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Diagnostics and optimisation of mineral nutrition quality of pome fruit crops

Tetiana Maliuk[1,3*], Pachev Ivan[2], Liliia Kozlova[1], Natalia Pcholkina[1] and Liubov Pokopseva[3]

[1] *Institute of Horticulture, Melitopol Research Fruit Growing Station Named "M. F. Sydorenko", 72311 Melitopol, Ukraine*
[2] *Institute of Viticulture and Enology, 5800 Pleven, Bulgaria*
[3] *Dmytro Motornyi Tavria State Agrotechnological University, 72310 Melitopol, Ukraine*
[*]*Corresponding author:* t.malyuk@ukr.net

Abstract

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The research is devoted to diagnostics mineral nutrition of fruit crops, particularly apples and pears, based on related study of soil properties changes, as a result of fertilization and complex of criteria that characterise the quality of plants nutrition. The research was held on the basis of field experiments that studied systems of mineral nutrition of pears and apples, taking the features of soil conditions of the South of Ukraine, age periods, and technology of growth in the lands of Melitopol fruit growing research station named after M.F. Sidorenko of IH of NAAS into consideration. Schemes of the experiments reckon for the study, the effect of application of different doses, methods, and ratios of nitrogen, phosphorus, and potassium in orchards on 4 pear varieties (Vesilna, Pektoral, Izuminka Krimu, Conference) and 2 apple varieties (Idared and Florina). It has been determined that the level of nutrients accumulation in southern chernozem and intensity of their absorption by the trees depend on changes of contents of nutrients as a result of fertilization, and hydrothermal regime of the soil as well. It has been also proved that balanced mineral nutrition increases overall resistance of fruit trees against unfavourable factors.

Keywords: diagnostics of nutrition; apple and pear orchards; herbal diagnostics; plant nutrition quality; yield optimal fertilization system

Introduction

Perennial fruit crops are of great importance for proper human nutrition. Their fruits have valuable nutritional qualities and are an important addition to the traditional monotonous diet of cereals and tubers (Srivastava & Malhotra, 2017). In addition, they play an important role in the economy of many regions of the world and world trade in general (Carranca et al., 2018). Ukraine also belongs to such regions. The country (especially the southern region), has soil and climatic conditions favorable for the cultivation of many deciduous fruit crops. The dominant crops are apple and pear trees. In general, Ukraine is one of the leaders in Europe in terms of apple tree cultivation area (Pereira-Lorenzo et al., 2009).

The application of mineral fertilizers is undoubtedly a powerful anthropogenic factor that affects the nutrition of fruit trees, determines the size of their yield and the quality of the fruit. Fertilizers alter the intensity of soil processes, activate microbiological activity, affect the physicochemical properties of the soil and soil solution, the quality and health of the soil (El-Ramady et al., 2004; White & Brown, 2010), and fruit trees react to these changes. The reaction of fruit crops to changes in the conditions of mineral nutrition is expressed in different manifestations of plant functions. This can be an increase in vegetative growth, an increase in the setting of fruit buds and fruit setting, a decrease in fruit cast, the process of formation and quality of fruits (Fallahi et al., 2010; Brunetto et al., 2015; Johnson, 2006; Uçgun & Gezgin, 2017). The combination of these elements ultimately consists of the fertilizers effect on the yield of trees, and this is the main indicator, when assessing the positive influence (or lack thereof) of the mineral fertilizers effect on plants (Lominadze et al., 2018; Scudellari et al., 1993).

As a result, if we establish the effect of mineral fertilizers on the agrochemical properties of the soil and the dependence of the plant nutrition quality on these changes, then it is possible to promptly manage productivity and control the environmental consequences of the application of fertilizers (El-Ramady et al., 2004; White & Brown, 2010). This is due to the fact that all production processes of plants are closely related to the nutritional ones, and it directly depends on the quality of the soil.

The diagnostics of soils and plants mineral regime attracts special attention of researchers. This is due to the need to predict the effect and aftereffect of fertilizers. Based on this, it is possible to clarify the optimal doses and the terms of their application (White & Brown, 2010; Fallahi et al., 2010; Pole, 2017; Maarschalkerweerd van & Husted, 2015).

Therefore, studies on the influence of different schemes of mineral fertilization on the complex of indicators of the soils nutrient regime and production processes of plants remain relevant. This includes the mandatory establishment of statistical links between indicators.

Various parameters are used for diagnostic purposes. These are the content of humus, common forms of elements in soil and plants, the ability of soils to accumulate mineral forms of elements during incubation, the photochemical activity of chloroplast suspension measurement, analysis of tree blossoms, and many others (Carranca et al., 2018; Bould et al., 1960; Angelis de et al., 2011; Pestana et al., 2001; Portela & Louzada, 2012). That is, the assessment of the plant nutrition quality can be carried out by different methods.

