Supply of Nutrients of Zonal Soil Subtypes and Macronutrients Balance in Fodder Crop Rotation Links on Irrigation

M M Okonov¹, T I Bakinova¹, V A Batyrov¹, S A Orosov¹, R M Shabanov², E A Dzhirgalova¹, S V Ubushaeva¹ and A N Mandzhieva¹

¹ Agriculture Department, Kalmyk State University named after V.V. Gorodovikov, 11, Pushkin st., Elista, Russia, 358000
² Kalmyk Branch of the Federal State Budgetary Scientific Institution All-Russian Research Institute of Hydraulic Engineering and Land Reclamation named after A.N. Kostyakov, 1, O.I. Gorodovikova Ave., Elista, Russia, 358011

E–mail: okonov.51@mail.ru

Abstract. The paper presents the results of long-term studies aimed to assess the fertility of zonal soil subtypes during irrigation. Besides, the work presents data on soil nutrient supply and the consumption of nutrients by fodder crops. The reproduction management of soil fertility is carried out through a system-based influence on the mineralization and humification of organic matter, the activity of soil biota, the transformation of mineral chemical compounds and the accumulation of available forms of nutrients in the soil. The balance of macronutrients in the links of fodder crop rotation was calculated. The optimal doses of fertilizers were calculated for different levels of the planned harvest in the conditions of Kalmykia. Based on long–term experimental data, the parameters of biological consumption of nutrients by annual fodder crops were substantiated. Their return in the form of plant residues, and balance calculations were performed. When the calculated doses of fertilizers are applied to the planned yield levels, the nitrogen balance is negative, the phosphorus balance is slightly positive or negative, and the potassium balance is persistently negative.

1. Introduction

The theory of soil fertility reproduction in agricultural landscapes in modern farming systems requires the solution of many urgent problems, i.e. the intensification and biologization of agriculture, the use of resource-saving and environmental technologies; the use of crop rotations with a scientifically grounded compatibility of crops with high biological productivity; the maximum possible use of natural and anthropogenic resources; the use of adaptive soil protection methods of soil cultivation; smart use of fertilizers in doses for the planned harvest; widespread use of the organic matter in the form of plant residues and many other methods.

Organic matter is the basis of soil fertility and its multipurpose energy resource. It significantly affects the parameters of agrophysical, agrochemical and biological indicators. When applying mineral fertilizers, agricultural crops satisfy the need for nitrogen within 50 % due to the organic matter. The rest is satisfied due to the mineral fertilizers.
To increase the content of soil organic matter, the amount of nutrients available to plants, time and material resources are needed. These possibilities are implemented most effectively with a systematic substantiation of practical methods for the rational use of irrigated lands.

2. Methodology
The soil cover of the Republic of Kalmykia is characterized by a wide complexity due to the developed microrelief, insufficient atmospheric moisture, and aridity of the entire territory.

The most widespread soils in the zone of dry steppe, semi-desert and desert are light chestnut and brown soils of varying degrees of alkalinity. The most fertile chernozems and dark chestnut soils in the zone occupy the largest area of no more than 15 % in the structure of agricultural land [1, 4].

A common characteristic of almost all subtypes of soil for one or another indicator is a relatively low level of fertility. Thus, the weighted average humus content on light chestnut soil varies within 1.31–1.52 %, and on brown semi-desert soils is only 1.07–1.20 %. On all soil types, mobile phosphorus is found in the first minimum. The agrochemical surveys on an area of more than 1.5 thousand hectares completed in the period 2010–2015 (Agrochemical Service Station Kalmytskaya) showed that the weighted average content (P$_2$O$_5$) is 16–21 mg/kg of soil. The supply of exchangeable potassium (K$_2$O) to soils is generally quite good.

3. Results
Currently the main task of agrochemical research in irrigated agriculture is to study the interaction between plant, soil and fertilizers against the background of adaptive soil conservation agriculture on the one hand and the maximum possible biologization of agriculture and management of the balance of nutrients in the soil, taking into account environmental requirements. Indicators of the balance of nutrients in the soil, taking into account a specific level of fertility, is the most objective criterion for the efficiency of ecological use of arable land resources. For the irrigated conditions of the dry steppe zone of the Lower Volga Region, as a result of lengthy detailed studies, V.I. Filin, V.N. Pozhilov et al. developed and then tested a calculation method for setting fertilizer doses for planned harvests using differentiated coefficients of compensation for the removal of nutrients from the soil. In accordance with the proposed principles of fertilizer application and mineral nutrition rationing, the expediency of maintaining a deficit–free nitrogen balance in the crop rotation is envisaged.

