Potential Development of Fertigation and its Effect on Fertilizer Use

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Abstract

Worldwide, the area of irrigated land has doubled impressively from 139 million ha in the 1960s to 276 million ha, i.e. ~20% of all arable land, in 2002. Of the irrigated land, 75% is in developing countries, which are thus enabled to produce more food for their growing populations, on the same land base. Because of this development, agricultural water withdrawal increased from 1,100 to 2,650 km^3 per year between 1950 and 1998-2002. Urbanization and improvement in the standard of living have led to rapid growth in domestic (municipal) and industrial water withdrawals, which have reached 40% of the global agricultural withdrawal.

Whereas 50% of the agricultural water withdrawal is consumed by plants (through evaporation and transpiration), up to 90% of the domestic and industrial water withdrawal is returned to rivers and aquifers, so creating a large potential source for the expansion of irrigation. However, only a limited proportion of this water is treated sufficiently to match the quality for agricultural usage, and full utilization of treated wastewater (TWW) might enable an increase of 10-70% in the total water drawn for agriculture.

The levels of nutrients found in TWW (typically 50, 30 and 35 ppm of N, P_2O_5 and K_2O, respectively) could supply a large proportion of the nutrient requirements of TWW-irrigated fields, and this needs to be reflected in fertilizer recommendations. Theoretically, full utilization of the output from conventional sewage treatment facilities could contribute 13.3, 8 and 9.3 million tonnes of N, P_2O_5 and K_2O, respectively, worldwide.

The development of fertigation is driven by water scarcity and the resulting introduction of localized irrigation, as well as by the environmental pressure to treat and dispose of TWW properly. The cultivation of vegetables and orchard fruits near megalopolises is an economically driven practice, which competes strongly for potable water, but which also has high synergy with disposal of well treated municipal wastewater via localized irrigation.

A large-scale survey of plots irrigated with water from various sources, including TWW, showed that the available nutrients in TWW, especially phosphorus, must be taken into account when calculating fertilizer recommendations, nutrient balances and the selection of water emitters.

This paper describes the options and implications for increased fertigation using TWW.

Keywords: fertigation, nutrients, potassium, localized irrigation, treated wastewater, water withdrawal.

Introduction

Development of irrigation and potential of TWW

Worldwide, the irrigated land area has increased from 139 m hectares in the 1960s to 276 million ha in 2002; it now amounts to ~20% percent of all arable land (Fig. 1). In 2002, 75% of the irrigated land was in developing countries, which irrigation enabled to produce more food for their growing populations, on the same land base. Because of the expansion of irrigated land, the agricultural water withdrawal increased from 1,100 to 2,650 km^3 between 1950 and 1998-2002 (Table 1, Fig. 1). Urbanization and improvements in the standard of living have led to a parallel rapid growth in domestic and industrial water withdrawals, which now account for 30% of the global water withdrawal. Demand for water for non-agricultural uses is still increasing, in response to economic growth, rising populations and increased urbanization (FAO, 2004). Rosegrant *et al.* (2002) predicted that the absolute growth in non-agricultural demand for water would exceed that in agricultural demand, which would result in a reduction in agriculture’s share of total water consumption in developing countries from 86% in 1995 to 76% in 2025 (FAO, 2004).

The increase in municipal water use, from 100 to 380 km^3 per year (Table 1, Fig. 1) is, however, of great potential value for agriculture: water from these sources is easily collected through sewage systems and can be treated to quality levels suitable for agricultural irrigation. An extreme example of the potential for municipal water use is found in Israel, where 95% of the population is connected to sewerage systems, 80% of the wastewater is treated in wastewater plants, and ~70% of the treated urban wastewater is used for agriculture (Icekson-Tal *et al.*, 2003). Currently 30% of irrigation water used in Israel is

TWW, and in the near future this will increase to more than 50% (personal communication, J. Tarchitzky).

Table 1. Estimated global water withdrawal (km^3 per year and as percentages of total withdrawal).