A debatable issue is the use of the plant method, or the soil method to determine the fertilizer requirements of plants. Nowadays and earlier, chemical analysis of soil is used much more often than analysis of mineral substances of plants. Marie van Maarschalkerweerd and Søren Husted report, for example, that fewer than 400 plant samples were registered in certified laboratories in Denmark during the 2012 growing season, and more than 100,000 soil analyzes were performed during the same period (Maarschalkerweerd van & Husted, 2015). To diagnose plant nutrition in the main elements, mineral nitrogen is most often used (the sum of $N\text{-}NO_3^-$ and $N\text{-}NH_4^+$), as well as mineral compounds P and K. For nitrogen, only $N\text{-}NO_3$ is used (Zhang, 2015; Maliuk, 2019). It is generally accepted that the analysis of soils is well suited for the diagnostics of plant nutrition and in some cases is a fairly reliable indicator of plant supply (Uçgun & Gezgin, 2017; Binkley & Vitousek, 1989; Franco-Hermida et al., 2017; Alva, 2006). Soil sampling in general has several advantages over the analysis of plant minerals and can be conveniently performed in less busy seasons, when there is no crop in the field (after harvest or before planting) (Maarschalkerweerd van & Husted, 2015).

At the same time, the availability of basic nutrients to plants often cannot be estimated using traditional methods of soil research, since they cannot reflect the complex chemical composition of the soil, the associated effects of the rhizosphere, and cannot show how many elements from the soil the plant will assimilate (Maarschalkerweerd van & Husted, 2015; Bould et al., 1960; Debnath, 2010; Quiñones et al., 2013). The same and other authors (Bould et al., 1960; Portela & Louzada, 2012; Quiñones et al., 2013), believe that foliar analysis is the most appropriate diagnostic criterion. In their opinion, soil analysis has a much lower efficiency and effectiveness for assessing the quality of plants nutrition, including fruit ones.

Other scientists believe that using only foliar analysis may lead to an incorrect result (Fallahi et a, 2010; Fischer, 2021; Menino, 2012). In addition, an important issue for the correct diagnostics of foliar mineral nutrition is the choice of an adequate period for the selection of foliage for analysis (Bould et al., 1960; Portela & Louzada, 2012; Quiñones et al., 2013). Mid-summer foliar analysis has traditionally been used as the standard method around the world for assessing the nutrition of fruit trees. But by this time it may be too late to correct nutrition disorders (Uçgun & Gezgin, 2017). The results of Regina Menino, 2012 also show that the quality of nutritional diagnostics is highly dependent on the interpretation of the same foliar analysis results. This is also noted in (Bould et al., 1960).

In addition, the diagnostics of the mineral nutrition of fruit crops is very difficult, because trees have a specific pattern of absorption and accumulation of elements by wood, roots and other organs (Carranca et al., 2018; Angelis de et al., 2011). And besides, mineral fertilizers affect not only the yield of the current year, but also the harvest of the next one (Angelis de et al., 2011).

Traditionally, soil and plant analysis results have been compared to critical nutrient ranges based on the probability that plants will respond to nutrient inputs (Brunetto et al., 2015; Bould et al., 1960; Portela & Louzada, 2012; Soler & Legaz, 2013; Menino, 2012). In some cases, other criteria are also considered, such as expected yield, plant growth, which can be estimated from the length of new sprouts and fruit analysis (Brunetto et al., 2015). But not all fertilization recommendations for temperate fruit crops are based on long-term regional studies. In addition, the optimal and critical ranges of the nutrients content in the same crops may differ depending on local conditions, may change over time under the influence of climate and soil conditions, depend on the variety, the emergence of new varieties, use of new technologies, etc. (Brunetto et al., 2015; Malyuk et al., 2014; Lucena, 1997).

To overcome the problem of low fertilizer efficiency and develop the right fertilizer system, it is important to find the right diagnostic criteria and tools that most closely correlate with yield and will allow timely detection and correction of nutrient substances in the field conditions (Maarschalkerweerd van & Husted, 2015; Samborski et al., 2009; Lemaire et al., 2008).

Due to the difficulties of diagnostics, various methods of complex assessment of the plants mineral nutrition have recently been used: taking into account the ratio of elements among themselves DRIS (Menino, 2012), the concentration and activity of chlorophyll in foliage (Sharma & Bali, 2018), a combination of indirect measurements of the status of an element with dynamic models of growth and development crops (Lemaire et al., 2008), complex plant analysis and analysis of soil extracts (Franco-Hermida et al., 2017). In the research of, foliar analysis identifies the most limited nutrients for a high yield, and soil analysis makes it easier to adjust the fertilizer composition for fertigation. Sharma, Bali, 2018 had summarized a very large array of experiments results with different crops, and they noted that one cannot use one diagnostic method separately, but using a combined approach can help to improve plant nutrition. Research in France (Ravier, 2018) has led to a new method based on 3 principles: regular monitoring plant nitrogen nutrition, accepting periods of nitrogen deficiency in crops, and modeling short-term nitrogen availability in soil using a crop model. They showed that by combining them together, an innovative fertilization method has been developed that is radically different from the dominant paradigm and is well received by users.

