WATER INNOVATION TECHNOLOGIES PROJECT (WIT)

TECHNICAL REFERENCE: ROLE OF WATER-SAVING TECHNOLOGIES IN IMPROVING AGRICULTURAL WATER PRODUCTIVITY

APRIL 2021

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Technical Reference: Role of Water Saving Technologies in Improving Agricultural Water Productivity

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1. Introduction

Irrigation is vital for meeting crop water needs in arid and semi-arid environments. Crop production in Jordan, for example, heavily depends on irrigation. A process of mixing fertilizers with irrigation water, or fertigation, is practiced to improve productivity, specifically in fruit orchards in Zarqa and Mafraq governates.

Farming management practices, such us fertigation, pest and weed control, usually ensure higher fruit production and fruit quality. However, the conventional irrigation methods and applications used are not uniform or efficient. Efficient and uniform fertigation can minimize fertilizer losses through leaching and accordingly increase crop benefits from it and reduce fertigation heterogeneity in the field.

Irrigation should be scheduled to meet the irrigation water needs for each crop. The same for fertigation, the right amount of fertilizers should be applied according to the plants needs and should match the irrigation schedule. The appropriate irrigation system design and routine maintenance can help avoid dripper blockage, system pressure drop, and mechanical damage. insufficient irrigation can reduce plants growth, yield, and fruit quality due to water stress.

Over irrigation causes several problems: 1) over fertilization due to increasing nutrient leaching, in addition to water stagnation, soil saturation and tree root suffocation problems; 2) increase the incidence of pests and diseases; 3) increase the associated cost of frequent operation and maintenance; 4) yield losses; and 5) adverse environmental effects such as the leaching of agrochemicals into groundwater aquifers, the overexploitation of water reservoirs, and the rise in water and soil salinity.

The use of water-saving technologies, practices, and inputs improves nutrient efficiency and reduces production costs. Indeed, water-saving technologies allow farmers to save resources like water, time, energy, labor, and money for irrigation and fertilizers.

2. Attitudes to water-saving technologies

Farmers have a vast practical experience based on their observations in the field. Usually, these practices are not based on technical background or knowledge of modern irrigation and farming practices. Many farmers believe they are appropriately growing their crops, and they are irrigating their crops with the right amount of water. This is the main reason behind lacking wider adoption of the water-saving technologies in many farms in Azraq and Mafraq regions. However, it has been noticed recently that this perception is changing, and farmers are more excited to adopt new water-saving technologies. This behavioral change is due to the water shortage problems that the farmers face in their farms and the high electricity bill they pay.

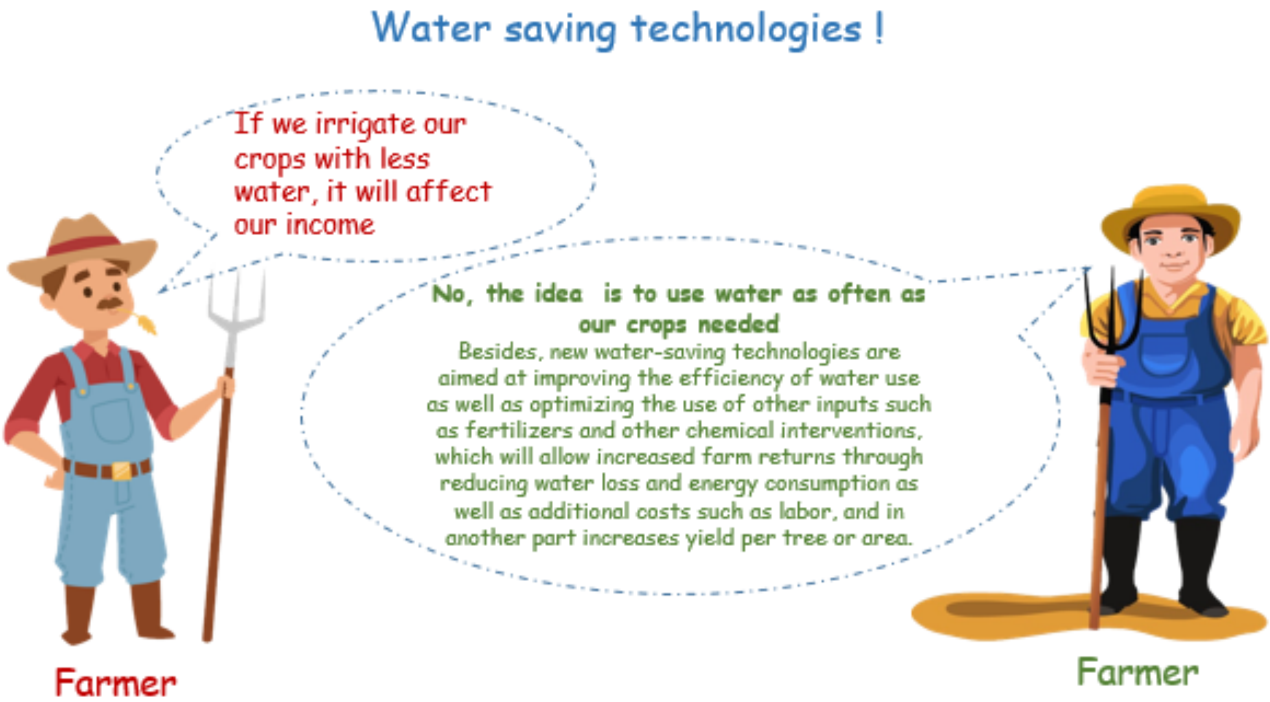
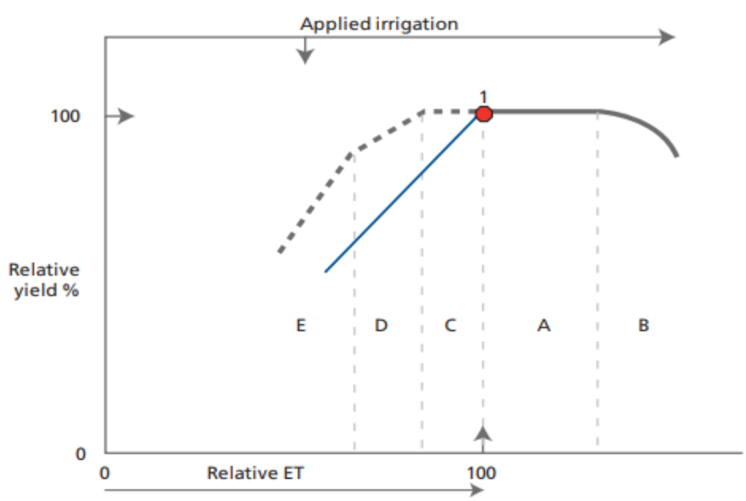


