Indian J.Dryland Agric. Res. & Dev. 2012 27(1) : 58-69

Contribution of Nutrients through Critical Irrigation from Diverse Water Sources in Selected Watersheds of Semi-arid Tropical India

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ABSTRACT : Critical irrigation is one of the most important management options to protect the crop during weather aberrations like dry spells at critical stages of the crop growth in semi arid condition. Various water harvesting structures are useful in watershed areas to cope up with mid-season droughts. These structures provide critical irrigations at sensitive crop growth stages by which they supply essential nutrients to some extent. We estimated the contribution of various sources of water in terms of plant nutrients and to what extent critical irrigations meet nutrient requirements of various crops. By giving 4 cm irrigation, the maximum major nutrient (kg ha^{-1}) addition in the studied watersheds is of the following order NO_3 (5.2, Kothapalli); SO_4 (15.2, Kolar); Na (72.0, Haveri); K (3.6, Govardhanapura); Ca (38.5, Semli and Shyamapura); Mg (20.5, Kothapalli) and for micronutrients (g ha^{-1}) Fe (109, Kolar); Zn (40, Kothapalli); Mn (90, Kolar); Cu (120, ICRISAT) and B (190, ICRISAT). Percentage of recommended dose of nutrients which can be met by three irrigations in cereal crops (5-10, 15-100, 10-20% in N,S,K respectively); legumes (5-30,10-100, 5-10% of N,S,K respectively); cotton (10-15, 25-30, 5-10% of N,S,K, respectively) and micronutrients such as Fe, Zn, Mn, Cu and B to the full extent. With the number of critical irrigations increased, application of secondary and micro nutrients should be avoided which otherwise leads to higher cost of alleviation and environmental pollution.

Key words: Watershed, Water Sources, Nutrient Contribution, Critical Irrigation, Management Practices, Rainfed Crops

Introduction

In semi-arid regions, the climatic conditions with high atmospheric evaporative demand and highly variable rainfall on both spatial and temporal scales make rainfed farming a risky business with lack of sufficient soil moisture. During the crop growing duration, intermittent dry spells of variable length occur at any stage (Muchow, 1989). Dry spells relate directly to agricultural impacts since their frequency and duration indicate the degree of stress plants are exposed to (Muhammad and Reason, 2004). Water stress during crop growth, even during short periods of a couple of weeks, is a major cause of yield reduction (Rao *et al*., 2010). These water stress periods are called 'breaks' in the monsoon and may occur in any of the monsoon months. And also during spring, plants grow faster with high evapotranspiration rate and rapid soil moisture depletion due to higher evaporative demand conditions (Srivastava *et al*., 2010). Thus, a stage of increasing moisture stress starts in the spring and continues until the end of the season (Oweis and Hachum, 2004). Agricultural production in these semi-arid areas is therefore marginal because the rainfed crops suffer from the vagaries of monsoon rains. An agricultural drought occurs when the cumulative plant available soil water is significantly lower than cumulative crop water requirements and dry spells occurs as short periods of water stress, often only a couple of weeks long, during crop growth (Rockstrom, 2000). From an agricultural perspective the only way to combat a meteorological drought or dry spell is by irrigation (Barron, 2004). Intensive and extensive cultivation of land by irrigation depends mainly on the availability of water i.e. surface water and groundwater. Surface water basins all over the world are very crucial for irrigation purposes (Yidana *et al*., 2011). As the surface water resources are scarce in the semi-arid regions, ground water forms a very important and reliable resource which, if available in a farmer's plot of land and if utilized prudently for irrigation could transform the farmer's livelihoods (Eberhard and Yongxin, 2010; Gordon *et al*., 2010). Groundwater abstraction is the process of taking water from a ground source, either temporarily or permanently. Most of this water is used for irrigation or treated to produce drinking water. Nonrenewable groundwater abstraction contributes approximately 20% to the global gross irrigation water demand for the year 2000. The contribution of nonrenewable groundwater abstraction to irrigation is largest in India 68 km^3 yr^{-1} (Wada *et al*., 2012).

Harvesting rainwater to recharge groundwater aquifers can help sustain more water intensive agricultural production. Investments in rainwater harvesting are highly popular in India's semi-arid regions, since they help to recharge groundwater aquifers (Batchelor *et al*., 2003). Farmers have increasingly recognized the enhanced reliability of supplementary wet season and dry season irrigation with groundwater that brings with it reduced risk of investment losses and higher levels of agricultural productivity (Bhaduri *et al*., 2009; Sharma *et al*., 2010).

Critical irrigations from harvested water are given from farm ponds, community tanks and for high values crops from bore wells and open wells (Wani *et al*., 2003). These open wells and farm ponds are recharged with water from conservation structures in the watersheds and also due to land management interventions. Medium and minor irrigation schemes are implemented in various watersheds of the country for augmenting critical irrigation for agriculture. Critical irrigation can stabilize and increase the crop outputs in quantity and in quality in regions where insufficient rainfall does not allow optimal crop development. The conjunctive use of harvested water resources (i.e. irrigation water to supplement rainfall) can, in fact, increase considerably the efficiency of the use of water resources as a whole for the production of food (Hamdy *et al*., 2005).

The nutrients from the ground water sources can act as additional enrichment sources, especially at the time of critical stages of plant growth. The nutrients present in the groundwater sources can be due to various factors, i.e. due to the parent material, soluble minerals leaving nutrients into water aquifer; runoff, top fertile soil can add all the nutrients and added fertilizer. Plants require macro nutrients, secondary nutrients and micro nutrients for their growth. All these nutrients can be supplied in small amounts by ground water sources such as farm ponds, community tanks, open wells and bore wells (Hodges, 2001). The amounts of macro, secondary and micronutrients added through various water sources used for irrigation during the critical stages of plant growth supplements the nutrients along with the chemical fertilizers and animal dung based manure addition. However, higher concentrations of these nutrients present in groundwater, especially sodium and boron can lead to plant toxicity (Shahinasi and Kashuta, 2008).

