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ORIGINAL ARTICLE

Sustainable agriculture in conditions of climate changes: Possible problems and ways of their solving in the South Steppe zone of Ukraine

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Global warming inputs in agricultural production are considered to be valuable enough. The goal of our study was to determine possible consequences and main trends of climate changes in the Kherson region, Steppe zone of Ukraine. We used perennial meteorological data, gathered at the Kherson regional hydro-meteorological station, for assessment of climate processes in the region. Additionally, we calculated the most important for sustainable crop production meteorological indexes by using the modern methods and software application CROPWAT 8.0, such as effective rainfall amounts, evapotranspiration and moisture deficit. Evapotranspiration in the region in the period from 2005 to 2016 averaged to 4.3 mm/ha per day, that is quite high value of the index. We determined that evapotranspiration increase under the progressive air temperatures rise cannot be covered at the expense of natural humidification, although rainfall amounts are tending to increase too. Moisture deficit remains high enough and reached the maximum value of 680 mm/ha in 2014. Regression models of the processes in climate of the zone showed stable, weakly progressive trend to dryness increase (from 462 mm/ha of moisture deficit in 2005 to 502 mm/ha in 2016). The greater moisture deficit is, the greater demand for irrigation is. Ignoring this fact and taking no steps to solve the problem of irrigation would cause drastic decrease of crop production in the region. So, climate changes in the Kherson region should be taken in account when planning the development of sustainable crop production in the region in changeable biosphere conditions. We also suggest that development and application of modern irrigation methods, such as drip and subsurface ones, are a priority direction of agricultural production in the zone in connection with modern climate conditions and possible deterioration of water quality.

Keywords: Global warming; climate changes; agricultural production; evapotranspiration; rainfall; temperature

Introduction

Climate changes are unavoidable. Presently we are facing the challenges of global warming. Mainly it is manifested, and associated in minds of most of people, with progressive increase in air temperatures. As a matter of fact, this opinion is quite sensible: scientists from all over the world are stating about increase of average global temperature (Schar et al., 2004; Patz et al., 2005). But global warming is not limited to only temperature increase. It also has its influence on precipitation amounts and their distribution in time and place; it also led to glaciers melting, changing directions of the streams, displacement of climatic zones, etc. According to agronomic research, global warming is highly likely to affect agricultural production sustainability (Parry and Carter, 1989; Reilly, 1995; Gitay et al., 2001; Chang, 2017). A number of scientific studies show that without adaptation, climate changes are quite hard challenge for agricultural production, particularly, in non-irrigated conditions of arid and semi-arid zones, but rationale adaptation measures can reduce susceptibility of agriculture (Nordhaus, 1991; Easterling et al., 1993; Rosenzwieg and Parry, 1994; Fankhauser, 1996; Smith, 1996; Mendelsohn, 1998; Wheaton and McIver, 1999). Especially, taking into account that fact that water demand would be increased not only for needs of agricultural production, but for urban needs too. And this increase estimated by 80% to 2050 would be really crucial (Florke et al., 2018). It was predicted that temperature increase of 1-3oC over the nearest decades would increase global potential evapotranspiration by 75-225 mm per year, while precipitation amounts would likely decrease by about 4-5% (Le Houerou, 1996). Recent studies stated about increasing of drought periods longevity in the Eastern Africa, which is traced back to the climate change (Cook and Vizy, 2013; Lott et al., 2013). Drought periods would be more frequent and common phenomenon over the continent in the XXI century (Niang et al., 2014). Other studies state about temperature increases that may have significant impact on crop yields (Battisti and Naylor, 2009; Schlenker and Lobell, 2010; Lobell et al., 2011; Sonwa et al., 2017). At the same time, this awful prognosis is not considered convincing enough. Some studies established that water resources supply would not decline with climate changes (Fleischer et al., 2008). In opinion of some scientists, there would be no harm to agricultural production sustainability because of global warming at the irrigated lands (Dinar and Yaron, 1990; Dinar and Zilberman, 1991; Dinar et al., 1992; Mendelsohn and Dinar, 2003). We agree with the statement that climate changes impacts on agricultural systems should be studied differently in the irrigated and non-irrigated croplands (Jablonski et al., 2002; Schlenker et al., 2005). So, the goal of our study was to determine possible effects of modern climate changes on crop production sustainability in the Kherson region both at the irrigated and non-irrigated lands, and to suggest some ways of solving the problems, which may occur, particularly, by application of modern irrigation methods.