For sustainable amelioration of zonal soil subtypes, the following should be applied: adaptive soil protection methods of soil cultivation; rational use of fertilizers in doses for planned harvest; widespread use of the organic matter in the form of plant residues and many other methods and techniques. The reproduction management of soil fertility is carried out through a system-based influence on the mineralization and humification of the organic matter, the activity of soil biota, the transformation of mineral chemical compounds and the accumulation of available forms of nutrients in the soil.

The organic matter is the basis of soil fertility and its multipurpose energy resource. It significantly affects the parameters of agrophysical, agrochemical and biological indicators. Agricultural crops, when applying mineral fertilizers, satisfy the need for nitrogen within 50 % due to mineral fertilizers. To significantly increase the content of soil organic matter, the amount of nutrients available to plants, time and material resources are needed. These possibilities are implemented most effectively in case of systematic substantiation of practical methods for the rational use of irrigated lands. Soil fertility and yielding of agricultural crops still largely depend on the structure of areas under crops, the amount of fertilizers applied, the level of biologization of agriculture, etc.

In the Republic of Kalmykia, the level of chemicals use is at a low level. So, in 2011–2015, agricultural producers applied on average 1,941 thousand tons of the active substance of mineral fertilizers, the main share of which is nitrogen – 79 %; phosphorus–containing fertilizers were used much less – 0.376 thousand tons or 19 %. In general, the fertilized area was about 40 thousand hectares, or 5 % of arable land, and 53 kg of the active substance was applied to 1 hectare of the fertilized area [1]. With the significant resources available, the organic fertilizers were practically not
applied, which is unacceptable taking into account high prices for mineral fertilizers. According to calculations, the balance of nutrients for a long time is negative for all subtypes of soil, and the return of nutrients taken out with the harvest was as follows: 12% of nitrogen, 6% of phosphorus and 1.4% of potassium. Thus, the optimization of fertilization in order to increase soil fertility and crop productivity is the most relevant in the system of zonal agro-engineering measures.

Quantitatively, the balance of nutrients can be assessed both in absolute values in kg/ha with a (+) or (−) sign, and in relative values in fractions of a unit or percentage, expressing possible changes in the content of nutrients in the soil. In recent years, the term “return rate” has been widely used as relative balance indicators. With the return coefficient of any macronutrient removal equal to 1.0, the balance intensity is equal to 100%, and the balance itself will be zero. If the coefficient is > 1.0, the balance is positive and, on the contrary, if <1.0, it is negative. The input part of the nutrient balance usually includes doses of organomineral fertilizers, atmospheric precipitation, and biological nitrogen fixation by soil microorganisms, crop residues, cuttings and root residues.

The expenditure side includes the consumption of nutrients by agricultural crops to create a crop, both main and secondary, as well as various losses of nutrients from the soil of different genesis. Taking into account all the listed items of the input and consumption of nutrients, the balance is considered to be biological, and when all plant residues are excluded, it is considered to be an economic balance [14, 15].

The approximate sizes of the incoming and outgoing items of the balance of nutrients in the soils of different zones are given in various reference books, scientific recommendations, and more precisely, for each soil-climatic zone, they are established experimentally as a result of many years of stationary field experiments. Zonal light chestnut and brown semi-desert soils are characterized primarily by carbonate content, an alkaline reaction of the soil solution, a heavy or medium particle size distribution, and a weak level of aeration. Under these conditions, it becomes possible for an increasing loss of nitrogen in the form of ammonia and various oxides. According to averaged data, gaseous nitrogen losses from the applied fertilizers on zonal light chestnut soils can be at the level of 20% [16].

In addition, on such soils, part of the nitrogen is fixed in the form of ammonium. Nitrogen immobilization from soil resources and fertilizers is one of the most noticeable items of the expenditure side of the nitrogen balance, which amounts to 25%. In intensive fodder production for irrigation due to the cultivation of perennial and annual grasses in the incoming part of the soil balance, postcuts, stubbles and root residues are of prime importance. A lot of works have been devoted to the agronomic assessment of the accumulation of postcut-root residues in the soil, the degree of their mineralization in irrigated agriculture in the Lower Volga Region including Kalmykia [5, 6, 11, 13].

