

## Yield Formation and Consumption of Fertilizers by Cabbage in Long-Term and Systematic Use of Mineral Fertilizers

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The article presents results of studies of late cabbage grown in the four-field intensive crop rotation secured in 1992 on a dark brown soil. The studies have shown that coefficients of fertilizer nutrients in nitrogen ranged 71-86%, in phosphorus 20-21% and in potassium 109-154%. At that a high coefficient in nitrogen (86%), phosphorus (21%) and potassium (154%) was detected in a sample with a double dose of complete fertilizer. With the increase of nutrient removal fertilizer coefficients increased.

**Key words:** Fertilizer, Cabbage, Yield, soil, Nitrogen, Phosphorus, Potassium.

Cabbage (*Brassica oleracea* L.) is a member of the cole crops, and it is important fresh and vegetable crop in most of the countries of the world<sup>1</sup>. The Food and Agricultural Organization<sup>2</sup> has identified cabbage as one of the top twenty vegetables and an important source of food globally. Cabbage has been domesticated and used for human consumption since the earliest antiquity<sup>3</sup>. It has high nutritive value supplying essential vitamins, proteins, carbohydrates and vital minerals<sup>4</sup>. It is a rich source of vitamin A and C. The green outer leaves of cabbage are richer in vitamin A, calcium and iron than the white inner leaves. Fertilizers in general are one of the major inputs for increased agricultural productivity.

Cabbage is a heavy user of nitrogen, phosphorus, and potassium and requires frequent side dressing<sup>5</sup>. It is considered a hard crop on the land, and many growers will rotate with other crops that do not have such high fertility requirements. Application of nitrogenous fertilizers occurs at intervals up to flowering stage<sup>6, 7</sup>. Optimally, cabbage requires 60-85 kg of N; 60-80 kg of P<sub>2</sub>O<sub>5</sub> and 30-90 kg of K<sub>2</sub>O per hectare<sup>8</sup>. Bhardwaj and others (2000) [9] and Muhammed and others (2007)<sup>10</sup> observed that higher yield and nutritional quality in cabbage at the rate of 60 kg/ha of N from organic fertilizer sources (neem) and NPK. For optimum plant growth, nutrient must be available in sufficient and balanced quantities. Soil contains natural reserve of plant nutrients, but these reserves are largely in forms unavailable to plants, and only a minor portion is released each year through biological activities and chemical processes. Therefore, fertilizers are designed to

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supplement the nutrients already present in the soil. The type of fertilizer and quantity to apply depends on soil type, initial nutrient reserves in the soil and yield level. A headed cabbage with a yield of 25 t/ha approximately absorbs 100 kg of N, 12 kg of P and 75 kg of K<sup>11</sup>. Huett and Dettmann (1989)<sup>12</sup> reported maximum marketable heads at fertilizer level of 60 to 120 kg of N and 30-90 kg of P<sub>2</sub>O<sub>5</sub> per hectare. However many investigations in area of nutrition and knowledge about how organic and mineral fertilizers influence growth and yield of crops, there is need to investigate further on the effect of fertilization on the production of cabbage. Therefore the objective of this study is to determine the best ratios of fertilizers for the maximum growth and yield of cabbage variety in dark chestnut soil of Southeast Kazakhstan.

## MATERIALS AND METHODS

Field experiments were conducted at the Southeast Kazakhstan, Kazakh Research Institute of Potato Growing and Vegetable Growing (KRIPGVG), Kainar (43°09'2 N, 76°26'2 E, and 789 masl), Almaty Region, in the 2012-2013 crop seasons. Conditions at Kainar are characterized by over 414.6 mm of rainfall. The irrigated foothill

zone where KRIPGVG is located is a relatively well-watered location; the experimental materials were irrigated 3 times during their development at a rate 600 m<sup>3</sup>/ha and kept free from weeds. Experiments were made in 4 randomized blocks. Individual plot size was 67.2 m<sup>2</sup> (4.2 m × 16 m).

Studies were carried out under conditions of the four-field intensive crop rotation secured in 1992. Late cabbage of "Snow White" variety was studied.

The experiment was deployed in space and time. Crop rotation underwent 6 rotations. Four-field intensive crop rotation secured in 1992 on a dark brown soil: 1. White cabbage (late); 2. Cucumber; 3. Tomato; 4. Root vegetables (carrots, red beet).

Cabbage fertilization program: 1. Monitoring (without fertilizers); 2. N<sub>60</sub>P<sub>30</sub>K<sub>30</sub> (single dose); 3. N<sub>120</sub>P<sub>60</sub>K<sub>60</sub> (double dose); 4. N<sub>180</sub>P<sub>90</sub>K<sub>90</sub> (triple dose).

Types of fertilizers applied in intensive crop rotation: urea, double superphosphate and potassium chloride.