Methods

Long-term meteorological data were got at the Kherson Regional Hydro-meteorological Center (latitude 46°38'24''N, longitude 32°36'52''E, altitude 41 m). Calculation of effectivwe rainfall amounts was conducted with accordance to the US Bureau of Reclamation (Dastane, 1978). Hydro-thermal coefficient was estimated by using the formula 1 (Meshherskaja et al., 1978):

$$HTC = \frac{10 \times R}{t} \qquad (1)$$

where HTC is the hydrothermal coefficient value, units; R is the rainfall amounts within the period, mm; t is the sum of positive temperatures above 10°C.
Evapotranspiration was calculated by the Penman-Monteith methodology (Zotarelli et al., 2010). To avoid handling of enormous calculations, all the computations were carried out within CROPWAT 8.0 software application (Swennenhuis, 2009). Moisture deficit was assessed by the disparity between evapotranspiration and effective rainfall amounts.
Standard deviation of the average annual meteorological inexes was calculated by using the formula 2 (Furness and Bryant, 1996; Logan, 2011):

$$SD = \sqrt{\frac{\sum_{i=1}^{N}\left(x_i - \overline{x}\right)^2}{N-1}} \qquad (2)$$

where SD is the standard deviation; x_1, ..., x_n are the observed values of the average annual meteorological inexes; N is the number of observations.
The coefficient of variation of the average annual meteorological inexes was calculated by using the formula 3 (Everitt and Skrondal, 2002):

$$CV = \frac{SD}{\overline{x}} \qquad (3)$$

where CV is the coefficient of variation; SD is the standard deviation; $\bar{x}$is the mean value of the water quality criterion. The linear regression trend lines were built by using the common calculation methods within LibreOffice Calc 6 software application analysis tools (Montgomery et al., 2012; Seber and Lee, 2012; Draper and Smith, 2014). The coefficient of determination was calculated by using the formula 4 (Ezekiel and Fox, 1967; Devore, 2011):

$$R^2 = 1 - \frac{V(y/x)}{V(y)} \qquad (4)$$

Results

Results of the study state about evident and considerable changes in climate patterns of the Kherson region. It was also established that these changes had appeared far long ago. Figure 1 demonstrates highly reliable (coefficient of determination R^2 is 0.82) tendency to increasing the rainfall amounts. The tendency had appeared in the XIX century, and it is going on nowadays. But it is weaker now than it used to be in the above-mentioned period. This fact can be proved by the meteorological data obtained in the period from 2005 to 2016 at the Kherson regional hydro-meteorological station (Figure 2). The coefficient of determination is many times lower (R^2 is only 0.15 vs. 0.82), although the tendency remains quite recognizable and definite. We also determined that rainfall amounts, both gross and effective, are highly variable indexes: coefficient of variation (CV) was high enough and averaged to 27.5% and 21.9%, correspondingly (Table 1).

