

Efficiency in Potato Growing with Irrigation in Dry Climate

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Abstract Improvements were introduced in technology of potato cultivation under irrigation in the conditions of the Southern Urals steppes. Key elements of agronomical complexes aimed to cultivate the crop were developed in experiments. They provide control of light regime and feeding schedule, phytosanitary characteristics of seeds to gain different levels of the expected yield. We defined water consumption regime of the crop in ontogeny for regional conditions. On the result of multivariate evaluation we defined percent of impact of the examined factors on potato crop capacity. It was set out that if water and feeding regime of soil are combined in the optimum way the potato crop makes 49 tons per 1 hectare.

Keywords Potatoes, Degree Of Density, Productivity, Soil Water Regime, Nitrate Concentration, Fertilizers, Rate Application

1. Introduction

Agriculture and practice have defined the main trends of improving stability in production. They are: agricultural technology improvement, use of climatic cropping pattern, selection and others. But the only thing that may contribute to the dry areas of Russia with mean stability of guaranteed yield volume is improvement of cropland efficiency with some of its part being irrigated.

Steppe zone of South Ural is well provided with photosynthetic active radiation, but because of lack of rainfall in natural conditions of moisture it does not give high crops or yield stability, so it can not be classified as industrially developed land producing potato crops. But the need for such useful feeding stuff as potatoes is very high, so the part of irrigated land is given for this type of crops cultivated with ridge – like technology.

In this regard it becomes very important to develop the main methods aimed to get the scheduled yield volume by means of satisfying biological needs of plants.

2. Materials and Methods

Experimental part of the research (1999 – 2003) took place in Orenburg company “Samorodovo” (JSC), later named as JSC “Agrofirma Promyshlennaya”.

The soil of the experimental part of the land is characterized as southern chernozem, bench type, medium-humic, with medium productivity, deeply solonized, with medium and high concentration of loam, brown and straw coloured, deposited on carbonated alluvial soil.

In the plough-layer organic matter makes 4,8%. The soil is moderately provided with nitrogen derivatives (6,95 mgr/100 g of soil), poorly provided with phosphorus (2,63...3,96) and highly - with exchange potassium (30...40 mgr/100 g of soil).

Hydro-physical characteristic of soil in the layer 0...1,0 m is the following: minimum water-holding capacity - 23,8%, maximum hygroscopicity - 8,3%, permanent wilting point - 12,5% of dry land mass, density of meter long layer - 1,29 t/m³. The experimental part of the land is plain land slightly sloped (up to 0,001) in the north-east direction. Underground water basin is 8...10 m. below. The irrigation network is of combined type. The source for the irrigated land is the water-storage basin containing 1,5...2,0 mln. m³ of water, 95% of water comes from the river Ural, 5% is thawing water.

Earth irrigation canals, each 800...1000 m long, are located every 120 m. Irrigation machines ДДА - 100МА were used.

The experiment №1 (1999-2001) was aimed to discover the impact that the following factors produce on the yield and tuber quality: density of planting, application rate of mineral fertilizers, cultivars of potatoes. The research work was carried out on the cultivars *Karatop* and *Krasnopolskiy*. Each experiment included 5 variants classified according to rate of fertilizer application calculated for output per hectare: control was carried out without fertilizer treatment; 30 t of tubers - N₉₉P₄₅K₁₆₂; 40 t - N₁₃₂P₆₀K₂₁₆; 50 t - N₁₆₅P₇₅K₂₇₀ and 60 t - N₁₉₈P₉₀K₃₂₄. To justify the optimum density of planting the experiments were carried out with the following figures: 40,

45, 50, 55 and 60 thous. of tubers per one hectare.

Experiment №2 (2001-2003) was aimed to study how the ridge tillage time effect on content of impurities and crop yield of potatoes. The ridge tillage time: 1 – on the day of planting, 2 – in 10 days, 3 – 20; 4 – 30 and 5 – in 40 days after planting. The nil treatment, with the ridge tillage time- on the day of planting was used as the sample for control.