The aim of this paper is therefore, to examine the extent of nutrient additions through irrigations from various sources of groundwater, and if we give one critical irrigation to various rainfed crops or two to three critical irrigations for high value vegetables, what are the nutrient additions from the various sources of groundwater.

Materials and Methods

Background of the study

Locations for sampling of various sources of irrigation water were identified to represent wide range of crops, rainfall, soil type and nitrogen (N) management options in semi-arid tropical region of India. Samples were collected at various locations in the subtropical region of India with varying agricultural management practices. Depth of water sampling varied among watersheds, month, crop season and year of sampling. The description of location of watersheds and the sources of irrigation water monitored for nutrients during 2006-2008 are given in (Table 1).

Sampling of irrigation water

Farm Ponds (FP), Bore Well (BW), Open Wells (OW), Community Tank (CT) and Hand Pump (HP) were identified as the potential water sources. Water samples were drawn from respective study location in the months of May, June, August and October during the years of 2006 to 2008 from different water bodies.

Analysis

Samples were collected in polyethylene bottles and closed air tight and transported to laboratory for analysis. The micro, secondary and macro nutrient analysis of Boron (B); Iron (Fe); Copper (Cu); Zinc (Zn); Manganese (Mn) and Sulphate (SO_4^{-2}) were carried out by Inductively Coupled Plasma (ICP); and Sodium (Na); Potassium (K); Calcium (Ca) and Magnesium (Mg) by Atomic Absorption Spectroscopy (AAS). Nitrate-N (NO_3-N) in the water was obtained by reducing it using Devadra alloy followed by distillation.

Computation of nutrient additions

The nutrient concentrations in the water sources are converted from mg L^{-1} to kg ha^{-1} with regards to surface irrigation considering, 100,000 L of water per hectare is required for 1cm depth of irrigation (Rao *et al*., 2009). For surface irrigation for various crops, calculations were drawn up to 4cm depth. The concentrations of macro, secondary and micro nutrients (mg L^{-1}) in various groundwater sources are given in Table. 2 and the computed nutrient additions through irrigation water in (kg ha^{-1}) are given in Table. 3.

Results and Discussion

The soil types in the studied watershed with the parent materials such as basaltic (Black soils), calcareous (Alluvial) and granite-gneiss (Red soils) ranged from Alfisols to Vertisols to Entisols and cover diverse geographical regions, and will therefore have an influence on the concentrations of nutrients present in their respective groundwater sources. In the studied watersheds, various sources of water contributed to nutrient additions through irrigations in variable quantities. Bore well water from all the studied sites showed a higher nutrient content and could contribute to a larger extent to crop nutrient requirements. Nutrient application to crops grown in the studied watersheds is suboptimal and in some cases completely lacks the application of secondary and micronutrients (Srinivasarao *et al*., 2008, 2009). Therefore, the soils of the studied watersheds are deficient in essential plant nutrients such as Ca, Mg, Fe, Zn, Mn, Zn, and B. Under improved management practices in the studied watersheds; interventions have recommended application of $ZnSO_4$, gypsum and borax/agribor to supply Zn, S, B depending upon soil test values and crop nutrient uptake. These applications will have a direct influence on the availability of Zn, SO_4 and B specific nutrients in groundwater. However, Zn which is a valuable micro nutrient for crops such as maize was present in small amounts in all of the studied watershed water sources. As crops grown and their nutrient requirement differ among studied watersheds the results are presented below.

Haveri Watershed

Among the seven watersheds, Haveri watershed has the maximum nutrient concentration in various sources of irrigation water (Table 2). Secondary nutrients added through critical irrigations from bore well groundwater ranged as follows: Na (72 kg ha^{-1}), Ca (34 kg ha^{-1}), Mg (22 kg ha^{-1}), SO_4 (13 kg ha^{-1}) and micronutrients as follows: B (100 g ha^{-1}), Fe (60 g ha^{-1}) (Table 3). Although Na concentration was high in water it is still within the critical limit of 80 kg ha^{-1} (Fardous *et al*., 2010). NO_3 (1.1 kg ha^{-1}) and K (1.7 kg ha^{-1}) concentrations were minimal in this watershed. As both high value crops and cereal crops are grown in this watershed (Table 1) with irrigations varying 1 to 3, we found that a considerable amount of nutrients are added. Macronutrients can act as 10-50% of crop requirement supplementary additions along with the fertilizer addition, whereas secondary (S, Ca, Mg) and micronutrients (Zn, Fe, Mn, Cu, B) are completely met through 2 critical irrigations. The nutrient requirement of per tonne of predominant crops grown in Haveri watershed is presented in Table 4. If two to three critical irrigations are given to maize, chickpea and pigeonpea at sensitive stages given in Table 5; S, Ca and Mg requirements are met along with micronutrients such

Table 1 : Location of watersheds in semi-arid tropical India and the sources of irrigation water monitored for nutrients during 2006-2008.

State/Watershed	Geographical information Longitude/Latitude	Soil type	Average annual Rainfall (mm)	Groundwater sources	Crops grown
Karnataka-Haveri	75°00' to75°49"E 14°16' to 15°00"N	Vertisols	750	Bore Well	Vegetables, Chickpea, Pigeonpea, Maize
Karnataka- Kolar	76°00' to76°50"E 26°16' to 26°14'N	Alfisols	500	Farm Pond, Bore Well	Fingermillet, Sorghum, Vegetables
Madhya Pradesh-Semli & Shyamapura	75°19' to75°25"E 25°22' to 25°35"N	Vertisols	1000	Farm Pond, Bore Well, Community Tank	Chickpea, Wheat, Soybean, Sorghum
Andhra Pradesh-ICRISAT	78°5' to 78°8'' E 17°20' to 17°24'' N	Vertisols	750	Farm Pond, Bore Well, Open Well	Sorghum, Chickpea
Rajasthan – Thana	77°21' to78°35"E 20°46' to 130°58"N	Entisols	650	Farm Pond, Hand Pump	Maize, Wheat, Chickpea, Fodder
Andhra Pradesh-Kothapalli	78°16' to 78°30"E 17°30' to 17°43"N	Vertisols	800	Bore Well, Open Well	Cotton, Vegetables, Sorghum, Food legumes
Rajasthan- Govardhanapura	75°11' to75°47"E 27°16' to 27°43"N	Entisols	750	Farm Pond	Fodder, Wheat, Chickpea, Maize

as Cu, Mn and B. However, tomato is grown with 8-10 irrigations in this district, so larger contribution of these nutrients to tomato is met by water. However, major nutrients (NPK) contribution is far lesser than crop needs; addition of NPK should therefore be continued may be by fertilization or manure addition.

