Chapter

Agricultural Management Strategies for Countering Drought Conditions in Eastern Croatia

Ivan Mustać, Vilim Filipović, Lana Filipović, Gabrijel Ondrašek and Dragutin Petošić

Abstract

The occurrence of drought periods which last for several months is becoming increasingly frequent, even in regions which have not encountered them before. Agricultural production is very sensitive to drought, and in areas where such conditions were rather unexpected, it is also unprepared for limited water management. As an example, in the area of the Biđ-Bosut field located in eastern Croatia, a significant change in the agricultural soil water regime is noticed during a long-term study (2003–2018). From 2003 to 2018, the groundwater level at 4 m below the soil surface showed a decreasing trend of 6–10 cm annually, while this negative trend was even more prominent from 2014 to 2018 (18–71 cm annually). Furthermore, water level in a groundwater aquifer at 15 m below the soil surface showed a decreasing trend of 26–77 cm during 2015–2018. In accordance with the obtained results, this study proposes certain agro-hydrotechnical strategies which can be used in agricultural production to alleviate the effects of drought period. Although these management strategies are primarily described on an eastern continental Croatia example, they can also be applied in all agricultural areas with similar agroecological conditions.

Keywords: water availability, agricultural management, groundwater level, irrigation, monitoring

1. Introduction

Drought is commonly defined as below-usual water availability [1–3]. Even though drought is commonly associated with arid regions [4], it can also occur in more humid regions [5], which has been confirmed by climate models from various authors [6, 7]. Short-term drought periods (lasting for days or months) usually do not cause permanent or substantial environmental issues in humid areas; however, they can still be reflected on a seasonal agricultural production. Furthermore, if drought periods would last longer (for years or even decades), a negative impact on both the environment and the socioeconomic circumstances of the region can undoubtedly be expected. Agricultural crop production is particularly dependent on precipitation and therefore sensitive to the appearance of drought. Climate change predictions include uncharacteristic drought periods which besides the limited water availability for plants can also have a detrimental effect on other soil organisms (e.g., microbes) [8] and indirectly influence plant growth and development by restricting nutrient availability in soil. Thus, drought periods may lead to an overall decreased fertility of soils. Furthermore, prolonged dry conditions in soil may increase the susceptibility of soil to wind erosion, that is, frequent and severe drought periods can reduce the plant cover and expose the soil to wind, resulting in erosion and desertification [9].

Although drought periods are not unusual for the coastal parts of Croatia, in the last several decades, they have become more frequent and long-lasting, for example [10] and recently are even recorded in the continental parts of the country [11]. This is also confirmed by this hydrological study in the area of the Biđ-Bosut field, an area of 7200 ha of agricultural soil for which the construction of the Biđ field irrigation canal is planned (**Figure 1**). During the monitoring (2003–2018), significant changes of water regime, as well as soil and water management difficulties were recorded in the agricultural part of the studied area. For example, agricultural soils showed a noticeable lowering of groundwater levels, and this negative trend showed a tendency of becoming even more rapid in the future.

In the studied area, the unfavorable annual distribution of precipitation, the absence of snow cover during winter, and the rising of air temperature, all are contributing to drying conditions in agricultural soils, thus already negatively affecting local agricultural production, that is, crop rotation is becoming more and more simplified, the germination and sprouting of crops are impaired by the lack of precipitation, the yield is weather-dependent and unstable, and economic projections are frequently unreliable. Understanding of the changes in the soil water regime

