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AGROCHEMISTRY.
SOIL SCIENCE

Effect of Local Fertilization and Water Reclamation on Soil Parameters of Orchard Cenoses

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Abstract—It has been proposed to estimate the spatial heterogeneity of soil parameters during the agrochemical soil survey of high-input orchards with consideration for the orchard design features and soil microvariability due to the local application of fertilizers by fertigation. Soil samples should be taken separately within and beyond the local fertilization sites. An indicator of the agrogenic differentiation of soil parameters at the local application of fertilizers with small-volume irrigation has been proposed.

Keywords: fruit orchards, drip irrigation, fertigation, leached chernozem, soil agrochemical properties, agrogenic differentiation of soils

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INTRODUCTION

Optimum water and nutritive conditions in orchard cenoses are created using local application of mineral fertilizers and small-volume irrigation, which ensure the formation of increased concentrations of nutrients and water in the zone of actively absorbing roots [1–4]. The high content of nutrients in the fertilization zone persists for a long time, usually longer than one vegetation period [5].

It is known from the literature that the long-term local fertilization of fruit plantations in combination with drip irrigation also affects the salt regime of soil at the localization sites of irrigation water [6, 7] and its microbiological activity [8] and provokes a nonuniform distribution of soil moisture [9, 10] and, hence, roots of fruit trees in the near-stem zone [11]. The agrogenic differentiation of soil properties in the root-inhabited zone of fruit trees has a higher effect on the variability of soil fertility than the natural genetic factors [12]. The determination of the variation features of soil fertility in orchard cenoses serves as the main criterion of the necessity and efficiency of differentiated fertilization [13].

EXPERIMENTAL

Studies were conducted within the typical zonal agrolandscape of an orchard cenosis under unsteady wetting conditions of Krasnodar krai. The soil cover consisted of extradeep, low-humus, light-clay leached chernozem on loess-like clays. The experiment was established in the high-input production plantations of winter apple trees on the dwarfing stock M9 of the Tsentral'noe farm. The trees were planted at distances of 4.5 × 1.2 m in the spring of 2009; the experimental plot area was 2.6 ha.

The study involved stepwise solutions of several problems.

I. Revelation of the spatial heterogeneity features of agrochemical and physicochemical properties of soils in the orchard cenosis. Split application of dissolved mineral fertilizers was performed using the drip irrigation system throughout the vegetation period. The single fertigation rate was N_4K_8. The fertilizers were applied with irrigation water five times; the fertigation was alternated with drip irrigation. The application rate of fertilizers during the fertigation of apple-tree plantations was $N_{20}K_{40}$ per vegetation period. The drip irrigation of fruit plantations was performed under droughty conditions at a rate of 25–28 m^3/ha every 3–5 days.

Georeferential precision agrochemical survey of soils in the orchard cenosis was performed in the course of study [14]. Soil samples were taken on a grid of 27 × 30 m over the entire orchard area. The configuration of elementary plots for taking an average soil sample (transect) depended on the tree distribution pattern; the plot width (27 m) was equal to the row spacing (6 tree rows), and the plot length (30 m) was equal to the distance between the trees (25 tress). A total of 32 elementary plots were set up; each mixed sample consisted of 24 individual samples. Soil samples were taken from the 0- to 30-cm layer separately within and beyond the sites of local application of mineral fertilizers during drip irrigation.

II. Determination of the differentiation parameters of chernozemic soils in the zone of local application of

Statistical parameters of leached chernozem fertility at the fertigation of apple tree plantations (0- to 30-cm layer)

