DOI: 10.2478/frp-2018-0002
Wersja PDF: www.lesne-prace-badawcze.pl
Leśne Prace Badawcze / *Forest Research Papers*
Marzec / March 2018, Vol. 79 (1): 13–21
ORIGINAL RESEARCH ARTICLE
e-ISSN 2082-8926

Supplementary irrigation at container nursery

Grzegorz Durło[1*], Krystyna Jagiełło-Leńczuk[1], Mariusz Kormanek[2], Stanisław Małek[3], Jacek Banach[4]

[1]University of Agriculture in Kracow, Faculty of Forestry, Institute of Forest Ecosystems Protection, Department of Forest Protection Entomology and Forest Climatology, Al. 29 listopada 46, 31–425 Kraków, Poland; [2]University of Agriculture in Kracow, Faculty of Forestry, Institute of Forest Utilization and Forest Technology, Department of Forest Work Mechanization, Al. 29 listopada 46, 31–425 Kraków, Poland; [3]University of Agriculture in Kracow, Faculty of Forestry, Institute of Forest Ecology and Silviculture, Department of Forest Ecology and Reclamation, Al. 29 listopada 46, 31–425 Kraków, Poland; [4]University of Agriculture in Kracow, Faculty of Forestry, Institute of Forest Ecology and Silviculture, Department of Genetics and Forest Tree Breeding, Al. 29 listopada 46, 31–425 Kraków, Poland

[*]Tel. +48 12 6625142, e-mail: rldurlo@cyf-kr.edu.pl

Abstract. For the period from the 1st of May to the 30th of October 2014, the water balance for Scots pine, Norway spruce, Pedunculate oak and European beech seedlings in a plantation setting was analysed. The experiment was conducted at the container nursery in the Rudy Raciborskie Forest District, Poland. Water was supplied by natural rainfall as well as a by small-droplet irrigation system and two automatic weather stations combined with 32 rain collectors were used to monitor rainfall throughout this research. Rain gauges were located 25 cm above the metal pallets and 10 cm below the nursery containers. An average of 987 mm·m^{-2} of water reached the plantation, of which 53% were provided by the irrigation system. Most water was supplied to the oak field, whereas least was given to the spruce plantations and the irrigation water amounted to 535 liters and 422 liters per square meter, respectively. The amount of water percolating through the substrate was approximately 50–65%, depending on the tree species. An average sum of evapotranspiration at the container nursery was estimated to amount to 520 mm·m^{-2} during the growth season leading to a total water balance of +463 mm.

Keywords: water balance, forest seedlings, forest nursery, spruce, pine, oak, beech

1. Introduction

The technology of producing seedlings of forest trees using container method is of great interest because of considerable demand for nursery materials intended for reforestation and forestation especially in places with difficult soil and habitat conditions or climatic conditions unfavourable for the renewal. This situation is increasingly affected by frequent disaster phenomena and extreme weather conditions that can be dangerous for forests. The issues related to the cultivation of high-quality planting material are the basis of modern research concerning nursery production optimisation and the search for new solutions to improve its efficiency (Day 1980; McDonald 1984; Helenius et al. 2002; Szabla 2009; Warsaw 2009).

Modern selective systems of meteorological services for forestry have mainly focused on the problems related to water management and issues of hydrological nature that can constitute an important element in management strategies especially for seedlings cultivation. The basic factors determining the need for plants watering are weather conditions and technologies of nursery materials production. For seedlings production using container method, irrigation is a necessity, unlike in case of an open cultivation in which production without irrigation is possible; however, the quality of seedlings is closely dependent on the amount of precipitation during the vegetation season. Water balance within the production fields in container system determines plants, growth and development, physiological activity and effectiveness of fertigation. In addition, water balance affects the physical parameters of the substrate and air humidity just above the active surface of the plants (Stubbs 1977; Day 1980; Prévost et al. 1989; Benson, Knox 1991, Goodwin et al. 2003; Chochura 2006; Warsaw 2009).