Figure 1: Farmers perception of using water-saving technologies



The yield of the crop and quality of the fruits are usually affected by the quantity of applied irrigation water in the field, where after a particular threshold value- depending upon the crop needs- a decline of the crop yield can be noticed (Figure 2). Water clogging and plant disease are other factors that prevent the plant uptake of the right quantity of water.

A- Maximum yield region with increasing drainage losses after Point 1 (The soil water level increases with irrigation).
B- Region of excess water reducing yield.
C- Region of yield maintenance with deficit irrigation.
D- Region of yield loss with deficit irrigation.
E- Region of a high risk of commercial losses because of severe water stress.

Figure 2: General relationship between yield, ETc and applied irrigation water in fruit trees. The dotted line represents the expected response of fruit and nut trees while the solid blue line indicates the typical response of an annual field crop for comparative purposes.

3. How to approach farmers about water-saving technologies and optimal input use

Poor soil and limited rainfall in Azraq and Mafraq urge for the immediate application of appropriate water saving technologies and right fertigation to improve agricultural production in these regions. Farmers and suppliers need to be aware about the best on-farm practices for using these technologies and applications.

The following tips could be of help:

- Focus on other aspects rather than solely water saving as the main objective of water-saving technologies as new technologies help better nutrient use by plants, reduce disease and weed. Otherwise, the chemical intervention will never give good results.

- Assess farm productivity and advice on the adoption of WST to ensure irrigation efficiency and indirectly other inputs supplies efficiency like fertilizer, in interactions with farmers.

- Make a quick fundamental cost-benefit analysis of water-saving technologies vis-à-vis the current practices on the farm on reducing diseases and weed effects, enhance chemical intervention efficacy.

Indeed, farmers over irrigated their field and/or not applying the right irrigation scheduling can observe that chemical intervention (insecticide, fungicide, acaricide, etc.) is not efficient and does not meet with their expectations.

- Highlight in a straightforward way the positive impact of considering crop water and nutrient requirements.
- Mention precautions to consider when using water-saving technologies such as the PC dripper.
- Document farm water and input supplies, data which can help the farmer later.
- Follow up, if needed.

Figure 3: Interaction with farmers about water-saving technologies.

4. Precision agriculture improves water saving

Proper irrigation management is crucial for water conservation under arid and saline conditions. It helps maintain soil water content in the root zone that the crop can efficiently use the water and minimize its loss below the root zone. In recent years sensors have been developed to ensure cost-effective near-continuous monitoring of water content and movement in the soil and monitoring all the other production components such as soil fertility and pest control. This is part of a growing trend in precision agriculture.

Precision agriculture helps decision-makers and farmers to maximize the efficient use of resources such as water. By using sensors, farmers can understand their crops on a micro-scale, conserve resources and reduce environmental impacts. As a first step, the precise estimation of crop water requirements, fertilizer requirements, and pest control through early detection are essential. Warning The numbers and disposal (layout) of any sensor needs to be managed carefully to have representative data for the target area. Then, large Agro-business can adopt these technologies efficiently.

