INFLUENCE OF SUCCESION CROPPING ON ECONOMIC EFFICIENCY OF NO-TILL CROP ROTATIONS

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Abstract

This study was aimed at examining the influence of succession cropping on the economic efficiency of no-till field crop rotations on the black earth in the zone of unstable moistening of the Stavropol krai. A long-term stationary experiment was conducted to examine for the purpose nine field crop rotation patterns different in the number of fields (four to six), set of crops, and their succession in crop rotation. The respective shares of legumes, oilseeds, and cereals in the cropping pattern were 17 to 33, 17 to 40, and 50 to 67 %. It has been established that in case of no-till field crop cultivation the economic efficiency of plant production depends on the set of crops and their succession in rotation. The most economically efficient type of crop rotation is the soya-winter wheat-peas-winter wheat-sunflower-corn six-field rotation with two fields of legumes: in this rotation 1 ha of crop rotation area yields 3 850 grain units per ha at a grain unit prime cost of 5.46 roubles; the plant production output return and profitability were 20,888 roubles per ha and 113 %, respectively. The high production profitabilities provided by the soya-winter wheat-sunflower four-field and the soya-winter-wheat-sunflower-corn-winter wheat five-field crop rotation are 108.7 and 106.2 %, respectively. The inclusion of winter wheat in crop rotation for two years in a row reduces the second winter wheat crop yield by 80 to 100 %, which means a certain reduction in the grain unit harvesting rate to 3.48-3.57 thousands per ha of rotation area and cuts the production profitability down to 84.4-92.3 %. This is why, no-till cropping should not include winter wheat for a second time.

Keywords: No-till technology; crop rotation; predecessor; yield; return; profitability.
I. Introduction

Crop rotation plays an important role in gathering bumper and annually consistent crop harvests [II, VII]. Crop rotation is especially important to no-till field cropping, which is conditioned by the absence of tillage and the need for attaining an optimal soil density by rotating plants with a tap-root and a fibrous root system [VIII, X, IV]. Crop rotations also play a significant role in pest control and preventing wind and water erosion that make the soil less fertile [VI]. Crop rotations must also favour high yields and economic efficiency of plant production, which largely depends on the selection of plants for cultivation and their succession in rotation.

Therefore, this study was conducted to examine the influence of succession of various crops on the economic efficiency of no-till field crop rotations on the black earth in the zone of unstable moistening of the Stavropol krai.

II. Materials and Methods

The research works were carried out on the trial plot of the North Caucasus Federal Agricultural Research Centre found in a zone of unstable moistening. In this place the aggregate annual effective temperature is 3 000 to 3 200°C, the total annual precipitations are 540 to 570 mm but their distribution from year to year and across vegetation periods is uneven. The hydrothermal index is 0.9 to 1.1 [I]. The trial plot is located on common, deep, and heavy loamy black earth. In the years of research the amount of precipitation in May and August ranged, respectively, from 103 to 174 and from 15 to 28 mm against the respective climate normal of 64 and 48 mm. The rains in May positively affected the growth and development of winter wheat, whereas the dry spell in August negatively affected the crop yield of soya, sunflower, and corn. The year 2015 was drier: back then the amount of precipitation was 528 mm, which was 26 mm below the average long-term level. The years 2016 and 2017 were wetter: the respective amounts of precipitation were 649 and 631 mm.

The tests were conducted in 2015-17 in a long-term stationary experiment, including nine patterns of field crop rotations different in the number of fields, set of crops, and their succession in crop rotation (Table 1).

| Table 1: Succession of crops in examined crop rotations |
|---------------------------------------------|
| 1       | 2         | 3     | 4 | 5 | 6   | 7   | 8   | 9   |
| Soya    | Soya      | Peas  | Flax | Soya | Soya | Soya | Soya | Soya |
| Winter wheat | Winter wheat | Winter wheat | Winter wheat | Corn | Winter wheat | Winter wheat | Winter wheat | Winter wheat |
| Sunflower | Sunflower | Sunflower | Sunflower | Winter wheat | Winter wheat | Winter wheat | Peas | Winter wheat |
The second, third, and fourth rotations differ in the first crop in rotation. The second and fifth rotations have an identical set of crops but with a different order of succession. The eighth rotation has two fields of legumes, whereas in the sixth and ninth rotation winter wheat is cultivated for two years in a row. Each rotation has one field of sunflower seeded after winter wheat. The number of winter wheat fields ranges from one in the first rotation to three in the sixth, seventh, and ninth rotation.

