

USING THE RECLAMATION REGIME EQUATION TO SAVE IRRIGATION WATER

UTILISATION DE L'ÉQUATION DU RÉGIME DE MISE EN VALEUR POUR ÉCONOMISER L'EAU D'IRRIGATION

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ABSTRACT

Water conservation issues are very relevant in times of climate change. Despite the huge amount of water resources in Russia, water conservation during irrigation has always been given great attention. [1] In order to optimize the distribution of water during the growing season, a mathematical model was developed that allowed us to obtain an analytical dependence of the relative productivity on the irrigation rate. This allows, when optimizing the irrigation regime, to reduce the irrigation rate almost twice, and the yield, at the same time, decreased only by 10-15%. [2] However, at present, when the technical accuracy of irrigation has been improved and the neural network technologies has become possible to use, these opportunities can be expanded.

According to forecasts of the Institute of Water Problems of the Russian Academy of Sciences, the south of Europe, the East of the USA and the South of Russia are threatened by decrease in surface runoff, so additional opportunities for integrated improvement regulation could be used for irrigation.

The paper considers new methodological approaches that make it possible to differentially assess the accuracy of complex land reclamation regulation based on a mathematical model of the land reclamation regime. "Reclamation regime", applied to agricultural land, is a set of requirements for controlled factors of soil formation, plant growth and environmental impacts, which must be provided by a system of reclamation measures to achieve the goal. [3]

The reclamation regime is described by a system of equations, the parameters of which vary over time, depending on the ecotype of the plant and the environmental factor. They are quasi-bell-shaped and can be asymmetrical with respect to the central axis. [4]

But, despite the wide variety of curves, several reclamation management zones are steadily formed inside the "dome". The first zone is the optimal level of productivity from 1.0 to 0.8. The second zone is critical, the level of productivity is from 0.8 to 0.3 (0.5). The third zone is a survival zone with a productivity level from 0.3 to 0.

Each zone has two characteristics. The first characteristic is the level of productivity that is provided by being in this zone. The second characteristic is the level of control accuracy that is necessary to stay in this zone. At each level of productivity, on a given zone may require a different amount of resource, such as water or fertilizer. In particular, for some crops, the optimal range will be narrow (high-yielding crops), for some it will be wider ("natural" varieties). Depending on the phenotype of the agricultural crop, different asymmetries of the reclamation regime curve are possible:

The optimal range width determines the critical control accuracy and may show itself in different ways in different zones. If we estimate critical accuracy as a change in productivity per unit (fraction) of environmental factors, then in the second zone, the slightest change in the value of the factor leads to a significant decrease of productivity.

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Thus, the "optimal" range of environmental factor control lies to the left of the "maximum" point of productivity and is substantially narrow as it is given in regulatory documents (approximately twice), but at the same time it has a "minimal control error", since it uses the natural potential of plant self-regulation. Using this approach could be a guarantee of stretch resource at a given level of productivity.

Moreover, determining the width of optimal conditions zone, based on the reclamation regime equation, guarantees not only to maximize the resource potential ability of plant self-regulation, but also reduces the impact of regulatory errors to the crop yield. [5]

Keywords : Water conservation; mathematical model; environmental factor; environmental factor; level of productivity.

RESUME

Les préoccupations de conservation de l'eau sont très pertinentes en période de changement climatique. Malgré l'abondance des ressources en eau en Russie, la question de conservation de l'eau pendant l'irrigation a toujours fait l'objet d'une attention particulière. [1]

Afin d'optimiser la distribution de l'eau pendant la saison de croissance, un modèle mathématique a été développé qui nous a permis d'obtenir une dépendance analytique de la productivité relative au taux d'irrigation. Cela permet, lors de l'optimisation du régime d'irrigation, de réduire le taux d'irrigation de près de moitié, et le rendement, dans le même temps, n'a diminué que de 10-15%. [2] Cependant, à l'heure actuelle, lorsque la précision technique de l'irrigation a été améliorée et que les technologies des réseaux neuronaux sont devenues utilisables, ces possibilités peuvent être élargies.