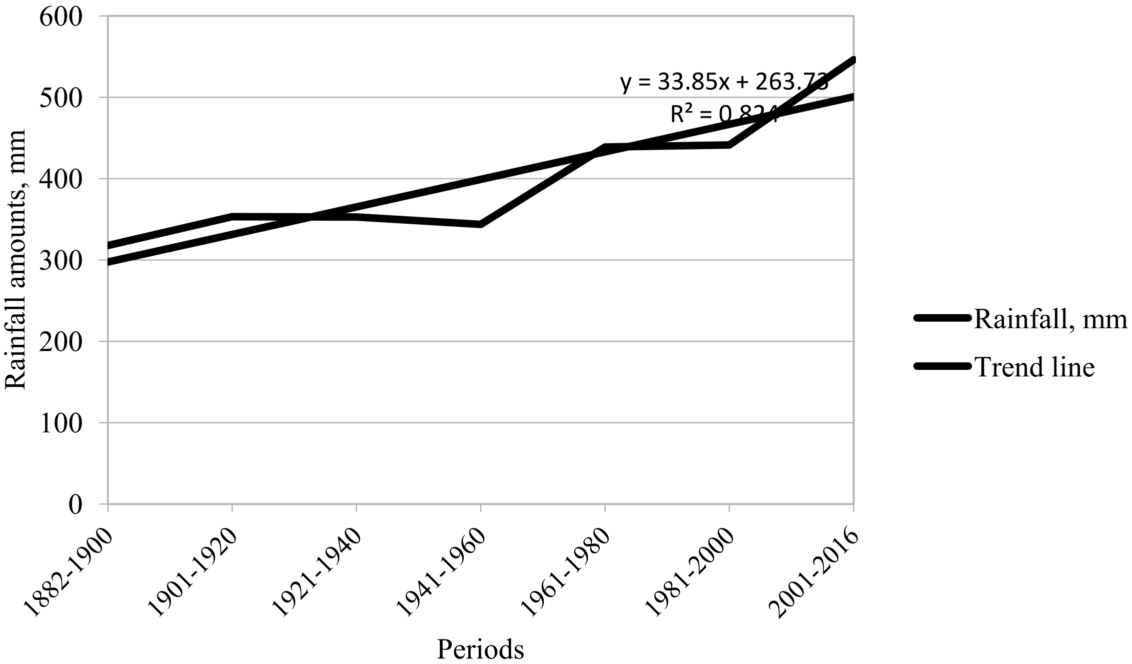

Figure 1. Average annual rainfall amounts during the last 134 years (from 1882 to 2016).

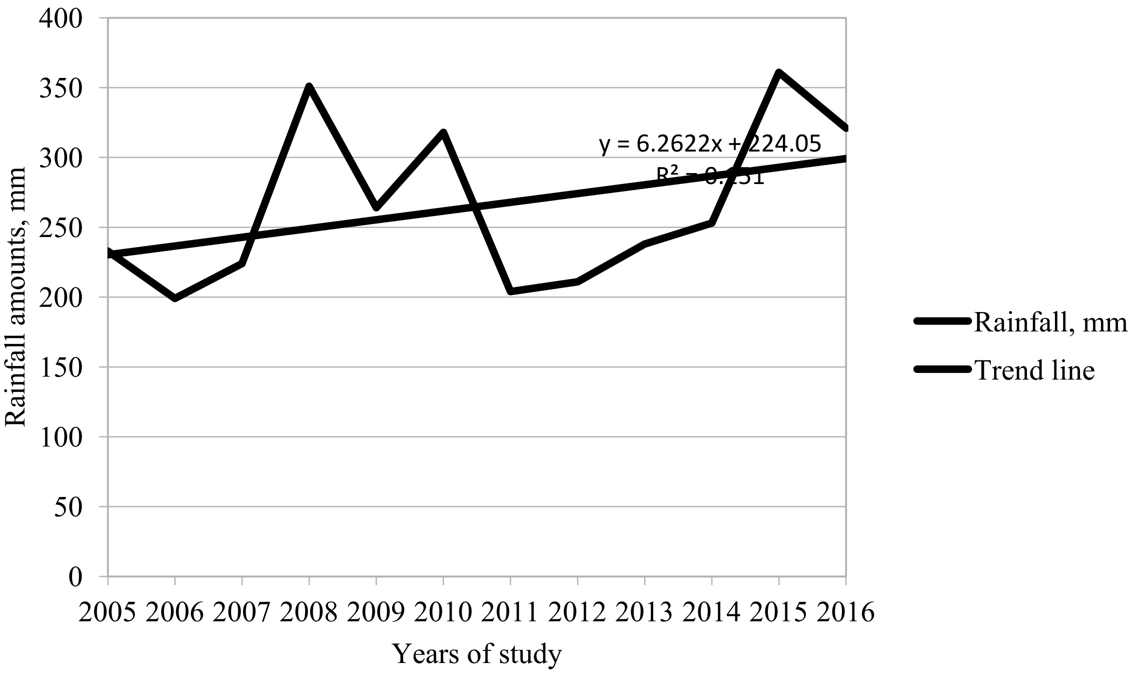

Figure 2. Average annual effective rainfall amounts expressed in mm/ha for the studied period from April to September of 2005-2016.

Amounts of effective rainfall increase from year to year during the last twelve years and reached their maximum of 361 mm/ha in 2015 (Table 1). But sum of positive temperatures above 10oC is also increasing considerably (Table 1, Figure 3).

