INTENSIVE PRODUCTION OF VEGETABLES UNDER IRRIGATION

A A COHEN, International Potash Institute

Introduction

- In South Africa and in other developed countries, vegetable production takes a large place both in the *human diet* and in the *agricultural economy.*

The recognized value of vegetable crops for developing countries is based on their role in the agricultural production.

(a) Improving human nutrition.
(b) Generating income for the subsistance farmer
(c) Increasing the efficiency of cropping systems by improving soil vertility.

- Recent trends in South Africa show *a polarization of production* in larger farms in areas which enjoy relative advantages regarding climate, land, and water supply. For example tomato production in North-eastern Transvaal and onions in Northern Transvaal.

The markets for vegetables are expanding rapidly, thanks to the possibility of preserving and processing the products for local consumption and for export. Factories for frozen or dehydrated vegetables require certain quality specifications of the product.

Fresh vegetables are highly perishable and seasonal production varies from year to year with the weather so the price is determined by the supply and demand. This makes it difficult to speak of maximum economic yield. One can only speak of maximum yield of the best quality.

TABLE 1: Vegetables Production in S.A. (1983)

Area =	Potatoes:	60 000 ha
	Fresh market:	33 450
	Canned:	9 750
	Fresh Export:	3 470
	Others:	13 330
	Total:	120 000 ha

Production (Tons, Millions)		value (R, Millions)
Potatoes =	0,9	160
Vegetables	3,5	733
Total	4,4	893

Fresh market

	Tomatoes	Onions	Cabbages	Carrots	Pumpkin
tons x 1 000	412	156	243	124	154
Rand	90 000	36 660	17 982	15 872	16 632

- Although the area under vegetables is relatively small at about 1,5% of total crop area, the *gross income* from vegetables is relatively high at 10 - 12% of total agricultural income.

- Most of the *vegetables are intensively grown* under irrigation producing high yields and a high economic return per unit area, especially in the case of protected crops.

The production of maximum yields of vegetables require the following conditions:

(a) Intensive management — capital, labour, input
(a) Irrigation through a reliable and efficient system
(c) High level of fertilization and manuring
(d) High value of input — seeds or planting material, pesticides, herbicides, soil fumigants etc.
(e) High product value — quality, marketing season, packaging, distribution.

- Fairly high yields of potatoes, onions, cabbage, can be produced under *rainfall conditions,* but only irrigation can ensure a steady production during the whole year. In order to make full use of the great potential presented in dry areas by the combination of high radiation and an optimum water regime, fertilizers must be applied at very high rates. These high levels implying high costs and high salinity hazards make it imperative to develop the best practices of water and nutrient application.

In this paper we intend to give examples of experiments which can help us to determine the amounts of water and nutrients needed and when and how they should be applied to the crop. The examples include one long growing season crop, the tomato and one shorter, the lettuce.

Irrigation of vegetable crops

- Under irrigation *maximum yields* are theoretically possible through the combination of practically unlimited radiation, long growing seasons and an optimal soil moisture regime.

- Irrigation significantly *increases crop yields* in areas of insufficient rainfall but one should not be satisfied by removing a constraint, but should try to optimize the use of irrigation in order to produce the highest yields possible under given environmental conditions.

TABLE 2 (a): Yields of tomatoes and peppers under different irrigation treatments on saline soil from Russo D (1983)

Crop	Q	0,4 Eo		0,8 Eo		1,2 Eo	
	I	1	2	1	2	1	2
Tomatoes	ton/ha	109,6	86,2	125,5	113,8	126,1	125,6
	n x 10^7	1,14	0,932	1,29	1,17	1,29	1,24
	w (g)	96,07	92,42	97,31	97,27	97,62	101,13
		0,8 Eo		1,2 Eo		1,6 Eo	
		1	2	1	2	1	2
Peppers	ton/ha	54,4	53,0	59,0	56,4	62,7	56,8
	n/ha/10^6	5,46	5,01	6,06	5,55	6,46	5,99
	w (g)	99,5	105,7	97,5	101,7	97,1	94,8

Q = Volume of water
I = Irrigation Interval-days
n = number of fruits/ha
w = average fruit weight
Eo = class A Pan evaporation

TABLE 2 (b)

Soil Fertilization

Feed lot Manure =	80m³/ha	in furrows 20 x 20 cm
Superphosphate =	1 500 kg/ha	
Potassium chloride =	750 kg/ha	

Fertigation: Ammon Nitrate sol. + KNO_3 + H_3PO_4

	N	P	K	Period
Tomatoes —	350	68	400	183 days
Peppers —	490	112	600	225 days

Plant Population: Tomatoes = 12 500 plants/ha
Peppers = 62 500 plants/ha

- Successful irrigation becomes an effective mean for increasing crop production only when applied within an *intensive cropping system* with advanced soil management, higher plant population, effective control of diseases, pests and weeds, as well as efficient irrigation methods and adequate nutrient supply.

