Review of Literature
Contents

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# Glossary of plant species cited in the text

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<td>Hyacinth beans</td>
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<td>Indian goose berry</td>
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<td>Kidney bean/Frenchbean/Stringebean/Bush bean</td>
<td>Phaseolus vulgaris</td>
</tr>
<tr>
<td>Lady’s finger</td>
<td>Abelmoschus esculentus</td>
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</table>
Lentil
Lettuce/Butterhead lettuce
Leucerne
Linseed
Maize/Corn
Oats
Onion
Parsley/Persele
Pea
Pearl millet/Bajra
Pigeonpea
Potato
Radish
Rape/Mustard/Winter rape/Springe rape
Rice
Rye grass
Sorghum
Soybean
Spearming
Spinach
Strawberries
Sugarbeet/Beet root
Sweet basil
Sweet cherry
Tomato
Triticale
Tropical duckweed/Water lettuce
Turnip
Water hyacinth
Water spinach
Water thyme
Wheat
White popinac/Horse tamarind
Vetch

Lens culinaris
Lactuca sativa
Medicago sativa
Linum usitatissimum
Zea mays
Avena sativa
Allium cepa
Apium petroselinum
Pisum sativum
Pennisetum typhoides
Cajanus cajan
Solanum tuberosum
Raphanus sativus
Brassica juncea
Oryza sativa
Eruca vesicaria
Sorghum vulgare
Glycine max
Metha spicata
Spinacea oleracea
Fragaria vesca
Beta vulgaris
Ocimum basilicum
Prunus avium
Lycopersicon esculentum
Triticale hexploid
Pistia stratoites
Brassica rapa
Eichhornia crassipes
Ipomea aquatia
Hydrilla verticillata
Triticum aestivum
Lucaena leucocephala
Vicia sativa
The present chapter is divided in four sections. Section 2.1 is directly related to the study where utility of wastewater was studied while taking various vegetable crops. However, it may be noted that only a few studies were available when the vegetables were grown under wastewater. Therefore, section 2.2 was added where wastewater with other crops was studied to take the broader view of wastewater use in agriculture. The last two sections, one on fenugreek 2.3 and another on spinach 2.4 were included where only fertilizer doses were studied when the two crops were grow with normal irrigation water.

2.1 Effect of wastewater on vegetables

Al-Nakshabandi et al. (1980) found that germination in corn, barley and alfalfa was not affected by crude wastewater of refinery, while radish was affected. Growth was enhanced under all treatments when compared with control. They also noted that the crops tested tolerated wastewater treatments, except unusually higher pollutant concentration of the wastewater. Singh (1981) at Muzaffarnagar (U.P.) investigated the effect of paper mill wastewater on pea and lentil. The seeds were soaked in different concentrations for a period of 4 and 8 hours. It was observed that in higher concentration and long soaking treatment only, the percentage of germination, speed of germination index and seedling growth were markedly affected.

Ajmal and Khan (1983) at Aligarh studied the effect of 100, 75, 50 and 25% sugar factory effluent of Aligarh and Bulandshahr on soil, kidney bean and pearl millet and observed that germination was 100% in the water-irrigated soil, while it was between 99% and 91% in different concentrations of wastewater. The ground water and 25% effluent irrigated soils were more suitable for germination. Therefore, they suggested that the effluent may be used for irrigation after suitable dilution. Ajmal and Khan (1984a) further studied the effect of effluent from Mohan Meakin breweries Ltd., Ghaziabad (MMBL). Germination of wheat and pea was restricted to 80 and 90% respectively under 100% effluent but with 50 and 25% concentration, it was quick. Similarly, the growth was also restricted with 100% effluent while 50% proved
beneficial. During the same year (1984b) they also applied four concentrations of vegetable ghee manufacturing effluent to pea and mustard and noted that germination was delayed and restricted to 90% of normal when undiluted effluent was used, whereas it was normal under other concentrations. Undiluted effluent inhibited the growth whereas 75% effluent enhanced it. They were of the opinion that this concentration was suitable as it can supply some of the nutrients required by the plant. Similarly, Ajmal et al. (1984), applied Glaxo Laboratory India Ltd. effluent (GLLE) to kidney bean and pearl millet. The undiluted GLLE checked the germination in kidney bean to some extent while in pearmiillet it was beneficial, while 75% effluent in pearl millet and 25% in kidney bean enhanced the height of plant whereas 100% GLLE retarded it in both crops. In continuation, Ajmal and Khan (1985a) also studied the effect of Modi textile factory effluent, Modinagar (U.P.) on kidney bean and lady’s finger. They observed gradual increase in Na⁺ content of plants with increase in effluent concentrations. In plants grown under 50% effluent, the concentration of K⁺, Ca²⁺, Mg²⁺ was highest followed by 25%, 75% and 100%. Higher concentrations (100% and 75%) inhibited and delayed the germination but it was normal with lower concentrations. In another experiment (1985b), they applied 0.1, 0.2, 0.4, 0.6, 0.8, 1.0, 1.5, 2.0, 2.5, 3.0 and 4.0 dilutions of electroplating factory effluent to hyacinth beans and mustard. Germination was delayed with increase in concentrations and in mustard it was totally inhibited in 1.5% effluent. The metal content in the hyacinth bean plants increased with increasing concentration but after 1.0% effluent, the concentration of Ca, Mg, Na, K, Cu, Zn and Fe was decreased in plants except Cr which increased throughout, while Cd, Ni, Co, Mn and Pb were not detected in hyacinth bean plant. It may be pointed out that work undertaken by Ajmal and his associates at Department of Applied Chemistry of this University was based mainly on chemistry of soil and wastewater and its effect on some plants including the vegetables. However, their work was restricted to seed germination and up to seedling growth only and not in terms of crop growth and productivity.

Goel and Mandavekar (1983) at Karad (Maharashtra) observed that cluster bean, if irrigated with 10% distillery effluent recorded more nodulation. They further observed that higher concentration increased the salt contents and organic matter in the soil thus, suppressing the nodulation but in such condition more nitrogen was absorbed by the plants. During the same year, Shinde and Trivedi also at Karad
studied the effect of distillery wastewater on various characteristics of lady’s finger and corn which were adversely affected at concentration of more than 25%. However, 10% of wastewater proved beneficial while reduction in root length was observed with all dilutions. They also reported that corn was more tolerant to distillery waste than lady’s finger.

Hemphill et al. (1985) in USA, while studying the effect of tannery effluent on lettuce and broccoli reported that nitrogen concentration of lettuce was higher than that of lettuce grown on untreated soil. They also observed that yields of both crops increased when grown on tannery waste amended soil.

Monem (1988) studied the bacteriological examination of vegetables irrigated with wastewater at Dakahlia (Egypt). Post harvest tests on vegetables like radish, green onion, spinach, lettuce, pepper and tomato were taken up irrigated with wastewater. It was noted that the highest bacterial count on leafy vegetables, spinach with 800,000 total coliform (TC) and 15,000 faecal coliform (FC) and lettuce with 1,30,000 TC and 7000 (FC) which has decreased after washing. This decrease varied according to the nature and structure of plant organ. Naheed et al. (1988) at Lahore (Pakistan) irrigated sugarbeets, carrots, spinach, cauliflower, coriander, lettuce, turnip and radish with raw sewage after dilution (1:1) and ground water. The accumulation of heavy metals was in the order of Na > K > Fe > Cu > Cr > Pb > Ni. They also noted that raw sewage significantly affected the growth as well as the taste of vegetables studied by them. Sahai and Srivastava (1988a), studied the seed germination and seedling growth of cauliflower and cabbage using various concentrations ranging from 1, 2.5, 5, 10, 25, 50, 75 and 100% of fertilizer factory effluent. They observed a corresponding decrease in percentage of seed germination and speed of germination index with increase of concentration. In 75% and 100%, no germination took place while that 2.5% wastewater proved best for seedling growth. They were of the opinion that high toxicity of the effluent may be due to the presence of urea nitrogen and ammonia-N in the effluent, therefore, recommended that 2.5% concentration of the wastewater may be used as liquid fertilizer. During the same year (1988b), they also studied the impact of fertilizer factory wastewater on french beans. They noted increase in chlorophyll a and chlorophyll b of seedlings up to 2.5% effluent only and decrease thereafter. The carotenoid content, however, increased gradually with increase in concentration.
Bahadur and Sharma (1989) studied the effect of combined effluent from Indian Turpentine and Rosin Co. Ltd., Western India Match Co. Ltd. and Camphor and Allied Products Ltd. at Bareilly on the growth of pea. They observed that shoot length, root length, number of leaves, branches and inflorescence, leaf area, dry weight of shoot, root, seed yield and biomass decreased significantly in plants receiving effluent after 30, 75 and 135 DAS. They attributed this decrease due to the presence of various pollutants in wastewater. Uskov and Mart (1989) conducted an experiment at Kursk Nuclear Power Station (Russia) and irrigated growing vegetables with warm water discharged from the power station which resulted in increase in yields of cucumber (47%), late cabbage (29%), beet roots (60%) and sugar beet (48%). They observed that surface irrigation produced more yield than sprinkling. It was also noted that under the influence of warm water irrigation, the soil warmed up earlier in spring and vegetation was prolonged in autumn. Maturation of crops was accelerated and a second harvest was possible.

