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ORIGINAL PAPER

EFFECT OF NITROGEN FERTILIZATION ON YIELD OF GRAPES AND FERTILIZATION EFFICIENCY IN GISSAR VALLEY OF THE REPUBLIC OF TAJIKISTAN*

Marcin Niemiec[1], Maciej Chowaniak[2], Dagmara Zuzek[3], Monika Komorowska[4], Gulov Saidali Mamurovich[5], Kobil Kodirov Gafurovich[5], Nenmat Usmanov[6], Dilrabo Kamilova[7], Jamylia Rahmonova[7], Naim Rashidov[7]

[1] Department of Agricultural and Environmental Chemistry
[2] Department of Agrotechnology and Plant Production
[3] Department of Economy and Economic Policy
[4] Department of Vegetable and Medicinal Plants
University of Agriculture in Krakow, Poland
[5] Tajik Agrarian University named Shirinsho Shotemur, Dushanbe, Republic of Tajikistan
[6] Head of collective farm VATAN-2008, Republic of Tajikistan
[7] Polytechnic Institute of Tajik Technical University, named after M.S. Osimi, Republic of Tajikistan

Abstract

The issue of optimizing plant fertilization is important in quality systems, such as Integrated Plant Production, GLOBAL G.A.P., or SAI. Effective implementation of these systems depends on the use of a plant nutrition technology based on plants' nutrient demand. In developing countries, low efficiency production technologies are used very frequently, and a significant level of anthropogenic pressure is therefore observable. The objective of this research was to assess grapevine fertilization efficiency according to particular nitrogen fertilization strategies. Within the scope of the research, a two-factor field experiment was conducted in a commercial vineyard located in Gissar Valley, the Republic of Tajikistan, in 2018. The experiment was established on sandy soils and involved the following factors: the overall quantity of mineral nitrogen used, and the number of fertilizer application cycles (one or three). The designed systems were assessed on the basis of commercial yield, productivity ratio, agronomic efficiency ratio, removal

dr inż. Maciej Chowaniak, Department of Agrotechnology and Agricultural Ecology, University of Agriculture in Krakow, Al. Mickiewicza 21, 31-120 Kraków, Poland, e-mail: maciek.chowaniak@gmail.com
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efficiency ratio, and physiological efficiency ratio. The findings obtained from the field experiment indicate that the plant yield was the highest, at 24.85 Mg ha^{-1}, in the conventionally fertilized object, with the nitrogen dosage of 250 kg N ha^{-1}. Similar yield was obtained when the amount of nitrogen was divided into 3 doses. In this variant, the values of ratios representing fertilization efficiency, such as the agronomic efficiency ratio, removal ratio and productivity ratio, were the most beneficial as well. No significant variations were determined in respect of the physiological efficiency ratio value, which may be an indication that no factors occurred in any of the variants which would distort the plants' growth and development. Optimizing fertilization is an important aspect that defines the quality and safety of products of agricultural origin, especially in developing countries.

Keywords: nitrogen, fertilization, grape, yield, quality.

INTRODUCTION

Improvement of nitrogen fertilization efficiency is strategic to the agricultural growth, particularly in developing countries. The key aspect of a reasonable approach to biomass production, be it for food or for energy purposes, is the improved utilization of energy resources and organic carbon (Sikora et al. 2018, Szeląg-Sikora et al. 2019, Paluch et al. 2020). Fertilization of plants is an essential factor determining the product life cycles in the context of energy consumption and greenhouse gas emissions. Moreover, a proper approach to plant nutrition can alleviate the negative effects that farming has on the natural environment (Chowaniak et al. 2016). Inadequate fertilization may lead to increased susceptibility of plants to disease or pests; consequently, larger quantities of pesticides may need to be used (May-De-Miom et al. 2008). Those fertilizer components that are not used by plants are leached from soil and discharged to surface and underground waters, thus contributing to intensified eutrophication processes (Thomidis et al. 2016). In the case of vineyard farming, the issue of reasonable fertilization, particularly with nitrogen, is particularly important as most vineyards are situated on slopes; this type of location is conducive to the leaching of fertilizer components and to denudation. Furthermore, soils used for growing grapevine are very frequently characterized by low sorption capacity, which further increases the risk of fertilizer component losses in a low efficiency fertilization technology environment. In addition, excessively intensive fertilization stimulates the growth of shoots and leaves, thus reducing fruit yields and deteriorating the commercial quality of fruit.