The planting pattern in the crop rotations depends on the set of crops. The respective shares of legumes, and oil plants, sunflower included, range from 17 to 33 and from 17 to 40 (17 to 25) % (Table 2).

### Table 2: Planting pattern in examined rotations, %

| Crop            | Crop rotation no. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|-----------------|-------------------|---|---|---|---|---|---|---|---|---|
| Legumes         |                   | 25| 20| 20| - | 20| 20| 17| 33| 17|
| Oil plants      |                   | 25| 20| 20| 40| 20| 20| 17| 17| 17|
| incl. sunflower |                   | 25| 20| 20| 20| 20| 20| 17| 17| 17|
| Cereals         |                   | 50| 60| 60| 60| 60| 60| 67| 50| 67|
| Incl. wheat     |                   | 25| 40| 40| 40| 40| 60| 50| 33| 50|

The share of cereals ranges from 50 % in the first and eighth rotation to 67 % in the seventh and ninth rotation, including the share of winter wheat ranging from 25 % in the first rotation to 60 % in the sixth rotation.

The crop rotations are spread out in space in three replications across all the fields and placed in a randomized manner at three levels, each of which is an experimental replication with crop rotation patterns displaced in space. The crops in the rotations are placed in a systematic manner. The plot area is 408 sq. m (10.2 x 40 m), the respective declared areas for close-growing and clean-cultivated crops are 72 and 84 sq. m.

All the crops were cultivated by the no-till technology. The experiment involved sowing the varieties and hybrids approved for use in the region of North
Caucasus. The Gimetal sowing machine used to carry out the planting sowed all the examined crops to untilled soil with residues of previous plants on the surface. The planting dates and techniques, the seeding norms, and the applied fertilizer rates as well as the crop tending and weed, pest, and disease control during the vegetation of all the examined crops complied with the cultivation technologies recommended by the regional scientific institutions [IX]. When weeds of no more than 10 cm in height appeared after the harvesting of the early harvested crops (winter wheat, peas, oil flax), weed control was applied by sprinkling the plots with Hurricane forte contact weedicide at a rate of 1.5 l/ha. That weedicide was also used to carry out the sprinkling five to seven days before planting all the crops but for planting winter wheat after the delayed-harvesting plants of soya, sunflower, and corn that required no sprinkling.

The crop yield in the experiment was measured by swathing the plot across the centre on a Sampo 130 and a Sampo 2010 harvester (for corn and sunflower) and then converting the measured data to standard moisture content and cleanness by state variety testing. The crop capacity was converted to grain units by multiplying the yield by conversion coefficients [III]. The economic efficiency of the crop cultivation and rotations in general were defined as the difference between the cost of products at prices established in the market and the expenditures on making them found according to crop raising flow sheets [XII].

III. Results and Discussion

The yield of the cultivated crops was heavily affected by the previous crops, i.e., their placement in rotation. The highest average yield of winter wheat over the years of examination in all the rotations was attained by planting it after peas and soya and amounted to 5.15 and 4.96 t/ha, respectively. The yield of the wheat planted after oil flax, corn, and sunflower was 4.74, 4.16, and 4.01 t/ha, whereas the lowest winter wheat yield of 2.68 t/ha was observed after the repeated planting of that crop.

The baking quality of winter wheat grain was also heavily affected by the predecessors. The respective protein content in the wheat planted after peas and soya, oil flax, corn, and sunflower, and planted repeatedly ranged from 12.4 to 13.4, 11.1 to 11.9, and 9.2 to 9.6 %. In the first two cases wheat can be used to bake bread, whereas in the third one it can be used only as livestock feed, which significantly affected its cost.