Jabeen and Saxena (1990) studied the effect of Sarya distillery and fertilizer factory on pea at Gorakhpur. Growth was favourable when lower concentration up to 5% of distillery and 2.5% of fertilizer factory were used which ultimately increased the dry matter, pigment and protein contents. They concluded that both wastewaters after proper dilution may be used for irrigation and may be an additional source of nutrients. Truby and Raba (1990) at Freiburg (Germany) noted uptake of Zn, Cd and Pb by Chinese cabbage, lettuce, fodder beets, spinach, cabbage, carrots, potatoes, radish, beet roots, celery, onions, bush beans, strawberries, cucumbers and tomatoes when irrigated with sewage wastewater. They noted low levels of heavy metals in the fruit vegetables and strawberries. However, lettuce, fodder beets, spinach, celery and carrots grown in a neighbouring uncontaminated field also had high Cd contents. They concluded that uptake of heavy metals by vegetables could not be predicted by measuring them in the soil alone.

Wang (1990) while assessing toxicity of pre-treated industrial wastewater using higher plants at Peoria (USA) remarked that out of tested plants rice was more sensitive to toxicity than duck-weed and lettuce and rice root elongation was markedly decreased as compared to lettuce. Pratibha (1991) while working on the growth of coriander and fenugreek irrigated with sewage wastewater at Hyderabad
(A.P.) observed increase in growth and yield of the two crops when compared with tap-water irrigation. Sharma and Naik (1991) at Raipur (Chattisgarh), observed the effect of steel mill wastewater and reported that effluent irrigation decreased the germination percentage as well as other germination parameters but increased ash and nutrient content in all parts of cluster bean. It also increased the pigment and protein concentration in leaves and soil nitrogen concentration significantly. Srivastava (1991) at Jabalpur, observed the effect of paper mill and chlor-alkali plant effluent on seed germination, root length, shoot length and number of secondary roots of radish and onion. He reported that chlor-alkali plant effluent was highly deleterious for germination and early growth performance of seeds as compared to paper mill effluent.

Abasheeva and Revenskii (1992) in Russia, while working on oats, rape and peas in pots using alluvial meadow or grey forest soil and taking clean water or purified wastewater from a cellulose and cardboard mill containing 1 g salt litre⁻¹, observed that dry matter yield of oats on both soils and peas on grey forest soil was increased and didn’t affect those of rape on either soil or peas on alluvial meadow soil. No adverse effect on chemical composition or feed value was reported by them. Goswami and Naik (1992) also at Raipur, performed an experiment to evaluate the effect of fertilizer factory effluent on chlorophyll contents of cluster bean. They reported improvement in chlorophyll content at 10% effluent whereas it was adversely affected at higher concentrations and virtually a negative correlation existed between the two. Somashekar et al. (1992) at Bangalore conducted laboratory experiments to evaluate the effect of distillery wastewater on germination and growth of cowpea and fenugreek and reported that with increase in effluent concentration, the germination percentage decreased, but was not completely suppressed. At 10% concentration, 80% of cowpea seeds germinated while 53% germinated at 100% concentration against 89% recorded for the control. Again 93% germination was observed for control and only 65% of seeds of fenugreek germinated at 100% concentration. With increase in concentration of effluent, relative survival percentage was also decreased. They also reported that as compared to fenugreek, plants of cowpea absorbed more Ca, K and Mn whereas, B was absorbed more by fenugreek as compared to cowpea and almost same amount of P, Mg and Fe was absorbed by two crops. At lowest concentration of effluent, shoot and root lengths were closer to
control values and around 49.9% and 59.9% shoot and root inhibition respectively was recorded for cowpea at 100% concentration. In case of fenugreek percentage of shoot inhibition was more than root inhibition.

Iqbal et al. (1994) studied the growth of coriander and spinach with municipal wastewater and sewage sludge giving:

- **T₁**: A medium of 1:2 fine sand and cattle manure and irrigated with sewage water.
- **T₂**: A medium of 1:2 fine sand and raw sludge. Tap water was used for irrigation.
- **T₃**: A medium of 1:2 fine sand and raw sludge using sewage water.
- **T₄**: Control, medium of fine sand and irrigated with tap water.

It was found that for both the crops fresh weight and dry weight were lowest for the first harvest in all treatments. For coriander, dry weight was lowest in **T₃** and highest in **T₁** while for spinach **T₁** resulted in greater biomass and control gave the lowest value. Karunyal et al. (1994) at Madurai studied the effect of tannery wastewater. Germination of paddy abutilon and white popinac was inhibited by 25% and 50% and prevented by 75% and 100% wastewater. Leaf area and biomass of cotton, blackgram, cowpea and tomato seedlings were higher than those of controls. It was also noted that protein and chlorophyll contents were also increased by 25%. Tannery wastewater at 75% and 100% killed the plants and only 25%o proved suitable for growth compensating for fertilizer. At Santiniketan, during the same year, Saha and Ray observed symptoms of phytotoxicity while observing the role of carbon black factory wastewater and a chemical factory wastewater on the growth of radicles of rice, mustard, lentil, green gram and pea.

Inam and his associates have also undertaken some studies at Aligarh on wastewater quality and vegetable cultivation. Mention may be made of Aziz and Inam (1995) where post irrigation effect of sewage water on some crop plants and agricultural soil was observed. The pH of sewage was almost neutral but the values for EC, total dissolved salts and cations were very high compared to Indian standards. Soil irrigated with sewage showed no significant change in pH, EC, organic carbon and some cations. On the other hand the soil as well as the crops studied showed the accumulation of heavy metals in general and Pb, Cr and Ni in particular. Among the
crops, in general N and Ca content was more in leaves of all crops as compared to other plant parts and maximum in radish while minimum in cauliflower leaves. P was more in leafy vegetables except cauliflower while grain of wheat and stem of mustard had more phosphorus. P, K contents were more in leaves of wheat and spinach as compared to stem while the reverse was true in the case of mustard, cucumber and radish. Except radish, all crops contained more Na in leaves as compared to any other part. Khan et al. (2003) taking the same wastewater in a preliminary study on morphophysiology and yield of spinach and fenugreek concluded that sewage wastewater application enhanced chlorophyll a, b and total chlorophyll contents, photosynthetic rate, photosynthetic water use efficiency, growth and yield of both crops.

Salim et al. (1995) in Palestine studied the effect of root treatment of cauliflower, spinach, and parsley plants with Pb and Cd. They irrigated vegetables with sewage water contaminated by heavy metals and reported that both metal ions inhibited growth, with plants treated with Cd showing more symptoms of toxicity than Pb. Cd was more in the edible parts of the three treated plants whereas, Pb was more in cauliflower and spinach. Metal ion concentration and total metal content of treated plants increased with the increase of concentration of Cd or Pb ions. Metal ion concentration and metal uptake were higher in the plants treated with Cd than in those treated with Pb. Sharma and Habib (1995) while working at Bareilly on the effect of rubber factory wastewater on different cultivars of wheat, gram, pea, mustard and barley observed that in the straw and dried hay of all the cultivars irrigated with wastewater, concentration of Mg decreased and also percentage of Ca, K, PO$_4$ and total nitrogen, crude protein was significantly lower in the seeds of wastewater treated gram. However, concentration of Na, Fe, SO$_4$, total carbohydrates, total ash and chloride increased significantly. Singh and Bahadur (1995) at Pantnagar (Uttaranchal) germinated seeds of various crops in 0-100% distillery wastewater and observed no germination in 100% wastewater. Maize, rice, mustard, blackgram, pigeonpea, soybean and chickpea seeds germinated in 20% concentration whereas, greengram seeds germinated normally in 50%. Vazquez-Mantiel et al. (1995) at Apartado (Mexico) in a glass house experiment applied various concentrations of treated effluent from a trickling filter wastewater treatment plant to soybean and maize under controlled conditions. Both crops responded well to effluent irrigation but with
important differences between them were in terms of grain dry matter and nitrogen uptake. They also reported improvement in N utilization when an effluent deficit vegetative stage was followed by full effluent irrigation applied during the reproductive period.

Eid and Shereif (1996) while working in Egypt irrigated barley, broad bean and rape by (I) raw wastewater (untreated), mixed with fresh water (1:2) for a final EC of 5 ms cm$^{-1}$; (II) raw wastewater, mixed with fresh water (1:6) for a final EC of 2 ms cm$^{-1}$ (III) treated wastewater mixed with fresh water (1:6) for a final EC of 7 ms cm$^{-1}$. The dry matter yield was greatest from raw wastewater mixed with fresh water (1:6). They reported that the effect of irrigation was insignificant on Zn and Cu contents of plant. However, the content of P, N, Mn and Ni increased significantly with mixed wastewater compared to fresh water. The contents of Fe and Mn in straw were significantly greater than in grain or seed while the contents of N, P and K were significantly greater in grain or seed than in straw. Shalaby et al. (1996) at Shebin el Kan (Egypt) performed a green house experiment to study the effect of different types of waters (sewage wastewater, oil and soap company and superphosphate factory) on the mineral composition of anise, caraway, coriander, spearmint, geranium and sweet basil. These plants were irrigated by three dilutions of each waste (1:1, 1:3, 1:6) with tap water till the ripening stage. They reported that application of sewage effluent and fertilizer waters especially at diluted treatments increased the N and P concentration of the plants. But oil and soap wastewater decreased their contents at all added concentrations. P content in different plants was promoted due to higher P contents of the fertilizer waste added to the soil. They also observed that lower dilutions of the fertilizer waste decreased K, Mg and N per cent of the plants. Fe, Mn, Zn, Cu, Pb, Co, Ni and Cd were enhanced according to either the source or the concentration of the applied wastes.

