Productive moisture stock assessment in the apple orchards soils of forest steppe north

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Abstract. The research was carried out in the north of forest steppe zone of Russia. The research subjects are soils under which apple trees of fruit-bearing age are located (16-24 years). Over the years of the research 50 soil cuts were laid in the apple orchards. United soil samples were formed by mixing the samples from near-stalk stripes and row-spacing. The total depth of searched cuts was 220 m. All the soil moisture capacity categories were determined by thermostat weight method: maximum water adsorption after airy dry soil condition in desiccators at air humidity close to 100%, limit field or the least soil moisture capacity after moist soil condition on the plaster casts and after free gravitational moisture coming down the profile on the flooded areas, the capillary bonding breakage humidity by multiplication of limit field soil moisture capacity and coefficient of 0.6. The total moisture stock was calculated as multiplication of soil density, layer thickness and limit field soil moisture capacity. Remote moisture stock was calculated as multiplication of soil density, layer thickness, maximum water adsorption and coefficient of 1.37. It was established that limit field soil moisture capacity significantly varies not only within one searched farm but inside soil type and soil subtype. Productive moisture stock in spring in ploughing soil layer occupied by the apple orchards of forest steppe north are described as good and represent 406-720 m$^3$/ha (41-72 mm). Productive moisture stock in one-meter soil layer of apple orchards are assessed as very good and vary from 2993 to 4822 m$^3$/ha (293-482 mm). According to productive moisture stock increasing in a meter layer apple orchards soils of forest steppe north can be placed in the following order: podzolic chernozem < chernozem moist meadow < grey forest < chernozem meadow < typical chernozem < leached chernozem < meadow chernozem < meadowish chernozem.

1. Introduction
Soil moisture is very important in apple orchards irrigation by means of subsurface infiltration [1] and soil pit method [2]. If soil humidity is expressed as a percentage of its least moisture, a very significant indicator arises that allows comparing soils in humidity rate even if they have different density and moisture capacity [3]. The application of organic fertilizers to the soil in the form of compost allows to raise soil moisture capacity [4]. It is necessary to be aware of moisture stock in the apple orchards soil in the study of mulching [5] and orchard water consumption [6]. Moisture stock in the soil is decreasing with the age of an apple orchard [7]. Starting from the 10th year of apple tree life moisture stock in the orchard soil is substantially lower than in the ploughing soils of field crop rotation. These variations increase by an orchard age of 19 years [8]. The purpose of our research is the assessment of productive
moisture stock in the soils of different types occupied by apple orchards in fruit-bearing age in the north part of Russian forest steppe zone.