The principle of rational water management is based on the assumption that cultured plants should have permanent access to moisture, even if weather conditions fail to maintain the appropriate level. In contrast to the ground nursery, the container system requires constant monitoring of this parameter, because it is one of the most important factors determining the process of seedling production. The cassettes suspended on racks are filled with a small amount of medium-concentrated substrate with high air capacity and low capillary water capacity. In the initial period of

Submitted: 4.07.2017, reviewed: 5.10.2017, accepted after revision: 11.10.2017

development, the plants require frequent spraying to compensate small retention of water with a high demand for it (Lamach, Niemiera 1993; Szabla, Pabian 2003; Cameron et al. 2004; Warsaw 2009; Million, Yeager 2012).

This paper presents the results of the study on water resources management in vegetation season 2014 in one of the largest container nursery located in Europe (Rudy Raciborskie Forest Inspectorate, Regional Directorate of State Forests in Katowice, Poland). We assumed that it will be possible to reduce the water consumption during the production of nursery material in container technology based on the water balance control in the production fields using a radiotelemetric measurement system.

2. Materials and Methods

Water management research on the production fields of Scots pine, Norway spruce, English oak and beech produced using container technology was performed in the Nursery Farm 'Nędza' in Rudy Raciborskie Forest Inspectorate (Regional Directorate of State Forests in Katowice, Poland) during the period from 1 April, 2014 to 30 October, 2014 (Photo 1).

In the first month, the observations were carried out only in the tents that controlled the water flow from irrigation system. The principal studies on water management were conducted only from the beginning of May when the nursery materials were transported to the production fields. We designed the monitoring system based on two automatic meteorological stations, VP2PLUS (Davis Instruments Corp.), equipped with radiotelemetric modules and 32 rain collectors of IM7857M type arranged in the equal share above plants surface and under the nursery cassettes. Eight rain collectors were installed within each production field that were connected using RJ-11 type wires with ATK6332-type radio transmitters (Davis Instruments Corp.), operating in frequency-hopping spread spectrum system, at variable frequencies (Fig. 1).

Photo 1. Localisation of research plots in the nursery farm.
Source: Google Earth 7.1.7.2606, Image Landsat, 650 m a.g.l, date of acquisition: 1 September 2016.

Particular measurement modules (rain collector with transmitter) worked in the frequency range from 8 MHz, with the possibility of eight independent channels encoding, which allowed flexible design the acquisition system. Adjustment of communication devices consisted addresses pairing, whilst the control of information exchange was remote and was subject to verification in automatic mode, every 10 min on an average, for the whole day.

The area covered by pine (plot 4), spruce (plot 5) and beech (plot 3) was 120 m^2, representing 5.0% of the production field (2 255 m^2). For oak (plot 9), it was 2.5% of the field with an area of 3 855 m^2 (Photo 1). The seedlings of forest trees' were produced on a standard substrate: 90–95% peat moss (usually 93%), 5–10% of perlite (usually 6–10%) and 2.5–3.5 kg of dolomite (usually 3.0 $kg{\cdot}m^{-3}$). Water holging capacity of peat-moss substrate was 54%. Quality control of substrate was performed on the Swedish BCC Filling & Seeding Line type 357-55. The uniformity of the substrate guarantees the comparability of the production conditions during the growing season (Heiskanen 1995a, 1995b).

The capturing devices were arranged at a distance of about 0.5 m from the edge of the field. They were in the range of nozzles and concurrently beyond the range of additional extreme nozzle, which increases the amount of water reaching the cassettes deposited along the edge of production patch. The outflow of rain water from the collectors installed in the soil (substrate) cavities was possible via the drainage system in the gravel substrate (Fig. 1). Parameters such as sum of precipitation (*Ro*), intensity of precipitation (*RNo*), transient precipitation (*Rm*), maximum precipitation (*Rmax*), start and end precipitation time/date, number of days with precipitation (*Ldo*), precipitation abundance (*GRo*), sum of irrigation rates (*Rod*) and water percolation (*Rp*) were deter-