The best predecessor for corn was soya, after which the corn yield was 4.69 t/ha. The respective yield of the corn planted after sunflower and winter wheat was by 0.48 and 0.53 t/ha lower. However, when placed against those predecessors, corn showed a yield that fell within the experimental error and amounted to 4.21 and 4.16 t/ha, respectively. This is very important because it allows placing corn in rotation not only after winter wheat as one of the best predecessors [XIII], but also after such a hard-to-handle predecessor as sunflower, and, at the same time, attain identical crop yield levels.

The soya yield against all the predecessors was low and ranged from 1.14 to 1.80 t/ha. That was conditioned by the low precipitation amounts in the second half of soya’s vegetation: the actual precipitation in August 2015, 2016, and 2017 was 15, 2016, and 2017 was 15,
28, and 12 mm, respectively, against the climate normal of 48 mm. The low precipitation amounts at elevated air temperatures of more than 35 and, on some days, 40°C led to heavy air and soil draughts. In 2015 and 2017 that draught was intensified by insufficient precipitation in July. In those conditions there were falls of flowers and even peas and the formed seeds were underdeveloped [V].

The set and succession of crops in the rotations significantly affected not only the yield levels but also the number of grain units gathered from one ha of rotation area. The first four-field rotation with a field of soya, a field of winter wheat, a field of sunflower, and a field of corn lagged was inferior to other five-field rotations (second and fifth) with the same set of crops, though with two fields of winter wheat (Table 3).

Table 3: Crop yield and harvesting of grain units in various rotations in case of no-till field cropping

| Crop rotation | Crop yield, t/ha | Grain units, 10^3/ha | Crop rotation | Crop yield, t/ha | Grain units, 10^3/ha |
|---------------|------------------|----------------------|---------------|------------------|----------------------|
| 1             |                  |                      | 6             |                  |                      |
| Soya          | 1.42             | 1.66                 | Soya          | 1.60             | 1.87                 |
| Winter wheat  | 5.14             | 5.14                 | Winter wheat  | 5.16             | 5.16                 |
| Sunflower     | 2.00             | 2.94                 | Winter wheat  | 2.56             | 2.56                 |
| Corn          | 4.06             | 4.63                 | Sunflower     | 2.47             | 3.63                 |
| Average       | -                | 3.59                 | Winter wheat  | 4.19             | 4.19                 |
| 2             |                  |                      |               |                  |                      |
| Soya          | 1.45             | 1.70                 | Average       | -                | 3.48                 |
| Winter wheat  | 5.01             | 5.01                 | Soya          | 1.59             | 1.86                 |
| Sunflower     | 2.23             | 3.28                 | Winter wheat  | 5.03             | 5.03                 |
| Corn          | 4.69             | 5.35                 | Peas          | 2.67             | 2.64                 |
| Winter wheat  | 4.37             | 4.37                 | Winter wheat  | 5.17             | 5.17                 |
| Average       | -                | 3.94                 | Sunflower     | 2.40             | 3.53                 |
| 3             |                  |                      |               |                  |                      |
| Peas          | 2.26             | 2.24                 | Corn          | 4.28             | 4.88                 |
| Winter wheat  | 5.11             | 5.11                 | Average       | -                | 3.85                 |
| Sunflower     | 2.10             | 3.09                 | Soya          | 1.50             | 1.76                 |
The highest ingathering of grain units was attained in the soya-winter wheat-sunflower-corn-winter wheat second five-field rotation and the soya-winter wheat-peas-winter wheat-sunflower-corn seventh six-field rotation. The inclusion of oil flax in rotation, repeated plantings of winter wheat and its placement in rotation after sunflower and corn reliably reduced the ingathering of grain units per ha of rotation area.

The highest and year-wise stable economic efficiency of cultivating soya in all the crop rotations. Despite a comparatively scarce harvest, it ensures a production profitability of 100 to 120 %, which is conditioned by the expensiveness of soya beans in the domestic market.