Kolar Watershed,

Kolar watershed showed high concentration of Na, Ca and Mg in the selected groundwater sources i.e. farm pond and bore well (Table 2). The maximum nutrient concentrations added through critical irrigation from farm pond ranged as follows: Na (63 kg ha^{-1}), Ca (34 kg ha^{-1}) and Mg (18 kg ha^{-1}) (Table 3). Critical irrigations through bore well groundwater had high concentration of NO_3 (3 kg ha^{-1}) and SO_4 (15 kg ha^{-1}) on comparison with farm pond. Micronutrient concentrations were minimal with Fe showing higher incidence in farm pond (109 g ha^{-1}) and Mn in bore well groundwater (80 g ha^{-1}).

Semli and Shyamapura

Semli and Shyamapura had high concentrations of Na (37), Ca (39) and Mg (17) kg ha^{-1} (Table 3) added through critical irrigation from the bore well water, followed by farm pond and community tank. NO_3 concentrations were also considerably higher in this watershed especially in the bore well groundwater, K concentration (0.9 kg ha^{-1}) was moderate, and the micro nutrient concentrations were less in all of the water sources.

ICRISAT Watershed

ICRISAT watershed showed high concentration of Na, Ca and Mg in the selected groundwater sources i.e. farm pond, bore well and open well. The maximum nutrient concentrations added through critical irrigation from bore well groundwater ranged as follows: Na (30 kg ha^{-1}), Ca (16 kg ha^{-1}) and Mg (17 kg ha^{-1}) kg ha^{-1} (Table 3). NO_3 and SO_4 concentrations were also higher in this groundwater source. K concentration was however, comparatively higher in the farm pond.

Thana Watershed

Maximum nutrient concentrations were found in the water sources of hand pump (Table 2). The maximum nutrient concentrations added through critical irrigation from hand pump ranged as follows: Na (24 kg ha^{-1}), Ca (28 kg ha^{-}1) and Mg (11 kg ha^{-}1) (Table 3). NO_3 and SO_4 concentrations were also higher in this groundwater source on comparison with farm pond. However, high concentrations of K were found in farm pond (3 kg ha^{-1}).

Kothapalli Watershed

Among the seven watersheds, Kothapalli watershed showed maximum nutrient concentration for NO_3 in various sources of irrigation water (Table 2), which could be accounted for high N fertilizer application in this region. NO_3 added through critical irrigation was of the order of 5.2 kg ha^{-1}. Other nutrient additions ranged as follows: SO_4 (3.8 kg ha^{-1}); Na (8.1 kg ha^{-1}); Ca (15.1 kg ha^{-1}) and Mg (20.5 kg ha^{-1}) (Table 3), and were found to be moderate in the bore well groundwater source. K and other micronutrients concentrations were minimal and higher in the bore well groundwater samples.

Govardhanapura Watershed

Govardhanapura watershed showed high concentration of Na, Ca and Mg in the selected groundwater sources and the highest K concentration among the studied watersheds (Table 2). The amount of nutrients added through critical irrigation (Table 3) ranged as follows: Na (17.5 kg ha^{-1}), Ca (16.7 kg ha^{-1}) and Mg (9.0 kg ha^{-1}) and moderate concentration of NO_3 (1.3 kg ha^{-1}) and SO_4 (1.5 kg ha^{-1}). K (3.6 kg ha^{-1}) is the highest among all the studied watersheds. Micronutrient concentrations were minimal in the water sources of this watershed, except for B that showed (70 g ha^{-1}).

Out of all the studied watersheds, Haveri and Kolar had higher SO_4 concentrations which could be imparted due to gypsum and $ZnSO_4$ application and also sulfide-mineral oxidation and dissolution which is identified as being a potential source for sulfate and metals concentrations in bedrock ground waters (Hem, 1985; Drever, 1988; Robinson *et al*., 1997). Among the seven watersheds monitored, the major cation Na was generally dominant representing on average 51.0 % of all the cations, whereas calcium and magnesium nutrients were of second in order, representing on average 32.1 and 21.5%. Such higher levels of Na concentrations 64.1% followed by calcium and magnesium concentrations of the order of 30.4 and 4.8% were found in the groundwater of semi-arid tropics

Table 2 : Mean nutrient contents in various sources of irrigation water (mg L^{-1} and µg L^{-1}) in several watersheds in semi arid tropics of India determined during 2006-2008