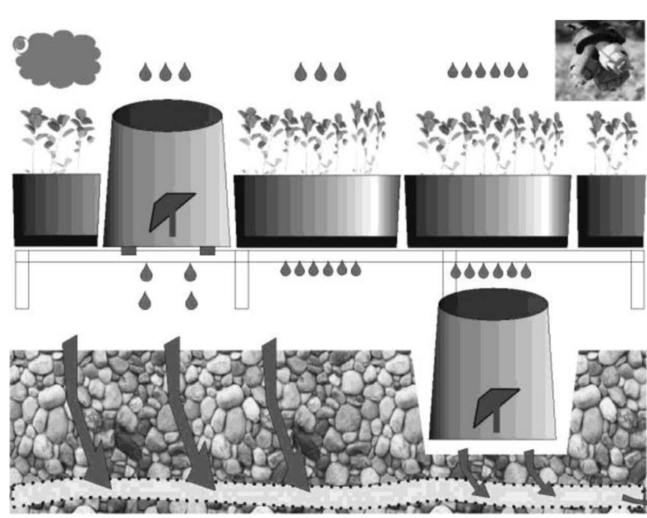

Figure 1. The scheme of the measurement post on the production field using rain collectors

mined based on the materials collected. The latter parameter was determined based on the difference between the sum of precipitation in the meteorological station and indications of devices within a field. The identification of the liquid origin during the days with atmospheric precipitation in which irrigation was performed was based on the indications of LWS6420 leaf wetness sensor (Davis Instruments) mounted within the cassettes with the seedlings. The measuring interval was 1 min, the data were archived every 14 days (recorded in the format: such as BIN, SQL, CSV, XLS), the average size of the base file was 500 kB, the number of records in the file was 2.016 and number of the data was 263.50 per one pluviometer per 1 month. In total, 210.800 pieces of data were collected from one field within 30 days (1.26 million of data in the season). The correction of water amount that reached the surface of substrate and the size of percolation was based on the comparison of results from the following devices: one rain collector outside the production field (weather station), four rain collectors in the field that are 30 cm above the upper edge of the cassette and four rain collectors that are 10 cm below its lower edge (Fig. 1). The total water balance *KBW0* (station) and *KBW1* (field) was based on the comparison of the amount of water in the system and the losses resulting from evapotranspiration (*ETo*), which was calculated according to the following formula provided by the *California Department of Water Resources* (Synder, Pruitt 1992):

$$ET_O = W \cdot \frac{R_n}{\lambda} + (1 - W) \cdot (e_a - e_d) \cdot F$$

where ET_o is the hourly sum of potential evapotranspiration (mm) W is the weighting factor expressing relative share of radiation factor e_a is the maximum water vapour pressure (kPa) R_n is the average hourly value of net solar radiation ($W \cdot m^{-2}$); λ is the latent heat of vaporisation – the size determining the amount of net energy of solar radiation in $W \cdot m^{-2}$ used in the process of water evaporation from the active surface, which sum is specified in, e_d is the actual water vapour pressure (kPa) F is the function of wind speed describing the course of evaporation process which is calculated separately for daylight hours and for the night.

The data on climatic and synoptic conditions were obtained from the resources of the Institute of Meteorology and Water Management National Research Institute in Warsaw (Poland) the precipitation yearbooks of Hydro-Meteorological station in Racibórz, number 12540 and the IMGW Internet Service (www.pogodynka.pl).

3. Results

The sum of precipitation (R_o) in vegetation season 2014 (from March 8 to October 30) reached 555 mm, that is, it was 35% higher than the long-term average for this area. The most abundant period in precipitation was found to be the past decade of June when the precipitation was 93 mm. The highest monthly sum was recorded in August − which was 110.5 mm, while the lowest was recorded in October − which was only 4.5 mm. The highest daily precipitation was observed on June wich was 26–33.6 mm of water fallen from 24:00 to 6:00 − with an average intensity of 5.6 $mm \cdot h^{-1}$. The number of days with precipitation (*Ldo*) during the vegetation season was 141 (150% of long-term standard), with peak records in August and September − 26 days in each. Year 2014 exceptionally received abundant rainfall, and the precipitation density ratio (*GRO*) reached a value of more than 6.7 in May, June, and July (Table 1).