The economic efficiency of the other crops heavily depended on their placement in rotation because the predecessor determined not only the yield and quality of the resulting products but even the production expenditures. For example, the production expenditures on cultivating winter wheat after early harvested peas, oil flax, and winter wheat are by 1 600 to 1 877 RUB/ha or by 9 to 10.7 % higher than on its cultivation after the late harvested crops of soya, corn, and sunflower. This is

| Crop      | 4.01 | 4.57 | 4.65 | 4.65 |
|-----------|------|------|------|------|
| Winter wheat | 3.95 | 3.95 |      |      |
| **Average** |      | 3.79 |      |      |
| Flax      | 0.98 | 1.62 |      |      |
| Winter wheat | 4.74 | 4.74 |      |      |
| Sunflower | 2.10 | 3.09 |      |      |
| Corn      | 4.01 | 4.57 |      |      |
| Winter wheat | 3.94 | 3.94 |      |      |
| **Average** |      | 3.59 |      |      |
| Soya      | 1.47 | 1.72 | 1.36 | 1.59 |
| Winter wheat | 4.69 | 5.35 | 5.02 | 5.02 |
| Winter wheat | 4.42 | 4.42 |      |      |
| Sunflower | 2.07 | 3.04 |      |      |
| Winter wheat | 4.32 | 4.32 |      |      |
| **Average** |      | 3.77 |      |      |
conditioned by the need for weed control in the period from gathering early harvested predecessors to planting winter wheat by sprinkling plots with contact weedicides (Table 4).

Table 4: Influence of predecessors on economic efficiency of winter wheat

| Index                  | Predecessor | soya | peas | oil flax | corn | sunflower | winter wheat |
|------------------------|-------------|------|------|----------|------|-----------|--------------|
| Grain cost, RUB/ha     |             | 39,680 | 41,200 | 35,550 | 31,200 | 30,075 | 18,760       |
| Production costs, RUB/ha |           | 17,751 | 19,351 | 19,351 | 17,593 | 17,580 | 19,457       |
| Prime cost, RUB/t      |             | 3,579  | 3,757 | 4,082   | 4,229 | 4,384  | 7,260        |
| Return, RUB/ha         |             | 21,929 | 21,849 | 16,199 | 13,607 | 12,495 | -697         |
| Profitability, %       |             | 123.5  | 112.9 | 83.7    | 77.3  | 71.1    | -3.6         |

This is why, considering the higher yield and cost of the grain planted after early harvested peas, the grain prime cost is higher and the respective return and profitability are lower than after late harvested soya, where the production expenditures are lower than after peas. The placement of winter wheat after oil flax, corn, and sunflower makes it significantly less efficient economically due to its lower yield. Nonetheless, the profitability attained against these predecessors at a level of 71.1 to 83.7 % allows ensuring an expanded reproduction of materials, equipment, and manpower [XI].

In case of the winter wheat repeatedly planted after winter wheat the prime cost of the produced grain exceeds its sales price, which results in losses on this planting. This stems from a heavy decline in the crop yield as compared with the other predecessors and the production of fodder grain unsuitable for bakery. This is why, the winter wheat cultivated by the no-till technology should not be seeded repeatedly.

The best predecessor for corn is soya, after which the lowest grain prime cost of 3,543 RUB/t and the highest respective return and production profitability of 24,045 RUB/ha and 117.2 % are attained. Whereas the corn yields after winter wheat and corn are the same, the respective return and profitability attained after corn (18,501 RUB/ha and 90.9 %) were somewhat higher than the ones after winter wheat (17,735 RUB/ha and 83.2 %). This is conditioned by large expenditures on cultivating corn after winter wheat, again due to the need for weed control over a fairly long period from harvesting winter wheat to planting corn. This is a crucial circumstance because, after sunflower as the hardest predecessor for all crops, the field is usually rendered suitable for complete fallow.

