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Review

Rethinking the sustainability of Israel's irrigation practices in the Drylands☆

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ABSTRACT

Broad utilization of drip irrigation technologies in Israel has contributed to the 1600 percent increase in the value of produce grown by local farmers over the past sixty-five years. The recycling of 86% of Israeli sewage now provides 50% of the country's irrigation water and is the second, idiosyncratic component in Israel's strategy to overcome water scarcity and maintain agriculture in a dryland region. The sustainability of these two practices is evaluated in light of decades of experience and ongoing research by the local scientific community. The review confirms the dramatic advantages of drip irrigation over time, relative to flood, furrow and sprinkler irrigation and its significance as a central component in agricultural production, especially under arid conditions. In contrast, empirical findings increasingly report damage to soil and to crops from salinization caused by irrigation with effluents. To be environmentally and agriculturally sustainable over time, wastewater reuse programs must ensure extremely high quality treated effluents and ultimately seek the desalinization of recycled sewage.

Contents

1. Introduction 387
2. Drip irrigation: sustainability concerns 389
3. Wastewater reuse: sustainability concerns 390
4. Lessons for the drylands from Israel's irrigation experience 392
5. Conclusions 393
References 393

1. Introduction

Israel's efforts to combat desertification are often considered a unique, but largely successful story (Tal, 2006). The country is comprised almost entirely (93%) of drylands – meaning that most lands have an annual aridity index or precipitation to potential evapotranspiration ratio (P/PET) ranging between 0.05 and 0.65 (United Nations Environmental Management Group, 2011). According to conventional UN and international standards (Falkenmark, 1989, Falkenmark and Widstrand, 1992), the country suffers from acute water scarcity. Nonetheless, over the past sixty years it has seen a 1600 percent increase in the value of the produce grown by local farmers (Kislev and Tsaban, 2013). The astonishing surge in agricultural productivity has been part and parcel of the country's land management policies and its ambitious and innovative new irrigation strategies. The two central components of this strategy are: wide utilization of drip irrigation technologies and a complete commitment to "marginal" irrigation water sources, in particular recycled wastewater. Initial results have been hailed as extraordinarily impressive. Traditionally local water managers and scientists joined international experts from Australia (Derry, 2011), Brazil, (Marques et al., 2011) Europe (Raso, 2013) and the U.S (U.S. National Research Council, 2012) in endorsing wastewater reuse. Yet, a growing Israeli scientific consensus suggests that this "grand

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experiment” may be fundamentally unsustainable. In this review, Israel's experience in irrigation, especially in the country's agriculturally revived drylands is considered along with lessons learned and the long-term environmental and agronomic implications.

Irrigation in sundry forms has been utilized for 4000 years. For much of human history it was linked to the development of agricultural surpluses that allowed urban civilizations to emerge (Hillel, 1992). It did not take long for the vast majority of water utilized by humans on the planet to be directed to irrigation (McNeil, 2001) – today 69 percent of the estimated 3240 cubic kilometers (Gleick, 2000, UN, 2014). This is especially the case in the arid regions that cover 42% of the planet's surface. It is true that the United Nations reports that only 20% of cultivated agricultural lands on the planet utilize irrigation (UN -IFAD, 2015). But these technologies are increasingly synonymous with agronomic efficiency: irrigated fields and orchards already produce 40% of the world's crops (UN, 2014). According to one estimate, moving from rain-fed to irrigated agriculture, especially in water scarce regions, boosts crop yields by 300% (Howell, 2001). Any compelling vision of future international food security involves dramatic increases in irrigation globally.

This may be more difficult than many people imagine. According to UNESCO, water extraction on the planet has tripled over the past 50 years (UNESCO, 2012). As the scope of irrigated lands doubled between 1961 and 2000 (Ansfeld, 2010) physical limitations began to emerge. In many areas of the world, especially in dryland regions, irrigation relies primarily on groundwater sources (Siebert et al., 2010). Famiglietti (2014) estimates that over 50 percent of the water used to irrigate the world's crops is supplied from underground sources, with over two billion people directly dependent on groundwater as their primary water source, The estimated 8–10 million cubic kilometers of groundwater on the earth ostensibly constitute an inexhaustible resource, two thousand times the current annual withdrawal of surface water and groundwater combined (Van der Gun, 2012). But a closer look suggests otherwise.