Parameter	pH_{water}	Humus, %	Nitrate nitrogen, mg/kg	Ammonium nitrogen, mg/kg	Available phosphorus, mg/kg	Exchangeable potassium, mg/kg	Exchangeable calcium, meq/100 g	Exchangeable magnesium, meq/100 g	Exchangeable sodium, meq/100 g
Sampling beyond the localization zone of fertilizers and soil moisture									
Arithmetic mean, $\bar{X}_{mean}$	7.22 ± 0.16	3.47 ± 0.14	7.58 ± 2.13	7.11 ± 1.22	493.47 ± 107.35	251.53 ± 71.09	22.52 ± 1.02	5.11 ± 1.02	0.29 ± 0.09
X_{min}	6.96	3.22	4.40	4.70	315.00	184.00	20.33	2.94	0.16
X_{max}	7.50	3.66	14.30	9.70	735.00	525.00	23.81	6.15	0.44
Variation coefficient, %	2.26	4.14	28.11	17.16	21.75	28.26	4.55	20.05	32.58
Sampling within the localization zone of fertilizers and soil moisture									
Arithmetic mean, $\bar{X}_{mean}$	7.58 ± 0.10	3.38 ± 0.13	26.86 ± 11.94	11.85 ± 3.47	453.31 ± 104.87	344.03 ± 62.27	20.55 ± 1.64	7.83 ± 1.62	0.52 ± 0.07
X_{min}	7.34	3.15	11.00	8.20	299.00	236.00	16.18	4.28	0.42
X_{max}	7.83	3.53	63.50	25.10	722.00	525.00	23.00	11.05	0.65
Variation coefficient, %	1.26	3.95	44.44	29.28	23.13	18.10	8.03	20.72	13.98
Changes in soil parameters within the localization zone of mineral fertilizers									
Arithmetic mean, $\bar{X}_{mean}$	0.36	−0.09	19.28	4.74	−40.16	92.50	−1.97	2.72	0.23
X_{min}	0.12	−0.25	3.10	0	−114.00	0	−7.63	0.91	0.09
X_{max}	0.59	0	52.90	15.90	19.00	210.00	0.16	8.11	0.33

