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Impact of NPK fertilization on hazelnut yield and soil chemical-microbiological properties of Hazelnut Orchards in Western Georgia

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Abstract

In this study, the effects of ground and foliar applications of the NPK fertilizers in hazelnut orchards on the soil chemical and microbiological properties and hazelnut yield were investigated. The fertilization practicesses from ground were done two times using NPK (20:10:10 +trace elements) on March and May while the fertilization practices from leaf were done three times using NK (15:12 +trace elements) on May, June and July at six different hazelnut orchards located on Samegrelo, Guria and Adjara regions in Western Georgia in 2018. The alkaline characterized fertilizer applications from soil generally increased soil reaction (pH), nutrient contents and EC values in different magnitude depends on the soil characteristics of locations. The lowest soil pH (4,40) and EC (0,107 dS m^{-1}) values showed the highest increment (10,7% and 77,6%, respectively) over the control. The basal soil respiration and C_{mic} values of all hazelnut orchards were generally increased by the NPK ferilization. Increasing soil pH and EC by the fertilization also increased CA and DHA activity. The mean values of percent increase in yield and yield parameters by the NPK fertilization were obtained as 8,3% in yield, 13,3% in shelled nut weight, 10,0% in kernel weight and 5,1% in percent kernel efficiency. The hazelnut yield value had significant positive correlation with soil pH (0,669*), EC (0,652*) and C_{mic} (0,620*) values. The foliar fertilization and improving the soil properties of hazelnut orchards by the application of alkaline characteristic NPK fertilizer from soil increased hazelnut yield and yield parameters compare with the farmer applications or control treatments. The increments in soil microbiological properties and nutrients are considered as a desirable result in terms of sustainable soil management and plant nutrition for hazelnut orchards.

Keywords: Hazelnut, soil, fertilization, microbiological properties

Introduction

Hazelnut is one of the most widely cultivated hard-shelled fruit in the world. The main top of the hazelnut producer countries are Turkey, Italy, Spain, USA, Georgia, Azerbaijan, China, Iran, Chile, Australia and France. The world hazelnut production has come close to one million tons in recent years. Hazelnut cultivation in Georgia is carried approximately 26 thousand hectares. Hazelnut plantations occupied 8-10 times more territory than in Soviet times and it has a high economic value for Georgia which exportes hazelnuts to the EU countries in large quantities. The hazelnut production is mainly taking place in Western Georgia, including Samegrelo, Guria, Adjara, and Imereti regions (Mirotadze, 2004). Agricultural productivity, which is influenced by many factors such as climate, irrigation, fertilization, cultural practices and soil quality, is

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ensured by the optimum formation of multifaceted conditions. Especially in hazelnut cultivation, where cultural practices are utilized at a minimum, the importance of agricultural practices increases still more. Moreover, in recent years, hazelnut came to bear great importance as raw material for the food industry besides its quality as an agricultural product. Increasing the efficiency and quality values of hazelnut, which is an important export product of Georgia, is also vital for meeting the economic needs of the regional producer (Mirotadze, 2004; Chanishvili, 2019).

In hazelnut farming, producer characteristics, agricultural production practices, productivity parameters need to be established together. Fertilization activities carried out in hazelnut fields change all soil properties and will contribute to improvement of yield. Olsen et al. (2000) studied the effect of isotopically labeled nitrogen on the uptake, storage, and remobilization of N in hazelnut trees for both ground and foliar N applications at various timings. They reported that hazelnut trees rely heavily on stored N reserves to fuel leaf and nut production and new growth in early spring, and also ground application of N in June was less efficient than March applications. Bignami et al. (2004) reported that in the adult hazelnut orchard, nuts represented 46% of the biomass and the highest N content in the leaves is in spring, it reduces during the growing season and N accumulation in shoots startes only after harvest. Snare (2008) indicated that hazelnuts benefit from a balanced nutritional program such as annual applications of a complete NPK fertilizer and N, K, B are the elements most commonly found deficient in hazelnuts. Tous et al. (2004) reported that in a mature hazelnut orchard in north-east Spain, the greater amount of N (100 kg N/ha) resulted in significantly lower production and kernel yield from hazelnut trees, whereas a B foliar and Fe chelate treatment increased production. Applying 50 kg N/ha when the leaf N level was about 2.4% of the dry mass in July and two B foliar sprays with soil Fe chelates in spring was the optimum fertilization obtaining higher production and better nut quality. Nicolosi et al. (2009) studied the effect of foliar fertilization on hazelnuts growing with applying a 8.5% organic nitrogen fertilizer and an NPK fertilizer (20:20:20) plus chelated micro-elements (3%) at three different times during the vegetation. Treatments had significantly higher kernel weight and nut size as compared to the control plants. Wei and Zhai (2010) found that the NPK contents in the hazelnut fruit continued to increase from kernel growth stage till nut maturity stage, in which the P content in the hazelnut fruit decreased dramatically due to the great consumption in the kernel development and less absorption. They reported that NPK in fruits had a significant or very significant positive correlation in the development course of hazelnut fruit and there was a dynamic equilibrium of coordination among the three elements.