Proper chemical composition of grapevine fruit determines its fitness for industrial purposes. In the climate and soil conditions typical of Tajikistan, where fertilizers are primarily applied to soil, there is a risk of insufficient nitrogen supply to plants. Therefore, it seems indispensable for contemporary grape production to use foliar fertilizers at specific stages of the production cycle, which is pointed out by Gutiérrez-Gamboa et al. (2018). These authors emphasize a more significant effect of foliar application of nitrogen on the development of fruit chemistry, as compared to fertilizer application to soil. At the moment, foliar fertilization is used in a very restricted scope in the territory of the Republic of Tajikistan, and the range of marketable fertilizer products for foliar application is very narrow. Therefore, optimization of fertilizer application to the soil should be sought for in order to optimize the production and environmental effects. A single application of mineral fertilizer is a standard production practice in the region of study, which is an agrotechnical mistake in terms of production optimization. The reason behind it is the inadequate development of agriculture, as well as the absence of market requirements regarding production with a limited effect on the natural environment. The climate in the Republic of Tajikistan is suitable for production of good quality grapes, yet in order to introduce these products into international markets, environmentally efficient production methods would have to be implemented. Therefore, research focused on improvement in the efficiency of production resource management in agriculture is an essential element of agricultural development. Implementation of environmentally and economically efficient production methods is a very important measure that determines the quality of agricultural products (Kocira et al. 2017).

The objective of the research project was to assess grapevine fertilization efficiency according to the overall quantity of nitrogen and the number of fertilizer doses during the plant growing season. The point of reference for the proposed fertilization methods was an object fertilized according to the production practice implemented in the vineyard chosen for the study.

MATERIALS AND METHODS

Field trial design and treatments

Within the scope of the research, a two-factor field experiment was conducted in a commercial vineyard located in the Hisor district, Republic of Tajikistan, in 2018. The vineyard is located in Gissar Valley (38°27′36.0″N 68°35′43.8″E). The climate, soil conditions and availability of water for watering are suitable for growing cotton, fruit and vegetables. The Tempranillo variety grapevine was planted in 2009. Monthly data for temperature and precipitation are presented in Figure 1. With the east-west orientation of rows, the planting was such that grapevine plants were spaced at 2.80 m x 1.20 m, with 3000 plants per hectare. The grapevine was grafted on 1103-Paulsen rootstock. The experiment was conducted on sandy loam. The soil properties are presented in Table 1. The vineyard was located at 335 m a.s.l. During the study year, the plants were irrigated six times, with the overall quantity of water equal 500 mm. Surface water was used for irrigation. The experiment involved the following factors: the overall quantity of mineral nitrogen used, and the number of fertilizer application

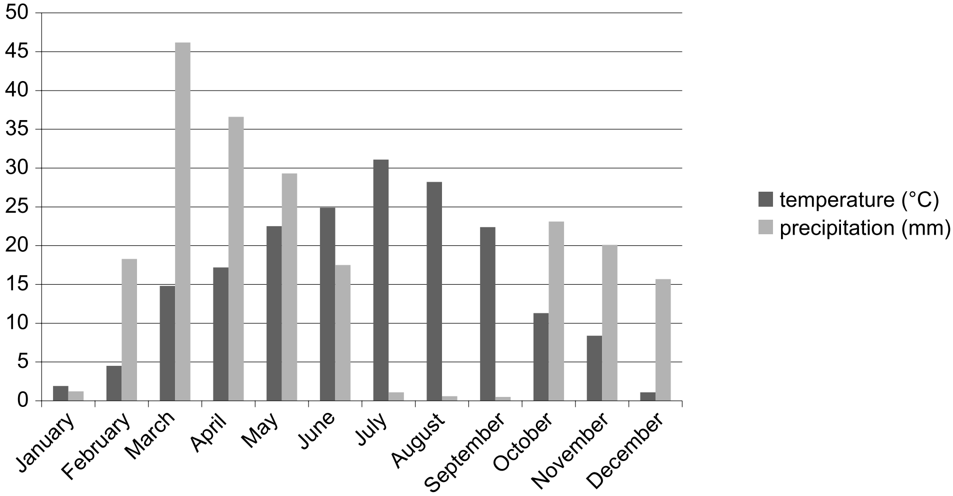

Table 1

Properties of the soil in the experiment

pH in H_2O	pH in KCl	N total	C org	N min	P	K	Mg	Ca
		(g kg^{-1})		(mg kg^{-1})				
6.48	6.36	1.145	20.07	23.11	109.6	228.6	113.4	1452