Watershed/ Source/	Month of Irrigation	NO_3-N	SO_4	Na	K	Ca	Mg	Fe	Zn	Mn	Cu	B
		Macro & Secondary Nutrients (mg L^{-1})						Micro Nutrients (µg L^{-1})				
Haveri, Karnataka												
Borewell	May	2.0 ± 0.1*	37.3 ± 1.8	175.9 ± 8.7	1.10± 0.0	9.5± 0.4	52.7±2.6	70 ± 3.5	60 ± 2.4	40 ± 1.6	20 ± 0.8	220 ± 11.0
	June	2.2 ± 0.1	31.9 ± 1.6	177.4 ± 8.9	1.12± 0.0	13.0±0.6	51.8±2.5	70 ± 3.5	40 ± 1.6	90 ± 3.6	20 ± 0.8	200 ± 10.0
	September	0.8 ± 0.0	30.5 ± 1.5	180.1 ± 9.0	0.90± 0.0	36.8±1.8	55.1±2.7	160 ± 8.0	80 ± 3.2	70 ± 2.8	10 ± 0.4	240 ± 12.0
Kolar, Karnataka												
Farm pond	May	2.7 ± 0.1	27.2 ± 1.3	149.0 ± 7.4	4.15± 0.2	84.4±4.2	45.3±2.2	4990 ± 249.5	10 ± 0.4	20 ± 0.8	20 ± 0.8	60 ± 3.0
	June	3.7 ± 0.2	25.9 ± 1.3	157.8 ± 7.9	5.10± 0.2	84.8±4.2	43.4±2.1	4670 ± 233.5	10 ± 0.4	20 ± 0.8	10 ± 0.4	110 ± 5.5
Bore well	May	6.7 ± 0.3	37.2 ± 1.8	105.0 ± 5.2	4.30± 0.2	61.8±3.0	43.9±2.1	40 ± 2.0	50 ± 2.0	30 ± 1.2	20 ± 0.8	80 ± 4.0
	June	7.2 ± 0.3	38.1 ± 1.9	105.8 ± 5.3	4.58± 0.2	62.7±3.1	44.0±2.2	70 ± 3.5	10 ± 0.4	80 ± 3.2	10 ± 0.4	80 ± 4.0
Semli & Shyamapura, Madhya Pradesh												
Farm pond	June	5.7 ± 0.3	1.7 ± 0.0	70.2 ± 3.5	2.33± 0.1	35.0±1.7	33.5±1.6	100 ± 5.0	40 ± 1.6	20 ±0.8	60 ± 2.4	180 ± 9.0
	July	6.4 ± 0.3	4.0 ± 0.2	49.2 ± 2.4	4.19± 0.3	29.8±1.4	22.5±1.2	190 ± 9.5	60 ± 2.4	50 ± 2.0	20 ± 0.8	220 ± 11.0
	August	6.3 ± 0.3	2.8 ± 0.1	27.7 ± 1.4	1.67± 0.0	58.5±2.9	25.2±1.2	140 ± 7.0	10 ± 0.4	10 ± 0.4	10 ± 0.4	210 ± 10.5
Bore well	June	6.3 ± 0.3	1.8 ± 0.0	92.8 ± 4.6	1.50± 0.0	51.7±2.5	39.7±1.9	120 ± 6.0	40 ± 1.6	10 ± 0.4	20 ± 0.8	240 ± 12.0
	July	12.4 ± 0.6	3.8 ± 0.2	73.5 ± 3.7	1.33± 0.0	69.2±3.4	42.1±2.1	220 ± 11.0	90 ± 3.6	60 ± 2.4	10 ± 0.4	390 ± 19.5
	August	12.8 ± 0.6	1.8 ± 0.0	57.2 ± 2.8	1.01± 0.0	96.3±4.8	33.7±1.6	160 ± 8.0	240 ± 9.6	10 ± 0.4	30 ± 1.2	240 ± 12.0
Community tank	June	4.9 ± 0.2	3.0 ± 0.1	33.0 ± 1.6	2.20± 0.3	18.0±0.9	10.1±0.5	150 ± 7.5	20 ± 0.8	40 ± 1.6	10 ± 0.4	80 ± 4.0
	July	5.7 ± 0.3	2.5 ± 0.1	16.0 ± 0.8	1.50± 0.0	41.5±2.0	10.0±0.5	110 ± 5.5	50 ± 2.0	10 ± 0.4	30 ± 1.2	100 ± 5.0
	August	4.7 ± 0.2	3.8 ± 0.2	13.3 ± 0.7	1.00± 0.0	41.0±2.0	11.0±0.5	170 ± 8.5	10 ± 0.4	70 ± 2.8	10 ± 0.4	130 ± 6.5
ICRISAT, Patancheru, Andhra Pradesh												
Farm pond	July	2.1 ± 0.1	6.5 ± 0.3	44.8 ± 2.2	7.05± 0.3	22.5±1.1	13.1±0.6	150 ± 7.5	30 ± 1.2	60 ± 2.4	90 ± 3.6	190 ± 9.5
	October	1.9 ± 0.0	3.4 ± 0.1	19.5 ± 0.9	4.83± 0.2	31.8±1.5	11.2±0.5	580 ± 29.0	50 ± 2.0	100 ± 4.0	80 ± 3.6	50 ± 2.5
Bore well	July	4.3 ± 0.2	19.3 ± 0.9	62.9 ± 3.1	1.73± 0.0	33.6±1.6	42.9±2.1	90 ± 4.5	20 ± 0.8	10 ± 0.4	60 ± 2.4	100 ± 5.0
	October	3.3 ± 0.1	9.4 ± 0.4	37.7 ± 1.9	1.87± 0.0	33.8±1.6	32.7±1.6	10 ± 0.5	10 ± 0.4	10 ± 0.4	20 ± 0.8	10 ± 0.5
Open well	July	2.7 ± 0.1	11.8 ± 0.5	74.1 ± 3.7	4.80± 0.2	16.4±0.8	27.6±1.3	40 ± 2.0	60 ± 2.4	90 ± 3.6	120 ± 4.8	190 ± 9.5
	October	1.5 ± 0.0	15.1± 0.7	66.7 ± 3.3	4.40± 0.2	29.1±1.4	28.6±1.4	140 ± 7.0	50 ± 2.0	30 ± 1.2	70 ± 2.8	200 ± 10.0
Thana, Rajasthan												
Farm pond	August	0.8 ± 0.0	2.5 ± 0.1	33.2 ±1.6	9.00± 0.3	64.0±1.2	23.4±0.4	70 ± 3.5	50 ± 2.0	10 ± 0.41	30 ± 1.2	130 ± 6.5
Hand pump	August	4.3 ± 0.2	5.5 ± 0.2	60.3 ±3.0	6.00± 0.3	68.8±1.3	27.8±0.5	40 ± 2.0	10 ± 0.4	50 ± 2.0	20 ± 0.8	130 ± 6.5
Kothapalli, Andhra Pradesh												
Bore well	July	13.1 ± 0.6	7.8 ± 0.1	19.1 ±0.9	0.35± 0.1	35.0±0.4	51.3±1.0	20 ± 1.0	30 ± 1.2	20 ± 0.8	50 ± 2.0	50 ± 2.5
	August	12.1 ± 0.6	9.6 ± 0.4	20.4 ±1.2	0.97± 0.0	37.8±0.6	49.9±0.9	40 ± 2.0	80 ± 3.2	40 ± 1.6	60 ± 2.4	50 ± 2.5
Open well	July	7.4 ± 0.3	4.7 ± 0.3	17.9 ±0.8	0.14±0.0	27.1±0.5	40.5±0.8	50 ± 2.5	30 ± 1.2	10 ± 0.4	60 ± 2.4	70 ± 3.5
	August	6.2 ± 0.3	6.1 ± 0.3	17.4 ±0.8	0.60±0.0	32.3±0.6	37.4±0.7	50 ± 2.5	50 ± 2.0	30 ± 1.2	30 ± 1.2	30 ± 1.5
Govardhanapura, Rajasthan												
Farm pond	June	3.3 ± 0.02	3.8 ± 0.2	42.8 ±2.1	4.20±0.2	14.0±0.2	20.8±0.4	80 ± 4.0	10 ± 0.4	30 ± 1.2	50 ± 2.0	170 ± 8.5
	August	1.5 ± 0.0	3.4 ± 0.2	43.8 ±2.1	7.40±0.3	41.8±0.8	22.6±0.4	40 ± 2.0	10 ± 0.4	20 ± 0.8	40 ± 1.6	160 ± 8.0