At the same time, the issues of studying the balance of nutrients in the soils of Kalmykia have not been sufficiently studied; therefore, this problem was one of the priority topics in terms of research work of the Department of Agronomy together with colleagues from other research and industrial institutions. In particular, it was revealed that with the intensive use of irrigated land by growing annual fodder crops in the main and intermediate crops in order to obtain two and three harvests per year, up to 8.9–11.8 t/ha of dry organic matter accumulates in the soil.

When fertilizers are used, the total mass of plant residues increases 1.6–2.1 times in the system of two yields (peas + oats + sunflower) and postcut maize + soybeans in comparison with the option without fertilizers. When growing three crops per year with the participation of winter rye, corn and Sudan grass, the amount of plant residues plowed into the soil increases up to 1.72–2.25 times with the introduction of nitrogen-phosphorus fertilizers. The cuttings and root residues were also subjected to complete chemical analysis. The data obtained showed significant differences in the chemical composition of aboveground remains and roots. So nitrogen accumulates more in the aboveground residues, and phosphorus and potassium in the roots (Table 1). The rate of decomposition of plant residues in the irrigated soil depends on the nitrogen content and the ratio of this element to carbon.
A.M. Gavrilov (1977) believes that annual fodder crops have a rather narrow C–N ratio and, therefore, provide subsequent crops with nutrients.

### Table 1. Nutrient content in postcut-root residues, % of dry weight

| Crop                          | Plant residue | Fertilized ground | Nonfertilized ground |
|-------------------------------|---------------|-------------------|----------------------|
|                               |               | N    | P₂O₅ | K₂O | N    | P₂O₅ | K₂O |
| Legume–bluegrass mixture      | stubble       | 1.08 | 0.44 | 0.56 | 0.77 | 0.35 | 0.52 |
| Corn mixed with soy           | roots         | 0.67 | 0.53 | 1.11 | 0.53 | 0.41 | 0.83 |
| Winter rye                    | stubble       | 0.89 | 0.47 | 0.63 | 0.77 | 0.36 | 0.49 |
| Corn mixed with soy           | roots         | 0.70 | 0.49 | 0.72 | 0.58 | 0.39 | 0.54 |
| Sudan grass                   | stubble       | 0.71 | 0.43 | 0.54 | 0.53 | 0.33 | 0.51 |
| Sudan grass                   | roots         | 0.55 | 0.51 | 0.69 | 0.49 | 0.38 | 0.60 |
| Winter rye                    | stubble       | 0.79 | 0.51 | 0.60 | 0.67 | 0.35 | 0.47 |
| Winter rye                    | roots         | 0.58 | 0.54 | 0.66 | 0.49 | 0.38 | 0.52 |
| Corn mixed with Sudan grass   | stubble       | 0.74 | 0.48 | 0.57 | 0.63 | 0.30 | 0.42 |
| Corn mixed with Sudan grass   | roots         | 0.52 | 0.53 | 0.58 | 0.44 | 0.34 | 0.47 |

The chemical composition data of plant residues makes it possible to judge only the content and the ratio of elements in plant residues. To determine the role of aboveground and root residues in the organic matter reproduction in the soil, balance calculations were carried out for the mineralization and synthesis of humic substances according to the method of A.M. Lykov. Based on the results of balance calculations, they came to the conclusion that even in the system of obtaining two or three yields of annual forage crops, 9.0–11.5 t/ha of plant residues accumulate, and even under these conditions a negative balance is observed on zonal soils [3, 14, 15]. Studies of the transformation of non–humified organic residues under stationary field conditions have shown that the rate of their decomposition on irrigation increases significantly.

