Improving biochemical processes in soils by applying chemicals with irrigation

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Abstract. The analysis of the state of the land indicates the need to revise approaches to agricultural processes in general. More than half of the land in the Russian Federation is experiencing degradation, and there is a need to fundamentally improve the biochemical processes in the soil while ensuring environmentally friendly and safe use of technical equipment. This article analyzes the integration of technological operations using wide-range sprinkler systems. Sprinkler irrigation can be effectively combined with the application of agrochemicals, including fertilizers, trace elements, soil amendments, and pesticides, through the irrigation water. In this integrated approach, the sprinkler unit itself serves as the primary mechanism for transport and distribution. This multifunctionality reduces the reliance on additional machinery, thereby minimizing soil compaction from wheeled systems, enhancing operational productivity, and decreasing both the time and labor intensity of field operations. The synchronization of irrigation with chemical application streamlines the overall agronomic management process. The study provides an analysis of work schedules and types, outlines required irrigation norms, and identifies suitable crops for such combined systems. Furthermore, it details the specific requirements for fertilizers compatible with irrigation water and offers application guidelines. A schematic representation of the interaction between system components and control systems is examined to illustrate the framework for maximizing operational synergy.

1 Introduction

The integration of agrotechnical operations—specifically, the application of fertilizers, pesticides, and micronutrients through irrigation water—using wide-span sprinkler systems enables a significant reduction in the required fleet of specialized machinery. This approach diminishes the need for numerous single-purpose implements, thereby lowering capital and operational costs for equipment. Furthermore, it mitigates soil compaction caused by the wheel systems of multiple machines, as the sprinkler unit serves as the primary base vehicle. The consolidation of these operations enhances overall productivity, reduces time expenditure, and consequently lowers labor costs. While the concept of integrating chemical application with irrigation is not novel, its historical implementation, particularly

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during the Soviet era, faced significant challenges. These included rudimentary automation systems, relatively low machine reliability, and a lack of digital controls and sensor technology, which collectively hindered development. The dissolution of the land reclamation infrastructure in the 1990s further decelerated progress in irrigation technology. This decline is reflected in a reduction of irrigated land from 6.1 million hectares to 4.3 million hectares over a 20-year period, accompanied by a near 15-fold decrease in the sprinkler equipment fleet [1].

An analysis of land conditions underscores the urgent need for a paradigm shift in agricultural practices. Current research indicates that a substantial portion of Russia's arable land is degraded: of 116 million hectares, approximately 35 million hectares are eroded, and 50 million hectares are classified as erosion-prone. Additionally, an estimated 250 thousand hectares are contaminated with heavy metals. The problem of salinization is also widespread, affecting nearly 89% of the nation's agricultural land [2].

Experimental studies conducted across various regions of the country demonstrate that fertigation—the application of fertilizers through irrigation water—increases crop yields by 9-12% compared to methods where fertilization and irrigation are performed separately. Furthermore, the annual depletion of soil nutrients currently exceeds the rate of replenishment through fertilization by a factor of five.

The reduction in chemical reclamation of acidic soils has exacerbated the degradation of agricultural ecosystems. The area of acidic soils in the Russian Federation has expanded significantly, from 36.7 million hectares in the early 2000s to approximately 60 million hectares at present. The efficacy of mineral fertilizers on such soils can decrease by nearly one-third, resulting in substantial agricultural losses; for grain alone, these deficits are estimated at 16 million tons annually.

These challenges necessitate a qualitatively new research approach to integrate irrigation with the application of mineral and organic fertilizers, micronutrients, pesticides, and growth regulators, while ensuring both maximum efficiency and environmental safety. The concept of fertigation is well-documented in the scientific literature [1-6]. In sprinkler systems, this is achieved by installing hydraulic feeding devices, or chemigation units, which introduce various nutrients into the irrigation water.

This irrigation technology can also be adapted to distribute other agrochemicals, including pesticides, defoliants, soil-structuring agents, and growth stimulants. Among eighteen classes of pesticides, most are compatible with irrigation or spray application. These include herbicides, fungicides, insecticides, bactericides, acaricides, repellents, nematocides, phytohormones, defoliants, and desiccants. Significant practical experience has already been accumulated with herbicides, defoliants, and desiccants.

The use of wide-span sprinklers for pesticide application offers considerable advantages due to their extensive coverage, high uniformity, and potential for full process automation. This automation minimizes human exposure to hazardous substances. Ultimately, the simultaneous execution of multiple technological operations through integrated systems leads to significant labor savings and a substantial reduction in operational time.

According to research, the introduction of multi-purpose irrigation technologies will lead to resource savings [4]:

water - by 15-20%,
land - by 5-10,
labor - for 15-25,
material - by 5-10%,
energy - by 10-15%,
temporary - by 15-20%.

