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Recharging infiltration of precipitation water through the light soil, in the absence of surface runoff

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Abstract

The article presents the value of recharging infiltration of precipitation through the light soil and its distribution over time, based on five-year of lysimetric research. The effect of organic and mineral fertilization on the infiltration was studied. In lysimeters does not occur the phenomenon of surface runoff, and thus, by analogy, the results of the research can be applied to agriculturally used lowland areas with sandy soils. The results showed that the infiltration is very changeable in time. On its value, in addition to precipitation, the greatest influence has evapotranspiration. The largest infiltration occurs in March after the spring thaws (*IE* = 70–81% monthly precipitation) and the smallest in August (*IE* = 1.2–15.0% precipitation, depending on the type of fertilizer used and the level of fertilization). The soil fertilization, especially by using organic fertilizer (compost), is a factor, which has significantly influence on reduction of the recharging infiltration. The soil fertilization with compost reduced the infiltration of 7.4–9.0%, and with mineral fertilization of 5.4–7.0% of annual precipitation totals, compared with the infiltration through the soil not fertilized. The average annual index of infiltration was 21.8–25.3% of annual precipitation totals in variant of soil fertilized and 30.7% in case of the soil not fertilized.

Key words: *infiltration, light soil, precipitation, water resources*

INTRODUCTION

Groundwater resources are supplied and recharged by precipitation penetrated deep into the soil. One of methods for the groundwater resources renewable determination it is to estimate the effective rainfall infiltration of the first water – bearing level [HERBICH *et al.* 2013; TARKA 2001]. According to the Dictionary of Hydrogeological, published by Polish Geological Institute a rainfall effective (successful) it is a part of the water coming from precipitation which after reduction of the volume associated with runoff, evapotranspiration and with the process of molecular binding forces of the soil grains in the unsaturated zone, gets into the saturation zone and groundwater supplies [BOCHEŃSKA *et al.* 2002].

Effective infiltration (*IE*) can be expressed by the following formula:

$$IE = P - S - ET - R \tag{1}$$

where: P = precipitation, S = surface runoff, ET = evapotranspiration, R = molecularly bound water in the soil (ground).

An infiltration and a level of groundwater supply depends mainly on size of precipitation, the permeability of the soil, retention properties, landform and its plant cover, surface runoff and evapotranspiration. Precipitation can soak into the soil and penetrate into the groundwater run down to the surface receivers and back to the atmosphere by field evaporation processes (evaporation from the free surface of the water and the soil, transpiration and sublimation).The decisive factor in the distribution of rainfall for the different phases of water cycle has an active surface formed by soils and vegetation. In addition to the size of the active surface area of precipitation affects the intensity of infiltration, surface runoff and soil retention [MICHALCZYK 2004]. Elements of water balance also largely depend on catchment usage [GRAF, KRAJEWSKI 2013; MIODUSZEWSKI 2009]. The amount of rainwater infiltrated groundwater also depends on the type of agriculture fertilizers used and fertilization level [CZYŻYK, RAJMUND 2013; 2014]. Renewability of groundwater resources is the result of many factors and it is practically difficult to determine precisely. This applies especially to areas of varying land shape, high soil volatility and changing in soil use. To determine the sustainability of groundwater resource they use different methods mainly based on determining the rate of infiltration linked with the type of rock (ground) and layers of subsurface lithology or for the analysis of natural fluctuations of the water level in hydrogeological holes. Reported in the literature evaluation of renewable sources of groundwater, are determined by various methods, so they are so widely divergent [PACZYŃSKI *et al.* 1996; TARKA 2001]. The effective infiltration in the catchment plains with a single type of soil can be assessed relatively accurately. On the flat the plain with well permeable light soils, surface runoff do not occur or are negligible and are not a significant element of water balance. In this study the size and time distribution of effective infiltration of rainwater through the soil light, established by method of lysimetric studies, conducted in the five-years period are presented.

