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Management of Water Resources in Poland

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Chapter 19
The Effects of Plant Irrigation in Poland

Renata Kuśmierek-Tomaszewska and Jacek Żarski

Abstract On the global scale, the main criterion for the advisability of using plant irrigation is the climatic condition – in particular, the amount and distribution of atmospheric precipitation. Therefore, irrigation is mainly applied in regularly or periodically arid climatic zones, because it is in these areas where food production would not be possible without an additional water supply. It is different in Poland, placed in the moderate climatic zone, where irrigation of plants is basically a contingency procedure applicable to supplement the periodic shortages of rainfall in relation to the water requirements of plants. It applies particularly to sandy soils with reduced water retention capacity, situated in the central, lowland part of the country. Droughts in Poland are weather phenomena unfavourable for agricultural production, appearing quite often but irregularly. On the other hand, conditions of fully or excessively moisturized soils during growing seasons occur with a similar frequency to droughts. For this reason, the irrigated area in Poland covers only about 73 thousand hectares. The main indicators of the advisability of applying irrigation and considering its role in domestic agriculture and water management are production effects, i.e., the absolute yield increase obtained under the influence of this treatment in agricultural raw materials production. Irrigation is the most economically effective treatment in horticultural crop production, including orchards, vegetables, and berry plants. In the case of agricultural plants, the indicators of profitability are much less – the only positive financial effect may be obtained in the case of table potato production.

Keywords Water deficit · Supplementary irrigation · Drought · Irrigation efficiency · Poland

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19.1 Introduction

Plant irrigation is a water supply to the soil profile in order to provide or improve the growth, development and yielding conditions of crop plants. Irrigation is considered to be an agrotechnical practice and is one of the very first anthropogenic modifications of the natural environment, originating about 7500 years ago in Mesopotamia.

According to current data published by the International Commission on Irrigation and Drainage [1] and Food and Agriculture Organization of the United Nations [2], around 300 million hectares are irrigated worldwide, which accounts for approximately 20% of the total of agricultural land. It is estimated that about 40% of the global food supply comes from irrigated land. The spatial distribution of the irrigated area, as an essential indicator of water management and food security, is important subject for statistics and scientific research. Recent studies based on vegetation indices used in remote sensing measurements [3] show that the global irrigated area is even higher than that reported in the statistics and possibly amounts to as much as 367 million hectares.

On the global scale, the main criterion for the advisability of using plant irrigation is the climatic condition, in particular, the amount and distribution of atmospheric precipitation. Therefore, irrigation is mainly applied in regularly or periodically arid climatic zones because it is in these areas where food production would not be possible without an additional water supply.

It seems different in Poland (in the moderate zone), where irrigation of plants is basically a contingency procedure, applicable to supplement the periodic shortages of atmospheric precipitation in relation to the water requirements of plants. In terms of the average conditions, these shortages result from too low multiannual average precipitation in relation to the water needs of plants, expressed by mean values of evapotranspiration or optimal precipitation. It particularly applies to sandy soils with reduced water retention capacity, situated in the central lowland part of the country. In selected growing seasons (April–September), or some periods occurring in the middle of them, these shortages result in temporary rainfall scarcity leading to meteorological and agricultural droughts. In the moderate, transitional climate of Poland, these droughts are weather phenomena and are unfavourable for agricultural production, appearing quite often but irregularly. A great example to illustrate the climate risk due to this hazard, in the cultivation of cereal crops and winter rape, (which dominate in the sowings structure), is the occurrence of meteorological drought in the region of Pomorze and Kujawy from May to June between 1981–2010 (Table 19.1). In the analysed multi-annual period in particular cities of the region, meteorological droughts occurred in 7–9 cases, which means a frequency of 23.3–30.0%. This is entirely consistent with the results of research conducted by Łąbędzki for central Poland [4].

