A Training Manual for Training of Trainers on Nutrient Requirement of Major Horticultural Crops in Ethiopia

Volume 5

By

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Nutrient Requirement of Major Vegetable Crops in Ethiopia

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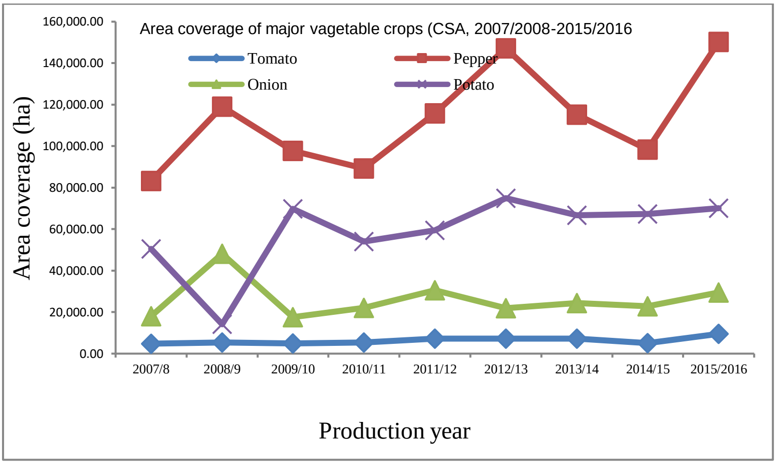
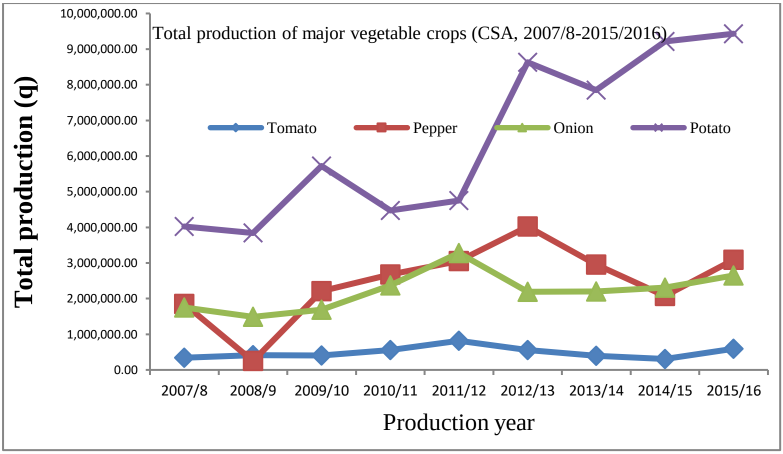
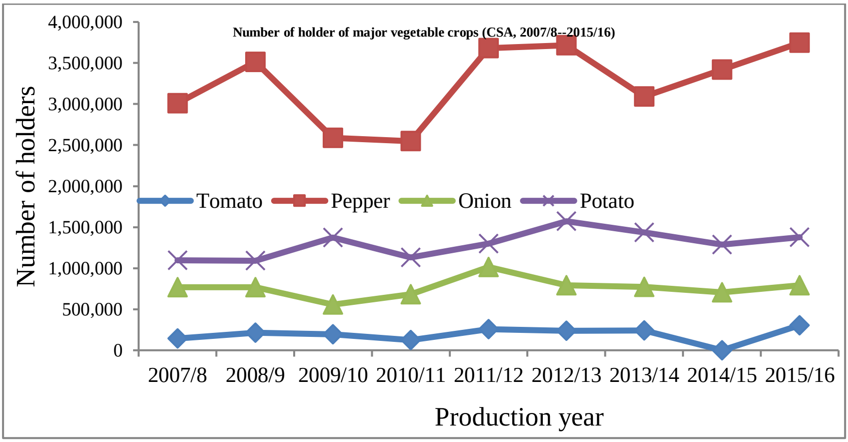
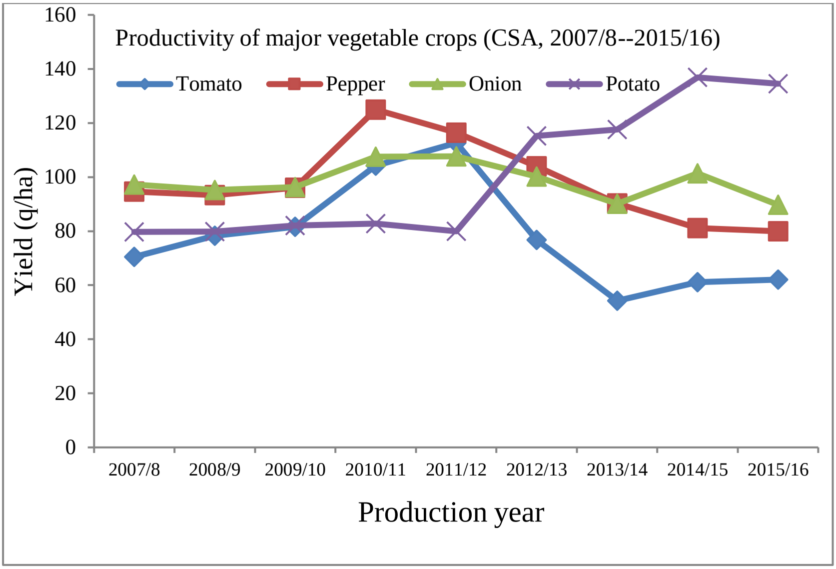
Introduction

There are many vegetable crops cultivated in Ethiopia such as: Pepper, Tomato, Onion Artichoke, Lettuce, Cabbage and Ethiopian Kale (*Gomen* and *Brango*), Cauliflower and Broccoli, Spinach, Cucumber, Melon, Pumpkin and Squash, Watermelon, Pea, Snap Bean, Okra, Asparagus, Eggplant, Carrot, etc... In addition, there are many African Indigenous vegetable crops such as Amaranthus, cow pea, Jute mellow, etc... cultivated and used in many areas of Ethiopia. Cultivating all these crops is not without nutrient amendment. However, research attention was not given at all these crops except few ones.




Total production of major vegetable crops (CSA, 2007/8-2015/2016)
Total production (q)
10,000,000.00
9,000,000.00
8,000,000.00
7,000,000.00
6,000,000.00
5,000,000.00
4,000,000.00
3,000,000.00
2,000,000.00
1,000,000.00
0.00
Tomato
Pepper
Onion
Potato
2007/8
2008/9
2009/10
2010/11
2011/12
2012/13
2013/14
2014/15
2015/16
Production year


Number of holder of major vegetable crops (CSA, 2007/8--2015/16)
Number of holders
4,000,000
3,500,000
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
Tomato
Pepper
Onion
Potato
2007/8
2008/9
2009/10
2010/11
2011/12
2012/13
2013/14
2014/15
2015/16
Production year

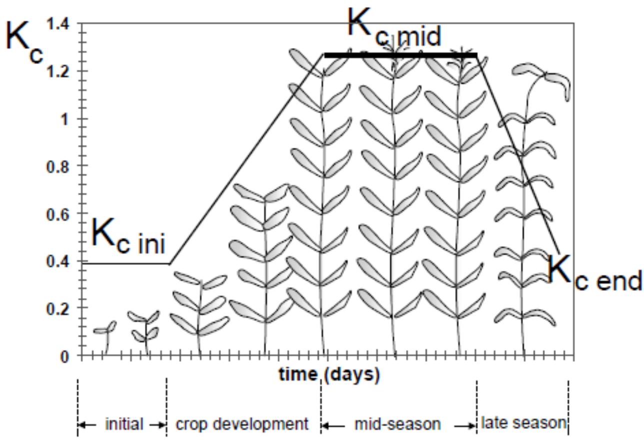


In general, based on the CSA data, the productivity of major vegetable crops on the farmers fields in Ethiopia are very low while in the research field are more than quadruple, and still more than 8 to 10 times in other parts of the world. These is because all these crops are not getting any proper field managements at all including nutrient requirements.

Crop growth stages of annual vegetable crops

The growing period of all annual crops can be divided into four distinct growth stages: initial, crop development, mid-season and late season. As the crop develops, the ground cover, crop height and the leaf area change. Due to differences in evapotranspiration during the various growth stages, the Kc for a given crop will vary over the growing period. The critical growth stages had related with not only critical water requirement periods but also with nutrient requirement. This figure illustrates the general sequence and proportion of these stages for annual crops.

FIGURE 25
Generalized crop coefficient curve for the single crop coefficient approach



The initial stage (10% ground cover), length of the initial period is highly dependent on the crop, the crop variety, the planting date and the climate. The crop development stage runs from 10% ground cover to effective full cover. The mid-season stage runs from effective full cover to the start of maturity. The late season stage runs from the start of maturity to harvest or full senescence.

Where there is higher temperature, there would be shorter growth periods for a given crop variety and vice versa. Thus, the critical time for irrigation and nutrient application for a given crop variety would vary accordingly (variety, altitude, management practices, planting density, etc...) for all crops.

Most vegetables require high amount of nutrients in a relatively short growth period. Sustaining adequate NPK concentrations in the soil solution during active growth period is crucial for increasing productivity.

Essential elements in plant

There are 13 elements in addition to C H O - essential nutrients in crop growth and development. The first criterion of essentiality is 1) the element is essential for a plant to complete its life cycle, has historically been the one with which essentiality is established.

2) the role of the element must be unique in plant metabolism or physiology, meaning that no other element will substitute fully for this function. A partial substitution might be possible. For example, a substitution of manganese for magnesium in enzymatic reactions may occur, but no other element will substitute for magnesium in its role as a constituent of chlorophyll.

3) the essentiality of the element is universal among plants. Elements can affect plant growth without being considered as essential elements. All the essential elements are grouped in to macro elements (N, P, K, Mg, S) and micro elements (Boron, Cl, Copper, Iron, Mn, Molybdenum, Nickel and Zinc). All crops require, all these nutrients equally important.

Liebig's law of the minimum

In crops nutrient management, the most limiting constraint must be relieved before other changes will be effective where water and light are not limiting.