Humidity of active layer of the soil in the experiments was reserved at min 75...80% HB level. The experiment used the split-plot method in three replications [2]. Hydro-physical characteristics of soil were defined [4 и 9], irrigation depth and consumptive water use was calculated [5]. The yield was calculated separately on each plot.

The experiments were aimed to discover energy efficiency [1], regression analysis was carried out [10] using in calculations the application program package STATGRAPHICS-2.6 (Russian version). Application rate of mineral fertilizers for the scheduled yield of potatoes was calculated as per methodology of programming station of Volgograd State Agricultural Academy, Russia.

3. Conclusion

Comparative valuation as per potatoes growth stage terms

(seedling emergence, budding, coming into flower) showed, that in the first half of vegetation period cultivar *Krasnopolskiy* was in advance of cultivar *Karatop* (average 2...4 days in advance). But both cultivars grew fully ripe together, in 117...119 days after being planted.

Works [3],[7],[8] and other scientists discovered that photosynthesis process is strongly effected by leaf-area duration growth. Our experiments on the initial stages of potatoes growth showed that application rate of mineral fertilizers and plant population had practically no effect on leaf-area duration. But by the period of flowering all samples of variable plant population (both fertilized cultivars) showed almost twofold leaf-area growth as compared to non-fertilized. Leaf-area showed max size 57,2 thous. m²/ha for *Krasnopolskiy* cultivar and 61,2 thous. m²/ha for *Karatop* cultivar. It took place in the first decade of August in the inter-stage period: beginning of flowering-vine wilting, for samples with plant population 60 thous. units/ha.

Photosynthetic potential showed its maximum index to the end of vegetation period for cultivar *Krasnopolskiy* when fertilized for yield of 50 and 60 t per ha, its average index was 1,66 and 1,75 mln for the years of the research. For *Karatop* cultivar it showed 1,69 and 1,78 mln m² day/ha. Photosynthesis was most active in June at high growth of vine and in July-August at tubers' mass growth.

Table 1. Potatoes yield, t/ha (average for 1999-2001)

| Plant population, unit/ha | Krasnopolskiy | | | | | Karatop | | | | |
|---------------------------|----------------|--------------------------------------|------|------|------|----------------|--------------------------------------|------|------|------|
| | Non fertilized | Fertilized for scheduled yield, t/ha | | | | Non fertilized | Fertilized for scheduled yield, t/ha | | | |
| | | 30 | 40 | 50 | 60 | | 30 | 40 | 50 | 60 |
| 40 | 17,4 | 21,8 | 27,4 | 28,1 | 27,6 | 18,9 | 27,1 | 33,0 | 34,8 | 34,5 |
| 45 | 18,3 | 22,9 | 28,2 | 28,8 | 28,5 | 20,6 | 29,2 | 36,1 | 39,0 | 37,4 |
| 50 | 19,6 | 24,6 | 29,2 | 29,3 | 29,6 | 21,7 | 30,2 | 38,0 | 41,7 | 40,8 |
| 55 | 21,1 | 26,2 | 28,9 | 28,8 | 29,0 | 23,5 | 31,3 | 40,6 | 45,9 | 44,0 |
| 60 | 21,5 | 27,8 | 29,8 | 30,3 | 30,1 | 24,0 | 31,8 | 41,8 | 46,6 | 44,5 |

Table 2. Dependence of variability of *Krasnopolskiy* cultivar crop capacity on density of planting and NPK dose rate (75 reports are taken into account)

| Free variable | Regression coefficient | Standard error | Significance level |
|--------------------------------------------------------------------------------------------------------------------|------------------------|--------------------------------------------------------------|--------------------|
| Free term | 10.747 | 1.20 | 0.00 |
| NPK | 0.0814 | 0.008 | 0.00 |
| Density | 0.1735 | 0.023 | 0.00 |
| NPK ² | -0.00016 | 0.00004 | 0.00 |
| For total regression: standard error of estimation ±1.41 R-squared =0.88 F _(theoretical) =178.756 | | Percent of factors' impact: NPK – 78.9% density – 9.3% | |

