Agronomy Research **15**(2), 444–455, 2017

Soil fertility and productivity of apple orchard under a long-term use of different fertilizer systems

P. Kopytko, V. Karpenko*, R. Yakovenko and I. Mostoviak

Uman National University of Horticulture, 1 Instytutska str., UK20305 Uman city, Ukraine
*Correspondence: v-biology@mail.ru

Abstract. An apple should be planted on suitable soils which can be used for growing two or more generations of gardens for decades. This can be reached by creating and supporting an optimum level of mineral nutrients for fruit trees. The aim of this study was to compare the long-term effect of mineral or organic fertilization on apple tree growth and yield and soil fertility. The research has been conducted since 1931, when an apple orchard of Winter-Calville on seedlings was established on dark-grey heavy loam soil of Uman National University of Horticulture. The non-irrigated trees were subjected to the following treatments: 1. Unfertilized (control); 2. Application of cattle manure 40 t ha^{-1} (organic); 3. N_{120} P_{120} K_{120} (mineral); 4. 20 t ha^{-1} of humus N_{60} P_{60} K_{60} (organic-mineral). In 1982 the first orchard was removed and 2 year later another one was re-planted on the same soil. The second orchard, that included, beside the same variety also Idared grafted on seedling and on M4, was subjected to the same treatments.
Soil fertility and apple tree productivity increased under the use of organic fertilizer system. Organic-mineral fertilizer system provided almost the same response, while mineral fertilizer system provided the lowest one.
During the study a decreased uptake of nutrients applied with fertilizers was often related to insufficient soil moisture supply. Soluble nitrogen was washed out of root layer into ground water, while phosphorus and potassium were transformed into compounds and forms inaccessible for plant nutrition. Thus it is necessary to apply those rates of fertilizers that are insufficient in the soil to reach the optimal levels of content of corresponding nutrients which should be determined by agrochemical analysis.
It is possible to maintain an optimal fertility of soil in orchards by applying only organic fertilizers. Alkalization of inter-row spacing with regular grass mowing (turf and humus soil management system) provided the same humus content in soil as application of 40 t of humus per ha in a year after the use of fallow system.

Key words: apple tree, soil fertility, fertilizer system, nutrition elements, yielding capacity, long-term research.

INTRODUCTION

The yielding capacity and quality fruit of an apple tree, the most important horticultural crop in Ukraine, depends on natural factors: such as soil and climate conditions that influence processes of plant nutrition depending on the level of soil fertility and water supply and create favourable or stressful conditions of external influence on plant bodies and biological properties of cultivated rootstock variety combinations, as well as technological factors: soil management (pre-planting, fertilization, tillage, irrigation) and plant care measures (canopy training depending on tree spacing, pruning, fruit bearing control, nutrition, disease and pest management, etc.).

As to the efficient use of natural factors it is very important to place industrial apple plantations on the most suitable soils with optimal physical and chemical parameters of fertility (Atucha et al., 2011; Zuoping et al., 2014; Wang et al., 2015; Wang et al., 2016), that are evaluated by the previous soil and agrochemical examination of plots of land where orchards are laid out and cultivated (Fura, 2009). To improve the properties of soil that are not optimal enough it is essential to carry out its pre-planting preparation with relevant cultivation and fertilization (Wawrzynczczak et al., 2012).

In the process of a long-term cultivation of apple orchards it is necessary to maintain high level of soil fertility over many decades for functioning plantings even for several generations of plantations on the same areas that were selected according to suitability of soil and water supply (for the irrigation of intensive plantings) and take into account the established horticultural infrastructure. There is no point to relocate new plantings on less fertile soils as they will be less productive while the expenses on the improvement and maintenance of the necessary level of soil fertility will be considerably higher. The refore it is more profitable to cultivate trees on the same areas where the old ones had been grown. With such a change of generations of fruit plantations, old and less productive rootstock variety combinations are replaced by more productive, gardens with better progressive constructions with cultivars that have better parameters of yielding capacity and quality of fruits are laid out. To ensure high productivity of apple trees it is essential for the soil to remain fertile for sufficient nutrition of new fruitful trees according to their productivity potential. Under such conditions a negative impact of soil fatigue caused by a long-term growing of a previous orchard is less tangible.

If it becomes necessary to decrease a negative influence of soil fatigue before planting new trees the soil should be specially prepared: it is required to enrich the soil with organic substances for enhancing biological activity and with elements of mineral nutrition insufficient for optimal levels, to optimize acidity of the soil, to loosen the soil deeply for the improvement of water-air regime, etc (Gasparatos et al., 2011; Vliegen-Verschure, 2013).