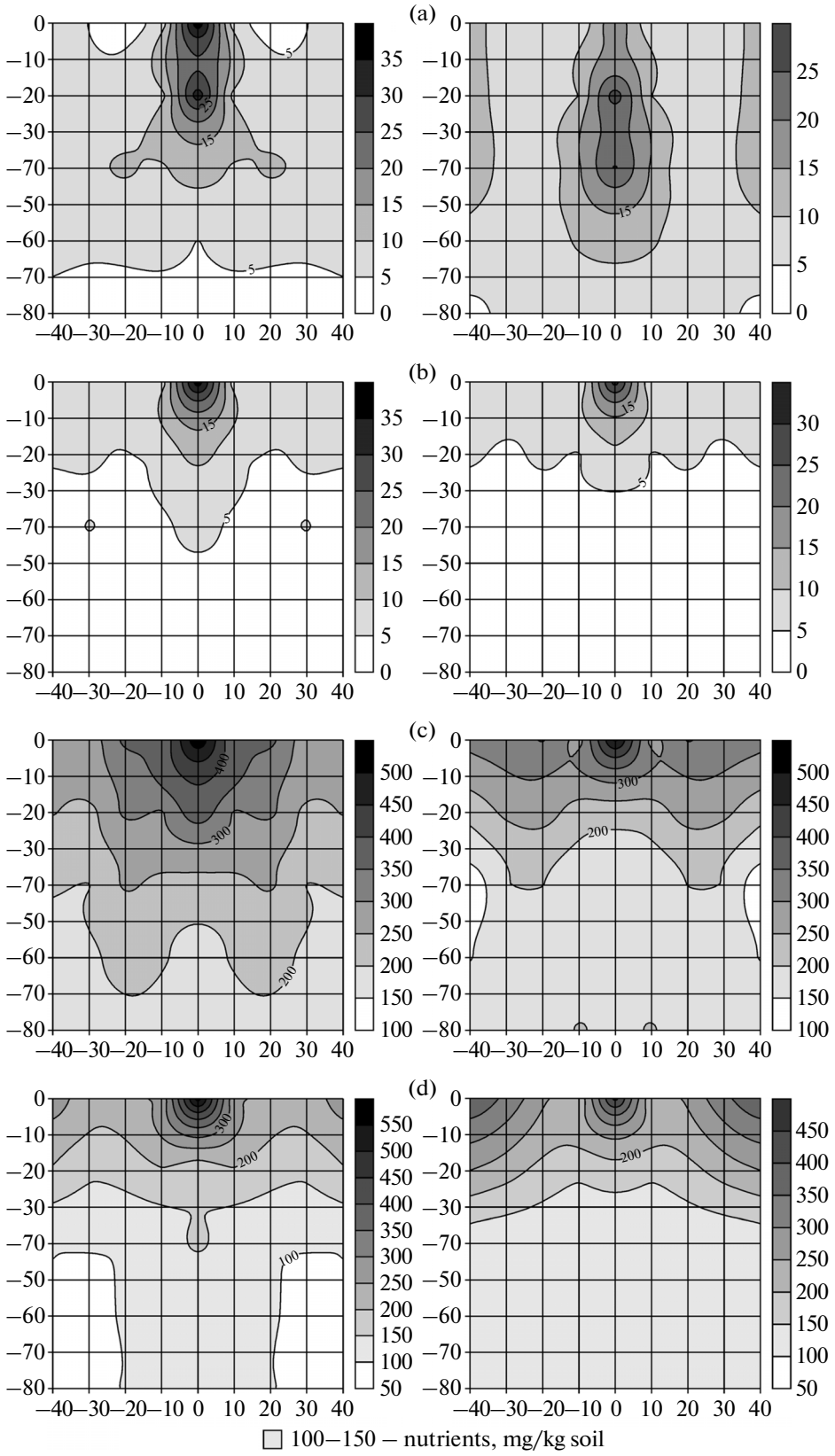
mineral fertilizers. The study was performed within one selected transect in the treatments with different application rates of mineral fertilizers: fertigation at a rate of $N_{60}P_{30}K_{60}$ and fertigation at a rate of $N_{30}P_{15}K_{30}$ + soil application of fertilizers at a rate of $N_{30}P_{15}K_{30}$. The local soil application of fertilizers was performed in early spring to a depth of 15–20 cm at 0.7–0.8 m from the tree stems. Soil samples were taken from the 0- to 10-, 10- to 30-, 30- to 50-, 50- to 70-, and 70- to 90-cm layers at the sites of irrigation water impact and with 10- or 20-cm intervals toward the row middle during the filling and ripening of apple fruits (August through September). The soil pH, mineral nitrogen forms ($N-NO_3$ and $N-NH_4$), available phosphorus and exchangeable potassium (the TsINAO modification of the Chirikov method), total humus, and exchangeable bases (Ca^{2+}, Mg^{2+}, and Na^+) were determined in the soil samples using the conventional procedures (Russian standards).

The analysis of experimental data was performed by mathematical statistics methods, including analysis of variance, using StatSoft Statistica 8.0 and Microsoft Office Excel 2003 software in accordance with the procedures of field experiments [15].

RESULTS AND DISCUSSION

Significant variation of soil fertility parameters was observed among the zones of soil sampling (table). At the local fertilization sites, the contents of nitrate nitrogen, ammonium nitrogen, and exchangeable potassium in the 0- to 30-cm soil layer increased by 19.3, 4.7, and 92.5 mg/kg on average compared to the corresponding values beyond the fertilizer application site. In the treatments without application of phosphorus fertilizers, the content of available phosphorus in the soil decreased at the irrigation sites by 40.2 mg/kg on average. The content of humus decreased by 0.1%, which could be related to the migration of labile humus forms with irrigation water throughout the soil profile and their more intensive degradation by microorganisms under optimum soil moisture conditions.

The presence of harmful alkaline salts in the irrigation water resulted in soil alkalization at the impact sites of mineral fertilizer solution drops; the soil pH increased by 5.0% on average. The soil exchange complex was also affected: at the localization sites of irrigation water, the content of exchangeable Ca^{2+} decreased by 1.97 meq/100 g on average, and the contents of exchangeable Na^+ and Mg^{2+} increased by 0.23 and 2.72 meq/100 g, respectively, compared to the initial values.