- The *interaction between soil moisture and nutrient supply* has been intensively studied with consistent results (Fereres, 1983).

Irrigation, by improving the soil water status increases the nutrient uptake as the shoot growth is accelerated upon relief of water stress.

The higher transpiration under irrigated conditions increases convective transport to the root and therefore a greater contribution of nutrients by mass flow.

Irrigation also increases the diffusion of nutrients in the soil by increasing the cross sectional area for nutrient movement.

- Irrigation affects *root growth,* rooting depth and mainly the distributing of root length density in the soil profile. This should be kept in mind for a fertilizer placement strategy.

- Irrigation method can *solve many nutrition problems* (Fereres ibid).

Under micro and macro-irrigation it is possible to improve the migration of P and K to the level where the active roots are concentrated and to ensure a better uptake of less mobile nutrients. Lechkiri (1983) in Citrus, Bar Yosef (1980) in tomatoes, Guenelon (1980) in apple trees.

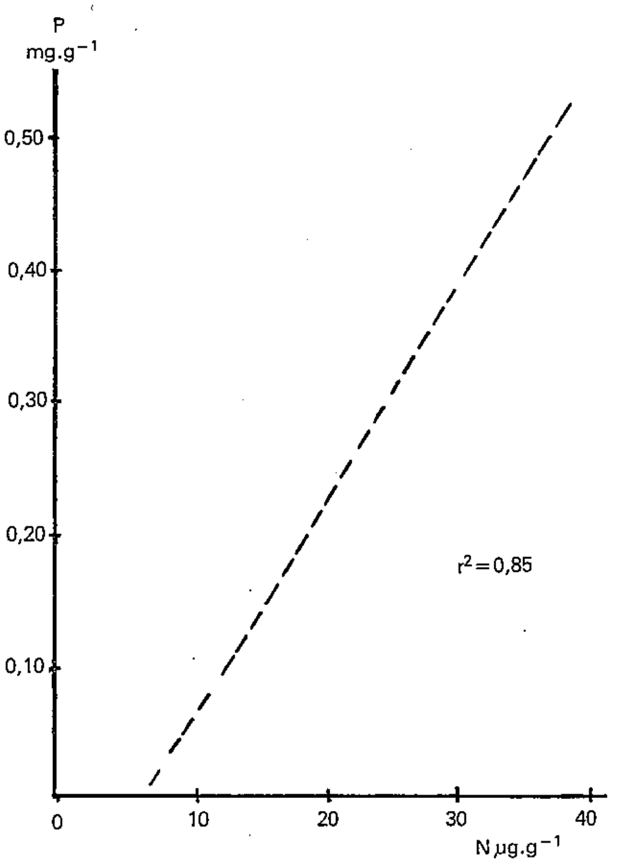
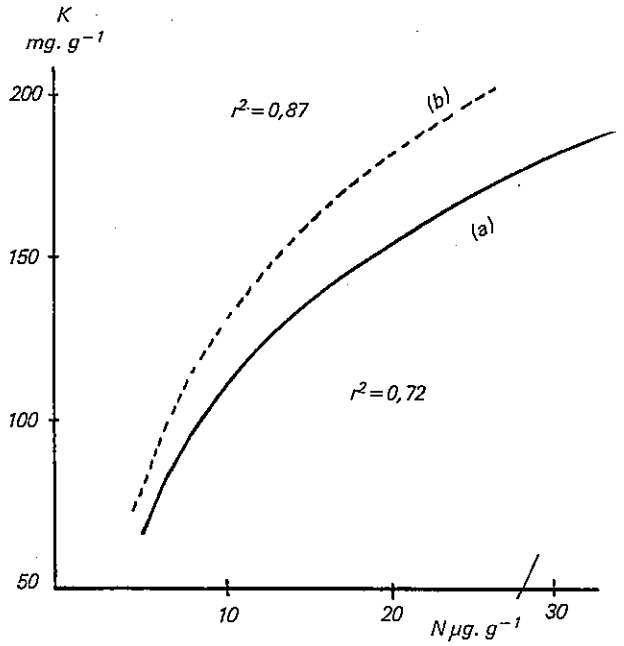


FIG 1: P versus N in drip irrigation with fertilizers, perpendicular to plantation line.



10 to 60cm from dripper (a) *60 to 120cm from dripper (curve b)*

FIG 2: K versus N in drip-irrigation with fertilizers, perpendicular to plantation line:

Drip irrigation and fertigation

- In order to apply the high levels of nutrients required for maximum yields in horticulture, one must maintain a consistently *high soil water potential.*

The precise control of soil water regime by drip irrigation also makes possible a uniform application of fertilizers through the irrigation system. Such possibility which also exists with mechanized sprinkler systems, such as centre pivot becomes imperative under drip irrigation where the localized wetting patterns may present limitation to nutrient uptake.