In this regard the objective of the research was to substantiate the results of a long-term experiment with different fertilizer systems applied in apple orchard, which has been carried out during 85-year period at Uman National University of Horticulture and according to the state executive order was included into State Register of scientific objects of national asset as 'Unique research agroecosystem of apple tree orchard of National University of Horticulture'. The study was also aimed at working out recommendations for optimal fertilization of an orchard with the purpose of obtaining maximal productivity. The authors directly participated in obtaining, analyzing and interpreting experimental data.

MATERIALS AND METHODS

The experiment was started in the autumn of 1931 by professor S.S. Rubin in the orchard planted in the spring of the same year on plot of land of dark-grey heavy loam soil. The experiment scheme included three systems of fertilization: organic – the application of cattle manure 40 t ha^{-1}, mineral – $N_{120}P_{120}K_{120}$, organic-mineral –

20 t ha^{-1} of humus + N_{60} P_{60} K_{60} and also the unfertilized control. All mentioned rates of fertilizers were introduced into the soil once in two years at the time of autumn re-ploughing at the depth of 18−20 cm within 10 meters wide inter-row spacing (trees of Winter-Calville apple variety on seedling rootstock were planted at a distance of 10 m x10 m).

The research had been conducted for 50 years till the orchard was removed in 1982. Experimental plots of all experimental variants were marked out and preserved for the following study of the newly re-planted orchard in spring of 1984. The new orchard included, beside Winter-Calville on seedling rootstock, also Idared on both vigorous seedling and medium-growth vegetative rootstock M.4, planted at a distance of 7 m x 5 m. Within the period of 1982−1984 the soil of the uprooted orchard was cleared of residual root pieces and ploughed at the depth of 50 cm.

During the growth period of the old orchard as well as the new experimental orchard without irrigation, the soil was maintained under fallow. During spring-summer period the soil was cultivated for weed killing and loosening, while in spring it was ploughed in inter-row spacing at the depth of 18–20 cm.

Nitrogenous fertilizers have been applied half-dose annually according to the scheme of the experiment in the newly cultivated orchard since 1984. They have been applied within rows during spring soil cultivation to reduce unproductive losses of nitrogen.

To evaluate soil conditions in the experimental garden the following methods were used: Tiurin method to determine the humus content; Kappen method to identify reaction of soil solution (pH) – in extraction 0.1 n KCl; hydrolytic soil acidity; Kappen-Hilkovitz method to define the sum of absorbed bases (Ca and Mg); Kjeldahl method to determine nitrogen and distillation method to determine mineral compounds; organic nitrogen was defined by the difference between total content and mineral compounds content; Ginsburg-Lebedeva method to find out phosphorus compounds of different solubility; Vozhenin method to determine potassium of different level of solubility and fixation by soil minerals; Kravkov method in modification of Bolotina, Abramova to determine the forms of main macroelements of nitrogen, phosphorus and potassium available for fruit trees nutrition under 14-day composting of soil samples in thermostat (NO_3) and Egner-Riehm-Domingo method (P_2O_5 and K_2O) (above mentioned techniques were described by Z.M. Hrytsayenko et al., 2003).

The productivity of apple plantings was evaluated by measurements of annual increment of all above ground tree organs (trunks, shoots, leaves) and periodically roots (under digging) and by direct weighing of fruit crop from every registered tree (in the orchard of the 1st generation) and from registered plots (in the orchard of the 2d generation).

Validity of the research and substantiality of differences among productivity indexes in the experimental studies were assessed according to the results of dispersion analysis of mathematical statistics (Ehrmantraut et al., 2000).

RESULTS AND DISCUSSION

The long-term experiment proved that under fallow the processes of mineralization of organic substances prevail over the processes of their humification. To maintain sufficient level of humification of soil, it is necessary to enrich it regularly with organic substances by application of appropriate fertilizers. This is confirmed by the results of the research into dynamics of humus (Fig. 1). The results show that during the initial period of growth of young apple trees, when the soil in wide inter-row spacing was under tillage systematically and too little organic matter came into it from plants, the level of humus in the root layer of 0–60 cm reduced significantly by 1956 in all experimental plots compared to the initial level (2.04%).