The economic efficiency indicators of soya placed after winter wheat and corn are very close; however, the planting after corn does have some advantage: the
respective prime cost of grain after winter wheat and corn is 12,616 and 12,305 RUB/t, whereas the respective profitability is 106.1 and 111.3%.

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On the whole, the most economically sound rotation is the seventh rotation with two fields of legumes (peas and soya), two fields of winter wheat, a field or sunflower, and a field of corn. This rotation yields the highest prime cost of product obtained from 1 ha of rotation area (39,373 RUB/ha), the lowest output prime cost (4,597 RUB/1K grain units), and the highest return (20,888 RUB/ha) on and profitability (113%) of production (Table 5).

Table 5: Economic efficiency of crop rotations in no-till field cropping

| Crop rotation no. | Product cost, RUB/ha | Production costs, RUB/ha | Grain unit prime cost, RUB | Return, RUB/ha | Profitability, % |
|-------------------|---------------------|-------------------------|--------------------------|----------------|-----------------|
| 1                 | 38,152              | 18,281                  | 4.89                     | 19,871         | 108.7           |
| 2                 | 39,050              | 18,941                  | 4.66                     | 20,109         | 106.2           |
| 3                 | 34,740              | 18,607                  | 5.04                     | 16,133         | 86.7            |
| 4                 | 31,335              | 17,735                  | 4.94                     | 13,600         | 76.7            |
| 5                 | 37,117              | 18,551                  | 4.78                     | 18,566         | 100.1           |
| 6                 | 35,337              | 18,380                  | 5.08                     | 16,957         | 92.3            |
| 7                 | 39,373              | 18,485                  | 4.59                     | 20,888         | 113.0           |
| 8                 | 36,894              | 18,350                  | 4.68                     | 18,544         | 101.2           |
| 9                 | 34,411              | 18,661                  | 5.08                     | 15,750         | 84.4            |
The increase to three fields in the share of winter wheat in rotation by excluding peas (eighth rotation) and alternation of these fields with fields of soya, sunflower, and corn significantly reduces the return being formed by 2,344 RUB/ha or by 11.2%; however, this rotation still remains fairly profitable (by 101.2%).

At the same time, when the set of crops is the same but has a different succession, with winter wheat cultivated for two years in a row (ninth rotation), there occur a significant increase in the prime cost and a reduction in the cost of output, attained returns and profitability.

The second rotation (soya-winter wheat-sunflower-corn-winter wheat) was the most efficient one among the five-field rotations. The change in succession cropping in this rotation, with soya placed after corn and winter wheat planted after sunflower (fifth rotation), made this rotation less economically efficient, though the production profitability (100.1%) and other indices also remained quite acceptable for expanded reproduction.

A significant decline in economic indicators was observed for the same set of crops but with repeatedly planted winter wheat (sixth rotation) and after replacing soya with oil flax (third and fourth rotation). This was conditioned by a significant decline in the yield and quality of repeatedly planted winter wheat and also by the lower efficiency of peas and, especially, oil flax as compared with soya.

It should be noted that, despite some reduction in the productivity per ha of rotation area, the soya-winter wheat-sunflower-corn four-field rotation has one of the best cost effectiveness indicators. This rotation delivers one of the highest levels of product cost, return, and profitability, lagging behind only the seventh rotation as the best one by cost effectiveness.

IV. Conclusion

1. The most economically efficient is the soya-winter wheat-peas-winter wheat-sunflower-corn six-field rotation with an output of 3,850 grain units per ha of rotation area, the highest return of 20,888 RUB/ha, and the highest crop production profitability of 113.0%.

2. The high respective returns of 19,871 and 20,109 RUB/ha and production profitability of 108.7 and 106.2% are provided by the soya-winter wheat-sunflower-corn four-field rotation and the soya-winter wheat-sunflower-corn-winter wheat five-field rotation.

3. The planting of winter wheat for two years in a row reduces the second wheat yield by 80 to 100% and makes its production wasteful, which results in a major decline in the rotation’s cost effectiveness.
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