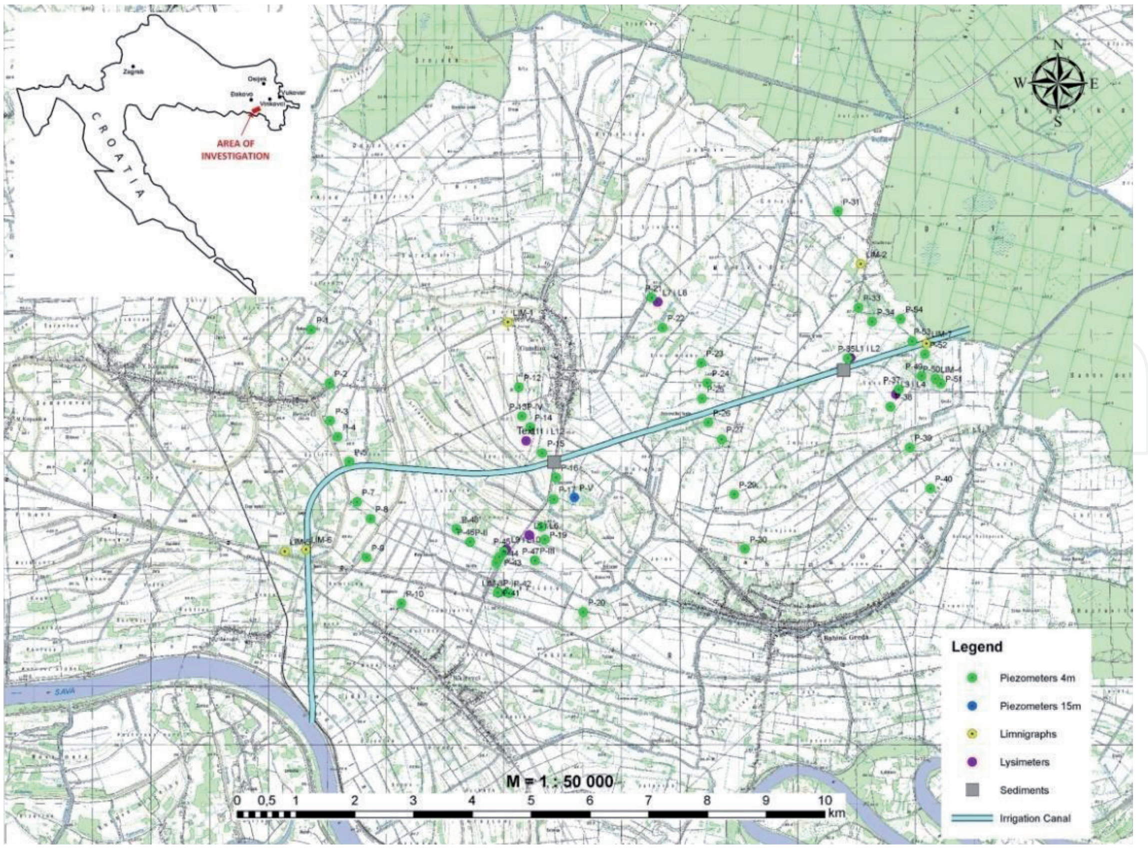

Figure 1.
The monitoring area (2003–2018) of the Biđ-Bosut field presented with the indication of used field equipment.

is of major importance for selecting the appropriate strategies for the drought risk management in agricultural systems and countering the harmful effects of climate change [12].

In this chapter, climatic and hydrological data from the Bið-Bosut field agricultural area are presented, with a description of practical strategies which could, at least to a certain extent, alleviate the negative impact of drought on the agricultural production. One of such strategies is the installation of irrigation systems, which imposes as a relatively obvious or a simple solution, but it is not traditionally applied in agricultural production in the eastern continental Croatia, mostly because until recently drought was non-occurring or the occurrence was mostly of a relatively short duration and/or of mild intensity and because the initial cost of implementing the irrigation systems may be considered high. However, if drought periods should occur during sensitive crop developmental stages (e.g., sprouting) or extend during prolonged periods, implementing the irrigation systems could prove to be extremely beneficial for the local agriculture, as well as cost-effective in the aftermath of plant production. The fundamental basis for introducing the irrigation systems in this area was met by proceeding with the construction of the irrigation canal in 2018. However, even though the use of irrigation is a possible solution for plant production under drought conditions [13], it is by no means the only action which should be taken, especially considering that water is not an unlimited resource. Thus, the existing network of drainage canals, built in the 1960s and 1970s, could with certain modifications be used to maintain the groundwater level and contribute to the total amount of water available for irrigation. Also, the proper selection of crops and management techniques can help to facilitate plant production and, keeping the before-mentioned in mind, contribute to alleviating the negative impacts of drought on agricultural production.

2. Climate and water regime monitoring in the studied area

Climate and water regime monitoring at the Bið-Bosut field started in 2003, with the aim of determining the impact of the irrigation canal construction on the groundwater dynamics and the surrounding agroecosystem. From the preliminary tracking of initial conditions, the monitoring evolved into a very valuable source of information with the majority of relevant agroecological data regarding the surface water, groundwater, leachate, as well as the agricultural soils in the studied area recorded. For tracking the groundwater dynamics, 50 shallow (up to 4 m of depth) and 5 deep (up to 15 m of depth) piezometers and 5 limnigraphs (up to 4 m of depth) were used. Measurements using the piezometers were done manually (by measuring tape) every 10 days, while the limnigraphs (Orpheus Mini) recorded groundwater levels daily.

The monitoring area is located at intersect between a semiarid into a semihumid moderate continental climate [14]. Meteorological data were analyzed for 2003–2018 and collected from the nearest meteorological station, the national meteorological station Gradište (45°09′ N; 18°42′ E). Data regarding the Sava river, to which the irrigation canal is connected, were taken from the Sava-Slavonski Šamac national measurement station for the years 2014–2018. The values are given on a monthly basis and are also transformed into annual values for easier following.

2.1 Precipitation dynamics

Figure 2 shows the monthly values of precipitation during the observed period. The monthly precipitation amounts (2003–2018) show a positive but nonsignificant upward trend (0.010 mm per month, that is, 0.12 mm per year), which is in accordance with the multiannual findings from similar studies [15]. In the last 5 years, a mildly negative but also nonsignificant trend (−0.40 mm per year) is visible. Moreover, the average annual sum of precipitation exhibits a mild but constant rise (682.7 mm for 1981–2018; 688.6 mm for 2003–2018; 728.8 mm for 2014–2018). Also, irregular precipitation extremes have been recorded (e.g., in June 2018; **Figure 2**). However, it should be noted here that high amounts of precipitation in a very short period actually have an extremely low effective value for crops (as explained in detail in Section 3.2).

2.2 Air temperature dynamics

The trend of increased average monthly air temperatures by 0.084°C per year (2003–2018) was recorded (**Figure 3**). If the determined value is used for the prediction of an air temperature after a longer period, data suggest that an increase of as much as 4.7°C may be expected in 50 years. The average multiannual temperature sequences also exhibit an increase (11.8°C for 1981–2018; 12.3°C for 2003–2018; 12.7°C for 2014–2018). Although these data are not sufficiently long-term in nature for solid conclusions, it is still may be considered as indicative of a general increase in air temperature.

2.3 Groundwater dynamics

Through detailed hydro-pedological research of the monitored area, a pedological characterization survey was completed with five soil-systematic units defined [16]. The classification was done according to [17], and the determined pedological units were semigleyic, hypogleyic, humogleyic, amphygleyic, and hydromeliorated soil. **Figure 4** shows the average monthly values of groundwater levels obtained by shallow piezometers located at 4 m from the soil surface, with a regard to the before-mentioned soil-systematic units.