### Table 2. Nutrient balance in light chestnut soil on irrigation when growing two or three crops per year

| Fertilizer dose options, kg/ha of substance dose | Biological removal with harvest, kg/ha | NPK content in postcuts and fodder residues, kg/ha | Economic take-out with harvest, kg/ha | NPK balance, profit (+), loss (–) |
|-------------------------------------------------|---------------------------------------|--------------------------------------------------|---------------------------------------|----------------------------------|
|                                                 | N    | P₂O₅ | K₂O | N    | P₂O₅ | K₂O | N    | P₂O₅ | K₂O | N    | P₂O₅ | K₂O |
| two harvests per year                           |      |      |     |      |      |     |      |      |     |      |      |     |
| 1. without fertilizers                          | 144  | 56   | 120 | 34   | 15   | 27  | 115  | 51   | 106 | –115 | –51  | –106 |
| 2. N₁₈₀P₁₀₀K₀                             | 270 | 92  | 166 | 51  | 28  | 40  | 219  | 83  | 120 | –59  | +17  | –40  |
| 3. N₁₉₀P₁₂₀K₁₂₀                          | 324 | 107 | 210 | 65  | 32  | 56  | 245  | 95  | 154 | –50  | +35  | –34  |
| 4. N₂₄₀P₁₄₀K₁₄₀                          | 359 | 136 | 243 | 80  | 39  | 64  | 269  | 117 | 179 | –29  | +63  | –39  |
| three harvests per year                        |      |      |     |      |      |     |      |      |     |      |      |     |
| 1. without fertilizers                          | 174 | 99   | 205 | 48  | 26  | 37  | 126  | 70   | 168 | –126 | –70  | –168 |
| 2. N₁₇₀P₉₀                             | 423 | 189 | 442 | 74  | 47  | 71  | 349  | 142  | 371 | –174 | –52  | –371 |
| 3. N₂₉₀P₁₂₅                          | 515 | 230 | 494 | 99  | 56  | 81  | 416  | 174  | 413 | –126 | –49  | –413 |
| 4. N₃₈₀P₁₆₅                          | 548 | 247 | 518 | 104 | 66  | 97  | 444  | 181  | 421 | –84  | –16  | –421 |

For the period of five months of irrigation of light chestnut soil the plant residues decomposed 1.78–1.95 times more in comparison with non–irrigated soil. Regarding dark chestnut soil there was 1.22–1.25 time increase. The mineralization coefficients also increased to a greater extent (1.5–1.6 times) in the light chestnut soil. Consequently, on irrigation under the conditions of light chestnut and brown soil, the mineralization of soil humus can increase by 1.4–1.55 times, and the humification of organic residues by 1.58–2.1 times. This creates good prerequisites for maintaining a deficit–free humus balance provided that the plant residues of crops grown on irrigation are maximized. This is
achieved by the presence of biologized crop rotations, saturated by at least 60% with perennial grasses, highly productive annual crops, as well as systemic management of soil supply nutrient with the help of the organic fertilizers in calculated doses for the planned harvest levels [18, 19].

Our studies on the dynamics of nutrients in soil and plants at different levels of mineral nutrition served as the basis for calculating the balance of nutrients in the links of fodder crop rotations on light chestnut soil. Since most of the studies carried out in the Caspian lowland on irrigation were of an industrial nature, therefore, average yields were planned and nitrogen-phosphorus fertilizers were mainly used to achieve them. At the same time, on the irrigated lands of the eastern zone of Kalmykia, the removal of nitrogen on average was 115 kg per hectare, phosphorus was 51 kg and potassium was 106 kg. The option without fertilizers and the fertilized option with two yields constituted from 219 to 269 kg of nitrogen, 83–117 kg of phosphorus and 120–179 kg of potassium. With three harvests per year, the removal of NPK by the household crop increased significantly due to the absence of the legume component in the crops (Table 2).

4. Conclusion

Based on long-term experimental data, the parameters of biological consumption of nutrients by annual fodder crops were substantiated. Their return in the form of plant residues, and balance calculations were performed. Even when the calculated doses of fertilizers were applied to the planned yield levels, the nitrogen balance was negative, the phosphorus balance was slightly positive or negative, and the potassium balance was persistently negative.

Therefore, it is necessary to provide the following improvements: the nitrogen balance in the soil not only by means of fertilizers, but also by the inclusion of leguminous components, green manures in the crop rotation. In the system of three harvests per year, where there is no legume component, there is also a negative balance for phosphorus. A stable negative balance of potassium develops when the crops of annual fodder crops are irrigated. Consequently, in the system of three harvests per year, it is also necessary to apply potassium-containing fertilizers.