Shahalam et al. (1998) at Irbid (Jorden) carried out an investigation to test the feasibility of using effluent of a rotating biological cofactors (RBC) unit treating wastewater. The objective of this study was to monitor the impact of wastewater irrigation on the soil percolating water, crop growth and the pathogenic condition within the immediate vicinity of wastewater application. Lucerne, radish and tomato
were irrigated with fresh water and wastewater with fertilizer and no fertilizer. Yield from the wastewater with fertilizer were compatible to those of freshwater with fertilizer in most of the cases. Srikantha et al. also in the same year at Bangalore conducted a pot experiment on fench beans and amaranth using various concentration of dairy wastewater. In both crops germination percentage decreased with the increase in the quantity of wastewater. It was 87.5 and 95.5% in french beans and amaranth respectively in raw wastewater. Dry matter yield of the two crops was lowest in raw wastewater and highest in control and decreased with increase in concentration of wastewater. Compared to control, plant nutrients viz. N, P also decreased due to effluents. The decrease in the uptake of these nutrients was attributed to the high concentration of Na in the effluent, which interfered with their uptake. In both crops, Na content increased with increase in concentration while Mg and Ca content were decreased.

Ghosh et al. (1999) at Patna (Bihar) studied the effect of various concentrations of distillery effluent on germination of pea, gram and blackgram. They observed that percentage germination increased up to 75% effluent in gram and pea and up to 50% in blackgram. Plumule and radicle growth generally increased up to 50% effluent and than decreased while root- shoot ratio decreased with increasing concentration.

Ahmad et al. (2000) in Pakistan analysed fertilizer effluent, evaluated hazardous pollutants and studied their effects on crop plants and vegetables including spinach and fenugreek. The samples were analysed for pH, conductivity, hardness, alkalinity, dissolved solids, suspended solids, COD, chlorides, sulphates, sulphides, phosphates, silica, chlorine, ammonia, Ca, Mg and Fe. Trace metals like Cd, Cr, Co, Cu, Pb, Mn, Ni, Sn and Zn were also checked. Effect of these effluents on crop plants and vegetables was observed and remedial measures for the hazardous pollutants of these effluent were suggested.

Kanwar and Sandha (2000) while observing the waste pollution injury to vegetable crops reported that wastewater was contaminated with trace elements like Pb, Cd, Ni, Hg, U, Cu, Zn, B, Co, Cr, As, Mo, Mn etc. Many of these are non essential and are toxic to plants, animals and human beings. They also reported the
sensitivity of vegetable crops like lettuce, parsley, cabbage, onion, spinach, carrot, fennel, radish, tomato to water pollutants. They suggested that wastewater may be suitable for irrigation if the content of toxic elements were reduced considerably. Sundarmoorthy et al. (2000) at Annamalainagar (TN) studied the effect of varying concentrations (1, 2.5, 5, 10, 25, 75 and 100) of fertilizer factory wastewater on greengram, blackgram, groundnut, soybean, paddy and sorghum. It was reported that percentage of germination, seedling growth and dry weight of all seedlings showed a gradual decline with increase in wastewater concentration. The best germination, seedling growth and dry weight was observed at 10% concentration, beyond which seedling growth decreased positively. Thus, they proposed that the wastewater could be used safely for irrigation purpose after proper dilution.

Chow et al. (2001) in Israel evaluated the potential of butterhead lettuce and Chinese cabbage using municipal wastewater in deep flow technique. They had grown seedling with three treatments: primary effluent, secondary effluent and half strength nutrient solution (control). Crop growth measurements, tissue minerals and quality of primary and secondary wastewater effluents were tested at 16 and 32 days after transplanting. Phytotoxicity symptom on Chinese cabbage grown in primary as well as secondary effluents were observed, while butterhead lettuce grew to maturity with little adverse effects. However, the yield of butterhead lettuce and Chinese cabbage were lower than those grown in control. Primary effluent produced the lowest yield.

Baskar et al. (2003) observed eco-friendly utilization of distillery effluent in agriculture. They reported that wastewater was of purely plant origin and contained large quantities of soluble organic matter and plant nutrients. It does not contain any toxic elements/compounds. The only problem was excessive BOD, COD and EC which could be overcome either by proper dilution with irrigation water or by preplant application to give sufficient time for the natural oxidation of organic matter. They observed that distillery effluent significantly increased the yield of sorghum, wheat, maize, sugar cane, cotton, groundnut, sunflower, soybean, sugarbeet, potato and other vegetables, forage crops and tree crops, but had adverse effect on legumes and no effect on rice.

Cui et al. (2003) studied the treatment and utilization of septic tank effluent to (i) use the nutrients in the treated effluents for hydroponic cultivation of vegetables
and to purify wastewater further by the plant root system and (ii) to cultivate ornamental plants and other commercial flowers in vertical flow constructed wetlands surface for enhancing its economic benefit and aesthetic value. The results indicated that using treated effluents for hydroponic cultivation of vegetables could reduce the nitrate content in vegetables. Results also indicated that vertical flow constructed wetlands surface could be used for ornamental plants or other commercial flowers. Dengyi and Youbao (2003) studied the effects of irrigation with wastewater on the growth and scavenging system of activated oxygen in moong and radish. They irrigated the seedling for 14 days, and the irrigated water was changed every 2 days. After sewage irrigation the activated oxygen eliminating system of the crop was damaged and activities of peroxidase, superoxide dismutase and catalase were decreased. Lone et al. (2003) conducted an experiment in Pakistan to investigate the effect of irrigation with sewage and tubewell water or mixtures of both contaminated with heavy metals and micronutrients on okra and spinach. The application of the water types affected the Ni, Cd, Cr and Pb contents in okra fruits. The highest amount of heavy metals in spinach leaves was found in the treatment with sewage water, and the lowest was with tube-well water. In spinach Ni content was the highest, followed by Pb, Cr and Cd. They reported that all micronutrients increased in leaves and fruits treated with sewage water. Ni, Cd, Pb and Cr were higher than the permissible limits in the edible parts with the application of sewage water and a mixture of tube well and sewage water.

Turkman et al. (2004) conducted an experiment in Turkey to study the sewage as a substitute for mineral fertilization (MF) of spinach at two growing periods. They assessed the suitability of sewage sludge to supply some essential plant nutrients, observed the optimum application rate of sewage sludge; and evaluated and compared the effect of mineral fertilizers and sludge on the yield and chemical composition. They had sown the spinach seeds for spring production on 30 April 2000 and for winter production on 26 September 2000. The plants were harvested on 27 June 2000 and 10 May 2001, respectively. The treatments comprised : no fertilizer; 100% sewage sludge (SS). Winter production gave higher spinach yields than spring production. In winter production, the treatment with 100% MF produced the highest spinach yield. In spring production, 50% SS + 50% MF and 75% SS + 25% MF gave higher yields than other treatments. There was no significant difference between
spring and winter production for dry matter percentages. Farmyard manure application had the highest dry matter in both seasons. The N content of spinach grown in spring production was higher than N contents in both production seasons. The macro and micro nutrient elements, and heavy metal contents were generally higher in spring production than in winter production. N, P and K contents of leaves grown with mineral fertilizers were more. For macro elements, mineral fertilizer alone was followed by sewage sludge alone, and combination of sewage sludge and mineral fertilizer.

Lonigaro et al. (2007) at Bari (Italy) studied vegetable crop under tertiary membrane filtered municipal wastewater as an alternative to natural fresh water. They considered membrane filtration as a viable technology to reclaim wastewater for irrigation, and the microbial and heavy metal impact on crops and soil was also studied. They used the water which produced for drip irrigation on three vegetable crops in succession processing tomato, fennel and lettuce and compared with conventional water. It was observed that microbial content of the soil and the crops did not show any relevant differences in relation to the two types of water and the measured values and filtered wastewater never caused an increase of bacterial concentration in the soil nor on edible part of crops. Therefore, they suggested that the tertiary filtered municipal wastewater can be considered a valid alternative source of water for vegetable crop irrigation.