In connection with all of the above mentioned, it is of considerable interest to identify diagnostic indicators that most closely correlate with the yield of fruit trees and can be used to develop and adjust plant fertilization systems.

Problem setting

There is still a great need for research on the optimal mineral nutrition of fruit trees. This is the basis for the adequate application of mineral fertilizers and, as a result, will determine the economic competitiveness of fruit production and their environmental friendliness. This fact is consistent with the opinion of a number of scientists (White & Brown, 2010; Brunetto et al., 2015; Lucena, 1997) But the diagnostics of perennial plants nutrition is very difficult, because they have a complex regulation of the external factors impact (including mineral fertilizers) on different processes and yield (Carranca et al., 2018; White & Brown, 2010; Angelis de et al., 2011; Sharma & Bali, 2018). First of all, diagnostics should be based on a joint study of changes in the agrochemical properties of soils under the influence of fertilizers and a correct assessment of plants response to these changes. More complete information on the system “soil – fruit tree – fertilizer” and the assessment of mineral fertilizers effect on various indicators of this system will help in developing more efficient systems for fertilizing trees with nitrogen, phosphorus and potassium and reduce the environmental load on soil and plants.

Purpose and scope of work

The purpose of the study is to investigate the dynamics and accumulation of nitrogen, phosphorus and potassium compounds in the soil and foliage of fruit trees and the factors influencing this, to establish a relationship between different indicators of soil and plants and the yield of fruit trees in long-term field experiments with fertilizers. This, in turn, will help in the development of more efficient systems for fertilizing trees with nitrogen, phosphorus and potassium and will reduce the environmental load on soil and plants.

Objective, Scope and Method of Work

Characteristics of the research region

The research was carried out at Melitopol fruit growing research station named “M.F. Sidorenko” of IH of NAAS (46° 50′36.2″N 35°21′22.6″ E), Melitopol, Ukraine. Their duration was 10 years (2006–2015).

The climate of the research region is temperate continental, characteristic of the arid southern steppe zone of Ukraine. During the years of research, the average temperature for the year was 10.1–12.1°C, the amount of precipitation per year was 363-669 mm, during the active growing season (April–October) – 165–389 mm, the sum of active air temperatures > 10°C is 3400–3700°C. Weather data were collected during the experimental period from Melitopol meteorological station, which is located directly on the territory of the growing research station (Table 1).

Table 1. Meteorological indicators in the study region, 2006-2015

Indicator	Year									
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Average annual air temperature, °C	10.2	12.1	11.0	11.1	11.9	10.3	11.7	11.7	11.3	11.9
Annual precipitation, mm	550	370	383	486	669	471	337	363	543	458
Precipitation during the growing season (April-October), mm	373	165	280	182	379	370	178	170	389	238
Relative humidity, %	69	60	67	62	65	66	62	64	62	61

Characteristics of plantings

Apple (*Malus domestica* Borkh.) and pear (*Pirus communis* L.) orchards were planted during the research in 2003, using apple varieties Idared and Florina (rootstock M.9) and pear varieties Vesilna, Pektoral, Izuminka Krimu, Conference. The apple tree has a tree planting scheme of 4 × 1 m (2500 trees per 1 ha), a pear tree – 4 × 3 m (667 trees per 1 ha). The rootstock for the apple tree is M9, for the pear – Quince A. In the gardens there is irrigation with a stationary drip irrigation system, which helps to maintain soil moisture at a level of 75–80% of the full saturation of soil moisture with a free outflow of water.

The experiment included the application of different doses of mineral fertilizers. The dose range is $N_{30\text{-}120}P_{15\text{-}75}K_{15\text{-}75}$. All trees (except control ones) were fertilized every year. Ammonium nitrate, superphosphate, and potassium sulphate were used in the experiment. No fertilizers were used on the control variants. Each variant consisted of 6-10 trees and was randomly distributed, within 4-6 repetitions, that is, each variant included from 24 to 60 trees. There were 2-4 trees of protection between repetitions of variants in pear and apple orchards.

Characterization, sampling and analysis of soil

The soil of the apple and pear orchards is the same – Haplic Chernozems, ID 14-2, according to (IUSS Working Group, 2015), heavy loam (the soil has a heavy loamy texture). The parent rock of the soil is carbonate loess-like clays (parent rocks of these soils consist of carbonate loess-like clays).