On the fertilized irrigated fields at leaf-area extension period photosynthesis net productivity reduced from 9,5 till 8,9 g/m² per day for cultivar *Krasnopolskiy* and from 9,3 till 8,6 g/m² – for cultivar *Karatop*. Well formed leaf surface due to fertilizers and rich moisture regime contributed to improvement of tubers' daily growth for both cultivars, average by 20...46 %, and improvement of tubers' growth terms by 20 days, compared to non fertilized.

The experiment produced maximum crop capacity due to use of the fertilizers with dose rate N₁₆₅P₇₅K₂₇₀ with density of planting 60 thousand items per 1 hectar. The figures made 30.3 tons per 1 hectar for *Krasnopolskiy* cultivar and 46.6 tons per 1 hectar for *Karatop* cultivar (table 1).

Growth of application rate of mineral fertilizers and reduction of plant population provided reduction of yield for both cultivars of potatoes.

The research showed that cultivar *Karatop* in favorable water regime of the soil was more sensitive to fertilizers than *Krasnopolskiy*. Application of N₉₉P₄₅K₁₆₂ contributed to yield growth by 7,7...8,2 t/ha as compared to non fertilized samples. Growth for *Krasnopolskiy* cultivar made 3...5 t/ha.

Further growth of application rate till N₁₃₂P₆₀K₂₁₆ provided the scheduled crop volume 40 t/ha with plant population 55 thous. units/ha. With plant population 60 thous. units/ha it grew by 1,8 t/ha.

Evaluation of multiregression which describes dependence of variability of *Krasnopolskiy* cultivar crop capacity on density of planting and NPK dose rate, shows that in 88% cases dispersion of crop capacity of the examined cultivar is characterized by indices presented in table 2. Thereby the impact percent of the fertilizer in the previously mentioned dose rate on the potato crop capacity made 78.9%, the impact percent of the density of crop on the crop capacity made 9.3%.

Evaluation of multiregression which describes dependence of *Karatop* cultivar crop capacity on density of planting and NPK dose rate showed that density of planting is leveled by NPK.

Thereby we got two models of paired association where dependence of crop capacity on NPK dose rate is characterized as R-KB=0.74 (table 3), and density R-squared =0.13 (table 4).

Table 3. Dependence of variability of *Karatop* cultivar crop capacity on NPK dose rate

| Free variable | Regression coefficient | Standard error | Significance level |
|------------------------------------------------------------------------------------------------|------------------------|----------------|--------------------|
| Free term | 21.75 | 0.97 | 0.00 |
| NPK | 0.1047 | 0.007 | 0.00 |
| standard error of estimation ±4.19 R-squared = 0.74 F _{(theoretical)}} = 215.81 | | | |

Comparative analysis of ridge tillage time showed better figures for 30 days after planting potatoes. In this case annual weeds contamination level reduced up to one grade, for perennial weeds the same figure is 3 grades, soil density in

0...0,30 m deep by the time of yield remained 1,10 t/m³ or within the limits optimal for tuber development. During the whole vegetation period of the crop the soil at the tuber depth had optimal temperature: from 14,4°C in the first decade of May to 22°C in the second decade of June. This fact had a favorable impact on the potatoes root formation, growth and development of the tops.