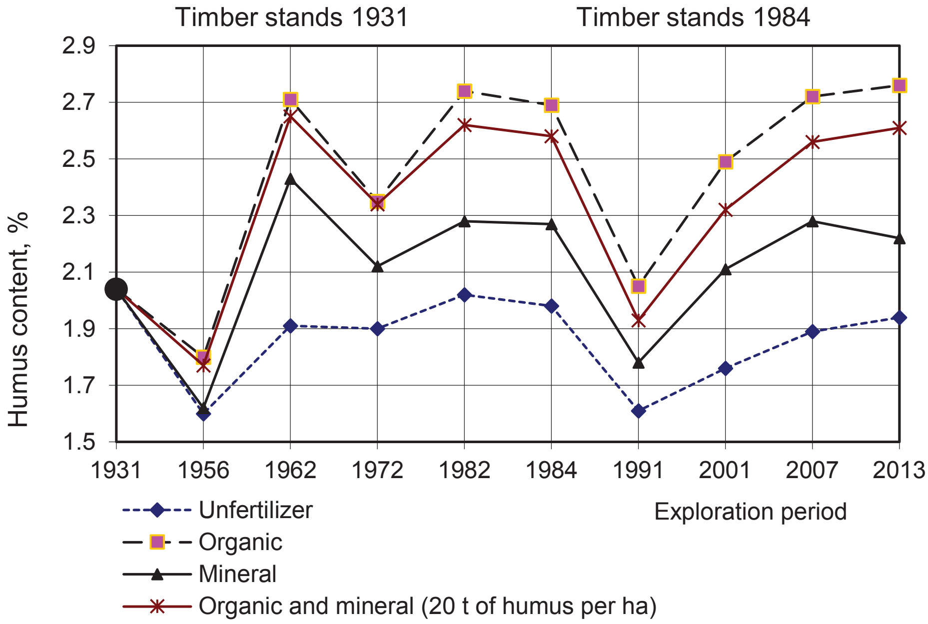


Figure 1. The dynamics of humus content in the soil layer of 0–60 cm under a long-term use of different fertilizer systems in the apple orchard, %.

Under organic and to a lesser extent under organic-mineral fertilizer system the humus content exceeded the indexes of its level in the control variant.

In the following period, till 1962, the humification of soil increased on fertilized plots and exceeded the initial level of 1931 especially under organic, organic-mineral fertilizer system. The reduction of humus concentration by 1972 was caused by the rejuvenation of the experimental orchard; in 1965, perennial branches were pruned and the canopies were considerably reduced. As a result in the following years less organic matter came into soil from plant residues.

The soil humification rate increased significantly under the intensive growth of tree canopy and corresponding leaf shedding in 1982, which occurred rather intensively in a manured soil.

The same dynamics of humus substances in soil was observed during the period of 1984–2013, when new apple trees were planted. At first humus concentration decreased by 0.37% up to 1991 in unfertilized soil and by 0.49–0.65% in fertilized soil, and later it increased till 2007 upon which the balance of soil humification was established. It was the highest level under organic fertilizer system (2.72–2.76%), slightly lower under organic-mineral fertilizer system (2.56–2.61%), and it was significantly lower under mineral fertilizer system (2.22−2.28%). During the research period, the lowest level of soil humification was on control unfertilized plots. The highest content of humus in the soil was in 1982 (2.02%) and in 2013 (1.94%), i.e. the content of humus in the soil was lower throughout 83-year period of research compared to the initial period in 1931.

Physicochemical and biological indicators of soil fertility are closely related to organic matter and humic substances in particular. Research data (Table 1) show changes in a number of physicochemical indicators under long-term fertilization. If organic fertilization scheme fostered the shifting of exchange soil acidity in the direction to neutral (up to pH 5.5), then mineral fertilization system acidified the reaction of the medium (up to pH 4.4). Hydrolytic acidity has changed in the same direction. The increase of calcium and magnesium concentration in soil was revealed under the use of organic fertilizer system, while the use of mineral fertilizer system led to its decrease. This was due to the fact that mineral fertilizers stimulated soil disturbance processes. As a result, more soluble mineral compounds of these elements were formed and washed out into deeper layers of the soil profile.

Table 1. Physicochemical parameters of dark-grey heavy loam soil in 0−60 cm-layer after a 50-year use of different fertilizer systems

Fertilizer systems	pH_{KCl}	Hydrolytic acidity, mg-eq (100 g)$^{-1}$ soil	Soil absorption complex, mg (100 g)$^{-1}$ of soil		Degree of saturation with soil absorbing complex,%
			Ca	Mg	
Unfertilized (control)	5.1	2.5	19.5	4.1	90.4
Organic (humus 40 t ha^{-1})	5.5	1.9	20.5	4.7	93.0
Mineral ($N_{120} P_{120} K_{120}$)	4.7	3.6	18.0	3.8	86.0
Organic-mineral (humus 20 t ha^{-1} +$N_{60} P_{60} K_{60}$)	5.2	2.4	19.8	4.3	90.7

Microbiological processes were more active in systematically fertilized soil (Styła et al., 2010). As a result cellulose decomposed rather intensively (by 4−11%), CO_2 liberation from the soil surface increased by 19–28% and the production of nitrate nitrogen increased by 116–160% under optimal hydrothermal conditions for nitrification in thermostat. Organic fertilizer system promoted these processes to a greater extent due to the best provision of soil with organic substances as energetic material for enhancing vital activity of microbiota.

