

WATER USE EFFICIENCY IN BIOLOGY, AGRICULTURE AND SUSTAINABLE DEVELOPMENT

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Summary. In the Republic of Moldova 2017-2023 water use efficiency in rainfed soybean fields was in the range of 0,3-0,8 g grain/kg water. Under field conditions, for the Ladutsa soybean variety, a WUE of 0,75 g of grain/kg of water was obtained with seasonal precipitation of 94 mm, which is several times less than 317 mm, considered optimal for achieving the average agricultural WUE of 0,57.

Keywords: water use efficiency, sustainable development, field soybean.

Introduction

In biology and agriculture, water use efficiency (WUE) is usually considered from leaf to field. At the leaf level, the value of WUE is usually defined as the ratio of the intensity of photosynthesis (CO₂ assimilation) to the intensity of transpiration [Sinclair T.R. et al., 1984]. At the level of plants growing in the soil, WUE is defined as the ratio of the amount of dry matter produced (g) to the amount of water used (kg), while the amount of water used includes precipitation and changes in soil moisture reserves [Passiora J.B., 1977, p. 117]. In field studies, WUE is defined as a ratio of yield to the water used [Passiora J.B., 1977, p. 117]. As a measure of used water, evapotranspiration (ET) is usually used - the mass of water evaporated in a field during the growing season by the soil (evaporation, E) together with plants (transpiration, T). E is included in water demand starting with Briggs L.E. and Shantz H.L. (1913). An essentially constant (or linear) relationship between biomass and transpiration has been observed since the early 1900s [Perry C. et al., 2009], therefore, total water consumption is divided into useful (T) and useless (E) components. In modern agriculture, the main trend is to minimize the ratio between evaporation and evapotranspiration (E/ET). As for formal terminology, instead of the traditional terminology “water use efficiency” (WUE), the FAO (Food and Agriculture Organization) proposed using the term “water productivity” (CWP, crop water productivity) to assess agronomic WUE [Zwart S.J., Bastiaanssen W.J.M., 2004], reserving the term “water use efficiency” for water use technology: FAO has proposed that “water productivity” be defined as yield per unit of evapotranspiration or yield per unit of water supply [Sadras V.O. et al., 2012, p. 16]. The term “water productivity” is equivalent to the term “water use efficiency” in its agronomic sense.

At the level of society and the state, the water use efficiency is determined based on the objectives of the country’s sustainable development. The term “sustainable development” was first coined in 1987 by the World Commission on Environment and Development (The Brundtland Commission) in the report “Our Common Future” [United Nations, 1987]. The Brundtland Report gave a universal definition of sustainability: “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. In September 2015, the General Assembly adopted the 2030 Agenda for Sustainable Development, which includes 17 Sustainable Development Goals (SDGs). One of the targets of SDG 6 (Ensure availability and sustainable management of water and sanitation for all) is Target 6.4. (By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity). In the modern period, the fundamental documents of sustainable

development are the 2030 Agenda for Sustainable Development [United Nations, 2015] and Strategia Națională de Dezvoltare (SND) "European Moldova 2030" [Lege Republicii Moldova nr. 315 din 17.11.2022]. In sustainable development of society, a goal related to the rational use of water resources (Sustainable Development Goal, SDG 6 Ensure availability and sustainable management of water and sanitation for all) is not finite in itself. Water is needed as a means to achieve the resulting goal of sustainable development: meet the needs of the present generation without compromising the ability of future generations to meet their own needs. In SND "European Moldova 2030" according to General objective 10 "Ensuring a healthy and safe environment" it is necessary to increase water productivity (USD PPC, m³) from 45 (2020) to 55 by 2025 and to 70 – by 2030" [Lege RM nr. 315, 2022, Table 5].

This paper aims to analyze the issue of water use efficiency and the possibility of increasing WUE within the framework of the concept of sustainable development.