Table 1. Average annual meteorological indexes for the studied period (April - September of 2005-2016).

Indexes	Years												Mean value	CV, %	SD
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016			
Rainfall, mm/ha	259	221	249	439	293	397	227	235	264	316	451	401	313	27.5	86.1
Effective rainfall, mm/ha	233	199	224	351	264	318	204	211	238	253	361	321	265	21.9	58.1
Sum of temperatures above 10oC	3496	3283	3482	3286	3353	3539	3327	3858	3534	3570	3476	3574	3482	4.6	160.2

Hydro-thermal coefficient, units	0.74	0.68	0.72	1.34	0.87	1.12	0.68	0.61	0.75	0.88	1.30	1.12	0.90	28.3	0.25
Relative air humidity, %	63.7	64.3	59.4	67.0	59.5	65.8	62.6	60.1	61.7	60.0	65.1	66.0	62.9	4.4	2.8
Evapotranspiration, mm/ha (per day)	3.8	4.0	4.5	3.9	4.3	4.0	4.1	4.2	4.3	5.1	4.6	4.5	4.3	8.5	0.4
Evapotranspiration, mm/ha (total)	695	732	823	714	787	732	750	767	787	933	842	823	782	8.5	66.2
Moisture deficit, mm/ha	462	533	599	363	523	414	546	556	549	680	481	502	517	16.1	83.0

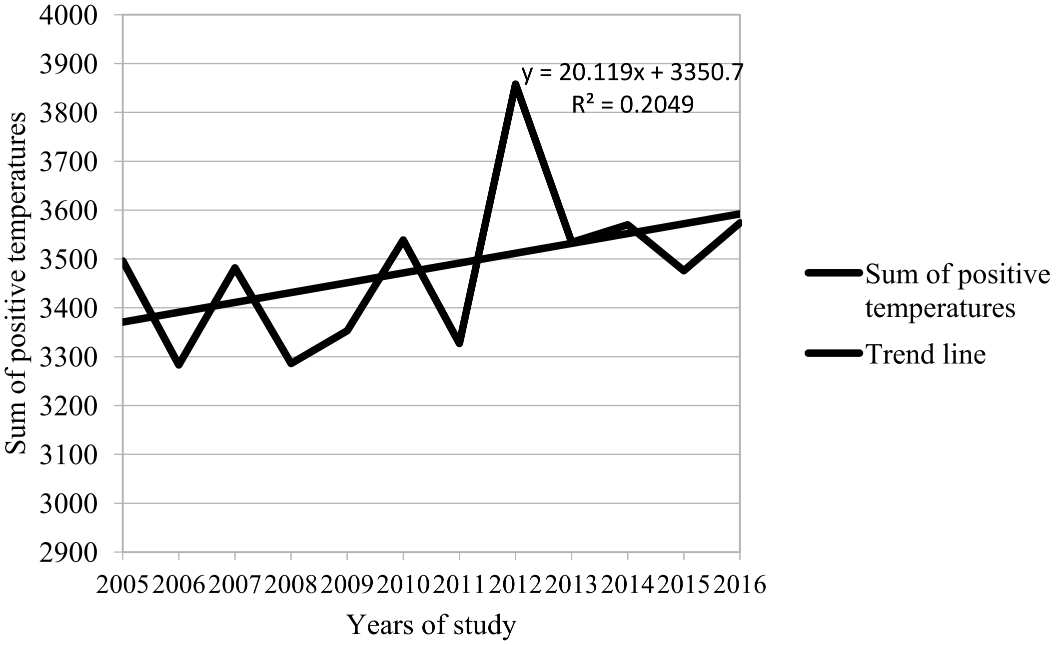

Figure 3. Average annual sum of positive temperatures (above 10oC) for the studied period from April to September of 2005-2016.

And increase of the latter climate index seems to be much more influential than of precipitation amounts. The fact is that moisture deficit during the last twelve years shows tendency to growth in spite of more humidification with greater rainfall amounts.

The calculations have proved previous statement, and Figure 4 reflects the above-mentioned fact. So, natural humidification is still incapable to provide sufficient moisture level, required for sustainable and effective cultivation of the major crops in the region without artificial irrigation. And it is considered that further climate changes will only strengthen the tendency to drought increase.