Table 4. Dependence of variability of *Karatop* cultivar crop capacity on density of planting (75 reports are taken into account)

| Free variable | Regression coefficient | Standard error | Significance level |
|----------------------------------------------------------------------------------------------------------------|------------------------|----------------|--------------------|
| Free term | 13.110667 | 6.33 | 0.042 |
| density | 0.4244 | 0.125 | 0.001 |
| For total regression: standard error of estimation ±7.67 R-squared =0.13 F _{proportion}} =11.46 | | | |

Table 5. Potatoes yield of the *Karatop* cultivar, t/ha (average for 2001-2003)

| Non fertilized | Fertilized for scheduled yield, t/ha | | | |
|---------------------|--------------------------------------|------|------|------|
| | 30 | 40 | 50 | 60 |
| 18,2 | 29,6 | 37,8 | 42,0 | 43,4 |
| Days after planting | | | | |
| 19,2 | 30,3 | 38,0 | 42,3 | 43,9 |
| 20,7 | 31,9 | 39,5 | 44,0 | 46,0 |
| 23,0 | 33,2 | 41,0 | 46,9 | 49,3 |
| 17,3 | 27,1 | 36,1 | 40,0 | 43,1 |

Combination of ridge tillage time in 30 days after planting with rate of fertilizer application N₁₉₈P₉₀K₃₂₄ in this experiment produced maximum potatoes yield of the *Karatop* cultivar 49,3 t per 1 ha (table. 5).

Besides fertilizers impact on the potatoes yield growth was set as 92 %, the same figure for ridge tillage time was 4,2%. I.S. Shatilov [11], I.P. Kruzhilin and others [6] pointed out close relationship between the potato tuber quality and rate of mineral supply of the plant.

Really our experiments showed that growth of mineral supply contributed not only to yield improvement, but also provided tuber quality improvement. At that, average tuber mass grew (by 31...43%) and quantity of tubers per one plant also grew (average, by 9...11%).

On the average the years of research showed max tuber mass per one plant for *Krasnopolskiy* cultivar (715 g) with plant population 40 thousand per 1 ha when fertilized to output 50 t per hectare. *Karatop* cultivar showed maximum tuber mass per one plant as 780 g. with plant population 40 thousand per 1 ha when fertilized to output 60 t per hectare. The same cultivar had max tuber mass per one plant as 779 g. with plant population 60 thousand per 1 ha when fertilized to output 50 t per hectare.

Optimization of soil water regime is the essential condition to produce scheduled yield. Depending on the year

of the research it took from 5 to 10 wetting with volume 200 - 480 m³/ha to preserve humidity level min 75...80 % HB in the active layer of the soil cultivated for potatoes. At that, irrigation need changed from 2240 to 3250 m³/ha.

The achieved figures on moistness average daily flow during the vegetation period prove that they are effected by degree of soil wetting, the plant development stage and weather conditions. Maximum level of daily water requirement for potatoes (4,9...5,1 mm) was set in July-August, in the inter phase periods of budding – beginning of flowering and beginning of flowering - wilting of potato tops. These periods are characterized by most rapid tops growth, maximum leaf – area and vegetation mass, as well as rapid formation and growth of potato tubers. Maximum humidity plow continued up to the third decade of August and then it reduced till 3,4...2,1 mm in the inter phase period: wilting of the tops – tuber ripening.

Potatoes need minimum of irrigation at the beginning of the vegetation period because the sprouting use water mainly from mother tuber, evaporating surface is small. Thus daily water consumption changes within limits 1,8...2,3 mm.

Increase of plant population and rate of fertilizers application result in reduction of flow intensity needed to produce one unit

of the crop. Minimum water-use ratio for potatoes was showed by samples with plant population 60 thousand units/ha when N₁₆₅P₇₅K₂₇₀ was applied and made 155 m³/t for *Krasnopol'skiy* and 101 – for *Karatop*. Combination of ridge tillage time 30 days after planting with fertilization N₁₉₈P₉₀K₃₂₄ provided further reduction of water-use ratio up to 85 m³/t.

Nitrate concentration in potato tubers grows after application of fertilizers in high degrees. Their use within limits of the examined measures had no negative effect on the tubers quality (table 6).

Maximum permitted level is 250 mg/kg of wet weight.

Note. Average for 1999-2003.