2.2 Effect of wastewater on other crops

In addition to vegetables cited above, wastewater was also tested on other crops and a brief account was given of the work carried out up to 1990. Therefore, mention may be made of Martin et al. (1980) at Minnesota (USA) using municipal wastewater on maize and reed canary grass, Reynolds et al. (1980) at Utah (USA) testing treated municipal effluent on alfalfa; Satterthwaite and Longnecter (1984) in USA spraying treated effluent on a golf course and two other areas; Goetz et al. (1985) at Berlin (Germany) irrigating orchard grass, dasnel maize, summer barley and winter rye with sewage wastewater and Vimal and Talashikar (1985) at Delhi recycling the sewage waste in agriculture. Similarly, Adhikari and Sahu (1986) at Keonjhar (Orissa) studied the effect of distillery wastewater and blue green alga (Anabena) on rice; Bhatnagar et al. (1986) at Ahmedabad observed the pre-soaking of
rice seeds with sugar factory effluent, Butler et al. (1986) in USA worked on maize and a mixture of oats and ryegrass using either dairy wastewater or commercial wastewater and Oran and DeMalach (1987a) at Beer Sheva city (Israel) examined the cotton with domestic wastewater. Again Oran and DeMalach (1987b) applied sewage wastewater to cotton, wheat, alfalfa and maize,Veer and Lata (1987) at Meerut used municipal wastewater on wheat; Papadopoulos and Stylianou (1988a) at Nicosia observed the municipal treated effluent in trickle irrigation. In continuation they (1988b) also evaluated secondary treated effluent on Sudax crop, ragi and barley crop was tested by Chaudhary et al. (1989) at Darbhanga using paper mill effluent; Deivasigamani et al. (1989) at Annamalainagar worked on raw textile factory wastewater and blackgram. Lately, Khan and Varshney (1989) at Bareilly studied the effect of wastewater of synthetic and chemical Ltd. (rubber factory) on some forage crops. During the same year, Thukral applied wastewater discharged from Khetri copper plant, Khetrinagar (Rajasthan) on greengram, cluster bean, pearl millet, wheat, barley and mustard, while Vijyakumari and Kumudha (1990) worked at Erode with distillery wastewater on black gram and greengram and Subramanian et al. (1990a) grown blackgram under distillery wastewater at Annamalainagar. In another experiment (1990b) they used green gram while Kumar et al. (1990) worked out the impact of pharmaceutical factory wastewater on mustard. Again Kumar et al. (1991) at Ahmedabad (Gujarat) tested mustard in the field after subjecting the seeds to pre-soaking treatment with 10, 20, 30, 40, 50 and 60% concentrations of pharmaceutical factory effluent.

Bishnoi and Gautam (1991) while taking 20, 50, 75 and 100% concentrations of dairy effluent studied some kharif crop plants at Bikaner (Rajasthan). They reported that increasing effluent concentration decreased the percentage of germination. Misra and Behera (1991) at Berhampur studied paper mill effluents (25, 50, 75 and 100%) and observed that growth of rice seedlings was decreased with increase in time of exposure as well as concentration. Also in 1991, Neilson et al. in Canada studied the response of wastewater to soil and sweet cherry while applying combinations of well water and municipal wastewater and nitrogen @ 0, 68, 136 g as NH₄NO₃ tree⁻¹ year⁻¹. Wastewater irrigation increased leaf Mg and Ca and growth was also increased after two years but not after 5 years by wastewater.
During the same year, Shukla and Pandey (1991) at Raipur (Chattisgarh) soaked the seeds of maize, blackgram and greengram in 25, 50, 75 and 100% concentration of wastewater from an oxalic acid manufacturing plant. Seed germination in three crops decreased from 100% under distilled water to 86, 32 and 55% respectively in 25% and 52, 12 and 15% respectively in 50% wastewater. In another study, also at Raipur, by Goswami and Naik (1992) while evaluating the effect of fertilizer factory effluent on cluster bean observed improvement in chlorophyll content under 10% effluent whereas it was adversely affected under higher concentration and virtually a negative correlation was observed between the two. Shivhare and Pandey (1995) at the same place taking the concentrate effluent and crops like gram, moong, wheat, maize and paddy rice reported that percentage germination and seedling height was concentration dependent, with 40% showing a favourable effect while 100% proving deleterious.

Swaminathan and Vaidheeswaran (1991) at Coimbatore (TN) noted that diluted dyeing factory effluent increased the physiological components of groundnut seedlings whereas pure effluent decreased the chlorophyll, carbohydrate and protein contents. Similar effect was also found for seed germination and seedling development.

Arora and Chhibba (1992) collected samples of soil and leaf of wheat as well as rice from farmers fields in Punjab along a water drain in which the sewage water was discharged. The concentration of Cu and Fe in wheat leaves was found to be higher while that of Mn and S was less but rice leaves had higher concentration of Zn, Cu, Fe as well as of Mn.

Al-Jaloud et al. (1993) observed the impact of wastewater on growth of maize and sorghum in a pot experiment at Riyadh (Saudi Arabia). They reported that in different water salinity treatments mean dry matter yield and mean biomass for maize was 28.9 to 38.3 and 159 to 210 g pot\(^{-1}\) respectively and for sorghum it was 34.9 to 50.4 and 162 to 212 g pot\(^{-1}\). They also reported that with increase in water salinity, crop yield showed significant increase which was attributed to the presence of nutrients in wastewater, especially N. They were of the opinion that decrease in plant yield at a water salinity level of 2330 mg litre\(^{-1}\) (TDS), indicates that high water salinity can neutralize the beneficial effects of nutrients present in wastewater.
As pointed out earlier, sufficient work on wastewater was also undertaken at Aligarh by Inam and his associates while taking other crops. It may be pointed out that a long term research work was carried out at the specially established research field adjacent to Mathura oil refinery situated at a distance of 70 km from Aligarh. The work was carried out for fifteen years on different crops along with the study of soil and water quality and a continuous monitoring of heavy metals build up in the soil and their accumulation in crop produce. The following references will cover part of the data generated which was published in national and international journals. Mention may be made of Aziz et al. (1993a) who studied the refinery wastewater on nitrate reductase activity (NR activity) of greengram. The experiment was conducted at the experimental farm of Mathura oil refinery, Mathura (U.P.) and reported that wastewater contained considerable amount of nitrate nitrogen, phosphate, potassium, calcium, chloride, sodium, sulphate as compared to ground water, and stimulated NR activity at all the sampling stages. Another field experiment at the same place was also conducted by them (1993b) on lentil. After two years of study, it was found that application of wastewater increased the vegetative characteristics. However, no significant difference in seed yield was observed during first year, but in the following year, the wastewater significantly increased the seed yield by 6.4% as compared to ground water. Aziz et al. (1994) further conducted a field study to evaluate the irrigational utility of treated refinery effluent. They studied growth and yield of three cultivars of triticale and one of wheat and also analysed the effluent, ground water and soil samples for various physico-chemical properties. Treated effluent increased the growth and yield parameters of the two crops and triticale performed better than wheat. They again (1995) conducted a field experiment on four cultivars of wheat and reported improvement in growth and yield parameters. In continuation, (1996a), Aziz et al. studied the long term effects of the same water on six crops and soil. Wastewater irrigation resulted in increased seed yield of wheat, triticale, chickpea, lentil and pigeonpea except that of summer moong, in which 16.6% more seed yield was obtained in fresh water. Aziz et al. (1996b) further observed another leguminous crop, berseem for two consecutive years. The data revealed that wastewater treatment, fertilizer treatment and their interactions improved the growth. While taking the same effluent earlier Inam et al. (1993) conducted a field experiment to compare the treated effluent and groundwater on seedling emergence of triticales (Delfin, Telfin 419 and
Driera) and wheat (HD-2004). No adverse effect on seedling emergence as compared to ground water was observed. In the following year, Samiullah et al. (1994) in two years experiment studied the refinery effluent on wheat and reported that yield characteristics and final yield ha\(^{-1}\) of crop was enhanced by effluent irrigation. Siddiqui et al. (1994) carried out a three year experimental study to evaluate the response of moong to treated effluent. Contrary to earlier findings, shoot length, root length, nodule number, fresh and dry weight and yield attributing parameters including seed yield, showed poor response to refinery wastewater as compared to ground water.

Hayat et al. (2000) also at Aligarh in continuation grew mustard in a split plot design under same treated effluent for two years. They (2002) further studied the long term effect of same wastewater on crop yield, heavy metal accumulation in soil and plant. The seed yield in mustard and wheat irrigated with wastewater, was more while, the seed yield in moong was not consistent. Hayat et al. (2007) more recently studied the performance of pigeonpea, in the presence and absence of Bradyrhizobium sp. and reported that treated effluent was rich in essential nutrients, therefore the crop exhibited better growth and produced more seeds. The nodule number, their fresh and dry weight was also significantly improved in the presence of biofertilizer.

