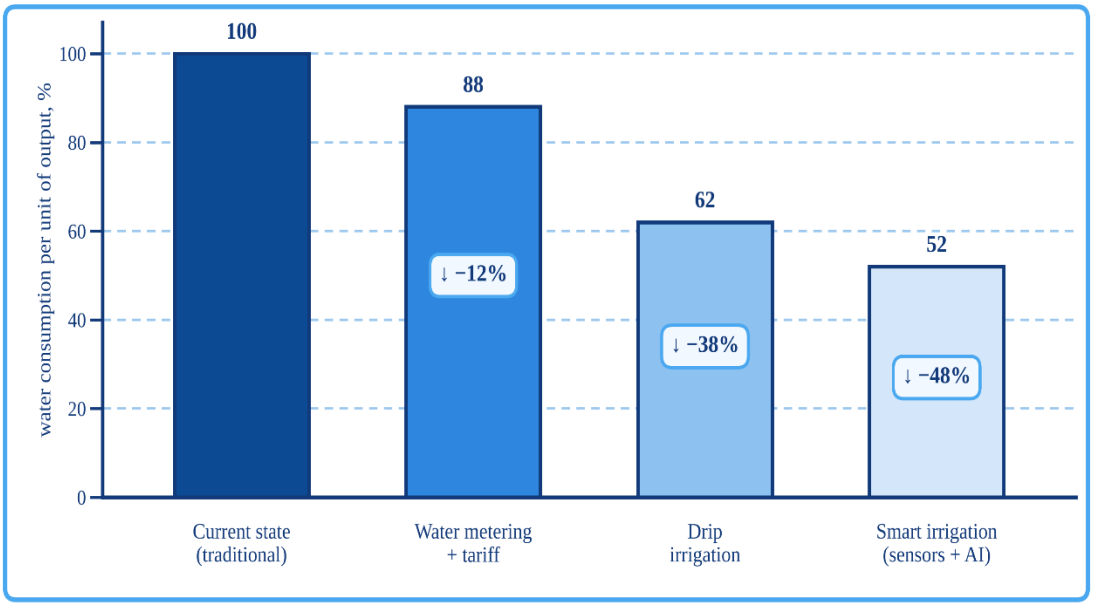


Figure 2. Water consumption per unit of output by technological solution (baseline = 100 %)

Table 3 Comparative characteristics of water-saving technological solutions

Solution	**Mechanism of impact**	**Reduction in water consumption**	**Initial cost**	**Implementation complexity**
Water metering and tariff-setting	Changing behaviour through economic incentives	Up to 12 %	Low to medium	Medium: meters and tariff system
Drip irrigation	Delivering water directly to the root zone, reducing evaporation	Up to 38 %	High	Medium: equipment and maintenance
Smart irrigation (sensors and artificial intelligence)	Automatic adjustment of irrigation timing and rate according to soil condition	Up to 48 %	High	High: infrastructure and skills
Crop rotation optimisation	Increasing the share of low-water-demand crops	Depends on crop structure	Low	Low: methodological recommendations

The analysis of the chart and table shows an efficiency hierarchy among the solutions. Smart irrigation systems deliver the greatest effect, but they also entail the highest cost and complexity. Notably, the transition from drip irrigation to smart irrigation yields an additional saving of 10 percentage points – significantly less than the 38 percentage points delivered by drip irrigation itself.

This pattern is a manifestation of the principle of diminishing returns and has practical significance: under resource constraints, it is advisable first to introduce simple and inexpensive solutions on a broad scale, and to apply complex solutions on the plots that yield the highest returns. An attempt to cover the entire area with the most advanced technology at once leads to inefficient use of resources.

The water metering and tariff-setting solution deserves special attention. Its technical effect is the lowest (up to 12 percent), but its initial cost is also relatively low and, most importantly, it creates the economic foundation for all the other solutions. Where water is free or very cheap, investing in drip irrigation is economically unjustified for a farm, since the saved water has no value. For this reason, this solution has an institutional rather than a technical priority.

The crop rotation optimisation solution is the lowest-cost option, and in fact it is already being implemented spontaneously in the region: as shown in previous studies, leguminous grain crops have increased 28.6-fold, while rice has decreased 2.7-fold. The role of digital tools here is to replace a spontaneous process with evidence-based recommendations: calculating the optimal crop structure for each plot based on soil condition and the water-supply forecast.

It is also necessary to clarify the scope of application of artificial intelligence tools in the agrarian sector. They are most effective in two types of tasks: first, forecasting across a large number of variables (yield, water demand, disease risk); second, detecting anomalies in large volumes of data (identifying salinity hotspots in satellite imagery or faults in the irrigation system).

At the same time, artificial intelligence solutions have two serious limitations. First, they rely on historical data and therefore produce unreliable results under previously unobserved conditions. Under climate change, this limitation is particularly pronounced. Second, how the model arrived at its conclusion is often not explained, which limits the agricultural specialist's ability to evaluate the recommendation. For this reason, the principle stated above – that the system should not replace the decision but provide a basis for it – is of fundamental importance.