Lysimeters conditions were similar to natural field conditions in lowland area, where there is no runoff of rainwater. The actual volume of rainwater infiltrated aquifer is practically immeasurable using methods of the field. Lysimeter studies allow measure its precise.

MATERIALS AND METHODS

The study was conducted from April 1, 2002 to March 31, 2007, in lysimeters filled with slightly loamy, containing 13% of earthy fraction parts (<0.02 mm), 24.8% of the dust parts (0.02–0.1 mm) and 62.2% of sand (0.1–1.0 mm). Lysimeters with a diameter of 100 cm and 130 cm deep are completely submerged in the ground. The soil in the lysimeters was fertilized with two types of fertilizers (compost and mineral fertilizers). The conditions in the lysimeters were similar to the natural conditions of the land used for agricultural purposes (crop rotation and fertilization). In subsequent years, the research lysimeters were sown with a mix of grasses, corn, sugar beets, yellow mustard and triticale. In order to investigate the effect of the fertilizer applied on infiltration following variants were used: "0" – without fertilization, two variants with organic fertilizing using compost K1 – 10 g $\mathrm{N \cdot m^{-2}}$, and K2 – 15 g $\mathrm{N \cdot m^{-2}}$, and two variants of mineral fertilization: NPK1 and NPK2 and the equivalent doses of N in the form of ammonium nitrate and PK in the form of superphosphate and potassium salt. All variants were introduced in triplicate. The research began in the last days of March 2002 under full soil moisture (the moment of the disappearance of lysimeters leachate), and was completed at the turn of March and April 2007 in the same moisture conditions. In this case, spreads rainwater from the entire study does not take into account the volume of water retained in the soil.

RESULTS AND DISCUSSION

Individual years of the study period were significantly different in terms of size of precipitation (Tab. 1). Assuming that in the area of Wroclaw annual rainfall are less than 500 mm, with a probability of 50-100%, refer to dry years, the year 2003 can be considered to be dry [DUBICKI *et al.* 2002].Years of total precipitation exceeding 600 mm are included while the wet so 2005 (697.5 mm) and 2006 (613.7 mm) years were wet. Other years can be classified in terms of the average size of precipitation. More accurate assessment of the conditions of precipitation (humidity) is obtained using the criteria defined by KACZOROWSKA [1962] according to which the individual years are:

- average, if the annual rainfall is between 90–110% of average of sum in a long-term,
- dry when total precipitation is 75–90% of average of sum in a long-term,

Table 1. Precipitations (mm) at the Research Station of the Institute of Technology and Life Sciences in Kamieniec Wrocławski in the years 2002–2007

Years	Precipitations in months												Annual precipitation I–XII
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
2002	–	–	–	32.9	37.1	68.2	49.5	78.7	52.2	61.2	52.3	16.2	448.3 1)
2003	40.0	2.8	18.7	11.9	80.5	24.3	58.8	55.3	42.4	51.5	27.8	47.3	461.3
2004	31.2	60.6	56.6	24.5	35.2	40.5	88.5	50.8	21.8	45.6	81.4	15.4	552.1
2005	46.2	51.2	11.5	27.0	150.8	46.8	122.6	54.4	24.9	6.7	31.0	106.4	679.5
2006	28.9	43.7	26.1	54.2	21.9	56.6	12.0	179.3	20.3	68.4	65.6	36.7	613.7
2007	64.6	53.3	55.5	–	–	–	–	–	–	–	–	–	173.4 2)
Sum	210.9	211.6	168.4	150.5	325.5	236.4	331.4	418.5	161.6	233.4	258.1	222.0	2 928.3

1) Total precipitation from the period IV–XII. 2) Total precipitation from the period I–III.
Source: own study.

- very dry when total precipitation is less than 75% of average of sum in a long-term,
- wet, when total precipitation is 110–125% of average of sum in a long-term,
- very wet when total precipitation is more than 125% of average of sum in a long-term.