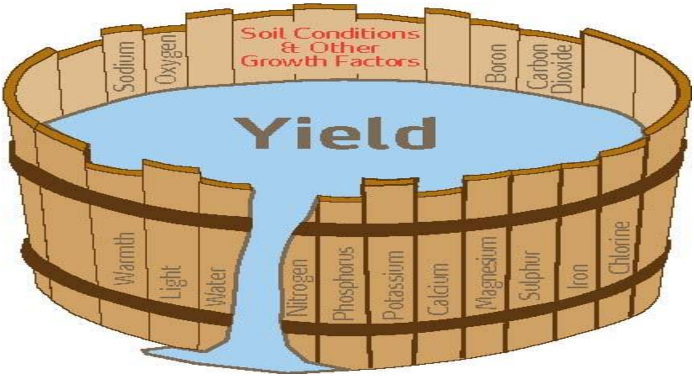


Figure. Liebig's law of the minimum

Main functions of plant nutrients

Table 5: Summary of main functions of plant nutrients:

Nutrient	Functions
Nitrogen (N)	Synthesis of proteins (growth and yield).
Phosphorus (P)	Cellular division and formation of energetic structures.
Potassium (K)	Transport of sugars, stomata control, cofactor of many enzymes, reduces susceptibility to plant diseases.
Calcium (Ca)	A major building block in cell walls, and reduces susceptibility to diseases.
Sulphur (S)	Synthesis of essential amino acids cystin and methionine.
Magnesium (Mg)	Central part of chlorophyll molecule.
Iron (Fe)	Chlorophyll synthesis.
Manganese (Mn)	Necessary in the photosynthesis process.
Boron (B)	Formation of cell wall. Germination and elongation of pollen tube. Participates in the metabolism and transport of sugars.
Zinc (Zn)	Auxins synthesis.
Copper (Cu)	Influences in the metabolism of nitrogen and carbohydrates.
Molybdenum (Mo)	Component of nitrate-reductase and nitrogenase enzymes.

Integrated plant nutrient management

Crops obtain nutrients from **several sources**:

- Mineralization of soil organic matter (all nutrients)
- Deposition from the atmosphere (mainly nitrogen and sulphur)
- Weathering of soil minerals (especially potash)
- Biological nitrogen fixation (legumes)
- Application of organic manures (all nutrients)

- Application of manufactured fertilizers (all nutrients)
- Other materials added to land e.g. soil conditioners, etc....

For **good nutrient management**, the total supply of a nutrient from all these sources must meet, but not exceed, crop requirement. Crop requirement varies with species (and sometimes variety of the crop), with yield potential (this in turn depends on soil properties, weather and water supply) and intended use (for example feed and milling wheat). Nutrients should be applied in organic manures or in fertilizers only if the supply from other sources fails to meet crop need. Where nutrients are applied, the amounts should be just sufficient to bring the total supply to meet crop need.

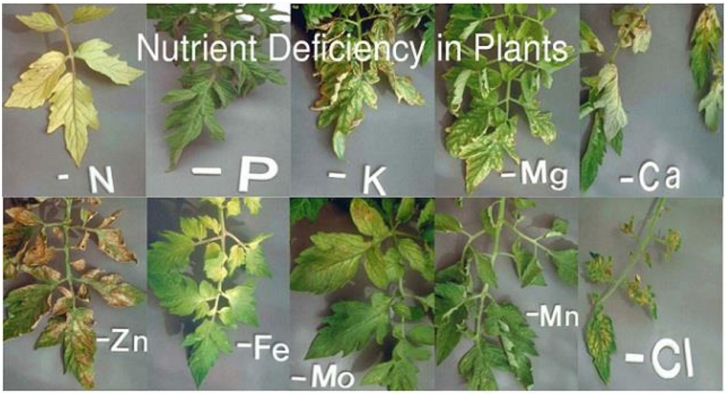
Matching nutrient supply to crop requirement involves several steps, some clear to the grower or adviser. Every time updated scientific guide would help to match nutrient applications to crop need, maximizing economic return and minimizing costly nutrient loss to water and air.

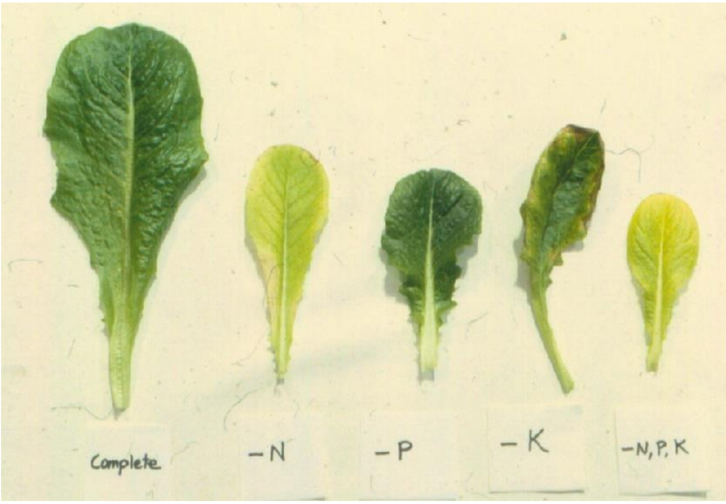
Diagnostic Criteria of Essential Elements

Essential elements deficiencies could be identified through

1. Visual diagnosis

Symptoms of disorders of essential elements deficiencies are usually observed at the early growth stages, therefore, provide a guide to identify nutritional deficiencies in plants. There are many guidelines with color charts (photos) showing each essential element for each horticultural crops and any one can get from many web sites.





2. Tissue testing

Plant tissue testing is a technique for rapid determination of the nutritional status of a crop and is often conducted on the field sites where crops are grown sampled at the proper stages (there are standard guideline for each crops). The test generally assesses the nutrient status by direct measurements of the unassimilated fraction of the nutrient in question in the given plant. There are lists of established standards of nutrient concentration (% dry mass of leaves) for each crop, showing **low**, **sufficiency** (**optimal**), and **high** indicating that the corresponding nutrient required are variable.

Concentrations of nitrogen in leaves of various fruits crops under cultivated conditions

The *critical concentration* of a nutrient is defined as the concentration of the nutrient below which yields are suppressed. In the determination of critical concentration, analysis of a specific tissue of a specific organ at a designated state of development is required. Because of the amount of work involved, critical concentrations are rarely determined; consequently, *ranges of sufficiency* are most commonly used in assessment of plant nutrition. For each nutrient or beneficial element, ranges of sufficiency are reported.

Nutrient concentration in plants

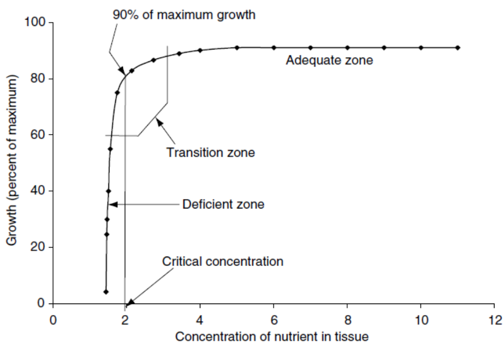


FIGURE 2.2 Model of plant growth response to concentration of nutrients in plant tissue. Units of concentration of nutrient in tissue are arbitrary. The model shows the critical concentration of nutrient at a response that is 90% of the maximum growth obtained by nutrient accumulation in the tissue. Deficient zone, transition zone, and adequate zone indicate concentrations at which nutrients may be lacking, marginal, or sufficient for crop yields.

Sufficiency' is mean range of lower and upper concentrations commonly reported in healthy plants showing no deficiencies.

'High' is a concentration that might represent excessive accumulation of nitrogen.

Optimum or sufficient values for maximum yield or for healthy growth of plants will vary with species, age, and nutrition of plant, position of organ on plant, portion of plant part sampled, and other factors.

3. Soil tests

A soil test is a chemical or physical measurement of soil properties based on a sample of soil. Commonly, however, a soil test is considered as a rapid chemical analysis or quick test to assess the readily extractable chemical elements of a soil. Interpretations of soil tests provide assessments of the amount of *available nutrients*, which plants may absorb from a soil. Recommendations for fertilization may be based on the results of soil tests. Chemical soil tests may also measure salinity, pH, and presence of elements that may have inhibitory effects on plant growth.

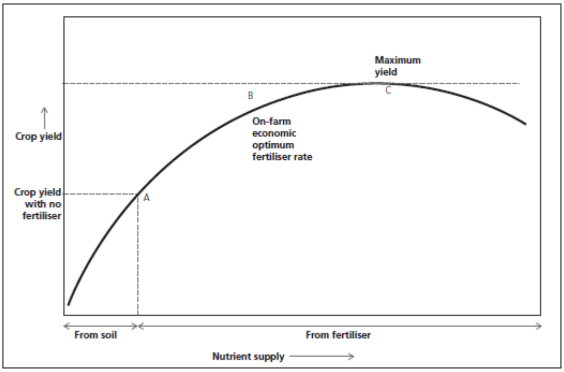
Table 1. Mehlich-1 soil-test interpretations used for vegetable crops on mineral soils.

	Parts Per Million				
Element	Very Low	Low	Medium	High	Very High
P	< 10	10 - 15	16 - 30	31 - 60	> 60
K	< 20	20 - 35	36 - 60	61 - 125	> 125
Mg	--	< 15	15 - 30	> 30	--
Ca	< 50	50-100	101-300	301-500	> 500

Researchers identified a three-phase model, in this model, growth curves describe a deficient level of nutrient accumulation, region of poverty adjustment, or minimum percentage where yields rise with increasing internal concentrations of nitrogen. In the second zone of the growth curve, a transition from deficiency to sufficiency occurs followed by a region known as luxury consumption in which internal concentration of nitrogen rises but yield does not rise. The concentration of nitrogen at the transition from deficiency to sufficiency is known as the *critical concentration*.

Nitrogen response curve

A Typical Nitrogen Response Curve



With reference to diagram above:

• Without applied nitrogen, yield typically is low (A).

• As nitrogen use increases from very small amounts, there is a large increase in yield up to the '*on-farm* economic optimum' nitrogen rate (B). This rate depends on the cost of the applied nitrogen and on the value of the crop ('breakeven ratio') as well as on the shape of the response curve. **All recommendations should be calculated using a typical breakeven ratio to provide the best on farm economic rate of nitrogen to apply**. Substantial changes in the value of the crop produce or in the cost of nitrogen are needed to alter the recommendations.

