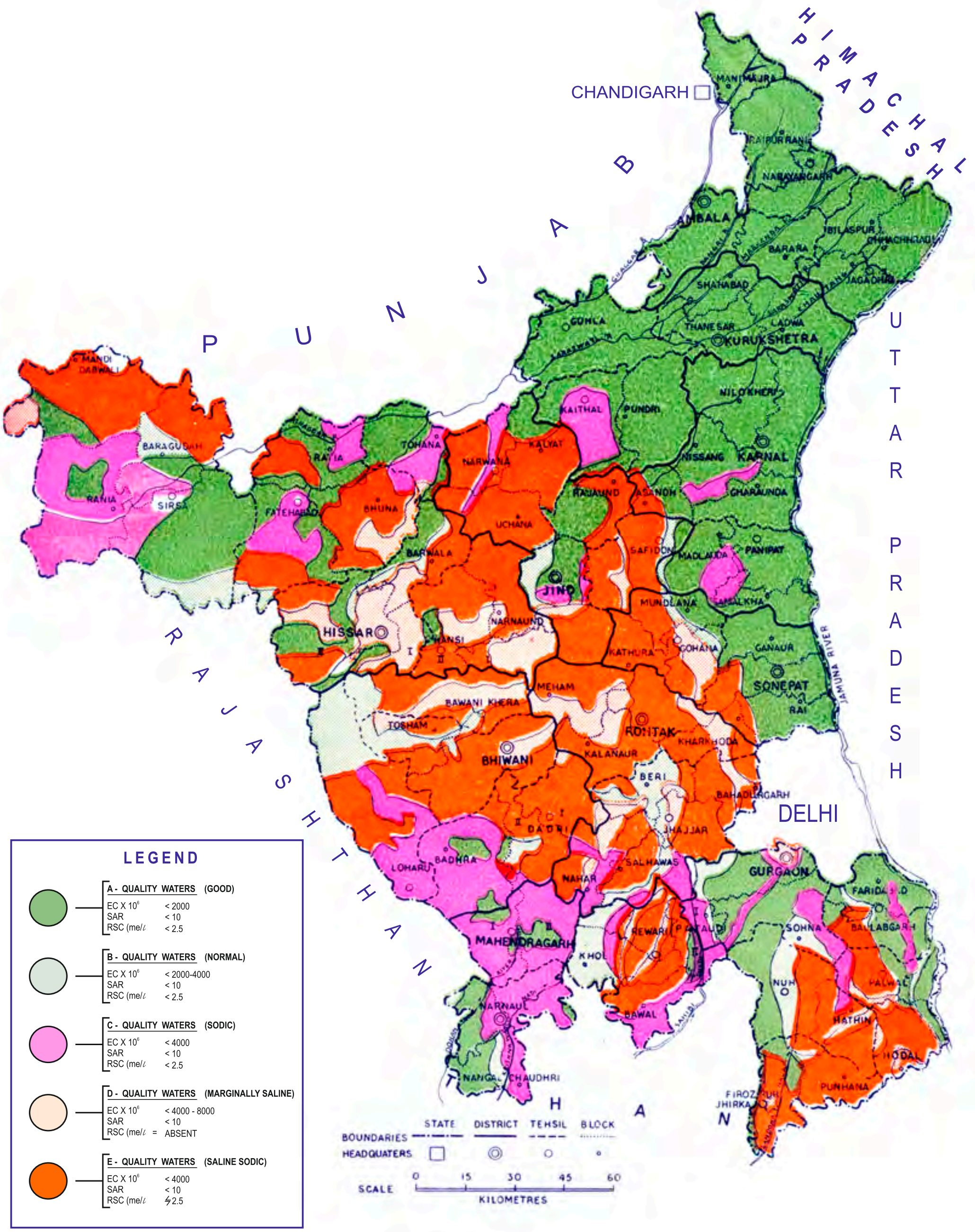
Vegetable Cultivation with Poor Quality Water

Vinod Phogat | S.K. Sharma | Sanjay Kumar | Satyavan | S.K. Gupta

Department of Soil Science
CCS Haryana Agricultural University
Hisar - 125 004, Haryana

UNDERGROUND WATER QUALITY IN HARYANA STATE



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Vinod Phogat
Soil Scientist

S.K. Sharma
Senior Soil Scientist

Sanjay Kumar
Scientist (SWE)

Satyavan
Agronomist

DEPARTMENT OF SOIL SCIENCE
CCS Haryana Agricultural University
Hisar - 125 004

S.K. Gupta
Project Co-ordinator
AICRP on Management of Salt Affected Soils and
Use of Saline Water in Agriculture

CENTRAL SOIL SALINITY RESEARCH INSTITUTE,
Karnal - 132 001

Department of Soil Science
CCS Haryana Agricultural University
Hisar - 125 004

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FOREWORD

Good quality water is the most critical and scarce resource for drinking, agriculture and environment, more so in arid and semi-arid regions. The present trends of population dynamics and shrinking land holding call for harnessing poor quality available groundwater by evolving suitable technologies, adopting management practices and selecting suitable crops and cropping sequences including vegetables and their varieties. It assumes greater importance for the state of Haryana, where groundwater contributes 50% to the irrigated area and more than half of these waters (55%) are of poor quality. The continuous use of these waters without proper management and amendments would adversely affect the soil physical conditions, mineral composition, plant nutrients uptake and yield of crops, especially vegetables, which are quite sensitive to salts.

Currently, India's share in the world's total vegetable production is 13.6 per cent and the demand for vegetables is projected to rise to 170 million tons by the year 2025. In Haryana, the area under vegetables is 0.28 million ha with a production of 3.3 million tons. Despite the huge potential of vegetables in the state, farmers are reluctant to grow vegetables due to the perishable nature. Vegetables are high water requiring crops and good quality water is scarce and not available all the time. Mostly the vegetables are grown near the cities irrigated with sewage water or marginal quality water. In order to save the soil resource and increase productivity of vegetables, interventions are needed to manage poor quality water resource for this production system. Hence the present research bulletin on "Vegetable Cultivation with Poor Quality Water" is very timely and would prove to be a stepping stone for enhancing vegetable production in the state.

I congratulate the authors for bringing out this compilation of research work and technologies relevant to vegetable production with poor quality waters. I hope this publication will prove useful to students, teachers, researchers and farmers for enhancing the production of vegetables through judicious use of poor quality waters. This bulletin would also provide technical guidelines to formulate strategies for proper utilization of the water resources.

K. S. KHOKHAR
Vice-Chancellor
CCS Haryana Agricultural University, Hisar-125 004

Jan., 2010
Hisar

PREFACE

Water is vital for realizing the full potential of the agricultural sector. One of the major obstacles to increase food production in arid and semi-arid regions is the lack of fresh water resources. As population rise remains unabated, proper management of available land and water resources would play a significant role in enhancing the food production to meet ever-growing demand for food in the country. Since, all the groundwaters are not of good quality and contain various kinds and amounts of salts particularly in arid and semiarid regions, the continuous use of such water without proper management might adversely affect the soil health and crop yields. It has been reported that the water in 32-84% of the aquifers surveyed in different parts of the country are of poor quality. If the canal water supplies are either inadequate or unreliable, farmers would be lured to pump saline/alkali groundwater for crop production.

India has achieved self sufficiency and a good degree of stability in cereal production. This has created an urgent need for providing health security to our population by supplying nutrition through balanced diet. The per capita intake of vegetables in our country is 135 g against the recommendation of per capita consumption of 280 g/day by the Indian Council of Medical Research. To meet this guideline, the higher consumption of vegetables has to be ensured for which increasing productivity of vegetable crops would require urgent attention.

I am glad to know that the AICRP- Management of Salt Affected Soils and Use of Saline Water in Agriculture, Hisar Centre is bringing out a technical bulletin titled "Vegetable Cultivation with Poor Quality Water". The purpose of this bulletin is to collate and update the relevant information so that the latest synthesized knowledge becomes easily accessible to research workers, teachers, students, planners and policy makers and farmers who can utilize it profitably for better management and development of water resources for enhancing vegetable production.

I congratulate the authors for bringing out this compilation of research work and technologies relevant to vegetable production with poor quality waters.

R. P. NARWAL
Director of Research
CCS Haryana Agricultural University, Hisar-125 004

Jan., 2010
Hisar

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The words are not eloquent enough to express our special feeling for our family members for their moral support, deep affections and encouragement during preparation of this bulletin.

We wish to record the gratitude to our field staff, office staff and all who rendered their support and services in various capacities throughout the preparation of this document.

Vinod Phogat
S.K. Sharma
Sanjay Kumar
Satyavan
S.K. Gupta

EXECUTIVE SUMMARY

In India, almost all the vegetable cultivation demands supplemental irrigation. The scarcity of good quality surface as well as groundwater is the main cause of low productivity of vegetables in most of arid and semi-arid regions of the country. For such situations a number of technologies and management practices have been evolved which are discussed in this bulletin at length. The major contributions discussed in the bulletin are summarized as under:

- Under brackish water irrigation conditions, intra and inter-generic differences in salt tolerance of vegetable crops should be exploited to maximize the yield. The beans are sensitive to salinity as their yield is reduced to 50% even at low EC_e of 3 dS/m, but spinach, brinjal, celery and cabbage are relatively tolerant, as 50% reduction in yield takes place at a high EC_e of 10 dS/m. Brinjal, spinach and sugar beet are the most alkalinity tolerant crops. Hence, the vegetable crops which are semi-tolerant to tolerant, as well as those having low water requirement should be preferred with saline/alkali water.
- The salt and sodium tolerance of winter crops is generally higher than those grown during the hot season. It is, therefore, suggested that in low rainfall areas (<400 mm) vegetable crops may be grown during winter season (low ET) keeping the land under arable crop during summer.
- Waters of high salt concentration as an EC of 12 dS/m can be used for growing tolerant and semi-tolerant crops in coarse textured soils, provided the annual rainfall is not less than 400 mm. But in fine textured soils, waters with EC more than 2 dS/m would often create salinity problems.
- The options of utilizing the multi-quality waters have to be used either in mixing or cyclic mode. However, good quality water, if possible, should be used at the more critical stages of growth, e.g. nursery/germination and seedling establishment and the saline water at the stages where the crop has relatively more tolerance since most vegetables are known to tolerate the salinity better with aging. The blending of saline/alkali and canal water should be done in such proportion so that the final EC/RSC is maintained below the threshold limit of the crop to be grown.
- Surface irrigation methods generally result in excessive irrigation and non-uniformity in water application with low irrigation efficiency (60-70%). The pressurized irrigation methods such as sprinkler and drip which are more efficient as the quantity of water applied can be adequately controlled should be practiced wherever possible. These systems have great potential of application in the arid and semi-arid regions particularly on the light textured soils and undulating topography.

- Micro-irrigation systems enhance the threshold limits of salt tolerance by modifying the pattern of salt distribution and by maintaining high matric potential. A major limitation of these techniques is that they require huge initial investments beyond the reach of small and marginal farmers.
- The low cost and innovative methods of irrigation like Pitcher irrigation or Pitcher farming can be followed to grow vegetables with even higher salinity, undulating terrain and in remote areas where transport of vegetables is expensive and uneconomical.
- The organic materials like FYM, compost, press mud, crop residues etc. should be used for vegetable production. However, addition of organic amendments alone without gypsum are not capable of alleviating the harmful effects of alkali water. The addition of gypsum along with organic amendments triggers the process of amelioration of these waters and consequently enhanced the yields of crops.
- The results of a series of experiments have shown that application of gypsum improved the soil physico-chemical properties and reduced the harmful effects of alkali water by bringing down the pH and ESP and increasing infiltration rate, hydraulic conductivity and penetration of the soil.
- The addition of organic amendments like FYM, besides ameliorating the harmful effects of alkali water also contribute to the organic matter pool of the soil which is the reservoir of the available plant nutrients. The results revealed that the mean organic carbon of the soil increased from 0.36 to 0.61% and 0.38 to 0.71% with the addition of FYM @ 10 and 20 t/ha, respectively, registering an increase of 73 and 84%, respectively over no FYM in a time span of 15 years.
- Investigations have revealed that alkali water irrigation has a remarkable effect on quality traits of vegetable crops. It reduces the fruit weight, fruit length, fruit width, moisture, protein, fat, crude fibre, total soluble sugars, total dietary fibres but increases the firmness, TSS, acidity, β-carotene, ascorbic acid, oxalic acid and polyphenols content of tomato, cabbage and brinjal.
- Studies on the enhancement of salinity tolerance by sowing pre-soaked seeds and seedlings in water/ salt solutions and growth hormones showed that root dippings of transplants of tomato, onion and cauliflower and seed soaking of okra in 250 ppm solution of cycocel and NaCI for 2-8 hours improved the performance of these crops under saline conditions considerably.
- Research on the physiology of stress tolerance of vegetables has demonstrated that tolerance to a specific stress is determined by several component traits and controlled by corresponding genes. The use of molecular markers as a selection tool provides the potential for increasing the efficiency of breeding programs by reducing environmental variability, facilitating earlier selection, and reducing subsequent population sizes for field testing. A combination of a genome-wide scan of expression, using DNA arrays, and Quantitative Trait Loci (QTL) analysis could provide important information in identifying the major genes association with stress tolerance.
- The economic analysis has shown that use of brackish waters for vegetable production is a viable technology if used judiciously along with amendments.

1. INTRODUCTION

The continuous increase in the earth's population requires increasing quantities of water for domestic, industrial and agricultural needs. Presently about 15% of India's water resources are consumed in domestic and industrial requirements and share of these two sectors will grow to about 30% by 2050 (Minhas and Samra, 2004). The progressive requirement for more water to irrigate crops for food when water resources are limited has led to use of poor quality water in agriculture (Bouwer, 1994; Ragab, 2005). In many regions of the world, field drainage water is already used successfully for irrigation even when the water is saline (Grattan *et al.*, 1994). Irrigation with saline water has become necessary not only in parts of the world with limited supplies of good quality water but also in areas affected by shallow groundwater where the main purpose is to reduce the depth of the water table.

The large scale and indiscriminate use of poor quality waters cause secondary salinisation and sodification, which affects plant growth. The successful use of low quality water requires an integrated management plan based on crop management, soil management, choice of the most appropriate irrigation system or water management, chemical and rainwater management (Phogat *et al.*, 2007). The continuous use of alkali waters without amendments adversely affects the soil physical conditions and at the same time, it adversely affects the mineral composition, uptake and yield of crops under most situations. The benefits of a few of these options would be covered at appropriate places in this bulletin.

Vegetable production is threatened by increasing soil salinity particularly in irrigated croplands which provide 40% of the world's food (FAO, 2001). Although India is the second largest producer of vegetables next only to China but productivity of most of vegetables is far less than the world average. One of the main reasons behind low productivity may be use of poor quality water for irrigation. The scarcity of good quality surface as well as groundwater are the main constraints for success of agriculture in most of arid and semi-arid regions of the country. However, the groundwater is either saline or alkali and almost 60 per cent of it as such is not suitable for irrigation.

Concerted efforts have been made by researchers to evolve technologies and management practices to use saline and alkali waters for enhancing vegetable production but these are not properly documented. This bulletin looks at these issues, collates the existing experimental data sets establishing the salt tolerance limits of vegetable crops and describes the technologies that could be adopted to obtain higher yields of crops under saline/alkali environment either in the soil root zone or that created due to application of saline/alkali water for crop production.

1.1 Vegetable Production in India

Vegetable cultivation provides livelihood options to smallholder farmers with regular and much higher income. It also creates more jobs per ha than many staple crops (de la Pena and Hughes, 2007). From consumption point of view, vegetables form an indispensable nutritive component of a balanced diet, being the best source of micronutrients. These are excellent source of proteins, vitamins, carbohydrates, minerals like calcium and iron, fibre and antioxidants (Sahu, 2004). All these benefits are achieved with low calorific value (Varsha, 2007). As such, research reports link between increased consumption of vegetables and the reduced risk of chronic degenerative diseases like cardiovascular disease, cancer, obesity and diabetes. Since the per capita intake of vegetables in India is a meager 134g per day (Sahu, 2004) against the recommendations of Indian Council of Medical Research for a minimum per capita consumption of 280 g/day, cultivation of vegetable crops needs to be encouraged in various agro-ecological regions using poor quality water resources.

The worldwide production of vegetables has doubled over the past quarter century and the value of global trade in vegetables now exceeds that of cereals. In Asia, vegetable production grew at an annual average rate of 3.4%, 144 million metric ton from 12.0 million hectares in 1980 to 218 million metric ton from 16.3 million hectares in 1993 (Ali, 2000). In spite of a 268% simple growth rate (Kalloo and Pandey, 2002), and a 78.91% increase in production during the last four decades, India still remains deficient in vegetable production. Vegetables being sensitive to environmental extremes, high temperatures and limited soil moisture often results in low yields in the tropics and it would be further magnified by anticipated climate change.

In the Indian context, after achieving self sufficiency and a good degree of stability in food production, attention is being paid to provide health security to people by ensuring consumption of balanced diet. Fortunately, India is endowed with vast diversity of land, soil and agro-climatic conditions salubrious to grow large number of vegetables in different parts throughout the year. As such, it could claim to grow the largest number of vegetable crops compared to any other country of the world. As many as 61 annual and 4 perennial vegetable crops are commercially cultivated (Sidhu, 1998; Table 1.1). Currently, India's share in the world's total vegetable production is 13.6 per cent

Table 1.1 : Important vegetables grown in India

Solanaceous crops	brinjal, tomato, chillies, sweet pepper (capsicum).
Cole crops	cabbage, cauliflower, knol khol.
Bulbous vegetable	onion, garlic
Okra	okra
Cucurbits	long melon, muskmelon, snap melon, watermelon, cucumber, pumpkin, summer squash, bitter gourd, bottle gourd, pointed gourd (parwal), ridge gourd, round gourd, snake gourd, sponge gourd, wax gourd (ash gourd)
Root vegetables	carrot, radish, turnip
Leguminous vegetables	broad bean, cluster bean, cowpea, dolichos bean, french bean, peas
Leafy vegetables	amaranths, beet leaf, fenugreek, spinach
Salad vegetables	lettuce
Perennial vegetables	drumstick, curry leaf, agathi, paii

Sidhu (1998)

(Gopalkrishnan, 2007) but the requirement is projected to rise to 170 million tons by the year 2025 (IIVR, 2007).

The area and production of vegetables has registered a substantial increase, off-season vegetables making a discernible and worth mentioning dent. With the introduction of hybrid varieties of vegetables and a vast improvement in the production technologies, a 50% increase in production of vegetables in last decade has been registered. Crop wise area and production of different vegetables in India is depicted in Table 1.2 revealing increasing productivity trend (National Horticulture Board, 2008).

Table 1.2 : Crop-wise area, production and productivity of major vegetable crops in India

Crops	2006-07			2007-08		
	Area (000 ha)	Production (000 Mt)	Productivity (Mt/ha)	Area (000 ha)	Production (000 Mt)	Productivity (Mt/ha)
Potato	1743	28600	16.4	1786	34463	19.3
Onion	768	10847	14.1	805	12157	15.1
Tomato	596	10055	16.9	572	10261	17.9
Brinjal	568	9453	16.6	566	9596	17.0
Tapioca	256	8232	32.2	270	9054	33.5
Cabbage	250	5589	22.4	265	5888	22.2
Cauliflower	311	5579	18.0	321	5797	18.1
Okra	396	4070	10.3	409	4193	10.3
Peas	298	2402	8.1	314	2560	8.2
Sweet potato	123	1067	8.7	126	1146	9.1
Others	2277	29117	12.8	2370	30774	13.0
Total	7584	115012	15.2	7803	125887	16.1

National Horticulture Board (2008)

Andhra Pradesh, Bihar, Haryana, Karnataka, Kerala, Maharashtra, Orissa, Tamil Nadu, Uttar Pradesh and West Bengal are the major vegetable growing states of India contributing 88.89 and 82.14% to total vegetable area and production of India, respectively (Table 1.3). West Bengal leads in vegetable production, followed by Uttar Pradesh and Bihar. In Haryana, area under vegetables is 0.28 Mha with a total production of 3.3 Mt (Table 1.4). Potato, tomato, cucurbits, cauliflower, carrot, radish etc. are the major crops grown in the state. Despite the huge potential of vegetables in the state, farmers are reluctant to grow vegetables due their perishable nature. Moreover, vegetables are high water requiring crops and good quality water is scarce and not available all the time. Hence, the productivity of vegetables in Haryana is low as compared to other states. Thus, there is a need to extend the vegetable production on salt affected soils or soils irrigated with poor quality waters and develop technologies to improve productivity under stressed environment so that farmers could be sensitized to switchover to vegetable production.