Total fertilizers applied for 5 rotations of intensive crop rotation and separately for cabbage are shown in Table 1.

**Table 1.** The number of fertilizers applied for 5 rotations of intensive crop rotation and late cabbage (1992-2013), kg/ha

Experiment samples	For 5 crop rotations			For late cabbage		
	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O
Monitoring	0	0	0	0	0	0
N <sub>60</sub> P <sub>30</sub> K <sub>30</sub>	690	990	840	360	180	180
N <sub>120</sub> P <sub>60</sub> K <sub>60</sub>	1380	1680	1530	720	360	360
N <sub>180</sub> P <sub>90</sub> K <sub>90</sub>	2070	2370	2220	1080	540	540

In the soil samples selected the following was detected: nitrate nitrogen by Granval-Lyazh using a phenoldisulfonic acid; ammonium nitrogen with the Nessler reagent; labile phosphorus by the Machigin's method. In plant samples the following was detected: solids content by a thermostatic method (at 105°C); total nitrogen, phosphorus and potassium content – by wet ashing in modification of K.E. Ginzburg; Kjeldahl nitrogen; phosphorus – by Malyugina-Khrenova; potassium – by flame photometer<sup>13</sup>.

Crop was manually estimated for each

plot. Yield data has been mathematically processed using Excel.

## RESULTS AND DISCUSSION

The degree of soil nutrient element supply for plants is mainly characterized by the content of mobile forms and is closely connected with mineral fertilizers applied in the soil.

Under conditions of the south-east of Kazakhstan mineral nitrogen is mainly represented in a nitrate form and in addition to that a mobile

soil nitrogen fund is also represented in an ammonium form. These two forms of nitrogen are nutrient sources of equal value for crop plants.

The results of our studies show that use of nitrogen fertilizers significantly increases mineral nitrogen content. At that content of nitrate nitrogen was higher than that of ammonium nitrogen and its content depended on norms of nitrogen fertilizers, combination of nitrogen with other fertilizer elements (phosphorus and potassium) and finding it in certain phases of cabbage plant development. Table 2 presents data on average

seasonal content of mobile nutrient elements in a dark brown soil in various norms of mineral fertilizers for late cabbage. Thus, average seasonal nitrate content in a control sample in the 0-20 cm layer was 16.5 mg/kg when applying nitrogen fertilizer in increasing norms ( $N_{60,120,180}$ ) nitrate content increased to 26.9; 32.5 and 41.7 mg/kg, respectively. Ammonium nitrogen was also higher in fertilized samples and its Average seasonal content varied depending on the experiment sample from 10.1: 11.1 and 13.1 mg/kg while the control sample was 6.1 mg/kg of the soil.

**Table 2.** Average seasonal content of nutrient elements in a dark brown soil for late cabbage, mg/kg

Experiment sample	Soil layer, cm	Average seasonal content, mg/kg			
		N-NH <sub>4</sub>	N-NO <sub>3</sub>	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O
Monitoring	0-20	6.1	16.5	12.8	330.0
	20-40	3.7	13.7	10.2	310.0
$N_{60}P_{30}K_{30}$	0-20	10.1	26.9	43.0	350.0
	20-40	6.9	19.7	29.6	330.0
$N_{120}P_{60}K_{60}$	0-20	11.6	32.5	48.0	365.0
	20-40	8.4	26.7	38.7	340.0
$N_{180}P_{90}K_{90}$	0-20	13.1	41.7	57.5	375.0
	20-40	9.5	30.2	43.0	345.0

Content of mobile phosphorus in a dark brown soil in cabbage plants also depended on the norms for phosphorus fertilizer and its combination with other fertilizer elements. It should be noted that in fertilized samples content of mobile phosphorus was high according to gradation of soil phosphorus supply – 36-50 mg/kg as per B.Machigin<sup>13</sup>. This is due to systematic application of phosphorus high norms to create and study phosphorous backgrounds in order to determine their efficiency for vegetable crops. Thus, average seasonal content of mobile phosphorus in the 0-20 cm soil layer in the control sample was 12.8 mg, in the 20-40 cm layer – 10.2 mg/kg of the soil. Annual application of phosphorous fertilizers at a dose of  $P_{60}$  increased to 43.0 and 29.6 mg/kg in the 0-20 and 20-40 cm layer, respectively. When applying a double dose  $P_{120}$  increased to 48.0 and 38.7 mg/kg, triple dose of phosphorous fertilizer  $P_{180}$  increased content of mobile phosphorus to 57.5 and 43.0 mg/kg of the soil, respectively by soil layers.