From Figure 1, developed according to these criteria, it appears that during the study years 2002, 2004 and 2006 were average in terms of the conditions of precipitation, whereas 2003 was dry and 2005 was wet. Half of spring–summer (April–September) was average in the 2002–2003, dry in 2004, and wet in 2005 and 2006 years.

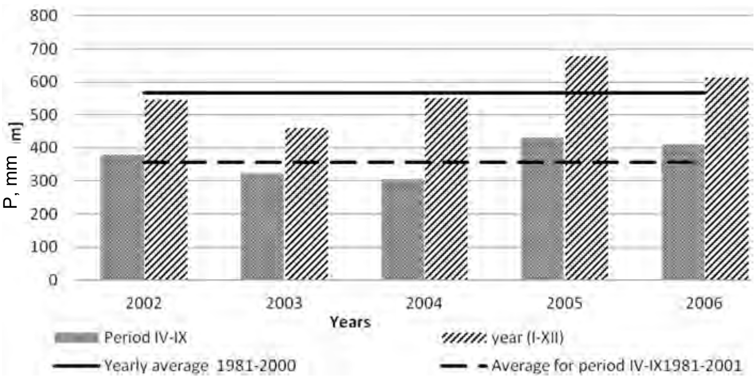

Fig. 1. Precipitation variability in the years 2001–2006 in relation to the years 1981–2000 in Wrocław; source: own study

In particular years of study there were dry periods with little rainfall and months of very heavy rain like May, July and December 2005 and August of 2006. Lysimeters leachates, which are part of the precipitation penetrating the sandy soil to a depth of 130 cm, occurred at a very high volatility.

Those quantity of leachates dependent not only on amount of precipitation, but season and humidity of the soil. The leachates appeared with a variable delay with respect to the occurrence of heavy rainfall. Under studies delay was not large and ranged from several hours to two days after the onset of precipitation, depending on a preceding state of soil moisture. In the winter months when rainfall was in the form of snow, and the soil was frozen, the delay depended on the duration of such conditions. That is why the biggest infiltration occurred in March, after the thaw internal, despite the fact that March was not the month with the biggest precipitation. Infiltration scale, the volume of effluent expressed in $dm^3 \cdot m^{-2}$, examined variants (Tab. 2) is characterized by very high volatility. During the months of late autumn and in the winter months, in all study period, there were the greatest volume of leachates, which were from about 40 to more than 80% the amount of precipitation (Tab. 3). It is a period when the scale of infiltration depended on the size of precipitation to the greatest extent. A close correlation between the amount of rainfall and infiltration showed many authors including works DYNOWSKA and TLAŁKA [1982], NOWAK [2007], BUCZYŃSKI and WCISŁO [2013]. According BUCZYŃSKI and WCISŁO [2013] the biggest raising of the ground water (the largest infiltration) occurred during the spring thaw and summer high rainfall. The results of lysimeter experiments showed the biggest infiltration in March (Fig. 2) after spring thaw. During the growing season the dependence of size infiltration from precipitation decreased. In some months of this period, especially from August to October in variants of soil fertilized appeared almost complete disappearance of infiltration despite the fact that August was the month with the largest sum of precipitation. Under experimental lysimeter conditions (with no surface runoff) measurements started and ended at the moment the same humidity conditions. In this situation, the only outflow elements of rainwater remain effective are an infiltration and evapotranspiration.

The results showed the overwhelming superiority of evapotranspiration over the effective infiltration (*IE* = 21.8–30.7% of annual precipitation). Similar proportions of these elements of the water balance showed GRAF and KRAJEWSKI [2013] in Mogilnica catchment experiments (basin of Warta), where evapotranspiration was 79%, infiltration 15% and surface runoff 6% of annual precipitation. According to KANECKA-GESZKE and ŁABĘDZKI [2006] average value of evapotranspiration on a sugar beet plantation in the area of Wrocław, ranged from 363 to 440 mm per year. In cited results of lysimeter experiments with sugar beet plants were grown in 2004. The amount of evapotranspiration calculated (based on data from Table 1 and 2) in this year were similar to cited above and ranged from 396 to 433 mm.