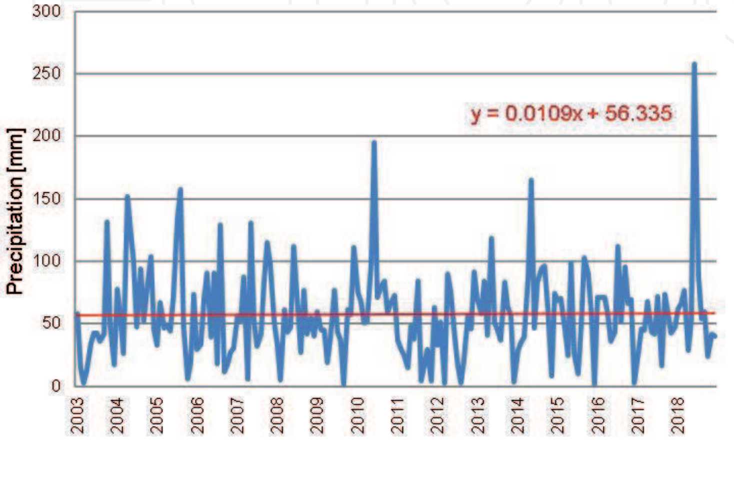

Figure 2.
The dynamics of average monthly precipitation (mm) at the monitored area of the Bið-Bosut field.

DOI: http://dx.doi.org/10.5772/intechopen.88503

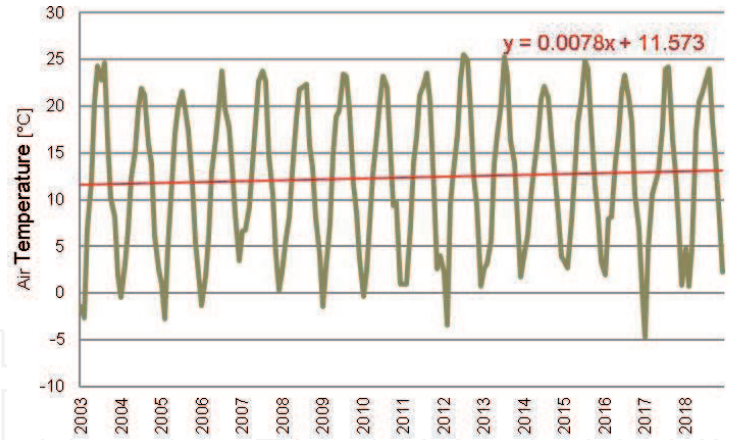

Figure 3.
The dynamics of average monthly air temperatures (°C) at the monitored area of the Biđ-Bosut field.

A relatively slight negative trend of groundwater levels (2003–2018) in the agricultural soils of the monitored area was recorded (6–10 cm per year). However, it should be noted that by observing only the last 5 years of monitoring (2014–2018), a negative trend was much more pronounce, ranging from 18 to 71 cm per year, that is, from 200% in semigleyic soil (negative trend for period 2003–2018 = 9 cm per year; period 2014–2018 = 19 cm per year) to 700% in hypogleyic soil (negative trend for period 2003–2018 = 10 cm per year; period 2014–2018 = 71 cm per year), depending on the soil type. Although the groundwater level was occasionally recorded below 4 m from the soil surface during the studied period, such occurrences were short-lasting (days) and irregular. However, in July 2017 and 2018, the groundwater level at the entire monitoring area lowered below 4 m from the soil surface and remained unchanged until the end of the year. The extremely low groundwater level which occurred in the second half of the last two research years is undoubtedly suggesting the need for further monitoring in the studied area.

The more frequent lowering of groundwater levels below 4 m from the soil surface was the reason for adding 5 deeper piezometers at 15 m from the soil surface during 2014. The average monthly groundwater level data obtained by deep piezometers are presented in **Figure 5**. The values were only slightly increased in comparison to the values measured by the shallow piezometers, which can be explained by a mild difference in pressure between the shallow soil aquifer and the deep water-bearing aquifer. The negative trend of a decreased groundwater level ranged from 26 to 77 cm per year, which is in agreement with the trends obtained by using shallow piezometers. However, data obtained from deep piezometers are for a relatively short period (4 years), and it is expected that after a longer research period, these values could even be rising.

All described climatic and water regime parameters suggest that in the studied Biđ-Bosut area, the agroecosystem changes are becoming more prominent. These changes are usually slow in progressing thus are hard to observe within shorter periods. However, field measurements and alterations of climatic and water regime parameters recorded during this study are contributing to the global predictions in which these changes in the agroecosystem are increasing in importance for the agricultural production. Finally, further continuous observation (monitoring) of climatic, water regime, and soil parameters should result in reliable databases, thus providing a foundation for the selection of appropriate site-specific strategies to counter the occurring changes and their possible negative impact on the agricultural production.