Sector	1950 [(1)]	1995 [(1)]	1998-2002 [(2)]
	------------------------ *km^3/year*	------------------------	
Agriculture	1,100	2,500	2,650
Percentage of total	*79*	*69*	*69*
Industries	200	750	776
Percentage of total	*14*	*21*	*20*
Municipalities	100	350	380
Percentage of total	*7*	*10*	*10*
Total	1,400	3,600	3,806

Source: [(1)]FAO, 2000. [(2)]Calculated from FAO AQUASTAT data base (http://www.fao.org/ag/agl/aglw/aquastat/dbase/index.stm)

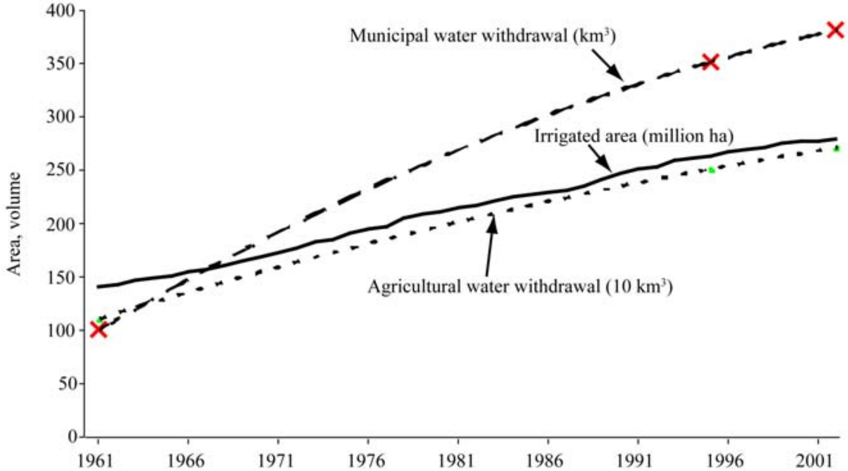

Fig. 1. Evolution of irrigated area, agricultural and municipal water withdrawal (1960 – 2003). *Source*: Area: FAO database; water withdrawal: FAO, 2000 (Crops and drops and FAO AQUASTAT).

In Asia, 84% of the water is used for irrigation, greater than the global share of 71% (Table 2). At the same time, the population in Asia consumes per capita only half of the global daily average (65 and 126 L/day per capita, respectively, Table 2). The demand for domestic water will increase significantly as both population and standard of living in the region rise, and thus the availability of wastewater for irrigation will also increase. For example, a city with a population of one million and water consumption of 200 L/day per capita would produce 62 million m^3 of wastewater per year, assuming that 85% flows into sewerage systems. Treated and supplied, this may be sufficient for the irrigation of 12,410 ha, or for production of 80,000 mt of grain.

Table 2. Annual water withdrawal and per capita consumption in Asia.

Region	Annual water withdrawal by sector [(1)]				Per capita consumption [(2)]	
	Agricultural		Domestic (municipal)		People (billion)	L/day
	km³	*% of total*	*km³*	*% of total*		
Asia	1,212.5	84	91.5	6	3,823	65
World	2,310	71	290.6	9	6,301	126
Asia as % of world	52.5		31.5		21.5	

Source:
[(1)] FAO AQUASTAT,
http://www.fao.org/ag/agl/aglw/aquastat/regions/asia/index4.stm, data from 1996.
[(2)] Calculated from FAO FAOSTAT,
http://faostat.fao.org/faostat/collections?version=ext&hasbulk=1&subset=agriculture, data from 2003.

Development of fertigation

The need to increase the efficient use of irrigation water is acute. The gap between the irrigation efficiency achieved in surface irrigation (25-40%) and that in pressurized localized irrigation (80-95%) justifies investment in the irrigation of marginal lands. The global area under sprinkler and micro-irrigation systems is estimated at 25 million ha, of which 40% are in the USA (ICID 2005), approximately 20% are under micro-irrigation. The USA, Spain, France, China, Italy and India each have over 1 million ha under sprinkler and micro-irrigation. In developed countries and those in arid and semi-arid regions, well over 80% of the irrigated land is under either sprinkler or micro-irrigation systems (ICID, 2005). The application of drip irrigation is expanding rapidly in India and China. In India the area under drip irrigation increased from about 1,000 ha in 1985 to 70,860 ha in 1991, mainly in Maharashtra (32,924 ha), Andhra Pradesh (11,585 ha) and Karnataka (11,412 ha). The drip-irrigated crops are mainly orchards (39,140 ha), but drip irrigation is also used for sugar cane (3,900 ha) and coconut (2,600 ha). The average cost of drip irrigation development ranges from US$750 to 2,000 per hectare. This fast growth can be partly attributed to the subsidies offered by the Government for the adoption of drip systems: a farmer can receive a subsidy up to US$750/ha (FAO, 1999). There are similar expansions occur in China, where the dependency on government subsidies is very high.