Indicates SE; P was omitted as P content in different water sources is negligible

Table 3 : Amounts of various nutrients added through critical irrigations (4 cm) from various sources of irrigation water in several watersheds in semi arid tropics of India

Watershed/Source/ Month of Irrigation		NO_3-N	SO_4	Na	K	Ca	Mg	Fe	Zn	Mn	Cu	B
		Macro & Secondary Nutrients (kg ha^{-1})						Micro Nutrients (g ha^{-1})				
Haveri, Karnataka												
Borewell	May	1.1 ± 0.0*	10.9 ± 0.4	59.6 ± 2.9	1.7 ± 0.0	14.7 ±0.7	18.1 ±0.9	30 ± 1.5	10 ± 0.5	20 ± 1.0	20 ± 1.0	90 ± 4.5
	June	0.9 ± 0.0	12.8 ± 0.5	70.9 ± 3.5	0.4 ± 0.0	5.2 ±0.2	20.7 ±1.0	30 ± 1.5	20 ± 1.0	10 ± 0.5	10 ± 0.5	90 ± 4.5
	September	0.3 ± 0.0	12.2 ± 0.4	72.0 ± 3.6	0.4 ± 0.0	33.8 ± 1.6	22.1 ±1.1	60 ± 3.0	10 ± 0.5	20 ± 1.0	20 ± 1.0	100 ± 5.0
Kolar, Karnataka												
Farm pond	May	1.1 ± 0.0	10.9 ± 0.4	59.6 ± 2.9	1.7 ± 0.0	33.8 ±1.6	18.2 ±0.9	109 ±5.4	10 ± 0.5	10 ± 0.5	10 ± 0.5	20 ± 1.0
	June	0.6 ± 0.0	10.4 ± 0.4	63.1 ± 3.1	2.0 ± 0.0	33.9 ±1.7	17.3 ±0.8	102 ±5.1	20 ± 1.0	40 ± 2.0	20 ± 1.0	40 ± 2.0
Bore well	May	2.7 ± 0.1	14.9 ± 0.5	42.0 ± 2.0	1.7 ± 0.0	24.7 ±1.2	17.6 ±0.8	20 ± 1.0	20 ± 1.0	10 ± 0.5	10 ± 0.5	30 ± 1.5
	June	2.9 ± 0.1	15.2 ± 0.6	42.3 ± 2.1	1.8 ± 0.0	25.1 ±1.2	17.6 ±0.8	30 ± 1.5	10 ± 0.5	90 ± 4.0	10 ± 0.5	30 ± 1.5
Semli & Shyamapura, Madhya Pradesh												
Farm pond	June	2.3 ± 0.0	0.7 ± 0.0	28.0 ±1.4	0.9 ± 0.0	14.0 ±0.7	13.4 ±0.6	40 ± 2.0	20 ± 1.0	20 ± 1.0	10 ± 0.5	70 ± 3.5
	July	2.6 ± 0.1	1.6 ± 0.0	19.7 ±0.9	1.7 ± 0.0	11.9 ±0.6	8.9 ±0.4	80 ± 4.0	20 ± 1.0	20 ± 1.0	10 ± 0.5	80 ± 4.0
	August	2.5 ± 0.1	1.1 ± 0.0	11.1 ±0.5	0.7 ± 0.0	23.4 ±1.1	10.0 ±0.5	50 ± 2.5	20 ± 1.0	10 ± 0.5	10 ± 0.5	80 ± 4.0
Bore well	June	2.5 ± 0.1	0.7 ± 0.0	37.1 ±1.8	0.6 ± 0.0	20.7 ±1.0	15.9 ±0.7	50 ± 2.5	10 ± 0.5	10 ± 0.5	20 ± 1.0	100 ± 5.0
	July	4.9 ± 0.2	1.5 ± 0.0	29.4 ±1.4	0.5 ± 0.0	27.7 ±1.3	16.9 ±0.8	90 ± 4.5	30 ± 2.0	20 ± 1.0	10 ± 0.5	160 ± 8.0
	August	5.1 ± 0.2	0.7 ± 0.0	22.9 ±1.1	0.4 ± 0.0	38.5 ±1.9	13.5 ±0.6	60 ± 3.0	20 ± 1.0	10 ± 0.5	10 ± 0.5	100 ± 5.0
Community tank	June	1.9 ± 0.0	1.2 ± 0.0	13.2 ±0.6	0.9 ± 0.0	7.2 ±0.3	4.0 ±0.2	60 ± 3.0	10 ± 0.5	20 ± 1.0	10 ± 0.5	30 ± 1.5
	July	2.3 ± 0.1	1.0 ± 0.0	6.4 ±0.3	0.6 ± 0.0	16.6 ±0.8	4.0 ±0.2	40 ± 2.0	20 ± 1.0	10 ± 0.5	10 ± 0.5	40 ± 2.0
	August	1.9 ± 0.0	1.5 ± 0.0	5.3 ±0.2	0.4 ± 0.0	16.4 ±0.8	4.4 ±0.2	70 ± 3.5	10 ± 0.5	20 ± 1.0	10 ± 0.5	50 ± 2.5
ICRISAT, Patancheru, Andhra Pradesh												
Farm pond	July	0.8 ± 0.0	2.6 ± 0.1	17.9 ± 0.8	2.8 ± 0.1	8.9 ±0.4	5.2 ±0.2	60 ± 3.0	20 ± 1.0	60 ± 3.0	90 ± 4.5	190 ± 9.5
	October	0.8 ± 0.0	1.4 ± 0.0	7.8 ± 0.3	1.9 ± 0.0	12.7 ±0.6	4.5 ±0.2	30 ±1.5	10 ± 0.5	60 ± 3.0	80 ± 4.0	50 ± 2.5
Bore well	July	1.7 ± 0.0	7.7 ± 0.3	29.7 ± 1.4	0.7 ± 0.0	13.5 ±0.6	17.2 ±0.8	30 ± 1.5	10 ± 0.5	30 ± 1.5	10 ± 0.5	90 ± 4.5
	October	1.3 ± 0.0	3.8 ± 0.1	26.7 ± 1.3	0.8 ± 0.0	13.5 ±0.6	13.1 ±0.6	10 ± 0.5	20 ± 1.0	20 ± 1.0	60 ± 3.0	30 ± 1.5
Open well	July	1.1 ± 0.0	4.7 ± 0.2	25.2 ± 1.3	1.9 ± 0.0	6.6 ±0.3	11.1 ±0.5	20 ± 1.0	10 ± 0.5	80 ± 4.5	120 ± 6.0	190 ± 9.5
	October	0.6 ± 0.0	6.0 ± 0.3	15.1 ± 0.7	1.8 ± 0.0	11.7 ±0.5	11.4 ±0.5	70 ± 3.5	20 ± 1.0	30 ± 1.5	70 ± 3.5	200 ± 10
Thana, Rajasthan												
Farm pond	August	0.3 ± 0.0	1.0 ± 0.0	13.3 ± 1.7	2.9 ±0.3	25.6 ±3.2	9.4 ±1.1	30 ± 1.5	20 ± 1.0	10 ± 0.5	20 ± 1.0	50 ± 2.5
Hand pump	August	1.7 ± 0.0	2.2 ± 0.2	24.1 ± 3.0	2.4 ± 0.2	27.5 ±3.4	11.1 ±1.3	20 ± 1.0	10 ± 0.5	20 ± 1.0	10 ± 0.5	50 ± 2.5
Kothapalli, Andhra Pradesh												
Bore well	July	5.2 ± 0.6	3.1 ± 0.3	7.7 ± 0.9	0.1 ± 0.0	14.0 ±1.7	20.5 ±2.5	10 ± 0.5	10 ± 0.5	10 ± 0.5	20 ± 1.0	20 ± 1.0
	August	4.8 ± 0.6	3.8 ± 0.4	8.1 ± 1.0	0.4 ± 0.0	15.1 ±1.8	19.9 ±2.4	20 ± 1.0	40 ± 1.5	20 ± 1.0	20 ± 1.0	20 ± 1.0
Open well	July	3.0 ± 0.3	1.9 ± 0.1	7.2 ± 0.9	0.1 ±0.0	10.8 ±1.3	16.2 ±2.0	20 ± 1.0	10 ± 0.5	10 ± 0.5	20 ± 1.0	30 ± 1.5
	August	2.5 ± 0.3	2.4 ± 0.3	6.9 ± 0.9	0.2 ±0.0	12.9 ±1.6	14.9 ±1.8	20 ± 1.0	10 ± 0.5	10 ± 0.5	10 ± 0.5	10 ± 0.5
Govardhanapura, Rajasthan												
Farm pond	June	1.3 ± 0.1	1.5 ± 0.1	17.1 ± 2.1	1.9 ±0.1	5.6 ±0.7	8.3 ±1.04	30 ± 1.5	10 ± 0.5	10 ± 0.5	20 ± 1.0	70 ± 3.5
	August	0.6 ± 0.0	1.4 ± 0.1	17.5 ± 2.2	3.6 ± 0.1	16.7 ±2.0	9.0 ±1.13	20 ± 1.0	10 ± 0.5	10 ± 0.5	10 ± 0.5	70 ± 3.5