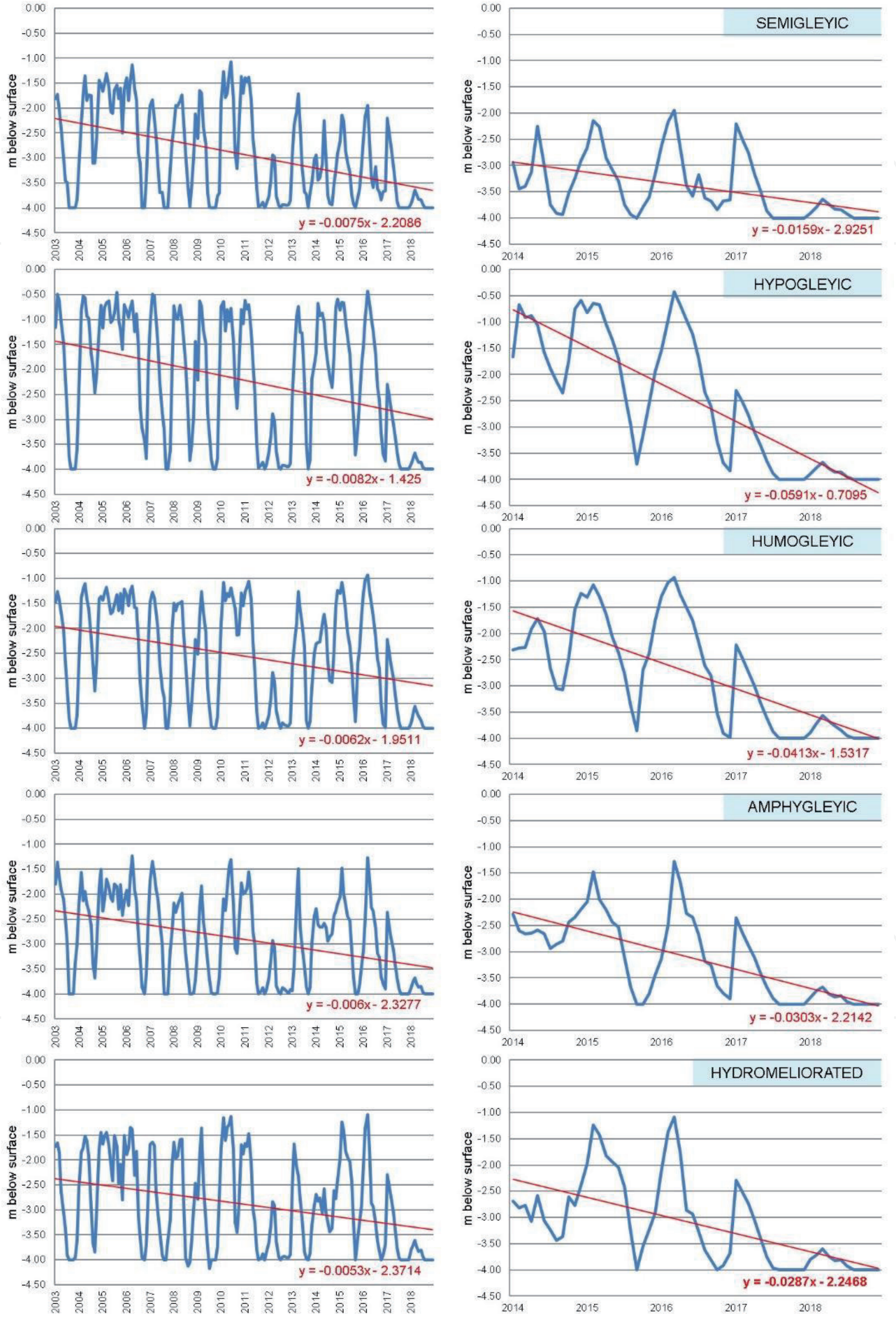

Figure 4.
The dynamics of average monthly groundwater levels in the shallow piezometers (located at 4 m from the soil surface) at the monitored area of the Biđ-Bosut field (left, groundwater levels in period 2003–2018; right, groundwater levels in period 2014–2018).