Conditions of sufficiently or excessively moisturized soils during some periods of plant vegetation, or even throughout the whole growing season, occur in Poland with a similar frequency to droughts. For this reason, among other things, the irrigated area in Poland covers only about 73 thousand hectares according to official data, including

Table 19.1 The occurrence of meteorological droughts in the period of high water needs of cereal crops and rapeseed (May–June) in the years 1981–2010 in the chosen locations of the region of Pomorze and Kujawy (Ed – extremely dry, Vd – very dry, Md – moderate dry, Sd – slightly dry) [5]

Year	Droughts in chosen locations of the region of Pomorze and Kujawy				
	Mochle	Chrząstowo	Toruń	Głodowo	Głębokie
1981	Md	Sd			
1982					
1983	Md	Sd	Sd	Vd	Vd
1984					
1985					
1986	Sd			Sd	
1987					
1988				Sd	
1989	Md	Ed	Ed		Vd
1990	Sd				Sd
1991					
1992	Sd	Md	Sd	Md	
1993					
1994				Md	
1995			Sd		
1996					
1997					
1998					Md
1999					
2000	Vd	Vd	Vd	Ed	Vd
2001					
2002		Sd			
2003	Md	Sd	Vd		
2004					
2005				Sd	
2006		Sd	Sd	Sd	Vd
2007					
2008	Ed	Ed	Md	Vd	Vd
2009					
2010					
Ed	1	2	1	1	0
Vd	1	1	2	2	5
Md	4	1	1	2	1
Sd	3	5	4	4	1

modern pressurized systems (sprinkler irrigation), applied mainly in horticultural crops at only 8.7 thousand hectares [6]. The dimension of these areas places Poland at a distant position from other countries around the world in terms of plant irrigation. According to the ICID record [1], which covers a rank of 46 developed countries with the USA as the leader, Poland maintains the 28th position, while in the classification of all 159 countries, in which China and India are the leaders in terms of irrigation, Poland shifts to the 105th place. A small irrigated area in Poland, covering only 0.5% of agricultural land allows for the conclusion that the importance of irrigation in Polish agriculture is insignificant compared to the area covered by it. This conclusion cannot be changed even by the fact that the actual area of irrigated crops in Poland is much larger than declared by the Statistics Poland [6]. The official data do not take into account systems such as micro-irrigation, especially the drip system, commonly used in horticulture. According to research published by Treder et al. [7], from 80 to 100 thousand hectares of fruit crops in Poland are under irrigation. On the other hand, Lipiński [8] estimates the area of irrigated vegetables in the country at about 45 thousand hectares.

Despite the limitations deriving primarily from economic conditions as well as from the insufficient sources of water and the amount of water available for agriculture, the irrigation of crops in Poland is an important element of water management in the country and the main element of water management in agriculture. This is a promising and perspective solution. The main factors that will accelerate the development of irrigation in the future include: assurance of higher, stable and good quality crop yields, the necessity to increase modernity and make increasingly expanding agricultural farms more competitive, and the expected climate change. In accordance with the theory of global warming, whose main manifestation is an increase in air temperature and evapotranspiration, the frequency of droughts in moderate latitudes is also forecasted to increase [9–11]. Some research results indicate that these changes are already taking place. According to the results of the research presented by Wibig [12], in Poland, one can observe a tendency towards more intense, longer-lasting droughts in the summer season, especially in the areas where water is the main yield-limiting factor.

19.2 Effects of Irrigation on Crop Production

The main indicators for the advisability of applying irrigation and considering its role in domestic agriculture and water management are production effects, i.e., the absolute yield increase obtained under the influence of this treatment in the technology of agricultural raw materials production. The amount and value of production efficiency under irrigation can be discussed in terms of an average approach (multi-annual mean), or in relation to the specific growing season. Positive effects of applying irrigation, such as yield increases, account for the basis of their economic efficiency assessment, which is the main argument for undertaking the investment. Modifications in the quality of yield under the influence of irrigation, which relates to the qualitative features that determine the suitability of the crop for consumption or the processing technology of the raw materials obtained, are also of great importance. An important aspect of irrigation efficiency is also an estimation of the amount of by-product and mass of crop residue, the increase of which improves soil properties.