cycles. The plots were replicated three times, with each replication covering a surface area of 0.05 ha. Depending on the experimental scheme, nitrogen was applied with one dose (A1, B1, C1, D), ot with three doses (A2, B2, C2) 50% of the total dose in early spring, at the beginning of the vegetation period, followed by 25% of the dose at the onset of blooming and 25% of the dose after blooming. Potential production output for the location was estimated at 30 Mg fruit ha^{-1}. Nitrogen requirement for the expected yield was calculated at 140 kg N ha^{-1}. Single mineral fertilization before commencement of the plant growing period is common practice in the vicinity of the study location. Ammonium phosphate and ammonium nitrate, the most commonly used fertilizers in that region, were used for fertilization. The experimental design is presented in Table 2. Phosphorus and potassium application levels were in accord with the prevalent production practice in the study region.

Measurements

Grapes were taken from each plot for yield evaluation and chemical analysis. Total sugar content was determined in fresh samples of fruits. A total sugar assay was performed by the anthrone method as described by Yemm and Wills (1954). The nitrogen content in berries was determined by an elemental analysis on a Elementar Vario Max Cube. For the pur-

Table 2

Design of the experiment

Objects	Number of doses	Nitrogen dose (kg)	K dose (kg)	P dose (kg)
Control	0	0	0	0
A1	one-time fertilization	50	166	87
B1		100	166	87
C1		150	166	87
A2	three-time fertilization	50	166	87
B2		100	166	87
C2		150	166	87
D	fertilization according to prevailing production practice	250	249	87

poses of determining the partial factor productivity (PFP), the following formula was used (IFA 2007):

$$PFP = (\text{kg kg}^{-1}) = \frac{Y}{F},$$

Y – crop yield per unit,

F – N applied per unit.

To determine the agronomic efficiency coefficient (AE), the following formula was used (IFA 2007):

$$AE = (\text{kg kg}^{-1}) = \frac{Y - Y_0}{F},$$

Y – yield in treatments with added N fertilizers,

Y_0 – yield without addition of N fertilizer (control),

F – N applied.

Removal efficiency (RE) was determined using the following formula (IFA 2007):

$$RE = (\text{kg kg}^{-1}) = \frac{C}{F}\cdot$$

C – N removed with yield,

F – N applied.

Physiological efficiency (IFA 2007) was derived from the formula:

$$PE = (\text{kg kg}^{-1}) = \frac{Y - Y_0}{U - U_0},$$

Y – yield in treatments with added N fertilizers,

Y_0 – yield without addition of fertilizer (control),

U – N uptake in aerial crop in treatments with added N fertilizers,

U_0 – N uptake in aerial crop in treatments without addition of fertilizer (cotrol).

Statistical analysis

ANOVA was applied to analyze the results. The significance of mean differences among the objects was tested with a multiple comparison procedure, and the Tukey's range test was applied at a significance level of α=0.05. All analyses were performed in a statistical software package Statistica v. 12.0 (StatSoft Inc. Tulsa, USA).

RESULTS AND DISCUSSION

Grapevine is not a high nitrogen demand plant. Its requirement for this element is at approximately 120 kg N ha^{-1}. During the initial phase of grapevine growth, the plants would use the nitrogen collected in lignified parts. During that period, excessive nitrogen content may lead to nitrogen losses, particularly if coinciding with high precipitation or unreasonable watering. Inadequate grapevine nutrition further leads to varying nitrogen compound quantities in fruit, which has a determining effect on the fermentation processes. Excessively low nitrogen compound levels in grapes distort the alcoholic fermentation closing processes (Canoura et al. 2018). Use of ammonium salts as fermentation process additives generates ethyl carbamate, which is carcinogenic. The only effective way to increase the nitrogen content in grapes is through an appropriate fertilization technology, which facilitates reduced foliage and shoots growth, leading to an increase in fruit production (González-Santamaría et al. 2018). In terms of maintaining natural soil fertility and achieving high grape yields, it is essential to maintain high organic carbon content in the soil. Insufficient quantities of organic soil matter reduces microbiological diversity and significantly decreases the use of nitrogen from fertilizers by plants (Perez et al. 2018).