The methodological basis of the model calculation needs to be clarified. Traditional furrow irrigation was adopted as the baseline, and its water consumption per unit of output was taken as 100 percent. For each subsequent solution, the saving coefficient was set at a value close to the lower bound of the ranges reported in international sources – this was done deliberately to keep the estimates conservative.

The choice of conservative estimation is justified, since several factors reduce effectiveness under local conditions: the deterioration of the irrigation network, the high silt content of water (which causes clogging of drip irrigation systems) and the inadequacy of the technical maintenance network. If these factors are not taken into account, the calculation results will prove overly optimistic.

The main barriers to the implementation of digital solutions are systematised in Table 4.

Table 4 Barriers to the implementation of digital technologies and mechanisms for overcoming them

Barrier	Nature	Mechanism for overcoming	Responsible actor
Small size and fragmentation of farms	Institutional	Shared-use model through cooperative and cluster structures	Regional administration, cooperatives
Volume of initial investment	Financial	Concessional leasing; subscription model; subsidies for pilot projects	Financial institutions, the state
Shortage of qualified personnel	Institutional	Advisory service network; integration into educational programmes	Research and educational institutions
Lack of a historical data array	Technical	Use of existing statistics; gradual accumulation	Statistical agencies, platform operator
Lack of economic incentive to save water	Institutional	Phased introduction of water metering and volume-based tariffs	Government bodies
Unstable internet and energy supply	Technical	Autonomous power sources; solutions operating in offline mode	Infrastructure operators

The table analysis shows the distribution of barriers by their nature: of the six barriers, three are institutional, two are technical and one is financial. The predominance of institutional barriers leads to an important conclusion – the main constraint on digital transformation is not the availability of technology but the absence of an institutional environment ready to adopt it.

The first barrier – the small size of farms – is the most significant. As established in previous studies, 89.9 percent of livestock output is produced on small dehkan farms. For such a farm, purchasing an individual digital solution is economically unjustified. The solution is to make use of the property of intellectual resources

noted above: to establish the platform as a shared-use resource and to provide access to it through a cooperative.

The fifth barrier – the lack of an economic incentive to save water – directly determines the effectiveness of technological solutions. If it is not removed, all the other measures will have to be implemented on the basis of administrative coercion, which is a far less effective and more costly path.

A practical recommendation can be made regarding the sixth barrier: given that internet and energy supply in the region are unstable, platform solutions should not rely on a permanent connection. Devices operating in a mode of storing data locally and transmitting it once the connection is restored should be selected – this technical requirement must be specified as early as the design stage.

A recommendation can be made on the sequence for removing the barriers. The fifth barrier – the lack of economic incentive – should be addressed first, since it determines the effectiveness of all the other measures. Second, the first barrier – the absence of an organisational intermediary link – should be removed. Only after that does it make sense to work on the technical and financial barriers.

Caution is needed when assessing the expected results of digital transformation. International experience shows that in the first one or two years after a technology is introduced, the effect is lower than expected: users are mastering the system, models are being calibrated and data are being accumulated. A significant result is usually obtained from the third year onwards. Failure to take this time lag into account in planning leads to the programme being prematurely judged ineffective.

Conclusions and recommendations

First, intellectual resources differ from traditional resources in three fundamental respects: they are not depleted in the process of use, their replication cost is minimal, and their economies of scale expand not with production volume but

with the number of users. This fundamentally changes small farms' access to modern technologies.

Second, a four-layer digital platform architecture has been developed. It is recommended that implementation begin not with the first layer but with the second and fourth layers – integrating existing data and building a recommendation system on that basis – since this delivers quick and inexpensive results.

Third, according to the model calculation, smart irrigation systems make it possible to reduce water consumption per unit of output by up to 48 percent. At the same time, the principle of diminishing returns applies: the transition from drip irrigation to smart irrigation yields an additional 10 percentage points. Under resource constraints, it is advisable to apply simple solutions on a broad scale and complex solutions in a targeted manner.

Fourth, the introduction of water metering and volume-based tariffs has an institutional rather than a technical priority: without it, investing in the other technological solutions remains economically unjustified for farms.

Fifth, three of the six implementation barriers are institutional in nature. Hence, the main constraint on digital transformation is not the availability of technology but the readiness of the institutional environment. As a first priority, a shared-use model needs to be established through cooperative structures.

Sixth, the effect of digital transformation is subject to a time lag: a significant result is usually obtained from the third year onwards. This must be taken into account in planning and evaluating programmes; otherwise, the initiative will be prematurely judged ineffective.

Further research is envisaged to develop a pilot version of the proposed platform and to test its effectiveness under field conditions, as well as to refine the model calculations on the basis of local experimental data.



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