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The Effect of Applying Mineral Fertilizers Through Drip Irrigation and Furrow Method on the Movement of Mobile Nutrients in the Soil and the Growth, Development, and Accumulation of Nutrients in the Walnut Leaves

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ABSTRACT

A task was set to reveal the effect of water-soluble fertilizers of new composition and quality on the content of available nutrients at different depths of the soil, depending on the movement of the irrigation water, irrigation time, as well as its effect on the growth, yielding capacity and the quality of fruit in commercial size walnut orchards. The research has shown that the movement of nutrients in the soil is completely dependent on the movement of water when applying water-soluble complex fertilizers with drip irrigation. Therefore, the amount of the water should be adjusted so that the nutrients are available to the plant's root system at all depths, improving the growth, and increasing the content of the basic nutrients in the leaves.Fertilizers with less water-solubility are mainly preserved at a 0 cm - 30 cm depth. When the root system grows and spreads to the inter-row spaces, it is appropriate to periodically fertilize also the inter-row spacing by the furrow method.

Introduction

The importance of fertilizers in maintaining the fertility of soils and increasing the yielding capacity of crops is well known (Melkonyan, et al., 2004; Ghazaryan, et al., 2022; Grigortsevich, 2011; Marchenko, et al., 2015; Mineyev, 2004; Polukhina, et al., 2018). It is common to define the plant nutrient supply through the chemical analysis of soil or plants (Ghazaryan, et al., 2022; Kuzin, 2015; Mineyev, 2004). In Europe, the USA, Japan, and other countries, it is more common to determine the plant nutrient supply through the pant analysis method. Moreover, the most sensitive organ – the leaf – is mostly analyzed (Volkova, 2019; Gorman, et al., 2021; Michurin, 1973; Yagodin, 1987), with the results being evaluated in three degrees of supply: “week”, “medium” and “good” supply of a particular nutrient. In developed countries, based on the results of numerous studies, a scale of the nutrient supply in soils and plants has been defined. Whereas in Armenia, only a scale of soil nutrient supply is defined (Melkonyan, et al., 2004; Ghazaryan, et al., 2022).

Walnut (Juglans. L) is a crop that produces strong aboveground and root systems; however, this occurs, if the soil contains the necessary amounts of nutrients and moisture (Mineyev, 2004; Trunov, 2005; Trusheva, 2014). Moreover, it has been proven that the expected age of the walnut (or other tree types) to bear fruits, the yielding capacity, and the quality of fruit, depends, among other factors, especially on the level of soil fertility. It can be checked by soil and plant (leaf) analysis, followed by setting the fertilizer application rates based on these data (Fomenko, et al., 2018; Trusheva, 2014; Polukhina, et al., 2018; Yagodin, 1987).

Even with all things considered, it should be noted that scientific studies on the fertilization of walnuts are extremely rare, with the Republic of Armenia nearly lacking such studies (Trunov, 2005; Trusheva, 2014; Fomenko, et al., 2018).

Currently, commercial-scale walnut orchards are being massively established in different climatic conditions in Armenia. Their fertilization is later performed through drip irrigation, using mainly water-soluble complex fertilizers, such as N:P: K=20:20:20 + microelements, N:P: K=6:14:35, etc., which, with the changes they have undergone in the soil, differ from the changes of phosphorus, potash and combined and complex fertilizers that are not completely water-soluble. Complex fertilizers well dissolved in water have been imported to Armenia only in recent years. However, their movement and changes in the soil have not been studied yet. Thuswise, it is important to reveal the effect of such fertilizers (NPK) on the content and movement of available nutrients in the soil, according to the depth and width, depending on the movement of the irrigation water and the time of irrigation, as well as its effect on the growth of walnut, NPK content in the leaves and the yielding capacity.

Materials and methods

The research was carried out in the Aygehat community, Lori Marz, in two different land plots: 1. a two-year-old non-yielding orchard and 2. a six-year-old orchard, just starting to bear fruits, with a plantation density of 35 m^2 (7 m x 5 m), and Fernor being the pollinated variety and Chandler – the pollinator.

The field trials were performed in 2021-2022, in four replicates, with 10 trees of similar growing capacity selected for each replicate, which were numbered. All the observations, measurements, and records were performed on these plants according to the methodology proposed by Michurin in 1973 (Michurin, 1973).