Irrigation at the nursery began in April 10–11 during the emergence of pine placed in foil tents; for other species, the sprinklers were launched on April 22. The irrigation on the production fields started on May 2 and lasted until October 13. The number of days on which irrigation was performed was 98 and the total number of days in which the surface of seedlings leaves was wetted with water (*Rod* ≥ 0.1 mm) was 172. On an average, from 5.6 to 6.2 mm of water m^{-2} reached daily on the production fields, with calculated per 100 m^2 are of the field throughout the whole season corresponds to 103 m^3 for pine and beech, 88 m^3 for spruce and 100 m^3 for oak. It was calculated that more than 9.860 m^3 of water in total, 47% of which was natural precipitation, reached during the 6 months of the vegetation time (1.05–30.10) on the surface which was within the range of spraying ramps (2.0 ha) (Fig. 2, Table 2).

The maximum amount of water that was provided during a day using the irrigation system was 16 mm. The sum of water losses resulting from evapotranspiration process amounted to 520 mm on an average; the highest sum of evaporation was recorded in May – 124.5 mm, whilst the highest daily evaporation occurred on May 19 and was 7.5 mm. The intensity of evaporation during sunny days with humidity deficiency of above 15 mbar reached a value of 1.15 $mm \cdot h^{-1}$; however, it usually did not exceed 0.45–0.55 mm to the small distance between the production fields, individual monthly indicators, as well as the cumulative precipitation, generally did not differ from each other; slightly

Table 1. Monthly pluvial indicators on the container nursery surface in Rudy Raciborskie Forest Inspectorate – vegetation season 2014

Months	III	IV	V	VI	VII	VIII	IX	X
Sum of rainfall (mm)	39.1	58.2	121.6	101.9	100.6	110.8	18.5	4.3
Number of days with precipitation	8	12	18	15	15	26	26	20
Precipitation abundance (mm)	4.9	4.8	6.8	6.8	6.7	4.3	0.7	0.2

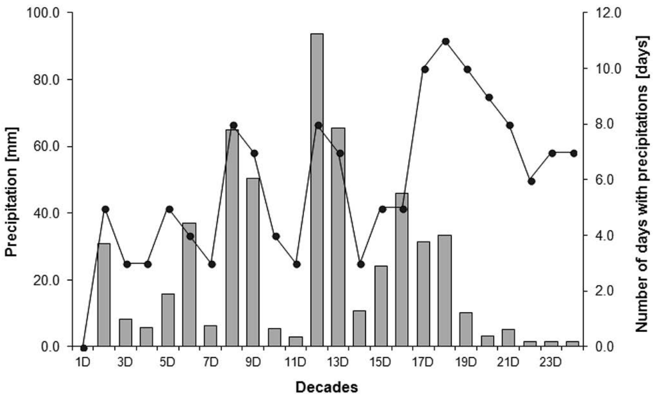

Figure 2. The 10-day (decades 'D'), sum of precipitation (bars) and the number of days with natural precipitation (line) at the container nursery in Rudy Raciborskie Forest Inspectorate from 1 March, 2014 to 31 October, 2014

lower indicators were recorded in the north-western part of the nursery because of the rain shadow caused by the activity of forest wall on the west side and forest protective zone on the east side.

The average difference did not exceed 5% in this case. Under irrigation conditions, the daily differences noted were from 3% to 8%, 5-day differences from 10% to 15%, 10-day differences from 15% to 20%, monthly differences more than 24%, and annual differences reached 15%. The highest disproportions in water supply for the production fields were reported for spruce and other species, especially in the second half of the production period. This variation was caused by the differences in fertilisation schedule and because of the periodical humidity control of the substrate. The results that show a clear water shortage, especially in conifers, which was a few percent larger than in the case of oak or beech, were obtained by comparing only the values of precipitation and evapotranspiration (Tables 2–5).

The cumulative values of precipitation and evaporation demonstrated that the losses resulting from evaporation were predominant almost for the whole vegetation period within the production field and only the irrigation process enabled to obtain safe reserve, especially that part of the water only shortly remained within the plant root system. Typically, after a few hours the seedlings required moisture resources completing (Fig. 3). It was found that the deficit can reach up to 9 mm during the days without precipitation. The potential number of days with a negative water balance during the course of vegetation season was 138 (80% of all days), while considering the process of irrigation, it was only 80 (46% of all days).