Table 1.3: State-wise area, production and productivity of vegetables during 2007-08

State	Area (000 ha)	Production (000 Mt)	Productivity (Mt/ha)
West Bengal	1313.19	22456.8	17.1
Uttar Pradesh	960.9	19790.3	20.6
Bihar	823.7	14067.7	17.1
Orissa	660.78	8214.6	12.4
Tamil Nadu	262.72	7975.7	30.4
Gujarat	411.73	7402.9	18.0
Maharashtra	455.25	6454.8	14.2
Karnataka	406.04	5030.9	12.4
Andhra Pradesh	284.07	4769.6	16.8
Assam	328.91	4474.2	13.6
Jharkhand	238.88	3639.7	15.2
Kerala	166.87	3479.1	20.8
Haryana	274.57	3277.1	11.9
Chhattisgarh	292.56	2934.3	10.0
Madhya Pradesh	209.34	2919.7	13.9
Punjab	171.72	2772.1	16.1
Jammu & Kashmir	58.55	1238.1	21.1
Himachal Pradesh	63.68	1150.7	18.1
Uttranchal	80.58	1036.2	12.9
Rajasthan	135.7	818.9	6.0
Delhi	42.7	595.6	13.9
Tripura	33.5	423.5	12.6
Meghalaya	42.45	352.5	8.3
Manipur	12.09	113.7	9.4
Arunachal Pradesh	23.74	110.0	4.6
Sikkim	20.07	95.9	4.8
Goa	8.50	85.0	10.0
Nagaland	10.38	63.5	6.1
Mizoram	1.21	37.3	30.9
Total	7803	125887	16.1

National Horticulture Board (2008)

Table 1.4: Area and production of vegetable crops in Haryana during 2006-07

Sr. No.	Vegetable	Area (ha)	Production (tons)
1	Potato	21503	361361
2	Onion	16430	247220
3	Tomato	22533	258758
4	Raddish	21534	335012
5	Carrot	19342	283354
6	Cabbage	10827	172885
7	Cauliflower	30324	418797
8	Chillies	12319	102876
9	Okra	15189	106360
10	Brinjal	16755	183278
11	Cucurbits	42608	364904
12	Peas	12092	112118
13	Leafy vegetables	26856	211076
14	Other vegetables	10833	158762
	Total	280070	3327600

Statistical Abstract, Haryana (2006-07)

2. SALT AFFECTED SOILS AND WATERS

2.1 Soil Quality: Kinds, Extent and Distribution

Salt affected soils are those which contain either excess soluble salts or exchangeable sodium or both which adversely affect the growth of most crops. Such soils commonly occur in arid and semi-arid tracts of the world where rainfall is much less than the evaporative demand of the atmosphere. In India, the area under salt-affected soil has been estimated to be 6.73 Mha (NRSA and Associates, 1996). However, during the last decade several agencies have given divergent estimates e.g. National Commission on Agriculture, 7.16 Mha; National Remote Sensing Agency 3.9 Mha; National Wasteland Development Board 1.5 Mha; National Bureau of Soil Survey and Land use Planning 6.2 Mha.

The data from various sources were critically evaluated at Central Soil Salinity Research Institute, Karnal and figure has now been modified to 6.73 Mha. The extent of this problem in some states is presented in Table 2.1. In Haryana saline soils covers an area of 2,32,556 ha, whereas, the alkali soils spreads in 1,83,399 ha area. The district wise distribution of salt affected soils in Haryana is given in Table 2.2.

Table 2.1: Extent of salt affected soils in India (ha)

State	Saline	Alkali	Total
Andhra Pradesh	77598	196609	274207
Andeman & Nicobar Island	77000	--	77000
Bihar	47301	105852	153153
Gujarat	1680570	541430	2222000
Haryana	49157	184399	232556
Karnataka	1893	1481136	150029
Kerala	20000	--	20000
Madhya Pradesh	--	139720	139720
Maharashtra	184089	422670	606759
Orissa	147138	--	147138
Punjab	--	151717	151717
Rajasthan	195571	179371	374942
Tamil Nadu	13231	354784	368015
Uttar Pradesh	21989	1346971	1368960
West Bengal	441272	--	441273
Total	2956809	3770659	6727468

NRSA and Associates (1996)

Table 2.2: Salt affected soil in Haryana (ha)

District	Saline	Alkali	Total
Hisar	7770	2868	10638
Ambala	718	5047	5765
Bhiwani	107	891	998
Fatehabad	--	10024	10024
Faridabad	3470	6015	9485
Gurgaon	8465	1229	9694
Kaithal	832	6685	7517
Karnal	3369	29792	33161
Kurukshetra	--	19674	19674
Jind	3680	21906	25586
Jhajjar	8357	647	9004
Panipat	872	35303	36175
Riwari	283	--	283
Rohtak	8563	3757	12320
Sirsa	291	4290	4581
Sonipat	2380	33679	36059
Yamunanagar	--	1592	1592
Total	49157	183399	232556

NRSA and Associates (1996)

2.1.1 Alkali Soils

These soils have Exchangeable Sodium Percentage/Sodium Adsorption Ratio (ESP/SAR) exceeding 15 that is reflected in the high pH of these soils (>8.2). The soluble salt content given by the Electrical Conductivity (EC) is variable and may or may not be high. As such, these soils have dispersed soil structure. Following an irrigation or rain event, water stagnates for longer period particularly in the lower spots. Upon drying, these soils develop 1-2 cm wide cracks. Organic matter present in the soil solution of highly alkali soils gets dispersed and is deposited on the soil surface through capillary action causing dark black surface – the reason why these soils have been termed as black alkali. The cropped fields have spotty growth. When the alkali status is high, crops show scorching and leaf burn typical of sodium toxicity or the yellowing of leaves resulting from poor soil physical properties. In extreme cases, the soils remain barren with practically very little or no vegetation. Many times alkali problem develops in the form of patches with good, medium or poor crop growth. Barren patches in such cases could be seen when such lands are cultivated. During monsoon season, some alkali tolerant grasses can be seen (Table 2.3). It is almost impossible to grow crops on highly deteriorated lands but depending upon the initial ESP crops could be selected for cultivation with addition of appropriate doses of chemical amendments.

A view of barren alkali soil

A view of barren water logged saline soil

Table 2.3: Visual observations distinguishing between an alkali and a saline soil

Observation	Alkali soil	Saline soil
Rain water stagnation	Stagnation for longer period	Relatively lesser period
Stagnated water type soapy	Dark coloured, muddy	Clear
Surface salt crust	Dark brown or ash coloured clay crust	White salt efflorescence
Groundwater	Usually good, occasionally with high Residual Sodium Carbonate (RSC)	Saline, some times with high SAR
Presence of nodules	$CaCO_3$ nodules are present	Gypsum may be present at some depth
Natural vegetation (grasses)	*Sporobolus marginatus, Desmostachya bipinata, Suaeda maritma, Diplachne fusca, Dichanthium annulatum,Cynodon dactylon, Chloris barbata, Brachiaria mutica Kochia indica, Panicum antidotale*	*Cressa cretica, Cyperus rotundus, Chloris pallida, Sporobolus pallidus, Haloxylon salicornicum, Acluropus lagopoides, Zygophyllum simplex, Dichanthium annulatum, Sueda furuticosa, Butea monosperma*

2.1.2 Saline Soils

These soils have EC of the saturation paste extract (EC_e) exceeding 4 dS/m and have a variable ESP usually in the low range with pH < 8.2. These soils support patchy growth of crops and sometimes, visible signs of salt injury such as tip burn or chlorosis (pale yellow colour) of leaves can be seen. Soluble salts, which are invariably present in large quantities, form a white efflorescence on the soil surface. For this reason, these soils are called white kallar. Since the neutral salts present in this type of soil can absorb moisture from the soil surface, these soils look wet although this water would not be available to the plants. Since salts get leached during the monsoon season, these soils can be identified from salt tolerant grasses that come up during the monsoon season (Table 2.4).

Table 2.4: Characteristics of alkali and saline soils

Characteristics	Alkali soils	Saline soils
EC_e (dS/m)	Variable	4.0 or more
ESP/SAR	15 or more	Variable
pH_s	8.2 or more	<8.2
Chemistry of soil solution	Carbonates and bicarbonates always present	Dominated by chloride and sulphate
Main adverse effect on plants	Alkalinity of soil solution	High osmotic pressure of soil solution
Geographical distribution	Associated with semi-arid and sub humid climates	Associated with arid and semi-arid climates
First step for reclamation	Lowering or neutralization of high pH using amendments	Removal of excess electrolytes through leaching

The visual characters of alkali and saline soils are briefly highlighted in Table 2.1. These characters help to make a first guess of the problem during reconnaissance surveys. To accurately characterize the soils, it is imperative that soil samples be drawn and analyzed in the laboratory. The soils, thereafter, could be characterized as alkali or saline according to the guidelines provided in Table 2.4.

2.2 Water Quality: Kinds, Extent and Distribution

Groundwater constitutes the most important source of supplemental irrigation in arid and semi-arid regions in India. Unfortunately the water in 32-84% of the aquifers surveyed in different states of the country has been observed to be of poor quality (Table 2.5). Depending upon the kinds of salts present and the problems encountered in their use, marginal and poor quality groundwaters have been categorized as saline, alkali, saline-alkali in nature (Table 2.6). District wise distribution of water quality in the state of Haryana is depicted in Table 2.7 revealing that Rewari has 87% poor quality groundwater. Current classification, however, does not recognize saline-alkali waters as these waters could be grouped either as saline or alkali depending upon the degree of the two

Table 2.5: Water quality distribution (%) in some states of India

States	Good	Marginal	Poor
Punjab	59	22	19
Rajasthan	16	16	68
Haryana	37	08	55
Uttar Pradesh	37	20	43
Madhya Pradesh	75	10	15
Gujarat	70	20	10
Karnataka	65	10	25
Average	51	15	34

Manchanda *et al.* (1989)

Table 2.6: Poor quality water distribution (%) in some states of India

States	Categories		
	Saline	Alkali	Saline-alkali
Punjab	22	54	24
Haryana	24	30	46
Rajasthan	16	35	49
Gujarat	20	28	52
Average	20	37	43

Manchanda *et al.* (1989)

Table 2.7: District-wise water quality distribution in Haryana

S/No.	District	Groundwater quality distribution (%)				
		Good	Marginal	Saline	Alkali	Saline-alkali
1.	Yamuna Nagar	100	Nil	Nil	Nil	Nil
2.	Ambala	100	Nil	Nil	Nil	Nil
3.	Kurukshetra	96	Nil	02	02	Nil
4.	Rewari	13	13	09	23	42
5.	Bhiwani	11	16	18	16	39
6.	Mahendergarh	23	08	07	50	12
7.	Panipat	50	06	08	26	10
8.	Gurgaon	24	19	11	15	37
9.	Kaithal	56	08	03	27	06
10.	Faridabad	35	10	12	15	28
11.	Sonepat	32	11	13	15	29
12.	Karnal	68	43	02	16	10
13.	Jind	14	07	12	11	45
14.	Rohtak	05	14	22	15	44
15.	Sirsa	23	12	22	26	22
16.	Hisar	20	09	07	22	38
	Average	37	08	11	18	26

Manchanda, (1976)

problems as management option has to address the major problem. Another group of waters is the toxic waters that have specific ions in excess over the threshold value and proves toxic to the plants. In this bulletin discussions would revolve around saline and alkali waters as toxic waters pose several problems that are being researched.

3. PARAMETERS TO ASSESS WATER QUALITY PROBLEMS

Salts are present in irrigation water in relatively small but significant amounts. The suitability of water for irrigation is determined not only by the total amount of salt present but also by the kind of salts. Various soil and cropping problems develop as the total salt content increases, and special management practices may be required to maintain acceptable crop yields. Water quality or suitability for use is judged on the potential severity of problems that can be expected to develop during long-term use. The most common problems resulting from irrigation with poor quality waters can be grouped into three categories viz. due to salinity, alkalinity and the toxicity hazards. Parameters usually monitored to evaluate salinity and alkalinity hazards, are discussed below.

3.1 Salinity Hazard

The total concentration of soluble salts is the single most important criterion which has been used conventionally for determining quality of irrigation water. It is measured quantitatively in terms of electrical conductivity (EC), because this is very closely related with the sum of major cations (or anions) determined by chemical analysis, and because this correlates well with the value of total dissolved solids, as well as osmotic potential. The EC, also called 'specific conductivity' or the conductance per unit cross-sectional area and across unit distance, is obtained from the resistance recorded across a conductivity cell from the following relationship:

EC = K/R where K = Cell constant and R = Resistance

It is expressed as deci Siemens per meter (dS/m), according to SI Units (from the system International d' Unite's). EC equal to 1 dS/m is nearly equal to 10.0 me/l of total cation concentration (TCC) or 640 mg/l of total dissolved solids (TDS). Both the relationships hold good in EC range from 1 to 5 dS/m. With further increase of EC from 5 to 10 dS/m, range of TCC and TDS tend to increase from 12 to 13 me/l and 900 to 1000 mg/l, respectively. EC of aqueous salt solution increases at the rate of approximately 2 per cent per degree centigrade rise in temperature. Osmotic pressure of 1 atmosphere (atm) is equal to 0.36 dS/m EC of irrigation water.

3.2 Alkalinity Hazard

Some of the irrigation waters when used for irrigation of crops have a tendency to produce alkalinity hazards depending upon the absolute and relative concentrations of specific cations and anions contained in them. The long-term effects of alkali waters containing high proportions of sodium (>75 % of total cations) and predominance of bicarbonate and carbonate ions relative to calcium and magnesium lead to development of high exchangeable sodium and high pH in soils. The high alkalinity and high pH adversely affect the soil physical properties and the effect are more pronounced following rainfall or an irrigation event which lead to stagnation of water and resultant aeration problems. Different parameters, which are generally analyzed for knowing their potential to create alkalinity hazards are as follows:

3.2.1 Sodium adsorption ratio (SAR)

Changes in the exchangeable cation composition of the soil following irrigation with alkalinity inducing waters are generally described on the basis of cation exchange equilibria. When soils are irrigated with bicarbonate type waters dominated by Na^+ ions, they usually accumulate excessive amounts of sodium on the exchange complex. A useful index for evaluating the alkali hazard of waters is the sodium adsorption ratio (SAR) given as follows:

$$ESR = \frac{Na}{CEC - Na} = K_G \frac{Na}{\sqrt{[(Ca + Mg)/2]}} = K_G \times SAR$$

Here, K_G is the Gapon selectivity coefficient and CEC is the cation exchange capacity of soil. Exchangeable cations are in meq l00/g and solution concentrations are in me/l. Instead of exchangeable sodium ratio (ESR), the exchangeable sodium percentage has been widely used in the soil literature. The latter describes the percent of the cation exchange capacity (CEC) occupied by Na^+ ions (Na/CEC). The ESP of a soil can be calculated from ESR using the expression:

$$ESP = \frac{100 \times ESR}{(1 + ESR)}$$

Paliwal and Maliwal (1971) reported that the ESP of soils of Bhilwara, Pali and Jodhpur regions could be predicted using the equation viz. ESP = 14.2 + 0.23 EC + 0.18 SAR. They also proposed an empirical equation to predict the ESP of soils of predominantly illitic clay mineralogy, irrigated with different quantity waters:

$$ESP = \frac{100(0.23 + 0.0042\,SAR)}{1 + (0.23 + 0.0042\,SAR)}$$

This equation has high values of selectivity coefficient and intercept. Even at zero SAR, expected ESP is about 19 which points towards its limited utility. It may be pointed out that the SAR concept does not take into account the reductions in free ion concentrations and inactivities due to ion pair formations (Sposito and Mattigod, 1977).

3.2.2 Residual sodium carbonate (RSC)

Alkalinity build-up in soils has also been observed to depend on the amounts of CO_3^{2-} and HCO_3^- ions in waters. These ions however, are not considered in SAR calculations. When drying occurs in between the irrigations, soil solutions concentrate leading to precipitation of these ions as $CaCO_3$. This results in removal of a part of Ca^{2+} ions from the soil solutions and an increase in the relative proportion of sodium or SAR of soil solution. Eaton (1950) presumed the complete precipitation of HCO_3^- plus CO_3^{2-} exceeded the divalent cations. He proposed the concept of residual sodium carbonate (RSC) for evaluating the alkalinity hazard of irrigation waters. In fact, RSC is an equivalent expression for the residual alkalinity (me/l) in waters;

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$$

The development of alkali soils (saline or non-saline) may be expected when irrigation water containing CO_3^{2-} + HCO_3^- higher than Ca + Mg is used for irrigation.

3.2.3 Adj. SAR/RNa

It was recognized that precipitation of Ca^{2+} would not be complete but increase in relative concentration of Na^+ to Ca^{2+} in soil solution. Therefore, the concepts of SAR and RSC have been refined from time to time to account for the effects of mineral weathering, leaching fraction, solution composition and PCO_2 in the root zone. The new adjusted SAR has been proposed and it can be calculated from (Ayers and Westcot, 1976):

$$\text{Adj. SAR} = \text{SAR}\,(1 + 8.4 - pH_c) \qquad (6)$$

Such that pH_c is calculated from:

$$pH_c = (pk_2 - pk_c) + p(Ca) + P(Alk) \qquad (2)$$

with (Ca + Mg) as proposed by Bower (1961). The tests on this equation proved that it over predict the sodium hazard and should be multiplied by a factor of 0.5 to evaluate more correctly the effect of HCO_3 on calcium precipitation (Oster and Rhoades, 1977, Ayers and Westcot, 1985).

To assess the dissolution and precipitation of calcium, Suarez (1981) proposed another equation and designated it as adjusted RNa. It is given as follows:

$$\text{adj. RNa} = \frac{\text{Na}}{\sqrt{(\text{CaX} + \text{Mg})/2}}$$

The values ‘X’ is the calculated value of Ca^{2+} concentration in the soil solutions (me/l) which depends upon the ratio of HCO_3^-/Ca^{2+} ions and the ionic strength. The table values of ‘X’ represent the Ca in applied water modified due to salinity, HCO_3/Ca ratio (concentration in me/l) at the estimated PCO_2 of 7x 10^4 MPa in surface few millimeters of soil. The value of ‘X’ thus represents the modified CaX values. Ayers and Westcot (1985) used the modified CaX values to adjust calcium concentration vis-a-vis the SAR of waters and used the term adj.RNa.

Besides, all the equations for predicting SAR or ESP are based on the assumption of attainment of steady state conditions. For the transient field conditions, prediction of alkalization rates from the SAR_{dw} below root zone is difficult because of deterioration of upper soil layers to effect infiltration of water. Also alternating of irrigation (rabi) and rainy season (kharif) induces a cycle of precipitation and dissolution of salts to hinder the attainment of steady state conditions. In a series of field microplot experiments ESP profiles as predicted for steady state conditions could not be obtained even after the use of alkali waters for 9 years. Thus, for transient field conditions, alkalization process continues mainly in surface layers preventing achievement of steady state conditions. It may also be pointed out that adj. SAR concept as proposed by Suarez (1981) only takes into account the HCO_3^- ions where as many alkali waters do contain some amounts of CO_3^{2-} ions. Alkali waters, when they have CO_3^{2-} ions are more hazardous to soils than the HCO_3^- type waters.