The trials were set up with the following versions:

Trial I – Two-year old orchard

1. Without fertilization (control version)
2. N_{60} ammonium nitrate + carbamide + ammonium sulphate (drip method)
3. $N_{60}P_{60}$ ammonium dihydrophosphate + ammonium nitrate, carbamide (drip method)
4. $N_{60}P_{60}K_{60}$ 20:20:20 (drip method)
5. $N_{60}P_{60}K_{60}$ 20:20:20 (drip method) + $N_{60}P_{60}K_{60}$ ammonium nitrate + carbamide + double superphosphate + potassium chloride, (furrow method), from both sides of the row, 28 cm – 30 cm deep.

Trial II – Six-year-old orchard starting to bear fruits. The distance between the plot of this trial from that of Trial I is 12.5 km.

1. Without fertilization (control version)
2. N_{120} ammonium nitrate + carbamide + ammonium sulphate (drip method)
3. $N_{120}P_{120}$ ammonium dihydrophosphate + ammonium nitrate, carbamide (drip method)
4. $N_{120}P_{120}K_{120}$ 20:20:20 (drip method)
5. $N_{120}P_{120}K_{120}$ 20:20:20 (drip method) + $N_{120}P_{120}K_{120}$ ammonium nitrate + carbamide + double superphosphate + potassium chloride (furrow method), from both sides of the row, 28 cm – 30 cm deep.

According to the trial versions, for drip irrigation, water-soluble complex fertilizers intended for that purpose were applied; in version 5, the fertilization was carried out by drip and furrow methods: For the furrow method, fertilizers intended for applying through overall, furrow, or other methods were applied. The time of each irrigation, depending on the growth stage of the plant has been determined whenever the soil moisture was 60 %-75 % of the maximum field water capacity. To present the agrochemical characteristics of the test plots, the mechanical composition of the soil was determined by the method of Kachinski; humus – by the method of Tyurin; carbonates – by calcimeter; the absorbed calcium and magnesium – by the trilonometric method; the content of mobile nitrogen was determined by the method of Tyurin-Kononova, that of mobile phosphorus – by the method of Machigin, the content of mobile potassium – in the Machigin solution extract; and humidity – by the weight method (Arinushkina, 1961).

To determine the total amounts of nitrogen, phosphorus, and potassium in the plant's leaves, the related portion was burned in an acidic medium, then the amount of the nitrogen was determined by distillation, phosphorus – with the help of colorimetric photometer and the potassium – with the help flame photometer (Yagodin, 1987). The growth and the lignification of one-year-old shoots of the plant were determined by the linear measurement method (Michurin, 1973).

Results and discussions

The field trials were carried out on brown forest carbonate soils, the characteristics of which are presented in Tables 1 and 2. Thus, according to the data of Table 1 (trial No. 1, two-year-old orchard), the content of humus in soil was

0.96 %-4.01 %, with the mechanical composition in the upper layers being light loam (physical clay: 25.3 % – 28.8 %), in the 3rd layer – heavy loam (the physical clay: 51.4 %), soil reaction (*pH*) is light alkaline, content of carbonates is 1.2 % – 9.8 %, that of the absorbed calcium – 19.0 mg-eq. – 26.3 mg-eq. and that of magnesium 9.4 mg-eq. – 11.7 mg-eq. in 100 grams of soil. The amount of available nitrogen, phosphorus, and potassium, according to the scale defined for the soils of the RA, is low and decreases further depending on the depth. This situation with the soil nutrient supply is characteristic also of the soils in the entire region; therefore, the need for applying fertilizers is very high (Melkonyan, et al., 2004; Michurin 1973).

The data in Table 2, providing the characteristics of the soils in Trial No. 2 (six-year-old orchard), indicate that the agrochemical characteristics of these soils are considerably different from the data of Trial No. 1, which is due to the application of bio humus and mineral fertilizers for years on about 14 hectares of the orchard before our trials.

According to the data of this table, the mechanical composition of the soil in the upper horizons is light clay, with heavy loam in the lower horizon, the content of carbonates is 3.1 % - 6.9 %, and pH – weak alkaline.