Contents of (a) nitrate nitrogen, (b) ammonium nitrogen, (c) available phosphorus, and (d) exchangeable potassium in the orchard soil in the localization zone of mineral fertilizers at the fertigation of apple trees (on the left, $N_{30}P_{15}K_{30}$ + soil application of fertilizers at the same rate; on the right, $N_{60}P_{30}K_{60}$); abscissa, distance from the point of drop impact toward the row middle; ordinate, distance from the point of drop impact deep into the soil.

Under fertigation conditions, higher variation coefficients were found for the contents of nitrate and ammonium nitrogen, available phosphorus, and exchangeable calcium than beyond the zone of fertilizer localization (table). For soil pH and the contents of humus and exchangeable potassium, the variation coefficients were lower, which was due to the formation of a more uniform background in the concentration zone of mineral fertilizers and irrigation water.

In the location zone of nutrients, the changes in soil fertility parameters varied, in spite of the similar fertilizer application rates ($N_{20}K_{40}$) and irrigation conditions. For the more objective assessment of nutritional conditions in the soil of orchard cenosis and the calculation of differential rates of fertilization, it is first necessary to understand the distribution of irrigation water and the migration of nutrients in the root-inhabited layer of soil in the fruit plantations.

The fertigation of apple tree plantations results in the formation of sites with increased nutrient concentrations, and the applied fertilizers have relatively small contact with the active roots of the fruit plants. Most nutrients were concentrated in the upper 0- to 30-cm soil layer at no more than 20 cm from the impact point of the nutrient solution.

The comparative study of changes of the soil parameters in the localization zone of mineral fertilizers depending on their application rates under fertigation showed that the increase in the fertilizer rates does not enhance the migration of nutrients in the soil. The shapes of the main zones of nutrient concentration were almost the same in all of the experimental treatments.

The highest concentration of nutrients in the localization zone of mineral fertilizers was observed for the combination of fertigation at a rate of $N_{30}P_{15}K_{30}$ with the soil application of fertilizers at the same rate. At the sites of the local application of fertilizers by fertigation, the contents of nitrate and ammonium nitrogen increased by 3.2 and 2.5 times, respectively, and the contents of available phosphorus and exchangeable potassium increased by 63 and 31%, respectively, compared to their concentrations in the analogous soil layer beyond the localization zone of fertilizers. During the period of apple ripening (September), no increase in the content of nutrients was observed at the sites of soil fertilization, which indicates an almost complete uptake of nutrients by tree roots (figure).

A lower increase in nutrient concentrations was observed at a fertigation rate of $N_{60}P_{30}K_{60}$. The different changes in soil parameters could be related to both the nonuniform uptake of the applied nutrients by apple trees and the partial transformation of nutrients into the forms hardly available to plants at the high application rates of fertilizers.

The prognosis of changes in the agrochemical properties of soil at the sites of the local application of mineral fertilizers requires continuous monitoring of soil fertility parameters in perennial plantations. In the calculation of the differential rates of mineral fertilizers, changes in the absolute parameters of soil agrochemical properties in this zone should be taken into consideration. Overfertilization can result in irreversible negative changes in the soil properties of orchard cenoses and a decrease in the productivity of perennial plants.

At the agrochemical survey of orchard cenosis soils, we propose to assess the spatial heterogeneity of soil parameters with consideration for the microdiversity due to the differentiation of soil properties caused by the application of mineral fertilizers. Soil sampling is recommended to be performed separately within and beyond the sites of local fertilization.

At the local application of mineral fertilizers with small-volume irrigation in fruit tree plantations, we propose to determine the degree of agrogenic differentiation of soil agrochemical properties (SD, %) from the following equation:

$$SD = (a - b) \times 100/b,$$

where a and b are the parameters of soil within and beyond the localization zone of mineral fertilizers, respectively, and 100 is the conversion factor to percentage.

The high values of SD indicate a significant change of soil properties in the localization zone of mineral fertilizers; however, SD is only a relative indicator. Its practical use for the correction of fertilizer rates showed its imperfection as a universal parameter. Therefore, we propose to introduce an additional correction factor (depending on the change in the absolute parameters of nutrient supply in the localization zone of mineral fertilizers) in the calculation of differential application rates of mineral fertilizers in fruit plantations. This will allow correcting the rates of mineral fertilizers with consideration for both the nutrient supply of soil and the degree of soil fertilization in this zone. This also requires the thorough elaboration of the soil classification based on the supply with mobile nutrients.