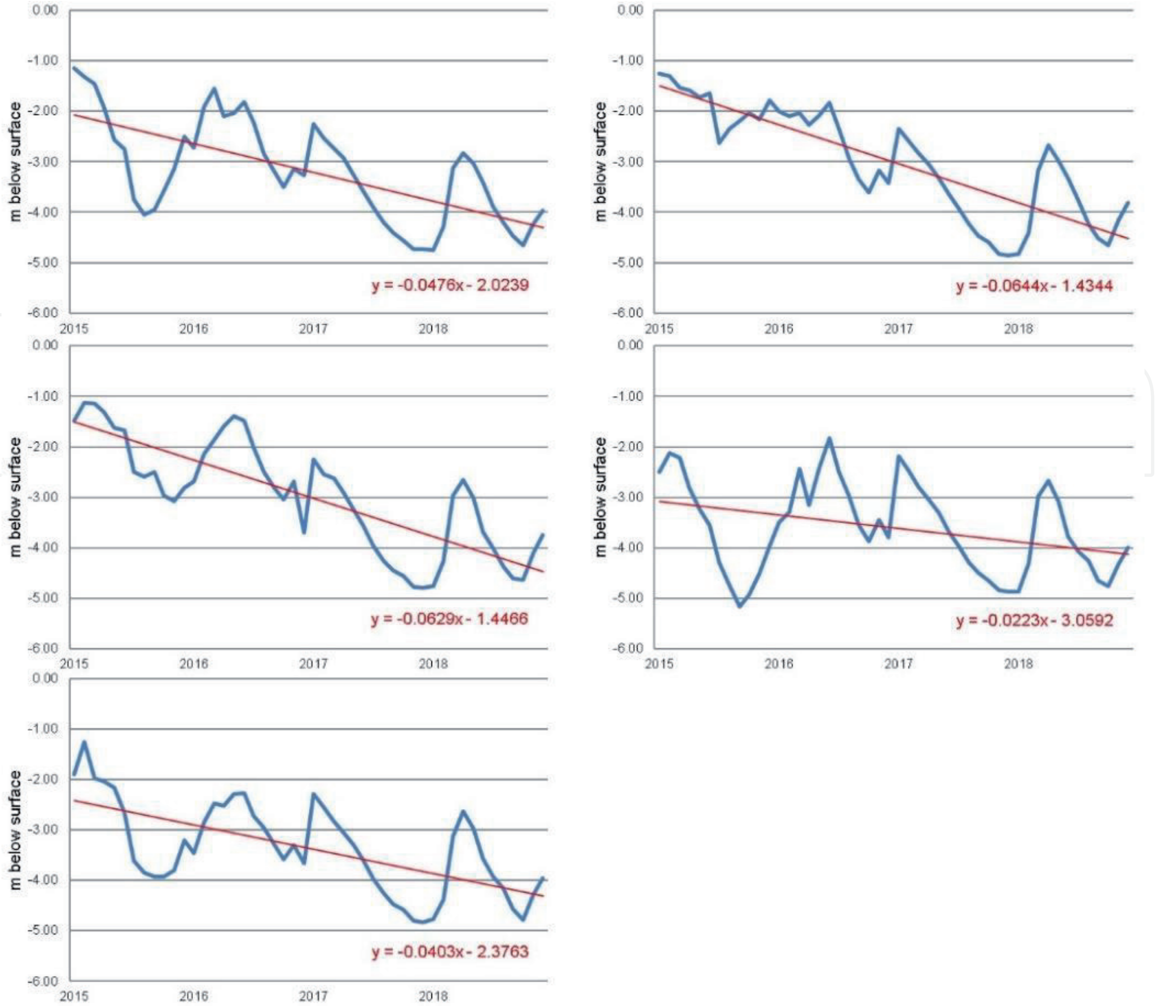

Figure 5.
The dynamics of average monthly groundwater levels in the deep piezometers (located at 15 m from the soil surface) at the monitored area of the Biđ-Bosut field.

3. Proposed measures for alleviating the consequences of drought

The measures proposed herein primarily focus not only on the eastern continental Croatia example but can also be applied to other agroecosystems with similar agroecological conditions [18]. Namely, according to the recent analyses for a 50-year period (1961–2010), it confirmed an evidence of increase in drought seasons (defined as consecutive dry days—CDD with daily precipitation <1–10 mm) notably in the eastern continental Croatia (e.g., Slavonia region) by 4%/decade to 7%/decade during summer [19]. In general, the studied agricultural area in continental Croatia characterizes relatively flat arable therein (with fluvisols, gleysols, and cambisols), positioned in between of Sava and Drava rivers, cultivated mostly with cereals and oil crops, with average annual effective precipitation of 521–890 mm and potential evapotranspiration (ET0) of 690–820 mm, as well as high irrigation demands, either in average (81–260 mm/annually) or dry (168–383 mm/annually) vegetation season [20].

3.1 Construction of the appropriate irrigation systems

Frequent periods during which groundwater level lowers below 4 m from the soil surface are imposing substantial limitations in the last decades for the agricultural production which lacks an irrigation system (such is the case in the Biđ-Bosut area). Agricultural production in the study (monitoring) area, although located in a traditionally agricultural region, so far does not rely on irrigation as a possible solution for alleviating occasional negative drought effects. The possible reason for that is because local agricultural production in this area is mostly located on hydromorphic soils, characterized by occasional or permanent moisturization by groundwater within 1 m from the soil surface [18]. Thus, the issue of lacking soil moisture which can last for several months has been an occurrence noted in this area only for the last 10 or so years, while before the main problem was the opposite: excess surface and groundwater amounts.

The completion of the irrigation canal in 2018 (**Figure 6**) was the main prerequisite for irrigation of the surrounding agricultural soils. The canal is connected to the Sava river, and, with the proper regulation of water levels in the canal, it could provide necessary and sustainable amount of irrigation water. It was projected that, during high water levels of the Sava river, water will be pumped into the melioration canal, from which it would then be channeled to the surrounding highly arable agricultural fields during the most of vegetation season given on negative water balance, for example [20]. More precisely, considering the amount of water in the Sava river [18], this hydrotechnical solution could help to ensure adequate amount of water for irrigation of the approximately 10,000 ha of surrounding agricultural soil. As for the quality of the water, studies from various authors have made it clear that the water from the Sava river is of ample quality to irrigate the local crops, for example [18]. However, water quality is an important factor when considering its use for crop irrigation; thus, if canal water is used for irrigation, it is necessary to implement permanent water quality control.

Application of appropriate water management strategies for the usage of Sava river water for irrigation of crops is of major importance. Such strategies include application of the modern low-pressurized/low-energized (fert)irrigation system, adaptation of cropping pattern (e.g., to give advantage to winter over spring cereals/cultivars and to those with shorter vegetation period when water balance is the most negative), modernization of conveyance systems (e.g., channel overlying or replacing with pipelines), conduct irrigation management on real time data measurements, application of conservation agriculture practices, and many others [20, 21]. Some of the most recent studies have confirmed that almost all crops cultivated on the studied areas are exposed to water stress (negative water balance) with significant yield losses even in normal (average) sessions. For instance, in Brodsko-posavska County (overspread on the most of elaborated area), an average annual (for 1963–2005 period) effective precipitation reaches 690 mm, while potential evapotranspiration (ET0) is 718 mm, causing the negative water balance during vegetation period for almost −200 mm [22]. According to the same study, irrigation requirements in average climate season for the most cropped cultures yield from 82 mm (corn) up to 160 mm (sugar beet) and over 200 mm (lucerne), while in dry seasons water requirements are higher by 1.8–1.9-fold (lucerne and sugar beet) up

Figure 6.
Opening of the Biđ-Bosut field irrigation canal.

to 2.6-fold (corn). The yield reduction in the case of nonirrigated conditions on this area is also significant for the most of crops, even in normal (from 11% in corn and soybean up to 25% in sugar beet on texture-lighter soils) and especially in dry seasons (from 25% in soybean up to 47% in sugar beet on texture-lighter soils).

Although Sava river can provide the required amount of water for irrigation, excessive (unsustainable) management measures could possibly create additional (agro)ecological issues regarding water levels of Sava river and even question the sustainability of such practice. This possibility is confirmed by the trend of lower levels of Sava river by 0.51 m per year for the period from 2014 to 2018 (**Figure 7**). Using Sava river water for irrigation should therefore be applied with the utmost rationality, that is, taking into consideration the optimal water regime within the river-soil-plant-atmosphere system, for example [23]. Additionally, the education of local farmers should be included as an important step in the planning and implementation of any irrigation system which is depending on a natural system, such as (Sava) river.