The content of available nitrogen is very low, with an almost high content of phosphorus in the upper horizon and a very low content of it in the depths of 30 cm–60 cm and 60 cm–100 cm. According to the depths, such a pattern is observed also in the content of mobile potassium. This state of the nutrients in the test plot is due to incorrect fertilization and irrigation operations. According to the field studies, these soils are hardened starting with 15 cm-20 cm depths, and are difficult to dig when drying.

Table 1. The agrochemical characteristics of the soil in Trial No. 1 before fertilization (two-year-old orchard)*

Sampling depth	Physical clay, %	Humus, %	$CaCO_3$, %	pH	Soluble salts, %	Absorbed Ca+Mg mg/eq. in 100 g of soil	Available nutrients of plants, mg in 100 g of soil		
							N	P_2O_5	K_2O
0-30	23.5	4.01	1.2	7.9	0.021	26.3+11.3	3.61	0.47	14.54
30-60	28.8	2.05	7.5	8.4	0.034	21.8+11.7	2.03	0.31	9.81
60-90	51.4	0.96	9.8	8.5	0.038	19.0+9.4	1.40	0.25	5.26

Table 2. The agrochemical characteristics of the soil in Trial No. 2 before fertilization (six-year-old orchard)*

Sampling	Physical clay, %	Humus, %	$CaCO_3$, %	pH	Soluble salts, %	Absorbed Ca+Mg mg/eq. in 100 g of soil	Available nutrients of plants, mg in 100 g of soil		
							N	P_2O_5	K_2O
0-30	65.4	4.42	3.1	7.7	0.046	30.1+10.3	1.39	5.60	47.94
30-60	60.8	3.18	5.7	7.8	0.031	21.2+10.4	1.02	1.26	4.23
60-90	56.5	0.73	6.9	8.4	0.028	20.8+9.9	1.04	0.51	4.71

*Composed by the authors.

Thus, the results of the analyses of the soils in trial plots have revealed that these soils are in the favorable range for the plants with their mechanical composition, pH, and content of carbonates, dissolved salts and the absorbed calcium and magnesium, while by the content of mobile nutrients, the soil in Trial No. 1 is weakly supplied with NPK at all 3 depths, and the soil in Trial No. 2 is poorly supplied with nitrogen, while it is well supplied with phosphorus at the depth of 0 cm-30 cm and poorly supplied at depths of 30 cm-60 cm and 60 cm-90 cm.

Tables 3 and 4 present the effect of fertilizers applied through drip irrigation (versions 2-4) and drip and furrow method (version 5) on the content of nutrients at different depths of soils. According to the data of these tables, in both trials, the fertilizers have had a significant effect on the content of mobile NPK in soil, with the level of impact being dependent on the version of fertilization and the year of trial.

Table 3. The effect of fertilizers applied through drip irrigation and drip-furrow method on the content of mobile nutrients in the soil, Trial No. 1*

Versions	Depth, cm	Mobile nutrients, mg in 100 g of soil					
		2021			2022		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O
1	0-30	2.15	0.41	14.33	2.06	0.41	13.81
	30-60	1.61	0.28	10.01	1.60	0.25	9.54
	60-90	1.14	0.25	5.17	1.08	0.17	4.36
2	0-30	3.54	0.39	12.64	4.35	0.41	13.14
	30-60	3.06	0.30	9.86	4.07	0.27	9.76
	60-90	1.45	0.22	5.08	2.16	0.16	4.78
3	0-30	3.86	3.41	10.36	5.91	5.77	11.63
	30-60	2.95	3.45	8.31	3.17	4.06	8.01
	60-90	1.76	2.14	6.07	2.93	1.58	5.84
4	0-30	4.06	3.51	25.07	6.17	6.98	44.40
	30-60	2.75	3.41	20.05	3.14	5.71	42.97
	60-90	2.06	1.97	18.8	2.84	4.02	30.08
5	0-30	3.91	3.37	25.78	5.87	6.84	38.11
	30-60	2.63	2.84	19.31	3.14	6.01	37.16
	60-90	1.85	2.01	17.65	2.91	3.86	31.42
6	0-30	21.87	28.6	88.70	50.18	65.88	164.56
	30-60	2.86	3.11	4.02	25.71	4.06	4.79
	60-90	1.95	1.75	3.51	7.65	2.04	4.27

Note: *Versions: 1. Without fertilization (control version), 2.* N_{60}*; 3.* $N_{60}P_{60}$*; 4.* $N_{60}P_{60}K_{60}$*; 5.* $N_{60}P_{60}K_{60}$ *(drip method) +* $N_{60}P_{60}K_{60}$ *(furrow method)*

*Composed by the authors.