A soil layer of 0-60 cm was mainly used in the studies. This is due to the fact that the root system of an apple tree on an M9 rootstock, as well as a pear on a quince A rootstock has a superficial location. The soil has the following average indicators: organic substance content 2.33–2.50%, pH (water) 7.7–7.9, total N – 0.17%, $CaCO_3$ – 4.5–6.5%.

Soil samples were taken during the growing season to a depth of 60 cm periodically, during the vegetation period (at least 4 times) to study the dynamics of nutrients. The terms of the selection were as follows: before fertilization, 1–3 times – during the period of active vegetative growth, 1–2 times during the laying of fruit buds and at the end of the vegetation. The soil was sampled with a soil drill with a cylinder diameter of 3 cm for each variant of the experiments in three repetitions at a distance of 0.5 m from the trunk of the tree in a row and in a row spacing.

The content of N-NO_3 и N-NH_4 was determined in soil samples using a spectrophotometer as described in (Houba et al., 2008; Houba et al., 1986). Mineral nitrogen (N_{min}) in the soil was determined as the sum of nitrates and ammonia.

Machigin's method was used to determine the content of phosphorus (P_2O_5) and potassium (K_2O). This method is based on the extraction of phosphorus and potassium mobile forms from the soil with a 1% solution of ammonium carbonate (pH 9) at a ratio of soil to solution of 1:20. The extracts stained with organic matter are decolourised prior to determination of phosphorus. This method is accepted as a standard for the determination of phosphorus and potassium in calcareous soils (black soils, chestnut soils, etc.). The extract is prepared as follows: 5 g of air-dry soil is placed in a 200–250 ml flask, 100 ml of a 1% ammonium carbonate solution is poured in, closed with a stopper and shaken on a rotator for 5 minutes. Then the flask is placed in a thermostat for 18-20 hours and kept at a temperature of 23–27°C. The suspension is shaken and filtered through a folded filter. The first portions of the filtrate are discarded. The filtrate should be clear. Phosphorus in the extract is determined as follows: 15 ml of the filtrate is transferred into a 50 ml volumetric flask, 35 ml of reagent B (a mixture of 30% sulfuric acid and potassium permanganate) is added and after 10 minutes it is colourimetried with a red filter, with a maximum transmission in the range of 600-750 nm. A T60V spectrophotometer was used for this. Determination of potassium is carried out on a flame photometer "Zeiss" from an aliquot of unbleached extract. If the extract is coloured with organic matter, it is discoloured as follows: 15 ml of the extract is transferred into a container made of heat-resistant glass, 2 ml of a mixture of 30% sulfuric acid and potassium permanganate is added, boiled for 2 min from the moment of boiling. After cooling, 36 ml of colouring reagent B are poured in. After 10 min, the solution is colourimetried.

Selection and analysis of foliage, yield accounting

For the analysis of plant material, the average foliage of growth shoots was selected from at least 15 trees in each variant, they were taken from 4 sides of the tree from the middle third of the branches of the year at a height of 1.5 m above the soil. In total, the sample contained at least 120 leaves. These leaves were washed and dried at 65°C until constant weight was reached and crushed to pass through a 1 mm diameter stainless steel mesh. After decomposition of the sample in a mixture of nitric and perchloric acid (Jones & Case, 1990) nitrogen (N) was determined in them with Nessler's reagent as described in (Hill-Cottingham & Wagner, 1962), phosphorus (P) was determined colourimetrically by the molybdenum-vanadium method, and potassium (K) was determined by flame photometry **(Varley, 1966).**

The yield of fruits from each tree (kg) was determined annually by taking into account their number and multiplying by the average weight of the fruit. The average fruit weight was determined as the average of 100 fruits. The yield of each tree was then multiplied by the number of trees per hectare to find out the yield per hectare (t/ha).

Statistical analysis

The data were subjected to ANOVA to test for significant differences based on the least significant difference (LSD) between fertilization doses for the average values of NPK content in the soil and foliage. Probability levels less than 0.05 were designated as significant and highly significant. Correlation and regression analysis were used to describe the relationship between NPK in soil, foliage, fertilizer doses, indicators of soil hydrothermal regime, and apple and pear trees productivity. They were carried out using software packages, including MS Excel, Statistica 10.0.

Research Results

Of considerable interest in this study is the identification of the mineral regime of soils and plants indicators, which most closely correlate with the productivity of apple and pear trees. This is important for determining the optimal system of fertilization in fruit plantations. In addition, they can be used to predict the yield of trees in a given condition because they are an important part of yield modeling (Grassini, 2015; Sardas, 2015). The solution to this can be the selection of an adequate mathematical model and the determination of the approximation error.

We carried out a correlation analysis and determined that in a number of cases there is a close relationship between the yield of apple and pear trees, doses of fertilizers, and indicators of the nutritional regime of the southern chernozem (Table 2).