Using geochemical, geologic, hydrological and geospatial data sets, Gleeson et al. (2015) recently estimated the total global supply of groundwater — with a focus on “modern” groundwater. Groundwater that is less than 50 years old accounts for less than 6 percent of all groundwater in earth's uppermost layers. Moreover, unfortunately, a high percentage of the world's aquifers are too salty to utilize, inaccessible, too costly to pump – or simply in the wrong place. Throughout the drylands, where groundwater is essential for irrigated agriculture, from northern China to the Middle East; from North Africa to the American Southwest, water tables are dropping, with most of the major aquifers in the world's arid and semi-arid regions exhibiting ”rapid rates of depletion” (Famiglietti 2014). After many years of projections warning about hydrological doom and gloom, many wells really are starting to dry up (Brambila, 2014; Erdbrink, 2015).

With irrigated lands continuing to grow globally at a rate of 0.6%/year, water shortages in many parts of the world are becoming more acute and increasingly constitute the limiting factor for expanding agricultural production or diversifying to water intensive crops (AQUASTAT, 2010). In short, growing water scarcity poses a grave danger for future food security. And if there is any single compelling lesson from irrigated agriculture in days gone by, it is that inappropriate irrigation practices that systematically deliver salt to soils will eventually be disastrous for the environment (Hillel, 1992). One estimate suggests that at least 20% of irrigated lands on the planet suffer from significant soil salinization. In 1995 the estimated economic price of associated lost land productivity was 12 billion dollars/year (Ghassemi et al., 1995). By 2014 the figure had jumped to 27 billion (Qadir et al., 2014). Climate change in many regions threatens to exacerbate salinization phenomena (Várallyay, 2010; Ashour and Al-Najar, 2012).

It was this general context which led to the emergence of drip irrigation some fifty years ago in Israel, a technology that was soon hailed as a breakthrough in agricultural efficiency (Siegel, 2015). In the country's early years, furrow and gravity based flooding systems were normative. But to accommodate a burgeoning population in the arid and semi-arid conditions prevailing throughout most of the country, it was critical to increase agricultural production *without* increasing water demand. Supported by an intensive extension service, farmers in thousands of new agricultural operations soon switched to pressure based sprinklers and with time to micro-irrigation systems based on drippers, micro-sprinklers and point based emitters (Postal, 1997).

Drip systems delivered tiny amounts of water and fertilizer directly to the root zone of plants and trees in a steady flow. Drip irrigation immediately produced significantly “more crop for the drop” and offered farmers myriad operational and environmental benefits (Camp, 1998; Rawlins and Raats, 1975). Drip irrigation can prevent disease by reducing water contact with stems, leaves and fruits; it reduces weed growth by keeping field rows dry; labor required to run irrigation systems dramatically decreases due to computerized operations; and finally, drip irrigation can eliminate nonpoint source runoff pollution, especially in hilly terrain while dramatically reducing the discharge of nutrients and chemicals below the root zone of plants.

While Israeli agriculture was embracing drip irrigation, a parallel process took place: treated sewage effluents became the predominant source of water for the Israeli agriculture sector. Faced by chronic water shortages, during the 1950s, an increasing number of Israeli farmers began to reuse sewage in order to expand their lands under cultivation. Rather than try to discourage the phenomenon, officials at the Ministry of Health, preferred to regulate it. The Ministry set standards for reuse of effluents and along with the Ministry of Agriculture supported a 1956 national masterplan that envisioned utilization of 150 million cubic meters of treated wastewater by Israel's agricultural sector (Tal, 2002). Today, three times that amount is recycled.

While there was initial resistance among some farmers due to aesthetic and health concerns, soon effluent recycling became commonplace and the new norm for irrigation. A range of pathogenic microorganisms' ability to survive extended periods of time in soils is well documented and several studies confirm pathogens ability to penetrate internal plant tissues via the root (Gagliardi and Karns, 2002; Natvig et al., 2002) as well as translocate and survive in edible, aerial plant tissues (Guo et al., 2002; Bernstein et al., 2007). Nonetheless, when the first epidemiological study among Israeli farmers using recycling effluents was conducted in the 1970s, no associated health effects were identified (Fattal and Shuval, 1981). Subsequent research in Israel suggests that if sewage undergoes conventional secondary treatment and water quality parameters are met, even following prolonged periods of irrigation, concentrations of coliforms and fecal pollution in leachate from growing beds remain low and comparable to those in conventional irrigation sources. (Bernstein, 2011).

Slowly and steadily, Israel pursued a policy of maximum effluent utilization. By 2015 the country recycles 86% (400 million m^3) of the sewage which arrives at the country's treatment plants (Kireshner, 2015). This is a *far* greater commitment than other countries. For instance, Spain, the European leader in the field, reportedly recycles 17% of its sewage (Kershner, 2015); Australia fell short of a 30% 2015 target, with wastewater recycling rates between 18% and 20% (Whiteoak et al., 2012). But around the world, there is a growing inclination to see sewage as a critical irrigation source for agriculture and horticulture (Scott et al., 2004). For instance, in California