Long-term regular fertilization in the orchard provided constant maintaining of the content of mobile compounds and forms of mineral nutrition elements within optimal levels or their exceeding. The concentration of nitrate nitrogen ($N-NO_3$), produced under optimum hydrothermal conditions, in the unfertilized soil layer (0−40 cm) of the control variant was always within 14−20 mg kg^{-1}, which is lower than the optimum level for an apple tree on a dark-grey heavy loam podzolic soil that makes up 22−25 mg kg^{-1}. The content of nitrate nitrogen on fertilized plots was 27−33 mg kg^{-1}, under the use of mineral fertilizer system was 22–24 and under the use of organic-mineral fertilizer system was 26–29 mg kg^{-1}. There was a sufficient amount of phosphorus mobile compounds determined in the layer of soil of 0−60 cm in all experimental variants: in the soil of control variant it was 80–140 mg kg^{-1}, under organic fertilizer system, 160–260 mg kg^{-1}, under mineral fertilizer system, 130–220 mg kg^{-1} and under organic-mineral fertilizer system, 150–270 mg kg^{-1} (optimum content is 70–100 mg kg^{-1}of soil). The concentration of potassium mobile compounds in the soil of control variant was within optimum level 230−280 mg kg^{-1} in certain years (230−260 mg kg^{-1}), but in most cases it was lower than optimal level and accounted for 130−220 mg kg^{-1}. Under the use of all fertilizer systems the concentration of potassium mobile compounds sometimes corresponded to the optimum level and exceeded the upper limit (280 mg kg^{-1}) more frequently under organic fertilizer system.

The research results confirm that mobilization of nitrogen into soluble compounds from soil supplies was stimulated by fertilization as well as its possible non-symbiotic fixation from atmosphere by soil microorganisms. Data mentioned above show significant unproductive nitrogen losses because of washing out outside root layer of the soil and possibility of ground waters contamination with nitrate and other compounds of this element.

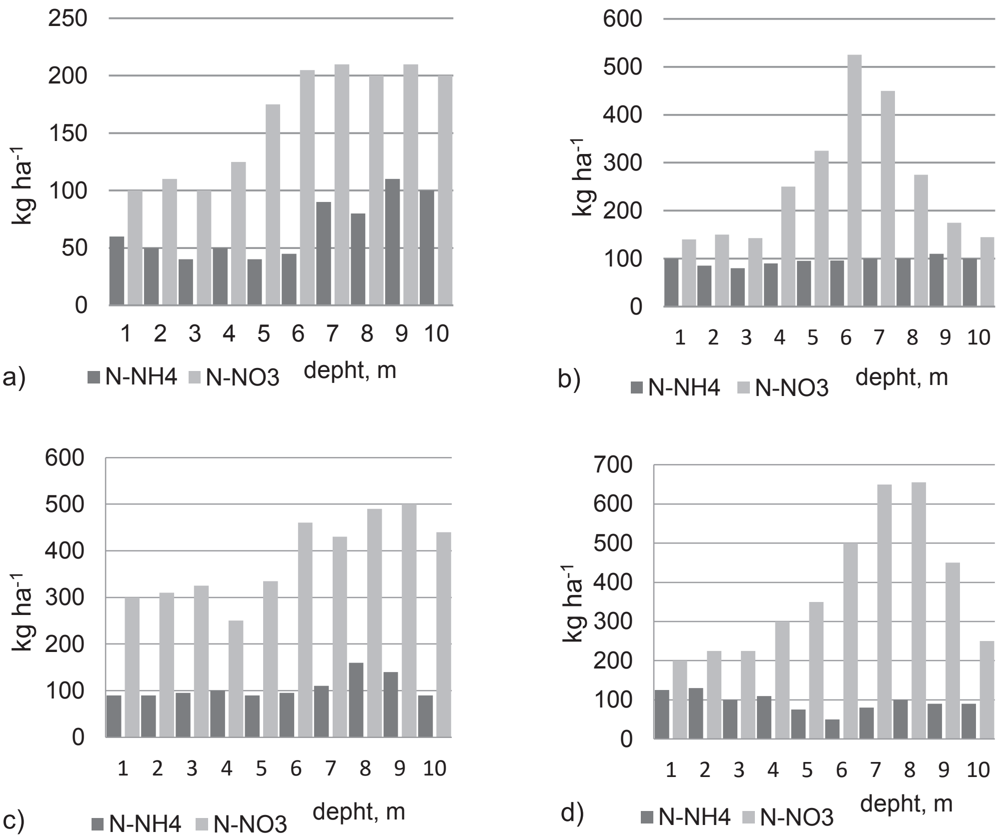
All amounts of P introduced with fertilizers and not used by trees remained in 1 meter soil stratum in different compounds with Ca, Al and Fe as well as in the composition of organic substances. In more humified 60 cm soil layer, potassium was found mainly in soil solution and in absorbed state on the surface of fine particles of colloidal fraction of soil (exchange potassium). At the depth of 60–100 cm potassium ions were found in the lattices of clay minerals enriching the content of exchange hydrolyzed and fixed potassium.