The yield of certain crops (and fruit crops too) can be represented as a function $Y = f(X_1, X_2 \dots X_n)$, where Y is the yield; $X_{1 \dots} X_n$ – factors that determine it. This equation confirms that the yield is an indicator of many processes and, in addition to mineral nutrition, is influenced by many factors (Grassini, 2015; Sardas, 2015). But the purpose of our work was precisely to establish the relationship between the

Table 2. The relationship between the soil mineral regime indicators, the doses of fertilizers, and the productivity of apple and pear trees

X	У	Correlation coefficient, r	Error, S_r	Essentiality, r
$N–NO_3$	Yield	0.69	0.13	**
$N–NH_4$		–0.36	0.19	ns
$N_{min.}$		0.57	0.13	**
P_2O_5		0.74	0.10	**
K_2O		0.54	0.11	*
$N–NO_3^-$	$N_{min.}$	0.95	0.08	***
$N–NO_3$	P_2O_5	–0.23	0.18	ns
P_2O_5	$N–NH_4$	0.19	0.09	ns
$N_{min.}$	K_2O	–0.43	0.18	*
K_2O	$N–NO_3^-$	–0.44	0.19	*
$N_{min.}$	Dose	0.91	0.08	***
$N–NO_3$		0.98	0.07	***
P_2O_5		0.83	0.11	***
K_2O		0.72	0.11	**

ns – correlation is insignificant, * – correlation is significant from 95%, ** – significant from 99 %, *** – significant from 99.9% levels of probability

Table 3. Dependence of yield on the mineral regime of the soil

№	Variety	Regression equation	Rejection error, t/ha	R^2
Apple				
1	Idared	$У = 1.57 x_1 + 0.18 x_2 + 0.18 x_3 + 0.01 x_4 + 0.69 x_5$	± 1.3	0.95
2	Florina	$У = 2.01 x_1 + 0.32 x_2 + 0.17 x_3 + 0.02 x_4 + 1.01 x_5$.	± 1.6	0.93
Pear				
1	Conference	$У = 2.56 x_1 + 0.20 x_2 + 0.09 x_3 + 0.10 x_4 + 1.01 x_5$	± 1.5	0.95
2	Vesilna	$У = 2.07 x_1 + 1.19 x_2 + 0.51 x_3 + 0.01 x_4 + 1.08 x_5$	± 2.5	0.86
3	Izuminka Krimu	$У = 3.33 x_1 + 0.36 x_2 + 0.26 x_3 + 0.11 x_4 + 0.79 x_5$	± 1.9	0.96
4	Pektoral'	$У = 1.52 x_1 + 0.77 x_2 + 0.89 x_3 + 0.04 x_4 + 0.43 x_5$	± 2.8	0.85

Note: Y – yield, t/ha; x_1 – content N-NO_3 x_2 – content N_{min}; x_3 – content P_2O_5; x_4 – content K_2O; x_5 – dose NPK, kg/ha

level of plant nutrition and its yield and to choose the optimal methods for diagnostics.

Since a close relationship was established between these indicators in our studies, a regression analysis was carried out and dependences of yield on the mineral regime of the soil indicators in the phase of active vegetative growth were found (Table 3). This phase was chosen because it is still possible to influence the harvest of the current year. The following factors were analyzed as the determining ones: the content of mineral and nitrate nitrogen, mobile forms of phosphorus and potassium, as well as the dose of fertilizers.

The results of the dispersion analysis of the regression main factors of the apple and pear trees productivity showed that the content of N-NO_3 in the soil has the greatest influence (29.6–41.4%), and K_2O content in the soil has the lowest (up to 10%) influence.

At the same time, the relationship between yield and soil indicators in shape may not be linear, while the correlation coefficient may indicate the absence of a linear relationship in the presence of a close curvilinear one and does not provide an explanation for causal relationships. (Aggarwal & Ranganathan, 2016).

Taking into account the close relationship between the yield (y) and the content of N–NO_3^- (x) in the soil, as well as the ability to determine only nitrate nitrogen of the soil in Haplic chernozems to diagnose the nitrogen regime (Maliuk, 2019), the relationship between these indicators was analysed. This is useful for predicting the yield level of trees and clarifying the optimal ranges of elements content. The presence of a close relationship of the parabolic type was established for each apple tree variety and for the culture in general (Figure 1).