Many studies were conducted in order to sustain hazelnut farming and increase productivity. Works aimed at improving the efficiency of soils often take into account the physical and chemical properties of the soils, but biological properties are as important and often ignored. Soil fertility is not only dependent on the physical conditions of the soil and the level of nutrients, but also closely related to the density of biological phenomena. The biological characteristics of soils are an important indicator of soil fertility, and also soil health and quality. Ding et al. (2016) reported that soil microbial community size was enhanced by the application of inorganic fertilizer and manure. They found that aoil microbial diversity was decreased by inorganic fertilizer and increased by the incorporation of inorganic fertilizer with manure. Basal soil respiration represents a fundamental component of the soil carbon cycle (Raich and Schlesinger, 1992) and is an indicator of soil carbon storage, soil biological activity and overall soil quality (Ewel et al., 1987). In general, soil respiration depends on the respiration of plant roots and soil microorganisms. Environmental factors such as soil temperature and soil humidity are known to have a significant effect on the seasonal dynamics of soil respiration (Lloyd and Taylor, 1994). Microbial biomass C plays a crucial role; as it is a much easier and faster determining method than microscopes or other coating methods in determining the mass of bacterial and fungal populations; and in terms of its effect on the disintegration of organic matter (Powlson and Brookes, 1987) and, in relation to it, the continuity of the nutrient cycle (Jenkinson and Parry, 1989).

The objective of this study was to investigate the changes in hazelnut yield, soil chemical and microbiological properties as a result of the ground and foliar applications of the NPK fertilizers in hazelnut orchards located on different regions in Western Georgia.

Material and Methods

Study sites

This study was carried out at the hazelnut orchards located on Samegrelo, Guria and Adjara regions in Western Georgia with different topographical positions in 2018 (Figure 1). The hazelnut orchards were selected for consistency in soil texture (clay to sandy clay loam) and slope (0–3%). The six different hazelnut orchards were on acidic soils and not irrigated. All sites have a history of chemical fertilizer use (e.g., diammonium phosphate, triple super phosphate and calcium ammonium nitrate) and pesticide applications for 10–15 years. During the field experiment, monthly precipitation and average temperature for the experimental locations are given in Figure 2. After transporting the soil samples to the laboratory, they were prepared for analysis by drying under shade, removing crop roots and stones by hand, smashing and sieving from a sieve having 2mm size opening. The soil physico-chemical properties were determined based on standard methods as follows: particle size distribution by the hydrometer method (Bouyoucos, 1962), $CaCO_3$ content by the volumetric method (Martin and Reeve, 1955), pH in 1:1 (w/v) in soil: water suspension by pH - meter (Rowell, 1996), electrical conductivity (EC) in the same soil suspension by EC - meter (Rowell, 1996). Whole soil samples were sieved through a 150 μm mesh to determine the total organic matter (SOM) by the wet oxidation method (Walkley-Black) with $K_2Cr_2O_7$ (Rowell, 1996).