3.2 Using the existing irrigation infrastructure for the purpose of collecting precipitation

During the 1960s and 1970s, the main issue for the agricultural production in the studied region was the excess amount of surface and groundwater. That is why the area has an abundance of drainage canal networks through which excessive water was channeled into the recipient—the Sava river.

However, in June 2018, 257.4 mm of precipitation was recorded (**Figure 2**), which exceeds the average monthly precipitation in this area by several times (320%). These extremes were usually accompanied by storms and hail, which is why the authorities declared a state of emergency for the years 2010, 2014, and 2018. As mentioned before, such high amount of precipitation in a very short time has a very small effective value for crops because in such conditions water cannot infiltrate in the soil, usually resulting in (sub) surface runoff. In the studied area, most of the water from surface runoff streams firstly into the drainage canals, then toward the Sava river, and finally reaching the Danube river and ultimately the Black Sea. Thus, water from surface runoff is basically lost from this area and does not have any effect on the water regime of the soils, although the possibilities and sustainability of some on-farm water storage systems (e.g., surface accumulations, public reservoirs) should be also evaluated. This was confirmed by field measurements (**Figures 2-5**), from which it is clear that even the abundant rainfall in June

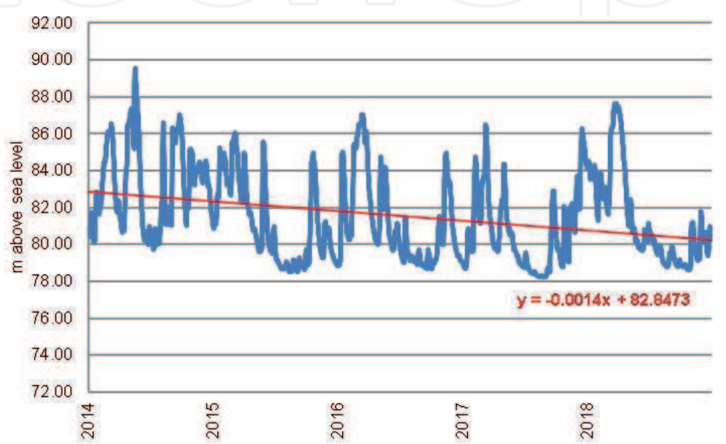

Figure 7.
The dynamics of Sava river daily levels at the Sava-Slavonski Šamac measuring station for the period from 2014 to 2018.

2018 did not lead to a noticeable rise in groundwater levels. Moreover, for the whole first half of 2018, the groundwater did not exceed the level of 3.7 m from the soil surface, and in July of the same year, groundwater level lowered below 4 m from the soil surface, remaining at stated level until the end of the year 2018.

The network of drainage canals was up until 10 years ago used exclusively for drainage of the excess water from the area. During the last 10 or so years, the appearance of excess water became increasingly rare, and in 2017 and 2018, no such occurrence was recorded, except for a few days in June 2018 (data not shown). What is more, in the last several years, the lack of moisture in soil has become especially noticeable and culminated in 2018. One possible hydrotechnical solution for such issue would be to modify the existing canal network by implementing the controlled drainage canal system (where water flow is controlled and limited by a regulating system) at the main drainage canals. This way, in cases of an extreme precipitation, the drainage canals would preserve their primary drainage function, but in case of lower precipitation (when no excessive water is present in soil but before the drought conditions), by closing the canal release point, the same canals could be used as a form of a precipitation retention system. This proposed system of a branched-out canal network could, with an adequate regulation of canal water release points, prove to be very useful when additional amount of water for the agricultural plant production is necessary, that is, under drought conditions. Using these drainage waters as a potentially valuable "resource" rather than considering them as a "waste" can contribute to the alleviation of water scarcity, thus the negative effects of drought conditions [24], which is also in accordance with the widely accepted and nowadays preferential concept of sustainability in agricultural production.

Additionally, if subsurface drainage systems are installed, there is also the possibility of implementing the subsurface drainage water regulation system which could control the groundwater level according to the soil moisture. According to [25], controlled drainage, also known as drainage water management, is a practice of using the water control structure at the drainage outlet in order to raise the groundwater level and thus retain water in soil during periods when drainage is not needed, but a deficiency of soil water is present. The implementation of controlled systems ($120 or $50–100 per ha if upgrading from conventional drainage systems) is relatively inexpensive [26] and therefore should be taken into account when designing an agricultural systems. However, considering the initial cost of installing such system, its introduction should be accompanied by a sufficiently profitable agricultural production that would presumably justify the additional investment.

3.3 Selection of crops and growing techniques in agricultural areas without the irrigation systems

Agricultural production without an irrigation system is completely depending on climate and available soil moisture (weather-dependent). In the context of increasingly important climate change, such production will presumably encounter more and more stressful conditions (i.e., plant water stress). In order to maintain the productivity, drought- and heat-tolerant crops/cultivars/hybrids must become the product of choice, as must the application of techniques to maintain the soil moisture by reducing evaporation [27, 28]. More precisely, evaporation occurs when moist soil is exposed to the atmosphere. In theory, to reduce the evaporation, it is necessary to reduce the exposed soil surface as much as possible and/or to shorten the time of the soil exposure to the atmosphere. In practice, mulching with plant residues and/or polyethylene foils can be used for this purpose [29]. Also, certain probiotic soil enhancers which have become available on the market recently can be used for the same purpose of reducing the evaporation [30]. These soil enhancers enrich the soil with beneficial microbes which accelerate decomposition of soil organic matter into smaller compounds capable to retain more water in the soil and further to plant-available nutrients, which increases the overall soil fertility but also improves soil capacity to retain moisture. Additionally, if the irrigation systems are applied in the studied area of Biđ-Bosut field, the appropriate irrigation systems are those with the localized water distribution (e.g., micro-sprinklers or drip irrigation), which distribute water only alongside the crops and thus reduce water losses and evaporation (in comparison with, e.g., irrigation boom).