3.3 Categorization of Underground Brackish Water

Water quality refers to the characteristics of a water supply that will influence its suitability for a specific use. There have been a number of different water quality guidelines related to irrigated agriculture. Each has been useful but none has been entirely satisfactory because of the wide variability in field conditions. Hopefully, each new set of guidelines has improved our predictive capability. For assessing the quality of irrigation water, main parameters determined are; salt content (EC, dS/m), sodium adsorption ration (SAR, me/l or mmol/l) and residual sodium carbonate (RSC, me/1). Several classifications of groundwater have been suggested, but the most acceptable and widely used classification is that given by AICRP on Use of Saline Water (Table 3.1). Based on extensive research and experience of farmers in different agro-ecological regions of India, irrigation

Table 3.1: Grouping of poor quality groundwater for irrigation in India

Quality parameters			Water quality class	
EC	RSC	SAR	Main	Subclass
< 2	< 2.5	< 10	Good	
2-4	< 2.5	< 10	Saline	Marginally saline
> 4	< 2.5	< 10		Saline
> 4	< 2.5	> 10		High SAR saline
< 2	2.5-4.0	< 10	Alkali	Marginally alkali
< 2	> 4.0	< 10		Alkali
Variable	> 4.0	> 10		High alkali

Gupta *et al.*(1994)

resources were grouped into good, saline and alkali waters (Gupta *et al.*, 1994). Depending upon the degree of restrictions, the two poor quality water classes were further sub-divided each into three subgroups. Since each subgroup needs specific treatment and practices, this classification also serves the purpose of planning their development and management at micro-niche level. However, different states are following different classification of salinity of groundwater for irrigation purposes e.g. the upper limit of salinity for irrigation water in Haryana, Punjab, Delhi, Rajasthan (Western, Eastern), Gujarat and Uttar Pradesh are 6, 4, 3, 8, 6, 3.46, 2.25 dS/m, respectively.

4. TOLERANCE OF VEGETABLES TO SALINITY AND ALKALINITY

4.1 Impact of Salt Stress on Vegetables

Excessive soil salinity reduces productivity of many agricultural crops, including most vegetables which are particularly sensitive throughout the ontogeny of the plant. Plant sensitivity to salt stress is reflected in loss of turgor, growth reduction, wilting, leaf curling and epinasty, leaf abscission, decreased photosynthesis, respiratory changes, loss of cellular integrity, tissue necrosis, and potentially death of the plant (Jones, 1986; Cheeseman, 1988). Salinity disrupts homeostasis in water potential and ionic distribution which influence various physiological and biochemical processes. The alterations in all these processes ultimately cause reduction in plant growth and productivity. Salinity also affects agriculture in coastal regions which are impacted by low-quality and high-saline irrigation water due to contamination of the groundwater and intrusion of saline water due to natural or man-made events. Salinity fluctuates with season, being generally high in the dry season and low during rainy season when freshwater flushing is prevalent. As such crop performance under soil salinity has been tested globally with a number of relative tolerance tables appearing in the literature (Annexure). Three such Tables are reproduced in the Annexure to provide a comprehensive assessment and to provide information on relative tolerance of vegetable crops for which data under Indian conditions is unavailable. It may be mentioned that not much data on alkali tolerance of vegetable crops is available in the literature and probably such studies reported in the bulletin would be a good source of this information.

4.1.1 Salinity tolerance of crops

Intra and inter-generic differences in salt tolerance have been have been known and extensively reported for arable and field crops; vegetable crops are no exception to the rule. Mangal *et al.* (1989) and Mangal *et al.* (1990a) studied the performance of a number of vegetable crops at different soil salinity levels (EC_e). The data showed that whereas beans are sensitive to salinity as their yield is reduced to 50% even at low EC_e of 3 dS/m, but spinach, celery and cabbage are relatively tolerant, as 50% reduction in yield takes place at a high EC_e of 10 dS/m (Table 4.1).

4.1.2 Varietal tolerance to salinity

As said before the varieties within a crop could also differ in their tolerance to salts. Some of better performing varieties under saline conditions have been listed in the Table 4.2 (Mangal *et al.*, 1990a).

Besides the intra and inter-generic differences in salt tolerance of crops, crops also differ in their tolerance to salts from one growth stage to another. While most crops are known to be sensitive to salts at germination and early growth stage, exceptions occur and few crops are sensitive to salts at flowering or at phase change stages. In order to assess the crop tolerance of vegetable crops,

Table 4.1: Per cent reduction in yield of different vegetable crops at different soil salinity levels

Sr.No.	Vegetable	Reduction at a given EC_e (dS/m)			
		None	25%	50%	100 %
1	Beans	1	2	3	5
2	Broad bean	2	4	7	12
3	Broccoli	3	6	9	12
4	Carrot	1	3	6	8
5	Carrot seed	1	4	7	13
6	Cauliflower seed	0.3	3	6	12
7	Cabbage	2	6	10	16
8	Celery	2	6	10	16
9	Chilli	1	4	6	11
10	Cucumber	3	5	7	12
11	Fennel	3	6	9	12
12	Garlic	2	3	7	10
13	Lettuce	1	3	5	9
14	Muskmelon	1	4	6	11
15	Onion	1	3	5	8
16	Onion seed	1	5	9	17
17	Okra	2	4	6	--
18	Palak	2	5	8	15
19	Pepper	2	3	7	10
20	Potato	2	4	7	11
21	Radish Seed	2	5	8	14
22	Spinach	2	5	10	16
23	Sweet potato	2	4	6	10
24	Sweet corn	2	4	6	10
25	Squash	3	5	6	--

Mangal (1993)

several experiments were conducted to evaluate their tolerance at various growth stages (Table 4.3). It was observed that crop like lettuce, (Exotic selection), tomato HS-101, fennel, methi, and brinjal showed less than 50% seed germination even at EC_e 4.0 dS/m, whereas similar degree of reduction was noticed in case of bitter gourd, muskmelon (Hara Madhu) and cauliflower at EC_e 5.0 dS/m. Since a good crop stand is necessary for higher yields, the crop sensitivity at germination/ initial growth stage must be kept in view while selecting a crop and to ensure optimum root environment for the selected crop.

On the basis of these and similar studies, Mangal *et al.* (1990a) classified vegetable crops into sensitive, semi-tolerant and tolerant categories (Table 4.4). The data on crop tolerance given in the table could be used to assess the crops that could be grown with saline waters considering climate and soil conditions. Vegetable crops which are semi-tolerant to tolerant, as well as those with low water requirement should be preferred with saline water.

4.2 Effect of Saline Water on Vegetables

4.2.1 Tolerance of vegetables to saline water

Saline water *per se* does not adversely affect the crop unless the salt accumulate in the soil to an extent that they affect the plant growth. Plant growth is affected adversely with saline irrigation primarily through the impacts of excessive salts on osmotic pressure of the soil solution, though excessive concentration and absorption of individual ions e.g. Na, Cl, B etc. may also prove toxic to plants and/or retard the absorption of other essential plant nutrients. The reduced water availability at high salinity thus causes water deficits for plants and the plant growth gets inhibited when soil solution concentration reaches a critical value often referred to as threshold salinity. Under the field situations, the first reaction of plants to the use of saline waters is reduction in the germination but the most conspicuous effect is the growth retardation of crops. It is now evident from long-term experiments on saline water use that an interplay of factors like climate, nature and content of soluble salts present in water, soil type, water table conditions, nature of crops grown and the water management practices, govern the salinity dynamics vis-a-vis crop performance. Apparently when soils are irrigated with saline water, the salinity build-up in the soil should be restricted to a level as determined by the salinity threshold level of a given crop. Since the salt accumulation in the soil depends on soil texture, being nearly one half that of irrigation water in coarse textured soils (loamy sand and sand) as a thumb rule. It is equal to that of irrigation water in medium textured sandy loam to loam soils and more than two times in fine textured soils (clay and clay loam). Thus, waters of as high salt concentration as an EC of 12 dS/

Table 4.2: Comparatively salinity tolerant varieties/lines

Sr. No.	Name of the crop	Variety/line
1.	Brinjal	Black beauty, R-34
2.	Cabbage	Golden arc
3.	Chilli	C-4, Musalwadi
4.	Garlic	HG-6
5.	Kharif onion	Basant
6.	Musk melon	Pula madhuras
7.	Onion	Hisar-2, Punjab selection, Udaipur-l02, Bombay Red, Pusa Ratnar
8.	Okra	Pula Sawani
9.	Peas	P-23, New line perfection, Market prize.
10.	Potato	JE-808, Kufri Chamatkar, CP-2059, JE-303, K-Sindburi
11.	Tomato	Hybrid 14, NT-3, Marglobe, Kalyanpur, T-l, Sabour Suphala, At-69, Hisar Arun

Table 4.3: Relative performance (%) of vegetables at different ECe levels in relation to different growth parameter

Crop (Variety)	Parameter	EC_e (dS/m)				
		2	4	6	8	10
Bitter gourd (HK-8)[1]	Germination	76	60	23	20	0
Bottle gourd (PSP)[1] long)	-do-	80	75	60	43	-
Brinjal (PH-4)[2]	Seed yield	85	35	22	-	-
Cauliflower (Hisar-l)[3]	-do-	81	80	44	35	35
Cabbage (Golden Arc)[4]	Yield	100	90	77	65	46
Carrot (Pusa Kesar)[2]	Seed yield	95	88	88	77	71
	1000-seed weight	96	91	57	47	46
Chillies (NP 46-A)[5]	No. of fruits/ plant	80	74	55	-	-
	Yield/ plant	86	81	61	0	-
Coriander (Narnaul	Germination	67	38	I5	0	0
Selection)[6]	Yield	76	39	31	-	-
Fennel (Selection)[6]	Germination	50	40	20	-	16
	Yield	76	50	30	20	10
Garlic (HG-6)[7]	Yield/plant	90	85	75	50	-
Kasturi Methi[7]	Seed yield	92	30	0	0	0
Kharif onion (N-53)[8]	Plant stand	94	75	58	30	11
	Bulb yield/ plant	84	68	50	24	16
Lettuce[3]	Seed yield	81	80	44	35	-
Muskmelon (Durgapure	Germination	100	100	-	43	17
Madhu)[9]	Yield/plant	-	-	55	50	-
Muskmelon (Hara Madhu)[9]	Germination	60	50	13	-	-
Methi Desi[10]	Seed yield	66	48	37	0	0
Okra (Pusa Sawani)[11]	No. of fruits/plant	72	63	56	54	-
	Yield/plant	100	65	47	27	-
Garlic (HG-6)[2]	Germination	90	85	75	50	-
Palak (S-23)[10]	Seed yield	89	80	68	39	18
Round ground (Hisar selection)[1]	Germination	80	66	40	16	13
Spong ground[1]	-do-	83	78	68	30	12
Tomato (HS-I01)[12]	Germination	70	40	-	-	-
	Yield	75	50	10	-	-
Water melon[9]	Germination	76	63	23	16	3

[1]Mangal and Singh (1985); [2]Mangal *et al.* (1990b); [3]Mangal *et al.* (1992); [4]Mangal *et al.* (1989); [5]Lal *et al.* (1990); [6]Mangal *et al.* (1986); [7]Mangal *et al.* (1988a); [8]Mangal *et al.* (1988b); [9]Mangal *et al.* (1988c); [10]Mangal *et al.* (1987); [11]Mangal (1971); [12]Lal *et al.* (1986);

Table 4.4: Vegetable crops tolerant to salinity (EC_e dS/m)

Sensitive crops (Up to 4)	Semi-tolerant (4-6)	Tolerant crops (6-8)
Bean, methi, raddish, celery, peas, brinjal,	Sweet potato, tomato, garlic, egg-plant, carrot, onion, cauliflower, muskmelon, chilli, water melon, cucumber, pumpkin, okra, potato, bottle gourd, lettuce, bell pepper, artichoke	Fennel, palak, spinach, turnip, carrot, bitter gourd, onion (seed crops), cabbage, beet root, asparagus

Table 4.5: Crop and soil interactions using saline water

	Crop tolerance to salinity (dS/m)		
Soil texture	Sensitive*	Moderately tolerant#	Tolerant@
Loamy sand	1.6	4.0	6.0
Loam	1.0	3.0	4.5
Loamy clay	0.8	2.0	3.0
Clay	0.4	1.0	1.6

*Sensitive: e.g. lettuce; #Moderately tolerant: e.g. broccoli; @Tolerant: non-vegetable crops
Shainberg and Shalhevet (1984)

m can be used for growing tolerant and semi-tolerant crops in coarse textured soils, provided the annual rainfall is not less than 400 mm. But in fine textured soils, waters with EC more than 2 dS/m would often create salinity problems. Shainberg and Shalhevet (1984) also highlighted this interaction, which is illustrated in Table 4.5 showing that more saline water could be used to grow the same crop on coarse than a fine textured soil.

Minhas and Gupta (1992) compiled the data available from various centers of AICRP on Management of Salt Affected Soils and Use of Saline Water and indicated that vegetable crops are generally more sensitive to salts than arable, fodder, pulse and oil seed crops. The effect of soil texture as well as differences in crop tolerance to salts is quite evident (Table 4.6).

Such experiments to assess the tolerance continue on various centers. At Agra the significant yield reduction was noted at EC_{iw} 4, 4 and 8 dS/m in cluster bean, fennel and methi (Table 4.7). Clearly methi emerges more tolerant than the cluster bean and fennel crops. Irrigation of luffa (Tori) with 3 EC dS/m water did not affect its yield, whereas it decreased bottle gourd yield by 33%. However, bottle gourd yielded only 29%, whereas luffa 41%, when irrigated with EC 6.0 dS/m water (Biennial Report, 2004-06).

4.2.2 Varietal response to saline water

The tolerance of twelve tomato hybrids tested under saline water revealed that the yield reduced significantly with increase in salinity of the irrigation water (Annual Report Hisar, 2003-04).

Table 4.6: Salinity limits of irrigation waters for vegetable crops

Crop/ Location	Soil type	No. of years	Previous crop	EC_{iw} (dS/m) for relative yield		
				90 %	75 %	50 %
Onion						
Agra	sl	5	Pigeon pea	1.8	2.3	3.3
Bapatla	s	5	Variable	5.1	6.0	7.5
Potato						
Agra	sl	5	Okra	2.1	4.3	7.8
Tomato						
Bapatla	s	3	Variable	2.4	4.1	6.9
Okra						
Agra	sl	5	Potato	2.7	5.6	10.5
Bapatla	s	2	Variable	2.1	3.9	6.7
Brinjal						
Bapatla	s	2	Variable	2.3	4.1	7.1
Fenugreek						
Jobner	ls	3	Pearl millet	3.1	4.8	7.6
Chillies						
Bapatla	s	2	Variable	1.8	2.9	4.9
Jobner	ls	2	"	4.5	7.5	12.5
Coriander						
Bapatla	s	3	"	2.9	5.8	10.7
Jobner	sl	2	"	9.8	15.4	
Bitter gourd						
Bapatla	s	3	"	2.0	3.4	5.8
Bottle gourd						
Bapatla	s	3	"	3.2	4.5	6.8

Annual rainfall at Agra, Bapatla, Dharwad and Jobner is 660, 803, 778, 750 and 500 mm, respectively

All hybrids except RTH-1 performed poorly as compared to the check (Hisar Arun). The tomato yield reduced by 31.56, 46.47, 59.3 and 65.23 % respectively, at EC_{iw} of 4, 6, 8 and 10 dS/m as compared to canal irrigation (Table 4.8).

Rajpaul *et al.*, (2006) developed regression equations between the yield and electrical conductivity of the irrigation waters for different Okra varieties (Fig. 4.1). Where, Y is the yield/pot and X is the electrical conductivity of the irrigation water. At comparable EC of the irrigation water, the yield was highest in HRB 108 followed by Hisar Unnat. At high EC values, Versa Uphar performed better than Hisar Unnat and HRB 107. It also revealed that with each unit increase in salinity of the irrigation water the yield decreased by 120.06, 108.33, 50.15 and 84.80 g in Hisar Unnat, HRB 108, Versa Uphar and HRB 107 varieties of okra respectively.

4.3 Induction of Salt Tolerance

Studies on the enhancement of salinity tolerance by sowing pre-soaked seeds and seedlings in water/ salt solutions and growth hormones was carried out in different crops/varieties at different growth stages (Table 4.9). The data showed that root dippings of transplants of tomato, onion and cauliflower and seed soaking of okra in 250 ppm solution of cycocel and NaCI for 2-8 hours improved the performance of these crops under saline conditions considerably.

4.4 Breeding for Salt Tolerance

Selection and breeding of salt-resistant crop varieties offer tremendous possibilities of utilizing saline water resources for crop production. Attempts to improve the salt tolerance of crops through conventional breeding programs have very limited success due to the genetic and physiologic complexity of this trait (Flowers, 2004).

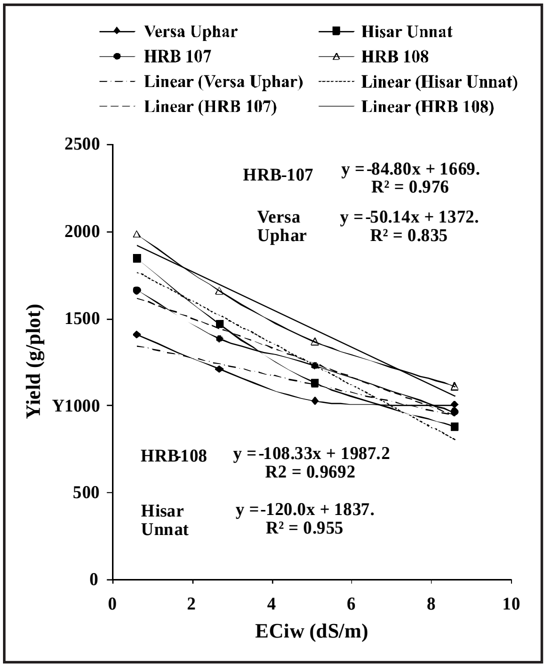


Fig. 4.1 : Yield of different varieties of okra as affected by EC of irrigation water

In addition, tolerance to saline conditions is a developmentally regulated, stage-specific phenomenon; tolerance at one stage of plant development does not always correlate with tolerance at other stages (Foolad, 2004). Success in breeding for salt tolerance requires effective screening methods, existence of genetic variability and ability to transfer the genes to the species of interest. Screening for salt tolerance in the field is not a recommended practice because of the variable levels of salinity in field soils. Screening should be done in soil-less culture with nutrient solutions of known salt concentrations (Cuartero and Fernandez-Munoz, 1999). Most commercial tomato cultivars are moderately sensitive to increased salinity and only limited variation exists in cultivated species.

Genetic variation for salt tolerance during seed germination in tomato has been identified within

Table 4.7: Effect of saline water on yield (q/ha) of cluster bean, fennel and methi

EC_{iw} (dS/m)	Cluster bean	Fennel	Methi
BAW	24	11	21
2	24	10	21
4	22	9	20
6	20	7	20
8	19	6	18
CD at 5%	2.0	1	2

Table 4.8: Effect of salinity levels of irrigation water on fruit yield (g/plant) of tomato hybrids

Hybrids	EC_{iw} (dS/m)					
	Control	4	6	8	10	Mean
RTH-1	550.0	350.0	280.0	248.0	200.0	325.6
ARTH-3	350.0	162.0	152.0	152.0	100.0	183.2
TH-317	277.7	100.0	100.0	69.3	51.33	119.7
Ruchi	152.0	100.0	59.0	43.0	37.0	78.2
Karishma	279.0	153.3	155.7	100.0	100.0	157.6
JKTH-3055	241.7	250.0	200.0	117.3	100.0	181.8
Akash	210.0	150.0	120.0	76.0	72.0	125.6
ZTH-3037	64.3	38.0	30.0	20.0	18.7	34.2
SUN-5003	75.0	49.0	49.3	36.0	32.7	48.4
JKTH-3064	56.7	58.0	46.0	22.0	18.0	40.1
Annapurna	200.0	137.7	112.0	82.0	82.0	122.7
Hisar Arun	610.0	550.0	330.0	282.0	250.0	404.4
Mean	255.5	174.8	136.2	104.0	88.5	

CD (5%)EC = 4.7; Hybrids = 7.3; EC x Hybrids = 16.3

cultivated and wild species. A cross between a salt-sensitive tomato line (UCT5) and a salt-tolerant *S. esculentum* accession (PI174263) showed that the ability of tomato seed to germinate rapidly under salt stress is genetically controlled with narrow-sense heritability (h2) of 0.75 (Foolad and Jones, 1991). Several studies indicate that salt tolerance during seed germination in tomato is controlled by genes with additive effects and could be improved by directional phenotypic selection (Foolad, 2004). In pepper, salt stress significantly decreases germination, shoot height, root length, fresh and dry weight, and yield. Yildirim and Guvenc (2006) reported that pepper genotypes Demre, Ilica 250, 11-B-14, Bagci Carliston, Mini Aci Sivri, Yalova Carliston, and Yaglik 28 can be useful as sources of genes to develop pepper cultivars with improved germination under salt stress.