Selon les prévisions faites par l'Institut des problèmes de l'eau de l'Académie russe des sciences, le sud de l'Europe, l'est des États-Unis et le sud de la Russie sont menacés par une diminution du ruissellement de surface, de sorte que des opportunités supplémentaires de régulation d'amélioration intégrée pourraient être utilisées pour l'irrigation.

L'article examine de nouvelles approches méthodologiques qui permettent d'évaluer de manière différentielle la précision de la régulation complexe de mise en valeur des terres sur la base d'un modèle mathématique du régime de mise en valeur des terres. Le "régime de mise en valeur", appliqué aux terres agricoles, est un ensemble d'exigences relatives à des facteurs contrôlés de la formation du sol, de la croissance des plantes et des impacts environnementaux, qui doivent être fournis par un système de mesures de mise en valeur pour atteindre l'objectif. [3]

Le régime de mise en valeur est décrit par un système d'équations dont les paramètres varient dans le temps, en fonction de l'écotype de la plante et du facteur environnemental. Ces paramètres sont quasi-en forme de cloche et peuvent être asymétriques par rapport à l'axe central. [4] Cependant, malgré la grande variété de courbes, plusieurs zones de gestion de mise en valeur se forment régulièrement à l'intérieur du «dôme».

La première zone est le niveau optimal de productivité de 1,0 à 0,8. La deuxième zone est critique, le niveau de productivité est de 0,8 à 0,3 (0,5). La troisième zone est une zone de survie avec un niveau de productivité de 0,3 à 0. Chaque zone a deux caractéristiques. La première caractéristique est le niveau de productivité qui est fourni en se situant dans cette zone. La deuxième caractéristique est le niveau de précision du contrôle nécessaire pour rester dans cette zone.

À chaque niveau de productivité, une zone donnée peut nécessiter une quantité différente de ressources, telles que l'eau ou les engrais. En particulier, pour certaines cultures, la gamme optimale sera étroite (cultures à haut rendement), tandis que pour d'autres, elle sera plus large (variétés "naturelles"). Selon le phénotype de la culture agricole, différentes asymétries de la courbe du régime de mise en valeur sont possibles :

La largeur de gamme optimale détermine la précision critique du contrôle et peut se manifester de différentes manières dans différentes zones. Si nous estimons la précision critique comme un changement de productivité par unité (fraction) des facteurs environnementaux, alors dans la deuxième zone, le moindre changement dans la valeur du facteur conduit à une diminution significative de la productivité.

Ainsi, la gamme «optimale» de contrôle des facteurs environnementaux se situe à gauche du point de productivité «maximale» et est nettement plus étroite que celle indiquée dans les documents réglementaires (environ deux fois); cependant, elle implique une «erreur de contrôle minimale» car elle tire parti du potentiel naturel d'autorégulation de la plante. Cette approche pourrait garantir une utilisation rationnelle des ressources pour un niveau de productivité donné.

De plus, la détermination de la largeur de la zone des conditions optimales, basée sur l'équation du régime de mise en valeur, garantit non seulement de maximiser la capacité d'autorégulation des plantes en termes de ressources potentielles, mais réduit également l'impact des erreurs réglementaires sur le rendement des cultures. [5]

Mots-clés : Conservation de l'eau; Modèle mathématique; Facteur environnemental; Facteur environnemental; Niveau de productivité.

Introduction

Water conservation issues have always been relevant in climate change time.

Despite the huge amount of water resources in Russia, irrigation water conservation has always been under careful observation. [Golovanov et al., 2008] In order to optimize the water distribution during the growing season, a mathematical model was developed that allowed us to obtain an analytical dependence of the relative productivity on the irrigation rate. The irrigation regime optimizing makes it possible to reduce the irrigation rate by almost half, and the yield, at the same time, decreased by no more than 10-15%. [Shabanov, 1981] However, nowadays, when the technical accuracy of irrigation has increased and the possibilities of using neural network technologies have appeared, these possibilities can be expanded.