2. Materials and methods

The research was conducted in 2000-2019. The objects of the search are the soils under which apple orchards of fruit-bearing and older ages (16-24 years) are located. Over the years of the research 50 soil cuts were laid in the apple orchards on the dwarf (62-396), semi-dwarf (54-118) and tall (seed) rootstocks. Tree allocation schemes are 5X3, 6X4 and 7X7 m. The apple varieties were Lobo, Melba, Mantet, Sinap Orlovsky, Northern Sinap, Zhigulevskoe, Wealthy, Pervenets, Streifling, Kitaika, Vishnyovoe, Spartan. The row-spacing in the orchards were held under the black steam. In spring harrowing was carried out by harrows BZL-0.6 3-5 cm deep. During summer as soon as weeds emerged the soil in the row-spacing was cultivated 5-6 times to the depth of 3-5 cm. KSG-5 cultivators and BDST-2.5 disk harrows were used for soil cultivation alternately. Once every four years ploughing was carried out by PLS-6-25 plow to the depth of 30-40 cm. Soil selection was conducted according to V.V. Tserling and L.A. Egorova’s methodological guidelines [9] from transitional (AB), illuvial (B), genetic horizons as well as from parent rocks (C). United soil samples were formed by mixing the samples from near-stalk stripes and row-spacing. The total depth of searched cuts was 220 m that coincided with the most rooting soil zone. Laboratory tests were carried out on the base of biochemistry laboratory of Michurinsk State Agrarian University (2000-2009), research laboratory of Michurinsk affiliate with Russian University of Cooperation (2010-2013) and research agrochemical laboratory of Yelets State Ivan Bunin University (2014-2019). All the moisture capacity categories were determined by thermostat weight method: maximum water adsorption (MA) after airy dry soil condition in desiccators at air humidity close to 100%, limit field or the least soil moisture capacity (LM) after moist soil condition on the plaster casts and after free gravitational moisture coming down the profile on the flooded areas, the capillary bonding breakage humidity (CBH) by multiplication of LM and coefficient of 0.6. The total moisture stock (TMS) was calculated as multiplication of soil density, layer thickness and LM. Remote moisture stock (RMS) was calculated as multiplication of soil density, layer thickness, MA and coefficient of 1.37. Multiplication of 1.37 MA corresponds to useless, inaccessible moisture for plants. It is lower than permanent wilting moisture. Productive moisture stock (PMS) was calculated as difference between TMS and RMS. Soil density was calculated by cutting cylinders method [10]. Calculations of productive moisture stock was based on A.F. Vadyunina and Z.A. Korchagina’s methodology [11], assessing moisture stock was estimated on N.A. Kachinsky’s scale: less 200 m$^3$/ha is insufficient stock, 200-390 is sufficient stock, more 400 is good stock. Assessing productive moisture stock in 0-100 cm layer the following scale was applied: less 900 m$^3$/ha is poor stock, 900-1300 is sufficient stock, 1300-1600 is good stock, more 1600 are very good stock [12].

3. Results and discussion

From all hydrological constants least (limit, field) moisture capacity has a great impact on available moisture stock for an apple tree in the soil. Therefore it should be examined further. On the example of the fruit-growing farm LLC «Timiryazevo» Dolgorukovsky district Lipetsk region it is obvious that LM achieves maximum in humus horizon (A) oftener, in transitional horizon less often (AB) (table1).

As A and AB horizon have nearly identical properties, we positioned humus horizon quantity as sum of A and AB. In the soils of LLC «Timiryazevo» on average horizon thickness A was 53 cm, AB was 79 cm, B was 52 cm, and parent rock started from 184 cm deep. The quantity of LM doesn’t depend on humus horizon thickness (A+AB) and layer depth but on the quantity of organic substantives and alphtitie in the soil [13]. Therefore LM significantly varies not only within one researched farm but inside the soil type (chernozem) and the soil subtype (podzolic).
IOP Conf. Series: Earth and Environmental Science 548 (2020) 062003    doi:10.1088/1755-1315/548/6/062003

Table 1. Least moisture capacity in apple orchards soil in LLC «Timiryazevo», % of the dry weight mass.

| Genetic horizon | Chernozem meadow (A+AB=110 cm) | Podzolic chernozem A+AB=140 cm | Podzolic chernozem A+AB=178 cm | Leached chernozem (A+AB=170 cm) |
|-----------------|--------------------------------|-------------------------------|-------------------------------|--------------------------------|
|                 | Mass, g/m³                     | CBH, %                        | LM, %                         | TMS, m³/ha                     |
| A               | 56.78                          | 57.26                         | 48.47                         | 39.72                          |
| AB              | 45.9                           | 49.76                         | 25.82                         | 56.0                           |
| B               | 29.91                          | 53.29                         | 31.3                          | 50.15                          |
| C               | 48.24                          | 41.02                         | 47.87                         | 40.62                          |

Since 70% of apple roots are in the layer of 0-100 cm [14] and assessment moisture stock in 1 meter soil layer is most appropriate for an apple-tree, we'll lead all the key moisture categories to the depth of 100 cm. On the basis of S.F. Negovelev and V.F. Valkov’s recommendations for loamy soils [15] in the years of our research soil density in 1 meter chernozem layer varied from overmellow to mellow, grey forest, chernozem moist meadow, meadowish chernozem, and meadow chernozem soils had density of hard enough, and chernozem meadow soil density was of solid condition (table 2).