Thus, according to the data provided in Table 3 (Trial No. 1), in the first year of the study, the content of mobile nitrogen in the control version was lower. In this version, the content of mobile nitrogen became even less in the second year of the trial. This pattern was preserved about the mobile phosphorus and partially mobile potassium. Meanwhile, in the versions with fertilizer application, the mobile amounts of the relevant nutrients in the soil have increased, which can be more clearly seen at depths of 0 cm-30 cm and 30 cm-60 cm. This pattern is preserved also in the second year of the trial, becoming even more explicit with the use of water-soluble complex fertilizers. This indicates that the applied fertilizers have remained mobile in the soil and have moved to the deeper layers with the irrigation water. According to different researchers, water-soluble complex fertilizers are effective also in the case of leaf nutrition (Bayrambekov, et al., 2019; Volkova, 2019; Gorman, et al., 2021; Popova, et al., 2009; Trunov, 2005). Meanwhile, numerous studies indicate that the traditional phosphoric (common and double superphosphates), as well as potassium (potassium chloride) fertilizers, are barely able to move in the soil compared with the mobility of nitrogen fertilizers as well as water-soluble complex fertilizers (Michurin, 1973; Osipov, et al., 2018; Polukhina, et al., 2018). The reason is that the water-solubility of the mentioned phosphoric and potassium fertilizers is low. On the other hand, these fertilizers interact with the soil more easily, with the interaction being even faster in carbonate soils, where pH is higher than 7.0-7.5, since in such soils, phosphorus compounds with low water-solubility are formed, while potassium, especially in loam soils, is partially absorbed by the absorbing complex in a non-exchange form (Ghazaryan, et al., 2022; Osipov, et al., 2018; Polukhina, et al. 2018; Trunov, 2005).

Meanwhile, the fertilizers produced for the purpose of drip irrigation contain surface-active agents that mitigate the possibility of comparatively rapid interaction between the fertilizer and the soil (Ghazaryan, et al., 2022; Popova, et al., 2009). As for ammonium and nitrate ions, it is known that the nitrate ion in the soil moves with no hindrance together with the movement of water, while the movement of ammonium ion slows down as it is partially absorbed by the absorbing complex (Ghazaryan, et al., 2022; Polukhina, et al., 2018; Trunov, 2005).

According to the data in Table 3, the movement of the fertilizer applied by the furrow method is extremely difficult, which is especially the case with phosphoric (double superphosphate) and potassium (potassium chloride) fertilizers and the ammonium ion of the ammonium nitrate (Melkonyan, et al., 2004; Ghazaryan, et al., 2022; Polukhina, et al., 2018; Popova, et al., 2009), although in this version, the irrigation water was used to ensure the same level of depth of soil moisture as it has been in the drip fertilization versions.

Table 4 provides the effect of fertilizers applied by drip irrigation and furrow method in Trial No. 2 on the content of mobile nutrients at different depths of the soil. According to the obtained data, the fertilizers have contributed to the increase of the amounts of mobile NPK, the size of which, however, just like in Trial No. 1, depends on the sampling depth, type of fertilizer, and the method of application. Thus, in the control (non-fertilized) version of the trial, the content of the available NPK is lower. In the case of applying only nitrogen fertilizer (version 2), the content of mobile nitrogen in soil has increased partially, which is perhaps more noticeable at the depth of 0 cm-30 cm. in the case of using phosphorus or phosphorus and potassium with nitrogen (version 3, 4), the content of these nutrients has increased, which is especially apparent at the depths of 0 cm-30 cm and 30 cm-60 cm. This indicates that the fertilizers applied through drip irrigation have moved through water also at 30 cm-60 cm and partially 60 cm - 90 cm depths. Meanwhile, in the case of applying fertilizers by the furrow method, mobile nutrients have mainly accumulated at the depths of 0 cm-30 cm and partially 30 cm-60 cm, which, as mentioned, is due to the properties of the fertilizers applied by the furrow method (Ghazaryan, et al., 2022; Trunov, 2005).