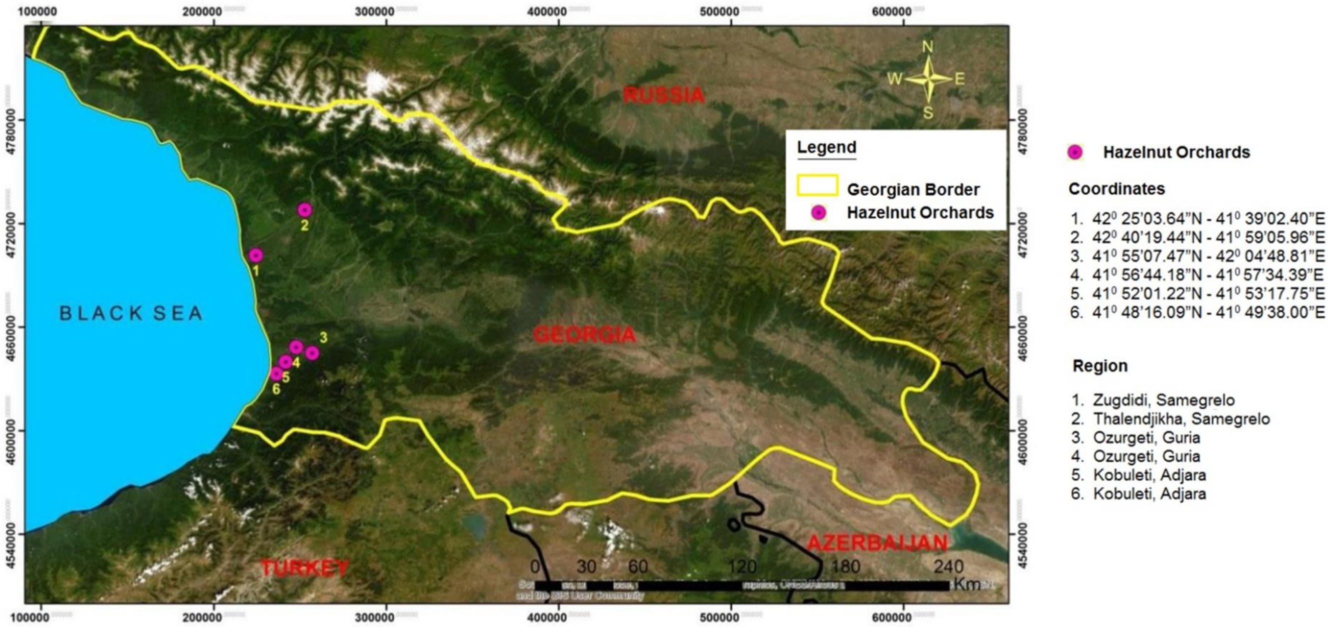


Figure 1. Locations of the hazelnut orchards

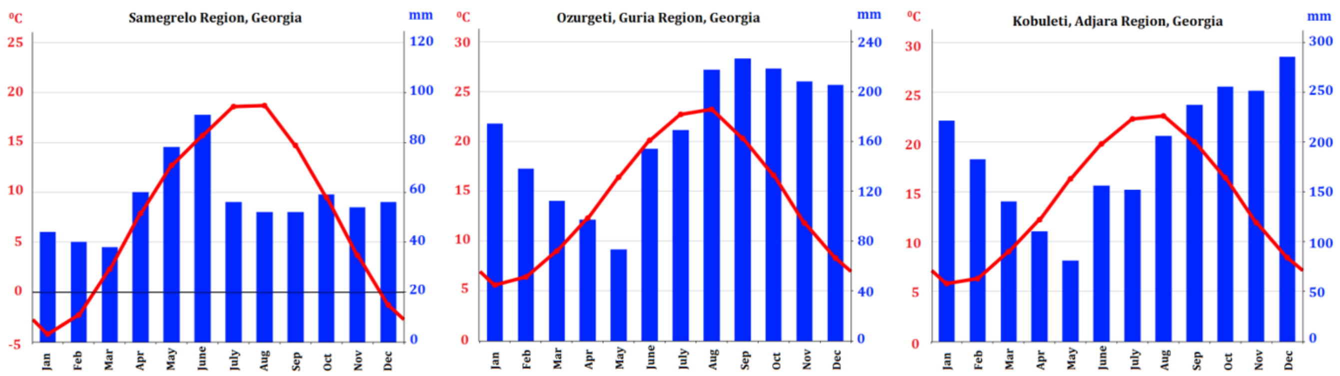


Figure 2. Montly average values of precipitation and temperature in the three locations of Western Georgia.

Fertilizers used in this study

The fertilizers used in this study were produced spesifically for hazelnut plant. The specific properties of the fertilizers are given below;

The fertilizer produced for soil application contains 20% N, 10% P_2O_5 and 10% K_2O (+trace elements): i) pH is over 7.50, and helps to neutralize soil acidity if regularly used, and helps to reduce or remove using "Agricultural Lime" in acidic soils, ii) It is a slow release fertilizer, melts easily and difficult to leach from soil profile, iii) It can provide essential nutrients for the hazelnut plant for a vegetation period if application is made in correct dose and timing.

The fertilizer produced for foliar application contains 15% N, and 12% K_2O (+trace elements): i) The pH level in the application dose are adjusted between 5.0-5.5 at that pH the leaf absorption is the highest, ii) The foliar fertilizer can be used with other physiological acid reaction pesticides such as hazelnut worm, which greatly harms the hazelnut plant, iii) The fertilizer is solid and completely melts in water solution, does not leave any residue/remnants in the fertilizer/disinfection engine, iv) Microelement contents within the fertilizer are chelated with EDTA to uptake esily by the plant and to get a greater effect.

Experimental design

Both fertilizations from soil and leaf were used in this experiment. The details of soil and foliar fertilization are given below.

Fertilization from ground: NPK (20:10:10 + trace elements) fertilizer was applied to band in two different period as follow; the first application was made at the end of February- start of March as 1000 g/tree (includes 12 or 15 hazelnut plants in each tree) (250 kg/ha for row planting) and the second application was made at the end of May and start of June; 750 g/tree (200 kg/ha for row planting).

Fertilization from leaf: The foliar fertilization was applied three times in the following periods: 500 g/100 L within April, 750 g/100 L at the end of May and 750 g/100 L at the end of June - start of July.