Related wild tomato species have shown strong salinity tolerance and are sources of genes as coastal areas are common habitat of some wild species. Studies have identified potential sources of resistance in the wild tomato species *S. cheesmanii*, *S. peruvianum*, *S pennelii*, *S. pimpinellifolium*, and *S. habrochaites* (Flowers, 2004; Foolad, 2004; Cuartero *et al.*, 2006). Attempts to transfer quantitative trait loci (QTLs) and elucidate the genetics of salt tolerance have been conducted using populations involving wild species. Elucidation of mechanism of salt tolerance at different growth periods and the introgression of salinity tolerance genes into vegetables would accelerate development of varieties that are able to withstand high or variable levels of salinity compatible with different production environments.

4.4.1 Genes for salt tolerance

Genetic enhancement using molecular technologies has revolutionized plant breeding. Advances in

Table 4.9: Induction of salt tolerance in vegetable crops

Crop variety	Effect on	Treatment	Hours of treatments	Relative performance at different EC_e levels (dS/m)				
				1	4	6	8	10
Okra (Pusa Sawani)[1]	i) Germination	Seed soaking in						
		i) Water	6.0	100	88	65	23	13
		ii) Cycocel	6.0	111	104	74	30	15
	ii) Fruit Yield	i) Water	-do-	100	84	58	40	17
		ii) Cycocel (250 ppm)	-do-	163	136	94	47	19
Potato (Kufri Badshah)[2]	i) Days taken for sprouting	Tuber soaking in						
		i) Water	2.0	10	13	15	18	-
		ii) NaCI (EC 6 dS/m)	2.0	11	13	13	14	-
		iii) Cycocel (250 ppm)	2.0	9	12	11	14	-
	ii) Yield/ plant	i) Water	-do-	100	66	11	25	-
		ii) NaCI (8 dS/m)	-do-	64	76	52	33	-
		iii) Cycocel (250 ppm)	-do-	93	85	63	39	-
Tomato (Hisar Arun)[1]	Fruit yield	Root dipping of tranplants in						
		i) Water	2	100	96	4	-	-
		ii) NaCI (8.0 dS/m)	2	93	96	8	65	-
Onion (Hisar-2)[3]	Bulb yield	Root dipping of transplants in						
		i) Water	8.0	100	85	7	60	-
		ii) Cycocel (1%)	8.0	110	85	85	73	-
Cauliflower (Early Kunwari)[4]	Curd yield	Root dipping of transplants in						
		i) Water	2.0	100	80	70	-	-
		ii) Cycocel (250ppm)	2.0	120	112	90	-	-

1Mangal *et al.* (1988a); 2Yadav *et al.* (2001); 3 Malik (1973); 4Singh and Mangal (1985) genetics and genomics have greatly improved our understanding of structural and functional aspects of plant genomes. Combining new knowledge from genomic research with traditional breeding methods enhances our ability to improve crop plants. The use of molecular markers as a selection tool provides the potential for increasing the efficiency of breeding programs by reducing environmental variability, facilitating earlier selection, and reducing subsequent population sizes for field testing. Molecular markers facilitate efficient introgression of superior alleles from wild species into the breeding programs and enable the pyramiding of genes controlling quantitative traits. Thus, enhancing and accelerating the development of stress tolerant and higher yielding cultivars for farmers in developing countries.

Molecular marker analysis of stress tolerance in vegetables is limited but efforts are underway to identify QTLs underlying tolerance to stresses. Martin *et al.* (1989) identified three tomato QTLs linked to water use efficiency in *S. pennellii* based on 13C composition. Three independent yield-promoting regions were identified in *S. pennellii* when grown in both wet and dry field conditions in Israel (Gur and Zamir, 2004), while Foolad *et al.* (2003) identified four QTLs associated with seed germination drought tolerance, two of which were contributed by *S. pimpinellifolium*. *S. pimpinellifolium* is also commonly investigated as source of salt tolerance. QTL mapping indicates that salt tolerance is quantitatively inherited (Foolad, 2004). Only a few major QTLs account for the majority of phenotypic variation indicating the potential for marker-assisted selection (MAS) for salt tolerance. Studies indicate that stress tolerance is quantitatively inherited and in some cases tolerance is dependent on the developmental stage of the plant. Consequently, multiple genes are predicted to be involved with the expression of stress tolerance. Studies on QTL analysis of stress tolerance is limited, and may reflect the limited variation of these traits. Furthermore, the environmental influence on the expression of stress tolerance traits is high and makes phenotyping difficult. Identification of environmentally-stable surrogate phenotypes or component traits is necessary to effectively evaluate genotypes and genetic populations. Many genes associated with stress tolerance have recently been determined using high throughput expression assays. Integration of QTL analysis with gene discovery and modeling of genetic networks will facilitate a comprehensive understanding of stress tolerance, permit the development of useful and effective markers for marker-assisted selection, and identify candidate genes for genetic engineering.

4.4.2 Engineering stress tolerance

Environmental stress tolerance is a complex trait and involves many genes (Wang *et al.* 2003). In response to stresses, both RNA and protein expression profiles change. Cell wall invertase (*INV*) and sucrose synthase (*SUSY*) play key roles in carbohydrate partitioning in plants (Déjardin *et al.*, 1999) and this regulation of carbohydrate metabolism in leaves may represent part of the general cellular response to acclimation and contribute to osmotic adjustment under stress. The *ERECTA* gene regulates plant transpiration efficiency in *Arabidopsis thaliana* (Masle *et al.*, 2005), and the *NHX* and *AVP1* genes are associated with ion transport (Zhang and Blumwald, 2001). There are many more genes implicated with stress response and the current challenge is to identify the ones that confer a tolerant phenotype in the crop of interest. Although the function of these genes has been elucidated, particularly in *A. thaliana*, only a few genes have contributed to a tolerant phenotype when over-expressed in vegetables (Zhang *et al.*, 2004). Expression of *AVP1*, a vacuolar H+ pyrophosphatase from *A. thaliana*, in tomato resulted in enhanced performance under soil water deficit (Park *et al.*, 2005). The engineered tomato has a stronger, larger root system that allows the roots to make better use of limited water. The control plants suffered irreversible damage after five days without water as opposed to transgenic tomatoes which began to show water-stress damage only after 13 days but recovered completely as soon as water was supplied. The *CBF/DREB1* genes have been used successfully to engineer drought tolerance in tomato and other crops (Hsieh *et al.*, 2002). Orthologous genes of *CBF* have been found in most crop plants and functional tests indicate conservation of the pathway in these plant species. Constitutive over-expression of *CBF* genes results in salt, cold, or drought tolerance in several plant species. However, in addition to increased stress tolerance, the transgenic plants were dark-green and were stunted, with higher levels of soluble sugars and proline (Liu *et al.*, 1998). The use of stress-inducible promoters that have a low background expression of *CBF* under normal growth conditions can achieve increased stress tolerance without plant growth retardation (Lee *et al.*, 2003). Maintaining a low cytosolic Na^+ concentration is essential to achieve salt tolerance and can be achieved by restricting inflow, increasing outflow, or increasing vacuole sequestration of Na^+ (Zhang *et al.*, 2004). Increased expression of the *A. thaliana* tonoplast membrane Na^+/H^+ antiporter, *AtNHX1*, under a strong constitutive promoter, was reported to result in salt-tolerant tomatoes (Zhang and Blumwald, 2001). The transgenic tomato plants grown in the presence of 200 mM NaCl were able to flower and set fruit. While the leaves accumulated high concentrations of sodium, the tomato fruits continued to contain only low concentrations of sodium. The *NHX1* system seems to be highly conserved between many different plant species and manipulation of this system in crop species is likely to result in improved salt tolerance. Research on the physiology of stress tolerance has demonstrated that tolerance to a specific stress is determined by several component traits and controlled by corresponding genes. A combination of a genome-wide scan of expression, using DNA arrays, and QTL analysis could provide important information in identifying the major genes association with stress tolerance.

4.5 Effect of Alkalinity on Vegetables

4.5.1 Alkalinity tolerance of crops

Most of the research endeavors, till now, have been aimed at identifying the genotypes and breeding new varieties of crops for normal or saline conditions, limited efforts have been made in this respect for alkali environment. Like salinity, there exists a wide genetic variation in crops and their varieties in relation to their tolerance to alkalinity. Crop yields are generally not significantly reduced until the salt concentration in the soil solution and ESP exceed the specific values for each crop. The salt and Na tolerance of winter crops is generally higher than those grown during the hot season. It is therefore suggested that in low rainfall areas (<400 mm) vegetable crops may be grown during winter season (low ET), keeping the land under arable crop during summer. The efficient strategy should aim at selecting a crop with low water requirement for rabi and a crop that can thrive on rain water for kharif.

Compilation of results of various studies revealed that Brinjal, spinach and sugar beet are the most alkalinity tolerant crops while others are semi-tolerant or sensitive (Table 4.10). These data sets could be used to identify crops and crop cultivars when alkali water is used to grow vegetable crops.

4.5.2 Varietal response to alkalinity

Table 4.10: Tolerance of vegetables to alkalinity

Sensitive Crops (ESP<20)	Semi-tolerant (ESP 20-40)	Tolerant Crops (ESP > 40)
Pea, cowpea, cluster bean, ginger, turmeric	Tomato, garlic, okra, radish, carrot, cauliflower, chilli, onion, potatoes, ash gourd, coriander, fenugreek, fennel	Brinjal, spinach, sugar beet

The cauliflower, cabbage, onion and garlic crops tested under alkalinity revealed that a reduction of 75, 70, 19 and 31% at an ESP of 39.0 as compared to ESP of 11.5 showing their tolerance in the order of onion > garlic > cabbage > cauliflower (Annual Report, Kanpur, 1999-2000). Besides crops, tolerance to alkalinity also differs in crop varieties also. Usually there is a negative correlation between tolerance of varieties and their potential yields. Hence there are not many varieties which are both tolerant to alkalinity and produce economic yield that is major concern for most farmers.

Some of better performing varieties under alkali conditions for select crops have been listed in the Table 4.11.

Table 4.11: Crop varieties tolerant to alkalinity

Crops	Varieties
Tomato	Angurlata, Azad T2
Methi	Pusa early bunching
Spinach	K Hari Chikari
Chillies	Jwala, Chaman
Garlic	Gattar gola, Hansa

Six varieties of tomato were tested under different levels of alkalinity (ESP 11.5, 16.5, 19.3, 27.0, 36.5, 46.7 and 51.1) and found that variety angurlata produced the highest yield at all ESP levels followed by Azad T2, KS-118 and Azanta (Annual Report, Kanpur, 1995-99; Fig. 4.2). Angurlata also showed the minimum Na/ K ratio at all the ESP levels as compared to other varieties/hybrids of tomato. Amongst the five varieties of chillies (KDCS-81, Chanchal, Chaman, Jwala and G-4) Jwala followed by Chaman recorded higher mean yield of green chillies (Table 4.12). Reduction of green chillies was the minimum in variety Jwala i.e. 45, 25 and 11 percent at ESP 37.0, 28.2 and 20.5 in 1998-99 and 41, 20 and 11 percent at ESP 35.5, 27.3 and 19.0 in 1999-2000 respectively.

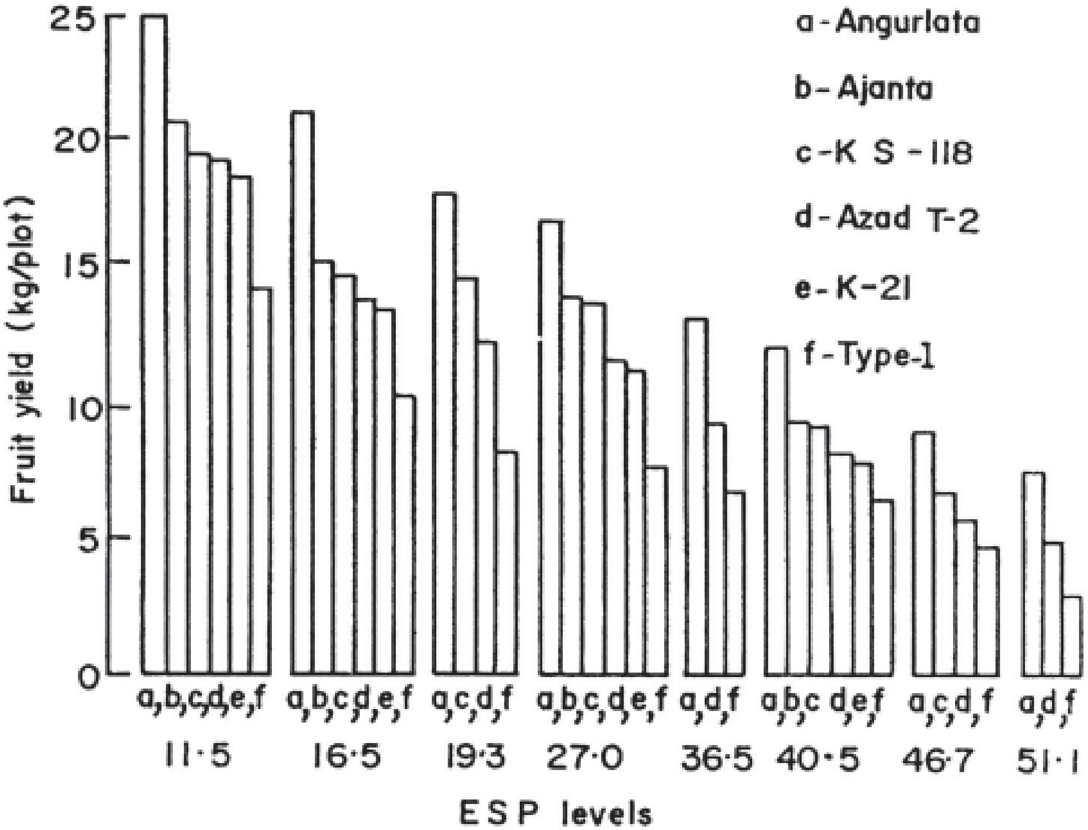


Fig. 4.2: Fruit yield of tomato cultivars at different ESP levels

Table 4.12: Effect of varying levels of alkalinity on fruit yield (q/ha) of green chillies

Varieties	ESP levels									
	1998-99					1999-2000				
	37.0	28.2	20.5	13.2	Mean	35.5	27.3	19.0	13.0	Mean
KDCS-81	27.2	38.2	50.0	65.7	44.7	28.3	41.7	57.7	73.6	50.3
Chanchal	20.7	25.7	32.5	47.9	31.7	22.2	30.3	36.8	53.5	35.7
Jwa1a	43.3	58.5	69.9	78.2	62.5	50.0	67.8	75.0	84.0	69.2
G-4	27.1	37.4	48.3	63.2	44.6	29.2	40.3	52.8	69.5	47.9
Chaman	37.0	50.3	60.9	69.9	54.5	41.0	56.3	68.8	77.8	61.0
CD(p=0.05)										
Variety	6.4	ESP	5.8	Var. x ESP	13.2	Variety	4.3	Var. x ESP	3.8	8.5

5. MANAGEMENT OF SALINE WATER

Besides, the crop tolerance studies, studies have also been conducted to assess the performance of various management options to use saline water for crop cultivations. Some of the options are conjunctive use of saline and fresh waters, switchover from surface to drip or other improved irrigation techniques and nutrient management. A brief account of these strategies is given in the following sections.

5.1 Conjunctive Use of Fresh and Saline Waters

There are situations where water is too saline and it cannot be used directly to grow the crops or good quality water available for irrigation is inadequate to meet the evapotranspiration requirement of the crops. Under these conditions, the strategies to obtain maximum crop production are to conjunctively use the saline and fresh water. In conjunctive mode, either the saline and fresh water could be mixed to obtain irrigation water of medium salinity for use throughout the cropping season. Alternatively, good quality water could be used for irrigation at the more critical stages of growth, e.g. germination and seedling establishment and the saline water at the stages where the crop has relatively more tolerance since most plants are known to tolerate the salinity better with aging (Minhas *et al*., 1989, 1990 a, b). Rhoades *et al.* (1992) have also advocated the seasonal cyclic use, called 'Dual Rotation', strategy where non-saline water is used for salt sensitive crops/initial stages of tolerant crops to leach out the accumulated salts from irrigations with salty waters to previously grown tolerant crops. Such a management strategy may work better for arid climates with very low rainfall but it is of natural occurrence under the monsoon climate.

Mixing of waters to arrive at acceptable quality for crops also results in improving stream size and thus enhances the uniformity in irrigation especially for the surface method practiced on sandy soils. Thus, the options of utilizing the multi- quality waters have to be either mixing or cyclic use. Recommendation has emerged that multi-salinity waters should be mixed if the resultant salinity of the mixed water could be brought within the threshold salinity of water for a given crop. If that is difficult, the waters should be used cyclically such that canal water is applied at early stages and the use of saline waters is delayed to later stages. Besides, cyclic use has operational advantages over mixing which requires creation of some infrastructure for mixing the two supplies in desired proportions.

Singh *et al.* (1981) studied the long-term effect on the performance of onion, okra, brinjal, chillies and tomato of different EC waters obtained by diluting a tube well water (EC_{iw} = 6.5 dS/m; SAR= 15.6; Cl = 44 me/l) with canal water in 1:1 and 1:2 ratios (canal: tube well). The data showed that onion bulb yield on an average decreased by 18, 38 and 65% when irrigated with EC 4, 5.3 and 6.5 dS/m respectively relative to canal water (Table 5.1). Okra yield was not affected by EC 4.0 but decreased by 25% with EC of 6.5 dS/m. Irrigation of chillies and tomatoes with EC 5.3 dS/m

Table 5.1: Long-term (5 years) effect of different salinity waters on the average yield (q/ha) of some vegetables with and without FYM

Crop	FYM (20 t/ha)	EC_{iw} (dS/m)			
		0.2 Canal	4.0 (SAR-10.7)	5.3 (SAR-13.5)	6.5 (SAR-15.6)
Onion	No	150 (100)	123 (82)	94 (62)	52 (35)
	Yes	183 (100)	142 (78)	125 (68)	78 (43)
Okra	No	11.8 (100)	11.8 (100)	10.9 (92)	8.83 (75)
	Yes	13.3 (100)	12.0 (91)	11.5 (87)	9.58 (72)
Brinjal	No	350 (100)	327 (93)	235 (67)	142 (41)
	Yes	421 (100)	328 (78)	296 (70)	229 (54)
Chillies	No	27.6 (100)	21.8 (79)	17.9 (65)	8.3 (30)
	Yes	42.9 (100)	35.5 (83)	23.7 (55)	9.9 (23)
Tomato	No	125.6 (100)	102.0 (81)	83.2 (66)	59.7 (48)
	Yes	155.0 (100)	134.1 (87)	112.9 (73)	77.9 (50)

Figures given in parentheses are per cent of canal water treatment.

decreased their fruit yields by 20%, whereas EC 6.5 dS/m water decreased their yield by 70 and 52%, respectively. However, brinjal yield was decreased by 33 and 59% when irrigated with 5.3 and 6.5 dS/m EC waters. These results pointed out that the use of EC 4 dS/m water did not affect okra and brinjal yields but decreased onion, chilly and tomato yields by 20%. The synergetic effect of application of FYM was also studied in this experiment and it emerged that the less fruit yield of the crops under irrigation with EC 6.5 dS/m was enhanced by 20-60% (Table 5.1) when FYM was added @ 20 t/ha than without FYM. Since SAR of the waters also differed, the overall effect might not be attributed to salinity alone.