Table 4. Effect of fertilizers applied by drip and furrow method on the content of mobile nutrients in the soil, Trial No. 2*

Versions	Depth, cm	Mobile nutrients, mg in 100 g of soil					
		2021			2022		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O
1	0-30	3.45	6.12	46.14	2.76	4.76	45.13
	30-60	2.77	1.84	8.82	2.86	2.01	5.86
	60-90	1.94	1.05	4.96	2.76	2.11	4.98
2	0-30	4.36	5.91	46.04	5.33	3.98	40.83
	30-60	2.88	2.01	8.16	4.06	1.95	5.06
	60-90	1.65	2.00	5.94	2.91	2.08	5.04
3	0-30	3.76	7.14	45.91	5.16	6.74	39.74
	30-60	2.85	2.95	7.14	3.74	3.06	8.12
	60-90	2.06	1.98	5.78	2.08	2.01	4.03
4	0-30	5.12	7.06	53.16	5.86	6.12	50.36
	30-60	4.04	3.02	12.08	3.65	4.95	11.46
	60-90	1.93	1.77	4.31	2.08	1.04	4.41
5	0-30	4.96	6.78	57.24	5.81	5.44	53.16
	30-60	4.01	3.48	13.17	3.45	5.06	10.85
	60-90	1.74	1.58	5.08	2.14	1.13	4.05
6	0-30	12.36	31.14	155.11	47.63	67.95	158.91
	30-60	8.04	9.33	13.82	21.14	12.31	10.62
	60-90	5.33	1.95	4.76	4.31	3.52	5.36

Note: *Versions: 1. Without fertilization (control version), 2. N_{120}; 3. $N_{120}P_{120}$; 4. $N_{120}P_{120}K_{120}$; 5. $N_{120}P_{120}K_{120}$ (drip)+ $N_{120}P_{120}K_{120}$ (furrow)*

*Composed by the authors.

From these data, we can conclude once again that fertilizers applied by drip irrigation move more easily with water in the soil compared to fertilizers intended to be applied by the overall, trunk, or furrow method.

It is known that to fully reveal the effect of fertilizers on plants, their effect on plant growth, lignification of annual shoots, and content of nutrients in leaves, as well as on yielding capacity and quality indicators is also studied.

The lignification of the shoots in perennial plantations is important because lignification improves the winter hardiness and frost resistance of plants (Volkova, 2019; Gorman, et al., 2021; Polukhina, et al., 2018; Popova, et al., 2009), and the definition of optimal amounts of nutrients in leaves during the vegetation period allows to find out the plant's nutrient supply and the necessity of fertilization (nutrition) (Volkova, 2019; Mineyev, 2004; Michurin, 1973). The data are presented in Tables 5 and 6.

According to the data of the tables, during the vegetation period, the size of the shoots, the degree of their lignification, as well as the content of NPK in the leaves depend on the fertilization system. Accordingly, the mentioned indicators are lower in the control versions. The effect of fertilizers on the lignification of annual shoots as well as on the content of NPK in the leaves are noticeable. Thus, the shoots were better lignified in cases where, in the fertilization system, in addition to nitrogen, also phosphorus or phosphorus and potassium were used. In the case of applying only nitrogen, lignification of shoots was the least, making only 82 %-83 %, while in the version with application of phosphorus and potassium, it made 91 %-95 %.

The effect of fertilizers is significant also on the content of NPK in leaves (Table 5, 6). According to the data of these tables, the effect is more noticeable in version 5 of Trial No. 2. This is due to two factors.

Table 5. Effect of fertilizers applied by drip and furrow methods on the growth, lignification, and content of NPK in the leaves of the walnut shoots, Trial No. 1*

Versions	Number of annual shoots	Average growth of shoots, cm	Lignification of annual shoots, %	Content of nutrients in leaves, % (average of two years)					
				The first decade of July			2nd decade of August		
				N	P_2O_5	K_20	N	P_2O_5	K_20
1	2.3	24	88	2.24	0.27	1.96	1.26	0.21	1.71
2	3.7	35	82	2.84	0.21	1.74	2.04	0.19	1.56
3	3.6	33	89	2.76	0.48	1.76	1.95	0.38	1.57
4	4.8	34	91	2.71	0.45	1.85	1.91	0.36	2.04
5	4.9	33	92	2.75	0.44	1.83	2.02	0.37	2.05