References

[1] Unkanzhinov G D (Ed.) 2013 Agrochemical Bulletin for the Republic of Kalmykia (Elista)
[2] Goldvarg B A, Sorokin A I, Bogzykov Yu S et al. 2016 Adaptive-landscape farming system of the Republic of Kalmykia [Monograph] (Elista: Publishing House of KalmSU)
[3] Ageev V V and Krivopyshko V P 1992 Fertilization system for main and catch crops under irrigation conditions Agrochemistry 8 49–56
[4] Bakinova T I, Vorobieva N P and Zelenskaya E A 1999 Soils of the Republic of Kalmykia (Elista: Yuzh Reserch Institute Giprozem)
[5] Gavrilov A M and Filin V I 1990 Intensive technology of fodder crops cultivation on irrigated lands In Intensive technology of growing fodder crops (theory and practice) Collection of research articles VASKHNIL (Moscow: Agropromizdat) pp 49–52
[6] Dedova E B and Davaev A V 2015 Fodder crops on reclaimed lands of the Republic of Kalmykia [Monograph] (Volgograd: Publishing house of the Volgograd SAU)
[7] Ivanov A L and Derzhavin L M 1996 Recommendations for the design of integrated use of chemical agents in the resource-saving technologies of adaptive landscape agriculture (Moscow: Kolos)
[8] Kiryushin V I and Ivanov A L 2005 Agroecological land assessment, design of adaptive landscape farming and agricultural technologies Methodical guidance (Moscow)
[9] Okonov M M and Dedova E B 2015 Adaptive land use on reclaimed agricultural landscapes of the Republic of Kalmykia [Monograph] (Elista: Publishing house of the Kalmyk State University)
[10] Okonov M M and Smykov A V 2014 The potential of irrigated agriculture in Kalmykia and use of fertilizers in sowing of forage crops Bulletin of the Nizhne-Volzhsky Agrarian University Complex 29–31
[11] Okonov M M, Ubushaeva S V and Ovadykova Zh V 2013 Development of integrated monitoring of irrigated lands in Kalmykia based on information technologies Topical issues of information technologies in the agro-industrial complex Materials of the international conference, ed. by A M Sysoev (Moscow: Federal State Budgetary Educational Institution of Higher Education Russian State Agrarian University; Moscow Agricultural Academy named after K.A. Timiryazev) pp 50–54

[12] Okonov M M, Bessarabov V F and Karavaev M A 2005 Biological sources of restoration of natural fertility of light chestnut soils Bulletin of the Saratov State Agrarian University 5 17–20

[13] Okonov M M 2001 Methods for regulating mineral nutrition and the basic principles of the use of fertilizers in irrigated agriculture in the Lower Volga region In At the turn of the millennium Collection of research articles (Rostov-on-Don: Publishing House of the North Caucasian Scientific Center Of Higher School) pp 89–93

[14] Podkolzin A I 1997 Soil fertility and efficiency of fertilizers in agriculture in the south of Russia (Moscow: Publishing house of Moscow State University)

[15] Sychev V G, Chernikov V A and Sokolov O A 2009 Methodology for assessing the ecological and economic efficiency of agricultural land use (Moscow: All-Russian Scientific Research Institute of Automation named after N L Dukhov)

[16] Filin V I 1994 Reference book on plant growing with the basics of programming the crop (Volgograd: Publishing house of the All-Russian State Agricultural Academy)

[17] Unkanzhinov G D et al. 2012 Ecological and toxicological assessment of the state of arable soils in the Republic of Kalmykia Agrochemical Bulletin 6 10–13

[18] Filin V I 1994 Theory and methods of managing the fertility of chestnut soils in ecologically balanced agriculture Soil resources of the Caspian region and their rational use in modern conditions International Scientific Conf. (Astrakhan: Russian Academy of Agricultural Sciences) pp 168–171

[19] Filin V I and Okonov M M 2004 Fertilization and irrigation of annual forage crops in intensive forage production in the Caspian region [Monograph] (Elista: Publishing house of APP Dzhangar)

[20] Okonov M M, Bakinova T I, Jirgalova E A and Ubushaeva S V 2020 Forecast methods for the total evapotranspiration of fodder crops in arid conditions of Kalmykia IOP Conference Series: Earth and Environmental Science. 6th International Conference on Agriproducts Processing and Farming 012132

[21] Okonov M M and Dedova E B 2015 Assessment of current state of meliorative regime of natural and anthropogenic complexes in Kalmykia Biosciences, Biotechnology Research Asia 12(3) 2441