The experiments were conducted in six different hazelnut orchards located in Samegrelo, Guria and Adjara Regions of Georgia. In each hazelnut orchard, 80 hazelnut trees (about 0,2 ha) were fertilized from soil and leaf in the recommended doses and periods given above. The yield and yield parameters (shelled nut weight, kernel weight and percent kernel efficiency) of hazelnut fertilized both from soil and leaf were determined and compared with the trees under the routine fertilization by the farmers used as a control treatments during the harvest. Percent kernel efficiency was estimated with dividing the kernel weight by the shelled nut weight. At the end of the harvest, soil samples were taken from the hazelnut orchards in each location. The following analyses were made in the soil samples.

Soil nutrient contents and some chemical properties

To analyze of some nutrient contents and chemical properties of soil samples, crop residues, root fragments and stones larger than 2 mm had been removed from air-dried soil samples and stored at room temperature after passing from 2 mm sieve. Soil nutrient contents were determined by the following methods: total N content was determined by digestion and subsequent measurement by the Kjeldahl method (Bremner, 1965), available P content was determined by 0.03 M NH_4F (Bray and Kurtz, 1945), exchangeable Ca, Mg, Na, K contents were determined by 1N NH_4OAc extraction (Rowell, 1996), pH was detrmined in 1:1 (w/v) in soil:water suspension by pH - meter (Rowell, 1996), electrical conductivity (EC) was determined in the same soil suspension by EC - meter (Rowell, 1996).

Soil microbiological characteristics

Basal soil respiration: Basal soil respiration (BSR) at field capacity (CO_2 production at 22°C without addition of glucose) was measured, as reported by Anderson (1982); by alkali ($Ba(OH)_2.8H_2O$ + $BaCl_2$) absorption of the CO_2 produced during the 24h incubation period, followed by titration of the residual OH^- with standardized hydrochloric acid, after adding three drops of phenolphthalein as an indicator. Three replicates of each sample were tested. Data was expressed as µg CO_2-C g^{-1} dry soil sample.

Microbial biomass carbon: Microbial biomass carbon (Cmic) was determined by the substrate-induced respiration method by Anderson and Domsch (1978). A moist soil sample equivalent to 100 g oven-dry soil was amended with a powder mixture containing 400 mg glucose. The CO_2 production rate was measured hourly using the method described by Anderson (1982). The pattern of respiratory response was recorded for 4 h. Microbial biomass carbon (Cmic) was calculated from the maximum initial respiratory response in terms of mg C g^{-1} soil as 40.04 mg CO_2 g^{-1} +3,75. Three replicates of each soil sample were tested. Data was expressed as mg CO_2-C 100 g^{-1} dry soil 1 h^{-1}.

Dehydrogenase activity: Dehydrogenase activity (DHA) was determined according to Pepper et al. (1995). Six grams of soil, 30 mg glucose, 1 ml of 3% 2,3,5-triphenyltetrazoliumchlorid (TTC) solution and 2.5 ml pure water were added. The samples were incubated for 24 h at 37°C. The formation of 1, 3, 5 triphenylformazan (TPF) was determined spectrophotometrically at 485 nm, and the results were expressed as µg TPF g^{-1} dry sample.

Catalase activity: Catalase activity (CA) was measured by the Beck method (Beck, 1971). Ten ml of phosphate buffer (pH, 7) and 5 ml of a 3% H_2O_2 substrate solution were added to 5 g of soil. The volume (ml) of O_2 released within 3 minutes at 200°C was determined. Three replicates of each sample were tested, and controls were tested in the same way, but with the addition of 2 ml of 6.5% (w/v) NaN_3. Results were expressed as ml O_2 g^{-1} dry soil.

The relationships between hazelnut yield parameters and the other factors were determined using the statistical software package SPSS. The relationships between soil microbiological and chemical properties were also estimated mainly by using principal component analysis.

Results and Discussion

Some soil properties of the orchards

The soil properties of hazelnut orchards are given in Table 1. Although the soil properties in the orchards show great differences in texture and organic matter content, all soils have acidic reactions (<6.5), nonsaline (<0.980 dS m^{-1}), and low in lime content ($CaCO_3$ < 5%).

Table 1. Some soil properties of the hazelnut orchards

Location Numbers of hazelnut orchards		Particle size distribution				$CaCO_3$,	pH	EC,	SOM,
		Clay, %	Silt, %	Sand, %	Class	%	(1:1)	dS m^{-1}	%
1L:	Zugdidi, Samegrelo	18,80	31,96	49,24	L	3,62	5,51	0,847	0,97
2L:	Thalendjikha, Samegrelo	43,15	37,70	19,15	C	3,22	4,54	0,618	1,58
3L:	Ozurgeti, Guria	19,65	21,20	59,15	SL	3,42	6,01	0,445	2,77
4L:	Ozurgeti, Guria	38,79	29,29	31,92	CL	3,30	4,40	0,107	3,54
5L:	Kobuleti, Adjara	39,66	23,51	36,83	CL	2,84	4,78	0,349	1,79
6L:	Kobuleti, Adjara	22,99	20,27	56,74	SCL	2,37	4,54	0,532	5,67