• Application of nitrogen above the on-farm economic optimum will increase yield slightly but this yield increase will be worth less than the cost of the extra nitrogen. • Maximum yield (C) is reached at a nitrogen rate greater than the on-farm economic optimum and this is never a target if farm profits are to be maximized. Application of nitrogen above point C does not increase yield, and with further applications yield falls and the need for agro-chemicals such as fungicides and growth regulators may increase.

The optimum level of agronomic practices such as fertilizer rates required for any given crop might vary with environment, soil types, crop variety and field management practices. Thus, it is very difficult to give general recommendations applicable to the different agro ecological zones. But to optimize crop productivity at a particular location a **full package of information** is required for specific growing system.

more frequently. N leaching depends on the fertilizers applied, timing of precipitation, irrigation, soil type and plant N uptake behavior. Split application of N fertilizers during a single cropping period is recommended for controlling N, especially NO_3^- leaching into groundwater.

Nutrient requirement of major vegetable crops in Ethiopia

Tomato

There are three types of cultivated tomato, indeterminate, semi-determinate and determinate.

Indeterminate plants are tall, frequently more than 2 m high, with vegetative growth continuing much longer after the start of flowering than in the other two types. Fruit ripens gradually, starting from the basal fruit clusters.

Semi-determinate plants are less tall than the former reaching a maximum height of 0.9-1.5 m, their characteristic is that the main fruit clusters ripen together, but the plant will also continue to produce additional fruit.

Indeterminate and semi-determinate tomatoes need to be staked or trellised, and are grown for the fresh market and harvested by hand. Determinate-types, the so-called bush tomato, mostly rest on the ground and have a relatively concentrated flowering and fruit setting lasting only about three weeks. In this period vegetative growth continues. Most fruit of determinate cultivars matures in a relatively short period and for this reason are suitable for mechanical harvesting. Processing tomato cultivars are bred for firmness and strong skin and are of the determinate type.

The fertilizer requirements of tomato are **high** and it needs frequent fertilizer applications. The key for growing high-yielding tomato is applying the right fertilizer mixture, at the right rate and at the right time. For tomato grown in soil, fertilizer recommendations should consider the yield goal, growth stage and field data, such as soil test results, water quality and tissue analysis.

Table 1. Nutrient uptake/removal of tomato fruit estimated based on target yield

Target yield	Nutrient uptake/removal (kg/ha)			Data Sources*
(t/ha)	N	P_2O_5	K_2O	
24	177	46	319	IFA, tropic conditions, various sources
40-50	100-150	20-40	150-300	IFA, temperate conditions
40	108	31	164	AVRDC, processing tomato, 2005
35	87	30	127	AVRDC, cherry tomato, 2001
40	132	37	202	IPNI, nutrient removal in selected vegetables, 1996-2007
50	140	65	190	IPNI, Dr. H. L. S. Tandon. Fertilizer Recommendation for Horticultural Crops, 2000
40	110	30	150	FAO, Fertilizer and their use, 2000

* IFA: International Fertilizer Industry Association
IPNI: International Plant Nutrition Institute
AVRDC: AVRDC - The World Vegetable Center

Each tomato types: determinate, semi-determinate and indeterminate requires different fertilizer rates and timing.

Nutrient requirement of tomato in Ethiopia

Various studies have been made in determining of tomato in Ethiopia, the results showed that different rates of N and P are required in different locations as indicated in the following table.

Table. Results of fertilizer studies for field tomato production in Ethiopia

Location	Melkassa (Blanket)	Mereb-lekhe District, N. Ethiopia	Melkassa (EE)
N (kg ha^{-1})	100 Urea	150 kg Urea ha^{-1}	N 60-100 kg ha^{-1}
P (P_2O_5 kg ha^{-1})	200 kg DAP ha^{-1}	DAP 200 kg ha^{-1}	P 48 kg ha^{-1}
Reference		Yemane Kahsay, Alemat Embaye, Guesh Tekle	Edossa Etissa, Nigussie Dechassa, Tena Alamirew, Yibekal Alemayehu and Lemma Desalegn

The treatments consisted of four rates of nitrogen (0, 50, 100 and 150 kg N ha^{-1}) and four rates of phosphorous (0, 46, 92 and 138 kg P ha^{-1}). The results indicated that application of combined 100 kg N ha^{-1} and rate at 46 kg P ha^{-1} gave the highest total fruit yield of furrow irrigated tomato during the cool season with *'Melkasholla'* variety at Melkassa. However, from regression lines fitted, peak yield of 73.45 t ha^{-1} total fruit yield was estimated from the application of 100 kg N ha^{-1}, while 70.003 t ha^{-1} total fruit yield was estimated from application of 85 kg P ha^{-1} (Edossa, 2014).

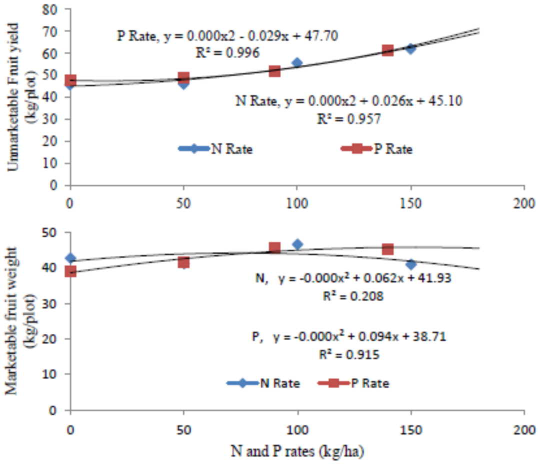


Figure 7. Relationships between inorganic N and P rates and fresh fruit yield of furrow irrigated tomato grown at Melkassa, Ethiopia

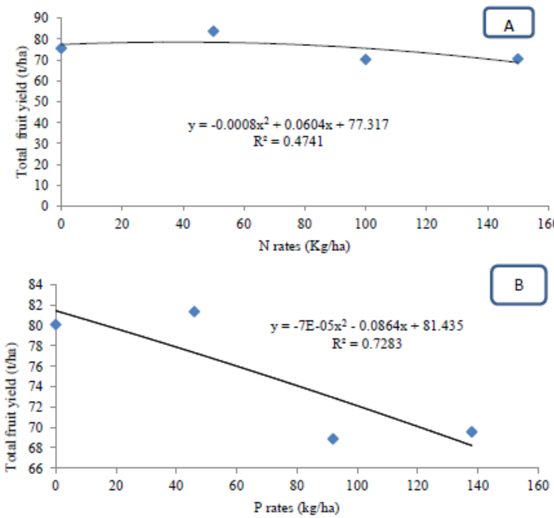
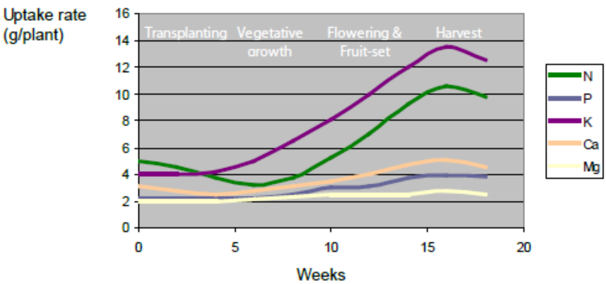


Figure 4. Estimated total fruit yield of tomato as a function of N and P fertilizers application rates under rainfed conditions at Melkassa

Fig 4. Growth of Tomato (Melkashola Var) 1.5 m height and yielding up to 900 qt/ ha

Figure 5: The uptake dynamics of the macro- and the secondary nutrients by a tomato plant
(Source: Huett, 1985)



Fertilizer requirements studies are limited to N and P only

Onion

Studies of Nutrient Requirement of onion in Ethiopia

Onion nutrient management improvement has an important role in normal plant growth and developments especially for the vegetative plant parts to give optimum yields. According to Assefa *et al.* (2015) finding, using the optimum amount of fertilizer nutrients substantially increases the productivity of onion bulbs beside to using of improved cultivars. Because of Onion is one of the heavy feeders vegetable crop, it requires more mineral fertilizers than other vegetables for a bulb and shot growth (Yohannes *et al*., 2013). According to Simon *et al.* (2015) report, three onion varieties (Adama Red, Bombe Red, and Nafis) have been tested at Humbo, Wolaita Zone; Ethiopia was responded to different application of nitrogen and phosphorous fertilizer rates. The finding revealed that the size and onion bulb yield has increased as the level of nitrogen and phosphorous were increased which implies as the optimum nutrient management has a positive contribution to yield improvement of onion production and productivity especially for those areas where a nutrient deficiency is critical. Yohanis *et al.* (2013) also reported a similar finding on the effects of combined application of nitrogen and farmyard manure which has increased the onion bulb yield at Jimma environmental condition, which has increased the onion bulb yield at Jimma environmental condition.

Furthermore, the effects of nitrogen and phosphorous on onion yield and yield components were studied on the vertisol of Shewa Robit, Northeast Ethiopia, has been responded to a different rate of the fertilizers and recommended based on the optimum yield obtained (Abdisa *et al.*, 2011)**.** Generally**,** all **t**he results of different nutrient management practices have been shown that the onion yield production and productivity can be maximized by applying different plant nutrient management systems for the specified soil types at specific locations.

Table. Fertilizer recommended for field onion production in Ethiopia

Location	Bahir Dar	Mekele Univ.	Dembiya/ North Gonder	Shire Endesilase	Centeral Tiray, Laely Maichew	Melkassa	Melkassa	Dugida (East Shoa)
N (kg ha^{-1})	100	92	N:P_2O_5:S fertilizer at the rate of 105:119.6:22 kg ha^{-1}	100	82	69 N kg ha^{-1} and 92 kg P_2O_5 ha^{-1} combined with 20 t FYM ha^{-1}	100 Urea	138 kg ha^{-1}
P (P_2O_5 kg ha^{-1})	P 17.5 kg/ha)	(P 20kg /ha)					200 DAP	92 P_2O_5 kg ha^{-1}
Reference	U. Aliyu, M.D. Magaji, A. Singh and S.G. Mohammed, 2017.	Negash Aregay, Mitiku Haile and Charles Yamoah, (2009)	Muluneh Nigatu, 2016	Kiros Gebretsadik and Nigussie Dechassa, 2018	Guesh Tekle, 2015. M Sc Thesis	Tekeste, N., Dechassa, N., Woldetsadik, K., Talae, A., Dessalegne, L. and Takele, A. 2017.	MARC	Agare Luphi (Melkassa)

Hot Pepper

Chili pepper (*Capsicum annuum*) is a popular vegetable valued around the world for the color, flavor, spice, and nutritional value it contributes to many meals. Pepper varieties display a wide range of plant and fruit traits, and production practices vary greatly from region to region. Chili pepper grows best in a loam or silt loam soil with good water-holding capacity, but can grow on many soil types, as long as the soil is well drained. Soil pH should be between 5.5 and 6.8.