The probability of water deficiency within the production fields was, therefore, reduced nearly by half using irrigation, and the possible losses for evaporation was reduced by up to 30% in absolute terms. For the whole season (from 1.05 to 31.10), the potential deficit on a level of about 60 mm per m^{-2} was compensated using small-droplet irrigation, which in turn gave the final balance at the level of +465 mm (Fig. 3, Table 3). The average amount of water captured under the cassettes with the seedlings was 600 mm, of which most of

Table 2. Summary of water management factors on the field with pine (*Pinus sylvestris* L.) in Rudy Raciborskie Forest Inspectorate – vegetation season 2014

Date	Ro	Ro+Rod	Rod	Rp	ETo	KBW0	KBW1
2014-05-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2014-05-15	24.4	42.7	18.3	29.5	50.3	-25.9	-7.6
2014-05-29	89.9	114.2	24.3	88.7	61.2	28.7	53.0
2014-06-12	12.8	38.0	25.2	21.5	62.4	-49.6	-24.4
2014-06-26	69.1	100.0	30.9	60.2	46.2	22.9	53.8
2014-07-10	93.1	114.5	21.4	61.3	48.3	44.8	66.2
2014-07-24	26.1	116.7	90.6	55.4	57.6	-31.5	59.1
2014-08-07	37.2	75.0	37.8	48.0	46.8	-9.6	28.2
2014-08-21	51.8	126.3	74.5	96.2	37.1	14.7	89.2
2014-09-04	31.6	114.5	82.9	74.3	27.7	3.9	86.8
2014-09-18	11.9	65.2	53.3	45.1	27.9	-16.0	37.3
2014-10-02	6.1	58.1	52.0	29.3	20.7	-14.6	37.4
2014-10-16	1.9	45.5	43.6	16.8	18.7	-16.8	26.8
2014-10-30	1.8	19.2	17.4	8.4	14.3	-12.5	4.9
Sum	457.7	1 029.9	572.2	634.7	519.2	-61.5	510.7

Table 3. Summary of water management factors on the field with spruce [*Picea abies* (L.) H. Karst)] in Rudy Raciborskie Forest Inspectorate – vegetation season 2014

Date	Ro	Ro+Rod	Rod	Rp	ETo	KBW0	KBW1
2014-05-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2014-05-15	24.4	55.3	30.9	38.6	50.3	-25.9	5.0
2014-05-29	89.9	115.7	25.8	76.4	61.3	28.6	54.4
2014-06-12	12.8	45.6	32.8	29.6	62.5	-49.7	-16.9
2014-06-26	69.1	112.3	43.2	67.8	46.3	22.8	66.1
2014-07-10	93.1	177.8	84.7	99.8	48.6	44.5	129.2
2014-07-24	26.1	66.7	40.6	30.5	57.7	-31.5	9.1
2014-08-07	37.2	49.5	12.3	24.7	46.9	-9.7	2.6
2014-08-21	51.8	78.2	26.4	40.5	37.4	14.4	40.8
2014-09-04	31.6	65.6	34.0	30.8	27.7	3.9	37.8
2014-09-18	11.9	23.5	11.6	9.5	27.9	-16.1	-4.5
2014-10-02	6.1	23.1	17.0	9.2	20.8	-14.7	2.3
2014-10-16	1.9	46.5	44.6	15.6	18.9	-17.0	27.6
2014-10-30	1.8	20.5	18.7	6.6	14.4	-12.5	6.2
Sum	457.7	880.3	422.6	479.6	520.6	-62.9	358.7

Table 4. Summary of water management factors on the field with oak (*Quercus robur* L.) in Rudy Raciborskie Forest Inspectorate – vegetation season 2014