So nitrate concentration in potato tubers for *Krasnopol'skiy* and *Karatop* cultivars when fertilized by N₁₉₈P₉₀K₃₂₄ made 61,53 and 60,07 mg/kg, which is 4 times less than maximum permitted level.

Energetic efficiency of the experiments was estimated by comparing figures of total energy used to produce the crops with indexes of energy received with the yield. Maximum net energetic income – 56,5 gigajoule /ha was produced by *Karatop* cultivar when fertilized by N₁₆₅P₇₅K₂₇₀ and plant population 60 thousand plants per 1 ha (table 7).

Table 6. Nitrate concentration in potato tubers, mg/kg

| Measures of fertilizers for the scheduled yield, rate of application in kg/ha | <i>Krasnopol'skiy</i> | <i>Karatop</i> |
|-------------------------------------------------------------------------------|-----------------------|----------------|
| Non fertilized | 37,57 | 45,17 |
| 30, N ₉₉ P ₄₅ K ₁₆₂ | 37,73 | 49,17 |
| 40, N ₁₃₂ P ₆₀ K ₂₁₆ | 46,63 | 50,73 |
| 50, N ₁₆₅ P ₇₅ K ₂₇₀ | 54,83 | 55,30 |
| 60, N ₁₉₈ P ₉₀ K ₃₂₄ | 61,53 | 60,07 |

Table 7. Energetic efficiency of potato crops

| index | <i>Krasnopol'skiy</i> | | | | <i>Karatop</i> | | |
|---------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------|----------------------------------------------------------------------|----------------------------------------------------------------------|----------------------------------------------------------------------|----------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| | Plant population (thousand. unit/ha), rate application of fertilizers (rate of application kg /ha), ridge tillage time, days. | | | | | | |
| | 45 thous. plants., N ₁₆₅ P ₇₅ K ₂₇₀ | 50 thous. plants., N ₁₃₂ P ₆₀ K ₂₁₆ | 45 thous. plants., N ₁₆₅ P ₇₅ K ₂₇₀ | 55 thous. plants., N ₁₆₅ P ₇₅ K ₂₇₀ | 60 thous. plants., N ₁₆₅ P ₇₅ K ₂₇₀ | 50 thous. plants., N ₁₆₅ P ₇₅ K ₂₇₀ in 30 days. | 50 thous. plants., N ₁₉₈ P ₉₀ K ₃₂₄ in 30 days. |
| yield, t/ha | 28,8 | 29,2 | 30,3 | 45,9 | 46,6 | 46,9 | 49,3 |
| Energy from the yield, gigajoule /ha | 72,0 | 72,9 | 75,7 | 114,7 | 116,4 | 117,2 | 123,2 |
| Energy spent, gigajoule /ha | 53,9 | 52,3 | 58,6 | 58,4 | 59,9 | 65,3 | 70,7 |
| Pure energetic income, gigajoule /ha | 18,1 | 20,6 | 17,1 | 56,3 | 56,5 | 51,9 | 52,5 |
| Energy efficiency ratio | 1,33 | 1,39 | 1,29 | 1,96 | 1,94 | 1,79 | 1,74 |
| Energy production cost, gigajoule /ha | 1,87 | 1,79 | 1,93 | 1,27 | 1,28 | 1,39 | 1,43 |

As a result, to produce 45...50 t of potatoes (*Karatop* cultivar) on 1 ha it is required to combine plant population of 50...55 thousand units per 1 ha with rate of application of $N_{165}P_{75}K_{270}$ or $N_{198}P_{90}K_{324}$ on 1 ha and ridge tillage time in 30 days after planting. To produce 30 t of potatoes (*Krasnopolskiy* cultivar) from 1 ha it is required to combine plant population of 45 thousand units per 1 ha with rate of application of $N_{165}P_{75}K_{270}$. Humidity in the active layer of the soil has to be kept min 75...80% HB during the whole period of vegetation of both cultivars.

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