Nutrient Requirement of hot pepper

The amount of fertilizer to apply depends on soil fertility, fertilizer recovery rate, soil organic matter, soil mineralization of N, and soil leaching of N. A soil test is highly recommended to determine the available N, P, and K. The amount to be applied can then be calculated based on your target yield and adjusted for residual nutrients.

For example, if the target yield is 2.5 t/ha and the soil test indicate that 100 kg each of N, P, and K are available, you would need to apply about 125 kg N, 10 kg P, and 10 kg K. Nutrient requirements for a target yield of 5 t/ ha (dry matter basis) are listed in Table 1. Forty percent of the N should be applied as basal fertilizer before transplanting. The remaining 60% should be side-dressed in three equal amounts at 2, 4, and 6 weeks after transplanting (WAT). Half of the P and K should be applied as basal fertilizer, and the remainder should be side dressed at 4 WATS. Fertilizer recommendations depend heavily on local conditions. Minor nutrient deficiencies, e.g. zinc, iron and calcium may also be factors in some localities.

AVRDC suggested that for example, if the target yield is 2.5 t/ha and the soil test indicate that 100 kg each of N, P, and K are available, you would need to apply about 125 kg N, 10 kg P, and 10 kg K. Nutrient requirements for a target yield of 5 t/ ha (dry matter basis) are listed in Table 1.

Table 1. N,P, and K requirements, expected recovery rate, and total amount to apply for a target yield of 5 t/ha of dried chili peppers

Nutrient	Nutrient requirement (kg/ha)	Nutrient recovery (%)	Amount needed[z] (kg/ha)
N	180	40	450
P	22	10	220
K	200	50	400

[z]Assuming no nutrients are available in the soil; the actual amount of fertilizer applied should be adjusted downward based on the soil test results.

Forty percent of the N should be applied as basal fertilizer before transplanting. The remaining 60% should be side-dressed in three equal amounts at 2, 4, and 6 weeks after transplanting (WAT). Half of the P and K should be applied as basal fertilizer, and the remainder should be side dressed at 4 WAT.

Studies of Nutrient Requirement of hot pepper in Ethiopia

Various nutrient studies across Ethiopia showed that hot pepper responds of nutrient applications.

Wakuma, 2018 found that the highest marketable (2.29 t ha^{-1}) and total dry pod yield ha^{-1} (2.44 t ha^{-1}) were recorded when Melkashote hot pepper cultivar combined with 84.5 NPSZn +136.5 urea Kg ha^{-1} at Rayana Azebo area.

He found Melkashote cultivar with 84.5 NPSZn +136.5 urea Kg ha^{-1} rate of fertilizer, followed by Melkaawaze cultivar with 65 NPSZn + 105 urea Kg ha^{-1} which gave total dry pod yield of 2.13 t ha^{-1}

M Sc thesis

Table 1. Description of blended fertilizers with pepper varieties treatment combinations (Rayana Azebo)

No.	Treatments		Nutrients concentration			
	Cultivars	Fertilizer NPSZn Kg/ha	N	P_2O_5	S	Zn
1	V1	0	0	0	0	0
2		26 NPSZn + 42.8 Urea	24	9	1.7	0.65
3		45.5 NPSZn + 73.5 Urea	42	16	3	1.13
4		65 NPSZn + 105 Urea	60	23	4.2	1.63
5		**84.5 NPSZn +136.5 Urea**	**78**	**30**	**5.3**	**2.11**
6		104 NPSZn + 168 Urea	96	37	6.7	2.6
7	V2	0	0	0	0	0
8		26 NPSZn + 42.8 Urea	24	9	1.7	0.65
9		45.5 NPSZn + 73.5 Urea	42	16	3	1.13
10		**65 NPSZn + 105 Urea**	**60**	**23**	**4.2**	**1.63**
11		84.5 NPSZn +136.5 Urea	78	30	5.3	2.11
12		104 NPSZn + 168 Urea	96	37	6.7	2.6

Another researcher Nimona (2018) reported from in Assosa area that soil test results indicated that the available P and available K of the study of Assosa are low, so potash fertilizer are needed to address the nutrient deficiencies in the tested soils. Similarly, low in S, Zn and B availability, while the cation exchange capacity of the experimental site was medium, the fertility status of the study site was low.

He suggested 100 -150 kg of blended fertilizer NPSBZn with 29- 44 kg of Urea for hot pepper production in Assosa.

Table 2. Treatment set up and nutrient contents of the recommended NP and the formula rates of the recommended blended fertilizer types for Assosa area

Treatment	Fertilizer type	Rate (kg ha^{-1})	Blended fertilizers' mineral contents (%)	**Net benefit (Birr)**	**MRR (%)**
0	Control	-	-		
Rec.NP	Urea & TSP	100 + 100	$46N + 46P_2O_5 + 18N$		
100%	NPSB	100 + 28N	$18.1\ N + 36.1\ P_2O_5 + 6.7\ S + 0.71\ B$		
150%	NPSB	150 + 42N	$27.1\ N + 54.15\ P_2O_5 + 10.1\ S + 1.1B$		
200%	NPSB	200 + 56N	$36.2\ N + 72.2\ P_2O_5 + 13.4\ S + 1.42B$		
100%	**NPSBZn**	**100 + 29N**	**$16.9\ N + 33.8\ P_2O_5 + 7.3\ S + 2.2Zn + 0.7B$**	**138,315.7**	**8422**
150%	**NPSBZn**	**150 + 44N**	**$25.4N + 50.7P_2O_5 + 10.9S + 3.4Zn + 1.0B$**	**168,070.2**	**5208**
200%	NPSBZn	200 + 58N	$33.8N + 67.6\ P_2O_5 + 14.6\ S + 4.5Zn + 1.3B$		

Hence, to obtain optimum economic return from the production of hot pepper at the study area, blended fertilizer rates of 100 kg NPSBZn + 29 kg N ha^{-1} and 150 kg NPSBZn + 44 kg N ha^{-1} could be recommended.

Table fertilizer requirement of pepper in Ethiopia

Location	Melkassa
N (kg ha^{-1})	100 kg ha^{-1} Urea
P (P_2O_5 kg ha^{-1})	D AP 200 kg ha^{-1}
K	
Reference	

Irrigating peppers

Pepper plants are fairly shallow-rooted and have low tolerance to drought or flooding. Fields should be irrigated if there are signs of wilting at midday. Thorough irrigation provides uniform soil moisture, essential for optimum plant and fruit growth. Furrow or drip irrigation are recommended; overhead irrigation should be avoided as wet leaves and fruits promote disease development.

Pepper plants cannot tolerate flooding and fields should be drained quickly after heavy rain. Pepper plants will generally wilt and die if they stand in water for more than 48 hours. *Phytophtora* blight and bacterial wilt may cause total crop loss following prolonged flooding.

Garlic

Bulb crops are a heavy feeder, requiring ample supplies of N, P, and K in either the form of inorganic or organic fertilizers or a combination of them. Sub-optimal levels of these nutrients in the soil adversely affect the yield, quality and storability of bulbs (Gubb & Tavis 2002). Garlic is very responsive to nutrient application. Garlic varieties may also differ in their response to source and rate of applied fertilizers (Zhou et al., 2005).

A blanket recommendation of 105 kg N ha^{-1} and 92 kg P_2O_5 ha^{-1} each of N and P fertilizer are being used for garlic variety 'Tseday' production in many areas (EARO, 2004) without specific research recommendation.

Nutrient requirement studies of garlic in Ethiopia

Table fertilizer requirement of garlic in Ethiopia

Location	**Melkassa**	**DeberZiet**	**Gantaafeshum/ Tigray**	**Haramaya**
N (kg ha^{-1})	Urea 150 kg ha^{-1}	92 kg N	82 kg N	130 kg N ha-1
P (P_2O_5 kg ha^{-1})	DAP 200 kg ha^{-1}	40 kg P		
Reference		Diriba-Shiferaw, Nigussie Dechassa, Kebede Woldetsadik, Getachew Tabor and Sharma J.J. (2015)	Tadesse Abadi, 2015	Fikru Tamiru Kenea and Fikreyohannes Gedamu

The study undertaken on two soils types by Diriba-Shiferaw *et al*. (2015) also showed that the growth, yield and economic potential of garlic were increased in response to the combined application of 92 kg N + 40 kg P + 30 kg S ha^{-1} with a benefit cost ratio of 6.44:1 on **Andosols** and 138 kg N + 40 kg P + 60 kg S ha^{-1} with a benefit cost ratio of 5.86:1 on **Vertisols**. However, they concluded that application of 92 kg N + 40 kg P + 30 kg S ha^{-1} combination along with 140 kg ha^{-1} **KCl** fertilizer on both soils are optimum and economical to attain better productivity of garlic crop to enhance household income and livelihoods of the farmers in the study areas.

Another study conducted by Tadesse, (2015) at Ganta afeshum in Tigray, the highest total garlic yield was obtained from the cultivar Bora 1 (12.61 t ha^{-1}) at the rate of 82 kg N ha-1 but the yield decreased to 12.27 t ha^{-1} as the nitrogen level increased to 123 kg N ha^{-1}.

The cost benefit analysis indicated that Felegdaero at 41kg N ha^{-1} followed by cultivar Bora-1at 41 kg N ha^{-1} rates had maximum marginal economic return of 148.24 and 135.84, respectively.