Suppliers could adopt and disseminate this knowledge and create a community of practice that enhances farmers' competitiveness. The irrigation scheduling approach proposed in this document is based on an automatic irrigation controller and a ground sensor system for monitoring reference and actual evapotranspiration, irrigation/over-irrigation:

- ✓ Automatic irrigation controller.
- ✓ Atmospheric demand monitoring using Agro-meteorological stations.

- ✓ Operational monitoring of irrigation efficiency for optimizing hardware use through additional ground sensor systems.

Data-driven irrigation scheduling facilitates significant on-farm water and energy saving. The variables important for irrigation management include:

- ✓ Above-ground data (atmospheric), which shows atmospheric evaporative demand, including air temperature, humidity, wind speed, solar radiation, and water provided as precipitation.

- ✓ Below-ground data, which shows water availability for meeting crop water requirements, including soil water content and potential, soil water salinity, soil temperature, and water movement within and below the root zone.

- ✓ Plant data, which shows the plant's response to atmospheric water demand and soil water supply, including sap flow, water potential, and canopy temperature.

The WIT project started the installation and operation of different equipment for data collection and monitoring in the Azraq and Mafraq areas.

The new sensor technologies are designed for quick and easy installation and monitoring and help to optimize crop yield while minimizing environmental effects and energy consumption at the farm level.

Suppliers and farmers can use some of the water-saving technologies without assistance from specialists.

5. Water-saving technologies improve fertilizer management

Jordanian growers use irrigation to meet their water needs and minimize yield losses. However, they need to consider the quality, amount, and timing of irrigation that each crop needs at different growth stages and water-saving technologies used with best practices help to achieve that. For example, water-saving technologies combined with adequate monitoring and management, like the pressure compensating system, added benefits include:

1. Better fertilizer management.
2. Water-saving technologies such as automated irrigation and PC emitters provide an adequate amount of water regardless of pressure changes due to long rows or terrain topography changes. Conventional irrigation methods are not suitable for sloped land and soil properties problem.

3. Better fertilizer distribution in the root zone, improving soil conditions, plant growth, and yield.
4. Poor-quality saline water can be effectively used since adequate fertigation quantities can be applied according to the plant needs. This could reduce TDS accumulation in the root zone.
5. The design of an irrigation system could be simplified to reduce costs and increase the efficiency.

Questions related to irrigation management

- How much water does a crop require?

✓ Too little causes crop stress, damage, and lost money.

✓ Too much costs money (water, energy, fertilizers).

Thus, the solution is proper irrigation scheduling respecting crop water requirements.

- How uniformly?

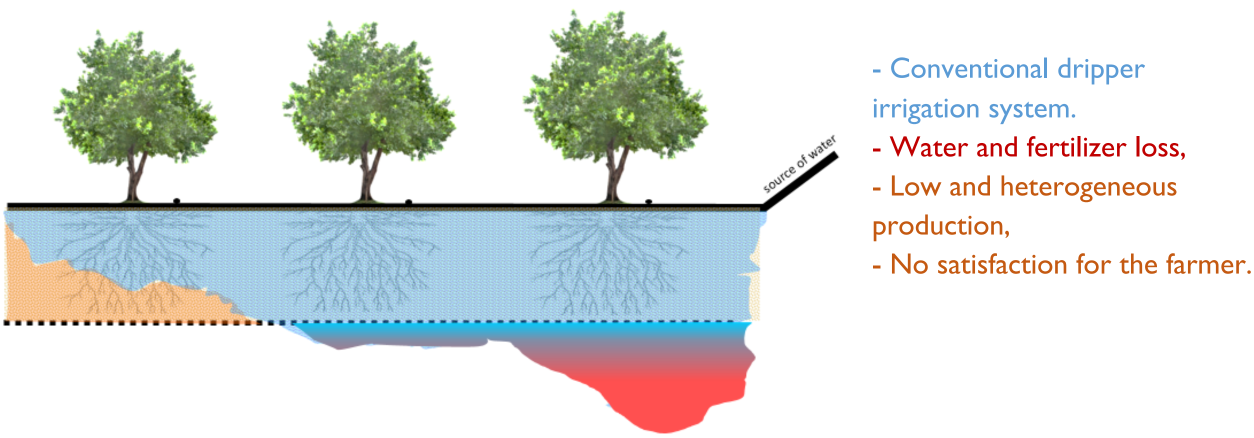


Figure 4: Non-uniform irrigation tends to increase the average irrigation depth, and fertilizers are lost mainly after over-irrigation.