Exchange potassium for almost all the crops is the third important macronutrient and plays

a crucial role in biochemical plant functions. Studies have shown that use of potassium fertilizers has a positive effect on potassium soil status. Average seasonal content of exchange potassium in the control sample was 330 and 310 mg/kg in the 0-20 and 20-40 cm layer, respectively. When applying fertilizers based on potassium at doses of 60, 90, 180 kg/ha in combination with nitrogen-phosphate fertilizers its content increased in the 0-20 cm layer to 350; 365; 375 mg/kg, and in the 20-40 cm layer to 330; 340; 345 mg/kg of the soil, respectively.

Thus, use of mineral fertilizers improves the nutrient status of a dark brown soil creating high background of nutrient forms easy digestible by plants. Application of 100 kg/ha of a primary nutrient of NPK fertilizers increases nitrate nitrogen content by 6-10 mg/kg, mobile phosphorus – by 6-13 mg/kg, exchange potassium – by 10-15 mg/kg of the soil.

Numerous studies show that fertilizers are an effective and fast acting factor that facilitates improvement of the crop quality. Using fertilizers

we can change orientation of metabolic processes to the desired direction, increase accumulation of organic substances (protein, fat and starch) and other substances in plants, influence the chemical composition of plants which determines the crop quality. It is therefore important to be familiar with the conditions of effective application of fertilizers not only to increase crop yields but also to improve the crop quality. Table 3 presents qualitative characteristics of late cabbage.

Mobile forms of nutrient elements of late cabbage crops gradually decrease over time by the end of the growing season which is due to their intensive consumption and creation of plants biomass. Clear relationship between the doses of mineral fertilizers applied and total nutrients in plants has been established. It has been demonstrated that application of single NPK doses increases content of total nitrogen by 3.9%,

phosphorus by 0.43% and potassium by 3.9% in plants. Double and triple NPK doses increased content of nitrogen by 4.6%; 4.7%, phosphorus by 0.52%; 0.58% and potassium by 4.7 and 5.0%, respectively. Solids content in the phase of industrial ripeness of late cabbage in the control sample was 10.7%, in fertilized samples this characteristic was higher and was 11.0; 11.6 and 11.7%, respectively. Total sugar content decreased with the increase of fertilizer doses and in fertilized samples it ranged from 5.35% to 5.40% while in the control sample it was 5.55%. Nitrate content also increased with the increase of nitrogen fertilizer doses but did not exceed the threshold allowable concentration. Thus, in the control nitrate sample it was 205 mg/kg of wet weight, in fertilized samples where nitrogen fertilizer doses increased from 60, 120, 180 kg/ha nitrate content ranged 335; 344 and 360 mg/kg, respectively.

**Table 3.** Qualitative characteristics of cabbage depending on the conditions of mineral nutrition, 2012-2014

Experiment sample	Content in plants, %			Solids, %	Vitamin C, mg, %	Total sugar, %	Nitrates, mg/kg
	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O				
N <sub>0</sub> P <sub>0</sub> K <sub>0</sub>	2.9	0.29	3.4	10.7	30.5	5.55	205
N <sub>60</sub> P <sub>30</sub> K <sub>30</sub>	3.9	0.43	3.9	11.0	32.3	5.38	335
N <sub>120</sub> P <sub>60</sub> K <sub>60</sub>	4.6	0.52	4.7	11.6	33.1	5.40	344
N <sub>180</sub> P <sub>90</sub> K <sub>90</sub>	4.7	0.58	5.0	11.7	33.4	5.35	360

While cabbage, especially its late varieties, forming a strong biomass can produce heavy yield of heads. It significantly differs among vegetables with its long period (up to 180 days) of absorption of nutrients and high level of their removal. Yield of late cabbage for 3 years of study on average was high in a sample with application of triple mineral fertilizer doses and was 44.5 t/ha while in the control sample it was 30.7 t/ha (Table

4). The increase in yield due to use of a triple fertilizer dose was 13.8 t/ha or 45.0%. In the samples with a single dose the yield of cabbage heads was 35.5 t/ha, double doses provided the yield of 41.0 t/ha, the increase was 4.8 and 10.3 t/ha or 5.6% and 33.5%, respectively. The least significant difference between samples was 1.72 t/ha with the accuracy of an experiment of 4.52 %.

**Table 4.** Effect of fertilizers on the yield of late cabbage heads in intensive crop rotation, 2012-2014

Samples	Years of the study, t/ha			Average yield t/ha	Yield increase	
	2012	2013	2014		t/ha	%
1. N <sub>0</sub> P <sub>0</sub> K <sub>0</sub>	31.7	30.2	30.4	30.7	-	-
2. N <sub>60</sub> P <sub>30</sub> K <sub>30</sub>	36.8	35.9	34.0	35.5	4.8	5.6
3. N <sub>120</sub> P <sub>60</sub> K <sub>60</sub>	43.5	40.5	39.1	41.0	10.3	33.5
4. N <sub>180</sub> P <sub>90</sub> K <sub>90</sub>	47.4	42.6	43.5	44.5	13.8	45.0

HCP<sub>0.95</sub> t/ha = 1.72, HCP, % = 4.52

With late cabbage crop the nutrients in different proportion are removed which are recovered by means of fertilizers. In fertilized samples nutrient removal was higher than in samples where fertilizers were not applied. Removal of fertilizer elements was the greatest in potassium and nitrogen and phosphorus was the least to remove.