Under the conditions of percolative regime in the soil in the orchard over the first 50-year period on the plots under experimental fertilizer systems the soil was enriched with phosphorus and potassium to the depth of 1 meter while nitrogen moved 10 meters deeper (up to 13 m) reaching ground waters (Fig. 2).

The greatest amount of nitrogen migrated as nitrate compounds and certain number as soluble organic matter (Fig. 3).

The total accumulation of nitrogen in the soil stratum deeper than 1m profile exceeded its amounts introduced with fertilizers over the whole 50-year period. Thus on a per hectar basis N was introduced together with humus – 3,520 kg and together with N P K – 2,760 kg, of which it 2,360 kg or 67,0% and 980 kg or 35.5% were found in 1m layer respectively. Fertilized trees used 160 and 141kg additionally. In total it accounted for 2,520 and 1,121 kg that is why 1,000 and 1,639 kg of nitrogen were lost respectively. But supplementary amounts of nitrogen 8,200 and 5,880 kg were found in the soil stratum deeper than 1m and up to 10 m which is 2.3 and 2.1 times more than introduced amounts.

These research results confirm that mobilization of nitrogen into soluble compounds from soil supplies was stimulated by fertilization as well as its possible non-symbiotic fixation from atmosphere by soil microorganisms. Data mentioned above show significant unproductive nitrogen losses because of washing out outside root layer of the soil and possibility of ground waters contamination with nitrate and other compounds of this element.



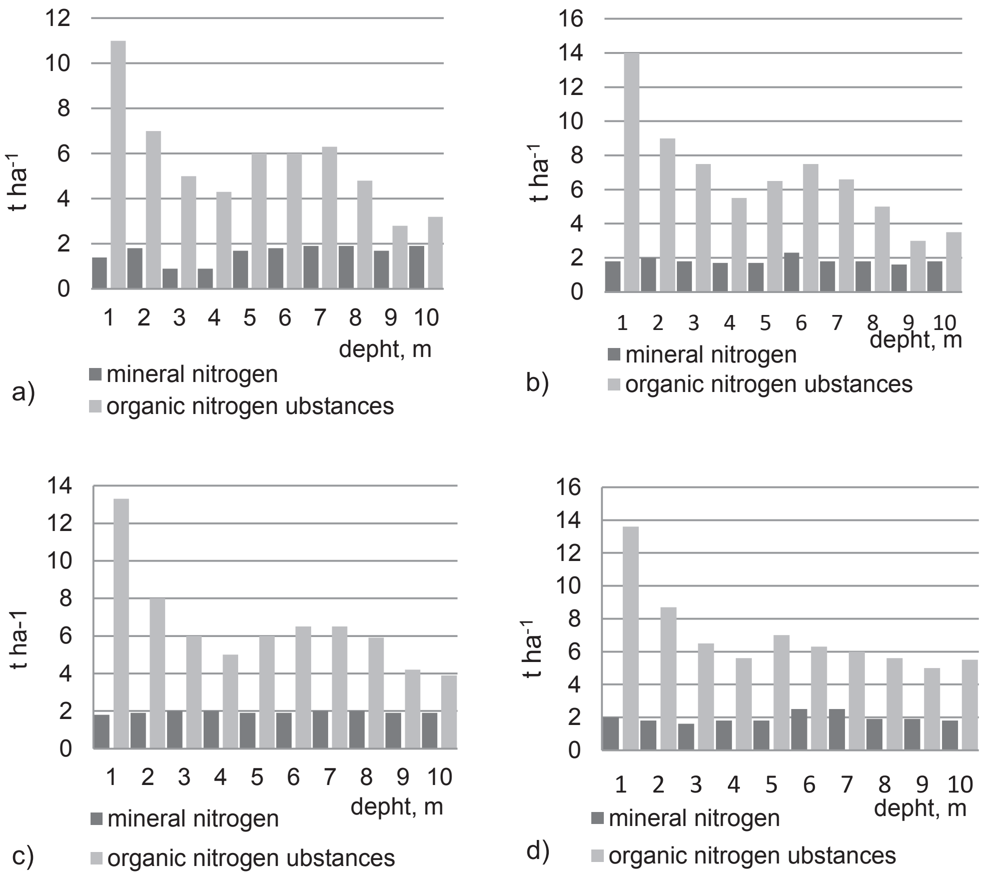
a) − Unfertilized (control); b) − Organic (humus 40 t ha^{-1}); c) − Mineral N_{120} P_{120} K_{120}; d) −Organic-mineral (humus 20 t ha^{-1} + $N_{60}P_{60}K_{60}$)

Figure 2. Mineral nitrogen in 10-meter soil profile after a 50-year period of fertilization of dark-grey podzolic soil in the experimental garden.