The results of showed study indicate that the decisive factor in the level of infiltration is evapotranspiration, which mainly depends on climatic conditions and land covering by plants and how to use it. In areas used for agriculture big impact on evapotranspiration size is obtained yields [ŁABĘDZKI 1997; MLADENOVA, VARLEV 2007; SZAJDA, ŁABĘDZKI 2016]. According to ŁABĘDZKI [1997] relation between the yield and the evapotranspiration is close to linear. The crop yields, and therefore infiltration and evapotranspiration primarily affects fertilization of the soil.

The results of lysimeter experiment showed that infiltration by light unfertilized soil was 30.7% of annual sum of precipitation, and to soil fertilized 21.8–25.3%, depending on kind and dose of fertilizer (Tab. 3, Fig. 3).The results in this paper can by analogy applied to agricultural use lowland, with sandy soils and shallow aquifers. The sandy soils are characterized by the highest indicators of infiltration. TARKA [2001] determining infiltration factors for the catchment with sandstone formations, received its relatively wide range of from 17.0 to 39.1% of the average annual rainfall in this area.

Table 2. The monthly and annuals volume of effluents from particular fertilization variants in the period of April 2002–March 2007

Years	Volume of effluents, dm^3												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I–XII
Variant 0 (without fertilization)													
2002	–	–	–	16.0	12.1	18.9	2.2	20.4	5.3	1.8	15.0	14.0	105.7
2003	27.4	7.6	17.8	5.2	21.7	3.8	2.5	0.0	0.0	1.9	0.4	18.0	106.3
2004	35.7	31.5	30.6	14.6	7.6	1.9	4.8	6.9	1.3	0.0	17.8	3.2	155.9
2005	14.4	11.2	19.1	4.5	40.5	17.5	15.9	15.5	5.5	0.0	0.0	42.7	186.8
2006	9.9	22.9	36.6	3.9	4.8	1.3	0.0	22.3	0.0	10.2	47.5	21.3	180.7
2007	20.0	31.6	32.0	–	–	–	–	–	–	–	–	–	83.6
Average	21.5	21.0	27.2	8.8	17.3	8.7	5.1	13.0	2.4	2.8	16.1	19.8	163.8
Variant K1 (organic fertilization, compost – 10 g N·m^{-2})													
2002	–	–	–	5.1	6.8	3.4	1.6	1.0	0.0	0.0	10.6	18.7	47.2
2003	20.0	9.0	9.0	3.2	17.6	3.8	2.5	0.0	0.0	0.0	0.0	18.9	84.0
2004	31.2	31.8	33.8	11.0	6.4	3.2	3.2	0.0	0.0	0.0	0.0	3.1	123.7
2005	9.4	13.1	20.4	3.1	43.3	26.1	5.7	0.0	0.0	0.0	0.0	21.7	142.8