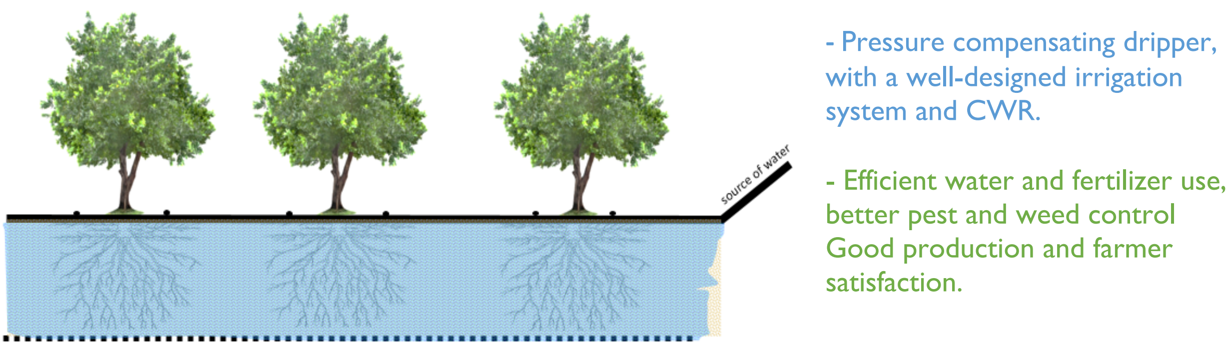


Figure 5: Uniform irrigation does not exceed the average depth and keeps the nutrients in the root zone.

Highlights:

- ✓ The fertigation, combined with the well-designed irrigation system (low flow emitters, PC or Non-PC emitters), enhances water and fertilizer efficiency, helps to keep fertilizer in the root zone, and avoid fertilizer loss by deep percolation through over-irrigation.
- ✓ Over-irrigation generally causes over-fertilization, so irrigation should be scheduled in advance, and fertilizer application is adjusted according to it.
- ✓ Unsuitable management with the presence of a load of suspended matter, chemical precipitates, and biological slimes may cause emitter clogging.

6. Water-saving technologies help with disease control

Providing the effective root zone with the right water quantity at the right time is essential for sustainable harvests. Over-irrigation, mainly when associated with over-fertilization, may result in the development of many fungal and bacterial plant diseases, which undermine quantity and quality. Indeed, irrigation systems, methods, and management substantially impact many crops' disease severity and epidemic progress rates. The impact may be indirect such as an increase in the population levels of a plant disease vector.

Pathogens can be transferred by water, wind, animals and equipment, but the dissemination via seeds and seedlings is the most dangerous form of transmission since it can occur over long distances. Pathogens can remain viable in the infected tissues of the seedlings, preserving the virulence and enabling the immediate formation of initial inoculum in new areas.

Excess water can provide moisture that encourages infection (allows the infection process to begin) and disease development from airborne pathogens and open basin water to disperse waterborne pathogens (environment).

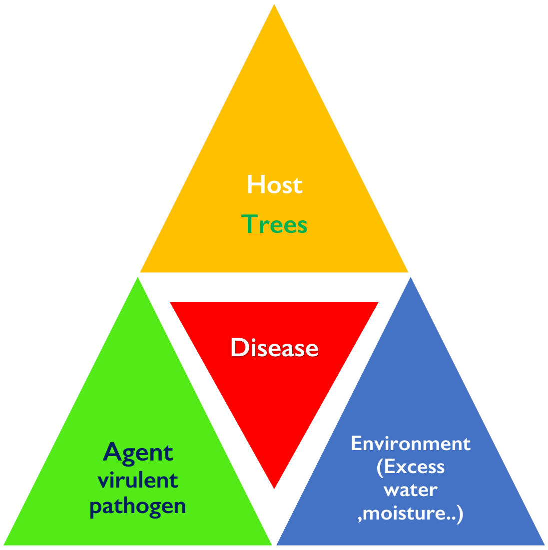


Figure 6: Disease results from a complex interaction between host, agent, and the environment (the equilateral triangle of plant diseases).

We should keep in mind that a susceptible host, a virulent pathogen, and favorable environmental conditions are needed for the disease to occur. Indeed, rain and irrigation water accompanied by other factors can spread the spores to nearby trees and fruits. Although fruit infection occurs in the orchard, fruit rot symptoms also develop during storage or in the market. Moreover, the disease causes sunken lesions with oozing resin or gum on the trunk, limbs, and twigs. Small twigs can be killed as the disease progresses.

- Solution:

- ✓ Enhance air circulation and prevent excessive irrigation. It is an effective practice for minimizing leaf spot diseases.
- ✓ Prune and remove deadwood.
- ✓ Irrigate during periods or seasons of dry weather. This helps reduce stress on plants and may minimize disease.
- ✓ Avoid having wetted soil for long time. This can allow fungal spores to germinate and develop.
- ✓ Observe irrigation timings:
  - Morning hours are best so that the water has time to reach the effective root zone before the irrigated field loses much water through evaporation.
  - Irrigation in the evening after the heat of the day will also work for most crops.
- ✓ If the farmer plans to irrigate in the evening, farmers must ensure that there enough time for the plants and soil to dry out before dew forms overnight the irrigation timing from late afternoon to early evening is best.