- An advantage of *localized nutrient application* by drip is the substantial dispersion in the soil of less mobile nutrients such as ammonium phosphate and potassium in clay soils, about ten times more than when the fertilizers are applied in the surface soil.

- By applying fertilizers through the irrigation system, it is possible to ensure *a uniformly high supply of plant nutrients* throughout growth or to adjust this supply to the different requirements of the crop at various stages by changing the amount, the concentration and the relative ratio of the main nutrient.

Fertilizing vegetables for high yields

- Most of *horticultural crops require very high inputs* and their value per hectare is quite large. The cost of fertilizer constitutes a small part of the total production costs at about 10% for field grown vegetables to 1% in heated glasshouses.

As an example, the costs of growing tomatoes under drip irrigation in South Africa is about R6 000/ha including 10% for fertilizers. (See Table 3 — Production costs of tomato under drip). Because of the high output value, the yield must not be limited by any factor that can be controlled. The grower is inclined to build up soil nutrient levels to ensure that even under the most favourable conditions, there is no risk that nutrient supply will ever become a limiting factor.

- To determine *optimum rates of fertilizers* for each combination of crop, soil type and management would need too many field experiments.

TABLE 3: Production costs of tomatoes, North Eastern Transvaal

Fertilizer + M.E.	10,0%
Soil Fumigation	1,1
Spraying Products	3,9
Labour	14,0
Salaries	13,0
Fuel	10,0
Electricity	3,5
Seedlings	0,6
Maintenance	11,5
Packing	13,4
Financing Costs	19,0
Total	100,0%

TABLE 4: Nutrient removal by vegetables crops (kg/ha)

Crop	Yield (t/ha)	N	P	K	Ca	Mg	Country
Potatoes	90	250	110	310	–	–	(V.K.)
Potatoes	50	225	40	375	–	11	(S.A.)
Tomatoes	100	350	60	500	256	30	(S.A.)
Cabbage	100	400	80	350	–	40	(S.A.)
Onions	100	265	50	195	–	26	(I.P.I.)
Melons	50	147	44	245	–	29	(I.P.I.)
Lettuce	60	100	20	200	–	–	(Israel)
Celery	185	300	79	680	–	–	(P.P.I.)
Bell pepper	60	400	66	528	–	904	(P.P.I.)
Cucumbers	25	99	35	158	–	27,5	(P.P.I.)

Tunnel and Glasshouse

Crop	t/ha days	N	P	K	Ca	Mg	Country
Cucumbers*	400 (360)	3 000	150	1 500	2 750	400	(S.A.)
Tomatoes	180 (220)	750	100	1 500	400	50	(U.K.)
Tomatoes	153 (173)	440	96	930	–	–	(Israel)

* Applied in base + fertigation

Reasonable prediction of the fertilizers needed can be made from the amounts taken up by the crop. (See Table 4 — Nutrient uptake by vegetables). For this purpose the maximum amounts of nutrients in the crop during the growing season is more relevant than the amounts removed at harvest, since these quantities must be available to the plant when maximum uptake occurs for optimum yield production.

TABLE 5: Interpretation of soil analysis
Actual levels (concentrations)

	Normal (±)	Low	High
pH	(H_2O) 5,8 - 6,8	<5,4	>7,5
P	(Bray 1) 8-30/60*	<8	>30/>60
K	60-150/100-250	<60/<100	>150/>250
Ca	300-2 000	<300	>2 000
Mg	80-200/120-300	<80/<120	>200/>300
Na	10-50	<100	>250

* underlined figures refer to vegetables and fruit trees

- *Building soil fertility levels*

Before starting a fertilization programme for an intensive crop, it is necessary to bring the soil fertility to the level suitable to this particular type of crop. Large differences exists when comparing field crops and vegetables (see Table 5 — Interpretation of soil analysis for fruit and vegetables).

In the case of fertigation one should remember that soil fertilization is always necessary before starting a fertigation programe.

This should include organic manure when available (F.Y.M., compost, organic fertilizers etc). These material are valuable in providing organic matter, phosphorus, potassium and micro-nutrients in a slow release form.

An economic evaluation of organic products is sometimes difficult because of their changing analysis, transport costs, etc. Liming is also important to maintain a desirable soil reaction.