Table 19. Interaction effect of cultivar and nitrogen fertilizer on total bulb yield of seven garlic cultivars at Guahgot (FTC) in Gantaafeshum District during 2014/15

	Total bulb yield (t ha^{-1})			
Cultivar	0 kg N ha^{-1}	41 kg N ha^{-1}	82 kg N ha^{-1}	123 kg N ha^{-1}
Bishoftu Nech (W-14)	8.631^{ijk}	9.207^{g-j}	9.068^{hij}	10.690^{def}
Tsedey (G-493)	8.423^{ijk}	8.943^{hij}	9.217^{ghi}	11.727^{a-d}
Kuriftu	7.143^{mln}	7.542^{klm}	8.021^{j-m}	10.039^{fgh}
Felegdaero	8.259^{i-l}	10.353^{efg}	10.735^{def}	11.011^{c-f}
Bora-1	10.019^{fgh}	11.939^{abc}	12.606^{a}	12.278^{ab}
Bora-2	8.433^{ijk}	9.028^{hij}	9.167^{g-j}	11.231^{a-d}
Guahgot local	5.313^{o}	6.007^{no}	6.994^{mn}	7.213^{ml}
Mean		9.259		
S.E. (±)		0.721		
LSD (0.05)		1.186		
CV (%)		7.792		

Means represented with same letter(s) in columns and rows are not significantly different from each other. SE (±) = standard error, LSD (5%) = least significant difference at $P<0.05$ and CV (%) = coefficient of variation.

Similar study was conducted in Adet Zuria, Yilmana Densa district, the highest yield of garlic was recorded by using N:P_2O_5:S fertilizer at the rate of 140:92:17 kg ha^{-1}.

Table 4. 5: Garlic yield parameters as affected by NPS fertilizer rates in Adet Zuria Kebele

N:P_2O_5:S application rate kg ha^{-1}	Parameters					
	BW	BL	BD	MYT	UMYT	TYT
T1(0:0:0)	32.83	3.22	3.48^{b}	9.97^{f}	0.85	10.82^{e}
T2(75.69:61.18)	40.33	3.60	4.01^{a}	13.60^{cde}	0.713	14.31^{cd}
T3(105:92:0)	43.50	3.71	4.16^{a}	14.81^{bcde}	0.34	15.16^{bcd}
T4(105:92:17)	41.33	3.77	4.20^{a}	15.03^{bcd}	0.65	15.67^{abc}
T5(105:61.4:11.3)	39.83	3.57	3.93a	13.08^{de}	1.08	14.17^{cd}
T6(105:122.6:22.6)	46.50	3.71	4.22^{a}	15.81^{abc}	0.61	16.42^{abc}
T7 (70:92:17)	40.17	3.72	4.10^{a}	13.68^{cde}	0.53	14.21^{cd}
T8(70:61.4:11.3)	39.17	3.47	3.95^{a}	12.49^{e}	0.59	13.08^{de}
T9(70:122.6:22.6)	39.33	3.68	4.17^{a}	14.36^{bcde}	0.45	14.81^{bcd}
T10(140:92:17)	43.83	3.84	4.1917^{a}	16.16^{ab}	0.57	16.74^{ab}
T11(140:61.4:11.3)	42.17	3.53	4.06^{a}	14.24^{bcde}	0.66	14.90^{bcd}
T12(140:122.6:22.6)	43.67	3.75	4.27^{a}	17.42^{a}	0.38	17.80^{a}
Mean	41.05	3.63	4.06	14.22	0.619	14.84
CV	11.40	6.51	5.38	9.89	39.90	9.38
Significant difference	NS	NS	*	**	NS	**

BW = Bulb weight (g) BL= Bulb length (cm) BD = Bulb diameter (cm) MYT = Marketable bulb yield (ton ha^{-1}) UMYT= Unmarketable bulb yield (ton ha^{-1}) TYT=Total bulb yield (ton ha^{-1}) CV=coefficient of variation, T1 –T12= Treatments 1 to 12 ,NS=non significant *= significant ($P < 0.05$), **= highly significant ($P<0.01$)

Shallot

Various nutrient requirement studies have been made on shallot in Ethiopia. An increased nitrogen dose to 100 kg ha^{-1} resulted in the increased yield of shallot bulbs to 30.2 t ha^{-1} at Jimma.

Table. Fertilizer requirement of shallot in Ethiopia

Location	Melkassa	Haramaya	Yilmana Densa	Jimma	DeberZiet
N (kg ha^{-1})	150 kg N ha^{-1}	N 150 kg ha^{-1}	N: P_2O_5:S fertilizer at the rate of 140:92:17 kg ha^{-1} .	N 100 kg ha^{-1}	
P (P_2O_5 kg ha^{-1})	200 kg DAP ha^{-1}				
Reference		Fikadu Negese, 2015	Shege Getu Yayeh, 2015		

Fikadu (2015) found that bulb yield of shallot at Jimma was statistically different or significantly affected by the application of nitrogen. An increased N doses to 100 kg ha^{-1} resulted in the increased yield of shallot bulbs to 30.2 t ha^{-1} which was significantly different from 0 and 150 kg ha^{-1}.

Cabbage and Kale

Brassica is a versatile species that under human selection has generated several crops (Cabbage, Ethiopian Kale, Cauliflower and Broccoli, Spinach, Chinese Cabbage, Broccoli, etc...), each targeting to a different organ of the plant (leaves along the stem: kales; leaves surrounding the terminal bud: cabbage; enlarged axillary buds: Brussels sprouts; inflorescences: cauliflower and broccoli; swollen stem: kohlrabi and marrow stem kale). There are several types of cabbages: white cabbage, red cabbage. These different crops have been classified as varieties.

Anyone can get all these vegetable crops in many local markets in Ethiopia cultivated locally, in different parts of the country however attention was/ is not given to any one of mentioned crops in Ethiopia except cabbage.

Table fertilizer requirement of cabbage in Ethiopia

Location	DZ
N (kg ha^{-1})	92 kg N ha^{-1}
P (P_2O_5 kg ha^{-1})	P 46 kg ha^{-1}
K	
Reference	

Amaranthus

Nutrient Requirement of Amaranthus

Table: Effect of N levels and harvesting frequency on Amaranthus, Jimma

Treatments		**Yield variables**	
Nitrogen (N kg ha^{-1})	Harvesting Frequency	**Fresh weight of lea per hectare (t)**	**Seed yield per hectare**
0	Weekly	5.83^{fg}	0.66^{g}
	Two weeks	7.23^{f}	0.76^{fg}
	Every three weeks	4.73^{g}	1.00^{ef}
34.5	Weekly	10.52^{e}	1.13^{e}
	Two weeks	14.60^{d}	1.40^{d}
	Every three weeks	11.13^{e}	1.70^{c}
69	Weekly	16.1^{d}	1.43^{d}
	Two weeks	23.25^{b}	1.76^{c}
	Every three weeks	14.97^{d}	2.36^{b}
103.5	Weekly	21.96^{bc}	1.76^{c}
	Two weeks	**30.33^{a}**	2.53^{b}
	Every three weeks	20.67^{c}	**3.23^{a}**
138	Weekly	23.59^{b}	1.80^{c}
	Two weeks	30.46^{a}	2.56^{b}
	Every three weeks	21.13^{c}	3.26^{a}
LSD (0.05)		1.75	0.26
CV %		6.3	7.2

Means within columns for each variable followed by different letters are statistically different from each other at ($p<0.01$) HF = Harvesting frequency

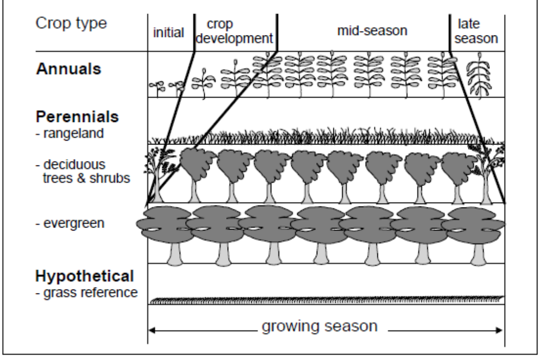
Tinsae (Jimma), 2018. <Applied N levels (0, 34.5, 69 or check, 103.5 and 138 kg N ha^{-1}) at Jimma. He found that application of 103.5 kg N ha^{-1} gave highest leaf yield

Nutrient Requirement of Major Fruit Crops

Although nutrient requirement of all perennial fruits are very high and seasonal specific with growth, no published information and recommendation available in Ethiopia. All the recommendation we have in the center are blankets recommendations. To have right fertilizer types, rates, timing (frequency) for each perennial fruit in every parts of the country- conducting long term experiments in ever fruits growing major agro-ecologies of Ethiopia are needed. This document highlights the general nature of perennial fruits crops which should be cascaded in the local conditions. Even more importantly all phenological growths, are very specific to crops, varieties, agro-ecologies of the production areas. Thus, there is no general rule for one variety across the country.

Crops growth and development in perennial crops

FIGURE 23
Crop growth stages for different types of crops



Where there is higher temperature, there would be shorter growth periods for each growth stages and vice versa. Thus, the critical time for irrigation and nutrient application for a given crop variety would vary accordingly.

DIAGNOSTIC CRITERIA

Visual Diagnosis

Symptoms of disorders, therefore, provide a guide to identify nutritional deficiencies in plants.

Tissue Testing

Plant tissue testing is a technique for rapid determination of the nutritional status of a crop and is often conducted on the field sites where crops are grown. The test generally assesses the nutrient status by direct measurements of the unassimilated fraction of the nutrient in question in the plant.

Concentrations of nitrogen in leaves of various fruits crops under cultivated conditions

The *critical concentration* of a nutrient is defined as the concentration of the nutrient below which yields are suppressed. In the determination of critical concentration, analysis of a specific tissue of a specific organ at a designated state of development is required. Because of the amount of work involved, critical concentrations are rarely determined; consequently, *ranges of sufficiency* are most commonly used in assessment of plant nutrition. For each nutrient or beneficial element, ranges of sufficiency are reported.