*Indicates SE; P was omitted as P content in different water sources is negligible of Iran (Khodapanah *et al*., 2009). All of the other nutrients i.e. Fe, Zn, Mn, Cu, B, SO_4, NO_3 and K showed minimal concentrations in the groundwater sources of all the studied watersheds. The concentrations of nutrients present in groundwater of the respective watersheds can have a direct influence on meeting nutrient requirements of high value vegetables such as bottle guard, ridge guard, brinjal, and tomato and ladies finger, and also other commercial and high value food/ fibre crops such as cotton, maize, wheat, soybean, chickpea, finger millet and pigeonpea.

In Haveri and Kolar watershed where vegetables are grown, usage of bore well ground water (two irrigations) will supplement the major nutrient requirements to the extent of 1.08-2.88 kg N ha^{-1} and 0.36-2.04 kg K ha^{-1} in both the watersheds respectively. The nutrient concentration of groundwater present in Haveri and Kolar watersheds show high concentrations of Na, Ca and Mg. As the nutrient requirements of chickpea and pigeonpea both grown in these watersheds has a nutrient requirement of 18.70-19.20 kg t^{-1} for Ca and 7.30-15.50 kg t^{-1} for Mg (Table 4), by using the groundwater sources with concentration of Ca and Mg ranging from (33.80-33.90 kg ha^{-1}) and (18.20-22.10 kg ha^{-1}) both these secondary nutrients can be supplemented (one irrigation) in the respective watersheds. Cotton crop has the maximum requirement for N, P and K nutrients, therefore farmers have the tendency to apply higher dosage of fertilizer in the watersheds where cotton is grown. Kothapalli watershed has the highest fertilizer application among all the studied watersheds (Wani *et al*., 2003), and the N concentration of bore well groundwater of this watershed is of the range of 5.24 kg ha^{-1}.