Effect of both soil and foliar fertilization on nutrient contents and some chemical soil soil properties of the hazelnut orchards comparing with the farmer applications as a control are given in Table 2. The fertilizers applied from soil generally increased soil nutrient contents and EC values. Also, the soil fertilizer having a physiological alkaline reaction increased soil pH. The 4th location having the lowest soil pH (4,40) and EC (0,107 dS m^{-1}) values showed the highest increment (10,7% and 77,6%, respectively) over the control by the fertilization.The 3rd location having a coarse soil textuture class (SL) had the highets increment in av. P (192,8%) and exch. K (54,8%) contents over the control by the fertilization. The highest increase in total N (26,1%) over the control was observed in the 2nd location including clay texture and low soil OM content. The increments in soil nutrients compared with control applications are considered as a desirable result in terms of sustainable soil management and plant nutrition for hazelnut orchards. Adeniyan et al. (2011) determined that the application of NPK (15:15:15) fertilizer enhanced availability of soil nutrients and cation exchange capacity considerably in acid soils and increased dry matter of maize. Wang et al. (2015) reported that soil nutrient contents with application of chemical fertilizers were generally significantly higher than those of the control without fertilization.

Table 2. The effect of fertilization on nutrient content and chemical properties of hazelnut orchard soils

Location No of the orchards		pH (1:1)	EC, dS m^{-1}	Total N, %	Av. P, mg kg^{-1}	Exchangeable cations, cmol kg^{-1}		
						Ca	Mg	K
1L	F	5,57	0,110	0,23	3,72	5,45	1,10	0,35
	C	5,51	0,085	0,23	4,24	5,51	0,84	0,29
2L	F	4,78	0,087	0,29	10,01	4,34	0,87	4,24
	C	4,54	0,062	0,23	7,26	4,54	0,61	3,72
3L	F	6,12	0,484	0,47	10,13	5,16	4,49	0,48
	C	6,01	0,445	0,41	3,46	6,01	1,18	0,31
4L	F	4,87	0,190	0,45	26,65	4,30	3,90	3,46
	C	4,40	0,107	0,54	11,58	4,40	1,07	2,75
5L	F	5,01	0,046	0,38	4,58	4,46	4,84	4,58
	C	4,78	0,035	0,32	1,94	4,78	0,84	3,50
6L	F	4,80	0,067	0,70	3,50	4,80	0,67	2,65
	C	4,54	0,053	0,73	2,75	4,54	0,53	1,94

F: Both soil and foliar fertilization; C: Farmer application as a control

Some microbiological soil properties of the orchards

The changes in microbiological properties of hazelnut orchard soils by the fertilization are given in Table 3. Soil microbiological characteristics of all hazelnut orchards were increased by the NPK ferilization. The highest value for BSR (0,424 µg CO_2-C g^{-1}) and C_{mic} (79,093 mg CO_2-C 100 g^{-1}) were obtained in the 6th location having the highest soil OM content (5,67%). However, the highest percent increment for BSR (142,2%) and C_{mic} (138,3%) over the control by the fertilization was determined in the 1st location having the lowest soil OM content (0,97%). It indicates that NPK fertilization was more effective in increasing BSR and C_{mic} at lower soil OM level. It is known that the soil properties such as texture, organic matter content, root density and microbial biomass affect the size of soil respiration (Haynes and Gower, 1995; Kelting et al, 1998; Raich and Tufekcioglu, 2000). Iovieno et al. (2009) reported that soil respiration and enzyme activities increased in compost-treated soils due to consequence of both microbial growth and stimulation of microbial activity by enhanced resource availability, as well as of changes in microbial community composition. Microbial biomass C enables the determination of the functional diversity of soil communities (Lupwayi et al., 1998, Altieri, 1999); and the causal effects on plant production and long-term soil management status. Zhang et al. (2017) found that application of inorganic fertilizer increased soil C_{mic} concentration.

The highest value for CA (220,742 ml O_2 g^{-1}) and DHA (2,704 μg TPF g^{-1}) were detrmined in the 4th location having the highest percent increase in soil pH (10,7%) and EC (77,6%) values over the control by the NPK fertilization. Increasing soil pH and EC by the fertilization increased CA and DHA activity in 4th location. Samuel et al. (2019) determined that catalase and dehydrogenase enzymatic activities were generally higher in NPK fertilized plots than in the unfertilized plot. Dehydrogenase activity reflects the total oxidative activity range of the soil's microflora and can ultimately be a good indicator of microbiological activity in the soil (Skujins, 1973). Dehydrogenase activities are not associated with microbial population and degradation of hydrocarbons, but are widely used to reflect microbial oxidative activity of soils. The enzyme catalase (H_2O_2:H_2O_2-oxidoreductase, EC 1.11.1.6.) is an enzyme that catalyzes the reaction of hydrogen peroxide (H_2O_2) to water and molecular oxygen. The enzyme catalase is closely related to the presence of the aerobic microbial population in the soil and the efficiency of the soil, and the determination of the enzyme catalase enzyme is used as an indicator in the assessment of the aerobic microorganism population available in the soil (Garcia and Hernandez, 1997). Hydrogen peroxide (H_2O_2) occurs in the respiratory processes of living organisms and at the end of various biochemical processes in which organic matter is oxidized (Weetall et al., 1965; Trevors, 1984).