Table 2. Productive moisture stock in chernozem soils.

| Layer, cm | Soil density, g/cm³ | MA, % | CBH, % | LM, % | TMS, m³/ha | RMS, m³/ha | PMS, m³/ha |
|-----------|---------------------|-------|--------|-------|------------|------------|------------|
| 0-10      | 1.07                | 13.47 | 26.97  | 44.95 | 480.96     | 197.46     | 283.5      |
| 10-55     | 1.2                 | 9.33  | 27.68  | 46.13 | 2491.02    | 690.23     | 1800.79    |
| 55-80     | 1.3                 | 11.43 | 26.53  | 44.22 | 1437.15    | 508.92     | 928.23     |
| 80-100    | 1.36                | 10.34 | 24.04  | 40.07 | 1089.9     | 385.3      | 704.6      |

| Layer, cm | Soil density, g/cm³ | MA, % | CBH, % | LM, % | TMS, m³/ha | RMS, m³/ha | PMS, m³/ha |
|-----------|---------------------|-------|--------|-------|------------|------------|------------|
| 0-10      | 0.96                | 9.63  | 27.29  | 45.48 | 436.6      | 126.65     | 309.95     |
| 10-65     | 1.15                | 11.02 | 29.29  | 48.82 | 3101.29    | 959.06     | 2142.23    |
| 65-100    | 1.31                | 9.51  | 26.62  | 44.37 | 2034.36    | 597.36     | 1437.0     |

| Layer, cm | Soil density, g/cm³ | MA, % | CBH, % | LM, % | TMS, m³/ha | RMS, m³/ha | PMS, m³/ha |
|-----------|---------------------|-------|--------|-------|------------|------------|------------|
| 0-10      | 1.05                | 10.76 | 20.44  | 34.07 | 357.73     | 154.78     | 202.95     |
| 10-64     | 1.12                | 11.03 | 22.3   | 37.17 | 2258.07    | 917.99     | 1340.08    |
| 64-80     | 1.24                | 9.52  | 24.46  | 40.77 | 808.87     | 258.76     | 550.11     |
| 80-100    | 1.32                | 9.52  | 26.92  | 44.86 | 1184.3     | 344.32     | 839.98     |

The soil density ranges from 1.3 to 1.35 g/cm³ is considered to be optimal for apple roots activity [16]. It means that on this indicator typical, leached and podzolic chernozem are considered to be the best soils for an apple tree in the forest steppe north conditions.

Soil maximum water adsorption within 0-100 cm layer was approximately at the same level in all examined chernozem soils. The capillary bonding breakage humidity (CBH) shows the soil condition when water movement in capillaries up, down and horizontally stops. Meanwhile, it was horizontal water movement that influences soil salt balance [17]. According to our estimates CHB also turned out to be inert and was observed at the level of 20.4-28.8% in chernozem soils. The least soil moisture capacity of chernozem soils was 30.0-57.3%.

Productive moisture stock in the ploughing layer (0-20 cm) of all three examined chernozem soils in the apple orchards were good and amounted 406-620 m³/ha. Productive moisture stock in 1 meter chernozem layer was very good and amounted (m³/ha): typical soils 3717.12; leached soils 3889.18; podzolic soils 2933.12.