The study findings indicate a very low yielding potential of the site where the experiment was established. Fruit yield from the control object reached 6.425 Mg ha^{-1} (Table 3). Nitrogen fertilization at 50 kg, divided into three doses, led to increasing fruit yields by more than double as compared to the control object. Further increase of nitrogen dosage would cause the plants to yield more fruit. Nitrogen was evaluated as a yielding reduction factor for the proposed fertilization strategy, based on the study findings. It was found through the experiment that an increased frequency of treatments had a positive effect on yield. With nitrogen application divided into 3 doses, plant yielding increased by approximately 15%. Following the fertilization scheme consistent with the traditional practice followed by producers in the research project region, at 250 kg pure nitrogen, yields were achieved at 23.85 Mg ha^{-1}. Where the level of fertilization was the highest, yields were more than three times higher than those from the control object. Optimization of nitrogen application technologies is of special importance in the context of yield volumes, fruit quality, and impact on the natural environment.

Table 3

Yield, dry mass, sugar and nitrogen content in grapes

Objects	Yield	Sugar content	Dry mass	Nitrogen content
	(Mg ha^{-1})	(%)		
Control	6.425*a*	16.956*a**	19.02*a*	0.723*a*
A1	10.68*b*	18.26*b*	20.68*a*	0.958*b*
B1	15.95*c*	19.88*c*	22.11*b*	1.052*bc*
C1	19.35*d*	20.25*c*	20.45*a*	1.022*b*
A2	14.61*c*	17.99*b*	20.52*ab*	0.858*b*
B2	19.82*d*	19.53*c*	21.98*ab*	0.942*b*
C2	23.56*e*	21.22*d*	23.85*b*	1.117*c*
D	24.85*e*	21.51*d*	23.11*b*	1.168*c*

* Different letters mean statistically significant differences at the significance level p=0.05.

Grapevine fertilization optimization not only involves the level of fertilization but also the form of nitrogen fertilizer and the application method. Garde-Cerdán et al. (2014) discovered the impact of fertilization level on the quantity of amino acids of strategic importance in terms of quality. The findings from this study indicate that an increase of nitrogen application to grapevine had a positive effect on the nitrogen content in fruit. This content was at 0.723% in the products obtained from the control object, while the same ratios for the objects fertilized with nitrogen at 150 kg ha^{-1} were at 1.022% for a single application and 1.117% for nitrogen doses divided into 3 treatments, respectively. In the object fertilized according to the prevailing production practice, the nitrogen content in the fruit was at 1.168%. Single application of mineral fertilizer is a standard production practice in the region, which is an agrotechnical mistake in terms of production optimization. No statistically significant difference was determined in the nitrogen content between the objects that underwent one or three treatments. The nitrogen content in fruit yielded by plants fertilized according to the prevailing production practice (at 250 kg N ha^{-1}) was comparable to that from the plot fertilized at 150 kg N ha^{-1}. Sugar content is a strategic parameter that defines the quality of grapevine fruit. Sugar affects the fermentation processes during wine production and determines the flavour. Sugar content in fruit is a product of weather conditions, water availability, and plant nutrition levels. The irrigation rates were at 500 mm during the vegetation season. The total volume of water used for watering exceeded the needs of the plants, which could have had an adverse effect on the quality of fruit. Watering is a very important part of agricultural engineering, which determines the levels of acidity, sugar contents, and anthocyanin content (Ju et al. 2019). The cited authors point to possible increases of these values during a periodical water shortage in grapevines designed for wine production.