Irrigation of brinjal variety pH-4 with drainage water (EC_{iw} = 2.5-3.5 dS/m; SAR=6-10; Cl = 60-80%) on a saline patch (EC_2 = 0.8-1.2 dS/m) for four years on an average decreased brinjal yield by only 14% relative (Table 5.2) to 47% in okra cv. Pusa Sawani (Manchanda *et al.*, 1991; Table 5.3). While alternate mode of canal and drainage water was found beneficial over mixing mode with okra as the test crop (Table 5.3), mixing mode proved slightly superior in case of brinjal although no firm conclusion can be made (Table 5.2).

Studies at Agra have established that when vegetable crops are taken in rotation with other crops, the most suitable irrigation mode was 2CW: 1SW when ECiw was 6.0 dS/m (Bhu Dayal *et al.*, 2009; Table 5.4).

5.2 Improved Irrigation Methods

In spite of their usefulness, surface irrigation methods; generally result in excessive irrigation and non-uniformity in water application. Consequently on-farm irrigation efficiency is low (60-70%).

Table 5.2 : Brinjal yield (q/ha) al influenced by drainage water alone and its combination with canal water

Treatment	1987-88	1989-90	1990-91	Average
Canal water (CW)	522.2	366.7	393.3	427.4 (100)
Alternate (CW & DW)	360.0	290.0	292.2	314.1 (74)
Mixed (CW+DW)	395.6	331.1	383.3	353.3 (83)
Drainage water (DW)	485.6	285.6	335.6	368.9 (86)*

*Figures given in parentheses are per cent of canal water.

Table 5.3: Okra yield (q/ha) al influenced by drainage water and its combination with canal water

Treatment	1987	1988	1989	1990	Average
Canal water (CW)	114.4	67.8	61.1	61.1	76.1 (100)*
Alternate (CW & DW)	90.0	61.1	35.6	47.8	58.6 (77)
Mixed (CW+DW)	65.6	34.4	23.3	31.1	38.6 (51)
Drainage water (DW)	65.6	43.4	21.2	30.0	40.0 (53)

*Figures given in parentheses are per cent of canal water treatment

Table 5.4: Most suitable conjunctive use of canal and saline water

Crop rotation	Crop	Year	EC_{iw} (dS/m)	Suitable mode	RY to CW
Urd-Potato-Moong	Urd	4	6	2CW:1SW	92
	Potato	4	6	2CW:1SW	97
	Moong	4	6	Crop could not survive	00
Soybean-Cabbage-Jowar (F)	Soybean	1	6	2CW:1SW	88
	Cabbage	2	6	2CW:1SW	88
	Sorghum (F)	1	6	2CW:1SW	94
Cluster bean-Pea-Moong	Cluster bean	2	6	2CW:1SW	87
	Pea	2	6	2CW:1SW	88
	Moong	4	6	Crop could not survive	00

Bhu Dayal *et al.* (2009)

The pressurized irrigation methods such as sprinkler and drip are more efficient as the quantity of water applied can be adequately controlled. These systems have on the other hand, great potential of application in vegetable crops in the arid and semi-arid regions particularly on the light textured soils and the land having undulating topography. Since, a regular and frequent water supply directed into the root zone is possible with drip system of irrigation, it has been observed to enhance the threshold limits of salt tolerance by modifying the pattern of salt distribution and by maintaining high matric potential. A major limitation of this technique is that it requires huge initial investments beyond the reach of small and marginal farmers. Although water saving and high water use efficiencies have been obtained with improved irrigation techniques, beneficial effects to use higher salinity water has not very clearly emerged under Indian conditions as has emerged elsewhere (Mieri and Plaut, 1985) except in the case of pitcher irrigation. It may be seen that threshold salinity is more and slope of the model less when drip is used compared to sprinkler irrigation (Table 5.5).

Table 5.5: Response function of potato with sprinkler and drip irrigation

Factor modified	Crop	Salinity considered	Response function	EC_0 (dS/m)	EC_{50} (dS/m)
Irrigation method	Potato	Sprinkler	RY=100 - 11.7 (EC_e 1.1)	10.1	5.4
		Drip	RY=100 - 6.3 (EC_e 2.6)	17.1	10.5

Mieri and Plaut (1985)

5.2.1 Drip irrigation

A comparative evaluation of drip and surface irrigation methods with brinjal as the test crop was carried (Biennial Report, Agra, 1998-2002). Irrigation interval for drip irrigation was 4 days where as D_{iw} for surface irrigation was 4 cm. The data showed that the yield of brinjal didn't vary significantly in drip and conventional methods in the first year but the yields reduced significantly in the subsequent year. Since the brinjal was grown during rainy season, the irrigation schedules got disturbed with rainfall events occurring at irregular intervals. Thus, the effects of different schedules of irrigation in general remained insignificant. However, IW/CPE ratio 1.0 produced higher yield in both drip and surface irrigations irrespective of salinity (Table 5.6). On the other hand, (Biennial Report, Bapatla, 2000-02) the highest yield of tomato was recorded in case of drip irrigation at 1.2 ET (29.8 t/ha) and the lowest with surface irrigation at 1.0 ET (17.5 t/ha). Higher salt deposition was observed at surface in drip and reverse was true for surface irrigation. The WUE were 11.5, 10.6 and 7.4 q/ha-cm under drip system with BAW, EC_{iw} 4 and 8 (dS/m) while the values for conventional system were 9.8, 8.1 and 5.5 q/ha-cm, respectively.

At Agra centre, the yield of onion, garlic and chillies under drip irrigation were reduced by 25, 36 and 56 percent; 15, 32 and 44 percent; and 38, 64 and 83 percent at EC_{iw} 4, 6 and 8 dS/m, respectively as compared to canal water (CW) thus indicating more sensitivity of chillies to salinity followed by onion and garlic. Salt build-up was also higher in treatments receiving saline irrigations through out the crop growth.

The drip irrigation alone or with plastic mulch gives better yield with irrigation water salinity around

Table 5.6 : Effect of different treatments on fruit yield of Brinjal (q/ha)

Treatments	Drip irrigation		Surface irrigation	
	1999	2000	1999	2000
Salinity levels (dS/m)				
Canal	215.4	204.1	168.4	209.5
4	200.2	191.1	168.0	164.4
8	184.8	184.2	149.7	150.8
CD (p=0.05)	NS	5.3	NS	7.6
Irrigation schedule(IW/CPE)				
0.75	208.3	199.2	167.4	185.5
1.00	215.1	195.1	158.1	175.9
1.25	176.6	185.2	160.6	163.4
CD (p=0.05)	NS	NS	NS	NS

EC 3.0 dS/m in light textured soils as compared to traditional method of cultivation with canal water (Biennial report, Bikaner, 2004-05; Table 5.7). At EC_{iw} above 4.0 dS/m, the crop yields start declining and at 6.0 EC_{iw} the yields are less around 10 % for bottle gourd and 36 % for tomato than the yields obtained under conventional method with canal water. Clearly yield with drip irrigation was higher with water salinity of 3.0 dS/m suggesting the use of high saline water for cultivation bottle gourd and tomato with drip irrigation. Similar results were obtained at Agra (Biennial Report, Agra, 2006-08) such that maximum yield of okra was obtained with a saline water of 3 dS/m with drip while with flood irrigation, it was obtained with BAW although it was not significantly different than the yield obtained with saline water of 3 dS/m (Table 5.8). In onion, maximum yield was recorded under drip irrigation with water having EC 3.0 dS/m with a significant decrease in yield at EC 6.0 dS/m. Drip method was superior with 24.1% higher yield compared to flood irrigation method.

Potato crop under drip irrigation

Table 5.7: Effect of water salinity on yield of bottle gourd and tomato under drip irrigation

ECiw (dS/m)	Bottle gourd*	Tomato#
0.25	204	428
0.25 +M	-	434
3.0	242	472
3.0+M	-	503
6.0	159	266
6.0+M	-	273
Flood	180	416
CD 5%	37	42

*mean of 3 years, #mean yield of two years

An experiment conducted at Hisar (Biennial report, Hisar, 1998-2002) to work out the irrigation scheduling for the cauliflower irrigated with saline irrigation under drip system revealed that the curd yield of cauliflower decreased significantly at EC 8 and 12 dS/m and the percent reduction in curd yield was 34.6 and 79.6 %, respectively, compared to non-saline treatment (Table 5.9). The data revealed that saline water of 4 dS/m could be used to irrigate the crop. But for tomato saline water of 4 dS/ m resulted in signicficant reduction in crop yield (Table 5.10). The non-significant yield differences between IW/CPE ratios of 0.66 and 1.0 showed that 33% water can be saved through drip method. The salt build-up was maximum in upper soil layers, which later decreased gradually up to 120 cm soil depth.

Table 5.8: Effect of irrigation water salinity on yield of okra and onion

Treatments	Okra				Onion
	2006	2007	2008	Mean	2008
		Drip irrigation			
BAW	3.36	4.92	4.15	4.14	13.2
3.0 dS/m	3.78	6.18	4.44	4.80	14.9
6.0 dS/m	2.45	3.79	2.69	2.97	11.1
		Flood irrigation			
BAW	1.7	4.26	3.08	3.01	11.6
3.0 dS/m	1.88	4	2.72	2.87	12.6
6.0 dS/m	1.49	3.02	1.81	2.11	7.4
S Em	0.17	0.27	0.28	-	0.9
CD (5%)	0.55	0.85	0.89	-	2.7

Table 5.9: Effect of quality of irrigation water and irrigation schedules on cauliflower crop under drip irrigation

Treatments	No. of leaves/plant	Weight of leaves/plant	Root length (cm)	Curd weight (q/ha)
Quality of irrigation water (dS/m)				
Non-saline	21.51	491.19	29.78	132.27
4	22.3	509.44	30.31	135.22
8	19.7	341.16	24.32	86.48
12	14.18	124.57	15.58	26.93
CD (5%)	1.15	9.12	1.03	6.64
Irrigation schedules (IW/CPE)				
0.33	18.16	311.75	26.66	81.45
0.66	19.97	387.62	24.5	100.98
1.0	20.14	400.39	23.84	103.24
CD (5%)	0.99	7.90	0.89	5.75

5.2.2 Sprinkler irrigation

A field experiment was conducted to evaluate tolerance of five crops viz. onion, spinach, watermelon, cucumber and cluster bean during 2001 and 2002 under sprinkler irrigation. Each crop was grown in three strips each of 36 m length. The production functions of different crops (Table 5.11) revealed that the threshold salinity of onion, spinach, watermelon, cucumber and clusterbean is 1.10, 2.18, 0.52, 1.67 and 1.06 dS/m respectively (Biennial report, Bapatla, 2000-02).

Table 5.10: Effect of quality of irrigation water and irrigation schedules on tomato crop under drip irrigation

Treatments	Plant height (cm)	Fruit Weight (g/fruit)	Fruit diameter (cm)	Tomato yield (g/fruit)
Quality of irrigation water (dS/m)				
Non-saline	45.32	21.25	4.25	207.11
4	42.18	20.02	3.98	184.67
8	35.18	17.54	3.26	124.89
CD (5%)	2.13	1.02	0.18	5.14
Irrigation schedules (IW/CPE)				
0.33	36.5	18.34	3.68	159.78
0.66	42.39	20.18	3.88	176.11
1.0	44.3	20.3	3.93	180.78
CD (5%)	2.13	1.02	0.18	5.14

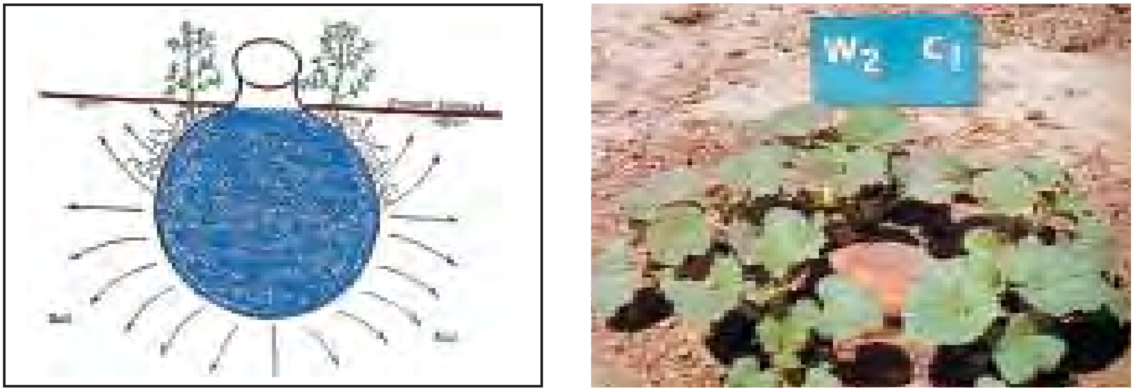
In a sprinkler experiment at Baptla, the percent yield reduction was 16, 50, 42 and 42 in respect to radish, cucumber, carrot and cabbage as the salinity of irrigation water increased from 1.06 to 5.36 dS/m. Utilizing the data of soil salinity of (0-60 cm) and ridge gourd yield, threshold soil salinity was estimated using SEGREG as 5.5 dS/m (R^2 = 0.46). In spite of some variations in soil salinity, relatively higher yields were recorded in plots irrigated through drip as compared to surface irrigation (Annual report, Gangawati, 2005-06).

Table 5.11: Expected yield and slope for different crops at various salinities under sprinkler irrigation

Crop	Yield maxima	EC_t (dS/m)	Slope	Expected yield (t/ha) at different ECiw (dS/m)			
				2	4	6	8
Onion	11.9	1.10	-0.2956	11.64	11.04	10.45	9.82
Spinach	8.4	2.18	-0.2676	8.45	7.91	7.38	6.84
Watermelon	8.5	0.52	-0.6871	7.48	6.11	4.73	3.36
Cucumber	12.5	1.67	-1.8379	11.90	8.22	4.55	0.87
Cluster bean	3.1	1.06	-0.3587	2.75	2.04	1.32	0.60

5.2.3 Pitcher Irrigation

Based on several experiments conducted at Central Soil Salinity Research Institute, Karnal, an alternative to drip irrigation has been developed. This new technique is called Pitcher *irrigation* or *Pitcher farming*. The technique derives its name from the baked earthen pitchers, which are used for water storage and distribution in this technique. This technique can be used most effectively under the following conditions:



Schematic diagrams showing vegetable cultivation with pitchers

Table 5.12 : Salinity of water used for the production of crops as equal to fresh water irrigation

Crop	Salinity of water (dS/m)
Tomato	5.7
Brinjal	9.8
Cauliflower	15.0
Ridge gourd	3.2
Cabbage	9.7
Watermelon	9.0
Musk melon	9.0
Grape	4.0

Gupta and Dubey (2001)

- Water is either scarce or expensive
- Soils are difficult to level such as under undulating terrain
- Water is saline and cannot be normally used in surface methods of irrigation
- In remote areas where transport of vegetables is expensive and uneconomical

Evidences have been generated to show that with pitcher technique, relatively high salinity water can be used to grow vegetables and horticulture crops (Gupta and Dubey, 2001). This conclusion is based on the fact that with surface irrigation methods, saline water in the range of 2-4 dS/m could only be used to grow most vegetable crops (Table 5.12).

6.0 MANAGEMENT OF ALKALI WATERS

Alkali waters are those that have a high proportion of sodium related to calcium and magnesium. High incidence (30–50%) of these waters is found in semiarid parts (annual rainfall 500–700 mm), which are the most intensively cultivated areas in the Indo-Gangetic plains. Prolonged use of these waters results in a rise in soil alkalinity thus adversely affecting the soil physical behaviour in terms of crusting, hard-setting and low intake rates. This not only decreases the crop yields but also limits the choice of crops that can be grown on these soils (Minhas and Gupta, 1992; Ayers and Westcot, 1985; Minhas, 1996; Oster and Jayawardene, 1998). The adverse effect of irrigation water quality on soil physical properties is associated with the accumulation of sodium ion on the soil exchange complex which imparts instability to the soil aggregates and whose disruption followed by dispersion of clay particles results in clogging of soil pores. Practical option for safe use of these waters for successful vegetable production should aim at improving the physical and chemical properties of soil receiving alkali waters. The management steps include the use of amendments, conjunctive use and application of organic residues. Irrigation management, crop management and fertility management are also extremely important for obtaining sustained crop yields in soil irrigated with alkali waters.

Alkali water irrigated dry soil

Water stagnation in alkali water irrigated soil

6.1 Use of Amendments

Since accumulation of the sodium ion on the exchange complex is mainly responsible for poor soil physical properties, irrigation water having a alkalinity hazard could be improved by increasing the soluble calcium status of the water, thereby decreasing the proportion of sodium to the divalent cations and therefore its adsorption on the soil exchange complex. Applied soluble calcium salts will also neutralize the bicarbonate and carbonate ions thereby reducing the alkalinity hazard of the water. To offset the harmful effects of alkali waters application of calcium-containing amendment such as gypsum is commonly recommended (Puntamkar *et al.*, 1972; Bajwa *et al.*, 1983; Ayers and Westcot, 1985). The other amendments are acid or acid forming substances (sulphuric acid or pyrites), which react with inherent mineral sources (such as $CaCO_3$) to release Ca to the soil solution. The gypsum requirement for neutralizing residual alkalinity in alkali water is of recurring nature and is determined by factors such as current level of soil deterioration, cropping intensity and water requirement of the crops to be grown. The quality of gypsum for neutralization of each me/l of RSC is 86 kg/ha for 10 cm depth of irrigation.

Heavy dressings of organic manures, regular incorporation of crop residues, application of such organic materials as rice hulls, sawdust, sugar factory wastes, etc., have all been found useful in maintaining and improving soil physical properties and in counteracting the adverse effect of high levels of exchangeable sodium. Wherever feasible therefore, organic matter application is recommended if irrigation water has a alkalinity hazard. However, additions of organic amendments alone without gypsum are not capable to alleviate the harmful effects of alkali water. The combined effect of FYM and gypsum has been investigated at Hisar centre in long-term experiments. These studies have shown that FYM along with gypsum significantly increased the yields of potato, tomato, brinjal, broccoli, cluster bean, cauliflower, cabbage, knol-khol, bottle gourd, ridge gourd and bitter gourd under alkali water (RSC 11.6 me/l; SAR 14.0 $(mmol/l)^{1/2}$) irrigation as compared to control treatment. The maximum yields of these crops were recorded with 100 % GR (F2 & F4) and FYM @ 20 t/ha (F2). The magnitude of increase was much higher with gypsum application than FYM. The alkalinity tolerance of crops was in the order: potato> tomato> brinjal>broccoli>cluster bean (Table 6.1) on the basis of the recovery of crop with the addition of FYM and gypsum. Cluster bean was found to be the most sensitive crop for alkali water tolerance. The yield variation of crops in various treatments was more pronounced because substantial ESP (40-45) has developed due to prior application of alkali water on the test plots.