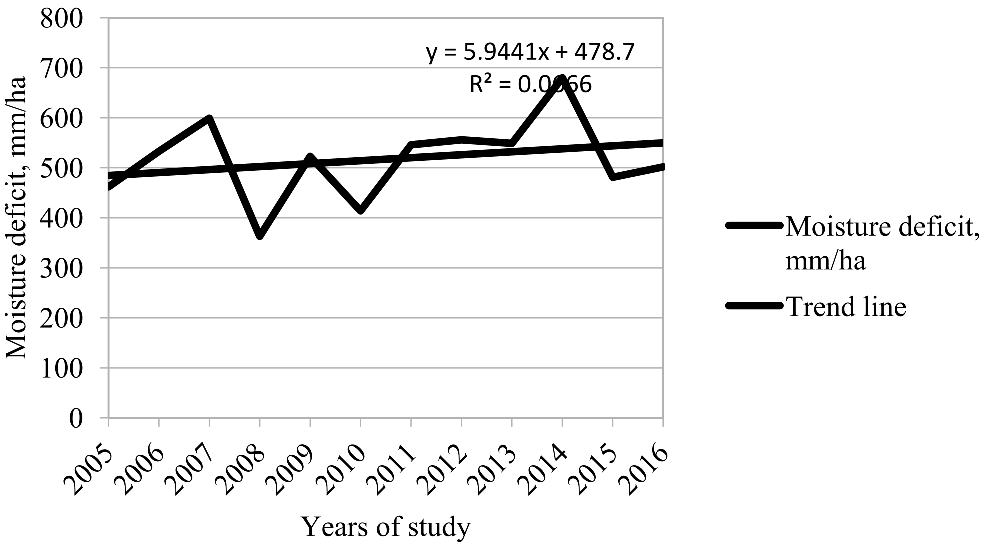

Figure 4. Average annual moisture deficit expressed in mm/ha for the studied period from April to September of 2005-2016.

It should be mentioned here that additionally we calculated the values of hydro-thermal coefficient (HTC). This methodology of humidification level assessment is quite old. The HTC values obtained through the calculations demonstrated absolutely opposite tendencies to the above: they are growing up and thos fact says about improvement of humidification conditions in the region (Figure 5). But we have to say that HTC cannot be considered as a reliable index any more. It takes into account limited number of meteorological factors (only temperature and rainfall amounts), when evapotranspiration calculated by the Penman-Monteith method figures on number of additional important indexes, for example, wind speed, solar radiation, vapor pressure, etc. (Allen et al., 1998). Besides, variability of the index is very high (CV 28.3%), so it is unstable enough to be considered trustworthy (Table 1). So, all the changes in climate, in our opinion, must be estimated by using the modern methodology of calculations provided by FAO.

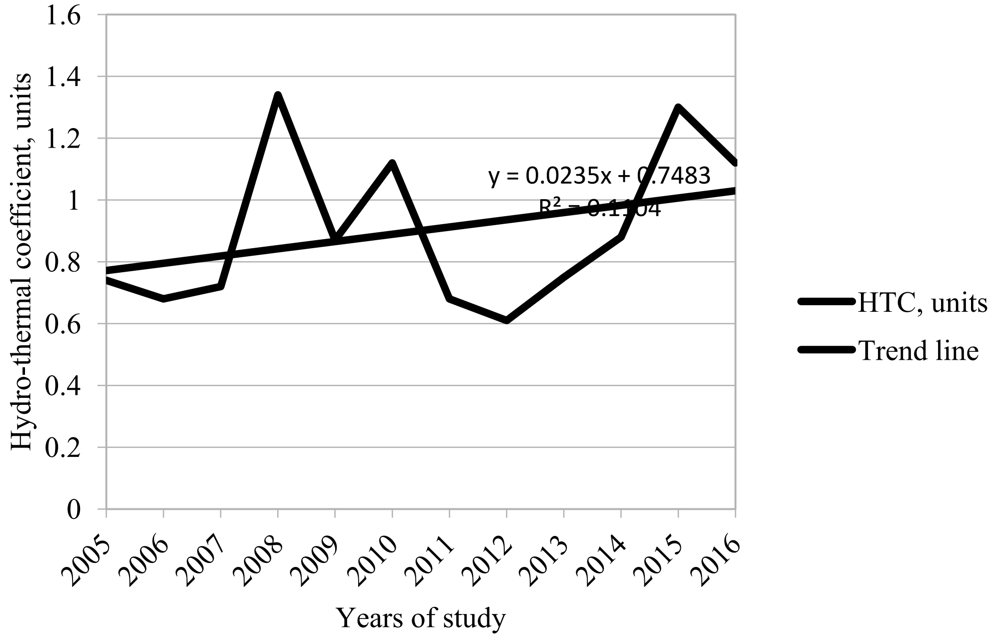

Figure 5. Average annual hydro-thermal coefficient values for the studied period from April to September of 2005-2016.