Javid et al. (2003) also at Aligarh while working on sewage wastewater reported that it promoted the growth and yield. N, P and K level was higher in wastewater irrigated plants while grain protein and carbohydrate was lower. More recently Javid et al. (2006) studied the photosynthesis, growth and yield response of blackgram to sewage and thermal power plant wastewater. They reported that wastewater increased chlorophyll content, net photosynthetic rate, photosynthetic water use efficiency, leaf number, leaf area and plant dry mass. Earlier Shah et al. (2004) also at Aligarh studied the response of Triticale under sewage wastewater on the basis of growth, leaf NPK, net assimilation rate, yield and quality of five triticales and one locally popular dwarf wheat as check. They reported that sewage wastewater proved better than ground water. Among the cultivars, Delfin performed best followed by TL-419 (Indian) and wheat while Juppa ‘S’ and Mula ‘S’ gave the poorest response. TL-419 also surpassed the wheat check in grain quality. Again in 2005, Shah et al. conducted a field experiment to study the comparative effect of
sewage wastewater and ground water and of six doses of nitrogen (N_{60}, N_{90}, N_{120}, N_{150}, N_{180} and N_{210}) on the performance of triticale, TL-419. Among nitrogen doses, N_{120} proved best for growth, yield as well as grain quality. Recently Akhtar et al. (2006) studied the effective use of thermal power plant wastewater (TPWW) as a source of irrigation and nutrients in productivity of linseed. The crop was supplemented with N_{0}, N_{45}, N_{68} and N_{90} along with uniform dose of P and K at the rate of 30 kg h^{-1} each and reported that the application of TPPW proved advantageous over GW, enhancing, growth, seed yield and oil content.

Kannabiran and Pragasam (1993) at Pondicherry observed that the seeds of black gram failed to germinate in undiluted distillery effluent. At 75%, radicles emerged, but further growth was inhibited from the third day, while at 50% the roots were very short and devoid of laterals, whereas at 25% roots showed few laterals. 10% showed slightly lower value than control, 1% and 5% concentration. Higher germination percentage and increased chl-a, chl-b and total chlorophyll contents were recorded in 2.5% and carotenoid content was maximum at 5%. Tiwari et al. (1993) at Varanasi studied the effect of distillery effluent on Indian mustard and found that seed germination and early growth decreased with increasing the effluent concentration and at higher concentration it was completely suppressed. Vijayarengan and Lakshmanachary (1993) while using textile mill wastewater on green gram at Annamalainagar reported that germination percentage decreased with increase in concentration. Wastewater at 5% and 10% increased the growth and dry weight of the seedlings while higher concentration caused deleterious effect.

Butorac et al. (1995a) at Croatia in a field trial studied the response of sugarbeet giving (a) no fertilizer (b) lime stone, micronutrients and nitrogen fixing bacteria (c) NPK-fertilizer (d) wastewater containing N, P, K, Ca, Na, micronutrients and organic matter (e) NPK + wastewater (f) NPK + b + wastewater or (g) b + wastewater. They noted that root and sugar yield were highest with (d), while sugar content was highest with (a). They further reported (1995b) the effect of the same treatments where wastewater application did not affect contents of heavy metals, boron or other toxic elements in roots or leaves. The treatment (b) had only a slight mitigating effect, as soil conditions were generally favourable for plant growth.
Goyal et al. (1995) at Hissar applied distillery wastewater on moong, which increased the dry matter production and N and P uptake but dry matter decreased markedly when quantity of wastewater was enhanced. Cisneros et al. (1995) used wastewater from Mexico valley, which was a mixture of domestic, industrial discharges and rainfall for irrigation purposes. Crop yields were above the national average particularly for maize and lucerne. Singh et al. (1995) at Rishikesh (U.P.) in a field experiment irrigated sorghum, maize and cowpea with treated sewage water and effluent from a pharmaceutical factory or water from a tube well applying 0, 50, 100 or 150 kg N + 60 kg P + 40 kg K ha\(^{-1}\) or no fertilizer. They reported that sorghum and maize fodder yields were highest with treated sewage and lowest with tube well water. They also reported that fertilizer application increased fodder yields. Response of NPK application was consistent in tube well irrigated maize and sorghum but variable in treatments irrigated with treated sewage or factory effluent. Cowpea fodder yield was not affected by irrigation source or fertilizer application. Shukla and Moitra (1995) at Shilong, soaked the seeds of gram, greengram, maize and rice, in 0, 25, 50, 75 and 100% concentration of steel plant wastewater. Seed germination and seedling growth of all crops decreased with increase in concentration.

Anjana and Rao (1996) at Jabalpur made an investigation for studying the effect of water coming out from wastewater treatment plant of Shaw-Wallace gelatin factory, main drain, dicalcium phosphate plant, water from Naramada river and found that percentage germination and seedling growth of some crops were improved. Elsokkary and Sharaf (1996) at Nile delta (Egypt) studied two cultivated regions representing alluvial (Region No. 1) and Lacustrine (Region No. 2) soils. The source of water irrigation in Region No. 1 was a mixture of agricultural drainage, and domestic effluents and that of Region No. 2 was a mixture of agricultural drainage, domestic and industrial effluent. However rain was another source of water in the winter season. Samples of water, soils and different plant species were collected in two crop seasons. The concentrations of Zn and Cd in the waters of the two regions were, on an average, 20 and 11 mg l\(^{-1}\) in Region No. 1 and 16.0 and 12 mg l\(^{-1}\) in Region No. 2 respectively. Metal contents in leaves of the different plant species varied markedly. Capacity of plant species to take up metal ions from the soil also varied according to plant species. The resulted bioaccumulation ratios of Zn in plants
followed the sequence: chard > spinach > lettuce > parsley > roquette coriander > clover.

Kumar et al. (1997) at Bhavnagar (Gujarat) moistened the seeds of green gram and black gram with 10, 25, 50, 75 and 100% of dairy wastewater and observed a gradual decrease in seed germination percentage, seedling growth and pigment contents at 25%. Bera and Saha (1998) at Mohanpur studied the effect of different concentrations of tannery effluent on pigeon pea and rice and found that seedling growth was stimulated under 10% and 5% concentration respectively.

Paliwal et al. (1998) examined the effect of different concentrations of sewage water (0, 25, 50 and 100%) on growth performance, biomass and nutrient accumulation of Anjan growing under nursery conditions. Biomass and leaf-area of the seedlings treated with 50% showed an increase over control. Photosynthetic pigments and total soluble protein decreased with increase in concentration. At the higher concentrations, the accumulation of both nitrogen and phosphorus in different components of seedlings was in order: root > stem > leaves. The accumulation of heavy metals resulting from short term application of sewage water was in order: Mn > Zn > Pb > Cu. The sewage water concentration at 75% and 100% retarded the growth of seedlings and only the 50% concentration was suitable for growth. Yamada et al. (1998) in Japan, sprayed wastewater obtained from disinfection of rice seeds (containing two fungicides viz. pofurazoate and oxolinic acid and an insecticide fenitrothion) on soil in nursery boxes. They observed that there was no appreciable effect on seedling emergence using dilutions 0, 2, 5, 10 or 20 times. However, seedling growth, especially root extension was suppressed at dilution rates lower than 10 times.

Tripathi et al. (1999) tested the industrial effluent (IW) and contaminated well water (CWW) observed no adverse effect of IW on wheat germination, whereas germination of cowpea, sesame and Indian goose berry was decreased. Germination of all species was generally decreased by CWW, particularly at higher concentration. Effect of IW and CWW varied with species and concentration. Seedling height, except of wheat in IW, was decreased by 100% IW or CWW, whereas lower concentrations sometimes produced an increase. Germination and seedling growth were inhibited in sesame.
Adjei and Rechcigl (2002) conducted an experiment on bahiagrass to compare the agronomic value of aerobically digested slurry biosolids, lime stabilized slurry biosolids, lime-stabilized cake biosolids and ammonium nitrate all applied to supply 90 or 180 kg N ha\(^{-1}\) vs. unfertilized control. They observed, the slurries and ammonium nitrate gave 50% or more forage and higher spring crude protein (CP) concentration. The CP was improved with ammonium nitrate in early spring, after which, there were no consistent differences in CP or in vitro organic matter digestion. Forage was deficient in K and Mn in summer across treatments. Lime stabilized biosolids could boost bahiagrass production in Florida because it was lower in pathogens, inexpensive, and provided lime and organic matter. Singh et al. (2002) at Lalkua (Uttaranchal) assessed agropotentiality of the effluent coming out from century pulp and paper mill, on wheat crop grown in two soils differing in texture with different effluent concentration. Diluted effluent increased the chlorophyll content, plant height, shoot and root biomass, grain yield, protein, carbohydrate and lipid contents in grains, while undiluted effluent caused inhibition in plant growth resulting in a sharp decline of yield. During the same year Zein et al. in Egypt investigated the effect of \(W_1\) Nile water, good quality water \(W_2\) mixed water, 50% Nile water + 50% WW and \(W_3\) WW, poor quality water, on the content of some heavy metals (Pb, Mn, Cu, Zn, Cd and Ni) and four sugar beet cultivars. Maribo cv. recorded the highest sugar yield at the two seasons for \(W_1\) and \(W_2\) while Dobreach (local cultivar) was superior in its root yield for these water quality treatments in the first season, while Maribo cv. was superior under \(W_2\) and \(W_3\) in the second season.