For production economics, the productivity ratio is the key parameter in an assessment of the production system. This ratio indicates the yield per 1 kg of the element in the form of fertilizer. Accomplishment of optimized productivity ratio values is based on a fertilization scheme with quantities applied corresponding to the plants' needs, based on the expected yield volume. Yield volume is assessed on the basis of the production potential of the site, depending on the soil fertility, water availability, weather condition trends during and outside the vegetation period, light quantity derived from solar radiation, and microclimate details (CILEK, BERBEROGLU 2019). The productivity ratio illustrates the efficiency of production resource utilization in specific production conditions (MOHAMMADI et al. 2019, SZELĄG-SIKORA et al. 2019). Optimization of a fertilization strategy may lead to an improvement of fertilizer component utilization by as much as several dozen per cent. Ding et al. (2018) note that with the use of slow-action fertilizers, the productivity ratio for nitrogen application to rice cultivation in China was even 40% higher than that achieved with conventional fertilization. Under excessive application, the productivity ratio decreases, which may involve deterioration of the commercial quality of yield (NIEMIEC et al. 2015b).

Based on this experiment, the calculated value of the productivity ratio ranged from 88.84 to 292.2 kg kg^{-1} for the applied nitrogen fertilization scheme (Table 4). The highest value of this ratio was determined on the site fertilized at 50 kg mineral nitrogen, yet the yield achieved in this variant was at approximately 30% of the site's potential output. The value of this ratio was the lowest in the variant fertilized conventionally, in accordance with the dominant production practice in the region. The study findings indicate statistically significant differences between the productivity ratios from objects fertilized with three instead of one dose of nitrogen. Considering

Table 4

Production efficiency ratios for particular variants of the experiment

Objects	Partial factor productivity (kg f.m. kg^{-1} N)	Agronomic efficiency (kg d.m. kg^{-1}) fertilizer applied	Removal efficiency (kg N kg^{-1} N) applied	Physiological efficiency (kg d.m. kg^{-1}) fertilizer applied
A1	213.6*d**	17.62*a*	0.423*bc*	87.99*a*
B1	159.5*bc*	21.07*b*	0.371*b*	83.46*a*
C1	129.0*b*	17.63*a*	0.270*ab*	87.25*a*
A2	292.2*d*	33.61*c*	0.514*c*	105.2*b*
B2	198.2*c*	29.45*c*	0.410*b*	97.34*b*
C2	157.1*b*	27.25*b*	0.418*bc*	81.54*a*
D	88.84*a*	15.45*a*	0.243*a*	77.77*a*

* Different letters represent statistically significant differences at the confidence level p=0.05
f.m. – fresh mass, d.m. – dry mass.

the yield, the productivity ratio was most advantageous on the site where nitrogen dose was divided into three parts and applied three times. Kafesu et al. (2018) emphasize that farming systems can only be assessed on the basis of the productivity ratio in coordination with yields and taking into account the potential output of the specific production site. Niemiec et al. (2015*a*) reported productivity values for growing celeriac at 151 kg N kg product dry mass, having applied slow-release fertilizers. On the other hand, Zhang et al. (2016) achieved the productivity values for corn at 29.19 kg N kg^{-1} with the use of biocarbon as a fertilizer improvement additive. The value of this ratio on the site where no biocarbon was added was only 17.38 kg N kg^{-1}. Li et al. (2012) were able to more than double the value of the productivity ratio where nitrogen fertilizers were applied under roots, as compared to traditional application.