Table 5 shows nutrient removal by late cabbage cultivated in crop rotation during 1992-2013 by experiment samples under study and for this period.

The main credit balance item is enrichment of the soil with nutrients and fertilizers at the beginning of the 6<sup>th</sup> rotation. As Table 1 shows the following was applied in a dark brown soil together with single norms of a primary nutrient

of NPK fertilizers: 360 kg/ha of nitrogen, 180 kg/ha of phosphorus and potassium each, double NPK norms: 720 kg/ha of nitrogen and 360 kg/ha of phosphorus and potassium each, and triple NPK norms 1080 and 540 kg/ha, respectively (Table 1).

Removal of fertilizer elements by alienated products at the beginning of the 6th crop rotation was defined as an expense balance item. Nutrient removal by late cabbage crop for 6 crop rotations in the control experiment sample on average was: 509.0 kg/ha of nitrogen, 51.0 kg/ha of phosphorus and 597.0 kg/ha of potassium, respectively. In fertilized samples NPK removal was higher and was: 794.0, 1129.0, 1279.0 kg/ha of nitrogen; 88.0, 128.0, 158.0 kg/ha of phosphorus; 794.0, 1153.0, 1360.0 kg/ha of potassium, respectively.

**Table 5.** Removal and balance of nutrients by cabbage (for 6 crop rotations)

Experiment samples	Removed with the yield			Balance						Fertilizer use efficiency, %		
				kg/ha			% to removal					
	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O
Monitoring	509	51	597	-509	-51	-597	-100	-100	-100	-	-	-
N <sub>60</sub> P <sub>30</sub> K <sub>30</sub>	794	88	794	-434	93	-614	-55	106	-77	79	20	109
N <sub>120</sub> P <sub>60</sub> K <sub>60</sub>	1129	128	1153	-409	233	-793	-36	182	-69	86	21	154
N <sub>180</sub> P <sub>90</sub> K <sub>90</sub>	1279	158	1360	-199	382	-820	-16	242	-60	71	20	141

The nutrient balance was calculated using a standard finite difference method and the balance of nitrogen, phosphorus and potassium was calculated in percent to removal. Overall balance values and balance of nitrogen, phosphorus and potassium in percent to removal significantly varied. Besides it mainly depended on the doses of the element under study. The positive balance of nutrients shows the high level of fertilizer application and facilitates improvement of effective soil fertility. However, as we can see in Table 3 the results of our study have shown that a positive balance is observed only in phosphorus and a negative balance is observed in potassium. Thus, in fertilized samples the nitrogen balance was -434.0; -409.0; -199.0 kg/ha, the phosphorus balance was 93.0, 233.0, 382.0 kg/ha and the potassium balance was 614.0, -793.0, 820.0 kg/ha, respectively.

The important indicator by the value of which we can judge of fertilizer efficiency is efficiency of nutrients from fertilizers applied.

It has been found in numerous studies that nutrient efficiency is not constant and varies greatly under the influence of soil, meteorological and other conditions even within one farm, they change under the influence of cultivated crops, varieties, state of farming techniques, weather and other factors.

The calculations performed show that coefficients of fertilizer nutrients in nitrogen ranged 79%, 86%, 71%; in phosphorus 20%, 21%, 20% and in potassium 109%, 154%, 141%. At that a high coefficient in nitrogen (86%), in phosphorus (21%) and in potassium (154%) was detected in a sample with a double dose of NPK. With the increase of nutrient removal fertilizer coefficients increased.

The removal balance when applying single, double and triple doses of NPK was: -55%, -36%, -16% of nitrogen; 106%, 182%, 242% of phosphorus and -77%, -69%, -60% of potassium, respectively.

## CONCLUSIONS

Thus, summarizing data obtained in capacity of crop cultivated in crop rotation it can be concluded that mineral fertilizers greatly affected the grain yield and quality of crop under study. The estimated nutrient balance data at the beginning of the 6th crop rotation show that a positive balance was observed in phosphorus and a negative balance was observed in nitrogen and in potassium. Thus, in fertilized samples balance of nitrogen was from -434.0 to -199.0 kg/ha, balance of phosphorus was from 93.0 to 382.0 and balance of potassium from -614.0 to -820.0 kg/ha. With the increase of late cabbage yield nutrient removal increases which in its turn affects the coefficients of fertilizer nutrients.

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