- Highlights

General:

- Several chemicals such as insecticides affect the plant water status and may induce symptoms similar to that caused by drought.
- Several chemicals such as fungicide play a double role as treatment and fertilizer, so consider this with crop water and nutrition requirements.
- Several chemicals, mainly fungicide, affect soil pH indirectly; it can be beneficial when soil already requires adjustment, and negative if the soil pH is at the right levels.
- Doses, including dilution fraction and quantity per area, should be used.
- Do not use chemicals in a state of complete calm as drift can be transmitted easily to the ground, or in windy or stormy conditions when wind speed is more than 16 km per hour (the best wind speed is no more than 1.6 km per hour).
- Spray chemicals early in the morning or late in the evening when the air is quieter than during the day.
- Do not spray during thermal inversions when the air closest to the ground is warmer than the air above it.

Management practices:

- Water-saving technologies help to provide crops with the exact water requirement, reduce disease infestation, so less chemical intervention will be made.
- Management practices to mitigate the risk of off-site movement include avoiding application when precipitation is expected, especially when the soil is saturated with previous irrigation.
- A pesticide requiring use during dormancy has a high run-off risk when applied to saturated soil or rain is expected.

Application equipment:

- Use a coarse spray while getting good coverage and control.
- Drop size is one of the most critical factors affecting the effectiveness of the intervention and reducing losses.
- Leaks in application equipment reduce the application efficiency and contaminate the soil, which can be transported off site with water.
- Use low pressure and spray volumes appropriate to the size of the canopy.
- Calibrate and adjust sprinklers to precisely direct the sprinkler to the target crop canopy.

7. Seed and new plant selection for selling by input suppliers

Water scarcity undermines agricultural production in Jordan. Therefore, the adoption of integrated management strategies will be useful for growing drought-tolerant crops, genotypes and/or rootstock and increasing water productivity.

Water productivity is defined as the return, or benefit derived, from each cubic meter of water consumed. This return may be biophysical (grain, meat, milk, fish, etc.), socioeconomic (employment, income), environmental (carbon sequestration, ecosystem services), or nutritional (protein, calories, etc.). Farmers are interested in yield per unit of irrigation water applied as they have to improve the yield through human-induced irrigation processes.

However, the downside is that not all irrigation water is used to generate crop production. Therefore, FAO defines water productivity as a ratio between a unit of output and a unit of input. Here, water productivity is used exclusively to indicate the product's amount or value over the volume or value of water depleted or diverted.

The water productivity of the tolerant and the susceptible crop/variety is the measure of the biophysical and economic gain from the use of a unit of water consumed. It is expressed in productive crop units of kg/m^3 and money unit/m^3.

In this respect, using tolerant crops and vigorous seedlings, increasing root depth, harvest index, and photosynthetic efficiency, are viable ways to increase water productivity. Drought escape through a short growing cycle for the annual crops and precocity for fruit trees is also an essential strategy for increasing water productivity.

Highlights:

- ✓ Water is essential for keeping crops healthy and productive.
- ✓ However, before irrigation, we should ask: What is the correct amount? When should you water?
- ✓ The aim is to make sure there is enough water to penetrate the soil to where the roots are.
- ✓ Establishing a plant: saplings should be irrigated frequently but with small amounts of water to initiate root growth. This is especially important for shrubs and trees.
- ✓ Once they are established, be sure not to over-irrigate. You can harm crops more by over-irrigating them than by under-irrigating them!
- ✓ Fungal leaf spots can be managed by growing resistant cultivars or using practices that limit disease development.

8. Irrigation practices for adequate seed and saplings

Water is vital for plant growth, but excessive irrigation of the field leads to waterlogging. Too much water is harmful to crop production:

1. Too much water in the soil inhibits the seed germination process, because, under these conditions, the seeds do not get enough air to respire. The seeds do not germinate with excess water in the field, which affects the aeration of the soil.
2. Roots do not develop well in a waterlogged field. Farmers must have observed similar phenomena in potted plants, where plants do not grow adequately if they get excess of water. The excess water affects the soil's aeration, and the plant's roots do not develop properly.
3. Excessive irrigation can lead to the lodging of the annual crop, and the tree falls due to heavy winds. Under over-wetted soil conditions, the plant roots cannot provide the necessary anchorage. Thus, over-irrigation can damage the crop and reduce the quantity and quality of the product. It also results in costly water wastage.
4. Over-irrigation raises the amount of TDS on the soil surface due to evaporation. The accumulation of salt reduces soil fertility and inhibits germination during the following seasons. Damage caused by excess water and the consequent development of TDS problems can be minimized by removing standing water from the fields and following the crop's water requirements, irrigation scheduling, and having a proper drainage system.

Figure 6: Salinity symptoms between trees in a pomegranate orchard in Azraq region.

Irrigation using poor quality water (salinity)

Farmers should keep the root zone watered all the time during the crop growth and physiological activities to keep salt far away from roots. If not, when soil moves from saturation to wilting point between irrigation events, the crop will be subjected to both drought and salt stress.

New irrigation technologies ensure a homogenous distribution around the tree and help to keep the salt away from the root zone.

Highlights:

For the sustainable management of crop growth in saline environments, soil-crop-water management interventions consistent with site-specific conditions need to be adopted. These may include cyclic or conjunctive saline water and freshwater use through proper irrigation scheduling to avoid salinity development.