All amounts of P introduced with fertilizers and not used by trees remained in 1 meter soil stratum in different compounds with Ca, Al and Fe as well as in the composition of organic substances. In more humified 60 cm soil layer, potassium was found mainly in soil solution and in absorbed state on the surface of fine particles of colloidal fraction of soil (exchange potassium). At the depth of 60–100 cm potassium ions were found in the lattices of clay minerals enriching the content of exchange hydrolyzed and fixed potassium.

Thus under systematic long-term soil fertilization of an orchard higher levels of fertility were created and maintained and mineral nutrition of fruit plants in particular.

Better nitrogenous nutrition was provided mainly by enriching the soil with organic substances, which is proved by the indexes of its higher humus content. Phosphorus and potassium nutrition was provided by increasing content of their mobile compounds and forms in the root layer of the soil. Higher levels of soil nutrition were created under the use of organic and organic-mineral fertilizer systems, compared to the mineral system. Other indicators of soil fertility (physicochemical and biological in particular) were more optimal under the use of organic and organic-mineral fertilizer systems. Moreover, under the application of organic fertilizer the soil was enriched not only with main nutrition elements (N, P, K), but also with the other micro- and macro-elements.



a) − Without fertilization (control); b) − Organic (humus 40 t ha^{-1}); c) − Mineral $N_{120} P_{120} K_{120}$;
d) − Organic-mineral (humus 20 t ha^{-1} + $N_{60} P_{60} K_{60}$)

Figure 3. Organic and mineral nitrogen in 10-meter soil profile after a 50-year period of fertilization of dark-grey podzolic soil in the experimental garden.

According to soil fertility, changes of apple tree productivity in the experimental orchard increased. The productivity was determined by the level of supply of fruit trees with water, which depended in non-irrigated orchard on regional climatic and weather conditions in certain years. Practically the level of available water supply was the main limiting factor for the growth and productivity of experimental apple trees in the zone of unstable moistening. Over the entire 42-year period of fruit-bearing (1940–1981) of experimental variety Winter Calville in the plantation of 1931 the average productivity was higher under organic, organic-mineral fertilizer systems and made up 13.2 t ha^{-1} and 13.4 t ha^{-1} respectively which is higher than productivity on non-fertilized plots of control variant (10.6 t ha^{-1}) by 2.6 t ha^{-1} and 2.8 t $ha^{-1}$and under mineral fertilizer system – by 2.8 t ha^{-1}.

Similar difference in the intensity of fruit-bearing found in Winter Calville in the first plantation, was observed in the second orchard re-planted in 1984 which had been grown on the same experimental plots (Table 2).

Table 2. The yielding capacity of Winter-Calville apple variety under the long-term use of different fertilizer systems, t ha^{-1}

Fertilizer systems	Plantations 1931 year		Plantations 1984 year	
	Growth and fruit-bearing period (1940−1946)	Fruiting period (1947−1963)	Growth and fruiting period (1990−1996)	Fruiting period (1997−2013)
Unfertilized (control)	2.5	7.5	3.5	12.1
Organic (humus 40 t ha^{-1})	3.2	10.6	4.8	16.7
Mineral ($N_{120}P_{120}K_{120}$)	2.8	9.1	4.5	14.9
Organic-mineral (humus 20 t ha^{-1} + $N_{60}P_{60}K_{60}$)	2.9	10.5	4.7	16.2
LSD_{05}	0.7	1.5	0.8	1.1

The initial period of fruiting of the trees planted in 1931 (1940−1946) was characterized by low yields, gain in weight of vegetative organs and decrease in soil humus content under the use of all fertilizer systems. As a result, fertility level on experimental plots as well as yielding capacity were slightly different, compared to the next fruiting season (1947−1963). Compared to non-fertilized plots (2.5 t ha^{-1}), yield was higher on fertilized plots by 12–28% and during the fruit-bearing period of well-formed trees it was higher by 21–41%. During the last period of fruit-bearing, the difference in yielding capacity under organic and organic-mineral fertilizer systems compared to the mineral system was rather noticeable, which was caused by unequal levels of soil fertility created over the years. Similar dependence of fruit-bearing results under various levels of soil fertility is confirmed by the indexes of yielding capacity of a subsequent plantation of 1984 during both growth and fruit-bearing periods. The indexes of fertilized plots exceeded the indexes of unfertilized plots (control) by 23–38% and were higher under organic and organic-mineral fertilizer systems by 34–38%, and lower under mineral fertilizer system – by 23–29%.