Agronomic efficiency indicates the increase of plant yields achieved when 1 kg of a specific nutrient in the form of fertilizer is used. The most common values of this ratio for intensive farming range from 40 to 80 kg kg^{-1} dry weight of yield (IFA 2007). A very high level of this ratio may indicate insufficient utilization of the site's production potential. In well-managed farming systems, the value of this ratio is typically above 60 kg product dry mass per kg of nitrogen $applied^{-1}$. Lower values of the agronomic efficiency ratio may indicate unreasonable mineral fertilization or very high content of mineral nitrogen in the soil, as pointed out by Niemiec et al. (2015*b*). Depending on the quantity of nitrogen used and the application strategy, the agronomic efficiency value in this study varied from 15.45 kg dry mass kg^{-1} N to 33.61. (Table 4). The value of this ratio was found to be the lowest in the plot fertilized in the conventional manner, in accordance with the prevailing production practice in the region. The value of the agronomic efficiency ratio was insignificantly higher after a single application of mineral fertilizers, irrespective of the nitrogen dosage. With nitrogen application divided into three doses, agronomic performance almost doubled compared to conventional fertilization. The values of agronomic efficiency factors determined in the variants with optimized fertilization were higher than typically recorded in agricultural systems of developing countries. Xu et al. (2017) indicate that this ratio in primitive farming systems is approximately 13 kg dry mass kg^{-1} N, which is comparable to the values determined in our study from the conventionally fertilized site. Kafesu et al. (2018) present agronomic efficiency values for corn at approximately 20 kg product dry mass kg^{-1} N when grown on low agricultural use soils. On the other hand, Niemiec et al. (2015*a*) present the value of this parameter in conventional celeriac farming at about 20 kg of product dry mass kg^{-1} N applied in a mineral fertilization scheme. With low performing agricultural methods, improvement of agronomic efficiency can be reached up to several dozen per cent in many areas worldwide through minor modifications of fertilization technologies based on optimization of fertilization techniques adapted to climate and soil conditions, as well as other agrotechnical treatments, such as watering (An et al. 2018).

Fertilizer element removal efficiency is the most essential indicator used to assess the effect of fertilization on the natural environment (Nardi et al. 2017. The average values of this parameter in our experiment ranged from 0.243 to 0.514 (Table 4). The value of this ratio was found to be the lowest in the variant fertilized in accordance with the production practice. There, only 25% of nitrogen introduced to the soil environment was removed together with the fruit yield. The fertilization strategy supplying 150 kg mineral nitrogen divided into 3 doses turned out to be the best for the natural environment. The same quantity of nitrogen applied once led to halving of the removal factor value. Dispersion of nitrogen compounds in the environment is among the most frequently identified adverse effects of agricultural activities. Vinzent et al. (2018) quote the nitrogen removal values from rapeseed fields in the range of 0.45 to 0.54 kg N kg^{-1} when nitrogen is applied in the form of mineral fertilizers, depending on the addition of urease inhibitors. These authors note the significant potential of slow-action fertilizers in the process of reducing eutrophication of waters and emissions of greenhouse gases to the atmosphere. Better nitrogen utilization potential for nitrogen applied in the form of slow-action fertilizers was also observed by Niemiec et al. (2015*a*, *b*), Purnomo et al. (2018). Our research findings indicate a major potential for modifying a fertilization scheme so as to improve nitrogen removal efficiency. If the optimization of watering and application of slow-action fertilizers were introduced, it would probably facilitate further improvement of performance ratios for the studied agricultural systems. High values of the removal ratio represent good nitrogen utilization from fertilizers and from soil resources. However, this ratio should always be assessed together with yield volumes. Where yields fell significantly below the production potential of the site, a high value of the removal ratio may indicate a deficit of nitrogen.

The physiological efficiency ratio illustrates the plant growth conditions, including the parameters of climate aspects, soil fertility, plant production potential, fertilization policy and plant protection strategies. Low values indicate the presence of a stressor that reduces the growth of plants. The value of the physiological efficiency ratio does not provide sufficient information to determine the actual causes of the problem, yet it is a reliable indication concerning the agricultural system performance. The values of the physiological efficiency ratio for the fertilization variants tested in this experiment did not vary significantly, from 77.77 to 105.2 kg of fruit dry mass kg^{-1} nitrogen consumed by plants with nitrogen fertilizers (Table 4). The lowest value was obtained for traditional fertilization, according to the prevailing production practice, while the highest value was achieved for nitrogen application at 50 kg N ha^{-1} in three doses. In terms of this parameter, no statistically significant differences were detected across all experimental variants. This suggests the absence of a stressor during the plant growing season.