There are no exact figures to quantify the penetration and development of fertigation systems. However, it is commonly perceived that the shift to localized irrigation requires adaptation of the fertilization practices, mainly because of the smaller active root zone, lower content of available organic matter, and the different flow rates of water and nutrients required, compared with those associated with other irrigation systems (Scaife and Bar-Yosef, 1995; Hagin *et al.*, 2002). Therefore, fertigation systems are to be found only in combination with pressurized irrigation systems, and mostly with localized systems, i.e., drip and other micro-jets, and mini-sprinklers.

Water scarcity for agriculture, together with large increases in water demand for municipal uses and the large investments in water treatment facilities that have been stimulated by environmental regulations, all create a significant source of water available for irrigation. Pathogenic viruses, bacteria, protozoa and helminths may be present in raw municipal wastewater, but after proper treatment do not pose any risk (Asano, 1989). In practice, the use of localized irrigation significantly lowers health risks as the water does not come into direct contact with the crop and the field workers, especially in drip and sub-soil drip systems.

Discussion

Value of nutrients in TWW

Even though irrigated land forms only 17% of global cropland, it provides 40% of global food production (FAO, 2000). If we assume that the amounts of nutrients supplied support a proportional amount food production, we can estimate that approximately 60 million tonnes of nutrients (40% of global nutrient consumption) are applied via irrigated agriculture. Similarly, we can estimate that the total amount of crop nutrients applied to land equipped with pressurized irrigation (25 million ha; ICID 2005) is in the order of 6 million tonnes, and that the amount applied via micro-irrigation (to approximately 4.5 million ha) is some 1.5 million tonnes, assumed to be applied mostly via fertigation.

How much of these nutrients is there in all domestic wastewater, worldwide? Theoretically, by multiplying the average concentrations of N, P and K in domestic wastewater, which are 50, 10 and 30 ppm, respectively (FAO, 2002), by the amount of municipal water withdrawal (380 km^3), and an efficiency factor of 0.7, we estimate that the total amounts of nutrients available are 13.3, 8.0 and 9.3 million tonnes of N, P_2O_5 and K_2O, respectively. These amounts are very significant, especially for potassium, for which this amount is approximately 35% of the global market.

Thus, the average contributions of nutrients from irrigation with TWW, assuming an annual application rate of 5000 m^3/ha, would be 250, 114 and 180 kg/ha of N, P_2O_5 and K_2O (FAO, 2002). A World Bank study estimated that the fertilizer value of nutrients (N, P and K) in treated municipal effluents was worth about 3 cent/m^3, which reflects a potential annual saving to the farmer of $130/ha in fertilizer costs (Hamoda, 2004). A similar calculation, based on data from Israel (Israel Ministry of Agriculture, 2004), shows that the total amounts of N, P_2O_5 and K_2O can reach 220, 30, and 290 kg/ha, respectively (Fig. 2), worth approximately $200/ha ($100, 30 and 75 for N, P and K, as urea, TSP and KCl, respectively). The value of nutrients in TWW can vary greatly, depending on the water source and treatment (Fig. 2). Cornel and Weber (2004) calculated that typical irrigation at 5,500 m^3/ha with TWW containing 50-54 and 7-8 ppm of available N and P, respectively, results in the application of N and P at 285 and 43 kg/ha, respectively; far more than is required by some summer crops in Germany.

The contribution of the nutrients in TWW is thus significant and plays a role in the decisions made by farmers. However, the balance may not be optimal, and the data indicate, especially, excessive P supply.

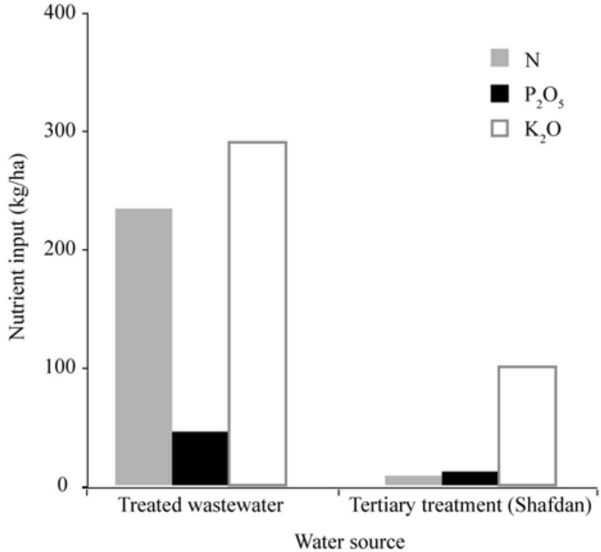

Fig. 2. Contributions of N, P_2O_5 and K_2O (kg/ha) from two sources of wastewater at standard irrigation rates. *Source*: Israel Ministry of Agriculture, 2004.