The goal is to improve irrigation technology with wide-range sprinklers while combining the technological operations of applying mineral and organic fertilizers, trace

elements, chemical meliorants, growth agents and pesticides while ensuring maximum efficiency and environmental safety of irrigation.

2 Materials and methods

The versatility of sprinkler irrigation allows for the combination of various technological operations, coordinated temporally and quantitatively with the irrigation events, as demonstrated in Figure 1 and summarized in Table 1.

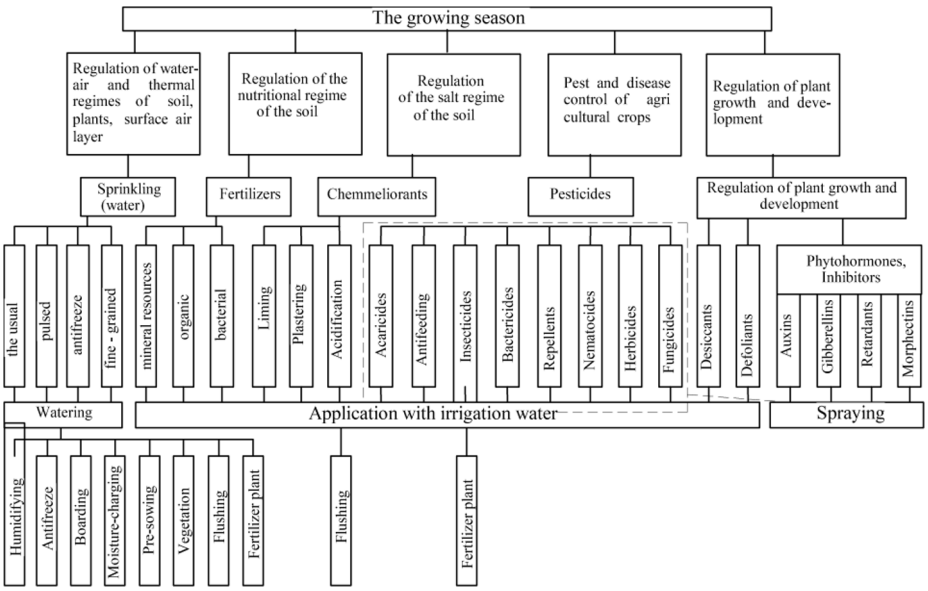

Fig. 1. Combining technological operations based on wide-range sprinklers dosing pump

Table 1 shows an analysis of the possibility of irrigation, the time of the technological operation, the required irrigation standards and crops for which these technologies are acceptable.

Table 1. Characteristics of watering, time and watering rate

Watering	Purpose and time of the event	Norm, m^3/ha	Culture
Vegetation period	The main type of irrigation	100-600	any
Moisture-charging	Creation of moisture reserves in the soil for autumn	1000-1200	Wheat, barley, corn, sunflower, sorghum, sugar beet, early potatoes, alfalfa, legumes
Refreshing	Sprinkling during the hot season of the day	30-100	any
Boarding	To improve survival	100-400	vegetables
Pre-sowing	To create the necessary moisture reserve in the soil	600-800	any
Flushing	Removal of excess salts in autumn and winter	2000-3500	Cereals, cotton, perennials, herbs, sugar beet, potatoes, vegetables

Antifreeze	Low intensity to protect against spring or autumn frosts up to minus 7-minus 12 °C	50-300	Vegetables, berry fields, orchards, vineyards
Fertilizer plant	It is combined with vegetation, pre-sowing, and planting watering.	100-120	any

An analysis of the potential for integrating agrochemical applications and other operations for winter and grain crops, utilizing a Kuban-LK sprinkler, is summarized in Table 2.

Table 2. Combining the applied substances and operations using a Kuban-LK type sprinkler.

Technological operations	**The possibility of conducting**
1. Watering:	
moisture-charging	Yes
washing facilities	Yes
2. Basic fertilization:	
mineral dry	Yes
liquid	Yes
micro fertilizers	
manure slurry	Yes
sapropel	Yes
3. Pesticides:	
4. Chemmeliorants:	Yes
1. Watering:	
Pre-sowing	Yes
Boarding gate	
2. Application of fertilizers:	
Mineral resources	Yes
Micro fertilizers	
Manure slurry	Yes
3. Pesticides	
1. Watering:	
Vegetation	Yes
Fertilizing plants	Yes
Refreshing drinks	Yes
Antifreeze	
2. Fertilizing with fertilizers:	
Mineral	Yes
Micro fertilizers	Yes
Organic	Yes
3. Pesticides	Yes
1. Defoliation	
2. Desiccation	Yes

3 Results

The feasibility of integrating agricultural operations requires careful analysis. For instance, the application rates for pre-season irrigation and primary fertilization are typically substantial for most crops. Combining these processes is, therefore, technologically sound, environmentally beneficial, and economically viable.