Table 3. The effect of fertilization on biological properties of hazelnut orchard soils

Location No of the orchards		BSR, μg CO_2-C g^{-1}	C_{mic}, mg CO_2-C 100 g^{-1}	CA, ml O_2 g^{-1}	DHA, μg TPF g^{-1}
1L	F	0,281	74,85	117,22	0,573
	C	0,116	31,41	78,91	0,308
2L	F	0,216	60,93	105,62	1,780
	C	0,207	32,63	57,15	0,197
3L	F	0,197	69,91	96,90	0,363
	C	0,186	68,87	82,73	0,276
4L	F	0,419	72,32	220,74	2,704
	C	0,229	48,93	110,79	0,576
5L	F	0,191	42,90	92,19	1,119
	C	0,190	41,80	44,56	1,066
6L	F	0,424	79,09	164,47	1,503
	C	0,303	50,78	120,63	0,883

F: Both soil and foliar fertilization; C: Farmer application as a control

The effect of fertilization on hazelnut yield and yield parameters

The results of the fertilization effects on yield and yield parameters of hazelnut obtained form the six different hazelnut orchards are given in Table 4. The yield and yield parameters in all hazelnut orchards increased by the fertilization from soil and leaf together compared with the control treatments (Figure 3). The mean values of pecent increase in yield and yield parameters over the control by the fertilization were obtained as 8,3% in yield, 13,3% in shelled nut weight, 10,0% in kernel weight and 5,1% in percent kernel efficiency. Ellena et al. (2012) studied on the application of different rates of NPK foliar nutrients on fruit yields and quality characteristic and found that there were significant differences between the treatments in yield, nut weighs, and kernel weighs compared with the untreated control.

The hazelnut yield values varied beteen 2,70 kg/tree in control application of 2nd location and 4,20 kg/tree in the fertilizer application of 3rd location. The highest percent increase (12,9%) in yield by the fertilization was determined in the 1st location. The shelled nut weight values varied beteen 2,41 g in control application of 5th location and 3,23 g in the fertilizer application of 3rd location. The highest percent increase in av. P (192,8%) and exch. K (54,8%) contents was also determined in the soil of 3rd location by the fertilization over the control. Increses in av. P and exch. K content in soil by the fertilization improved yield and shelled nut weight of hazelnut. The kernel weight values varied beteen 1,16 g in control application of 3rd location and 1,47 g in the fertilizer application of 3rd and 4th locations. Chen et al. (2014) studied the effects of foliar

N, P, and K applications on yield and fruit quality of hazelnut and reported that only a foliar N application at shoot growing stage significantly increased yield and single grain weight.

The highest percent increase (26,7%) in kernel weight by the fertilization was also determined in the 3rd location. The percent kernel efficiency values varied beteen 42,00% in control application of 2nd location and 53,80% in the fertilizer application of 5th location. The highest percent increase in shelled nut weight (22,8%) and in percent kernel efficiency (8,3%) by the fertilization was determined in the 6th location which had the highest total N and soil OM contents. In many researches on hazelnut, it has been reported that nut weight varied due to their genetic constitution of cultivar, crop load, cultural practices and regions (Bostan and Islam, 1999; Aziz et al.i 2007; Silva et al., 2007). Milošević and Milošević (2017) determined size and features of twelve different hazelnut varieties and reported that nut weight varied between 1,32 g and 4,00 g, kernel weight between 0,53 g and 1,76 g, and percent kernel between 36,47% and 49,59%.

Table 4. The effects of fertilization on yield and yield parameters of hazelnut.