In another long-term experiment at Hisar (Annual reports, Hisar, 2002-2009), the mean yield of

Cauliflower

Cluster bean

Irrigation with alkali water under different amendments

Table 6.1: Effect of gypsum and FYM treatments on mean yields (q/ha) of different crops

Treatments	Potato (3 years)	Tomato (3 years)	Brinjal (2 years)	Broccoli (4 years)	Cluster bean 3 (years)
FoGo	134.09	16.56	3.80	1.40	0.68
FoG1	210.93	236.04	167.25	43.17	95.73
FoG2	213.06	316.34	228.67	59.51	105.38
F1Go	190.91	22.91	13.50	14.47	1.93
F1G1	241.01	313.43	215.38	66.01	106.21
F1G2	248.62	400.65	264.27	92.91	114.43
F2Go	196.07	31.84	26.18	30.42	2.42
F2G1	252.78	304.19	236.47	81.25	111.04
F2G2	265.15	382.08	288.90	101.01	118.46
CD (5 %)					
Gypsum	24.68	10.94	28.83	10.54	6.10
FYM	24.68	10.94	28.83	10.54	6.10
GXF	31.01	16.45	NS	NS	NS

F0= no FYM; F1= 10 t/ha; F2= 20 t/ha; G0= no gypsum; G1= 50%; G2= 100%

cauliflower, cabbage, knol khol, bottle gourd, ridge gourd and bitter gourd increased by 16.1, 28.9, 9.1, 29.7 and 17.5%; and 30.3, 49.9, 24.2, 53.62 and 114.9%, respectively with the addition of FYM @ 10 t/ha (G0F1) and FYM @ 20 t/ha (G0F2) over control (Table 6.2). However addition of gypsum resulted in tremendous increase in the yields of all the crops. The combined addition of FYM and gypsum (F2G4) recorded the maximum yield in all the crops, which was statistically significant as compared to other treatments. The results of this experiment further confirmed that the addition of gypsum along with organic amendments has triggered the process of amelioration of alkali water and consequently enhanced the yields of crops. Singh *et al.* (2002) have reported

Broccoli

Irrigation with alkali water under different amendments

Table 6.2: Effect of gypsum and FYM treatments on mean yields (q/ha) of different crops

Treatments	Cauliflower	Cabbage	Knol khol	Bottle gourd	Ridge gourd	Bitter gourd
G0F0	72.71	114.25	16.00	40.15	35.60	1.03
G0F1	84.43	147.30	17.46	52.08	54.30	1.21
G0F2	94.72	171.34	19.87	61.68	76.50	1.8
G1F0	90.52	147.97	50.53	58.19	42.80	5.92
G1F1	97.92	174.80	61.94	71.11	62.90	12.86
G1F2	103.55	190.36	74.39	82.15	80.70	14.66
G2F0	112.29	181.90	66.77	75.22	45.30	8.49
G2F1	115.50	212.31	89.81	82.03	67.30	14.66
G2F2	130.91	224.76	97.81	88.23	85.40	20.58
G3F0	118.04	207.14	79.76	128.13	44.30	12.09
G3F1	131.80	247.22	96.37	169.48	71.70	21.92
G3F2	138.94	275.68	105.13	172.25	89.80	23.72
G4F0	123.17	231.47	95.93	141.63	49.70	14.66
G4F1	156.63	259.92	107.29	179.04	72.40	24.48
G4F2	150.97	334.16	122.51	188.22	92.60	30.09
CD (5%)						
Gypsum	8.33	15.84	5.41	1.83	2.40	1.47
FYM	6.44	12.27	4.18	1.42	2.10	1.44
GXF	10.72	19.74	7.46	3.18	3.80	2.5

F0= no FYM; F1= 10 t/ha; F2= 20 t/ha
G0= no gypsum; G1= 25%; G2= 50%; G3= 75% and G4= 100%

the synergistic effects of adding FYM and gypsum in improving the sugar yield when applied to alkali water irrigated soil than the soil irrigated with saline alkali water. However Gupta *et al.* (1984) cautioned against the use of organic manure on the soils undergoing alkalization process through irrigation with alkali waters. Organic matter was shown to enhance dispersion of soils due to greater inter-particle interactive forces at high pH. Similar results were obtained by Manchanda *et al.* 1985.

Yadav *et al*. (2002a) demonstrated that the alkali water irrigation reduced the tuber emergence, plant height, fresh foliage weight, No. of tubers/plot and tuber yield significantly (Table 6.3). The adverse impact of the alkali water ameliorated with the addition of gypsum and FYM showed a remarkable increase in the growth and yield parameters of the crop. However the magnitude of increase was higher with gypsum over FYM. They suggested that the delayed emergence of tuber under alkalinity may be due to higher alkalinity induced high pH which disturbed the physico-chemical environment of the rhizosphere. Toxic effects of sodium in soil solution are also greatly responsible for reduced tuber emergence of potato. Formation of hard crust on soil surface due to precipitated carbonates and bicarbonates further delayed the emergence of germinated tubers.

Table 6.3: Effect of gypsum and FYM under alkali water irrigation on potato yield

Treatments	Yield of tuber (kg/plot)						Total yield of tuber (kg/plot)		Total yield (q/ha)	
	Large size		Medium size		Small size					
	2001	2002	2001	2002	2001	2002	2001	2002	2001	2002
Control	5.90	6.70	13.47	12.95	2.93	3.15	22.30	22.80	247.77	253.33
FoGo	0.80	0.72	1.28	2.05	1.23	2.33	3.02	5.10	33.51	56.64
FoG1	3.03	3.31	11.07	11.38	2.13	2.47	16.23	17.16	180.35	190.63
FoG2	3.20	4.33	10.57	10.88	2.07	2.53	15.83	17.74	175.91	197.12
F1Go	0.50	1.30	3.47	5.53	2.17	3.08	6.13	9.92	68.13	110.17
F1G1	3.57	4.98	11.40	11.05	2.10	2.72	17.07	18.75	189.62	208.33
F1G2	4.37	5.98	11.10	10.15	2.10	3.22	17.57	19.35	195.17	214.98
F2Go	0.60	1.60	3.53	5.83	1.93	3.80	6.07	11.23	67.40	124.81
F2G1	4.10	6.05	11.57	10.37	1.77	3.22	17.43	19.63	193.68	218.13
F2G2	5.47	7.25	13.33	10.75	2.13	3.88	20.93	21.88	232.57	243.14
CD (5%)	0.32	0.28	0.41	0.47	0.12	0.10	1.23	1.45	13.66	16.13

F = FYM @ 10 and 20 t/ha; and G = Gypsum @ 0, 50 and 100% RSC neutralization


Vegetable crops irrigated with alkali water under different amendments levels

6.2 Conjunctive Use of Fresh and Alkali Waters

The conjunctive use of alkali and canal waters is another possibility to reduce alkalinity hazards of irrigation water. This is particularly relevant to the areas where canal water supplies are either unassured or in short supply and farmers use alkali groundwater for vegetable production. Like saline water, good-quality waters can be used to grow sensitive crops while alkali waters for tolerant crops. The more appropriate practice, however, could be the conjunctive use of these waters, following either of the options of (i) blending of alkali and canal waters, (ii) alternate use of alkali and canal water according to availability and crop needs; and (iii) switching these water sources during the growing season according to critical stage of growth. The blending of alkali and canal water should be done in such proportion so that the final RSC is maintained below the threshold limit of the crop to be grown. The alternate use is preferable and has operational advantages (Minhas, 1996).

Chauhan *et al.* (2007) evaluated the response of potato (*Solanum tuberosum*) to the combined use of a good quality canal water (CW, EC_{cw} 1.1 dS/m, RSC nil, SAR 1.8) and an alkali water (AW, EC_{aw} 3.6 dS/m, RSC 15.8 me/l, SAR 12.4) for 5 years (1998–2003) on a well drained sandy loam soil. Increase in soil pH (8.9–9.1), salinity (4.7–5.1 dS/m) and alkalinity (ESP 25–41) as a consequence of irrigation with alkali water affected the growth and yields of crop (Table 6.4). The sustainability yield index (SYI) when irrigated with AW was 0.063 indicating that these crops should not be irrigated with such high alkalinity waters. The SYI of potato improved to 0.703, 0.642, 0.442 and 0.579, respectively with the cyclic 1CW:1AW, 2CW:2AW, 2AW:2CW and CWp:AWs **(**Crop-wise alternations of water with application of CW to potato and AW to sunflower**)** treatments. The values of SYI were 0.633 and 0.415 for potato when irrigated with blends of CW and AW in the ratio 2:1 (2CW:1AW) and 1:2 (1CW:2AW), respectively. The mean relative yields (compared to CW) ranged from 65–85 for cyclic use and from 66–83 for blended waters. Cyclic use with cycle beginning with canal water marginally improved yields compared with blending.

Table 6.4: Effect of various modes of irrigation with alkali and canal water on yield of Potato (tubers) during different years and sustainability yield index (SYI)

Mode of water use	Yield (Mg/ha) during the year						RY (%)	SYI
	1998-99	1999-00	2000-01	2001-02	2002-03	Mean		
Canal water, CW	39.8	36.3	31.0	35.8	32.1	35.0		
Alkali water, AW	25.1	18.7	3.7	9.0	2.9	11.9	34.0	0.063
Cyclic use								
1CW:1AW	35.6	35.0	24.7	25.4	28.4	29.8	85.1	0.703
2CW:2AW	35.0	34.4	22.6	23.5	26.5	28.4	81.1	0.642
2AW:2CW	30.6	30.2	18.7	19.1	14.9	22.7	64.9	0.442
4AW:2CW	30.2	19.3	4.8	10.5	5.2	14.0	40.0	0.092
CWp:AWs	38.7	33.7	22.6	23.2	21.6	28.0	80.0	0.579
Blending use								
2CW:1AW	37.9	33.5	22.0	23.3	27.6	28.9	82.6	0.633
1CW:2AW	33.5	30.1	18.7	19.1	13.4	23.0	65.7	0.415
LSD (P = 0.05)	4.8	2.7	1.1	2.0	1.6	2.4	-	-

The water use efficiency (WUE) behaved in a similar manner as it declined with reduced yields and alkalinity development under various treatments (Table 6.5).

Table 6.5: Effect of various treatments on water use efficiency in potato

Mode of water use	WUE (kg/ha-cm)
Canal water, CW	1114
Alkali water, AW	454
Cyclic use	
1CW:1AW	972
2CW:2AW	947
2AW:2CW	792
4AW:2CW	492
CWp:AWs	942
Blending	
2CW:1AW	976
1CW:2AW	798

6.3 Impact of Amelioration on Soil Properties

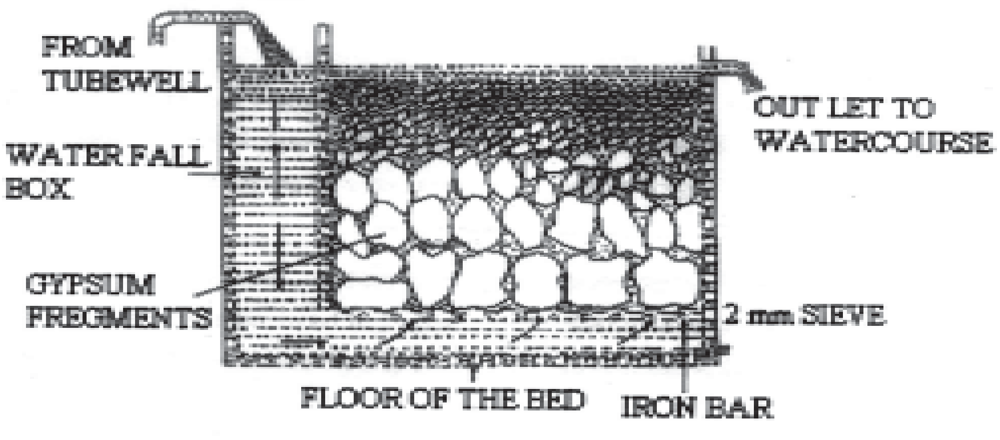
The beneficial effects of organic manure as a source of nutrients and on improvement of soil structure and permeability are well known. The long-term effect of gypsum application on soil physical properties was studied at three RSC levels. The moisture retention was significantly reduced, while infiltration rate and hydraulic conductivity improved with the gypsum application (Annual Reports, Hisar, 2002-08). Pal and Poonia (1979) and Singh *et al.* (1986) reported that alkali waters can be alternatively ameliorated by passing through 'gypsum beds' in channels before they enter the field. The dissolution of gypsum in these beds mainly depends upon their dimensions, which are determined by RSC of irrigation, tube-well discharge and size distribution of gypsum fragments.

The results of the experiments conducted at Hisar centre revealed that infiltration rate decreased with the increase in the FYM and increased with increasing levels of gypsum (Table 6.6). In case

Table 6.6: Effect of gypsum and FYM treatments on infiltration rate of soil

Treatments	Infiltration rate (cm/hr)	
	2002-03	2004-05
F0G0	0.19	0.16
F0G1	0.32	0.28
F0G2	0.48	0.37
F1G0	0.16	0.14
F1G1	0.28	0.25
F1G2	0.35	0.33
F2G0	0.14	0.13
F2G1	0.21	0.19
F2G2	0.23	0.26
CD (5 %)		
Gypsum	0.02	0.02
FYM	0.02	0.02
GXF	0.035	0.03

no gypsum, the mean basic infiltration rate decreased by 11.0 and 29.62 % in F1 (FYM @ 10 t/ha) and F2 (FYM @ 20 t/ha) respectively as compared to F0 (No FYM). However, addition of gypsum @ 50 (G1) and 100 % (G2) increased the infiltration rate by 71.42 and 128.57%, respectively when compared with gypsum control. Similar results were obtained in another study under cole crops-cucurbits crop rotation (Table 6.7). The infiltration rate decreased at higher FYM level due to the dispersion of FYM under alkali condition which resulted in the clogging of the pores. These results are in accordance with Sharma and Manchanda, 1989. The infiltration rate was well correlated (R^2 =0.86) with the ESP build up in the soil (Fig. 6.1). Besides it was observed that addition of FYM and gypsum increased the penetration by 12.12 and 33.3 % at the highest level of FYM and



Cross section of composite gypsum bed

gypsum, respectively as compared to control (Table 6.7). The minimum value was recorded in F0G0 (0.27 KN) treatment. It showed that the workability of soil could be improved by application of amendments and FYM.

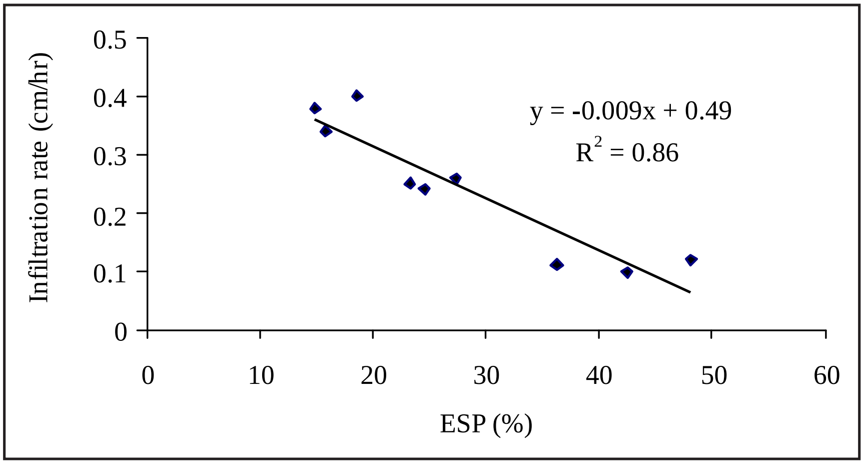


Fig. 6.1: Relationship between ESP and infiltration rate

Table 6.7: Effect of gypsum and FYM treatments on infiltration and penetration of the soil

Treatments	Infiltration (cm/hr)		Penetration rate
	2003-04	2005-06	2003-04
F0G0	0.21	0.18	0.27
F0G1	0.18	0.29	0.28
F0G2	0.32	0.36	0.35
F0G3	0.36	0.4	0.37
F0G4	0.41	0.48	0.38
F1G0	0.19	0.16	0.29
F1G1	0.25	0.24	0.32
F1G2	0.27	0.25	0.35
F1G3	0.31	0.32	0.37
F1G4	0.35	0.37	0.4
F2G0	0.18	0.13	0.33
F2G1	0.22	0.2	0.36
F2G2	0.24	0.22	0.38
F2G3	0.26	0.25	0.39
F2G4	0.29	0.27	0.41
CD (5 %)			
Gypsum	0.019	0.02	0.02
FYM	0.015	0.014	0.015
GXF	0.033	0.035	NS

The addition of organic amendments like FYM, besides ameliorating the harmful effects of alkali water also contribute to the organic matter pool of the soil which is the reservoir of the available plant nutrients. The results revealed that the mean organic carbon of the soil increased from 0.36 to 0.61 with the addition of FYM @ 10 t/ha and from 0.38 to 0.71 with 20 t/ha registering an increase of 73 and 84%, respectively over control (no FYM) in a time span of 15 years (Table 6.8).

The results of a series of experiments indicated that application of gypsum improved the soil physical and chemical properties and reduced the harmful effects of alkali water by bringing down the pH and ESP of the soil and consequently improved the permeability of the soil (Fig. 6.2 and Fig. 6.3). The reduction in pH is owing to the release of acids on decomposition of FYM which in turn decreased the pH of the soil. Similarly, the ESP of the soil decreased with the addition of gypsum

Table 6.8: Organic carbon (%) build-up in soil due to application of FYM and gypsum

Treatments	OC (%)		
	1994	2002	2009
F0G0	0.32	0.35	0.34
F0G1	0.31	0.36	0.37
F0G2	0.31	0.36	0.38
F1G0	0.35	0.45	0.54
F1G1	0.36	0.49	0.62
F1G2	0.35	0.52	0.68
F2G0	0.39	0.47	0.6
F2G1	0.38	0.54	0.72
F2G2	0.38	0.58	0.8

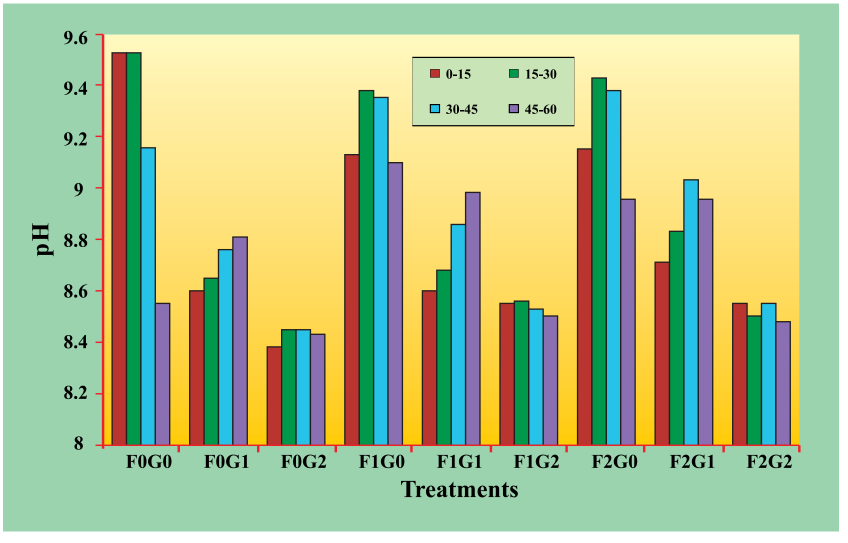


Fig. 6.2: Depth wise pH of the soil at the time of harvesting of broccoli as affected by FYM and gypsum addition

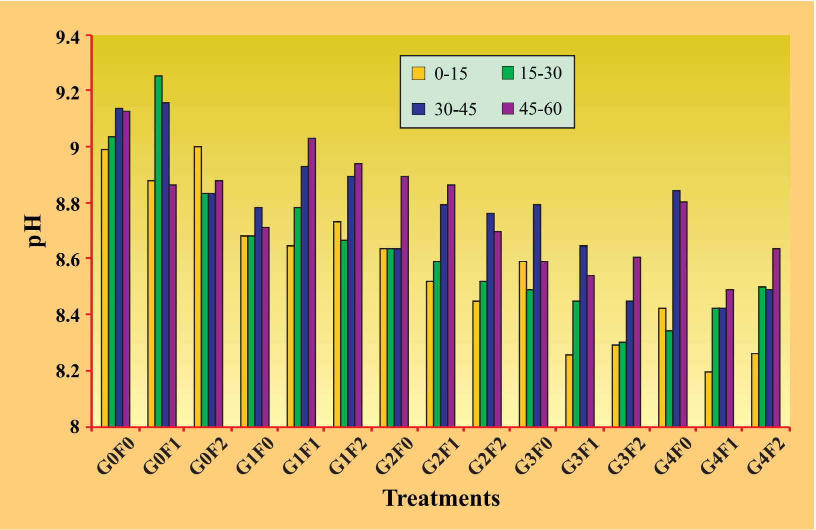


Fig. 6.3: Effect of FYM and gypsum levels on the pH at time of harvest of cabbage

in both the years. It was associated with exchange of Na on the exchange complex with Ca which in turn decreased the ESP of the soil. Yadav *et al.* (2002b) also found that the pH of the soil decreased significantly ($P<0.05$) with addition of FYM and gypsum (Table 6.9). The reduction with gypsum application was more pronounced as that of FYM.