In addition, we analyzed the dependence of the P_2O_5 content in the soil with the response of fruit trees to fertilization. This should be done to improve the diagnostics of the phosphorus regime of Haplic chernozems. The relevance of this is associated with the often low efficiency of phosphorus fertilizers in the orchards of the south of Ukraine, despite the

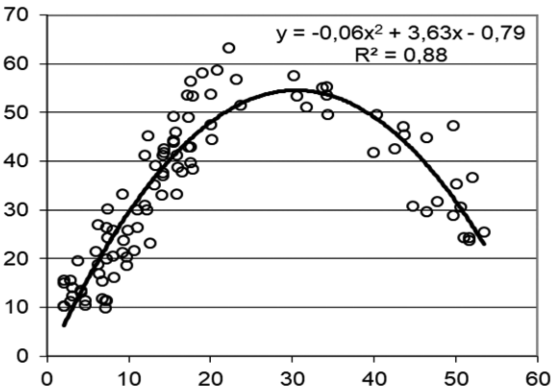

Fig. 1. Dependence of apple tree yield on the content of N–NO_3 in soil

rather high removal of phosphorus by pome crops and the insufficient level of soil supply with this element. Analysis of data for a 10-year period showed that, for example, for the formation of apple and pear trees productivity of more than 30 t/ha there should be P_2O_5 3.5–4.6 mg/kg in the soil (Figure 2). By the way, this corresponds to the average level of soil provision according to the gradations established for fruit crops (Rul'ev, 2003). Our studies have shown that if we further increase P_2O_5 in the soil due to an increase in fertilizer doses, then an increase in fruit yield does not occur. Similar regularities were obtained when processing data on the yield of apple and pear trees and the content of K_2O in the soil.

The level of NPK content in the soil, which ensured the receipt of the planned yield of high quality fruits and material resources economy (in this case, fertilizers) can be adopted as normative (optimal) in specific soil and climatic conditions.

Studies have also shown that the dynamics of NPK in Haplic chernozems under orchards is determined not only by the doses of fertilizers and the terms of soil sampling, but

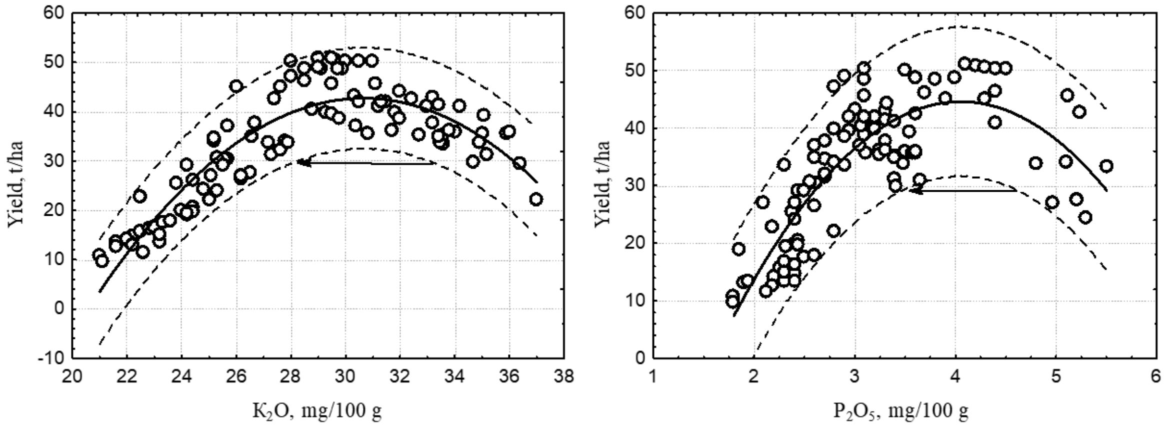

Fig. 2. Productivity of trees at different levels of phosphorus and potassium content in the soil (by the example of pear tree)

also by hydrothermal conditions. For example, soil moisture and temperature. For example, the mathematical analysis of the data showed that the proportion of the factor "fertilizer dose" influence on the N_{min} content in the soil was 28–46%, depending on the vegetation period of the trees. And the proportion of the combined influence of the factors "soil moisture" and "soil temperature" is 40–56%. There is also a difference in nitrogen forms: the change in N-NO_3 depended more on the hydrothermal regime of the soil (up to 77% of the influence), and the concentration of ammonia nitrogen depended more on the observation period. Strong variability of nitrogen in time and space and dependence on many factors is noted in other studies (Maliuk, 2019; Liu et al., 2014; Watts et al., 2010).

The dynamics of P_2O_5 in the soil depended more on the dose of phosphorus fertilizers, the proportion of which was 39% on average. The temperature and moisture content of the soil affected this indicator less (12–17% and 12–22%, respectively).

The content of K_2O had less change than other elements under the influence of these factors. This is due to the peculiarities of the soil-absorbing complex composition and the increased availability of this element to Haplic chernozems in the south of Ukraine.

As a result, we found that the formation of at least 30 t/ha of fruits occurs with such ranges of elements in Haplic chernozems: N-NO_3 – 12–24 mg/kg, P_2O_5 – 3–5 mg/100g, K_2O – 26–35 mg/100 g. This level is achieved by the annual application of moderate doses of mineral fertilizers. They should not exceed 20–40 kg/ha of active ingredient for potassium and phosphorus, 45–60 kg/ha of active ingredient for nitrogen.