A direct production effect of plant irrigation, such as an increase in the main yield and changes in its quality, is a consequence of modifications of plant growth and development caused by this treatment. In particular, irrigation has a beneficial effect on the activity of physiological processes, and the morphological and anatomical structure of the plant, and consequently on the canopy structure, and finally on yield components. According to the study by Karczmarczyk [13], irrigation combined with an optimal rate of Nitrogen, Phosphorous, and Potash fertilizers resulted in a significant increase in the intensity of physiological processes occurring in cereals leaves, and thus higher assimilation of carbon dioxide, transpiration and stomatal conductance. The intensification of physiological processes and the prolonged period of the physiological activity of irrigated plants resulted in more robust growth, the formation of taller and thicker stems with longer ears, as well as an increase in the number and weight of grains per ear. Irrigation also contributed to the increase in plant tillering and density of vegetation (the number of blades per unit area). In addition, advantageous changes in yield composition, related to the increased plant density on irrigated plots, higher abundance, and enlarged weight of a single component of the yield, were found in other crops, for instance winter oilseed rape [14], potato [15] and some vegetables [16, 17].

In order to determine the production effects of irrigated crops in Poland, numerous scientific experiments were performed. Then, the results of particular experiments were the subject of numerous syntheses. The most widely known synthesis works are the study by Dzieżyc [18] as well as the multiple-authors monograph edited by Karczmarczyk and Nowak [19]. An analysis of yield modification through the quantitative and qualitative aspects obtained under the influence of irrigation carried out on this basis leads to the conclusion that the yield depends primarily on two factors – rainfall conditions and soil properties.

19.2.1 Atmospheric Precipitation as the Factor Creating Yield

In Poland, in the zone of moderate transitory climate, irrigation treatment supplements the deficiencies of atmospheric precipitation, particularly during the period of high water needs for plants. Therefore, the meteorological factor that has the greatest impact on the production effects of irrigation is rainfall, especially total rainfall and rainfall distribution in time. Since rainfall is characterized by very high temporal variability in particular spans of the growing season, the effects of irrigation might be different in consecutive years. Despite this, the effects significantly correlate with the amount of rainfall during the period of high demand for water of individual species. This relationship, after regression equation transformation, can be generalized according to the formula (1) by Grabarczyk [20]:

$$Q = (P_{OPT} - P_A)k \tag{19.1}$$

where:

Q expected yield increase under the influence of irrigation (kg ha^1),
K yield increase per 1 mm of rainfall deficit supplemented by irrigation (kg ha^1),
P_{OPT} the total of optimal rainfall, i.e., this where no increases in yield due to irrigation are observed (mm),
P_A the total of actual rainfall in the period of the highest need for water of a given species (mm).

Formulas for selected crop species (Table 19.2) were derived on the basis of rigorous field experiments carried out simultaneously in the years 2006–2012 on sandy soil with a compacted subsoil, in the Research Center of the UTP University of Science and Technology located in the village of Mochełek near Bydgoszcz city (Kujawsko-Pomorskie province) [21]. These formulas enable the interpolation of data gained from research from other regions of the country, and for the determination of expected effects of plant irrigation in different zones of rainfall conditions in Poland, assuming congruent soil conditions. In the zone of the lowest rainfall totals during periods of high water needs for plants, which includes central Poland, the expected average yield increases will be the greatest, while in the areas with higher rainfall, in which the totals of atmospheric precipitation in the growing season exceed 400 mm – the increases will be respectively lesser.

The prognostic formulas also provide a determination of the variability of production effects under irrigation in a given area in consecutive vegetation seasons (temporal variation), resulting from uneven rainfall conditions in periods of high water needs of plants in subsequent years. This variability in the example of maize grown for grain in the years 2005–2016 is shown in Fig. 19.1 [22]. For this period, the average production effect of irrigation amounted to 4.63 t ha^{-1}, which constituted an increase in the grain yield of 51%. In particular seasons, the production effects of irrigation depended significantly on the rainfall totals during periods of high water need for maize amounting to 7.28 t ha^{-1} in the dry season, 5.52 t ha^{-1} in periods of

Table 19.2 Regression equations and prognostic formulas of the amount of irrigation effects of selected plant species based on rainfall totals in the period of high water needs [21]