At the end, the important viewpoint of the drought-alleviating management techniques is also from the economical aspect. Generally, adequate agricultural management includes the cost-benefit ratio regarding the crop value. Higher input into the agricultural production should be justified by investing into profitable crops, which will presumably pay out the initial investment. In this context, replacing the less profitable crops with crops for which the market demand is higher could be an appropriate action. However, this agricultural management strategy is not an easy task as it is not grounded on a permanent aspect but strongly relies on the current supply and demand market circumstances. Thus, additional economic analyses which include supplementary perspectives such as estimations of future market opportunities and trends may be of major importance.

4. Conclusion

Climatic and soil water regime data (2003–2018) suggest that the agroecosystem changes are becoming more prominent in the studied Biđ-Bosut area, and thus the future agricultural production may be exposed to the greater pressures regarding the insufficient amount of water in the soil. Also, some of the most recent midterm climate scenarios (models) performed for the studied and wider area support our theses. For instance, modern climate models from local to global scales employ relatively different horizontal resolutions from 10 to 300 km [19] and predict wide range of climate parameters, that is, scenarios. At the European scale (notably in its central part), it is expected that average seasonal near-surface temperature (Ta) is going to increase in the period 2011–2040 by 0.2–2°C [19]. According to the same authors and for the same midterm period, in Croatia the largest changes in Ta can be expected in the mid of vegetation session (summer) with an increase of Ta by 0.8–1°C in the central part of Croatia and around 0.8°C in eastern (Slavonia) region. As regards the average precipitation, a decrease of precipitation between 2 and 8% is predicted over the larger part of Croatia [19]. Consequently, higher evapotranspiration demands (over increasing average vegetation air temperature) and reduced average effective precipitations might further exacerbate water imbalances in the agroecosystems on the elaborated area.

Installation of the irrigation systems is a possible solution for countering the negative impact of drought, but other management strategies should also be implemented in order to achieve the sustainability of agricultural production. In this context, the education of local farmers should be included as an important step in the planning and implementation of any drought countering techniques, in order to achieve the highest success rate by adhering the rules and instructions referring to the rational and responsible water use. Finally, this study has shown that multiannual climate and soil water regime data may provide a good basis for the decision-making process in creating sustainable agricultural management policies (construction of the appropriate irrigation systems and use of the existing irrigation infrastructure for the purpose of collecting precipitation, use of drought- and heat-tolerant crops/cultivars/hybrids, and application of techniques to maintain the soil moisture by reducing evaporation, for example, mulching with plant residues and/or polyethylene foils and use of probiotic soil enhancers) focused on countering the negative impact of drought on the agricultural production.

Author details

Ivan Mustać*, Vilim Filipović, Lana Filipović, Gabrijel Ondrašek and Dragutin Petošić
Faculty of Agriculture, University of Zagreb, Zagreb, Croatia

*Address all correspondence to: imustac@agr.hr

References

[1] Wilhite DA, Glantz MH. Understanding: The drought phenomenon: The role of definitions. Water International. 1985;**10**(3):111-120. DOI: 10.1080/02508068508686328

[2] Tallaksen LM, Van Lanen HAJ, editors. Hydrological drought: Processes and estimation methods for streamflow and groundwater. In: Developments in Water Science. Vol. 48. Amsterdam, The Netherlands: Elsevier Science B.V; 2004. ISBN 978-0-444-51767-8

[3] Mishra AK, Singh VP. A review of drought concepts. Journal of Hydrology. 2010;**391**(1-2):202-216. DOI: 10.1016/j.jhydrol.2010.07.012

[4] Güneralp B, Güneralp İ, Liu Y. Changing global patterns of urban exposure to flood and drought hazards. Global Environmental Change. 2015;**31**:217-225. DOI: 10.1016/j.gloenvcha.-2015.01.002

[5] Goddard S, Harms SK, Reichenbach SE, Tadesse T, Waltman WJ. Geospatial decision support for drought risk management. Communications of the ACM. 2003;**46**(1):35-37. DOI: 10.1145/602421.-602442

[6] Sheffield J, Wood EF. Projected changes in drought occurrence under future global warming from multi-model, multi-scenario, IPCC AR4 simulations. Climate Dynamics. 2007;**31**(1):79-105. DOI: 10.1007/s00382-007-0340-z

[7] Seneviratne SI, Nicholls N, Easterling D, Goodess CM, Kanae S, Kossin J, et al. Changes in climate extremes and their impacts on the natural physical environment. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. Special Report of the Intergovernmental Panel on Climate Change. 2012:109-230. DOI: 10.1017/cbo9781139177245.006

[8] Gschwendtner S, Tejedor J, Bimueller C, Dannenmann M, Knabner IK, Schloter M. Climate change induces shifts in abundance and activity pattern of bacteria and archaea catalyzing major transformation steps in nitrogen turnover in a soil from a mid-European beech forest. PLoS One. 2014;**9**(12):e114278. DOI: 10.1371/journal.pone.0114278

[9] Jones A, Panagos P, Barcelo S, Bouraoui F, Bosco C, Dewitte O, et al. The State of Soil in Europe. Luxembourg: Publications Office of the European Union. Available from: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC68418/lbna25186enn.pdf; 2011 [Accessed: 27 March 2019]

[10] Romić D, Romić M, Ondrašek G, Zovko M, Bubalo M, Bakić H, et al. Monitoring zaslanjenja voda i poljoprivrednih tala na području doline Neretve. 2016; (report)