Diagnostic Range (% Dry Mass of Leaves)

Type of crop	Diagnostic Range (% Dry Mass of Leaves)		
	Low	Sufficiency	High
Citrus	<2.0 to 2.2	2.3 to 2.9	>3.3
Banana		3.0 to 3.8	
Pineapple		1.5 to 2.5	

Soil Tests

A soil test is a chemical or physical measurement of soil properties based on a sample of soil. Commonly, however, a soil test is considered as a rapid chemical analysis or quick test to assess the readily extractable chemical elements of a soil. Interpretations of soil tests provide assessments of the amount of *available nutrients*, which plants may absorb from a soil. Recommendations for fertilization may be based on the results of soil tests. Chemical soil tests may also measure salinity, pH, and presence of elements that may have inhibitory effects on plant growth.

Researchers identified a three-phase model, in this model, growth curves describe a deficient level of nutrient accumulation, region of poverty adjustment, or minimum percentage where yields rise with increasing internal concentrations of nitrogen. In the second zone of the growth curve, a transition from deficiency to sufficiency occurs followed by a region known as luxury consumption in which internal concentration of nitrogen rises but yield does not rise. The concentration of nitrogen at the transition from deficiency to sufficiency is known as the *critical concentration*.

Fruit crops collectively contributes to a large variation in nitrogen (N), phosphorus (P), and K removals from the soil. Nutrient removal by fruits and its use efficiency indicate mining of nutrients from soil. The nutrient use efficiency of N ranged from 20 to 40%, P from 5 to 20% and K from 50 to 100%, depending on the variety, growth rate and production potential. Most fruit crops are heavy feeders of plant nutrients and a number of fruit crops may absorb 500-1000 kg of N + P_2O_5 + K_2O /ha/year or even more under good management conditions. The K requirement of fruit crops is particularly high (Tandon, 1991).

Nutrient uptake by many fruits and vegetable crops is equal to or high than that of cereal crops (Table 1). To replenish the removal and to supply sufficient amount of nutrients at each stage of crop growth, adequate rates are needed in the fertilizer application program of these crops (Kemmler and Tandon, 1988)

Table 1. Average nutrients removed by some important fruit crops

Crop	Yield (t/ha)	Uptake (kg/ha)		
		N	P_2O_5	K_2O
Banana	40	250	60	1000
Citrus	30	270	60	350
Grapes	20	170	60	220
Mango	15	100	25	110
Papaya	50	90	25	130
Pineapple	50	185	55	350
Passion fruit	15	60	15	75
Apple	25	100	45	180

Banana remove the most K (20 kg K2O/t) (Table 2).

Table 2. Nutrient removal by some important fruit crops

Crop	Nutrient removal, kg/t of produce		
	N	P_2O_5	K_2O
Mango	6.7	1.7	6.7
Banana	5.6	1.3	20.3
Citrus	9.0	2.0	11.7
Apple	3.3	1.5	6.0
Guava	6.0	2.5	7.5
Pineapple	1.8	0.5	6.3
Sapota	1.6	0.6	2.1
Papaya	2.8	0.8	2.3
Grapes	8.0	2.0	9.0
Ber	4.0	1.8	6.3
Passion fruit	4.0	1.0	6.5
Lichchi	22.0	3.5	2.9
Mean	6.2	1.8	9.4

An average 11.9 t per ha fruit crop removes 91 kg N/ ha, 23 kg P_2O_5 /ha, and 153 kg K_2O/ha – with an N: P_2O_5: K_2O ratio of 100:29:152. Thus, the average uptake of K in contrast to N is 1.5 times larger. Continued nutrient depletion has resulted in many soils being re-categorized as medium or lower in K fertility status where earlier they were classified as high or medium. Economic responses to applied K on soils having low and medium K fertility status are common. Sustained production in high K soils is also ensured with application rates designed to maintain soil fertility at an advantageous level.

High rate of K is needed to achieve not only highest total fruit production, but also the greatest percentage of fruit production suitable for marketing. A high-unbalanced N:K ratio is associated with poor set fruit and poor carrying quality. According to Geraldson (1985), at the beginning of the season the N:K ratio must be 1:3 and then the ratio should be increased progressively to a 1:1 ratio.

Effects of moisture stress on phenological development

Water deficits affect the development of fruit trees and vines. Flower bud formation, floral development and fruit set are the main processes relevant to fruit production. For deciduous trees, fruit evolves from bud differentiation that occurs in the previous year. Thus, water deficits in one year may affect the return bloom and production of the following year. For some tree crops, water deficits negatively affect floral viability the following year, but there are also reports of enhanced return bloom following water stress in the previous summer. This response is critical for determining fruit load and therefore yield in relation to water. Since this response is species-dependent it is presented in the specific crop sections. However, a general truism is that periods of floral development and fruit set are very sensitive to water deficits, and thus, damaging water stress should be avoided. Nevertheless, occurrence of water stress during these developmental events is relatively rare for deciduous species since Tr is very low early in the season because of lack of leaf area and the generally low evaporative demand in temperate climates. In subtropical climates and for evergreen species, the likelihood of stress at flowering and fruit set is greater and should be managed accordingly (FAO66)

Banana

Banana's large biomass, and its high concentration of K in the fruit, are factors responsible for the crop's large annual demand for K. Biomass production ranging between 80 to 200 t/ha requires 290 to 1,970 kg K_2O/ ha.

Banana in particular being a K-loving crop requires nearly 1000-1500 kg of K_2O per hectare. Studies of the ontogenic course of potassium uptake under field conditions have shown an overall decrease in whole plant concentration of potassium in the dry matter from sucker to fruit harvest. The potassium uptake is proportionally greater than dry matter accumulation early in the life of the plant.

The potassium uptake is proportionally greater than dry matter accumulation early in the life of the plant. Under restricted potassium supply, the highest potassium uptake rate occurs during the first half of the vegetative phase. It is redistributed within the plant (Vorm and Diest, 1982) to allow further accumulation of dry matter. Where potassium supply is abundant, large amounts of potassium is absorbed during the latter half of the vegetative phase (Twyford and Walmsley, 1974) and have a special effect on the maturation process (Fox, 1989). Even when potassium supply is abundant, potassium uptake during the life cycle is appropriate to meet the needs of the main plant crop, but it is not relevant to ratoons, since in stools the mother plant and followers are present at the same time.

Due to high K accumulation in the fruit and plant tissue, K is considered the most important plant nutrient in banana production. It is the most abundant cation in the cells of the banana plant. Potassium does not play a direct role in the plant’s cell structure; K is fundamental, because it catalyzes important reactions such as respiration, photosynthesis, chlorophyll formation, and water regulation. The role of K in the transport and accumulation of sugars inside the plant is particularly important since, these processes allow fruit fill and, therefore, yield accumulation Banana responds heavily to nutrients. Yield and quality are strongly influenced by K nutrition. Potassium improves fruit weight and number of fruits per bunch and increases the content of total soluble solids, sugars and starch (Bhargava *et al*., 1993). In addition, K stimulates earlier fruit shooting and shortens the number of days to fruit maturity. Potassium has also a significant effect in improving resistance to diseases such as leaf spot and banana wilt (Von Uexkll, 1985).

Table 9. Effect of K levels on yield and quality of banana

K_2O (g/pl)	Bunch weight (kg)		Yield (t/ha)		Total sugar (%)		TSS (%)		Acidity (%)	
	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon
0	12.0	12.1	30.0	30.2	11.0	11.9	15.9	16.0	0.59	0.59
240	13.4	14.2	33.5	35.5	12.6	12.6	16.5	16.4	0.55	0.55
480	15.2	15.3	38.0	38.2	13.1	13.1	17.0	17.0	0.53	0.52

Low potassium nutrition results in thin and fragile bunch with shorter shelf life (Von Uexkll, 1985). Low K also induces poor buoyancy or ability to float, creating difficulties while packing, when the detached fruits must float in tanks for their cleaning and sorting (Martin-Prevel, 1989).

Numerous researchers have tested the response of banana at different sources and rate of K in several years of field study. In all years studied, the best economic response was obtained by application of 300 g K_2O/plant /crop in three splits at 90, 120 and 150 days after planting and 90 g P_2O_5/ plant/ crop, as basal dose has recorded significantly higher yield (Table 10). Studies have also revealed that significant responses were observed with high annual rates ranging from 600 to 675 kg K_2O/ha (Fig. 1).

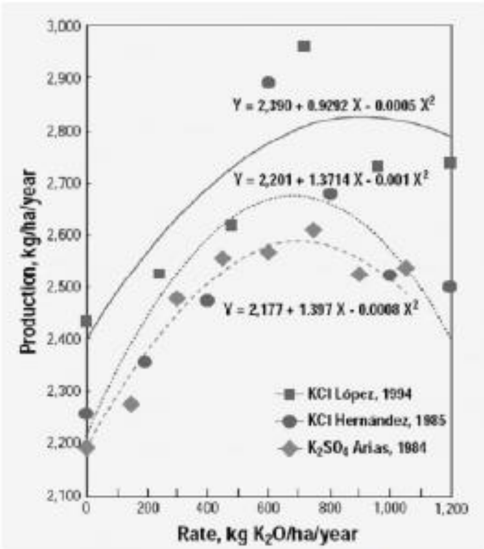


Fig. 1. Response of banana at rates and source of potassium

Table. Tentative nutrient application calendar of banana at Melkassa (blanket)

Months of the year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	August
Growth and Development	Uniform											
Kc	Uniform											
Water demand	Medium	H	H	H	H	H	H	H	H	H	Rain-No/ Medium	
Nutrient app. (Melkassa)	[75 gm Urea +75 gm DAP four splits], or [100 gm Urea + 100 gm DAP three split per tree] = [480 kg Urea +480 DAP kg per tree]] [four/ three splits per year]											

Papaya

Nutrient requirement and timing in papaya

Table. Tentative nutrient application calendar for papaya at Melkassa (Blanket)

Months of the year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	August
Growth and Development	Uniform											
Kc	Uniform											
Water demand		H	H	H	H	H	H	H	H			
Nutrient app. (Melkassa)	[75 gm Urea +75 gm DAP four splits], or [100 gm Urea + 100 gm DAP three split per tree] = [480 kg Urea +480 DAP kg per tree]] [four/ three splits per year]											

Mango

Assessment of the mineral status of mango trees is not without its challenges. Like many other tropical woody perennial tree crop species, mangoes have complicated and variable phenological cycles that influence the trees' uptake and translocation of minerals. Their extensive root system enables them to exploit unevenly distributed minerals throughout the soil profile; these minerals are often not assessed during routine soil analysis. The leaves, trunk, bark and roots act as mineral reserves that buffer many short-term mineral shortages (Robinson, 1986). Soil and leaf mineral analyses used as short-term indicators of tree mineral status, tree productivity or fruit quality are therefore difficult and unreliable (Catchpoole and Bally, 1995).