Productive moisture stock in 0-20 cm layer in meadow chernozem and meadowish chernozem soils was good and amounted (m³/ha): meadowish chernozem 4822.24; meadow chernozem 4070.0 (table 3).
Table 3. Productive moisture stock in meadow chernozem soils.

| Layer, cm | Soil density, g/cm³ | MA, % | CBH, % | LM, % | TMS, m³/ha | RMS, m³/ha | PMS, m³/ha |
|-----------|---------------------|-------|--------|-------|------------|------------|------------|
| Meadowish chernozem | 0-10 | 1.14 | 10.16 | 26.1 | 43.5 | 495.9 | 158.68 | 337.22 |
| | 10-60 | 1.5 | 8.68 | 28.5 | 47.5 | 3562.5 | 891.87 | 2670.63 |
| | 60-100 | 1.31 | 9.76 | 28.8 | 48.0 | 2515.2 | 700.65 | 1814.55 |

Productive moisture stock in 0-20 cm layer of waterlogged soils were very good and amounted 550 m³/ha. Available moisture stock for an apple tree in 1 meter layer of these soils was very good and amounted (m³/ha): chernozem meadow 3625.49; chernozem moist meadow 3042.67 (table 4).

Table 4. Productive moisture stock in waterlogged soils.

| Layer, cm | Soil density, g/cm³ | MA, % | CBH, % | LM, % | TMS, m³/ha | RMS, m³/ha | PMS, m³/ha |
|-----------|---------------------|-------|--------|-------|------------|------------|------------|
| Chernozem meadow | 0-10 | 1.04 | 10.24 | 24.41 | 40.68 | 423.07 | 145.9 | 277.17 |
| | 10-68 | 1.41 | 8.69 | 24.82 | 41.36 | 3382.42 | 973.61 | 2409.44 |
| | 68-100 | 1.59 | 12.18 | 21.08 | 35.14 | 1787.92 | 849.01 | 938.91 |

Chernozem moist meadow

| Layer, cm | Soil density, g/cm³ | MA, % | CBH, % | LM, % | TMS, m³/ha | RMS, m³/ha | PMS, m³/ha |
|-----------|---------------------|-------|--------|-------|------------|------------|------------|
| 0-10 | 1.1 | 8.79 | 22.4 | 37.33 | 410.63 | 132.46 | 278.17 |
| 10-50 | 1.4 | 12.22 | 23.1 | 38.5 | 2156.0 | 937.52 | 1218.48 |
| 50-100 | 1.45 | 15.88 | 25.85 | 43.08 | 3123.3 | 1577.28 | 1546.02 |

Grey forest soils occupied by apple commercial orchards had significantly less MA, CBH and LM than chernozem soils. However PMS in these soils is higher than in podzolic chernozem or chernozem moist meadow soils. The reason is that all genetic horizons of grey forest soils have high density.

Productive moisture stock in the ploughing layer of grey forest soils of apple orchards was good and amounted 430 m³/ha (table 5).

Table 5. Productive moisture stock in grey forest soils.

| Layer, cm | Soil density, g/cm³ | MA, % | CBH, % | LM, % | TMS, m³/ha | RMS, m³/ha | PMS, m³/ha |
|-----------|---------------------|-------|--------|-------|------------|------------|------------|
| 0-10 | 1.38 | 6.06 | 14.33 | 23.88 | 329.54 | 114.57 | 214.97 |
| 10-25 | 1.42 | 3.45 | 15.82 | 26.36 | 561.47 | 100.67 | 460.8 |
| 25-35 | 1.44 | 7.03 | 13.46 | 22.44 | 323.13 | 138.68 | 184.45 |
| 35-100 | 1.46 | 8.14 | 22.16 | 36.94 | 3505.6 | 1058.3 | 2447.3 |

Available moisture stock for an apple tree in 1 meter layer of grey forest soils was very good and amounted 3 m³/ha 307.52 m³/ha.

4. Conclusion

The Productive moisture stock in spring in the ploughing layer of the soil occupied by apple trees of forest steppe north is characterized as good and amounted 406-720 m³/ha (41-72 mm).

Productive moisture stock in 1 meter layer of apple orchards soils is assessed as very good and vary from 2933 to 4822 m³/ha (293-482 mm).

According to productive moisture stock increasing in a meter layer apple orchards soils of forest steppe north can be placed in the following order: podzolic chernozem < chernozem moist meadow <
grey forest < chernozem meadow < typical chernozem < leached chernozem < meadow chernozem < meadowish chernozem.

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