Jordahl et al. (2003) studied waste management using trees, wastewater, leachate and groundwater irrigation. Phytoirrigation provides a relatively inexpensive means of moving impaired water to a planted area or forest for treatment, greatly expanding the ways in which phytoremediation can be used. They designed the irrigation system designs based on trees and were particularly advantageous because of the high water use, deep rooting, and low operations and maintenance coasts of tree systems. They introduced the rationale for using many trees with irrigation to manage contaminated water. They also identified key limitations and described example projects such as municipal wastewater reuse at Woodburn, Oregon (USA), Swedish biomass production using wastewater and spray irrigation of New Zealand, pine trees.
Gori et al. (2004) carried out a three years study to evaluate the possibility of reusing reclaimed wastewater (RWW) in Pistoia’s nursery area (Italy). The research was aimed at: (1) identifying the best tertiary treatment facilities in order to make the effluent in compliance with the current Italian legislation for RWW reuse, (2) evaluating the effects of RWW irrigation on some ornamentals, (3) quantifying the fertilizing value and environmental impacts of RWW irrigation. Results indicated that filtration and disinfection with peracetic acid plus UV radiations were very effective in indicator bacteria removal, as a matter of fact, neither *Escherichia coli* nor total coliforms were detected in any samples of pilot plant effluent. Results of an agronomical experiment indicated the suitability of the tertiary effluent for the irrigation. At the end of the growing season a higher (or equal) total dry mass was detected in RWW irrigated plants than well water irrigated ones. Finally, they considered the tertiary effluent as an important source of fertilizer for container grown plants.

Mohammad and Mohammad (2004) in Jordan evaluated the effect of irrigation of forage crops with treated wastewater on the yield and nutrient uptake. They planted maize for two seasons while vetch for one and irrigated plots with either potable water (PW) or wastewater (WW) in amounts according to the following treatments: (i) PW equivalent to 100% class A pan reading (PW); (ii) WW equivalent to 100% class A pan reading (WW1); (iii) WW equivalent to 125% class A pan reading (WW2); and (iv) PW with application fertilizer equivalent to N and P content of WW1 (PWF). The plant analysed for dry weight, yield, yield components, and nutrient uptake. WW irrigation increased the yield of both maize and vetch. Both rates of WW application had similar effect on crop production. Supplemental fertilizer application with the potable water irrigation (PWF) enhanced vetch production and increased grain weight for maize in the second season. They observed that the uptake of nutrients by maize increased with WW irrigation while the uptake by vetch increased with both WW irrigation and PW supplemented with fertilizer application. They concluded that secondary treated WW could be a source of plant nutrients and can be reused for irrigation to increase forage crop production.

Khan et al. (2006) at Ghaziabad (U.P.) studied the ecotechnological reuse of distillery effluent as soil amendment and its biodynamic effect on growth and
physiology of sugarcane. They observed increase in germination percentage, number of nodes and internodes, girth, height, mellable cane per clump, chlorophyll content and yield over control.

Tabassum et al. (2007) at Aligarh studied the utility of city wastewater (50% and 100%WW) as a source of irrigation water for mustard cv. Varuna over a groundwater. They also supplied different doses of K (K₀, K₁₀, K₂₀ and K₃₀ kg ha⁻¹) with a uniform basal dose of 80 kg N ha⁻¹ and 30 kg P ha⁻¹ and the wastewater gave better response for leaf area, photosynthetic rate, stomatal conductance, photosynthetic water use efficiency, leaf NPK contents and seed yield. They also concluded that physico-chemical characteristics of wastewater met the irrigational quality requirements and most of them were within permissible limits.

2.3 Trigonella foenum-graecum and NPK fertilizers

Considerable work has been done on fenugreek and spinach while taking NPK as fertilizers under normal irrigation water. Therefore, references from 1990 onwards only were briefly reviewed here first for fenugreek and later for spinach to have an idea about the requirement of NPK without wastewater.

Verma et al. (1991) studied the response of fenugreek to N and P at Agra (U.P.) where seed yield was increased from 1.63-1.64 to 2.14-2.16 t ha⁻¹ during the years 1984-86 with 20 kg N ha⁻¹, and the yields could not be enhanced further with 40-60 kg N ha⁻¹. Increasing P₂O₅ rates from 0, 20, 40 and 60 kg ha⁻¹ increased the yields from 1.56-1.58 to 1.92-2.04 t ha⁻¹. It was also noted that flowering was delayed with higher P rates while N had no effect. Bhati (1993) in a field experiment on loamy sand at Jobner (Rajasthan) irrigated at (IW: CPE) ratios of 0.4, 0.6, 0.8 or 1.0 and given 0, 20, 40 or 60 kg P₂O₅ ha⁻¹ as superphosphate observed that the seed yield increased with increasing irrigation ratio and it was also dependent on P.

Banafar et al. (1995) applied nitrogen and phosphorus on chromustert soil of Madhya Pradesh. They conducted a field experiment with basal doses of 40 kg N (as urea) and 40 kg P (as superphosphate) ha⁻¹ plus 0, 20, 40, 60 or 80 kg N and 0, 15, 30 or 45 kg P ha⁻¹. Two cuttings were taken each year. They observed that seed yield was increased from 806 to 1200 kg ha⁻¹ at 0 to 80 kg N ha⁻¹ while with P application rates of 0 and 45 kg ha⁻¹, increase was 776 to 1105 kg ha⁻¹. On the other hand, vegetable
leaf yield increased from 290 to 490 kg ha$^{-1}$ from 0 and 80 kg N ha$^{-1}$, respectively and from 270 to 375 kg ha$^{-1}$ at 0 and 45 kg P ha$^{-1}$ respectively. Detroja et al. (1995) performed a field experiment at Junagarh (Gujarat) giving 0-60 kg N as urea, 0-120 kg P$_2$O$_5$ as single superphosphate and 0-30 kg K ha$^{-1}$ as muriate of potash. Seed yield was maximum with 30 kg N, 60 kg P$_2$O$_5$ and was also increased by 30 kg K. Fertilizer application also increased the uptake of the three nutrients. In other communication of Detroja et al., 1996 similar observations were observed under N,P and K. During the same year, Bajiya and Pareek (1996) studied the correlation and regression in fenugreek at Ludhiana (Punjab) and reported that seed yield was positively correlated with number of pods plant$^{-1}$, number of seeds pod$^{-1}$, test weight, total P and S uptake.

Field trial was conducted by Baboo (1997) at Lakhaoti (U.P.) on cutting management, nitrogen and phosphorus where seed yield was maximum with one cut at 20 days and with a combination of N + seed inoculation. They also reported that seed yield also increased with the rate of P in the second year. Kamal and Mehra (1997) at Jaipur (Rajasthan) applied 48 combinations of N and P and foliar sprays of NAA. Significant higher seed yield from 40 kg N, 90 kg P and NAA spray and also higher rotenoid (a naturally occurring insecticide) recovery from 20 kg N, 90 kg P ha$^{-1}$ and water spray were obtained.

Gogoi et al. (1998) studied the effect of phosphorus fertilization in a field experiment on a sandy loam soil in Assam, giving 0-50 kg P$_2$O$_5$ ha$^{-1}$ where seed yield was increased up to 30 kg P$_2$O$_5$. Jat et al. (1998) in a field experiment in Rajasthan, studied the effect of phosphorus, sulphur and growth regulator on yield attributes, yield and nutrient uptake. They supplied 20 or 40 kg P$_2$O$_5$, 0-90 kg S ha$^{-1}$, and sprayed with water or mixtalol (triacontanol). Seed yield was highest with 40 kg P$_2$O$_5$, 90 kg S and mixtalol. Halesh et al. (1998) in a field trial at Bangalore (Karnataka), supplied 0, 30, 60 and 90 kg ha$^{-1}$, as urea, 0, 30, 60 and 90 kg ha$^{-1}$, as single superphosphate with 50 kg ha$^{-1}$ as muriate of potash. Good plant growth and higher seed yield were obtained with the application of 60 kg N and 90 kg P$_2$O$_5$ ha$^{-1}$. The highest N rate delayed flowering and prolonged crop duration. Halesh et al. (2000) also conducted a field experiment to study the influence of N and P on growth, yield and nutrient content and the plants receiving 60 kg N were significantly superior and recorded maximum plant height, number of pods, dry weight and seed yield. They
also supplied the four P levels, with 90 kg P recorded significantly high plant height, maximum number of pods, dry weight and higher seed yield. Interaction of N at 60 kg ha\(^{-1}\) and P at 90 kg ha\(^{-1}\) was highly significant and concluded that 60:90:50 kg NPK were optimum for better growth, yield and nutrient content. Kumawat et al. (1998) at Jobner (Rajasthan) performed a field experiment in which fenugreek was grown at three row spacings, given three P\(_2\)O\(_5\) treatments and seed inoculated with rhizobium or not inoculated. Optimum treatments for seed yield were 30 cm spacing, 40 kg P\(_2\)O\(_5\) ha\(^{-1}\) and seed inoculation.