Sorghum, maize and wheat, N requirements are met to a certain extent by most of the watersheds by giving supplementary irrigation (3 irrigations). The supplementary irrigation not only enriches the soil, but also helps the farmer in reducing the amount of fertilizer addition especially at the time of critical plant growth stages. The highest supplementations of NO_3 and K through groundwater irrigation were found to be of the order of 5.20 and 3.60 kg ha^{-1} in the studied watersheds. Ashraf *et al*. (2006) showed that in tube well water, highest K concentration was observed at the last two fortnights and the lowest at the second fortnight during winter. However, in the studied watersheds K in groundwater differed significantly from monsoon to post monsoon season and was higher in monsoon season. K supplementation was low ranging from 0.10 kg ha^{-1} to 3.60 kg ha^{-1} in the studied watersheds. Although the concentrations of K was minimal, the water sources used to cultivate tomato and other vegetables by supplementing with irrigation water meets the nutrients requirements of 3.80 kg t^{-1} (Table 4) of these crops. Finally as the K additions are higher in ICRISAT (2.80 kg ha^{-1}), Thana (3.0 kg ha^{-1}) and Govardhanapura (3.60 kg ha^{-1}) watersheds, it would be beneficial for chickpea critical irrigation which has a crop requirement of 49.60 kg t^{-1} (Table 5).

Based on this, it can be derived as to what extent nutrient requirements can be met by three irrigations from irrigation water for all the crops grown in the studied

Table 4 : Nutrient requirements of various crops per tones of economic yields

	Major and secondary nutrients (kg t^{-1})						Micro nutrients (g t^{-1})				
Crop	**N**	**P**	**K**	**S**	**Ca**	**Mg**	**Fe**	**Zn**	**Mn**	**Cu**	**B**
Sorghum	23	13	34	5	2.7	2.3	720	70	50	6	54
Cotton	45	28	75	2	26	23	140	120	200	300	500
Chickpea	46	8	50	9	19	7	870	40	70	11	35
Maize	30	14	33	2	18	29	1200	130	320	130	45
Finger millet	24	10	31	4	9	13	430	145	301	134	41
Wheat	25	9	33	5	5	5	620	60	70	24	48
Pigeon pea	71	15	16	8	19	16	1200	30	110	25	32
Soybean	58	20	30	7	14	8	350	80	80	3	30

Source: Tandon, 1991

Table 5 : Critical stages for irrigation in selected crops grown in the studied watersheds

Name of the crop	Critical stages	Average yield levels in watersheds (t ha^{-1})
Sorghum	Booting, Blooming and Milky Dough Stage	1.2
Cotton	Flowering, Boll formation	1.5
Fingermillet	Primordial Initiation and Flowering	2.0
Pigeonpea	Flower initiation, Pod filling	1.0
Maize	Silking and Tasseling to Dough stage	2.0
Wheat	Crown root initiation, Tillering to Booting	2.0
Soybean	Blooming and Seed Formation	1.5
Chickpea	Late Vegetative phage	1.2

Source: Collected from various reports

watersheds i.e. Sorghum N=5-10%, K=15-20%, Sulphur = 100%; Cotton N=10-15%, K=25-30%, Sulphur = 25-30%; Fingermillet N=5-10%, K=20-25%, Sulphur = 15-20%; Pigeonpea N=5-10%, K=5-10%, Sulphur = 100%; Chickpea N=25-30%, K=5-10%, Sulphur = 10-15%; Maize N=5-10%, K=10-15%, Sulphur = 45-50%; Wheat N=5-10%, K=15-20%, Sulphur = 15-20% and Soybean N=15-20%, K=5-10%, Sulphur = 10-15%). Micronutrients Fe, Zn, Mn, Cu and B additions through critical irrigations can also enrich soils deficient of these nutrients and meet the nutrient requirements to the full extent. Figure 1 and Table 6 depict the macro, secondary and micro nutrient addition with 3 critical stage irrigations for predominant crops from groundwater sources in the studied watersheds in semi-arid tropics. Thus various water sources used either as supplemental irrigation or critical irrigation can be a potential and readily available form of nutrients to meet crop nutrition and can supplement the nutrient addition through fertilizers or manures.

Stigter *et al*. (2005) showed groundwater to have the potential of supplying more than 50% of the recommended N for citrus orchards in the semi-arid regions of Portugal. The N added in groundwater harvested water of all the studied watersheds showed moderate N in terms of kg ha^{1}. The maximum N of 5.20 kg ha^{-1} was present in the open wells of Kothapalli watershed. In this watershed vegetables are grown along with legumes, cotton and sorghum. Therefore N availability in open wells can be used for critical irrigation of these crops. In the other watersheds although N is moderate, the groundwater sources can still provide around 1-4 kg ha^{-1} of N which would supplement, along with the fertilizer addition. One of the important potential problems of groundwater irrigation could be secondary salinization. Substantial salinization potential is realized through natural weathering and dissolution of soil parent materials, and these salt contributions will attenuate or augment irrigation water ionic constituents especially Na which in higher concentrations can be toxic to plants (Grattan, 2002). Because of the slow processes of rock weathering and soil formation, it is very difficult to quantify Na release from parent rocks (Yuan, 1988; Zhu *et al*., 1999). Boron present in the ground water can be an additional source along with the high amounts of Borax/Agribor application farmers are practicing. If irrigation water contributes boron in sufficient quantity external application of boron in the form of Borax could increase the concentrations in the soil above the toxic limit, as concentration for required and toxic limits for these crop plants is narrow. Both Na and B in most of the studied watersheds are present within the critical limits for irrigation water, and as such do not pose any problem if administered for critical irrigation. However, if Na concentration is more as in the case of Haveri and Kolar watersheds, plant growth may be affected in salt sensitive crops like pulses/food legumes.