2006	7.6	11.8	24.5	4.1	1.1	0.0	0.0	5.7	5.0	6.4	39.0	15.9	121.1
2007	20.0	29.9	30.6	–	–	–	–	–	–	–	–	–	80.5
Average	17.6	19.1	23.7	5.3	15.0	7.3	2.6	1.3	1.0	1.3	9.9	15.7	119.9
Variant K2 (organic fertilization, compost – 15 g N·m^{-2})													
2002	–	–	–	6.1	5.4	2.8	0.5	0.0	0.0	0.0	10.6	11.5	36.9
2003	17.7	9.0	8.9	3.4	18.3	2.7	2.0	0.0	0.0	0.0	0.0	15.9	77.9
2004	33.8	28.0	32.5	10.3	3.8	2.9	3.8	0.0	0.0	0.0	3.3	1.7	120.1
2005	8.5	14.3	21.7	2.5	35.0	25.5	6.4	0.0	0.0	0.0	0.0	17.6	131.5
2006	9.3	13.6	25.1	2.9	1.0	0.0	0.0	5.1	5.1	5.7	33.8	10.4	112.0
2007	17.8	29.6	29.9	–	–	–	–	–	–	–	–	–	77.3
Average	17.4	18.9	23.6	5.0	12.7	6.8	2.5	1.0	1.0	1.1	9.5	11.4	111.1
Variant NPK1 (mineral fertilization – 10 g N·m^{-2})													
2002	–	–	–	14.0	7.9	2.5	0.6	0.3	0.0	0.0	11.0	21.0	57.3
2003	18.5	6.6	9.3	5.2	19.1	3.8	2.5	0.0	0.0	0.0	0.0	19.1	84.1
2004	34.4	32.5	33.6	10.4	8.9	3.2	3.2	0.0	0.0	0.0	0.0	2.5	128.7
2005	10.6	15.9	21.0	4.4	43.3	26.4	7.3	0.0	0.0	0.0	0.0	23.6	152.5
2006	8.5	13.4	26.8	4.4	1.1	0.0	0.0	7.6	7.0	7.5	44.2	18.7	139.2
2007	21.6	32.0	32.6	–	–	–	–	–	–	–	–	–	86.2
Average	18.7	20.1	24.7	7.7	16.1	7.2	2.7	1.6	1.4	1.5	11.0	17.0	129.6
Variant NPK2 (mineral fertilization – 15 g N·m^{-2})													
2002	–	–	–	9.6	8.9	5.5	0.4	0.8	0.8	0.0	12.1	15.2	53.3
2003	18.5	9.3	9.3	3.2	19.1	2.9	2.2	0.0	0.0	0.0	0.5	17.3	82.3
2004	34.4	29.9	31.0	9.6	3.8	1.9	4.1	1.5	0.0	0.0	0.0	3.2	119.4
2005	9.9	11.7	23.6	4.5	38.7	24.8	6.6	0.5	0.6	0.0	0.0	19.9	140.8
2006	10.4	17.7	25.5	2.8	1.3	2.3	0.0	5.1	6.0	7.3	35.7	16.6	130.7
2007	19.5	30.6	30.8	–	–	–	–	–	–	–	–	–	80.9
Average	18.5	19.8	24.0	5.9	14.4	7.5	2.7	1.6	1.5	1.5	9.7	14.4	121.5

Source: own study.

Table 3. Average monthly and annual recharging infiltration in the period April 2002–March 2007

Variant	Recharging infiltration in % precipitation totals												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	average
0	50.9	49.5	80.8	29.4	26.6	18.4	7.7	15.6	7.5	6.0	31.3	44.7	30.7
K1	41.8	45.2	70.2	17.6	23.1	15.4	3.9	1.6	3.1	2.7	19.2	35.3	23.3
K2	41.3	44.7	70.1	16.7	19.5	14.3	3.8	1.2	3.2	2.4	18.5	25.9	21.8
NPK1	44.4	47.4	73.2	25.5	24.7	15.2	4.1	1.9	4.3	3.2	21.4	38.2	25.3
NPK2	44.0	46.9	71.4	19.7	22.1	15.8	4.0	1.9	4.6	3.1	18.7	32.5	23.7

Source: own study.