In addition, we can add minimum leaching requirement if needed to control salts, using the following equation:

$$LR = \frac{EC_W}{5\,(EC_e) - EC_w}$$

Where:

- ECw: salinity of the applied irrigation water in dS/m.
- ECe: average soil salinity tolerated by the crop as measured on a soil saturation extract to obtain acceptable yield (for example only 10% of yield reduction).

Freshwater scarcity and other abiotic factors such as climate and soil salinity in some Jordanian regions affect crop production. Therefore, suppliers should be looking for salt-tolerant crops that can successfully be grown in these harsh environments using low-quality groundwater.

9. Water-saving technologies help to achieve increased yield, homogenous production, and better market prices

9.1. The quality of fruit

The quality of fruit is the most crucial factor that affects sales and profits. The fruit's main characteristics include visual appearance, firmness, and taste, particularly sugar content.

Over-irrigation may have an indirect negative impact on the yield and fruit quality through fungal disease proliferation. On the other hand, over-irrigation prevents fruits from reaching heightened sugar levels, even when there is a good fertilization plan. In this case, irrigation management, by respecting the crop water requirements, could be adjusted according to market needs.

Over-irrigation, combined with the absence of a drainage system and dense soil texture (root asphyxiation) results in yellow leaves and low production even with adequate fertilization.

In the case of deficiency combined with poor crop management, mainly fertilization, the plant's primary metabolism is affected. Consequently, it directs its metabolism towards stress tolerance. This results in a plant with fewer green leaves and a decrease in new buds. Ignoring the crop water requirements negatively affects the photosynthetic rate and photosynthetic metabolic potential. Also, a shortage of water after fructification to maturity can lead to low fruit quality. A reduction in fruit hardness is a result of reduced water content or volume. Fruit water content affects visual acceptability on the market.

9.2. Homogeneity of water and fertigation

High system efficiency can be obtained when design, maintenance, and management are done well. There are many factors we need to take into consideration when designing a drip irrigation system. Below is the purpose to be achieved from the following three design rules:

- ✓ Obtain a highly efficient system through high homogenization of water, and, consequently, fertilizer distribution.
- ✓ The system can be operated and maintained easily, in addition to giving the crop water and nutrients.
- ✓ Keep the initial and annual costs down to a minimum.

Irrigation has a significant role, as in drip irrigation, as plants benefit more from added fertilizer such as phosphate than flood irrigation in sandy soils.

The selection of drippers has a significant effect on achieving a high uniformity of distribution. For drippers to be ideal, the following conditions must be met:

- ✓ The emitter flow rate should not change significantly with the pressure fluctuation; this gives the system good water and fertilizer distribution homogeneity.
- ✓ It should have a relatively large cross-sectional area, which helps avoid clogging problems. There is a contradiction between the required characteristics. Whereas a low discharge rate requires narrow flow holes, a large cross-sectional area results in a high flow rate.

Drippers capable of self-washing to prevent clogging are complicated and expensive. Finally, the components used in the network installation should be resistant to deterioration with the use of chemicals.

Examples of the positive impact of the adoption of water-saving technologies

The results of this on-farm agronomic audit conducted by the WIT project confirmed the improvement of plant status after installing the new irrigation system, mainly the nitrogen balance, the chlorophyll index, and the fruits' sugar contents. These results are consistent with the hypostatic impact of proper irrigation management on crops.

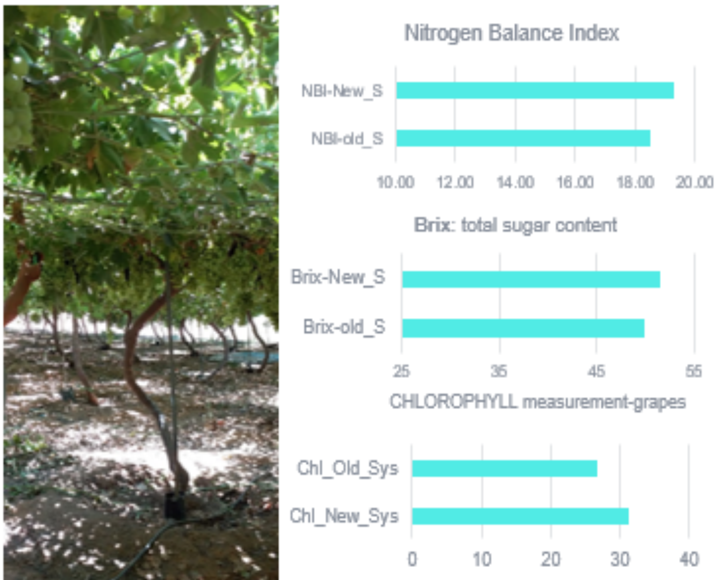


Figure 7: Nitrogen balance index

Besides, the installation of the PC system increased the homogeneity of production. The result of a baseline survey and a water audit proved the high heterogeneity on the emitters' flow rate before the installation of the PC system. The agronomic assessment confirms the effect of irrigation system efficiency on plant status (STD = 8.35).