Phosphorus concentrations in all of the groundwater sources of the entire studied watershed were found to be negligible. This could be accounted for P getting adsorbed onto the clay particles and getting associated with the positively charged cations (Nayak and Nandagiri, 2009). Transport of phosphorus to groundwater and potential P contributions to surface/ ground waters via base flow are generally assumed to be negligible because of the high potential for mobile phosphorus to be retained in the upper soil horizons by adsorption (e.g. to calcite) or metal complex formation (commonly with iron, aluminum or manganese in acidic

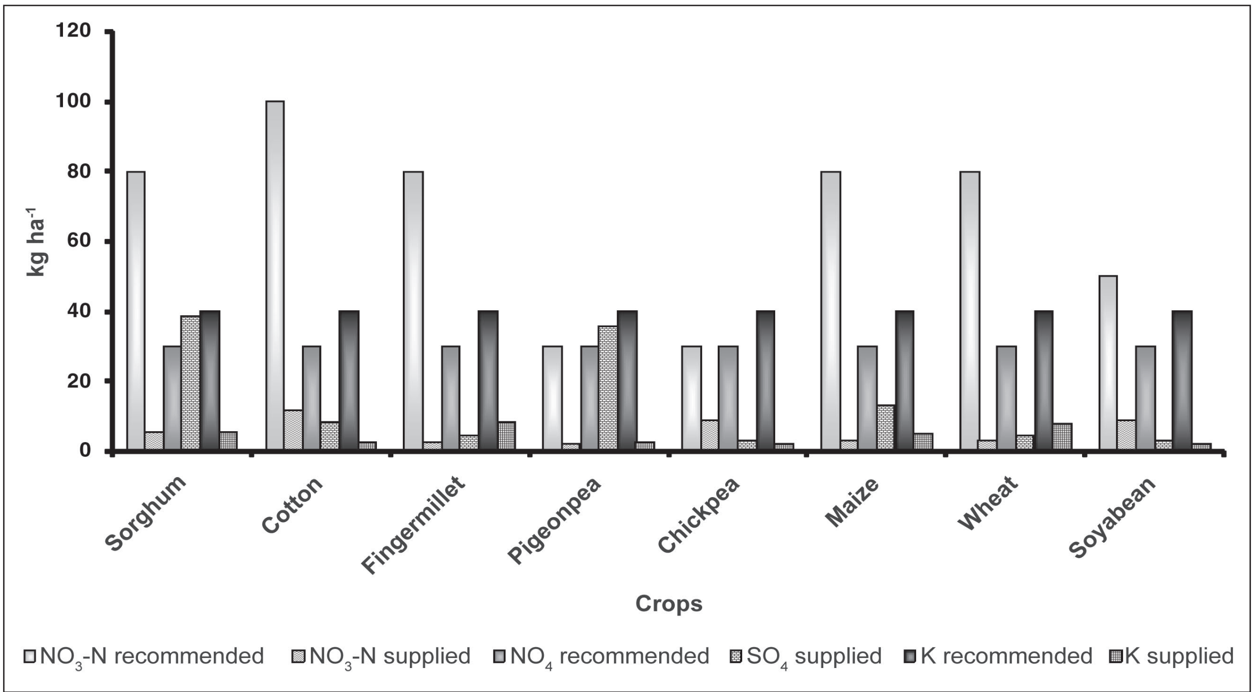

Fig. 1: Macro and secondary nutrient addition with 3 critical stage irrigations for predominant crops from groundwater sources in the studied watersheds in semi-arid tropics

Table 6 : Micro nutrient addition with 3 critical stage irrigations for predominant crops from groundwater sources in the studied watersheds in semi-arid tropical region of India

Name of the crop	Micronutrient addition (g ha^{-1})				
	Fe	Zn	Mn	Cu	B
Sorghum	197.7	45.0	112.5	37.5	90.0
Cotton	52.5	53.5	37.5	54.5	60.0
Fingermillet	37.5	30.0	30.0	45.0	210.0
Pigeonpea	120.0	39.9	49.9	49.9	279.9
Maize	109.9	45.0	139.9	214.9	375.0
Wheat	75.0	45.0	50.0	55.0	150.0
Soybean	180.0	53.3	46.6	33.3	236.6
Chickpea	180.0	53.3	46.6	33.3	236.6

soils (Addiscott and Thomas, 2000). On average 0.43 kg ha^{-1} P will be added to soil by the rainwater in the ICRISAT watershed, and this was accounted for terrestrial dust and sea spray. Studies on groundwater P (Atkinson, 1974) in Nebraska, USA, have shown to have orthophosphate concentrations generally in the range of 0.1 to 0.5 mg L^{-1}, and the presence of orthophosphate can be associated with moderate to high soil fertility, moderate to moderately high soil permeability, moderate to high permeability of the unsaturated zone, a relatively shallow water table, and seepage of municipal sewage effluent.

Conclusions

Results from this study give an overview of the nutrient status in various groundwater sources, and are a useful tool to complete and refine nutrient requirements to various crops grown in water sheds. Irrigated water contribution of nutrients is in water soluble form, this nutrient source is readily available and plants absorption is immediate. Besides, in agriculture, in semi-arid tropics which is often affected with soil moisture stress, fertilizer nutrient use efficiency is far less due to losses. Nutrient supplementation through various sources of irrigation water impacts the crop productivity positively, deriving the benefit of synergistic interaction of water-nutrient in agronomic managements of field crops in semi-arid tropics. This study helps in evaluating the nutrient prone water sources which could be potential for critical irrigation and also decide on the indirect benefit from nutrient additions through water sources especially in the regions of Haveri and Kolar where there is intensive cultivation of high value vegetables. As high value vegetables need up to 8 irrigations, by using harvested/groundwater sources the soils can be enriched with nutrients and thereby render higher crop yields. In Kothapalli and Semli and Shyamapura, NO_3 concentrations of open well and bore well groundwater sources can be beneficial in reducing the N fertilizer application particularly in sorghum if three critical irrigations are given.

Acknowledgements

The author would like to thank BAIF Development Research Foundation, MYRADA for their collaboration and would also like to thank technical staff of ICRISAT; L. Mohan Rao, L.J.Naidu, Ch. Sreenivasa Rao, Mathur, Pal, Nageshwar Reddy and all the participant farmers.

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