Date	Ro	Ro+Rd	Rod	Rp	ETo	KBW0	KBW1
2014-05-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2014-05-15	26.1	57.9	31.8	37.8	51.4	-25.2	6.5
2014-05-29	91.2	139.5	48.3	78.4	62.5	28.7	77.1
2014-06-12	13.4	28.1	14.7	17.1	63.1	-49.7	-35.0
2014-06-26	69.7	128.2	58.5	94.7	47.0	22.7	81.2
2014-07-10	94.5	166.0	71.5	118.7	49.7	44.8	116.3
2014-07-24	27.5	88.8	61.3	67.8	58.9	-31.4	29.9
2014-08-07	39.3	100.2	60.9	63.5	47.4	-8.1	52.8
2014-08-21	52.2	85.2	33.0	58.0	37.9	14.3	47.3
2014-09-04	32.5	84.9	52.4	40.1	27.9	4.5	56.9
2014-09-18	12.4	55.2	42.8	35.6	28.4	-15.9	26.9
2014-10-02	7.2	40.7	33.5	21.7	21.2	-13.9	19.5
2014-10-16	2.2	24.9	22.7	14.7	18.9	-16.7	5.9
2014-10-30	2.1	4.8	2.7	1.4	14.5	-12.5	-9.7
Sum	470.3	1 004.5	534.1	649.5	528.8	-58.5	465.6

Table 5. Summary of water management factors on the field with beech (*Fagus sylvatica* L.) in Rudy Raciborskie Forest Inspectorate – vegetation season 2014

Date	Ro	Ro+Rod	Rod	Rp	ETo	KBW0	KBW1
2014-05-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2014-05-15	24.4	43.8	19.4	30.2	50.0	-25.6	-6.2
2014-05-29	89.9	123.1	33.2	78.8	60.6	29.3	62.5
2014-06-12	12.8	45.7	32.9	29.8	61.4	-48.6	-15.7
2014-06-26	69.1	109.5	40.4	72.4	45.1	24.0	64.4
2014-07-10	93.1	119.5	26.4	81.8	47.0	46.1	72.5
2014-07-24	26.1	81.2	55.1	56.7	57.6	-31.5	23.6
2014-08-07	37.2	89.5	52.3	52.4	46.1	-8.9	43.4
2014-08-21	51.8	117.2	65.4	66.6	37.0	14.8	80.2
2014-09-04	31.6	115.4	83.8	66.6	27.2	4.5	88.3
2014-09-18	11.9	78.8	66.9	47.3	27.5	-15.6	51.3
2014-10-02	6.1	54.2	48.1	33.2	20.7	-14.6	33.5
2014-10-16	1.9	33.9	32.0	26.5	18.7	-16.8	15.2
2014-10-30	1.8	18.6	16.8	13.5	14.3	-12.5	4.3
Sum	457.7	1 030.4	572.7	655.8	513.1	-55.4	517.3

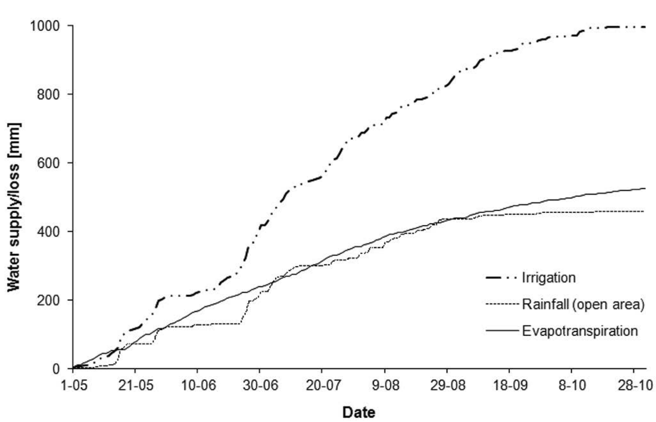

Figure 3. The cumulative sum of precipitation (*Ro*), sum of precipitation with water from irrigation system (*Rod*) and sum of evapotranspiration (*ETo*) at the container nursery in Rudy Raciborskie Forest Inspectorate from 1 March, 2014 to 31 October, 2014 (eg field with oak)

the water penetrated through the lumps with oak (650 mm per season) and the least with spruce (480 mm per season).