Discussion

Climate changes concerning to global warming are established in different parts of the world. For example, temperature increase of 1.8oC was recorded in Nepal for the period of 1975-2006 (Malla, 2009); Australia warmed of about 0.8oC during the last century (Hughes, 2003); forest fires occurrence is projected to be increased in Canada due to the global warming of 25-75% by the end of the 21st century (Wotton et al., 2010); changes in monsoon flow and pattern of precipitation are highly likely to be effected by the modern climate trends in India (Dash and Hunt, 2007); air temperatures are anticipated to be increased up to 2-3oC by 2065 in Pakistan (Gorst et al., 2015); climate and environmental conditions are being changed by the global warming in China (Qin et al., 2015). All the studies devoted to the subject determined evident tendency to climate change in Ukraine. It was stated that these changes are leading to significant climate warming, which increased the annual air temperature by 0.6±0.2oC per 100 years on the background of insignificant increase in the annual precipitation amounts by 5-7% per 100 years. And in the Steppe zone of Ukraine air temperature increase to 2070 is estimated even higher that is to say between 1.61-1.65°C. This causes strong tendency to evapotranspiration increase in the zone, which is also proved by our investigations (Muller et al., 2016). Climate changes are expected to make an influence on water resources, especially, in Southern and Eastern regions of the country. It should also be mentioned here, that water scarcity growth can cause additional problems under the global warming conditions, particularly, in use of the irrigation water with limited suitability, as it is in the Ingulets irrigation system of the Kherson region (Likhovid, 2015; Lykhovyd and Kozlenko, 2018). Climate changes can lead to appearance of unexpected hindrances in agricultural production (Boychenko et al., 2016). Correlating results of our study with previously conducted scientific investigations in this field we can see that most of domestic scientists are convinced in aggravation of agricultural production in connection with global warming, even to the level of desertification of some areas (Boychenko et al., 2016; Lykhovyd, 2018). But some foreign authors do not agree with the above-mentioned. There is a number of studies trying to convince us in benefits of climate changes for Ukrainian, Romanian, Moldavia, Hungarian and Bulgarian agricultural production. They state that the only restriction to growth of agricultural production may be improper irrigation (Bar et al., 2015). Some scientists forecast an increase in export of agricultural products in Ukraine and Russia (Ermolieva et al., 2015; Depperman et al., 2018). So, this question is disputable. But all the studies state, and ours is not an exception, that climate changes of global warming are coming and we have to take steps to deal with their challenges. Besides, we have focused our researches on the agricultural reactions on climate changes only. But everyone should understand significance of their impact on human health, life conditions (particularly, of weak and old people suffering from chronic diseases), wild nature (both flora and fauna) and natural biosystems and landscapes in general (Stone, 1995; Linder et al., 2010; Williams et al., 2013; Kruhlov et al., 2018).

Conclusions

Climate changes are unavoidable. It is evident that mankind should take steps to survive and keep up food support on appropriate level in the modern conditions of global warming, which causes great impact on agricultural systems functioning first. Our study has proved the fact of considerable moisture deficit increase, particularly, in the South Steppe zone. Growing moisture deficit is one of the most important limiting factors of sustainable crop production in the region. So, it requires scientifically based solving in the nearest future. We suggest introduction of drought-tolerant crops, viz., grain sorghum, safflower, millet, chickpea, etc., at the non-irrigated lands as possible alternative for some crops with high requirements to water supply, for example, corn. And as to irrigated agriculture we suggest introduction of modern water-saving irrigation methods (drip, subsurface irrigation, micro-sprinkler irrigation, etc.) as but one way to provide stable and high yields of major crops and to prevent further water scarcity in the region.

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