Depending on fertilizer systems the similar difference in yielding capacity was found in Idared apple variety on both rootstocks grown in a subsequent plantation of 1984 (Table 3). The highest yields were recorded under the use of organic fertilizer system that exceeded control indexes of yielding capacity of trees on seedlings by 33–36% and on vegetative M.4 rootstock by 21–31% and under organic-mineral fertilizer system – by 27–31% and by 23–31% respectively. Under mineral fertilizers application the corresponding exceeding in yielding capacity reached 19–20% and 14–19%. Considering fruit-bearing peculiarities of experimental trees it should be noted that Idared variety had better yielding capacity compared to Winter Calville.

Table 3. The productivity of Idared apple variety, planted in 1984, under the long-term use of different fertilizer systems, t ha^{-1}

Fertilizer systems	The period of growth and fruiting (1990−1996)		Fruiting season (1997−2013)	
	Seedling rootstock	Vegetative rootstock M.4	Seedling rootstock	Vegetative rootstock M.4
Unfertilized (control)	4.8	4.4	13.8	12.4
Organic (humus40 t ha^{-1})	6.4	5.3	18.7	16.2
Mineral ($N_{120}P_{120}K_{120}$)	5.7	5.0	16.5	14.8
Organo-mineral (humus 20 t ha^{-1} + $N_{60}P_{60}K_{60}$)	6.1	5.4	18.1	16.3
LSD_{05}	1.2	0.8	0.9	0.8

Considerably higher crop yield indexes of Winter-Calville were obtained in subsequent plantation of 1984 compared to the old plantation of 1931 as a result of high tree density in a new garden and improved plant care measures (except fertilization) which provided more stable fruiting every year. In the old garden the fruit-bearing was regular, but in the years (1952, 1953, 1954, 1960) the trees didn't bear fruit because of dry weather conditions during vegetation or because of damaged flowers by spring frosts (last year). The refore the average yielding capacity in the old garden only in bumper-crop years was twice as much as it was over all years. Sometimes the yielding capacity reached 20 t ha^{-1} on fertilized plots (1963) and was even higher 30 t ha^{-1} (1957). But in subsequent years after such heavy fruit-bearing the yielding capacity dropped sharply (1964) or the garden didn't bear fruit at all (1958).

Long-term study of different fertilizer systems for the plantations of apple trees enabled to establish that the highest level of soil fertility in the orchard is provided by systematic enrichment of the soil with organic substances applying organic fertilizers or its combination with mineral fertilizers.

Introducing mineral fertilizers only in inter-row spacing under fallow does not provide optimum soil fertility for fruit trees and to a great extent it causes losses of nutrients from root layer as a result of washing out soluble compounds and nitrate nitrogen in particular.

A great loss was recorded on all the fertilized plots, because under relatively low productivity caused by insufficient moisture supply trees didn't use all amounts of nutrient elements applied with fertilizations and a number of them was washed into deeper soil layers or was fixed by soil absorbing complex into insoluble compounds and forms inaccessible for plant nutrition. Being created in fruit tree plantings by pre-planting fertilization the optimum levels of content of fertilizer elements in soil should be maintained due to the introduction of fertilizers at the rates calculated according to the results of agrochemical analyses. These analyses should be carried out periodically (in 2–3) years and determine the content of compounds and forms of corresponding mineral elements available for nutrition of plants in a root layer. In other words, it is essential to apply only those fertilizers and in such quantities that are not sufficient to reach optimum levels. This fertilization ensures optimum nutrition of trees and under sufficient water supply they can produce a required yield of high-quality fruits.

In this case if there is need to enhance certain growth and generative processes (blossoming, fruit setting, increase in their weight and formation of better quality, differentiation of buds or shoot growth etc.) during vegetation it is worth applying special fertilizing – either outside root fertilizing or with irrigation water by fertigation. Under such integrated fertilization system applied in the garden fertilizers are used in the most cost-efficient way without considerable unproductive losses.

The results of the research in a long-term experiment have shown the optimum levels of nitric nitrogen concentration in dark-grey heavy loam soil for apple trees which is determined by 14-days composting of soil samples in thermostat under optimum hydro-thermal conditions for nitrification which are considered to be potential abilities of soil to produce $N\text{-}NO_3$ for the whole vegetation of plants and mobile compounds of phosphorus and potassium forms.

The possibility to constantly maintain optimum levels of all main indexes of soil fertility in a garden with the introduction of organic fertilizers only without mineral ones has been substantiated. It is important for organic gardening which is more environmentally friendly than traditional. In the experiment such soil fertility was provided by the introduction of 40 t ha^{-1} of humus in a year.