- *Practical conclusions of glasshouse and field experiments with tomatoes.*

Windsor (1976, 1982) reviewing the basis for fertilizer recommendations for vegetables in the UK stated that the uptake of nutrients does not vary as much as the nutrient concentration in the soil and

TABLE 6: Glasshouse tomatoes Fertigation Experiment (Bar-Yosef et al) 1980)

Treat-ment	Irrig coef	N ppm	Fertilizers kg/ha*			Uptake kg/ha			Yield t/ha		%
			N	P	K	N	P	K	Total	Export	
B11	0,75	200	880	160	1 100	400	96	930	153	83	54
B111	1,60	200	1 800	330	2 270	460	113	970	166	36	22
R	0,57	165	530	500	960	400	63	820	100	76	76

* Not including base fertilizers
B11, B111: Superphosphate Am Sulphate, Mg
R = Dry blood, K_2SO_4, Superphosphate, Mg

that the most important criterion for plant growth is the optimum concentration of the nutrients in the soil root zone. Bar Yosef (1982) summarizing field experiments with tomatoes under drip irrigation defined several parameters for recommending total and daily nitrogen application rates as well as N concentration in the irrigation water.

Maximum yield (112 t/ha) was obtained with 200 ppm N but the maximum quality yield needed only 130 ppm. This concentration as well as the amount of irrigation are related to climatic and soil factors.

A marked decrease in yield was observed when the soil water potential decreased from -50 to -150 centibar (mainly osmotic potential = 90%). On the other hand the dry matter content in tomato fruit improved from 5% at -70 centibar to 8% at -140 centibar, thus improving the fruit quality.

In glasshouse experiments with tomatoes under drip fertigation Bar-Yosef and Sagiv (1980) obtained an optimum yield of 166 t/ha with irrigation at 1,60 of evaporation from a Class A Pan located outside the glasshouse, and at 200 ppm N in the irrigation water.

The maximum yield in this experiment was 186 t/ha and the theoretical maximum yield was calculated at 204 t/ha. The maximum exportable yield in March, April and May, needed 440, 120 and 250 ppm N in the soil solution respectively, corresponding to irrigation solutions at 250, 70 and 110 ppm N.

Windsor (1961), studying the fruit quality and yield of glasshouse tomatoes found that the best quality and highest yields (180 t/ha) were obtained with a feeding solution at 2 000 kg K/ha and an N:K ratio equal to 1:2,5.

- *Dry matter production and nutrient uptake pattern.*

In a classical experiment, Halbrooks and Wilcox (1980) determined the growth and the elemental uptake of irrigated tomatoes from 21 days after emergence to harvest. Dry weight accumulation after 56 days was mainly as fruit at 4,9 g per day (Fig 3a, b, c, & d). Daily nutrient uptake also mainly in the fruit was (in mg/plant) N - 170, P - 23, K - 256 Ca - 126, Mg - 20. With a density of 24 000 plants per hectare, the daily uptake in kg/ha should be: N -4,08, P - 0,52, K - 6,14, Ca - 3,0, Mg - 0,48. These data are frequently used as a base for tomato fertilization in South Africa and Israel, resulting in a production in excess of 100 t/ha. (See Table 7 — 'Recommendations for fertilization of tomatoes and egg-plant. Min. of Agr. extension service, Israel 1982/83).

TABLE 7: Nutrient requirements of tomatoes (daily)
Source: Israel Dept of Agriculture
Ext. service 1982/83
(Plant population = 18 000 pp/ha)

From	*No of days*	*Water as m³/ha*	*N/ha (g)*	*P/ha (g)*	*K/ha (g)*
Seed	*21*	*30*	*1 200*	*300*	*2 400*
22	*45*	*50*	*2 000*	*300*	*3 200*
46	*70*	*35*	*2 500*	*300*	*3 000*
70	*110*	*30*	*3 500*	*350*	*4 400*
110	*End*	*30*	*2 500*	*200*	*1 400*

- *Fertilization of Lettuce and Cabbage*

  — Lettuce is a crop with a short growing period and a shallow root system. Fertigation is particularly well suited in sandy soils where accurate control of water and ions concentration is critical due to the low exchange capacity and the intensive leaching of nutrients in these soils.

  — In a field experiment with drip irrigation Bar-Yosef (1982) obtained maximum yield (83 t/ha) with irrigation at 0,80 of Class A Pan evaporation and fertilization at 240 kg N/ha with a solution N:P:K — 5:0,9:5,9. The optimum exportable