[11] Mustać I, Petošić D, Filipović V, Tomić F, Ondrašek G, Igrc MD, et al. Monitoring vodnog režima poljoprivrednih tala i kakvoće vode na području Dovodnog melioracijskog kanala za navodnjavanje Biđ-bosutskog polja za 2018. godinu. 2019; (report)

[12] FAO and ITPS. Status of the World's Soil Resources (SWSR)—Main Report. Rome, Italy: Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils; 2015. ISBN 978-92-5-109004-6

[13] Kour G, Bakshi P. Irrigation management practices and their influence on fruit agroecosystem. In: Ondrašek G, editor. Irrigation in Agroecosystems. Intech Open; 2019. DOI: 10.5772/intechopen.79569

[14] Köppen W. The thermal zones of the earth according to the duration of hot, moderate and cold periods and to the impact of heat on the organic world. Meteorologische Zeitschrift. 1884;**20**(3):351-360. (published 2011). Translated by Volken E; Brönnimann S

[15] Perčec Tadić M, Gajić-Čapka M, Zaninović K, Cindrić K. Drought vulnerability in Croatia. Agriculturae Conspectus Scientificus. 2014;**79**(1):31-38. Available from: https://hrcak.srce.hr/120753 [Accessed: 27 March 2019]

[16] Petošić D, Mustać I. Značajke vodnog režima i kakvoće poljoprivrednih tala na području Višenamjenskog kanala Dunav-Sava. Zagreb: Monografije Sveučilišta u Zagrebu-Agronomski fakultet. 2010. ISBN 978-953-6135-92-9

[17] Husnjak S. Sistematika tala Hrvatske. Udžbenici Sveučilišta u Zagrebu; 2014. ISBN 978-953169267-0

[18] Romić D, Marušić J, Tomić F, Petošić D, Šimunić I, Romić M, et al. Nacionalni projekt navodnjavanja i gospodarenja poljoprivrednim zemljištem i vodama u Republici Hrvatskoj. Agronomski fakultet Sveučilišta u Zagrebu; 2005

[19] Branković Č et al. Sixth National Communication of the Republic of Croatia under the United Nation Framework Convention on the Climate Change (UNFCCC) Selected Sections in Chapters: 7. Climate Change Impacts and daptation easures 8.Resarch, ystematic bservation and Monitoring. Zagreb: Meteorological and hydrological service of Croatia; 2013

[20] Ondrasek G. Water scarcity and water stress in agriculture. In: Ahmad P, Wani M, editors. Physiological Mechanisms and Adaptation Strategies in Plants Under Changing Environment. New York, NY: Springer; 2014. DOI: 10.1007/978-1-4614-8591-9_4

[21] Ondrašek G. Irrigation in agroecosystems. In: Ondrašek G, editor. Introductory Chapter: Irrigation after Millennia - Still One of the Most Effective Strategies for Sustainable Management of Water Footprint in Agricultural Crops. London, United Kingdom: IntechOpen; 2019. DOI: 10.5772/intechopen.73607

[22] Brodsko-posavska County (BPC). Conceptual solution of irrigation system Slobodnica. 2015

[23] Ondrašek G, Rengel Z, Petošic D, Filipović V. Land and water management strategies for the improvement of crop production. In: Ahmad P, Rasool S, editors. Emerging Technologies and Management of Crop Stress Tolerance. London, United Kingdom: Academic Press; 2014. pp. 291-313. ISBN 9780128008751

[24] Shideed K, Mazid A, Oweis T, van Ginkel M. Potential of rainfed agriculture and smallholder farmers in food self-sufficiency. In: Sadik A, El-Solh M, Saab N, editors. Arab Environment: Food Security. Annual Report of the Arab Forum for Environment and Development, Chapter: Potential of Rainfed Agriculture and Smallholder Farmers in Food Self-Sufficiency. Beirut, Lebanon: Technical Publications; 2014. pp. 74-102. Available from: https://www.researchgate.net/publication/313846915_Potential_of_Rainfed_Agriculture_and_Smallholder_Farmers_in_Food_Self-Sufficiency [Accessed: 27 March 2019]

[25] Fausey NR, Brown LC, Belcher HW, Kanwar RS. Drainage and water quality in Great Lakes and Cornbelt States. Journal of Irrigation and Drainage Engineering.

1995;**121**(4):283-288. DOI: 10.1061/(asce)0733-9437(1995)121:4(283)

[26] Richard C, Gary R, Larry B. Drainage Water Management: A Practice for Reducing Nitrate Loads from Subsurface Drainage Systems. Washington, DC: United States Environmental Protection Agency (EPA); 2006

[27] Veres S, Ondrašek G, Zsombik L. Wheat sensitivity to nitrogen supply under different climatic conditions. In: Fahad S, Basir A, Adnan M, editors. Global Wheat Production. London, United Kingdom: Intech Open; 2018. DOI: 10.5772/intechopen.76154

[28] Solh M, van Ginkel M. Drought preparedness and drought mitigation in the developing world's drylands. Weather and Climate Extremes. 2014;**3**:62-66. DOI: 10.1016/j.wace.2014.03.003

[29] Filipović V, Romić D, Romić M, Borošić J, Filipović L, Mallmann FJK, et al. Plastic mulch and nitrogen fertigation in growing vegetables modify soil temperature, water and nitrate dynamics: Experimental results and a modeling study. Agricultural Water Management. 2016;**176**:100-110. DOI: 10.1016/j.agwat.2016.04.020

[30] Pathak RK, Ram RA. Bio-enhancers: A potential tool to improve soil fertility, plant health in organic production of horticultural crops. Progressive Horticulture. 2013;**45**(2):237-254. Available from: http://krishikosh.egranth.ac.in/handle/1/5810021821 [Accessed: 27 March 2019]