However, the new irrigation system minimizes this heterogeneity (STD_PC = 3.71). Usually, homogenous production gets a better price on the market.

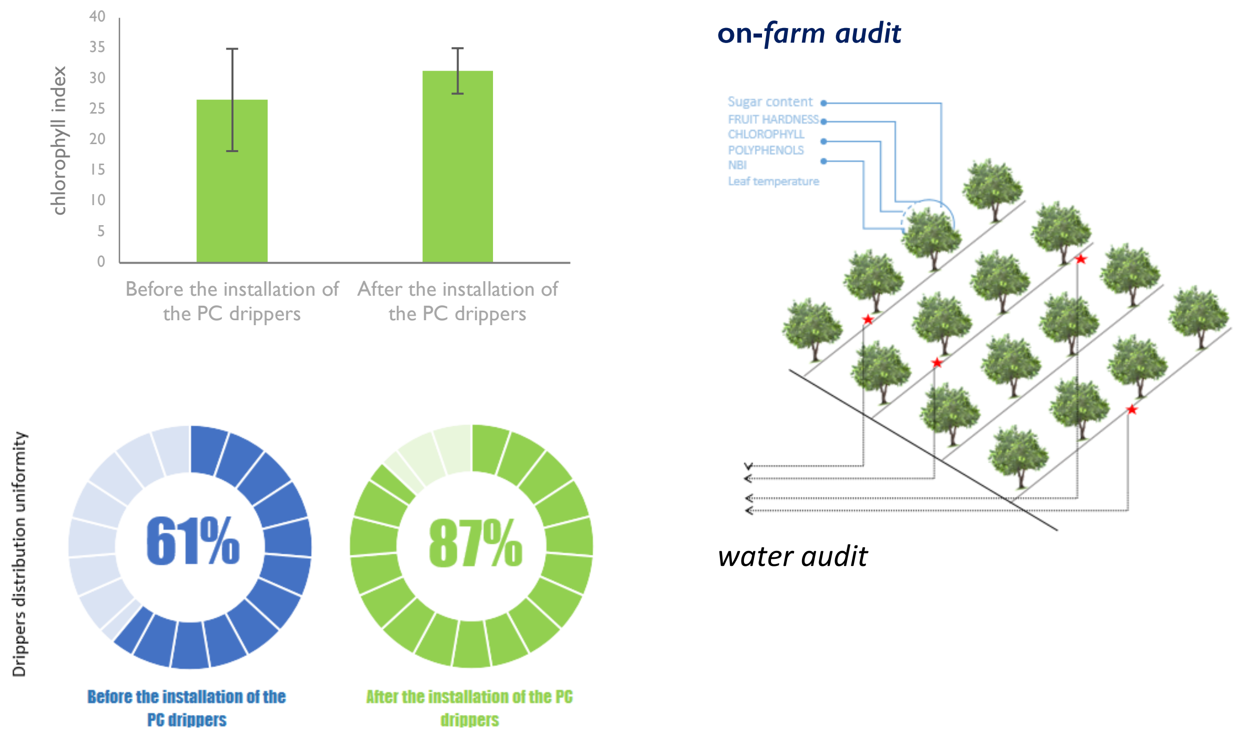


Figure 8: Heterogeneity levels of dripper flow and plant status under the new and old irrigation systems.

10. Basics of using fertilizers for fruit trees

There are some difficulties in the fertilization of fruit trees. In practice, it is challenging to ensure balanced fertilization, especially since fruit trees do not benefit from added fertilizers in the same way as annual crops.

The roots of fruit trees occupy a large soil volume, which increases as the tree ages and because of irrigation practices. We should know the value of the nutrition stocks in deep layers of soil and how much plants can obtain nutrition from these stocks, usually called the depth of the effective root zone. The fertilization process should not be concentrated only on the soil's surface layer because nitrogen moves downward from the top layer quickly, carried by the water in the soil. In contrast, potash does not percolate easily, and phosphorus does not move through the soil in practice. Fertilizer should be used to achieve the following goals:

1. Provide crops with the nutrients they need for production in the current season.

2. Enable the formation and differentiation of the fruiting shoots for the subsequent harvesting season.

3. Assist in the formation of nutrient stocks in the roots and branches for subsequent fruits.

The proper nutrition of fruit trees requires the presence of nutrients in a suitable form for absorption, proper soil management, and effective root activity. This is related to the soil's physical properties (construction, ventilation, humidity, temperature).

Fertilization monitoring can be ensured based on these main approaches:

- ✓ Scout for visual symptoms of deficiency and toxicity.
- ✓ See and observe.
- ✓ Perform soil tests before the orchard installation and every 3-5 years, or when visual symptoms indicate a problem. Soil testing should be for macro- and micro-nutrients, pH, cation exchange capacity, base saturation, organic matter, and soil texture.
- ✓ Conduct plant analysis via tissue testing every 1-2 years.
- ✓ Interpret the results correctly, which is critically important.