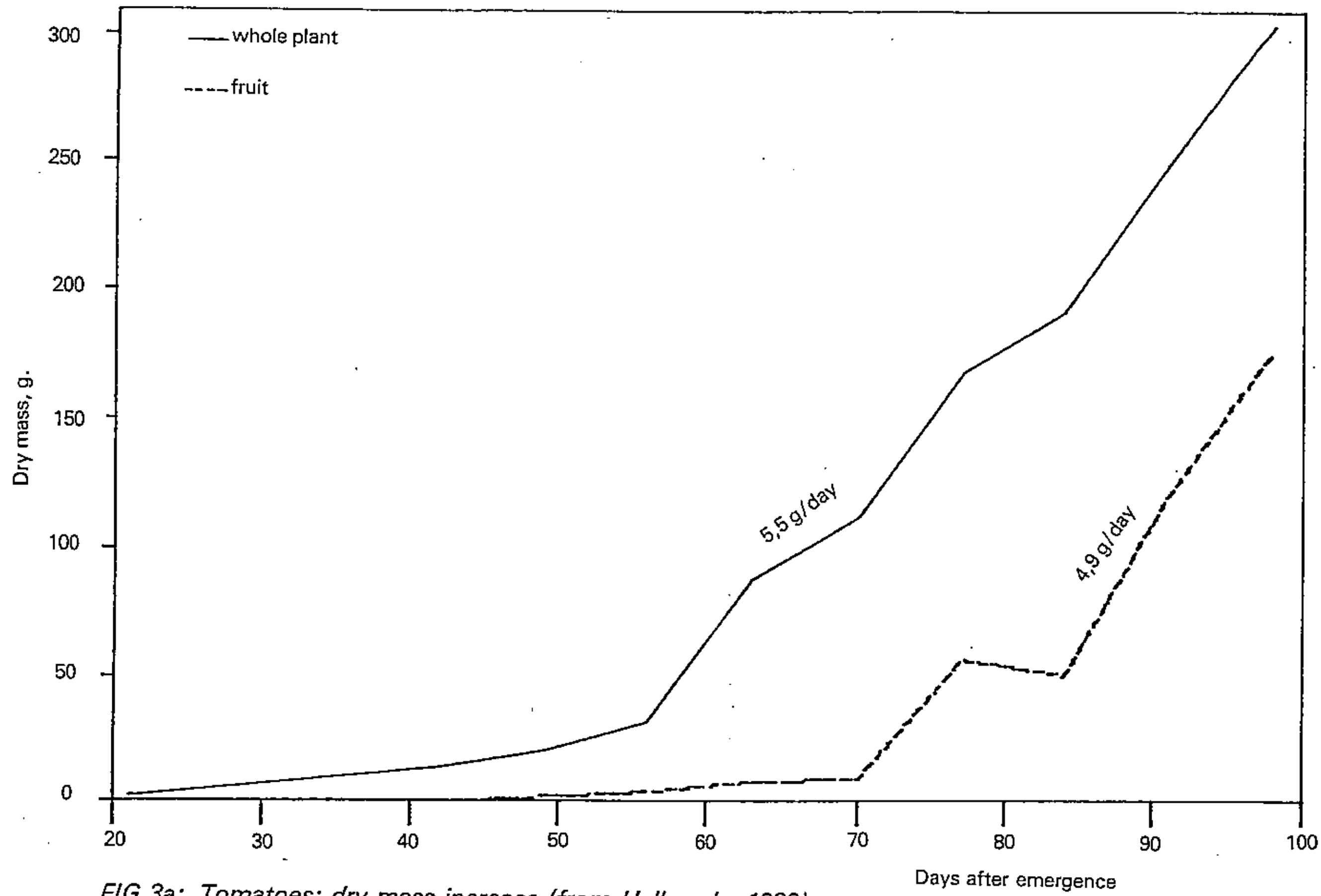


FIG 3a: Tomatoes: dry mass increase (from Halbrooks 1980)