Chaudhary (1999a) in a field experiment also at Jobner studied the response of N, P and rhizobium inoculation. Application of 40 kg N ha\(^{-1}\) significantly increased the growth and yield. Similarly, P at 40 kg ha\(^{-1}\) produced significantly higher yield attributes. He further studied (1999b) seed rate and fertilizer application on sandy loam soil low in N and P and medium in K and was sown at rates of 15, 20, 25 or 30 kg seed ha\(^{-1}\), and given 0:0, 20:20, 20:40, 20:60, 40:40 or 40:60 kg N P ha\(^{-1}\). A seedling rate of 25 kg ha\(^{-1}\) gave the highest mean seed yield. However, maximum pods plant\(^{-1}\) and straw yield were obtained with 15 and 30 kg seed ha\(^{-1}\), respectively and 40:40 kg N P gave the highest seed yield.

Sheoran et al. (1999a) conducted a field experiment at Hisar (Haryana) and studied the effect of sowing time and phosphorus application on growth and yield. They reported HM-65 was significantly superior to T-8 in terms of number of branches plant\(^{-1}\), pods plant\(^{-1}\) and test weight. These yield attributes resulted in higher seed and straw yields of HM-65. Similarly the crop sown on 1 December produced significantly increased yield attributes and yield. However, P had no significant effect on seed pod\(^{-1}\), test weight and harvest index. Among the yield attributes, seed yield was highly associated with pods plant\(^{-1}\) followed by seeds pod\(^{-1}\). They (1999b) further observed thermal efficiency of fenugreek genotype under different sowing environments and phosphorus levels reported that genotypes sown on December 1 showed maximum thermal efficiency and phosphorus application also improved it. Sheoran et al. (1999c) also studied the effect of 3 sowing dates and 4 P rates. HM-65 had higher yield and phosphorus use efficiency than T-8 in all treatments. Highest value for agronomic use efficiency of P was obtained when 30 kg P\(_2\)O\(_5\) ha\(^{-1}\) was applied to HM-65 under the 16 November sowing date. The physiological use
efficiency of P in crop sown on 16 November decreased with increasing P rates. In contrast, P at 60 kg P\textsubscript{2}O\textsubscript{5} ha\textsuperscript{-1} resulted in higher physiological use efficiency than the other P rates, in crop sown on 1 December. In another study (Sheoran et al., 2000), they reported that delayed sowing up to 16 December, significantly reduced the number of days required by the crop for flowering and maturity compared with early sowing. Increase in P rates up to 60 kg ha\textsuperscript{-1} significantly increased seed yield and productivity. Based on the pooled data, an increase in seed yield up to 19.4, 27.6 and 28.8\% was recorded under application of 30, 60 and 90 kg P\textsubscript{2}O\textsubscript{5} ha\textsuperscript{-1} respectively.

Chhibba et al. (2000) carried out an investigation to assess the variation in different varieties of fenugreek (methi and metha) with respect to green yield and mineral composition. Green yield of methi was 1.9 to 3.7 times higher than that of metha, irrespective of the variety. The varieties of both showed considerable variation in their green yield as well as mineral contents. Nevertheless, methi had relatively higher content of minerals. Mavai et al. (2000) applied 20, 40 and 60 kg N ha\textsuperscript{-1}, and 25, 50 and 75 kg P ha\textsuperscript{-1}, and sown at rates of 15, 20, 25 and 30 kg seed ha\textsuperscript{-1} in a field experiment and reported that harvest index was highest with 20 kg N ha\textsuperscript{-1} + 75 kg P ha\textsuperscript{-1} + 25 kg seed ha\textsuperscript{-1}.

Ram and Verma (2000) at Bichpuri applied P at 0, 26.4, 52.8 and 79.2 kg ha\textsuperscript{-1} and K at 0, 24.9, 49.8 and 74.7 kg ha\textsuperscript{-1}, singly and in combination and concluded that 52.8 kg P ha\textsuperscript{-1} as single superphosphate and 24.9 kg potash ha\textsuperscript{-1} should be applied to obtain maximum seed yield. Yield components were also favourably affected by the optimum P dose. During the following year (2001), Ram and Verma further studied the effect of 0, 60, 120 and 180 kg P ha\textsuperscript{-1} and 0, 30, 60 and 90 kg K ha\textsuperscript{-1} applied singly or in combination at Agra (U.P.). Yield attributing characters such as weight of seed plant\textsuperscript{-1}, number and weight of seed pod\textsuperscript{-1}, test weight and seed yield were favourably affected by 120 kg P\textsubscript{2}O\textsubscript{5} ha\textsuperscript{-1}. Similar observations were noted with 30 kg K\textsubscript{2}O ha\textsuperscript{-1}.

Khiriya et al. (2001) conducted two years field trial at Hissar while taking farmyard manure at 0, 5, 10 and 15 t ha\textsuperscript{-1} and P at 0, 20, 40 and 60 kg ha\textsuperscript{-1} (as diammonium phosphate) and two cultivars reported that NLM was significantly superior to HM-65 in terms of plant height, leaf area index, leaf area duration, crop growth, except at 30 DAS. These growth parameters in the genotype NLM resulted in higher seed yield. Growth parameters and seed yield were also increased with FYM.
The increasing level of P up to 40 kg ha\(^{-1}\) also significantly increased the growth and yield. They (2003) conducted another field experiment and observed the growth, yield and quality of same genotypes and suggested 40 kg P ha\(^{-1}\) as the optimum dose. Selvarajan et al. (2001) studied the effect of Azospirillum in combination with different levels of N in a field experiment conducted at Coimbatore (Tamil Nadu), recommended FYM at 20 tonnes ha\(^{-1}\), and N, P and K at 30, 25 and 40 kg ha\(^{-1}\), respectively, as basal and another dose of 20 kg ha\(^{-1}\) N at 30 days after planting.

Nehara et al. (2002) at Jobner conducted a field experiment on loamy sand soil taking 4 levels of P and 5 levels of K. Increasing levels of P up to 40 kg ha\(^{-1}\) and K up to 45 kg ha\(^{-1}\) significantly increased the growth characters. Thapa and Maity (2003) conducted an experiment at Mondouri (West Bengal) and applied 30, 40 and 50 kg N ha\(^{-1}\), 40 and 60 kg P ha\(^{-1}\) with 0, 1 and 2 cuttings on the greens and seed yield. Greens, seed yield and 1000 seed weight were influenced by the number of cuttings and green yield was highest under 50 kg N ha\(^{-1}\). The highest green, seed yield and 1000-seed weight were given by 60 kg P ha\(^{-1}\). Green yield was highest with two cuttings, while seed yield and 1000-seed weight with no cutting treatments. They again (2004) carried out an experiment to study the effect of N (30, 40 and 50 kg ha\(^{-1}\)), P (40 and 60 kg ha\(^{-1}\)) and frequency of cuttings (0, 1 and 2) on seed yield of fenugreek. Most of the parameters increased with increasing levels of N and P. But with the increasing frequency of cuttings the seed yield was reduced. They concluded that the 1000-seed weight and seed yield were significantly influenced by different levels of N, P and number of cuttings. The highest seed yield and 1000-seed weight were obtained with 50 kg N ha\(^{-1}\) while seed yield and 1000 seed weight were maximum under no cutting.

Datta et al. (2005) also at the same place studied the effect of different levels of N (0, 15, 30 and 45 kg ha\(^{-1}\)) and leaf cuttings (no cutting, 1 cutting at 30 DAS and two cuttings at 30 and 50 DAS). Plant height, different yield attributing characters, green leaf yield and seed yield were increased with the increase in nitrogen level. They noted that one cutting at 30 days did not affected vegetative and reproductive growth at later stages. Maximum seed yield was recorded with 45 kg N ha\(^{-1}\) without leaf cutting followed by 45 kg N ha\(^{-1}\) and one cut. The highest green leaf yield was recorded with 45 kg N ha\(^{-1}\) and two cuttings.
Kumar and Singh (2007) at Delhi observed P and cutting management. Application of 50 kg \( P_2O_5 \) ha\(^{-1} \) being at par with combined application of phosphate solubilizing bacteria (PSB), vesicular arbuscular mycorrhiza (VAM) and 25 kg \( P_2O_5 \) ha\(^{-1} \) + PSB + VAM treatment. Application of 25 kg \( P_2O_5 \) ha\(^{-1} \) along with PSB and VAM gave the maximum yield of green leaves. They also observed that the increasing number of leaf cutting from one to two, drastically reduced the plant height, pods plant\(^{-1} \), seeds pod\(^{-1} \), 1000-seed weight, seed yield, net and gross returns. However, there were significant improvements in branches plant\(^{-1} \) and green leaf yield with increased cuttings. In their opinion for getting higher yields and returns from fenugreek, the crop should be left for seed production after 1 cutting of green leaves and fertilized with 25 kg \( P_2O_5 \) ha\(^{-1} \) + PSB + VAM.

2.4 *Spinacea oleracea* and NPK fertilizers

El-Fadaly and Mishriky (1990) studied the effect of N sources and its levels on growth, yield and mineral composition at Cairo University. They supplied N in various forms at 0, 20, 40 or 60 kg feddan\(^{-1} \) (1 feddan = 0.42 ha). N increased yield and maximum being with 60 kg feddan\(^{-1} \). They concluded that ammonium sulphate and urea enhanced the accumulation of N and P, compared with ammonium nitrate. Leaf K, Fe, Zn and Mn concentration was not influenced by N application.