Crop	Type of yield	Period of high water needs	Regression equation	Prognostic formula
Table potato	Tubers	June–July	$Y = -0.15x + 36.1$	$Q = (240 - P_A)\cdot 150$
Maize for grain	Grain	June–July	$Y = -0.04x + 10.2$	$Q = (255 - P_A)\cdot 40$
Spring malting barley	Grain	May–June	$Y = -0.022x + 4.03$	$Q = (180 - P_A)\cdot 22$
Faba bean	Seeds	June–July	$Y = -0.013x + 3.13$	$Q = (240 - P_A)\cdot 13$

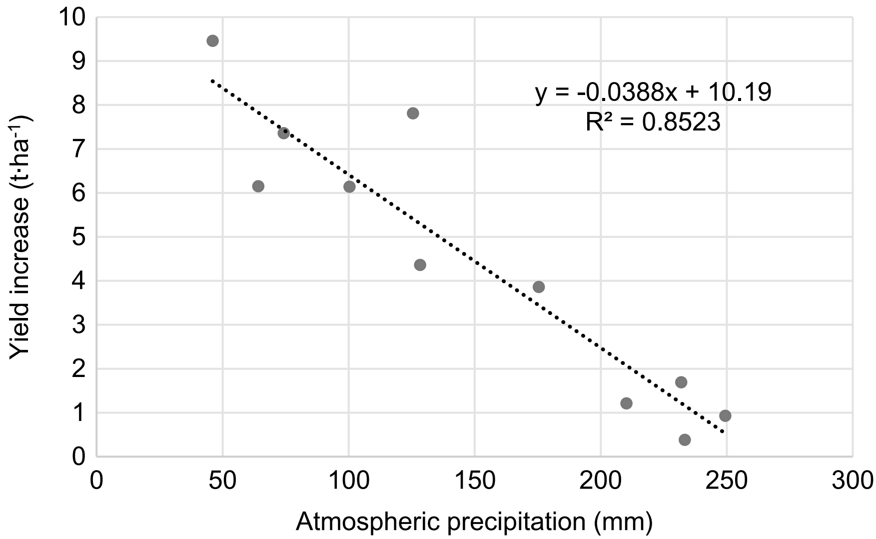

Fig. 19.1 Linear dependence of increase of maize grain yield under irrigation (t ha^{-1}) versus rainfall totals in the period of high water needs of the crop (June–July) [22]

the average rainfall conditions, and 1.05 t ha^{-1} in wet seasons. The regression equation shows that yield increases under irrigation were not significant only when the total of rainfall in the span of June–July exceeded 220–230 mm (Fig. 19.1). Attention should be paid to the high value of the coefficient of determination ($R^2 = 0.85$) describing the significant dependence, even though in the 12 analyzed subsequent growing season distributions of similar precipitation, totals in June–July span were different. Application of additional meteorological parameters and indicators in the formulas (air temperature, evapotranspiration, drought indicators) did not raise the coefficients of correlation and determination against the dependence of irrigation effects on the rainfall totals only.

19.2.2 Soil Conditions Influencing Production Effects

The extent of the production effects of plant irrigation depends significantly on the type of soil, especially its water properties which are usually determined by the degree of compactness. What matters is not only the compactness of topsoil (rich with humus) but also the kind of subsoil (abundant in minerals). According to the plentiful results of field experiments, the absolute and relative yield increases resulting from irrigation as well as from the unitary effects expressed by the yield increase per 1 mm of irrigation water, which are greater for the less compacted the soil is (Fig. 19.2).

The greatest effects of irrigation occur on sandy soils with a deep groundwater table, distinguished by a low water capacity and therefore a low range of ability to