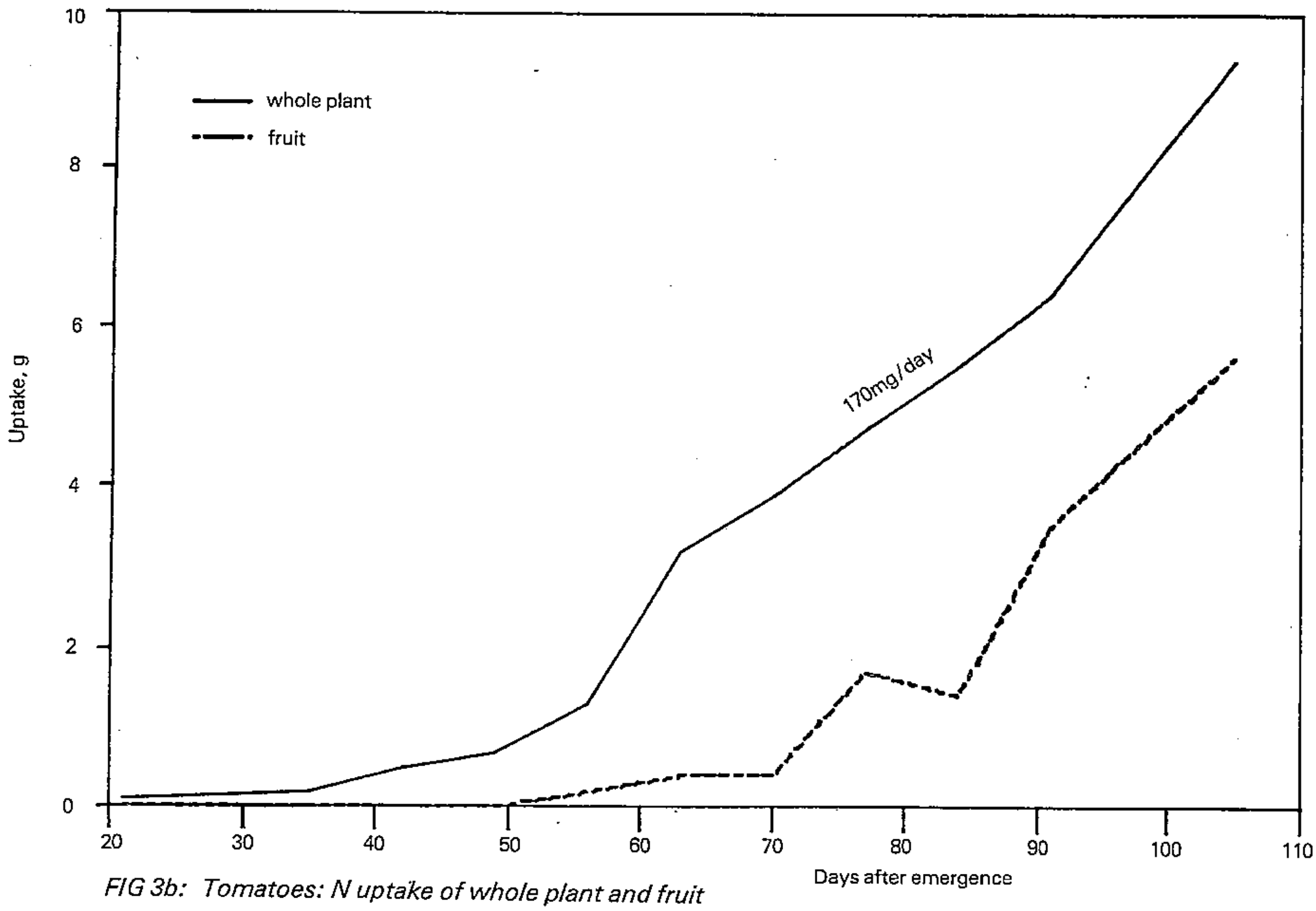


FIG 3b: Tomatoes: N uptake of whole plant and fruit

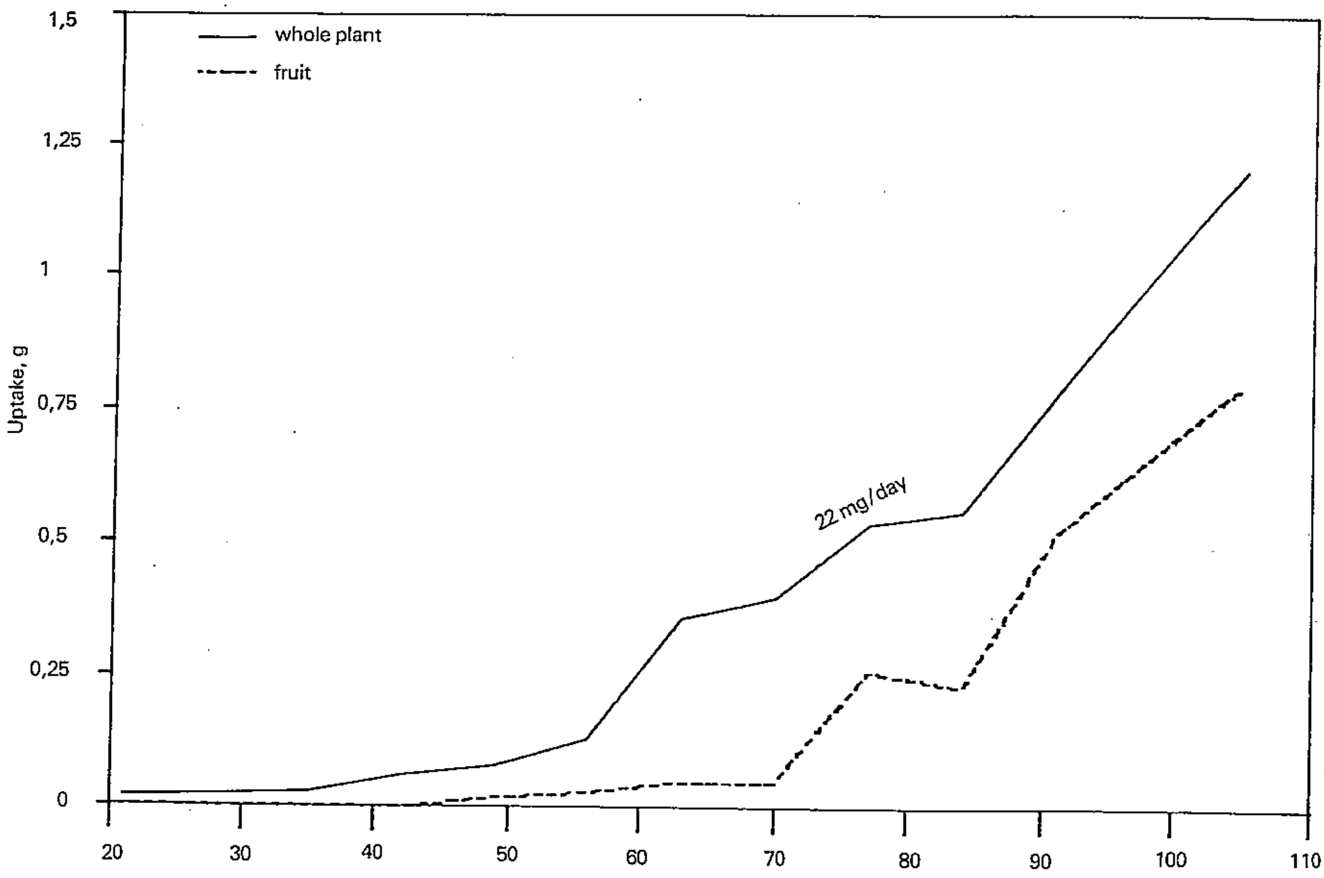


FIG 3c: P uptake of whole plant and fruit

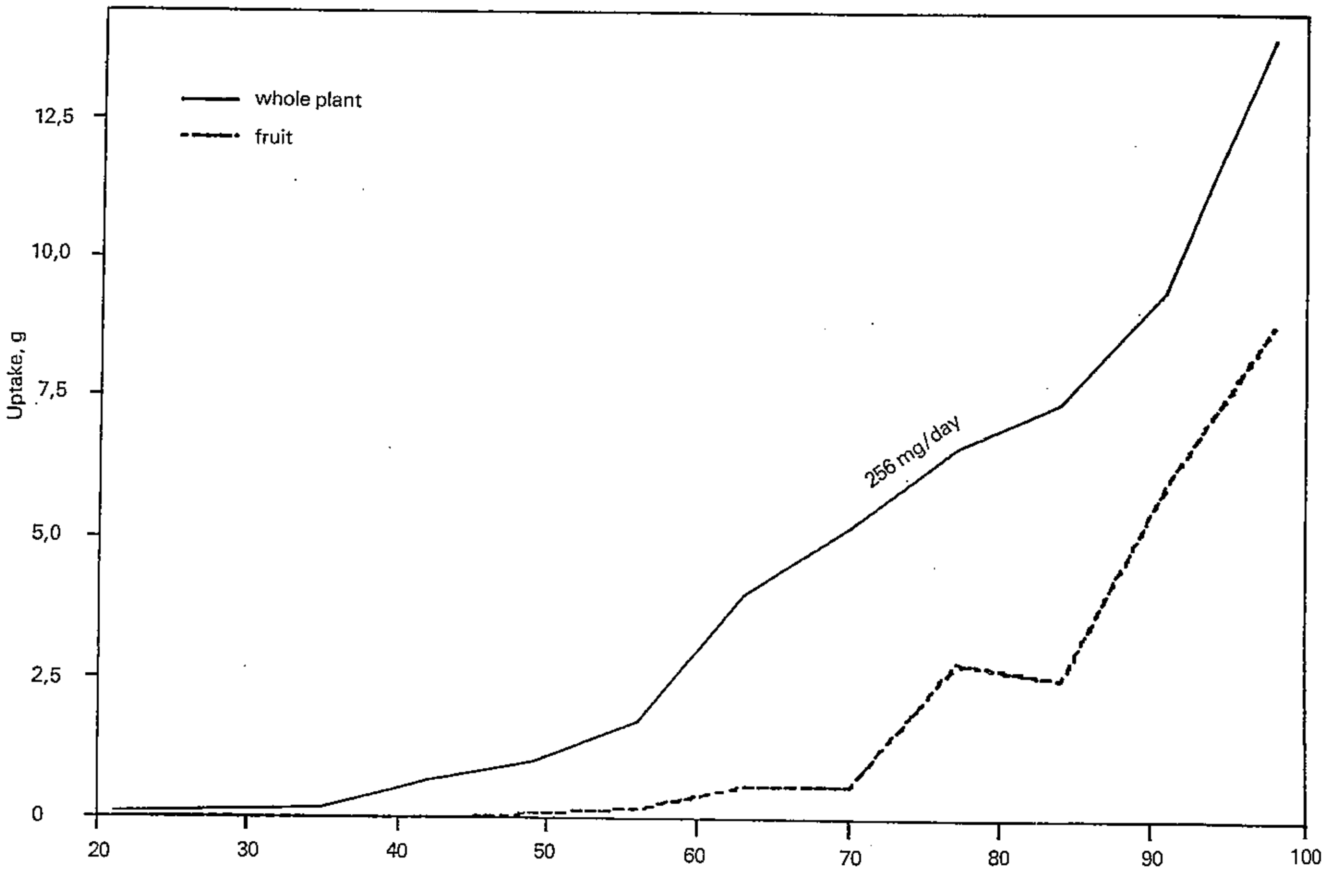


FIG 3d: Tomatoes: K uptake of whole plant and fruit

yield (45 t/ha) was obtained with irrigation at 1,20 of Class A pan and fertilization at 100 ppm N in the irrigation solution.

Considering total and exportable yield the optimum treatment was irrigation at 1,0 Class A Pan and fertigation at 100 ppm N, 18 ppm P and 120 ppm K. The NO_3:NH_4 molar ratio was 3:1.

At planting time, the soil contained 30 ppm P and 105 ppm K.

— Practical recommendations derived by the author from these results are presented in Tables 8a and 8b. In the USA Paterson (1979) conducted fertilizer experiments with lettuce on a soil high in phosphorus and low to high in potassium. The optimum economic yield was obtained with 67 N, 49 P and 150 K (kg/ha). Liming was necessary to raise the pH from 5,2 to 6,3. This programme returned $5918/ha. Omitting lime P or K reduced the profit drastically. Doubling N or K did not increase yield or reduced the profit (Tables 9 and 10).

TABLE 8a: Intensive production of head lettuce — Irrigation and fertilization practices winter season