Materials and methods. The studies were carried out in 2017-2023 at the fields of the Institute of Genetics, Physiology and Plant Protection (IGFPPP) with soybean varieties Amelina, Laduța and line A2. Location of our experiments (Republic of Moldova, Chisinau, IGFPP fields) in accordance with the accepted (Köppen-Geiger) classification [Kottek M. et al., 2006] characterized by a warm temperate climate, with dry winters and hot summers.

WUE in a soybean field is defined as seed yield divided by the sum of seasonal rainfall together with a seasonal decrease in soil water amount in the 0-150 cm layer. In the field at the leaf level instantaneous WUE was determined by portable photosynthesis system LCpro-SD (United Kingdom) as ratio of CO₂-assimilation to transpiration [Sinclair T.R. et al., 1984].

Results and discussion. Table 1 presents data on determining the WUE of soybean fields in 2017-2018.

Table 1

Efficiency of water use by a soybean field Amelina variety

year	Water consumption for the growing season, kg/m ²			Grain yield, g/m ²	WUE, g/kg
	rainfall	soil water	total (ET)		
2017	236,6	151,2	387,8	287±12	0,74±0,03
2018	317,7	103,7	421,4	365±36	0,87±0,08
average for two years (2017-2018)					0,80±0,06

2017 and 2018 were average in terms of moisture availability. The value of WUE for soybean fields of the Amelina variety on average over two years was 0,80±0,06 g grain/kg water (Table 1).

In the 2021 season, soybean fields were also provided with water: precipitations 309 mm from september 2020 to april 2021 года or 101% of the long-term average norm, and 307 mm or 165% of the long-term average norm during the growing season. In 2021 weather conditions, the Onika soybean variety (MG I) used less soil water during the growing season and, as a result, saved 50 mm more water on the field for the next season compared to the Pentata variety (MG III) [Malii A., Harciuc O., 2023].

Table 2 presents data on leaf CO₂-assimilation, transpiration and instantaneous WUE determined on soybean plants by portable photosynthesis system LCpro-SD (United Kingdom) in rainfed field in 2019, at term 97 DAS.

Table 2

Leaf transpiration intensity (T), CO₂-assimilation intensity (A) and instantaneous WUE (A/T) for leaves of soybean plants line A2 in the field (2019, 97 DAS).

T, mmol H ₂ O m ⁻² sec ⁻¹	A, μmol CO ₂ m ⁻² sec ⁻¹	Instantaneous WUE (A/T), g CO ₂ /kg H ₂ O
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2,09 ±0,12	13,33 ±0,86	15,6 ±0,3
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In summer 2019, according to measurements of transpiration and CO₂-assimilation of leaves on soybean plants under field conditions, at 97 days after sowing (DAS), the instantaneous WUE (A/T) at the leaf level was 15,6±0,3 gCO₂/kg H₂O (Table 2). Under optimal conditions (light and humidity) of soybean plants at the intensity of CO₂-assimilation 20 $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ sec}^{-1}$ the transpiration rate is 10 $\text{mmol H}_2\text{O m}^{-2} \text{ sec}^{-1}$ [Ye Z.P. et al., 2020, p. 4]. According to literature data, the WUE of rainfed soybean fields is 0,6-1,0 kg grain m⁻³ of evapotranspiration water [Sadras V.O. et al., 2012], this is an order of magnitude less than the optimal value of WUE at the leaf level of the soybean plant, ~5 g CO₂/kg H₂O [Ye Z.P. et al., 2020, p. 4]. Under the conditions of our field experiment, a significantly reduced value of leaf transpiration intensity indicates insufficient moisture supply to plants. In the 2019 field experiment, WUE was 0,50±0,03 g seeds kg⁻¹ evapotranspiration water. An increase in WUE in agricultural fields is possible mainly due to a decrease in evaporation.