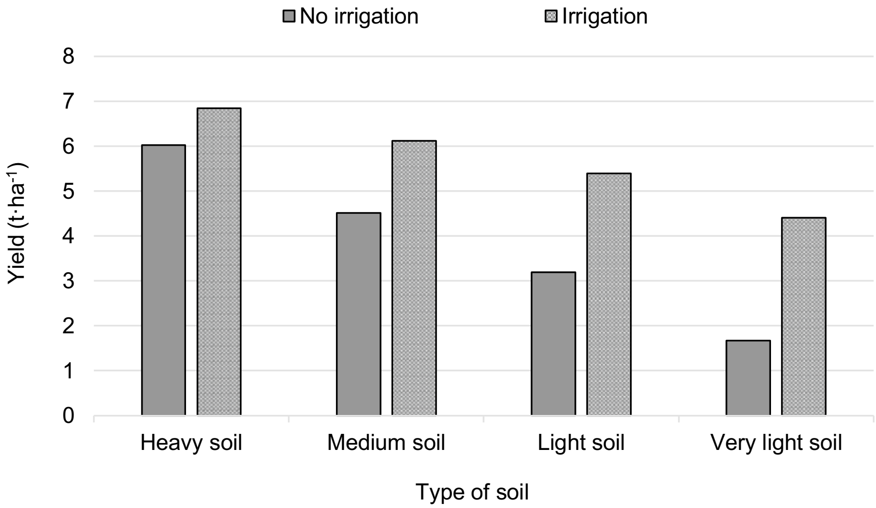

Fig. 19.2 Yield of non-irrigated and irrigated crops depending on the type of soil (based on [23])

perpetually supply plants with water. With the increase of soil compactness and soil water retention, the effects of cereal irrigation quite systematically decrease. In a few experiments carried out on heavy or very heavy soils (fen soil, loess soil), no significant differences were found between the yield of non-irrigated and irrigated crops. What is more, as a result of increased cereals lodging in selected years, the negative effects of irrigation were observed.

When soil factor influence on the crop yield increases is considered, it is extremely important to determine not only their absolute, relative, and unitary values, but also to assess the yield potential of crops grown on different soils under irrigation. It is noteworthy to mention that the yield of crops being irrigated on weak soils is comparable to the yield obtained on better soils without irrigation (Fig. 19.2). Therefore, the use of irrigation on weaker soils (e.g. the good rye, poor rye and very poor rye soil suitability complex related to the classification of complexes of agricultural soil suitability) is a treatment that only compensates production opportunities in relation to better soils (very good rye soil suitability complex and wheat soil suitability complexes).

19.2.3 Irrigation Effectiveness in Crop Groups and Species

Respective groups of crops, species, and cultivars respond to irrigation in different ways. It mainly results from their diverse conditionings of water management, including, e.g. the capability to use water for producing biomass, the properties of the root system and the type of photosynthesis. The different lengths of plant growth stages, as well as the type and the way of yield forming and the yield moisture content are also important.

Comparison of the effectiveness of irrigation in various plants requires the elimination of other impact factors, especially meteorological and soil factors. Experiments should be carried out under the same growing seasons and soil conditions while providing similar agrotechnical systems and ensuring a similar cover of plant water needs by irrigation systems. One of a few experiments that meets the requirements of such comparability of results was carried out in the years 2006–2012 on light soil with compacted subsoil, in the region of Bydgoszcz [21]. The seven-year study of four crop species consisted of growing seasons with different rainfall conditions, which provided considerable data for the average increased yield outputs. The comparison of the results shows that the increased yield outputs were similar in all tested crops and ranged from 37 to 51%, depending on the crop species. The highest relative increase in yield under irrigation was gained in maize for grain cultivation, while the lowest occurred in the raw material production for the brewing industry (malting barley) (Table 19.3). In the case of maize, the result is a consequence of the economic water management by the plant, C4 photosynthesis, and the fact that maize is a monoecious plant, which results in increased water requirements during pollination and fertilization. However, in the case of malting barley, this effect may result from low nitrogen fertilization due to malting production requirements. The absolute average multi-annual production effects of irrigation used in the cultivation of the crop were as follow table potato 12.1 t ha^{-1} of the fresh matter of tubers, maize 3.83 t ha^{-1} of dry matter of the grain, malting barley 1.44 t ha^{-1} of grain and 1.38 t ha^{-1} of faba bean seeds. The effects of unitary production of irrigation expressed in yield increases caused by the use of 1 mm of irrigation water, may be useful in water management optimization in agriculture. The effects amounted to

Table 19.3 Production effects of irrigation of selected agricultural crops on light soil (case of Bydgoszcz region) [21]