The soil nutrition conditions can be monitored using foliar analysis, and the results are compared with the optimal values. But the optimal indicators differ among different authors, they are highly variable and depend on many factors (Brunetto et al., 2015; Malyuk et al., 2014; Lucena, 1997), therefore, they require clarification and adjustment, taking into account local conditions and variability of factors.

Our results showed a clear seasonal rhythm of changes in NPK concentration in apple and pear trees foliage. It manifests itself in a decrease in the content of elements during vegetation. The highest concentration of NPK in foliage (regardless of fertilization) was in the initial phases of vegetation and amounts to N – 2.6–3.7%, P – 0.28–0.37% and K – 1.3–1.5% absolutely dry mass (a.d.m.). Further, their concentration decreased during vegetation. This matches the data received by (Nachtigall & Dechen, 2006; Kuzin, 2020). In the second half of summer (the traditional term for diagnostics) there were the following data: N – 1.44–2.46%, P – 0.10–0.20%, K – 0.4–1.0% (Table 4).

Fertilizers had a significant, but controversial, effect on the NPK content in foliage. For example, the use of N-fertilization (alone and as part of NPK) significantly authentically increased the nitrogen content in the foliage of apple and pear trees by 0.04–0.7% in 97% of cases. A moderate correlation was found between the N-fertilization dose and the N content in the foliage (r = 0.46–0.52). A similar regularity was observed for potassium and phosphorus (r = 0.43–0.66). The use of P-fertilization did not significantly affect the concentration of this element in the foliage in most cases. The N content in the foliage had a significant relationship with the N-NO_3 content in the soil (r = 0.72–0.87). At the same time, the concentration of P and K in the foliage did not directly

Table 4. NPK content in apple and pear trees foliage in dependence on fertilizer doses (on average over the years of research), %

Dose NPK,, kg/ha	Variety of apple tree		Variety of pear tree			
	Idared	Florina	Conference	Izuminka Krimu	Vesilna	Pektoral
Total N						
N_0	2.01e	1.54e	1.88e	1.64c	1.44e	1.45d
N_{30}	2.12d	1.65d	2.00d	1.72bc	1.60c	1.50c
N_{45}	2.24c	1.69c	2.04c	1.88a	1.48d	1.49c
N_{60}	2.45b	1.81b	2.25a	1.79b	1.86a	1.55b
N_{90}	2.06e	1.96a	2.26a	1.89a	1.72b	1.58b
N_{120}	2.79a	1.97a	2.12b	1.90a	1.88a	1.83a
LSD_{05}	0.05	0.05	0.04	0.05	0.03	0.03
Total P						
P_0	0.11c	0.17c	0.12b	0.18a	0.18ab	0.12c
P_{15}	0.08d	0.17c	0.09c	0.16b	0.15c	0.15b
P_{30}	0.14b	0.19bc	0.09c	0.17ab	0.17bc	0.15b
P_{45}	0.18a	0.20a	0.09c	0.16b	0.15c	0.18a
P_{60}	0.18a	0.20ab	0.10c	0.19a	0.17abc	0.17a
P_{75}	0.20a	0.19ab	0.20a	0.15b	0.19a	0.19a
LSD_{05}	0.02	0.01	0.03	0.02	0.02	0.02
Total K						
K_0	0.65d	0.68e	0.66d	0.74a	0.59ab	0.44a
K_{15}	0.66d	0.64f	0.73c	0.78b	0.65ab	0.48c
K_{30}	0.63d	0.70d	0.76b	0.79b	0.61c	0.52c
K_{45}	0.87b	0.90b	0.84a	0.85a	0.61d	0.49d
K_{60}	0.81c	0.82c	0.82a	0.74c	0.63b	0.46c
K_{75}	0.96a	1.00a	0.79b	0.80a	0.66a	0.58b
LSD_{05}	0.04	0.02	0.03	0.02	0.02	0.02

depend on their amount in the soil in most cases. This confirms the difficulty of diagnosing nutrition (especially trees) and coincides with the ambiguous data obtained in other experiments (Maarschalkerweerd van & Husted, 2015; Bould et al., 1960; Sharma & Bali, 2018).

The analysis of the N content in the foliage was also used to identify factors that affect its uptake by fruit trees. The N content in apple and pear trees foliage was determined by a set of conditions: it decreased with increasing plant age, depended on soil moisture and temperature and the content of $N\text{-}NO_3$ in it. The most active input of N into plants was at a soil moisture content of 70–80% of the lowest moisture capacity, soil temperature of 22–26°C and an $N\text{-}NO_3$ content of 14.5–21.7 mg/kg (Figure 3).