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REFERENCES

1. Ionova, Z.M. and Boiko, S.I., *Osnovnye dostizheniya v primenenii kapel'nogo orosheniya* (Major Achievements in the Application of Drip Irrigation), Moscow: VNIITEISKh, 1985.
2. Neilsen, G.H., Heilseh, D., Herbert, L.C., and Hogue, E.J., Response of apple to fertigation of N and

K under conditions susceptible to the development of K deficiency, *J. Am. Soc. Hortic. Sci.*, 2004, vol. 129, no. (1), pp. 26–31.

3. Ana Quicones, Belén Martinez-Alcántara, and Francisco Legaz, Influence of irrigation system and fertilization management on seasonal distribution of N in the soil profile and on N-uptake by citrus trees, *Agric., Ecosyst. Environ.*, 2007, vol. 122, pp. 399–409.
4. Fomenko, T.G., Popova, V.P., and Ivanov, A.I., Differentiation of properties of chernozem soils under local methods of irrigation and fertilizer application, *Probl. Agrokhim. Ekol.*, 2012, no. 4, pp. 8–13.
5. Korobskoi, N.F., *Agroekologicheskie problemy povysheniya plodorodiya chernozemov Zapadnogo Predkavkaz'ya* (Agri-Environmental Problems of Increasing Fertility of Chernozems of the Western Ciscaucasia), Pushchino: ONTI PNTs RAN, 1995.
6. Voevodina, A.N., Effect of drip irrigation on soil salinity, *Politematich. Setevoi Elektron. Nauchn. Zh. Kubanskogo Gos. Agrar. Univ.*, 2010, no. 64(10).
7. Popova, V.P. and Fomenko, T.G., Change in properties of chernozems of the north caucasus during drip irrigation of fruit orchards, *Russ. Agric. Sci.*, 2012, vol. 38, no. 3, pp. 226–229.
8. Venera, T. and Krasimov, K., Microbiological characteristics of the soil in different modes of drip irrigation in apple orchards, *Pochvoznan. Agrokhim. Ekol.*, 2002, no. 1–3, pp. 66–68.
9. Lubana, P.P.S. and Narda, N.K., Modelling soil water dynamics under trickle emitters—A review, *J. Agric. Eng. Res.*, 2001, vol. 78, no. 3, pp. 217–232.
10. Dubenok, N.N., Borodychev, V.V., Lytov, M.N., and Belik, O.A., Features of the water regime of the soil under drip irrigation of crops, *Dostizh. Nauki Tekh. APK*, 2009, no. 4, pp. 22–25.
11. Sokalska, D.I., Haman, D.Z., Szewczuk, A., Sobota, J., and Derec, D., Spatial root distribution of mature apple trees under drip irrigation system, *Agric. Water Manage.,* 2009, vol. 96, no. 6, pp. 917–924.
12. Beng P. Umali, Danielle P. Oliver, Sean Forrester, David J. Chittleborough, John L. Hutson, Rai S. Kookana, and Bertram Ostendorf, The effect of terrain and management on the spatial variability of soil properties in an apple orchard, *Catens*, 2012, vol. 93, pp. 38–48.
13. Aggelopoulou, K.D., Pateras, D., Fountas, S., and Gemtos, T.A., Soil spatial variability and site-specific fertilization maps in an apple orchard, *Precis. Agric.*, 2011, vol. 12, no. 1, pp. 118–129.
14. Yakushev, V.P. and Yakushev, V.V., *Informatsionnoe obespechenie tochnogo zemledeliya* (Information Support for Precision Agriculture), St. Petersburg: PIYaF RAN, 2007.
15. Dospekhov, B.A., *Metodika polevogo opyta (s osnovami statisticheskoi obrabotki rezul'tatov issledovanii)* (Field Experiment Methods (with Basics of Statistical Processing of Research Results)), Moscow: Agropromizdat, 1985.

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