During the day, the size of percolation ranged from 2.7 l for spruce to 4.0 l for oak. The volume of water captured under the cassettes (R_p) during the day was 3.3 l on an average. Under these conditions, maintaining the level of water supplied to the seedlings from 6.5 to 7.8 l per $m^2 \cdot d^{-1}$ seems tobe an optimum solution because it allows to maintain water balance at a safe level (Fig. 4).

Table 6. The climatic water balance (mm) on production fields with tree seedlings (KBW0, natural rainfall; KBW0+KBW1, rainfall + irrigation system; KBW_NEG, number of days with negative water balance) during the vegetation season 2014

Species Indices	Pine	Spruce	Beech	Oak
KBW0	-61.5	-62.9	-55.4	-58.5
KBW0+KBW1	510.7	358.7	517.3	465.6
KBW_NEG	81	75	88	84

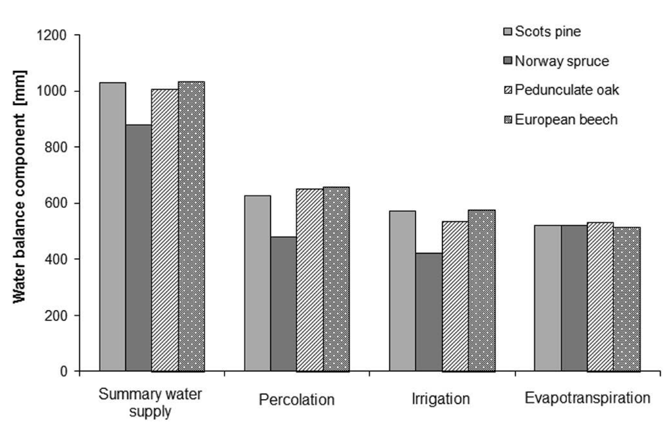

Figure 4. The aggregate value of water balance components in production fields at the container nursery in Rudy Raciborskie Forest Inspectorate 1 March, 2014 to 31 October, 2014

4. Discussion

Currently, people working at nurseries do not have sufficient knowledge or the right tools to periodically evaluate the effects of seedlings cultivation with covered root system based on a detailed analysis of the water balance. The general knowledge in this field is based mainly on statistics concerning the amount of water used in irrigation systems, which according to both domestic and international experiences is usually insufficient. Lack of information concerning evapotranspiration, the size of interception and the amount of water flowing out of the production area are the main factors that contribute to higher water consumption in many cases than the actual water required by plants currently (Bilderback 2002; Beeson et al. 2004; Warren, Bilderback 2004; Treder 2007; Marosz 2013).

Although the experienced people at nurseries demonstrate a unique intuition in this regard, this does not change the fact that water management, particularly in the context of the production, optimisation and its rational use, requires verification. No irrigation criteria, except the criterion of the soil, are used on the vast majority of container nurseries, which is sometimes unreliable, especially for deciduous species. However, an application of climatic and plant criteria requires some effort and a thorough knowledge of the biology and plants physiology; nevertheless, the development of telemetric technologies of irrigation systems can provide measurable cost savings at the final balance sheet. As emphasised by Cerny et al. (2002) and Treder (2009), rational and efficient management of water resources should be the rule not only for economic reasons but also for practical, and more importantly, environmental ones.

A large number of plant assortments with different water needs arising from individual characteristics, different rates of growth, development of assimilation apparatus as well as the rate of absorption of the mineral compounds are usually cultivated at the nursery farm. Particular species also differed in sensitivity to atmospheric and soil moisture deficit. Sometimes it is even not recommended to cultivate a species with extremely diverse requirements within a farm. The situation is further complicated by the high variability of weather conditions during the vegetation season, which happens often lately. Therefore, it seems reasonable to search for new solutions and improvements, especially when it comes to the use of balance models based on water losses estimated from the active surface area of production fields or nursery plots. The results of this study confirm that the relatively small financial outlay in the order of 2 500–3 000 EUR per one set and preparation of the measurement system (8–10 h/one working day) would provide access to data allowing the rational water management at the forest nursery, considering all possible production variants. Having in mind that the production of container seedlings only in the Regional Directorate of State Forests in Katowice has reached over 20 million of pieces (as of 31 December, 2013), and its further growth is planned in subsequent years, the economic cost of any failure can be very high. Elaboration of methodology, which guarantees repeatability of good cultivation results, will, therefore, be reflected in lower production costs in container nurseries (Goodwin et al. 2003; Szabla 2009; Warsaw 2009).