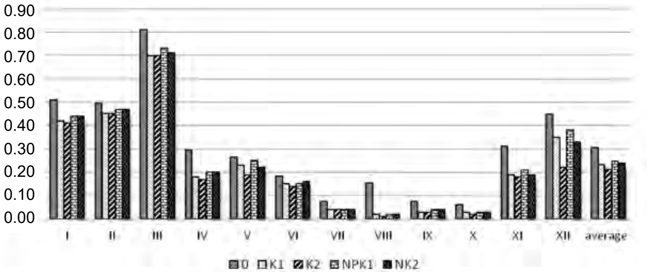

Fig. 2. Average indicators (monthly and annual) of recharging infiltration in the period April 2002–March 2007; source: own study

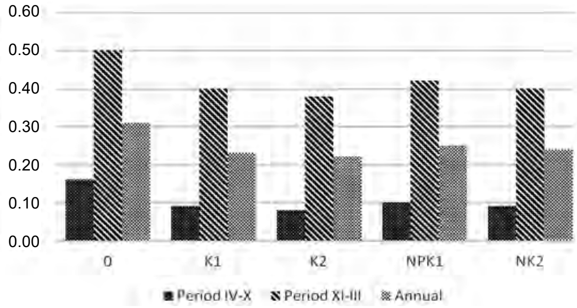

Fig. 3. Average indicators (periodic and annual) of recharging infiltration in the period April 2002–March 2007; source: own study

In lysimeter research discussed the range of infiltration estimate was much smaller and it is 21.8% to 30.7%. There were no variability of soil. Variable element was only fertilization of the soil, which caused a decrease in infiltration in relation to infiltrate through the soil unfertilized. Under the conditions of fertilization, with equivalent doses of nitrogen supplied in organic fertilizer (compost), and mineral, obtained infiltration variation within 2%. The organic fertilization decreased infiltration about 7.4–9.0%, and mineral about 5.4–7.0% of sum of precipitation, relative to unfertilized soil.

CONCLUSIONS

1. In the absence of surface runoff the main elements of outflow precipitation: infiltration and evapotranspiration are effective. The balance between these elements show a clear advantage of evapotranspiration over the infiltration.

2. The amount of the effective infiltration, is very variable in time and to the greatest extent depends on the intensity of evapotranspiration. The largest infiltration occurs in March after the thaw of spring and lowest in August

3. During the period from August to October, effective infiltration is negligible and has no practical importance in the supply of groundwater precipitation.

4. Soil fertilization especially organic fertilizers, is an indirect factor for reducing infiltration. Fertilization increases plant yield, and thus increases evapotranspiration and reduces the effective infiltration.

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Infiltracja efektywna wód opadowych przez glebę lekką w warunkach braku spływu powierzchniowego

STRESZCZENIE

W pracy przedstawiono wielkość infiltracji efektywnej (*IE*) opadów atmosferycznych przez glebę lekką oraz jej rozkład w czasie na podstawie pięcioletnich badań lizymetrycznych. Badano też wpływ nawożenia organicznego i mineralnego na wielkość infiltracji. W warunkach lizymetrów nie występuje zjawisko spływu powierzchniowego, a więc przez analogię wyniki badań można odnieść do użytkowanych rolniczo terenów równinnych z glebami piaszczystymi. Wyniki badań świadczą, że wielkość infiltracji jest bardzo zmienna w czasie. Oprócz opadów atmosferycznych, w największym stopniu wpływa na nią ewapotranspiracja. Największa infiltracja występuje w marcu po roztopach wiosennych (*IE* = 70–81% opadu miesięcznego), a najmniejsza w sierpniu (*IE* = 1,2–15% opadu, w zależności od rodzaju stosowanych nawozów i poziomu nawożenia). Nawożenie gleby, zwłaszcza nawozem organicznym (kompostem) jest czynnikiem mającym znaczący wpływ na zmniejszenie infiltracji efektywnej. Nawożenie gleby kompostem zmniejszyło infiltracje w porównaniu z notowaną przez glebę nienawożoną o 7,4–9,0%, a nawozami mineralnymi o 5,4–7,0% rocznej sumy opadów. Średni roczny wskaźnik infiltracji wyniósł 21,8–25,3% sumy opadów w wariancie z glebą nawożoną i 30,7% w wariancie kontrolnym (gleba nienawożona).

Słowa kluczowe: *gleba lekka, infiltracja, opady atmosferyczne*