Management of nutrients in TWW

Available nutrients in TWW are supplied at constant rates according to crop water requirements. However, this may lead to nutrient deficiencies at times when water requirements are relatively low, and vice versa. For example, a citrus orchard will require a high dose of phosphate in the spring and no nitrogen application later than a certain stage of fruit development. Cornel and Weber (2004) concluded that, depending on climate, plant, soil, and irrigation system, it is possible to satisfy a significant part of, if not the whole fertilizer demand by using TWW for irrigation.

Nitrogen in TWW is found in various forms (organic, as nitrate, and as ammonium), depending on the type of treatment undergone by the effluent. Phosphate is found as both orthophosphate and as inositol hexaphosphate (IHP), and potassium as cation K^+. Typical nutrient concentrations in various water sources are presented in Table 3. The various treatment processes affect the concentrations and ion types of N and P, whereas K concentrations in the outflow mostly reflect those at the inflow.

Table 3. Typical nutrient concentrations (ppm) in TWW (from various sources).

Water source	Typical domestic waste water	Secondary treatment before SAT [(1)]	Secondary treatment before SAT [(1)]	Tertiary treatment	Filtered effluent	Secondary treatment
	ppm					
Nitrogen (total as N)	85					
NH_4-N		7	<0.02	0.55		30-60
NO_3-N		0.28	9.34	7.74	0.08-20.6	
Phosphorus (as P)	20	2.2	<0.05	1.6	3.8-14.6	6-15
Potassium (as K)		18	24	15.5	13-31.2	30-120
Source (reference)	FAO 2002	Icekson-Tal *et al.*, 2003	Icekson-Tal *et al.*, 2003	Gori *et al.*, 2004	Asano, 1989	Israel Min. of Agr., 2004

[(1)] SAT: Soil Aquifer Treatment

Nutrient supply from TWW

The nutrient inputs from regular fertilization practices and those from TWW were compared at more than 130 plots in various locations in Israel during 2001-2003 (Israel Ministry of Agriculture, 2004). The fertilization practices were similar irrespective of which of three types of water was used: well (ground) water; secondary treatment wastewater; and water from tertiary treatment with SAT. As shown in Fig. 3, both TWW sources contributed significant amounts of N, P and K, but the inputs from the tertiary treatment were lower, especially for N. One of the conclusions to be drawn from the survey is that farmers' practices must include a calculation of the nutrient contribution from the water source, especially that of P, since its contribution from TWW is far larger than the crop requirement (Fig. 3), and this excess could accumulate after a relatively short period of time.

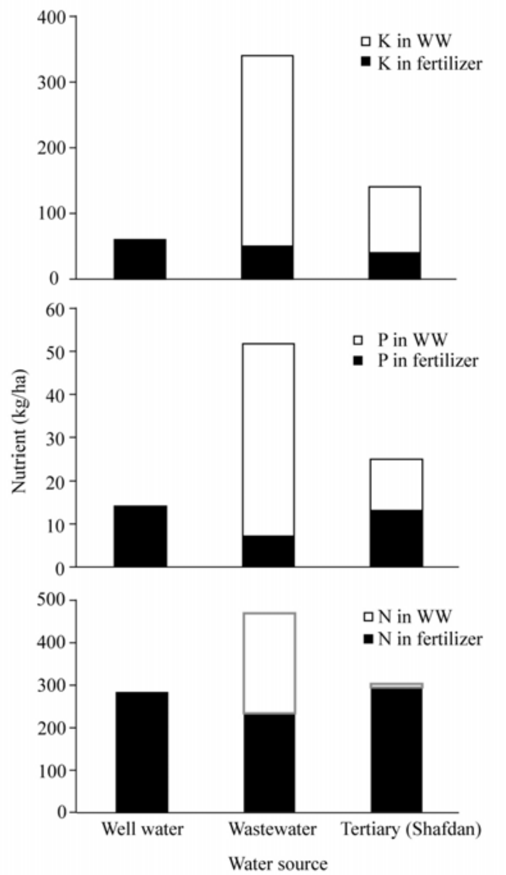

Fig. 3. Average inputs of N, P_2O_5 and K_2O (kg/ha) from both mineral fertilizers (in black) and three water sources at standard irrigation levels. *Source*: Israel Ministry of Agriculture, 2004.