Materials and methods

According to forecasts of Water Problems Institute of the Russian Academy of Sciences, the south part of Europe, the East of the USA and the South of Russia are under the risk of surface runoff decrease, so additional opportunities for integrated land reclamation regulation should be used for irrigation. This research considers new methodological approaches that make it possible to differentially assess the accuracy of complex land reclamation regulation based on a mathematical model of the land reclamation regime.

"Reclamation regime", as applied to agricultural land, is **a set of requirements for controlled factors** of soil formation, plant growth and environmental impacts, which must be provided by a system of reclamation measures to achieve the set goal. [Golovanov, 2011] The reclamation regime is described by a system of equations, the parameters of which vary over time, depending on the ecotype of the plant and the environmental factor. They are quasi-bell-shaped and can be asymmetrical to the central axis. [Shabanov, 1981] But, despite the wide variety of curves, several reclamation management zones are steadily formed inside the "dome". Recent studies³ have shown that the equation of the land reclamation regime can be considered as a special case of the phenotype-ecotype equation [Shabanov, 2026].

³ "Problem Laboratory for the Development of theoretical foundations of integrated Land Reclamation of the Russian State Agrarian University-Moscow Agricultural Academy" <https://www.timacad.ru/about/struktura-universiteta/nauchnye-podrazdeleniia/problemnaia-laboratoriia>

The reclamation regime equation can be written as:

$$S = \left(\frac{\varphi}{\varphi_{opt}} \right)^{\gamma \varphi_{opt}} \left(\frac{\varphi_{max} - \varphi}{\varphi_{max} - \varphi_{opt}} \right)^{\gamma (\varphi_{max} - \varphi_{opt})}$$

Where,

S – relative productivity, agricultural crops
 φ – relative value of productive moisture reserves
 φ_{max} – maximum value of productive moisture reserves
 φ_{opt} – optimal value of productive moisture reserves
 γ – self-regulation coefficient

Graphically, this equation can be represented as follows (Figure 1)

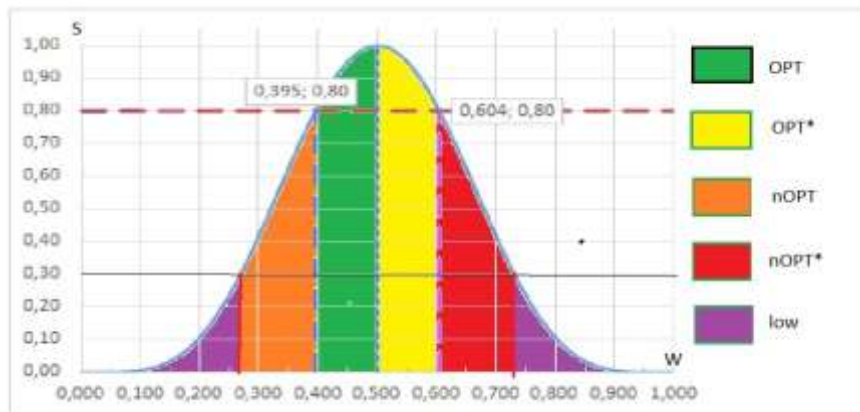


Figure 1. Dependence of the productivity level (W) on reclamation regime (S) and at the i -th time point with zones of different management quality

We could highlight the several zones:

- **The first and second zones (OPT) and (OPT*) are the optimal level of productivity** from 1.0 to 0.8.
- **The third (nOPT) and fourth (nOPT*) zones are critical.** The level of productivity is from 0.8 to 0.3 (0.5) and **a sharp drop in productivity with a slight deviation of the controlled value.**
- **Fifth and sixth zones (low) –survival zones** with a productivity level from 0.3 to 0.