Location No of the orchards		Yield (kg/tree)	Weight of shelled hazelnut, g	Kernel weight of hazelnut, g	Percent kernel efficiency, %
1L	F	3,50	3,20	1,40	45,00
	C	3,10	2,90	1,37	43,50
2L	F	3,00	2,80	1,20	43,00
	C	2,70	2,43	1,20	42,00
3L	F	4,20	3,23	1,47	45,40
	C	4,00	2,64	1,16	43,70
4L	F	3,20	3,03	1,47	49,20
	C	3,00	3,00	1,43	47,00
5L	F	3,50	2,60	1,40	53,80
	C	3,40	2,41	1,21	50,00
6L	F	3,90	3,18	1,41	48,10
	C	3,50	2,59	1,25	44,40
Mean	F	3,55	3,01	1,39	47,42
	C	3,28	2,66	1,27	45,10

F: Both soil and foliar fertilization; C: Farmer application as a control

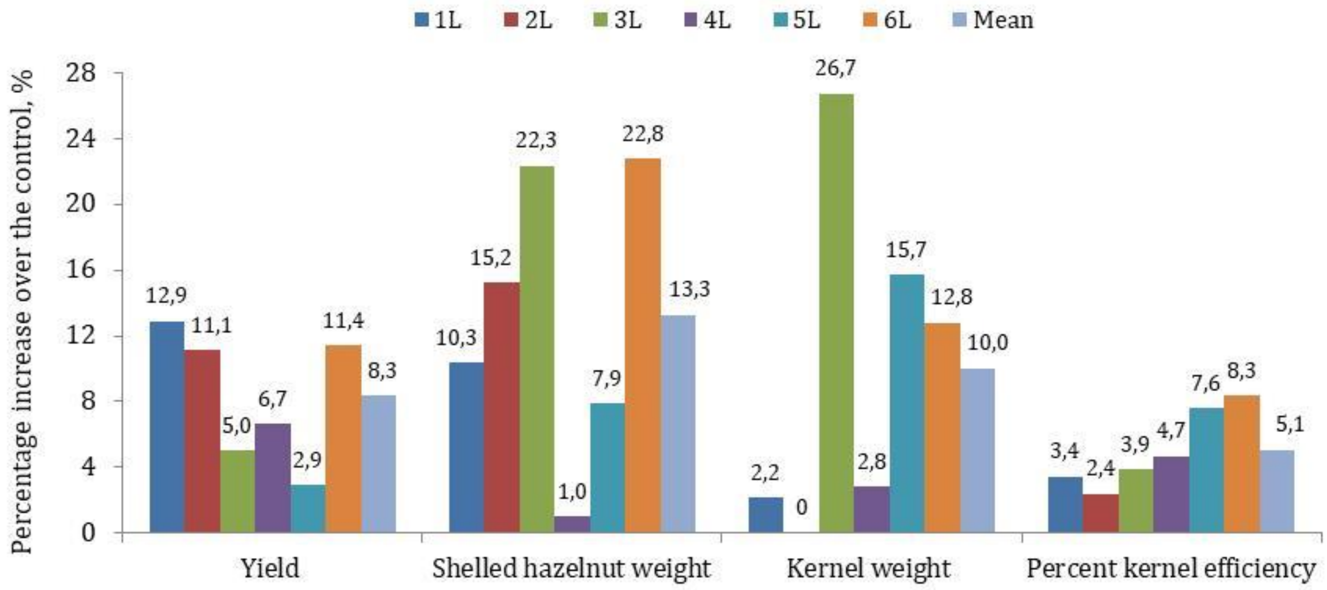


Figure 3. Effect of both ground and foliar fertilization on yield and some yield parameters compare with the farmer application as a control. (Locations; 1L: Zugdidi-Samegrelo, 2L: Thalendjikha-Samegrelo, 3L: Ozurgeti- Guria, 4L: Ozurgeti-Guria, 5L: Kobuleti-Adjara, 6L: Kobuleti-Adjara)

Relationships among the yield parameters and soil properties

A correlation matrix among the soil properties and the yield parameters is given in Table 5. The yield value had significant positive correlation with soil pH (0,669*), EC (0,652*) and Cmic (0,620*) values. It indicates that increasing of soil reaction, nutrient contents and microbial activity of hazelnut orchards due to the application of alkaline characteristic NPK fertilizer increased hazelnut yield values. Exch. Mg content had significant positive correlations with kernel weight (0,586*) and percent kernel efficiency (0,581*).