Exchangeable sodium percentage (ESP) is another property of the soil which is greatly influenced by the alkali water application. The addition of gypsum and organic amendments has a direct bearing on the amelioration of ESP of the soil. The results of long-term experiments (Annual reports, Hisar 2002-09) have shown that the ESP of the soil decreased tremendously with the addition of gypsum and FYM (Fig. 6.4). The reduction with gypsum application was more pronounced than FYM.

Table 6.9: Effect of FYM and gypsum on the pH of the soil with brinjal as test crop

Treatments	pH							
	1996				1998			
	F0	F1	F2	Mean	F0	F1	F2	Mean
G0	8.4	8.3	8.0	8.23	8.7	8.6	8.4	8.57
G1	7.9	8.0	7.7	7.87	8.3	8.4	8.0	8.23
G2	7.8	7.9	7.5	7.73	8.4	8.1	7.9	8.13
Mean	8.03	8.07	7.73		8.47	8.37	8.1	
CD (5%)	FYM = 0.18	Gypsum = 0.18	FYM x Gypsum = NS		FYM = 0.20	Gypsum = 0.20	FYM x Gypsum = NS	

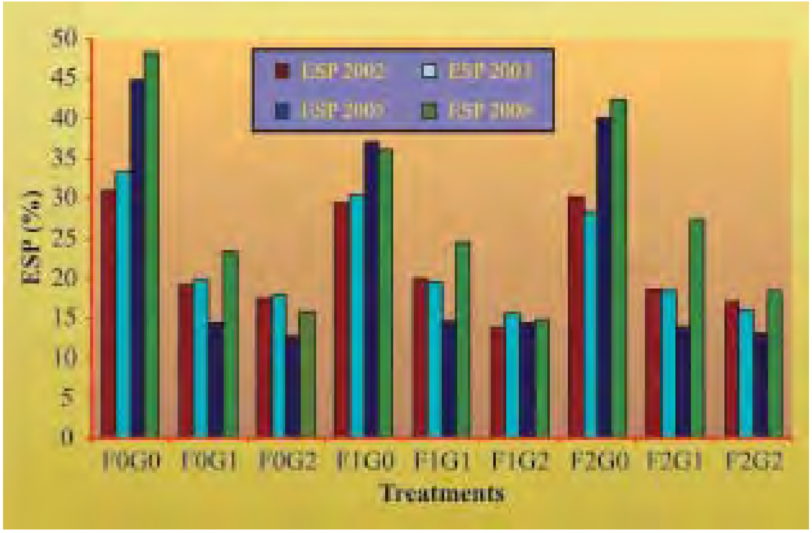


Fig. 6.4: Effect of different FYM and gypsum treatments on ESP of the soil

6.4 Effect of Alkali Water on Quality of Produce

Vegetables play an indispensable role in a well balanced nutritious diet not only by providing sufficient amount of vitamins, minerals but also by adding colour, flavour and texture. Unlike arable crops vegetables are perishable product and the market price fluctuates depending upon its size, visual look and shelf life. Besides the vegetable's nutritive value would be important to the consumer. As such a number of studies were made to assess the marketable and nutritive qualities of the vegetables wherein a number of quality parameters were investigated (Table 6.10).

6.4.1 Physico-chemical characteristics of vegetables

In a study on the quality of potato crop it was observed that irrigation with alkali water besides affecting crop yields, also affected quality of the produce. Lower grade potatoes (C grade) increased with decline in yield and the fraction of such potatoes was the greatest (0.56) when irrigated with AW compared with 0.13 for the CW. Storage quality of potatoes irrigated with alkali water also deteriorated as the potatoes shriveled with two-third-weight loss on storage for 90 days whereas the weight loss was just about two-fifth under CW. Yadav *et al.* (2002a) reported that number of large size (>70g) and medium size (40-70g) tubers were maximum in control followed by where gypsum @ t/ha and FYM @ t/ha was added.

Varsha (2007) and AICRP Hisar centre studied the effect of alkali water with 50% (G1) and 100% (G2) neutralization of RSC with gypsum and FYM @ 20 t/ha (F2) on nutritional and sensory characteristics of vegetables and their products and found that the vegetables i.e. tomato, cabbage and brinjal irrigated with G1F2 had significantly ($P<0.05$) lower fruit weight, length, width, pH and moisture and higher firmness (Table 6.11), total soluble solids, titratable acidity, β-carotene and ascorbic acid contents (Table 6.12) than vegetables irrigated with canal water (control) and G2F2

Table 6.10: Quality traits, their importance and contents in vegetables

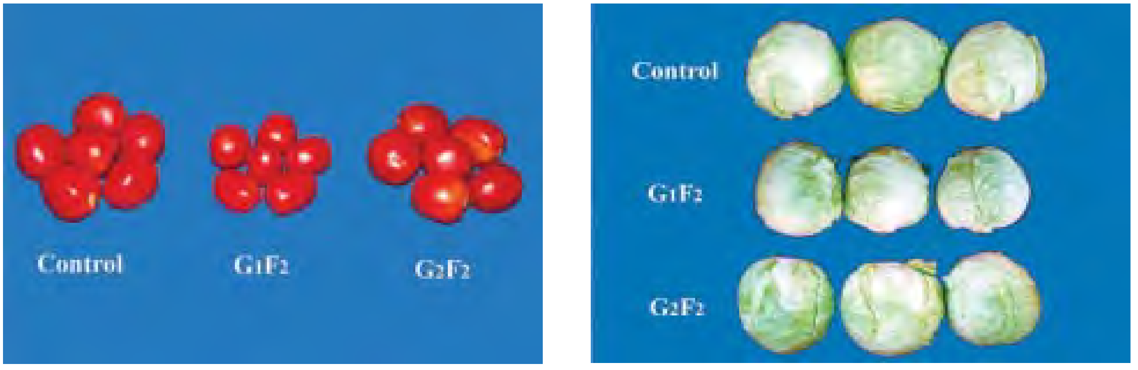
Quality trait	Marketing/ human dietary benefits	Content in vegetables
Fruit length, width, weight, firmness, moisture etc.	Decide market price	Variable
β-carotene (mg/100g)	Anti-oxidant, anti-caracinogen	Nil-20.0
Ascorbic acid (mg/100g)	Strong anti-oxidant, helps in healing of wounds, fractures, bruises and bleeding gums, increase iron absorption	Nil-220.0
Lycopene (mg/100g)	Anti-oxidant, reduce the risk of cardiovascular disease and cancer.	Nil-10.0
Chlorophyll (mg/100g)	Photosynthetic pigment	Nil-35.0
Anthocyanin (mg/100g)	Acts as powerful antioxidants	Nil-15.0
Protein (g/100g)	Growth and maintenance of body	0.2-7.5
Fat (g/100g)	Serves as fuel molecule and enhance palatability to diet	0.1-2.9
Crude fibre (g/100g)	used as a source of energy	0.5-6.5
Ash (g/100g)	Represents the content of minerals, acts as catalytic agent in any reactions	0.5-4.5
Carbohydrates (g/100g)	Source of energy	1.5-38.0
Total soluble sugar (%)	Source of energy in the diet	2.5-40.0
Reducing sugar (%)	-do-	0.5-40.0
Non-reducing sugar (%)	-do-	2.0-12.0
Starch (%)	Source of energy in the diet	2.0-70.0
Total dietary fibre (%)	decreases the disorders such as constipation, coronary heart diseases, diverticulosis diabetes, and obesity	1.1-8.5
Soluble dietary fibre (%)	reduces levels of blood cholesterol and increase the viscosity of the intestinal contents	0.2-2.1
Insoluble dietary fibre (%)	acts as a laxative	0.8-7.2
Oxalic acids (mg/100g)	function in the metabolic regulation, stimulation of lignin degradation, raises the risk of urinary stones, sequesters calcium	0-780.0
Polyphenols (mg/100g)	antioxidant activity, amelioration of cardiovascular diseases	38-290

Table 6.11: Effect of gypsum and FYM on physical characteristics of vegetables grown under alkali condition

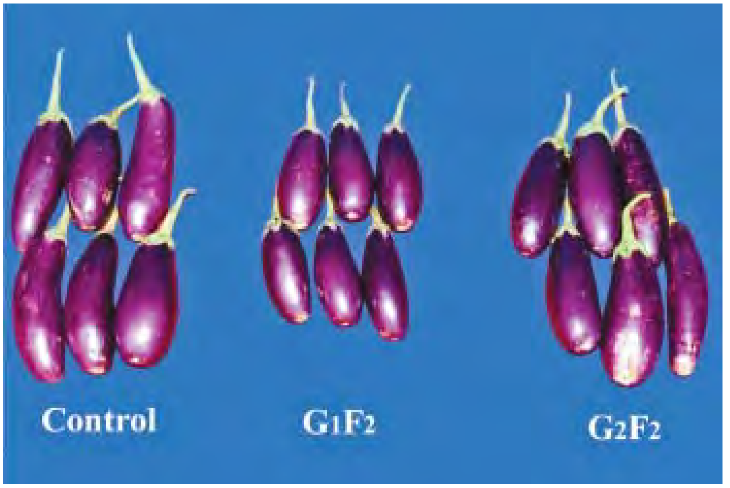
Treatments	Fruit weight (g)	Fruit length (cm)	Fruit width (cm)	Firmness (kg/cm^2)	Specific gravity
			Tomato		
Control (Canal water)	59.10	6.10	4.80	0.65	1.00
G1F2	46.95	5.50	4.60	0.98	1.00
G2F2	55.80	6.00	4.73	0.70	1.00
CD (P<0.05)	0.85	NS	NS	0.10	NS
			Cabbage		
Control (Canal water)	1270.90	17.50	14.03	3.94	1.06
G1F2	994.00	16.12	13.00	5.38	1.05
G2F2	1210.00	17.00	14.00	4.32	1.06
CD (P<0.05)	56.36	0.75	0.54	0.06	NS
			Brinjal		
Control (Canal water)	71.68	9.60	4.50	2.78	1.01
G1F2	67.13	8.50	4.10	5.32	1.01
G2F2	70.15	9.50	4.50	3.26	1.01
CD (P<0.05)	0.90	0.44	0.38	0.37	NS

Values are mean of three independent determinations
G1 : 50% neutralization of RSC with gypsum
G2 : Complete neutralization of RSC with gypsum
F2 : FYM @20 t/ha

treatment (100% neutralization and FYM @ 20 t/ha). The reduction in fruit weight and size of vegetables in G1F2 treatment might be due to decrease both in fruit water content and dry matter accumulation. The fruit weight and size of vegetables improved significantly where the RSC was



Effect of alkali water and amendments on tomato and cabbage



Effect of alkali water and amendments on brinjal

Table 6.12: Effect of gypsum and FYM on total soluble solids, titratable acidity and pH of vegetables grown under alkali condition (Fresh weight basis)

Treatments	Total soluble solids (%)	Titratable acidity (%)	pH
	Tomato		
Control (Canal water)	4.65±0.22	0.54±0.03	4.40±0.08
G1F2	5.90±0.41	0.61±0.01	4.03±0.06
G2F2	4.60±0.23	0.55±0.03	4.37±0.24
CD (P<0.05)	1.03	0.04	0.32
	Cabbage		
Control (Canal water)	5.50±0.25	0.14±0.01	6.60±0.18
G1F2	6.75±0.19	0.19±0.01	6.00±0.23
G2F2	5.45±0.30	0.15±0.01	6.50±0.17
CD (P<0.05)	0.87	0.03	0.40
	Brinjal		
Control (Canal water)	5.00±0.15	0.03±0.003	5.40±0.058
G1F2	6.00±0.19	0.05±0.003	5.00±0.34
G2F2	5.20±0.25	0.03±0.003	5.35±0.25
CD (P<0.05)	0.35	0.01	0.30

Values are mean of three independent determinations
G1 : 50% neutralization of RSC with gypsum
G2 : Complete neutralization of RSC with gypsum
F2 : FYM @20 t/ha

neutralized completely (G2F2). This might be due to the improved physical condition of soil, better availability of water to the plant and due to the association effect of other supplemented nutrient. Higher firmness of vegetables with G1F2 treatment water might be because vegetables grown at increased alkalinity consisted by smaller cells with thicker walls. The increased concentrations of TSS, ascorbic acid and titratable acidity of vegetables in G1F2 treatment were probably due to decrease in water contents of fruits/plants and new synthesis, due to accumulation of more solutes promoted by NaCl. Enhancement of carotenoids i.e. β-carotene and lycopene in salt stressed vegetables may be due to a concentration effect caused by reduced water content of salt stressed plants. The less chlorophyll content in salt stressed cabbage depended in part on change in tissue water content.

The antioxidant activity of fruits is important to assess its nutritional value and to maintain the stability of pigments. Tomatoes had the highest β-carotene (0.57 mg/100g), ascorbic acid (30.07 mg/100g) and lycopene (4.81 mg/100g) contents when irrigated with alkali water having 50% RSC neutralization with gypsum and FYM @ 20 t/ha (G1F2) treatment followed by G2F2 (50% RSC neutralization with gypsum and FYM @ 20 t/ha) and canal water irrigation (Table 6.13). Moisture content of tomatoes in G1F2 treatment was significantly ($P<0.05$) less than G2F2 and canal water whereas the difference between G2F2 and canal water was at par (Varsha, 2007).

In cabbage also the contents of β-carotene and ascorbic acid were significantly ($P<0.05$) higher in G1F2 treatment whereas the moisture content was significantly ($P<0.05$) lower compared to other treatments (Table 6.14). Though the content of chlorophyll a, chlorophyll b and total chlorophyll were higher in cabbage with G1F2 treatment but the differences among three treatments were not significant ($P<0.05$).

Similarly the moisture, β-carotene, ascorbic acid and anthocyanin contents of brinjal irrigated with alkali water in G1F2 (50% RSC neutralization with gypsum and FYM @ 20 t/ha) and G2F2 treatments varied from 92.1-92.5%, 0.09-0.1 mg, 13.22-15.59 mg and 8.5-10.0 mg/100g, respectively (Table 6.15). The contents of moisture and anthocyanin were found to be significantly ($P<0.05$) lower in G1F2 treatment whereas the content of b-carotene and ascorbic acid were significantly ($P<0.05$) higher within the same treatment, on the other hand, G2F2 treatment had almost similar contents.

Table 6.13: Effect of gypsum and FYM on moisture, vitamins and pigment contents of tomato grown under alkali condition (Fresh weight basis)

Treatments	Moisture (%)	β-carotene (mg/100g)	Ascorbic acid (mg/100g)	Lycopene (mg/100g)
Control (Canal water)	93.70±0.15	0.49±0.01	25.96±0.19	4.75±0.15
G1F2	93.00±0.23	0.57±0.02	30.07±0.27	4.81±0.04
G2F2	93.50±0.38	0.50±0.01	26.00±0.22	4.70±0.21
CD ($P<0.05$)	0.32	0.06	0.80	NS

Table 6.14: Effect of gypsum and FYM on moisture, vitamins and pigment contents of cabbage grown under alkali condition (Fresh weight basis)

Treatments	Moisture (%)	β-carotene (mg/100g)	Ascorbic acid (mg/100g)	Chlorophyll a (mg/100g)	Chlorophyll b (mg/100g)	Total Chlorophyll (mg/100g)
Control (Canal water)	91.6±1.0	0.13±0.02	34.34±0.24	5.48±0.28	2.79±0.16	8.27±0.33
G1F2	91.0±0.13	0.16±0.02	39.0±0.19	5.80±0.19	2.82±0.27	8.62±0.23
G2F2	91.45±0.41	0.14±0.03	34.20±0.20	5.54±0.09	2.76±0.26	8.30±0.32
CD (P<0.05)	0.28	0.007	0.75	NS	NS	NS

Values are mean of three independent determinations

G_1 : 50% neutralization of RSC with gypsum

G_2 : Complete neutralization of RSC with gypsum

F_2 : FYM @20 t/ha

Table 6.15: Effect of gypsum and FYM on moisture, vitamins and pigment content of brinjal grown under alkali condition (Fresh weight basis)

Treatments	Moisture	β-carotene (mg/100g)	Ascorbic acid (mg/100g)	Anthocyanin (mg/100g)
Control (Canal water)	92.50±0.32	0.090±0.003	13.26±0.21	10.00±0.06
G1F2	92.10±0.20	0.104±0.004	15.59±0.23	8.50±0.06
G2F2	92.45±0.36	0.092±0.002	13.22±0.16	9.50±0.58
CD (P<0.05)	0.40	0.01	0.71	0.60

Values are mean of three independent determinations
G1 : 50% neutralization of RSC with gypsum
G2 : Complete neutralization of RSC with gypsum
F2 : FYM @20 t/ha

Table 6.16: Effect of gypsum and FYM on proximate composition of vegetables grown under alkali condition (%, on dry matter basis)

Treatments	Protein	Fat	Crude fibre	Ash	Carbohydrate
			Tomato		
Control (Canal water)	15.84±0.21	3.17±0.23	10.31±0.23	8.73±0.26	61.90±0.18
G1F2	11.42±0.43	2.28±0.15	8.85±0.19	10.71±0.50	66.70±0.57
G2F2	16.90±0.25	3.00±0.24	10.00±0.14	8.46±0.26	61.60±0.20
CD (P<0.05)	1.07	0.73	0.66	1.24	1.28
			Cabbage		
Control (Canal water)	21.57±0.79	3.25±0.08	12.29±0.17	9.05±0.09	53.80±0.38
G1F2	16.66±0.27	2.55±0.17	10.50±0.32	11.10±0.20	59.15±0.40
G2F2	22.45±0.29	3.15±0.18	12.16±0.30	8.88±0.19	53.33±0.23
CD (P<0.05)	1.77	0.53	0.93	0.60	1.21
			Brinjal		
Control (Canal water)	18.66±0.21	3.33±0.19	17.33±0.25	7.33±0.25	53.33±0.33
G1F2	13.92±0.13	2.91±0.22	15.10±0.16	9.74±0.15	58.30±0.31
G2F2	19.37±0.27	3.31±0.18	17.21±0.17	7.28±0.25	52.83±0.14
CD (P<0.05)	0.73	NS	0.68	0.76	0.94

Values are mean of three independent determinations
G1 : 50% neutralization of RSC with gypsum
G2 : Complete neutralization of RSC with gypsum
F2 : FYM @20 t/ha

6.4.2 Proximate composition

Tomato, cabbage and brinjal irrigated with alkali water having 50% RSC neutralization with gypsum and FYM @ 20 t/ha (G1F2) had significantly (P<0.05) lower protein content than other treatments (Table 6.16). This decrease in protein content might be due to the competition between ions present in alkali water (chloride, carbonates and bicarbonates) and nitrates present in soil at the same absorption site, which ultimately caused reduced uptake of NO_3 and nitrogen. The higher ash content of vegetables in G1F2 treatment might be associated with the higher but misbalanced mineral contents of these vegetables. Singh *et al.* (2002) also observed that the nitrogen content was higher in potatoes produced with canal irrigated water and it decreased with increasing alkalinity, the maximum nitrogen content (1.58%) was observed in FYM 20t/ha + gypsum 5.4t/ha where alkalinity was 100 percent neutralized.