Improving the efficiency of fertilization is one of the strategic components of contemporary agriculture development. In poorly developed farming systems, a major increase of fertilization efficiency can be obtained by introducing minor modifications in the production process. The outcome of increased fertilization efficiency is higher production s well as better economic and environmental performance of agriculture. Optimized fertilization is important for yield quality in the context of food safety and mitigating negative effects that farming has on the natural environments. Both the safety of food products and the level of anthropogenic pressure exerted in relation to food production constitute quality, defined as a set of product qualities required by consumers, particularly from developed countries. Therefore, increasing fertilization efficiency is a very important reason justifying implementation of quality systems, which are indispensable for food export growth. Therefore, from both the scientific and production practice perspective, it is essential to continue research that leads to the development of such fertilization technologies which would reduce the volume of elements introduced to the soil ecosystems and at the same time facilitate the accomplishment of high, good quality yields.

CONCLUSIONS

1. Optimizing fertilization is an important aspect that defines the quality and safety of products of agricultural origin, especially in developing countries.

2. Owing to the optimization of a fertilization technology achieved by increasing the number of nitrogen treatments, total nitrogen dosage could be reduced by 40% with only a minor decrease in plant yields.

3. The highest sugar content in grapevine fruit was obtained in the conventionally fertilized plots, at 250 kg ha^{-1}, and for nitrogen applied at 150 kg ha^{-1} divided into 3 doses.

4. The values of the productivity ratio, agronomic efficiency ratio and removal ratio were the highest for nitrogen application at 50 kg ha^{-1} divided into doses.

5. Concerning yield volumes, the most positive effects on production and environmental influence were accomplished with nitrogen application at 150 kg ha^{-1} divided into 3 doses.

REFERENCES

An N., Wei W., Qiao L., Zhang F., Christie P., Jiang R., Dobermann A., Goulding K.W.T., Fand J., Fan M. 2018. *Agronomic and environmental causes of yield and nitrogen use efficiency gaps in Chinese rice farming systems.* Eur. J. Agron., 93: 40-49. DOI: 10.1016/j.eja.2017.11.001

Chowaniak M., Klima K., Niemiec M. 2016. *Impact of slope gradient, tillage system, and plant cover on soil losses of calcium and magnesium.* J. Elem., 21(2): 361-372. DOI: 10.5601/ /jelem.2015.20.2.873

Cilek A., Berberoglu S. 2019. *Biotope conservation in a Mediterranean agricultural land by incorporating crop modelling*. Ecol. Model., 392: 52-66. DOI: 10.1016/j.ecolmodel.2018.11.008

Ding W., Xu X., He P., Ullah S., Zhang J., Cui Z., Zhou W. 2018. *Improving yield and nitrogen use efficiency through alternative fertilization options for rice in China: A meta-analysis*. Field Crop. Res., 227: 11-18. DOI: 10.1016/j.fcr.2018.08.001

Garde-Cerdán T., López R., Portu J., González-Arenzana L., López-Alfaro I., Santamaría P. 2014. *Study of the effects of proline, phenylalanine, and urea foliar application to Tempranillo vineyards on grape amino acid content. Comparison with commercial nitrogen fertilisers*. Food Chem., 163(15): 136-141. DOI: 10.1016/j.foodchem.2014.04.101

Gutiérrez-Gamboa G., Marín-San Román S., Jofré V., Rubio-Bretón P., Pérez-Álvarez E.P., Garde-Cerdán T. 2018. *Effects on chlorophyll and carotenoid contents in different grape varieties (Vitis vinifera* L.*) after nitrogen and elicitor foliar applications to the vineyard*. Food Chem., 269: 380-386. DOI: 10.1016/j.foodchem.2018.07.019

IFA 2007. *Sustainable management of the nitrogen cycle in agriculture and mitigation of reactive nitrogen side effects*. International Fertilizer Industry Association. Paris, 32, ISBN 2-9523139-1-1

Ju Y., Yang B., He S., Tu T., Min Z., Yu-linFang Y., Xiang-YuSuna X. 2019. *Anthocyanin accumulation and biosynthesis are modulated by regulated deficit irrigation in Cabernet Sauvignon (Vitis vinifera* L.*) grapes and wines*. Plant Physiol. Bioch., 135: 469-479. DOI: 10.1016/j.plaphy.2018.11.013

Kafesu N., Chikowo R., Mazaruraa U., Gwenzi W., Snapp S., Zingored S. 2018. *Comparative fertilization effects on maize productivity under conservation and conventional tillage on sandy soils in a smallholder cropping system in Zimbabwe*. Field Crop Res., 218: 106-114. DOI: 10.1016/j.fcr.2018.01.014