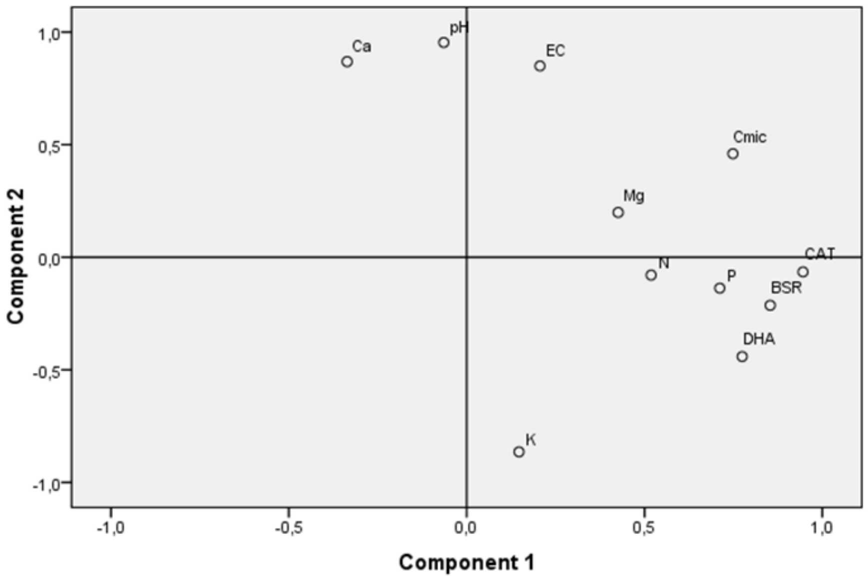
Increasing soil microbiological properties generally increased hazelnut yield parameters. Bodaghabadi et al. (2019) found that there was a relatively strong correspondence between yield and soil properties in pistachio orchards, clay, EC, K and B were negatively related, but sand and $CaCO_3$ significantly positive correlated with yield. Kainer et al. (2007) reported that Brazilian nut productivity had a positive relationship with cation exchange capacity levels and a weakly negative correlation with extractable P levels.

In PC1, CAT is the greatest contributor to the PC as given by the factor loading (Figure 4). A further 6 variables had highly weighted factor loadings, namely BSR, DHA, Cmic, P, N and Mg. Soil pH was the best representative of PC2 having the highest factor loading. While the the total N content had a significant positive correlation with BSR (0,591*), the available P content showed significant positive correlations with CAT (0,680*) and DHA (0,638*) (Table 5). Soil pH was one the most important soil properties which was influenced by the application of alkaline characterixezed NPK fertilizer from acidic soil (Figure 4). Soil EC and Ca had also highly weighted factor loadings positively in PC2. Soil microbial properties improved due to NPK fertilization generally had significant positive correlations eachother (Table 5). Singh et al. (2018) reported that there were significant improvements in microbial counts, microbial biomass carbon, soil respiration, soil enzymes and soil organic carbon with fertilization in lentil growth.

Table 5. Relationships among the soil properties and hazelnut yield parameters.

	Nut	Kernel	Keff.	pH	EC	N	P	K	Ca	Mg	BSR	Cmic	CAT	DHA
Yield	0,362	0,206	0,197	0,669*	0,652*	0,435	-0,260	-0,505	0,521	0,335	0,146	0,620*	0,113	-0,118
Nut		0,781**	-0,019	0,363	0,323	0,211	0,333	-0,440	0,166	0,240	0,416	0,685*	0,594*	0,161
Kernel			0,438	0,137	0,100	0,236	0,451	-0,139	-0,139	0,586*	0,368	0,328	0,579*	0,234
Keff.				-0,184	-0,228	0,215	0,125	0,467	-0,356	0,581*	0,241	0,040	0,235	0,445
pH					0,792**	-0,263	-0,140	-0,755**	0,835**	0,337	-0,332	0,362	-0,142	-0,379
EC						0,058	0,193	-0,571	0,556	0,397	-0,139	0,476	0,030	-0,243
N							0,029	0,009	-0,255	0,013	0,591*	0,370	0,487	0,231
P								0,266	-0,449	0,468	0,432	0,271	0,680*	0,638*
K									-0,860**	0,141	0,195	-0,274	0,082	0,564
Ca										-0,160	-0,368	0,193	-0,309	-0,589*
Mg											0,041	0,188	0,280	0,272
BSR												0,653*	0,873**	0,685*
Cmic													0,654*	0,388
CAT														0,749**

*significant at 0,05 level, **significant at 0,01 level.



	Component	
	1	2
pH	-0,064	0,954
EC	0,206	0,850
N	0,519	-0,079
P	0,712	-0,137
Ca	-0,336	0,869
Mg	0,426	0,199
K	0,147	-0,864
BSR	0,853	-0,214
Cmic	0,749	0,460
CAT	0,946	-0,065
DHA	0,775	-0,441

Figure 4. Rotated component matrix from the soil properties obtained from the hazelnut orchards.

Conclusion

At the end of the experiments conducted in six different hazelnut orchards in Georgia, the fertilizer applications improved soil chemical and biological properties and increased hazelnut yield and yield parameters. The fertilizer having alkaline reaction applied from soil increased soil pH, nutrient contents and EC values in all hazelnut orchards. Basal soil respiration, Cmic, DHA and CAT enzyme activities of soils in the hazelnut orchards were also increased by the soil application of NPK fertilizer. Total hazelnut yieled, shelled nut and kernel yields and percentage of kernel efficiency generally increased over the control in all orchards by the soil and foliar application of NPK fertilizers. It can be concluded that foliar fertilization and increasing of soil reaction, nutrient contents and microbial activity of hazelnut orchards due to the application of alkaline characteristic NPK fertilizer from soil increased hazelnut yield and yield parameters compare with the farmer applications or control treatments.

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