Growing-season irrigation constitutes the primary form of water application. The number of required irrigations can range from two to ten, depending on the climatic zone, the specific crop, and the prevalence of precipitation during the growing season. It is rational to combine these irrigation events with fertilizer application, utilizing sprinkler systems equipped with hydraulic injectors. Equipment selection should prioritize corrosion-resistant materials and sprinkler designs that are least susceptible to clogging.

Combining, for example, with rinsing irrigation is impractical, as it can lead to the removal of fertilizers along with the rinsing water. The operation of flushing irrigation equipment can be combined with the application of chemical fragrances. For example, a solution of sulfuric acid of 0.8-1.0% concentration or a solution of hydrochloric acid of 0.5% concentration with irrigation water.

If possible, it is advisable to carry out refreshing watering with low rates (less than 100 m^3/ha). Wide-range multi-support sprinkler equipment provides it by passing at high speed and is equipped with devices for aerosol or fine sprinkling. It is important to ensure low irrigation intensity.

The same equipment can be used to apply pesticides by spraying without irrigation.

Thus, the combination of operations during irrigation, fertilization and pesticides is rational according to the following technological schemes:

1. Soil preparation:
- rinsing irrigation with chemmeliorants;
- water-charging irrigation with the main application of fertilizers and pesticides.
2. Seeding:
-pre-sowing irrigation with fertilizers and pesticides.
3. Crop care:
- vegetative, refreshing and antifreeze watering;
-fertilizing irrigation with application of pesticides.
4. Cleaning:
- defoliation,
- desiccation.

The integration of specialized attachments onto sprinkler systems enables the combined application of irrigation water, fertilizers, chemical ameliorants, and pesticides. This approach allows multiple agronomic operations to be performed by a single primary unit—specifically, a wide-span sprinkler machine [5,6].

Effective planning for such operational combinations, including the selection of tools and assembly of systems, must account for fertilizer solubility and the corrosive effects of chemically aggressive substances on metal components. For nitrogen fertilization, highly water-soluble compounds like urea and ammonium nitrate are suitable; however, nitrate solutions are notably corrosive to both metal structures and plants. Among phosphorus fertilizers, ammophos is recommended due to its high solubility and minimal fine sediment formation. Because ammophos contains free acid, it is advisable to add urea to the solution, as its alkalizing effect provides neutralization. For potassium fertilization, neutral potassium chloride is preferred, as it generates minimal sediment.

When designing an irrigation regime, the parameters of the chemical injection system (hydraulic feeders) and the sprinklers' operational specifications must be considered. The following sequence is recommended: initial irrigation with clean water for 70% of the total cycle duration, followed by fertilization for 15% of the time, and a final flush with clean water for the remaining 15% to rinse fertilizer residues from plant surfaces and the internal irrigation equipment.

The functional interaction between the system components and the control system elements is illustrated in the schematic diagram presented in Figure 2.

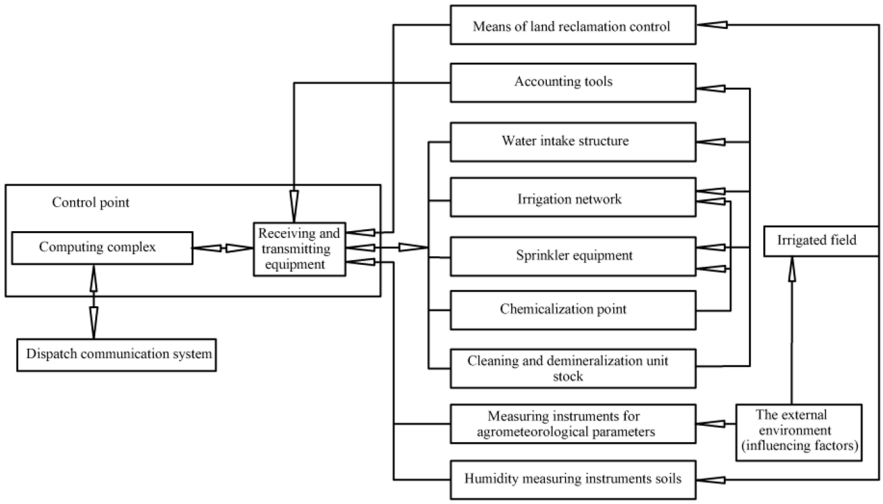

Fig. 2. Interaction of aggregates and control system elements

With regular irrigation, the doses and timing of nutrient supply are set depending on the biological characteristics of crops, soil conditions, planned harvest, and irrigation regime. The effectiveness of soil chemicalization is determined by the type of preparations used, the type, condition and humidity of the soil, the irrigation technology used, and other factors.

4 Conclusions

The integration of technological operations during irrigation using wide-span sprinkler systems—specifically, the simultaneous application of mineral and organic fertilizers, trace elements, chemical ameliorants, growth regulators, and pesticides with irrigation water—holds significant potential for enhancing agricultural productivity. However, its implementation necessitates further research, the development and deployment of new system components, and improvements to control systems.

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