These data were used for mathematical processing. We obtained the equation of multiple quadratic dependence, which shows the dependence of the nitrogen content in the

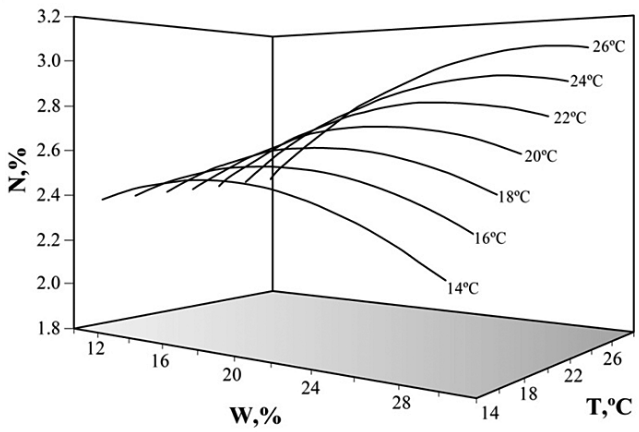

Fig. 3. Accumulation of nitrogen (N, %) in apple and pear trees foliage under the influence of soil temperature (T, °C) and moisture content in soil (W, %)

foliage of pome crops (for example, pear trees) on several factors (formula 7):

$$y = 2.87 + 0.39 \cdot x_1 + 0.02 \cdot x_2 - 0.6 \cdot x_3 - 0.5 \cdot 10^{-3} \cdot x_2^2 + 0.04 \cdot x_3^2 + 0.05\, x_3 \cdot x_4 + 0.001 \cdot x_4 \cdot x_2 - 0.18 \cdot x_1 \cdot x_{4,}$$

where y – N content in the foliage, %;

x_1 – N-NO_3 *co*ntent in the soil, mg/kg;

x_2 – soil humidity, %;

x_3 – observation period;

x_4 – soil layer temperature 0-20 *c*m, ^0C;

$r^2 = 0.986$, $p = 99$ %.

At lower soil temperatures (12–14^{0}C), the optimum moisture content for nitrogen absorption by fruit trees was within 18–20%. Raising the temperature linearly increases the nitrogen supply into the foliage. At sufficiently high moisture content (24–28%) and soil temperature (24–26°C), the content of this element reached its maximum values. The increase in N-NO_3 in the soil also causes the growth of N in the foliage. Similar regularities are observed for P and K. The highest absorption rate of these elements was when the content of P_2O_5 in the soil was 3.9–5.0 mg/100 g, K_2O –29–37 mg/100 g. If to use air temperature, but not soil temperature, the trees use NPK most productively at an air temperature of 26–28°C and an air humidity of at least 60%.

Thus, the maximum absorption of nutrients by trees occurs at high rates of soil and air moisture, a certain temperature and content of elements in the soil. But the maximum soil temperature together with low humidity (drought conditions) delay the absorption of elements by plants even with a sufficient level of NPK in Haplic chernozems.

In addition, we analyzed the relationship between apple and pear trees yield and NPK content in the foliage. This made it possible to refine the NPK optima for plant diagnostics. Fruit yield at the level of 30 t/ha and above with good quality can be with the content of N – 1.8–2.2%, P – 0.14–0.20%, potassium – 0.6–0.9 % in the foliage without significant differences between apple and pear trees. This is somewhat different from the average optima adopted in the south of Ukraine (Ruliev, 2003), which were higher, especially for K. But the research data and our earlier researches conducted by us (Malyuk et al., 2014) show that these ranges should be used for diagnostics. Their maintenance ensures high yields and fruit quality. The desire to achieve a higher level of elements in the foliage due to high doses of fertilizers does not lead to a significant increase in yield, reduces agronomic efficiency, and in most cases increases fertilizer losses and environmental pollution. The shift in element optima can be explained by changes in bioclimatic conditions, elements of cultivation technologies, expansion of variety-rootstock combinations, and, as a consequence, a change in the chemical composition of plants. Similar assumptions are described in (Brunetto et al., 2015; Malyuk et al., 2014; Lucena, 1997; Nachtigall & Dechen, 2006).

That is, the use of outdated optima for the development and refinement of doses, terms and methods of fertilization can lead to low agronomic and economic efficiency of fertilizers, an increase in their losses, as well as a violation of the ecological balance in the fruit agrocenosis.

Conclusions

The level of NPK accumulation in the soil and plants of apple and pear depends on the doses of fertilizers, temperature and soil moisture. A close relationship has been established between apple and pear trees productivity, fertilizer doses, indicators of the Haplic chernozems nutritional regimes and the chemical composition of the foliage.

Proper correction of the apple and pear trees mineral nutrition can be done by using the specified optimal NPK values in soil and foliage. Further research is needed on the interaction between nutrients to clarify the algorithm for adjusting the norm of the elements content during the growing season.

The data obtained can be used to monitor various methods of fertilization and to develop recommendations for the fertilization of apple and pear orchards in similar conditions.

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