Crop	Yield type	Absolute yield increase (t ha^{-1})		Relative yield increase (%)		Unitary yield increase (kg·ha^{-1} mm^{-1})	
		Mean	Range	Mean	Range	Mean	Range
Faba bean	Seeds of 15% moisture	1.38	0.12–3.12	44	2–538	15.0	0.0–34.8
Spring barley for malting	Grain of 15% moisture	1.44	0.0–3.39	37	0–171	18.3	0.0–29.8
Maize	Grain dry matter	3.83	0.32–8.47	51	2–1694	39.7	10.7–70.6
Potato medium-early	Tubers	12.1	0.0–28.7	42	0–204	128	0.0–139

Table 19.4 Average multi-annual production effects of irrigation in selected agricultural and horticultural crops cultivated on very light soil in the village of Kruszyn Krajeński near Bydgoszcz [24]

Agricultural crops	Absolute yield increase t ha^{-1}	Unitary yield increase kg ha^{-1} mm^{-1}	Horticultural crops	Absolute yield increase t ha^{-1}	Unitary yield increase kg ha^{-1} mm^{-1}
Spring wheat	2.27	19.2	Beetroot	17.4	108
Spring barley	2.37	19.5	Carrot	22.6	140
Oat	2.09	16.3	Radish	6.5	100
Sugar beet	19.8	115	Courgette	26.2	104
Early potato	13.1	135	Pumpkin	39.4	323
Late potato	19.8	138	Giant pumpkin	32.9	143
Yellow lupine	1.04	9.5	Black chokeberry	6.2	35
Faba bean	3.07	35.0	Blackberry	8.4	46
Maize (grain)	4.12	28.0	Strawberry	7.2	48

128.1 kg ha^{-1} of potato tubers, 39.7 kg ha^{-1} dry matter of maize grain, 18.3 kg ha^{-1} of barley grain and 15.0 kg ha^{-1} of faba bean seeds.

Production effects of sprinkler and drip irrigation of selected agricultural and horticultural crops, obtained in multi-annual experiments of the Department of Land Reclamation and Agrometeorology of the UTP University of Science and Technology in Bydgoszcz [24] on a very light soil in the location of Kruszyn Krajeński village in the vicinity of Bydgoszcz are presented in Table 19.4 These yield increments are difficult to achieve with limited agrotechnical treatments, such as only drainage or cultivation. The results indicate great prospects for the increase in domestic agriculture productivity, provided that the water factor is optimized. Moreover, they also indicate the potential benefits of sandy soils with low water retention for agricultural use.

19.3 Prospects for Irrigation Development in Poland

Two main factors determine the prospects for the development of plant irrigation in Poland: economic efficiency of this treatment (costs of investment, energy, and water) and the availability of water sources for irrigation purpose without additional investment by farms located near rivers and lakes or having access to easily renewable underground water sources.

Taking this into account, it can be estimated that irrigation development in Poland would primarily concern the large-scale intensive production of vegetables and fruit. In such conditions, it is possible to use micro-irrigation, i.e., low-pressure, precise

Table 19.5 Indicators of economic and financial efficiency of crops production under irrigation [26]

Crop	Profitability indicator
Winter wheat	35–81
Potato	121–217
Sugar beet	153–170
Headed cabbage	241
Onion	364–394
Carrot	419–529
Strawberry	447

irrigation techniques that supply water with drops or streams to the vicinity of plants or directly to the root zone. According to data presented by ICID [1], micro-irrigation is used in 14.4 million hectares throughout the world. This type of system enables fertigation as well as advanced automation based on perpetual monitoring of atmospheric conditions that allows determination of the water needs of the plants [25]. An important advantage of this type of system is that it ensures the economic management of water at the farm scale since there is no need to irrigate the whole field surface, but only precisely chosen parts of the plantation. This argument is particularly important because water resources that can be gained for irrigation purposes should be utilized in Poland in an especially rational manner.

Irrigation of horticultural crops, including orchards, vegetables, and berry plants, is unquestionably an economically effective agrotechnical treatment. This is shown by the profitability indicators for irrigation derived by Jankowiak and Rzekanowski [26] (Table 19.5), as well as the results of the research by Lipiński [8, 27] and Rolbiecki et al. [28]. According to these studies, all indicators of economic and financial efficiency were great; i.e., the capital expenditure for the drip irrigation system of highbush blueberry plantations constituted only 20% of the income increase in the first year of the investment [29].