The 2020 growing season was preceded by an unusual sequence of dry spells: for the first time in the history of meteorological observations since 1886, there were two consecutive dry periods of moisture accumulation in the soil, from September to April 2018/2019 and 2019/2020. Under the conditions of the 2020 drought (repeated after the 2019 drought, and more severe), water deficit in the upper soil layers was accompanied by a lack (after the 2019 drought) of available water even in deep soil layers. WUE was 0.36 kg m⁻³ of water or 0.36 g of seeds per 1 kg of water. During the severe drought conditions of 2020, the water use efficiency of the soybean field was reduced. In accordance with the conditions of 2017-2020. (primarily, water reserves in the soil by the sowing date) the WUE values for soybean fields in 2017, 2018, 2020 (variety Amelina) and 2019 (line A2) are: 0,74 ± 0,03 g grain/kg water in 2017; 0,87 ± 0,08 g grain/kg water in 2018; 0,50±0,03 g grain/kg water in 2019 and 0,36 ± 0.06 g grain/kg water in 2020.

Reducing soil moisture to a certain limit (increasing dryness) increases the weight of grain per unit of water used.

Analysis of data from [Giménez L. et al., 2017] and [Petty M.T. et al., 2020] shows that a change in the amount of water transpired by soybean plants in the field by 200 mm corresponds to a change in grain yield by 700 kg. In US agricultural practice, the maximum efficiency of water use (agronomic water productivity) in soybean fields as the ratio of seed yield to used water falls on the amount of seasonal (from sowing to harvesting) precipitation of 317 mm [Dietzel R. et al., p. 666, Fig. 9]. With an increase in precipitation (up to 1200 mm) and with its decrease (minimum to 200 mm) relative to the optimum of 317 mm (WUE 0,57 kg of grain/m³ of water), the efficiency of water use decreases. In soybean fields, an increase in the efficiency of transpiration water use as the ratio of seed yield to transpired (passed through the plant) water is observed with a decrease in the total transpiration of field plants [Giménez L. et al., 2017], for example to 170 mm [Petty M.T. et al., 2020]. The productivity of transpired water continuously decreases with an increase in the total transpiration of field plants from 170 to 500 mm. At the leaf level of the soybean plant, the optimum ratio of the intensity of photosynthesis (A) to the intensity of transpiration (T) of leaves is observed at a fraction of transpirable soil water (FTSW) of 0,20 of its maximum content: an increase in FTSW above 0.20 leads to a smooth decrease in A/T; a decrease in FTSW below 0.20 leads to a sharp drop in A/T [Liu F. et al., 2005].

The weather feature of 2023 was a small amount of precipitation during the growing season (94 mm) compared to 2022 (239 mm of precipitation). Table 3 shows data on the dynamics of water reserves in the soil in the Ladutsa soybean field in 2023 compared with the dynamics of water reserves in the soil in the line A2 soybean field in 2022.

As follows from the data in table. 3, the bulk of the soil water available to plants was used up by mid-July. In the seasons of 2022 and 2023, by the time of harvesting, soil water reserves became almost the same, 209.6 and 213.6 mm, despite the large difference in the amount of seasonal precipitation.

Table 3

**Total soil water content (mm) in soybean fields during the growing seasons
2022 (line A2) and 2023 (variety Ladutsa)**

layer, cm	2022			2023		
	15.04	26.07	9.09	4.05	18.07	30.08
0-40	109,3	37,1	67,4	97,4	59,0	49,4
40-100	129,3	83,1	85,2	152,0	89,0	94,6
100-160	94,3	59,1	57,1	115,1	88,0	69,6
0-160	332,9	179,4	209,6	364,6	236,0	213,6

In the surface, black soil layer (0-40 cm) of soybean fields, the change in humidity in the last part of the season was almost the same in the 2022 and 2023 seasons. At the same time, in 2023, in the period from mid-July to harvesting (when the seeds were filled), soil moisture in deep soil layers (deeper than 1.0 meters) decreased significantly, which was not the case in 2022. This difference can apparently be explained by different amounts of precipitation in these years, more significant in 2022. Water consumption in 2022 was carried out by soybean plants mainly from the fertile chernozem layer (0-40 cm), and in 2023 from deep horizons. Water use efficiency of soybean fields was higher in the 2023 season: 0,75 kg seeds/m³ of water versus 0,50 kg seeds/m³ of water in 2022.