Similarly, total soluble and reducing sugar in tomato in G1F2 treatment were significantly (P<0.05) higher than canal water and G2F2 treatment (Table 6.17). However, the differences for total soluble and reducing sugar between these two treatments were not significant. Different treatment given to water did not affect the starch content of tomatoes. Cabbage also showed similar results

Table 6.17: Effect of gypsum and FYM on sugar and starch contents of vegetables grown under alkali condition (%, on dry matter basis)

Treatments	Total soluble sugar	Reducing sugar	Non-reducing sugar	Starch
		Tomato		
Control (Canal water)	34.92±0.15	25.23±0.20	9.69±0.08	9.23±0.30
G1F2	37.71±0.44	29.14±0.18	8.57±0.27	9.14±0.26
G2F2	34.15±0.12	25.20±0.19	8.95±0.09	9.20±0.16
CD (P<0.05)	0.97	0.66	0.59	NS
		Cabbage		
Control (Canal water)	38.10±0.25	32.18±0.16	5.92±0.10	8.40±0.27
G1F2	42.88±0.23	36.22±0.30	6.66±0.09	8.30±0.26
G2F2	38.01±0.15	32.16±0.23	5.85±0.09	8.33±0.21
CD (P<0.05)	0.75	0.83	0.35	NS
		Brinjal		
Control (Canal water)	4.00±0.18	0.80±0.04	3.20±0.14	30.40±0.26
G1F2	4.55±0.27	0.88±0.02	3.67±0.25	29.70±0.19
G2F2	4.10±0.16	0.79±0.01	3.31±0.16	30.19±0.17
CD (P<0.05)	NS	0.08	NS	NS

Values are mean of three independent determinations

G1 : 50% neutralization of RSC with gypsum

G2 : Complete neutralization of RSC with gypsum

F2 : FYM @20 t/ha

as obtained in tomato for total soluble sugar (42.88%), reducing sugar (36.22%) and non-reducing sugar (6.66%). Starch content of cabbage remained at par among various treatments. However, in brinjal reducing sugar content in G1F2 treatment only had the significant differences as compared to values recorded in canal water and G2F2 treatment. The data on total soluble sugar, non-reducing sugar and starch contents did not show significant variation in different treatments. The increased sugar might be due to the decrease in water content of plants and new synthesis, due to accumulation of more solutes promoted by NaCl, $NaCO_3$ and $NaHCO_3$. The lower starch content might be due to decreased growth of plants which resulted in lower photosynthesis and therefore, translocation of less photosynthates to the vegetable fruits.

6.4.3 Dietary fibre constituents

The dietry fibre constituents i.e. total (27.57%), soluble (9.00%) and insoluble dietary fibres (18.57%) significantly ($P<0.05$) reduced in G1F2 treatment as compared to G2F2 (29.69, 9.69 and 20.00%, respectively) and canal water (30.69, 10.00 and 20.69%, respectively) (Table 6.18). However, the differences between canal water and G2F2 treatment were not significant. Similarly, total soluble and insoluble dietary fibre of cabbage ranged from 32.11-34.28, 7.56-8.09 and 24.55-26.19%, respectively. Brinjal also showed the same trend as obtained in tomato and cabbage. The total

Table 6.18: Effect of gypsum and FYM on dietary fibre constituents of vegetables grown under alkali condition (%, on dry matter basis)

Treatments	Total dietary fibre	Soluble dietary fibre	Insoluble dietary fibre
		Tomato	
Control (Canal water)	30.69±0.30	10.00±0.17	20.69±0.19
G1F2	27.57±0.22	9.00±0.14	18.57±0.13
G2F2	29.69±0.25	9.69±0.28	20.00±0.05
CD (P<0.05)	0.90	0.72	0.47
		Cabbage	
Control (Canal water)	34.28±0.26	8.09±0.18	26.19±0.20
G1F2	32.11±0.22	7.56±0.16	24.55±0.14
G2F2	33.80±0.17	7.96±0.18	25.84±0.01
CD (P<0.05)	0.78	NS	0.51
		Brinjal	
Control (Canal water)	53.33±0.18	13.33±0.20	40.00±0.04
G1F2	50.63±0.24	12.66±0.26	37.97±0.05
G2F2	52.98±0.15	13.25±0.24	39.73±0.09
CD (P<0.05)	0.68	NS	0.22

Values are mean of three independent determinations
G1 : 50% neutralization of RSC with gypsum
G2 : Complete neutralization of RSC with gypsum
F2 : FYM @20 t/ha

dietary fibre (50.63%) and insoluble dietary fibre (37.97%) contents in G1F2 treatment were significantly ($P<0.05$) lower than the values obtained in G2F2 and canal water treatment (Table 6.18). However a non significant difference existed for soluble dietary fibre content of brinjal.

6.4.2 Antinutrients

The study on the antinutrients revealed that oxalic acid content of tomatoes varied from 66.00-69.76 mg/100g in various treatments (Varsha, 2007). However, G1F2 treatment (50% RSC neutralization with gypsum and FYM @ 20 t/ha) had significantly higher oxalic acid content as compared to G2F2 and control treatment (Table 6.19). The polyphenols contents of tomatoes which varied from 1090.00-1150.00 mg/100g; being the highest in tomatoes irrigated with G1F2 treatment also showed the similar trend as obtained in case of oxalic acid content. Similar results were obtained in cabbage and brinjal also. In cabbage the oxalic acid content varied from 112 to 116.2 mg/100g and polyphenols ranged from 1266-1300 mg/100g. Oxalic acid content in brinjal ranged from 199.60-204.30 mg/100g. Polyphenols content ranged from 2216.00-2300.00 mg/100g in brinjal irrigated with different types of water.

6.5 Economic Gains from Cropping

Table 6.19: Effect of gypsum and FYM on antinutrient contents of vegetables grown under alkali condition (mg/100g on dry matter basis)

Treatments	Oxalic acid	Polyphenols
	Tomato	
Control (Canal water)	66.00±0.14	1090.00±4.62
G1F2	69.76±0.56	1150.00±6.39
G2F2	66.90±0.13	1100.66±3.48
CD ($P<0.05$)	1.18	20.76
	Cabbage	
Control (Canal water)	112.00±0.16	1266.00±5.19
G1F2	116.20±0.30	1300.00±5.77
G2F2	112.10±0.19	1275.00±5.09
CD ($P<0.05$)	1.78	15.67
	Brinjal	
Control (Canal water)	199.60±0.43	2225.00±3.75
G1F2	204.30±0.70	2300.00±4.04
G2F2	200.20±0.44	2216.00±4.33
CD ($P<0.05$)	1.86	14.00

Values are mean of three independent determinations

G1 : 50% neutralization of RSC with gypsum

G2 : Complete neutralization of RSC with gypsum

F2 : FYM @20 t/ha

There is sometimes a wrong notion that use of alkali waters for irrigation may not be a sound proposition since gypsum has to be added to the soil, repeatedly. The B:C ratio estimated for alkali water use along with FYM and gypsum at Hisar centre for tomato, broccoli, cauliflower, cabbage and bottle gourd were 3.02, 2.83, 2.46, 3.12 and 2.92 respectively (Table 6.20). The economic analysis has shown that use of brackish water for vegetable production is a viable technology if they are used judiciously along with amendments.

Similarly the economic analysis of different vegetable crops irrigated with marginally saline water (EC_{iw} 1.15 dS/m) under drip fertigation in vetisol reported that the B: C ratio in different crops varied from 1.25 to 3.20 (Table 6.21). The water melon had the maximum B:C ratio followed by bitter gourd. The lowest B:C ratio was recorded in onion. The WUE in potato (8.5 q/ha-cm) was much higher than other vegetables. The B:C ratio of potato, water melon, chili, capsicum, lady finger, bitter gourd, onion and tomato irrigated with saline water were 2.25, 3.20, 1.94, 1.60, 2.10, 3.11, 1.25 and 2.16, respectively (Annual report, Indore, 2006-07). The lowest B: C ratio was obtained in capsicum because it was adversely affected in latter stages of crop growth by increased salinity. It showed that the drip fertigation with marginal saline water in vertisols can be a viable option provided the salinity of the soil remains permissible limits.

Table 6.20: Economic analysis of vegetable crops grown with alkali water ameliorated with gypsum and FYM.

Name of crop	Cost of production (Rs./ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	B:C ratio
Tomato	23653	71433	47780	3.02
Broccoli	20558	58212	37654	2.83
Cauliflower	24556	60421	35865	2.46
Bottle gourd	19298	56466	37168	2.92
Cabbage	24546	76812	39204	3.12

Table 6.21: Economic analysis of vegetables grown with marginally saline water under drip fertigation

Name of crop	Cost of production (Rs./ha)	Gross returns (Rs./ha)	Net returns (Rs./ha)	B:C ratio	WUE (q/ha-cm)
Potato	80000	180000	100000	2.25	8.5
Water melon	80000	256000	176000	3.20	6.03
Chilli	90000	175000	85000	1.94	0.58
Capsicum	75000	120000	45000	1.60	0.67
Okra	80000	168000	88000	2.10	3.96
Bitter gourd	90000	280000	190000	3.11	2.92
Onion	80000	100000	20000	1.25	4.72
Tomato	95000	205000	110000	2.16	5.47
Total	670000	1484000	814000	2.21	3.31

7. GUIDELINES FOR USING SALINE AND ALKALI WATERS

Apart from its composition, assessing the suitability of specific water requires specifications of conditions of its use (soil, climate, crops etc), irrigation methods and other management practices followed. Because of inherent problems in integrating the effects of above factors, it is difficult to develop rigid standards for universal use. Therefore, broad guidelines for assessing suitability of irrigation waters have been suggested from time to time for average use conditions. A committee of consultants from AICRP-Saline Water, CSSRI, Haryana and Punjab Agricultural Universities

Table 7.1: Guidelines for using poor quality waters

a. Saline waters (RSC < 2.5 me/l)

Soil texture (% clay)	Upper limits of EC_{iw} (dS/m) for crops in rainfall (mm) region								
	Sensitive crops			Semi-tolerant crops			Tolerant crops		
	<350	350-500	550-750	<350	350-550	550-750	<350	350-550	550-750
Fine (>30)	1.0	1.0	1.5	1.5	2.0	3.0	2.0	3.0	4.5
Moderately Fine (20-30)	1.5	2.0	2.5	2.0	3.0	4.5	4.0	6.0	8.0
Moderately Coarse (10-20)	2.0	2.5	3.0	4.0	6.0	8.0	6.0	8.0	10.0
Coarse (<10)		3.0	3.0	6.0	7.5	9.0	8.0	10.0	12.5

b. Alkali water (RSC > 2.5 me/l and EC_e < 4.0 dS/m)

Soil texture (% clay)	SAR $(mmol/l)^{1/2}$	Upper limit of RSC (me/l)	Remarks
Fine (>30)	10	2.5-3.5	Limits pertain to kharif fallor/Rabi crop rotation when annual rainfall is 350-550 mm When the waters have Na < 75% (Ca + Mg > 25%) or rainfall is >550 mm, the upper limit of the RSC range 5 becomes safe. For double cropping RSC neutralization with gypsum is essential based on quantity of water used during the rabi season. Grow low water requiring crops during kharif. Avoid rice.
Moderately fine (20-30)	10	3.5-5.0	
Moderately Coarse (10-20)	10	5.0-7.5	
Coarse (<10)	10	7.5-10.0	

Joint recommendation of HAU, CSSRI and PAU Scientists (Minhas and Gupta, 1992) recommended the guidelines for utilising poor quality waters in 1990 for their wider applicability (Table 7.1). For meeting site specific water quality objectives, factors like water quality parameters, soil texture, crop tolerances and rainfall have been given due considerations. Some of the addendums added to these guidelines include

- Use of gypsum for saline water having SAR > 20 and/or Mg: Ca > 3 and rich in silica
- Fallowing during rainy season when SAR > 20 and higher salinity waters are used in low rainfall areas
- Additional phosphorous application, especially when $Cl:SO_4$ ratio is > 2.0
- Use of canal water preferably at early growth stages including pre-sowing irrigation for conjunctive use with saline waters
- Using 20 % extra seed rate and a quick post-sowing irrigation (within 2-3 days) for better germination
- When ECiw<ECe (0-45cm soil at harvest of rabi crops), use saline water for irrigation just before the onset of monsoons to lower soil salinity for higher antecedent soil moisture for greater salt removal by rains
- Use of organic materials in saline environment
- For soils having (i) shallow water table (within 1.5m in kharif) and (ii) hard subsoil layers, the next lower EC_{iw} values are applicable. .

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ANNEXURE

Table A-1: Vegetable crops water salinity tolerance (ECw)

This table indicates the yield reductions which could be expected when various vegetable crops are irrigated with saline water.

Vegetable crop	No reduction (dS/m)	10% reduction (dS/m)
Zucchini	3.1	3.8
Garden beet	2.7	3.4
Broccoli	1.9	2.6
Cucumber	1.7	2.2
Tomato	1.7	1.9
Cantaloupe/rockmelon	1.4	2.4
Watermelon	1.3	na
Spinach	1.3	2.2
Cabbage	1.2	1.9
Celery	1.2	2.2
Broad bean	1.1	1.8
Potato	1.1	1.7
Sweet potato	1.0	1.6
Capsicum	1.0	1.5
Sweet corn	1.0	1.7
Lettuce	0.9	1.4
Onion	0.8	1.2
Eggplant	0.7	1.6
Carrot	0.7	1.2
Beans	0.7	1.0
Radish	0.7	0.9
Turnip	0.6	1.3

Note: The salinity tolerance of seedlings of most vegetable plants is likely to be less than the levels shown.

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Table A-2: Salt tolerance for garden crops. Salinity level (µmhos/cm) for different yield loss columns of various crops.

Crop	Rooting depth@	Rating[b]	Yield decrease to be expected for certain crops due to soil salinity[a]				
			0% EC_E[1]	10% EC_E	25% EC_E	50% EC_E	Maximum EC_E
Asparagus	D	T	4100	9100	16600	29100	54100
Bean	M	S	1000	1525	2300	3650	6300
Beet, red	M	MT	4000	5100	6800	9600	15100
Broccoli	S	MS	2800	3900	5500	8300	13700
Brussels sprouts	S	MS*	--	--	--	--	--
Cabbage	S	MS	1800	2850	4400	7000	12100
Carrot	S	S	1000	1700	2800	4600	
Cauliflower	S	MS*	--	--	--	--	--
Celery	S	MS	1800	3400	5850	9900	17900
Corn, sweet	D	MS	1700	2550	3800	5900	10000
Cucumber	S-M	MS	2500	3300	4400	6400	10200
Eggplant	M	MS*	---	--	--	--	--
Lettuce	D	MS	1300	2100	3200	5200	9000
Muskmelon	S-M	MS	--	--	--	--	--
Onion	S	S	1200	1800	2800	4300	7500
Parsnip	D	S*	--	--	--	--	--
Pea	M	S*	--	--	--	--	--
Pepper	M	MS	1500	2250	3300	5100	8700
Potato	S-M	MS	1700	2550	3800	5900	10000
Pumpkin	D	MS*	--	--	--	--	--
Radish	S	MS	1200	2000	3150	5100	8900
Spinach	S-M	MS	2000	3300	5300	8600	15200
Squash, scallop	D	MT	3200	3800	4800	6300	9500
Squash, zucchini	M	MT	4700	5800	7400	10000	15300

Table A-3: Contd.

Crop	Rooting depth@	Rating[b]	Yield decrease to be expected for certain crops due to soil salinity[a]				
			0% EC_E[1]	10% EC_E	25% EC_E	50% EC_E	Maximum EC_E
Strawberry	S	S	1000	1300	1775	2525	4050
Sweet potato	D	MS	1500	2400	3800	6000	10600
Tomato	D	MS	2500	3500	5000	7500	12600
Turnip	M	MS	900	2000	3700	6500	12000
Watermelon	D	MS*	--	--	--	--	--

[a]These data serve only as a guideline to relative tolerance among crops. Absolute tolerances vary, depending upon climate, soil conditions and cultural practices.

[b]Ratings are S = sensitive; MS = moderately sensitive; MT = moderately tolerant; T = tolerant to salts.

[*]Rating with * are estimates.

[@]Rooting depths are shallow (S) =12-18"; medium (M) =18-24"; deep (D) = greater than 24" (after Sanders, 1993).

[1]EC_E = Electrical conductivity of the saturation extract of the average root zone (μmhos/cm).

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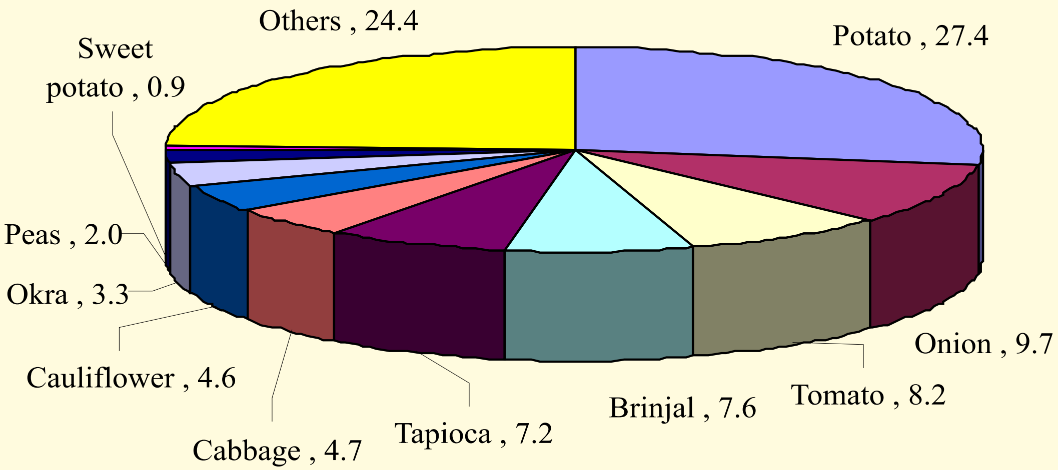
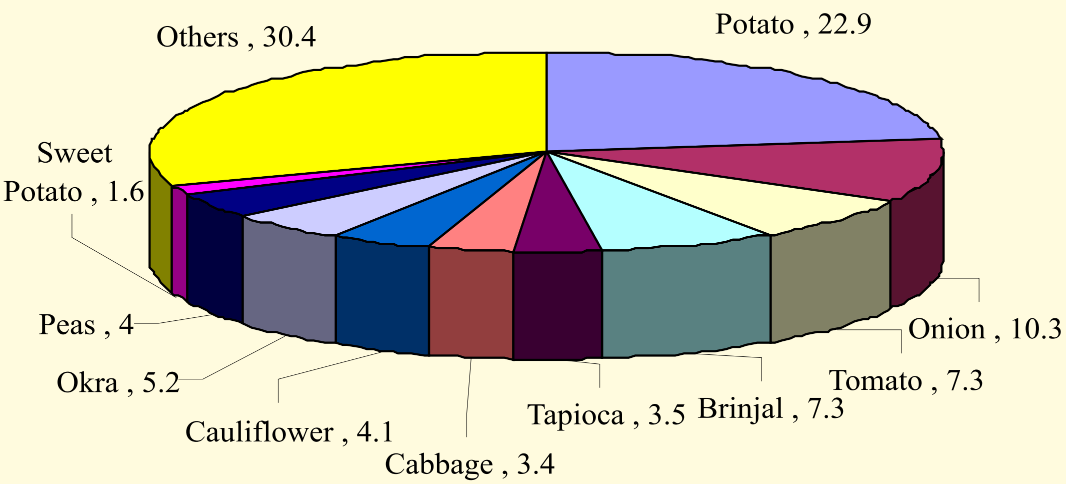
Table A-3: Salt tolerance of crops

Salt Sensitive Crops	Carrot, Cherry, Currant, Gooseberry, Nectarines, Onion, Parsnip, Raspberry, Strawberry
Moderately Sensitive	Broccoli, Cabbage, Cantaloupe, Cauliflower, Celery, Corn, Cucumber, Grape, Kale, Lettuce, Pea, Pepper, Potato, Pumpkin, Radish, Spinach, Sunflower, Tomato, Turnip, Watermelon
Moderately Tolerant	Beet, Olive
Tolerant	Asparagus

Donald Suarez . Salt in Your Wounds: Excess salt content in soil can wreak havoc on a farm. http://www.irrigation.org/ibt/0204/p20.htm



Production Share (%) of Major Vegetables in India (2007-08)



Area Share (%) of Major Vegetables in India (2007-08)

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