Kocira S., Kuboń, M., Sporysz M. 2017. *Impact of information on organic product packagings on the consumers decision concerning their purchase*. 17th Int. Multidisciplinary Scientific GeoConference SGEM 2017. Conf. Proc., 17(52): 499-506. DOI: 10.5593/sgem2017/52/S20.064

Li L., Liu Y., Lou S., Peng X. 2012. *Effects of nitrogen management on the yield of winterwheat in coldarea of northeastern China*. J. Integr. Agr., 11(6): 1020-1025. DOI: 10.1016/S2095--3119(12)60094-X

Mohammadi A., Sina Besharat S., Abbasi F. 2019. *Effects of irrigation and fertilization management on reducing nitrogen losses and increasing corn yield under furrow irrigation*. Agr. Water Manage., 213: 1116-1129. DOI: 10.1016/j.agwat.2018.11.007

May-De-Miom L.L., Tutidam I., Mottam A.C.V., Dolinskim M.A., Serrat B.M., Monteguti D. 2008. *Rate of application of nitrogen and potassium in relation to brown rot and scab in plum 'Reubennel' in the region of Araucaia, Parana*. Trop. Plant Pathol., 33: 35-40. DOI: 10.1590/S1982-56762008000100006

Niemiec M., Cupiał M., Szeląg-Sikora A. 2015*a*. *Evaluation of the efficiency of celeriac fertilization with the use of slow-acting fertilizers*. Agric. Agric. Sci. Proc., 7: 177-183. DOI: 10.1016//j.aaspro.2015.12.014

Niemiec M., Cupiał M., Szeląg-Sikora A., 2015*b*. *Efficiency of celeriac fertilization with phosphorus and potassium under conditions of integrated plant production*. Agric. Agric. Sci. Proc., 7: 184-191. DOI: 10.1016/j.aaspro.2015.12.015

Paluch Ł., Niemiec M., Mudryk K., Chowaniak M., Komorowska M. 2020. *The use of fertilizer produced from coal combustion by-products as a part of sustainable management of waste materials*. In: *Renewable Energy Sources: Engineering, Technology, Innovation*: ICORES 2018. Wróbel M., Jewiarz M., Szlęk A. (Eds.). Springer Proceedings in Energy, 311-322. DOI: 10.1007/978-3-030-13888-2_31

Perez L., Morugán-Coronado A., McMillan M., García-Orenes F. 2018. *Restoration of nitrogen cycling community in grapevine soil by a decade of organic fertilization*. Soil Till. Res., 179: 11-19. DOI: 10.1016/j.still.2018.01.007

Szeląg-Sikora A., Sikora J., Niemiec M., Gródek-Szostak Z., Kapusta-Duch J., Kuboń M., Komorowska M., Karcz J. 2019. *Impact of integrated and conventional plant production on selected soil parameters in carrot production.* Sustainability-Basel, 11(20): 5612. DOI: 10.3390/su11205612

Thomidis T., Zioziou E., Koundouras S., Karagiannidis C., Navrozidis I., Nikolaou N. 2016. *Effects of nitrogen and irrigation on the quality of grapes and the susceptibility to Botrytis bunch rot*. Sci Hortic., 212: 60-68. DOI: 10.1016/j.scienta.2016.09.036

Xu X., He P., Yang F., Ma J., Pampolino M.F., Johnston A.M., Zhou W. 2017. *Methodology of fertilizer recommendation based on yield response and agronomic efficiency for rice in China.* Field Crop. Res., 206: 33-42. DOI: 10.1016/j.fcr.2017.02.011

Yemm E. W., Wills A. J. 1954. *The estimation of carbohydrates in plant extracts by anthrome.* J. Biochem., 57: 508-514.

Zhang D., Pan G., Wu G., Kibue G.W., Li L., Zhang X., Zheng J., Zheng J., Cheng K., Joseph S., Liu X. 2016. *Biochar helps enhance maize productivity and reduce greenhouse gas emissions under balanced fertilization in a rainfed low fertility Inceptisol.* Chemosphere, 142: 106-113. DOI: 10.1016/j.chemosphere.2015.04.088