Additional study has showed that the same soil humification is provided by alkalization of inter-row spacing with periodical grass mowing during vegetation period (turf and humus system of soil maintaining). In this case the mass of dry substance of grass (the amount of above-ground part of roots) accumulates every year and is bigger than that one which is applied with 20 t ha^{-1} of humus per year. As a result physical, agrochemical and biological indexes of soil fertility improve. Therefore there is no need to introduce organic fertilizers as it is done under fallow system but feed grasses and trees with multiple-nutrient fertilizers.

CONCLUSIONS

1. Application of organic fertilizer system ensures the highest level of soil humification – at the end of 83-year period of growing experimental garden the exceeding over the initial level of humus content makes up 31% and under mineral fertilizer system – only 7%. Organic-mineral fertilizer system ensures intermediate level of humus content closer to organic fertilizer system.

2. Under organic fertilizer system other indexes of soil productivity improve to the fullest extent: reaction of soil solution, saturation of soil complex with bases, the level of hydrolytic acidity, biological activity of soil medium, provision of root soil layer with mobile compounds and minor plant nutrients (N, P_2O_2 i K_2O).

1. Under mineral fertilizer system the soil noticeably acidifies, exchangeable and hydrolytic acidity increases and saturation of soil absorbing complex with bases dicreases.

2. According to the increase in soil productivity under a long-term fertilization in the period of apple fruit bearing the yielding capacity increases the most – 31−41% under organic fertilizer system and it is the lowest under mineral fertilizer system – 21–23%. However, under climate conditions of unstable moisturizing the productivity of non-irrigated apple plantation is quite low – average yielding capacity doesn't exceed 16–19 t ha^{-1} on well fertilized plots because of insufficient moisturizing. That is why a

considerable part of nutrients mobilized in the soil, nitrogen in particular, isn't used by trees and is lost because of washing out into the deep subsoil horizons.

REFERENCES

Amaya Atucha, Merwin, Ian A. & Brown, Michael G. 2011. Long-term Effects of Four Groundcover Management Systems in an Apple Orchard. *Hort Science* **46**(8), 1176–1183. (in Greece).

Ehrmantraut, E. Shevchenko, I. & Nenyn, P. 2000. Mathematical analysis and interpretation of research. *Coll. Science. works Institute for Sugar Beet UAAS* **2**, 189–205. (in Ukraine).

Fura, A. 2009. Podstawy nawozenia. *Sad* **5**, 58–59. (in Polish).

Gasparatos, D. Roussos, P. Christofilopoulou, E. & Haidouti, C. 2011. Comparative effects of organic and conventional apple orchard management on soil chemical properties and plant mineral content under Mediterranean climate conditions. *Journal of Soil Science and Plant Nutrition* **11**(4), 105–117. (in Greece).

Hrytsayenko, Z. Hrytsayenko, A. & Karpenko, V. 2003. *Methods of biological and agrochemical research of plants and soil*. Kyiv: Nichlava, 320 p. (in Ukraine).

Styła, K. & Sawicka, A. 2010. Microbiological activity of soil against the background of differentiated irrigation and fertilization in apple (Malus domestica) orchard after replantation. *Agronomy Research* **8**(1), 827–836. (in Polish).

Vliegen-Verschure, A. 2013. Fumigation using mustard seed meal instead of mustard. *EFM* **2**, 6–7. (in Netherlands).

Wang, L. Yang, F. Yaoyao, E. Yuan, J. Raza, W. Huang Q. & Shen, Q. 2016. Long-Term Application of Bioorganic Fertilizers Improved Soil Biochemical Properties and Microbial Communities of an Apple Orchard Soil. *Front Microbiol* **7**. Open Access at 10.3389/fmicb.2016.01893. (in China).

Wang, R. Guo, S. Li, N. Li, R. Zhang, Y. Wang, J. Liu, Q. Wu, D. Sun, Q. Du, L. & Zhao, M. 2015. Phosphorus Accumulation and Sorption in Calcareous Soil under Long-Term Fertilization. *PLoS One* **10**(8). Open Access at 10.1371/journal.pone.0135160. (in China).

Wawrzynczczak, P. & Wojcik, P. 2012. Nawozenie doglebowe. *Sad* **3**, 60–65. (in Polish).

Zuoping, Z. Sha, Y. Fen, L. Puhui, J. Xiaoying, W. & Yan'an, T. 2014. Effects of chemical fertilizer combined with organic manure on Fuji apple quality, yield and soil fertility in apple orchard on the Loess Plateau of China. *International Journal of Agricultural and Biological Engineering* **7**(2), 45–54. (in China).