Accumulation of N, P and K in the soil profile was also studied in this survey. As shown in Fig. 4, under irrigation with TWW (ww1 and ww2), P was highly accumulated in the soil profile down to 60 cm (2.5-4.7 ppm in saturated paste). In contrast, under regular fertilization and irrigation with well water (fw1) only 0.8 ppm of P (in saturated paste) was found at -30 cm.

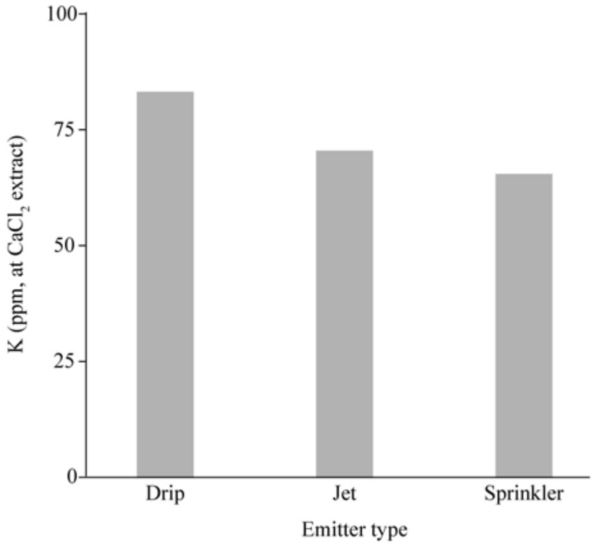

Fig. 4. P concentration in soil profile under irrigation from various water sources (ppm in saturated paste). *Source*: Israel Ministry of Agriculture, 2004.

The effect of different irrigation emitters on the nutrient concentration found in the soil and in the leaves of fruit trees grown in the surveyed plots was also investigated. The results show that for potassium there was an inverse response to the wetted area: the smallest wetted area (drip) corresponded to the highest K level in the soil solution in the 0 to 120 cm soil layer (Fig. 5) and in the leaves of the citrus and avocado trees tested (data not shown): the K concentration in saturated paste reached 82 ppm under the wetted area of the drippers, but only 65 ppm under the sprinklers. In the 130-plot survey the nutrient whose behavior was most clearly affected by the water emitter type was K. This implies that consideration must be given not only to the concentration of nutrients in the TWW, but also to the type of emitter used.

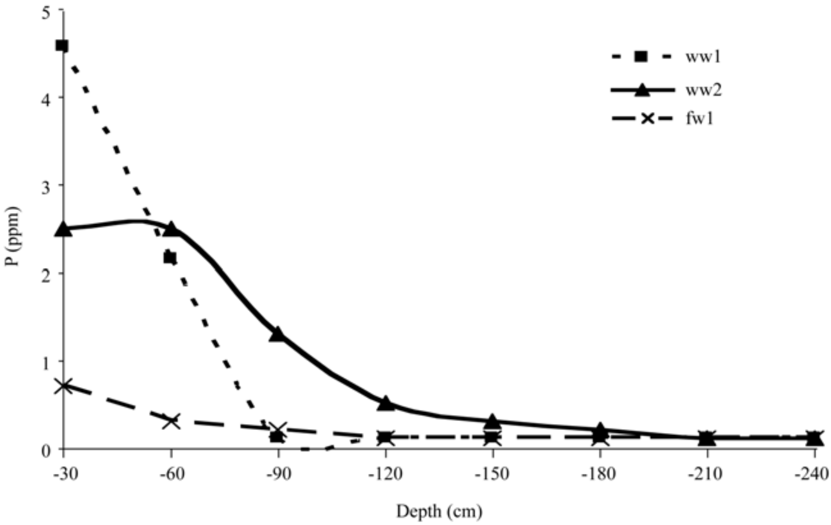

Fig. 5. K concentration (ppm, $CaCl_2$ extraction) in saturated paste of wetted area under drip, jet and sprinkler irrigation. *Source*: Israel Ministry of Agriculture, 2004.

Conclusions

Water scarcity and increased municipal water use are the main drivers for large-scale development of pressurized, localized irrigation systems, whose development will, in turn, stimulate the development of fertigation. Use of TWW in fertigation systems offers several advantages, including the value of the nutrients already present in the water, and may offer significant cost savings of US$100-200/ha, depending on the water quality. But whereas typical N and K levels in TWW already match plant demands, typical phosphate levels in TWW-irrigated plots cause high levels of P at various soil depths, which suggests that P is very mobile in soil profiles under such conditions, so that an excess concentration easily can be reached. In the future fertigation may closely linked to TWW irrigation, and the management of the system will need to address the nutrients as well as the soil and irrigation.

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