Ahmed (1991a) had grown seeds of spinach under balanced nutrient solution, deficient in N or P. Fresh and dry weight of shoots and roots were decreased and the deficiency of N and P was more apparent in shoots than in roots with leaf area, leaf weight and growth rate being reduced. He also reported that N-deficient plants had relatively high values for net assimilation rate and specific utilization rate at early growth, while these two parameters remained high throughout the growth in P deficient plants. He concluded that deficiencies of the two elements were accompanied by changes in the chemical composition of plants especially the shoots. The level of total free amino acid was increased by P-deficiency but decreased by N deficiency. Ahmed (1991b) carried out a sand culture experiment in 1989 on the same cultivar while earlier in 1990 pot and field trails were carried out with 10 fertilizer treatments. In the sand culture experiment, absence of N resulted in increased P, Zn and soluble phenols in roots and P, Mn, soluble phenols, reducing sugars and total sugar in shoots and decreased N, Na and amino acids in both. Absence of P resulted in
increased Fe, Zn, Cu and soluble phenols in roots and Mn, phenols, reducing sugars and total sugars in shoots and decreased P, K and Na in both. He further reported that the absence of N and P reduced the content and rate of production of most plant constituents particularly during the later stages of growth while N and P deficiencies affected the distribution of different constituents between plant organs, the shoot being more depressed than the root. The specific absorption rate of most nutrients was significantly reduced in N and P deficient plants. In clay soil experiments N, P and K deficiencies resulted in lower plant growth and yield. Plant growth and yield was also increased by late application of fertilizers compared with early application.

Gianquinto et al. (1992) had grown various vegetables on clay, peaty clay or sandy soil. Autumn lettuce was grown with no fertilizer, but other vegetables were treated with either no fertilizer or different doses of N, P₂O₅ and K₂O, applied as mineral fertilizer, farmyard manure or a combination of both. They reported that nitrate contents on a dry weight basis decreased in order: Kohlrabi, tomatoes, autumn grown lettuce, spinach and spring grown lettuce while on fresh weight basis it was highest in spinach and Kohlrabi and comparatively the highest nitrate contents were found in vegetables grown on peaty clay soil. In spring grown lettuce, nitrate content was increased by fertilizer and decreased by manure while in Kohlrabi controls gave the highest nitrate contents and manure treatments, the lowest while the other crops were not affected by fertilizer treatment. In autumn grown lettuce and kohlrabi, nitrate content was highest in the stems and in spring grown lettuce, it was highest in the external leaves.

Eppendorfer and Bille (1996) studied the free and total amino acid composition of edible parts of beans, kale, spinach, cauliflower and potatoes as influenced by N fertilization and P and K deficiency. These vegetables were grown in pots under different nutrient levels which greatly affected DM yields and total N concentrations in all crops. Nitrate N-contents were low and little affected by nutrient levels in cauliflower and potatoes, while highest and strongly affected in spinach and Kale. Shingade and Chavan (1996) studied unconventional leafy vegetables as a source of minerals growing naturally in degraded forest areas or on agricultural waste land at Dapoli (Maharashtra) and compared them with math and spinach. Math, drumstick, lakala and bharangi were richer in P, K, Ca and Mg while drumstick was rich in S.
Shahidulla et al. (1997) conducted an experiment in Bangladesh on the effect of plant age and nutrient content of three vegetables, including spinach and Indian spinach. The protein, fat, fibre and P content increased gradually with the increase in the age of the plant from 2 to 4 months in case of Indian spinach. Yamazaki and Roppongi (1998) studied the effect of soybean meal (SM), composted pig manure (PM) and composted cattle dung mixed with sawdust (CMS), applied singly or with chemical fertilizer on the yield and quality of spinach, lettuce and cabbage. Effect was related to the decomposition of organic nitrogen and was greater with SM than with either PM or CMS. They obtained better quality with PM and CMS than with chemical fertilizers. Leaf nitrate concentration was lower but sugar concentration was higher with PM and CMS than with chemical fertilizers.

Carranca et al. (2000) conducted an experiment in Spain and studied the effect of 30, 60, 90 and 120 kg N ha\(^{-1}\) on two spinach cultivars yield and quality particularly on NO\(_3\)-content in the leaves either for fresh consumption or for processing. The mean value of fresh weight, total N, exported N and NO\(_3\) were higher during 1995 than 1996. P, K, Mg, Na, Mo, Ni and Zn contents were significantly different between two cultivars. Jakse and Mihelic (2000) compared organic and mineral fertilizers in a three year vegetable crop rotation field trial in Slovenia with 6 vegetable crops including spinach and farmyard manure (FYM), compost of hen’s droppings, shredded wood and bark (COMP), and mineral fertilizer with one (NPK-2) or 2 (NPK-1) application of N during the growing season. Yield produced in 3 years on plots applied with inorganic fertilizers was almost twice as high as with COMP and 40% higher as compared to FYM.

Reddy and Bhatt (2001) determined the contents of selected minerals in spinach and ambat chuka cultivated in soil fortified with different chemical fertilizers in pot experiment. Addition of NPK (150, 50 and 50 kg h\(^{-1}\)) along with iron and zinc (10 and 20 kg ha\(^{-1}\) respectively) enhanced the concentration of Zn, Fe and Mg in selected green leafy vegetables while the concentration of Cu was not altered. K content in green leafy vegetables was not affected by addition of chemical fertilizers. Contents of K, Zn and Cu were significantly high in spinach, while Mg and Fe were markedly high in ambat chuka. Tomar (2001) conducted a field experiment in Madhya Pradesh to study the effects of cutting and 0, 20 and 30 kg P ha\(^{-1}\), and 0, 4
and 8 kg Mg ha\(^{-1}\), on the quality of spinach leaves. In both years they reported that the green leaf yield was highest during the second cutting, while yields during the first and third cuttings were at par. Carbohydrates, proteins, P, Fe contents in dried leaves were highest during the third cutting where Ca and Mg contents were highest during the second and first cutting, respectively. 30 kg P ha\(^{-1}\) recorded the highest yield, carbohydrate and protein content in leaves. The highest green leaf yield and carbohydrate and protein contents increased with the increase in Mg rate.

Gent (2002) studied the growth and composition of salad greens as affected by organic compared to nitrate fertilizer and by environment. They noted that interaction of environment and form of fertilizer was examined for salad greens grown as successive plantings in unheated high tunnels. Eight species including eleven plantings of lettuce and spinach were grown either with a nitrate based complete soluble fertilizer in perlite or with an organic fertilizer, namely leaf compost: perlite 1:1 v/v amended with cotton seed meal. They reported for each species that relative growth rate and specific leaf area varied with time of year. Fertilizer had little effect on growth rate but specific leaf area was generally greater for plants with organic fertilizer. For many species leaf concentration of NPK and Ca was raised by 10 to 20% with organic compared to nitrate based fertilizers. Organic fertilizer lowered Ca in spinach. Interaction effects of season and fertilizer was significant only for N and P in lettuce.

Wang and Li (2004) in China carried out a field experiment on vegetables to studied the effect of N forms and rates and P treatments on their growth and nitrate accumulation. Application of ammonium chloride, ammonium nitrate, sodium nitrate and urea significantly increased the yields and nitrate concentration of peking cabbage and spinach. Although N forms had no significant effect on yields, but addition of nitrate N fertilizer increased nitrate accumulation in vegetables much more than did ammonium N. With the addition of P fertilizer, yield of green cabbage and rape were increased, while those of spinach and cabbage had no significant changes. Different parts had different quantities of nitrate accumulation and its concentration was much more in roots than in the above ground parts at any N levels.

Lise et al. (2005) studied at Flakkebjerg (Denmark), the placement of N in spinach a method to increase seed yield. Seed production of spinach was positively
affected by increasing N, however regulations restrict the application rate of N in Danish agriculture. Seed yields were positively affected by the high N applications, but no difference was observed between 150 kg N ha$^{-1}$ broadcast at sowing, and 40 kg N ha$^{-1}$ broadcast at sowing with an additional late application at a rate based on soil mineral N analysis. They observed no consistent pattern between N management strategy and germination. A high N concentration in plants at the start of growth showed negative effects on final seed yield. In their opinion soil mineral analysis can be used as a tool to adjust the N application rate when a split application strategy is chosen.

Lefsrud et al. (2007) at Georgia (USA) studied the N levels influenced biomass, elemental accumulations and pigment concentration in spinach in greenhouse in nutrient solution culture under N treatments of 13, 26, 52 and 105 mg L$^{-1}$. They reported that leaf tissue biomass increased from 45.6 to 273.2 g plant$^{-1}$ and from 127.0 to 438.6 g plant$^{-1}$ as N increased from 13 to 105 mg L$^{-1}$ for two varieties respectively. Leaf tissue N, P, Ca, Mg, Cu and Zn responded to N treatments. N level had a significant effect on carotenoid accumulation in both varieties when the pigments were expressed on a dry weight basis.