However, soil mineral analyses can be useful for determining the availability of the essential minerals, and if they are within the optimal range for mango. Soil analysis also provides valuable information on other soil properties that can influence mineral availability to the tree, i.e. pH, electrical conductivity (Ec) and concentrations of organic matter and clays. Regular soil analysis in conjunction with tissue analysis in mature cropping orchards can provide useful information on the changes in soil minerals over time and on the influences of fertilizer programmes on soil and tree status.

In a long-term experiment on Alphonso mango conducted between 1977 and 1991 on Alfisols in India it was found that application of 100g N, 170g P_2O_5 and 80g K_2O/tree/year of tree age from 3rd to 10th year and continuing 10th year doze in subsequent years was found to be optimum for **maximizing** the fruit yield. But it was found highly uneconomical to apply such high amounts of fertilizers. Applying game theory to recommend economic levels of fertilizer applications to various categories of farmers based on risk taking capacity, a nutrient combination of 100g N+100g K_2O/tree/year tree age from 3rd to 10th year and continuing 10th year doze in subsequent years was found to give maximum returns over investment for all categories of farmers irrespective of risk bearing ability.

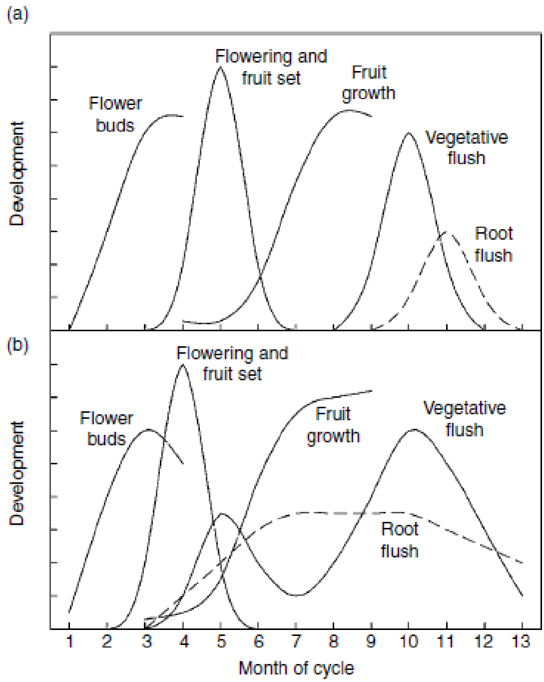


Fig. 10.4. Mango phenological cycle, having synchronous growth and flowering in (a) the subtropics (after Cull, 1991), and (b) the tropics, with asynchronous growth and flowering and a long juvenile phase (after Galán Saúco, 1996).

Positive relationships between leaf minerals and tree productivity have been reported. Oosthuyse (1997) determined that leaf concentrations of nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg) and Zn influenced the number of fruits retained, and that leaf Zn and Mg also influenced fruit size.

Leaf analysis

Leaf mineral analysis is commonly used to assess mango tree mineral status, and is useful for developing and monitoring tree fertilizer programmes. Leaves often display visual symptoms of toxic and deficient concentrations of many minerals. Sampling mango leaves for mineral analysis should be done when the tree is at its most phenologically quiescent stage, i.e. when leaf mineral concentrations are most stable. One of the most stable periods in the mango phenological cycle is the dormant phase, which occurs after the completion of flushing and approximately 2 weeks before the emergence of flower panicles. The common practice of withholding irrigation water leading up to flowering makes this period the most inactive of the year and an ideal time for leaf sampling. At other times of the year, leaf mineral concentrations sharply decrease when the tree is flowering and fruiting and increase in the months following harvesting (Catchpoole and Bally, 1995; Oosthuyse, 2000b). Sampling at an inactive growth stage reduces variability between leaf samples and provides a stable reference point for annual comparisons. Guides with respect to the most appropriate leaves for sampling have been variously reported (Kumar and Nauriyal, 1979; Chadha *et al.*, 1980; Smith, 1992; Catchpoole and Bally, 1995), and generally concur that the most appropriate leaves to sample are the third or fourth leaf behind the apical bud, or the fi rst full-size leaf of the most recently matured dormant fl ush where leaves are fully expanded and hardened off.

Table. Irrigation and nutrient application calendar of mango in relation to seasonal growth and development (Melkassa)

Months of the year	Sept.	Oct.	Nov.	Dec	Jan.	Feb.	March	April	May	June	July	August
Growth and Development	Dormancy/ Flushing	Brach lets mature	Flower induction	Flowering		Fruit set/ fruits development				Harvest/ dormancy		
Kc	**Low**	**High**								Low/ rainy season		
Time for leaf tissue sampling												
Water demand	**Low**	**High**							Low			

Pine apple

Pineapple responds well to application of both P and K. Experiments conducted on Kew variety of pineapple has shown that the fruit weight and fruit yield increase significantly with increase in the level of applied P and K up to 10g P/plant and 8g K/plant.

Citrus

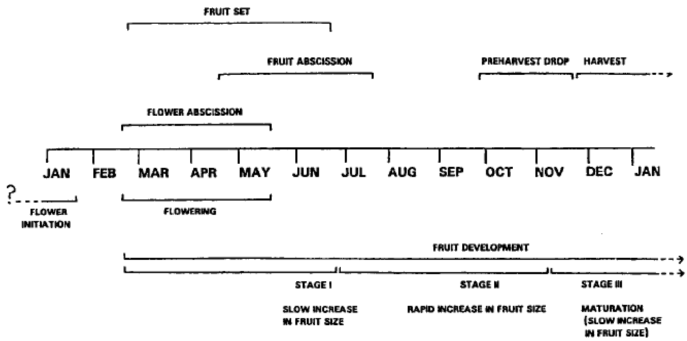


Fig. 1. Phenology model of the navel orange based on 25-year-old 'Washington' navel orange (*Citrus sinensis* L. Osbeck) trees on 'Troyer' citrange [*Poncirus trifoliate* (L. Raf) x *C. sinensis*] rootstock at Riverside, California.

uc an th in

Growth and Development in Relation to Yield Determination

The growth of citrus trees can be divided into vegetative and reproductive stages. Vegetative growth includes the growth of roots, stems, leaves and new flushes. Reproductive growth includes flower bud initiation, differentiation, flowering, fruit set, fruit development and fruit maturity.

Early vegetative and reproductive growth

Under subtropical climate conditions in the Northern Hemisphere (California, for example), the main vegetative growth flush occurs in late February and March. There are normally additional growth flushes in the summer and autumn. Leaves are viable for about two years. Leaves are continuously replenished although leaf drop is generally highest during the spring. Most citrus cultivars produce flowers in the spring and are self-compatible; they may be fertilized by their own pollen. In cool, coastal climates, flowers may be produced throughout the year but maximum flowering is also in the spring. Flowers develop in leaf axils on older shoots as opposed to shoots developing in growth flushes.

Citrus trees produce a large number of flowers resulting in small fruit. However, a large percentage of these small fruit drop from the tree apparently because of a combination of
physiological and environmental factors. There appears to be a hierarchy of flowers relative
to fruit drop; flower in locations with a higher flower/leaf ratio are more subject to drop.
Flowers that open late in the bloom period are more likely to set fruit that survives to harvest
than fruit set from early flowers. Likewise, faster growing fruit is less apt to drop than slow
growing fruit.

The primary factor controlling the dropping of flowers and young fruit is a weakening of tissue in a preformed abscission zone at the point of attachment at the base of the ovary to the disk or of the pedicel to the stem. The actual mechanism of the process is not well understood but is believed to be triggered by growth regulators in response to either external or internal changes. Young fruit that remain after the first period of dropping presumably are capable of developing to maturity if the weather is favorable. Nevertheless, some dropping of fruit occurs throughout the season. As the weather becomes hotter in the early summer months, there is generally a period of accelerated fruit drop, which is often referred to as the ‘June drop’ period. If the heat is severe and prolonged for several days, fruit drop can be heavy, resulting in a greatly reduced crop. This has been observed in several cultivars of the navel and Valencia types. Some cultivars, notably Valencia and mandarins, have an alternate bearing cycle; light crop years following heavy crop years.

In acid lime at a given level of nitrogen (600g/tree) the fruit yield per tree increased from 20.7kg fruits/ tree with no P and K to 34.34 kg fruits/tree with 300g each of P_2O_5 and K_2O. Beyond this level the yields declined (Table - 8).

Table 8. Effect of balanced fertilization on yield and quality of acid lime (mean of 5 yrs)

Treatments (kg/tree)			No. of Fruits	Weight of Fruits (kg/tree)	Weight of Fruits (g)	Volume (cc)	Juice (%)
N	P_2O_5	K_2O					
600	0	0	685	20.7	26.4	26.5	43.3
600	100	100	848	26.7	27.5	27.6	48.9
600	200	200	861	27.8	30.0	30.1	49.7
600	300	300	1020	34.3	33.2	33.5	52.4
600	400	400	950	31.4	31.8	32.1	51.7

Fruit development stage

Following early season fruit drop, and after the leaves of new flushes have fully expanded, the

remaining fruit begin to develop initially by rapid cell division. :

Apply nutrients according to the developmental stage of the trees

Apply in the planting hole

young orchard (1-4 years)

- Increase with age
- Apply before leaf flush
- Stage before blooming

Apply 2 months before blooming, fertilizer needs to be applied with the aim of:

Helping existing leaves to mature;

Preventing the appearance of new leaves, thus avoiding competition for nutrients; *and*,

Enhancing flower initiation.

Fruit setting stage

At this stage, the tree needs to receive equal amounts of N, P_2O_5 and K_2O. If nutrients cannot be supplied in time, some immature fruits will drop.

Fruit development stage

To improve the size and general quality of the fruit, fertilizer should be applied to the soil as well as in the form of a foliar spray. NPK fertilizer (N: P2O5:K2O in the proportion 1:1:1.5), should be applied to the soil. The foliar spray should have a high K content. Calcium nitrate is also recommended at this stage, as the calcium helps to increase the firmness of the flesh and the color of the fruit, as well as prolonging the storage life after harvest. Foliar fertilizer should be applied 4-5 times at this stage (Chau 1997).