In the case of irrigation used in agricultural plant production, the indicators of the profitability are much less in comparison to horticultural plants (Table 19.5). In particular, this refers to the most economically important cereal crops, which stand for about 73% of the sown area in Poland, and 61% of the area of irrigated fields worldwide. According to research carried out by Żarski [23], despite the low profitability ratio, cereals should be scheduled on the parts of fields equipped with irrigation systems dedicated primarily to other crop groups. The reasoning that underlies this proceeding is the indispensability of reasonable crop rotation and quality aspects of the yield. For this reason, it is recommended to sprinkle bread-wheat cultivars, but most notably – the malting barley cultivars.

The economic analysis carried out by Kledzik et al. [30], based on the direct surplus growth method, showed that great production effects do not always translate into economic profitability of irrigation. Out of all of the agricultural crops being compared, irrigation caused a positive financial effect only in the case of table potato.

In the production of spring barley and maize for grain, the deployment of this treatment was economically groundless, regardless of the plantation area. The advisability of root crops irrigation, in particular table potato, is proved by the indicators depicted in Table 19.5, or the results of study led by Lipiński [31] as well as the favourable changes in the technological quality and chemical composition of tubers under the influence of this treatment confirmed by Rolbiecki et al. [15] and Wszelaczyńska et al. [32].

Besides the use of irrigation in horticultural and agricultural root crops production, this treatment is also conventional in other areas related to agriculture. Primarly, it is important to mention the forest nurseries and forest planting material productions, irrigation of remediated land – post-mining dumps, dumps and excavations after depletion of surface raw materials, and finally irrigation of backyards, lawns, gardens and recreation areas. Those are relatively recent and perspective areas for fully automated and technically advanced sprinkler systems, often combined with automatic weather stations [24].

19.4 Conclusions

Poland is a country in the EU, which ranks among the last in terms of the availability of water resources per capita (1.6 thousand m^3) with the EU average three times higher. The vast majority of water in Poland comes from atmospheric precipitation (97%) but a large part of it is lost (no storage in drainage systems, reservoirs or rivers) and goes via rivers to the Baltic Sea. This condition, coupled with mild winters, the absence of snow cover in winter, and long periods of high temperatures, which sometimes begin in the early spring and occur in summer, may in some years result in very low water levels in rivers and low level of groundwater table.

On a global scale, agriculture is the largest consumer of drinking water. In Poland, water consumption in plant production is much lower than the average in the world, but as shown by research results and production statistics, plant production is very dependent on water and susceptible to its scarcity and the production effects depend significantly on soil and rainfall conditions over the period of high water needs of crops. Despite this, crops irrigation in Poland has still only a supplementary character.

Poland is an agricultural country with over 14 million hectares of agricultural land, most of which are light soils, with a limited share of organic matter, which consequences into limited water retention capacity. In the last years, the government of Poland has developed several instruments, like water fees, rain tax, as well as a new investment plans in water retention. Water fees are the obligation for the compliance with the EU Water Framework Directive and they also include fees for water taken for irrigation purposes in agricultural production. At present, there have been registered approximately 8% of farms covered by the water fees. Recently, the Polish government has announced the introduction of the Retention Program, which is to be implemented in the years 2021–2027. This program has a budget of EUR 3.11 billion (14 billion PLN), which is to be allocated to the construction of large and small retention reservoirs, especially important for rural areas. Not long ago, the Polish Minister of Agriculture has launched an irrigation program in agriculture. As part of the first call for projects 89 million EUR (400 million PLN) will be allocated to irrigation systems-related investments, and the total amount allocated to the program is 222.15 million EUR (1 billion PLN). The program is aimed primarily at farm owners in the areas most affected by drought in recent years [33]. However, the development of irrigation systems, and thus water consumption in plant production, will be determined by the productive and economic efficiency of agricultural crops.

19.5 Recommendations

The content presented in the chapter is significant for the proper and sustainable management of water resources in agriculture both on a national and regional scale as well as for the design and operation of irrigation systems in family farms or commercial enterprises.

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