Although the vegetation season 2014 had appropriate moisture levels, as evidenced by precipitation indicators (Tables 1 and 2), the fertigation schedule associated with the provision of fertilisers and sustaining of high humidity of the substrate was realise the production fields. It was found in many cases that the volume of water used for seedlings irrigation exceeded their current requirements. During the irrigation period in open space, that is, from early May to mid October, the irrigation could have been completely given up during 26 days, and in three cases the amount of water delivered to the plants exceeded twice the daily required limit. In turn, in 14 cases (days), the volume of water from the irrigation system only compensated the losses on evaporation ($KBW \pm 0.0$). A significant shortage of water was observed twice; however, that deficit was overcome the next day. Considering the number of days (98) in which the seedlings were subject to irrigation, the share of cases that may be considered inadequate to the situation in the production field was 16%, which in complex conditions such as that observed in the Nursery Farm 'Nędza' can be considered a very good result. According to the conservative estimates, the volume of water supplied in 2014 could have been reduced to about 23–25 m^3 per 1 are of production area.

Analysis of current water conditions on the container nursery during the course of vegetation season requires special attention, because the substrate located in the cassettes has a relatively small capillary water capacity, with concurrent large air capacity. The determination of all components of the water balance, therefore, requires continuous monitoring of parameters related *inter alia* to the size of interception and rate substrate drying depending on the precipitation intensity, water vapour potential in the atmosphere, and the degree of surface covering by the assimilation apparatus. The results presented in this study answer the current problems associated with container technology of seedlings production, and moreover, they introduce 'percolation size' as an important element in water use optimisation, which allows the evaluation of the losses resulting from the retention capacities of the system. The results confirmed that radiotelemetric integrated measurement system allows continuous tracking of irrigation conditions of the plants in the production fields and allows ad hoc response to any signals coming from the nursery area. The following conclusions were drawn, which summarise the results of the experiment, indicating concurrently the directions for further research in this area.

5. Conclusions

In 2014, the average value of water balance in the production fields of pine, spruce, oak, and beech was +465 mm m^{-2}, mainly due to irrigation, of which the total volume of water supplied to the seedlings of trees was 53%.

1. The climatic conditions in the region of Nursery Farm 'Nędza' and the data obtained from meteorological measurements in 2014 indicate that the potential water losses by evaporation during the vegetation season can reach 9 mm per day.

2. The use of irrigation treatment in the production fields in container technology reduces the risk of water deficiency for nearly 60% of the seedlings of forest trees.

3. Application of radiotelemetric measurement system enables the ongoing control of water balance in the production fields at every stage of forest trees' seedlings cultivation. The possibility to integrate the balance monitoring with irrigation controller will allow for complete automation of irrigation cycles regardless of the subjective assessment of the substrate moisture using organoleptic method. Such a solution also allows to reduce up to 20% of the amount of water used.

4. High rates of water volume penetrating through the substrate located in the cassettes – in some cases, it was as much as 60% – indicate the need to modify the scheduling of irrigation or improve the physical properties of the substrate. Generally, the amount of water penetrating through a lump of conifer seedlings was, on average, 9% lower compared to deciduous species.

Conflict of interest

The Authors declare no conflict of interest.

Acknowledgements and source of funding

This study was funded by The State Forest National Forest Holding, Grant Number ER 2717-4/14. Special thanks to the Staff of Rudy Raciborskie Forest Inspectorate and thanks to the Managers of Nędza Nursery Farm.

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Authors' contribution

G.D. – study concept, assumptions, goals and research organization, measurement, methods, analysis, review of bibliography, preparation and text editing, language correction; K.J.L. – study concept, assumptions, goals and research organization, measurement, preparation and text editing; M.K. – study concept, assumptions, review of bibliography, preparation and text editing; M.S. – study concept, assumptions, preparation and text editing, language correction; B.J. – study concept, assumptions, preparation and text editing.