The maximum WUE of soybeans under US production conditions (0,57 g grain/kg water) was observed at 317 mm of seasonal precipitation [Dietzel R. et al., p. 666, Fig. 9]. Maximum WUE for soybeans is observed with significantly less seasonal precipitation, by 113 mm, compared to corn [Dietzel R. et al., Fig. 8-9]. In a number of European countries (France, Italy, Hungary, Romania) there has been a tendency, in conditions of water shortages, to replace corn with soybeans [Lauerwald R. et al., 2023].

In 2023, under field conditions for growing soybean variety Ladutsa, we obtained a high WUE value (0,75 g of grain/kg of water) with precipitations of 94 mm.

In terms of economic sectors, in line with SDG indicator 6.4.1 (Change in water-use efficiency) and the International Standard Industrial Classification (ISIC) of economic activities, three major sectors were considered, i.e. •Agriculture; forestry; fishing (ISIC A), hereinafter “agriculture”; •mining and quarrying; manufacturing; electricity, gas, steam and air conditioning supply; constructions (ISIC B, C, D and F), hereinafter “MIMEC”; and •all the service sectors (ISIC E and ISIC G-T), hereinafter “services” [Rossi A. et al., 2018]. Sustainable Development Goal indicator 6.4.1 is defined as the change in water use efficiency over time and measured as the change in the ratio of gross economic value added by irrigated agriculture, industry and the services sector to the volume of water withdrawn over time [Hellegers P., van Halsema G., 2021]. Agricultural WUE in monetary terms coincides with the social indicator of SDG 6.4.1. for water efficiency.

Water-use efficiency (WUE), as measured by SDG indicator 6.4.1., tends to be higher in more advanced economies, with 8 countries scoring among the top 20 in terms of both GDP (Gross Domestic Product) per capita and WUE [Rossi A. et al., 2018, p. 3]. In European countries average WUE overall (79.66 USD/m³) is significantly higher than in agriculture (2.61 USD/m³); average WUE in other sectors, MIMEC and Services, 136.57 USD/m³ and 185.619 USD/m³ [Rossi A. et al., 2018, Table 1]. WUE in agriculture ranges between 0,7 and 1,9 percent of WUE in each of the other two sectors, MIMEC and services, except in Africa [Rossi A. et al., 2018, p. 5]. Over the past three to four decades, the economic WUE in most major developed countries and in most newly industrialized countries has increased due to the growing share of industry and services [Rossi A. et al., 2018].

In SND "European Moldova 2030" according to General objective 10 "Ensuring a healthy and safe environment" and SND development impact assessment indicator no. 99 "Water productivity"

it is necessary to increase water productivity (USD PPC, m³) from 45 (2020) to 55 by 2025 and to 70 – by 2030" [Lege RM nr. 315, 2022, Table 5], that can be achieved through other (except agriculture) industries at current levels of agricultural water productivity (2.61 USD/m³ in European countries) and PPC exchange rate (1 Peercoin = 0,39 USD as of 08/20/2024).

The GDP per capita index is one of the basic ones in international statistics. GDP per capita is the dollar value of a country's final income for the year divided by its population.

For countries and regions with water scarcity, factors for increasing GDP per capita include an increase in the service sector and a change in the traditional employment structure of the population. Water-poor countries are recommended to grow high value crops and use the proceeds to import food from water-rich countries under virtual water trade agreements [Kilemo D.B., 2022].

Conclusions

In the Republic of Moldova 2017-2023 water use efficiency in rainfed soybean fields was in the range of 0,36-0,87 g grain/kg water.

For countries and regions with water scarcity, factors for increasing GDP per capita and WUE overall include an increase in the service sector and a change in the traditional employment structure of the population.

Under field conditions, for the Ladutsa soybean variety, a WUE of 0,75 g of grain/kg of water was obtained with seasonal precipitation of 94 mm, which is several times less than 317 mm, considered optimal for achieving the average agricultural WUE of 0,57.

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