Each zone has two characteristics. The first characteristic is the level of productivity that is provided by being in this zone. The second characteristic is the level of control accuracy that is necessary to stay in this zone. At each level of productivity, being in a given zone, may require a different amount of resource, such as water or fertilizer. For example, the most comfortable zone is the first zone – optimal (OPT). Comfort consists not only in high productivity, but also in intensive "self-regulation" of a living organism (plant or soil biota).

In this zone, sufficiently "large" changes in environmental conditions lead to only minor changes in productivity. However, in the second zone (OPT*), higher resource costs (water, fertilizers, limestone) are required to maintain high productivity. As an example, we will give the calculation of the dependence of productivity on the irrigation rate.

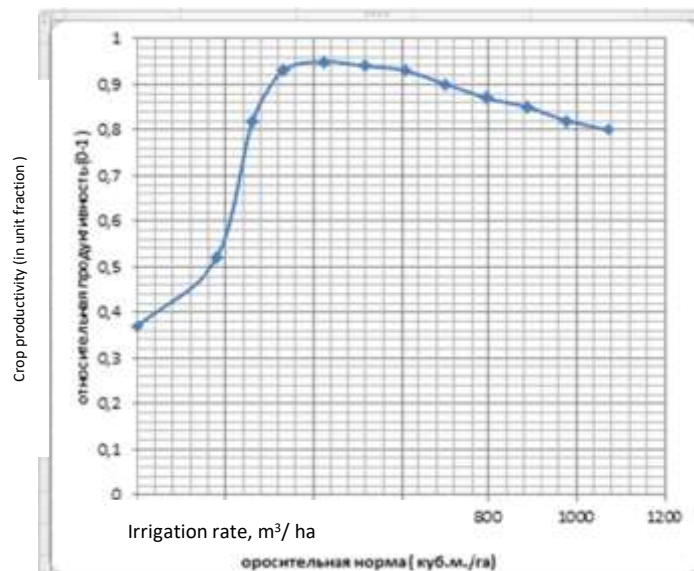


Figure 2 Dependence of crop productivity on irrigation rate.

The calculation had been done for an average wet year, so even low irrigation rate (400m³/ha) maximized productivity (Shabanov, 1981). This is the first zone of the reclamation regime curve in terms of humidity. A further increase of the irrigation rate (the second and fourth zones on the reclamation regime curve) leads to certain decrease of productivity, but at the same time significantly increases resource costs. Irrigation rates increase 2.5 times (right part of the curve - Figure 2).

The optimal range width determines the critical management accuracy and can appear in different ways in different zones. If we estimate critical accuracy as a change in productivity per unit (fraction) of environmental factors, then in the third and fourth zones, the slightest change in the value of the factor leads to a significant decrease in productivity.

Thus, the "optimal" range of environmental factor control lies to the left of "maximum" productivity point and is significantly narrower than specified in regulatory documents (approximately twice), but at the same time has a "minimal control error", because of use of plant self-regulation natural potential. This approach guarantees economical use of the resource at a predict level of productivity.

Moreover, determining the width of the zone of optimal conditions, based on the equation of the reclamation regime, guarantees the ability not only to maximize the resource potential of plant self-regulation, but also reduces the impact of regulatory errors to crop yield. [5]

Conclusion

1. To save water during irrigation, it is necessary to use a differentiated method for selecting the optimal control range.
2. The optimal range should be characterized not only by high productivity, but also by minimal resource costs for a production unit.
3. The optimal range that meets the requirements formulated above is located in the first zone of the reclamation regime curve (to the left of the maximum) and its width is approximately *twice* as narrower than defined in regulatory documents.
4. Reducing the width of the optimal range, in order to save resources (water, fertilizers, limestone) involves the development and implementation of methods of precise reclamation management

5. The application of the proposed approach can significantly (up to 2 times) reduce irrigation rates, with a slight reduction (5 %) of productivity.

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