Target yield =	120 000 heads/ha
Average weight:	0,500 kg/head of export quality
Total yield =	60 t/ha (4% dry matter)
Harvest =	starts 80 days from sowing date
Irrigation at sowing =	sprinkler — during 4 days.
Irrigation =	drip irrigation every 2-3 days.
Fertilizers kg/ha : N = 100	P = 20 K = 200

TABLE 8b: Amounts of Irrigation Water in terms of Class A Pan Evaporation (Eo) for lettuce under drip irrigation.

day from Sowing	% of Eo	Tensiometer readings
4-15	45- 50	-8 to -20 centibar
16-30	70- 75	
31-45	90-100	
46-60	90-100	
61-80	90-100	

TABLE 8b: Lettuce: Nutrient concentrations in the soil (0-40cm)

Days from Sowing	*N in Soil ppm		P in Soil ppm		K in soil ppm
	mg/l			mg/l	
4-15	50	60- 80	25-40	4	100-150
16-30	60	70-100	25-40	7	100-150
31-45	100	80-110	25-40	10	100-150
46-60	40	80- 60	20-35	5	100-150
61-80	0	10-30	15-30	0	90-130

* Mineral N — Sampling by suction probe
* P and K — Extractions by sodium bicarbonate

TABLE 9: Fertilizer experiment on lettuce (U.S.A.)

Treat ment	kg/ha					
	N	P	K	Yield t/ha	% Market	Net return $/ha
Optimum	67	49	150	42	90	5 918
−P	67	–	150	25	74	3 021
−K	67	49	–	20	88	2 735
− Lime	67	49	150	14	46	835
3 X N	201	49	150	21	70	2 107
2 X K	67	49	300	42,2	90	5 902

TABLE 10: Nutrients required by Lettuce kg/ha

Country	Yield t/ha	N	P	K
Israel (Fertigation)	60	100	20	200
Uptake per ton	–	1,66	0,33	3,32
USA (Soil fertilizer)	42	67	49	140
Uptake per ton	–	1,59	1,17	3,33

- *Experiments with cabbage in Natal* by Richards, Smith and Bennet (1983) showed that high yield of cabbage planted in June (136 t/ha) can be obtained with 300 kg N/ha split in three applications before, four weeks and eight weeks after transplanting.

  When cabbage were planted in March optimum yields (115 - 120 t/ha) were obtained with 225 - 300 kg N/ha.

Conclusion

Experiments with different water regimes and nutrient concentrations in the plant root volume are essential to determine the basis for fertilizing vegetables grown under irrigation.

Maximum yields of best fruit quality can be obtained by controlling the soil water tension, the electrical conductivity, the nutrient concentration in the soil solution and the nitrogen concentration in the irrigation water.

High fertility levels and a suitable pH are a prerequisite when applying fertilizers through the irrigation system.

When no direct experimental evidences exist as is often the case, one possible approach is by informed opinion based on practical experience of successful growers.

The danger exists that when recommendations have been formulated in this way it might be thought that further research is not justified.