Note: *Versions: 1. Without fertilization (control), 2.* N_{60}*; 3.* $N_{60}P_{60}$*; 4.* $N_{60}P_{60}K_{60}$*; 5.* $N_{60}P_{60}K_{60}$ *(drip)+* $N_{60}P_{60}K_{60}$ *(furrow).*

Table 6. Effect of fertilizers applied by drip and furrow methods on the growth, lignification, and content of NPK in the leaves, Trial No. 2*

Versions	Number of annual shoots	Average growth of shoots, cm	Lignification of annual shoots, %	Content of nutrients in leaves, % (average of two years)					
				Blooming stage			2nd decade of August		
				N	P_2O_5	K_20	N	P_2O_5	K_20
1	16.1	52	90	2.38	0.45	2.28	1.94	0.38	1.68
2	18.3	71	83	2.99	0.40	2.19	2.15	0.31	1.47
3	15.4	69	92	2.95	0.51	2.13	2.07	0.40	1.44
4	21.2	68	95	2.86	0.54	2.31	2.11	0.39	1.65
5	23.5	77	96	3.18	0.61	2.33	2.39	0.60	1.71

Note: *Versions: 1. Without fertilization (control), 2.* N_{120}*; 3.* $N_{120}P_{120}$*; 4.* $N_{120}P_{120}K_{120}$*; 5.* $N_{120}P_{120}K_{120}$ *(drip)+* $N_{120}P_{120}K_{120}$ *(durrow).*
*Composed by the authors.

First, the content of available nutrients in the soil of this trial was incomparably higher, which has occurred with fertilization through drip irrigation in the previous years. Secondly, according to our observations, part of the plant roots have grown in the inter-row spaces and are fed also by fertilizers applied through the furrow method.

Considering that the content of NPK in the plant leaves is closely related to the nutrient supply, it is possible to determine through leaf analysis the nutrient supply degrees as “weakly”, “averagely” and “strongly” supplied and determine the fertilization (nutrition) rates. Let us add that the methodology of determining the necessity of fertilization (nutrition) based on leaf analysis is widely used in European countries, the USA, and elsewhere (Fomenko, et al., 2018; Yagodin, 1987).

Conclusion

Based on the results of the fertilization trials in two- and six-year-old (starting to bear fruits) walnut orchards in 2021-2022, the following conclusions were made:

1. The natural supply of nitrogen, phosphorus, and potassium available for plants in brown forest carbonate soils in the Aygehat and adjacent communities, Lori marz, is very low, so there is a great need to apply appropriate fertilizers.

2. The soils in trials are significantly different from each other in terms of the content of mobile nitrogen, phosphorus, and potassium, since while establishing and further maintenance of the 6-year-old orchard, organic and mineral fertilizers were used. Thuswise, at the beginning of the trials, the soil in Trial No. 1 was poorly supplied

with nitrogen, phosphorus, and potassium available for plants, while the soil in Trial No. 2 was poorly supplied with nitrogen and well supplied with phosphorus and potassium at the depth of 0 cm-30 cm.

3. In the case of applying the water-soluble complex fertilizers through drip irrigation, they move with the water to deeper layers compared with the movement of fertilizers applied by the furrow method, although in both cases the moisture has gone down up to 80cm-90cm deep.

4. In the case of applying an effective fertilization system, the growth and lignification of shoots are enhanced, and the content of NPK increases in the leaves. The latter makes it possible to define through leaf analysis the supply of the particular nutrient at "week", "medium" and "good" levels and then determine the rates of fertilizer application, under the influence of which the plants enter the fruit bearing stage.

5. The effect of fertilizers applied by furrow method (from both sides of the row) on the growth of walnut, lignification of annual shoots, and the content of NPK in the leaves is noticeable only in the 6-year-old orchard (Trial 2), where the roots of the trees have spread to the interrows and are fed from those areas as well. Therefore, to enhance the efficiency of the producing orchards, in addition to the fertilization by drip irrigation, it is important to periodically perform also fertilization by the furrow method, with significantly cheaper, but effective fertilizers.

6. The results of the chemical analysis of the plant's leaves should be taken as a basis to define the fertilizer application rates.

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