Table. Irrigation and nutrient application calendar of citrus in relation to seasonal growth and development

Months of the year	Sept.	Oc t.	No v.	De c.	Ja n.	Fe b.	Mar ch	Apr il	Ma y	Jun e	Jul y	Augu st
Growth and Developm ent	Fl. initiati on	Flowering		Fruit set							Harvest	
Kc												
Water demand												
Time for leaf tissue sampling												
Nutrient appl.												

TABLE 1 Published monthly crop coefficients (K_c) for different mature orange cultivars from different locations. All studies used the water budget to determine consumptive use.

Source:	Castel & Buj, 1989	Castel *et al.*, 1987	Van Bavel *et al.*, 1967	Hoffman *et al.*, 1982	Kalma and Stanhill, 1969	García-Petillo and Castel, 2007
Cultivar:	Salustiana	Washington Navel	Washington Navel	Valencia	Shamouti	Valencia
Location:	Valencia, Spain	Valencia, Spain	Tempe, Arizona	Yuma, Arizona	Rehovot, Israel	Kiyú, Uruguay
January	0.66	0.54	0.57	0.43	1.08	0.51
February	0.65	0.63	0.46	0.42	1.37	0.62
March	0.66	0.47	0.43	0.66	0.73	0.71
April	0.62	0.53	0.55	0.56	0.63	0.78
May	0.55	0.48	0.72	0.69	0.70	0.83
June	0.62	0.57	0.74	0.74	0.56	0.86
July	0.68	0.59	0.75	0.78	0.56	0.88
Aug.	0.79	0.68	0.76	0.87	0.45	0.87
Sept.	0.74	0.62	0.76	0.87	0.41	0.85
Oct.	0.84	0.68	0.85	0.79	0.62	0.81
Nov.	0.73	0.75	0.93	0.45	0.70	0.75
Dec.	0.63	0.79	0.75	0.34	1.34	0.67
Mean	0.68	0.61	0.69	0.63	0.76	0.76
Dec., Jan., Feb.	0.65	0.65	0.59	0.40	1.27*	0.87
March, April, May	0.61	0.49	0.57	0.64	0.69	0.80
June, July, Aug.	0.70	0.61	0.75	0.80	0.52	0.60
Sept., Oct., Nov.	0.77	0.68	0.85	0.70	0.58	0.77

* *High K_c values in winter re ect high soil evaporation rates from seasonal rainfall in a Mediterranean environment.*

FAO66

Since citrus is an evergreen plant, many water use studies report a single crop coefficient (Kc) value. These include 0.62 for Valencia in Sunraysia (Grieve, 1989), 0.44 for clementines in Mazagon, Spain (Villalobos *et al.*, 2009), and 0.52 for lemons in Ventura, California (Grismer, 2000).

Others have divided the season into winter and summer and suggested that the Kc was 0.70 and 0.65, respectively. They suggested increasing these values by 0.1 or 0.2 for humid and semi humid regions (Allen *et al.*, 1998).

Avocado

Growth and Development in Relation to Yield Determination

Vegetative growth occurs in two flushes; a strong one in Oct Nov and a weaker May- June. Flowering occurs at the same time between early October and mid-November and is followed by fruit set. Heavy fruit drop takes place during the first 3-4 weeks after fruit set, at the end of the season, leading to a first adjustment in fruit number, which is further adjusted with an additional fruit drop period, which takes place around the end of around May June, when fruit size is between 10-40 percent of mature size.

The following figures depicts the developmental stages of avocado in different parts of the world.

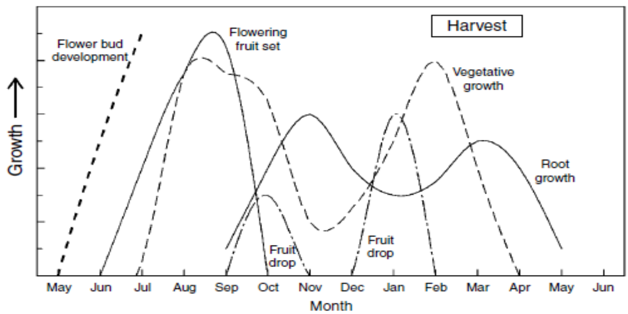


Fig. 7.3. Phenological cycle for bearing cv. 'Fuerte' in Queensland, Australia, showing the development and interaction between root, shoot, flower and fruit growth. The cycle will vary with the cultivar and needs to be determined for each location (redrawn from Whiley *et al.*, 1988a).

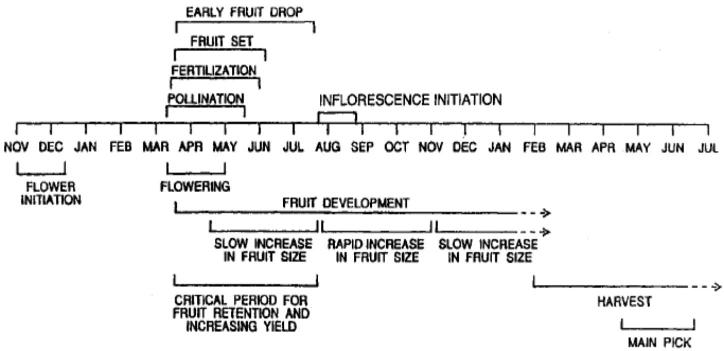


Fig. 2. Phenology model of the 'Hass' avocado (*Persea americana* Mill.) based on environmental conditions for southern California.

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Table 11.1. Crop factors based on Class A pan evaporation for irrigation of avocado in the Mediterranean climates of California (Meyer *et al.*, 1990) and the coastal plain of Israel (Anonymous, 2001; with variations).

Month	California	Israel
January	0.35	–
February	0.40	–
March	0.45	–
April	0.45	0.35–0.4
May	0.50	0.45–0.5
June	0.55	0.55–0.6
July	0.55	0.6
August	0.50	0.6–0.65
Sept.–Oct.	0.45	0.6–0.65
November	0.45	0.5
December	0.40	–

Research in Nayarit showed nutrient removal (kg) for a yield of 20 tons (t) of fresh Hass. avocado is: nitrogen (N), 51.5; phosphorus (P), 20.6; potassium (K), 93.8; calcium (Ca), 1.7; magnesium (Mg), 5.9; and sulfur (S), 6.9 (Salazar-García and Lazcano-Ferrat, 2001). Although each harvest removes smaller quantities of micronutrients such as iron (Fe), boron (B), and zinc (Zn), deficiencies do occur and have a negative effect on yield, fruit size, and quality of avocados (Salazar- García, 2002).

Site-specific fertilization increased yield and fruit size in 'Hass' Avocado

Consider - tree requirements as well as the amount, source, method, and frequency of fertilization,

Standard for leaf analysis

Table 11.8. Standards of avocado leaf analysis for diagnosing the nutrient status of mature trees.

Nutrient	Deficient (less than)	Commercial range	Excess (more than)
N (%)	1.60	1.6–2.8	3.0
P (%)	0.14	0.14–0.25	0.3
K (%)	0.9	0.9–2.0	3.0
Ca (%)	0.50	1.0–3.0	4.0
Mg (%)	0.15	0.25–0.80	1.0
S (%)	0.05	0.20–0.60	1.0
Mn (mg kg^{-1})	10–15	30–500	1000
Fe (mg kg^{-1})	20–40	50–200	?
Zn (mg kg^{-1})	10–20	40–80	100
B (mg kg^{-1})	10–20	40–60	100
Cu (mg kg^{-1})	2–3	5–15	25
Mo (mg kg^{-1})	0.01	0.05–1.0	?
Cl (%)	?	–	0.25–0.50
Na (%)	?	–	0.25–0.50

Nutrient concentrations (on a dry weight basis) were determined from expanded mature leaves from non-fruiting and non-flushing terminals on the spring shoot growth. The leaves were normally 5–7 months old. Data based on Embleton and Jones (1964), Lahav and Kadman (1980), Reuter and Robinson (1986) and Whiley *et al.* (1996).

Nutrient removal

Table 11.3. Nutrients removed in fruit from an avocado orchard by 10 t ha^{-1} crop (Lahav and Kadman, 1980).

Nutrient	% of dry weight	kg ha^{-1}	Nutrient	mg kg^{-1} of dry weight	kg ha^{-1}
N	0.54	11.3	Na	400	0.80
P	0.08	1.7	B	19	0.04
K	0.93	19.5	Fe	42	0.09
Ca	0.10	2.1	Zn	18	0.04
Mg	0.24	5.0	Mn	9	0.02
Cl	0.07	1.5	Cu	5	0.01
S	0.30	8.0			

Table 11.4. Mineral balance (g per tree) of a 7-year-old 'Lula' avocado in Martinique (after Marchal and Bertin, 1980).

Nutrient	Leaves and twigs	Branches	Trunk and dead wood	Roots	Fruit[a]	Total	Proportion removed by fruit (%)
N	706	567	76	195	89	1633	5.5
P	59	71	9	29	11	179	6.1
K	523	795	107	210	145	1780	8.1
Ca	439	344	65	85	4	937	0.4
Mg	96	62	10	23	6	197	3.0
Cl	49	270	13	13	2	347	0.6
Na	1.7	2.7	0.8	2.8	0.3	8.3	3.6
Fe	5.3	55.0	8.6	92.9	0.5	162.3	0.3
Mn	6.5	4.3	0.6	2.2	0.04	13.64	0.3
Zn	1.1	4.8	0.5	1.2	0.2	7.8	2.6

[a]Based on a medium crop of 32 kg tree^{-1}.

Nutrient Requirement of avocado

Table. Nutrient application calendar of avocado in relation to seasonal growth and development (blanket)

Months of the year	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	August
Growth and Development	**Harvest**	**Flushing to maturing leafs**	**Flowering initiation**		**Late blooming**	**After fruit set**		**Fruit development**			**Harvest**	
Kc												
Nutrient application												
N (gm/tree) Urea		100			100			100				
P (gm/tree) DAP		100			100			100				
Time for leaf tissue sampling												