Other recommendations

- ✓ There is no recipe for nutrition management.
- ✓ Only adequate fertilization can improve yield and quality.
- ✓ Multiple applications are better than a single large one.
- ✓ Soil treatments are usually more durable than foliar.
- ✓ Foliar feeds micronutrients and soil treats the macronutrients.
- ✓ For the acidic soils, try to use pH neutral fertilizers.
- ✓ Do not pollute, manage nutrients.
- ✓ Soil pH affects nutrient uptake and microbial activity.
- ✓ Pruning should be done to achieve the required balance between the root system and the shoot system.

11. Importance of soil organic amendment and mulching for water-saving

Adding organic manure, treated crushed pruning wood, mineral clays (like bentonite, palagonite, and montmorillonite) is essential because it corrects the soil pH, dissolves the captured (insoluble) elements, and improves the soil's physical properties.

Organic matter contains humus that performs the following functions:

- Improve the soil's physical properties: Humus is the primary factor in stabilizing soil construction and improving its ability to hold water; indeed, trees grown in humus-rich soils are more tolerant for drought.
- Improve the chemical properties of the soil: Humus increases the exchange capacity of soil ions. Humus is a source of plant nutrients (major elements).
- Increase the biological activity in the soil: Humus contains a large group of microorganisms. It also preserves the soil's microorganisms, making the soil a living medium, so it is considered the basis of vital microbial activity in the soil.

Humic acids improve plant growth by exerting an unusual activity not only in liberating the mineral elements contained in humus but also in improving various assimilation processes.

BENEFITS OF SOIL AMENDMENTS AND MULCHING

Soil amendments help to:

- Increase soil water-holding capacity by 10-30% on average.
- increase trees' resilience to drought by maintaining residual soil moisture during hot periods at high levels with respect to the depletion fraction (5-8 days security margin in case of disruption of water supply).
- improve the overall nutrition balance due to higher cationic exchange capacity and slower release of nutrient elements to the soil solution.
- improve soil structure by reduced macro-porosity and root desiccation.

Plastic and treated crushed pruning wood mulching helps to:

- Enhance water use.
- decrease direct soil water evaporation of top arable soil layer by 50-80%.
- increase net transpiration by 10-30%.
- prevent the development of weeds which are serious competitors to the crops.
- Suppress weeds hosting on/off-season foliar pathogens and harmful insects.

12. Recommendations on fertilization

12.1. General information

Fruit trees deplete large amounts of nutrients from the soil, and with the expansion of cultivation of high-yielding varieties and improvement of farming practices, increasing fruit production requires adding nutrients in the form of fertilizers.

Solutions of liquid compound fertilizers contain the main nutrients and are formed so that no precipitation or salt formation occurs at ordinary temperatures. The presence of sediments will lead to problems, especially when adding solutions through the irrigation network. Usually, the sources of the nutrients used are ammonia nitrate or urea, potassium nitrate, mono-ammonium phosphate or phosphoric acid, and some liquid fertilizers that may be added to this liquid fertilizer that help increase the solubility point and reduce the chances of sedimentation. The general recommendations on phosphate, potassium, and nitrogen fertilization is:

- **Recommendations on phosphate and potassium fertilization:**

✓ Phosphorous and potash play an essential role in obtaining good production. It is worth emphasizing that using a high amount of nitrogen does not lead to the desired results if the tree suffers from a deficiency of phosphorus or potassium.

✓ Potash is slightly mobile in the soil, while phosphorus is immobile in the soil, hence the main difficulty in placing these two nutrients. Meanwhile, the level of the roots of fruit trees that go deep into the soil, and the active roots are usually between 20–90 cm.

✓ Potassium sulfate: Dissolve potassium sulfate separately from the nitrogen fertilizer and leave it for 24 hours, then the clear solution is taken and added to the fertigation tank.

✓ In the case of using phosphoric acid for washing the irrigation network and as a source of phosphorus, its annual standard should be added in weekly batches (when needed) in the fertilizer alone or dissolved with nitrogen fertilizer, taking into account that the acid concentration does not exceed 0.2 g per liter of irrigation water and that the concentration of fertilizer salts in the solution does not exceed 0.5 g per liter.

✓ Care should be taken not to mix superphosphate with any fertilizer containing dissolved calcium or any fertilizer containing iron or ammonium so that the phosphate does not turn into an insoluble form, reducing the benefit from it.

✓ Only 10–20% of the phosphate fertilizer applied to soil is absorbed and utilized. The rest is fixed in the ground, and the plant cannot benefit from it. This is due to the degree of solubility of phosphate fertilizers. In the case of sandy soils that have a percentage of salt, the plant benefits from acid phosphate fertilizer (phosphoric acid) more than other phosphate fertilizers.

✓ In the case of salt lands, phosphoric acid is used as a source of phosphorous.

✓ In the case of high salinity land or water, the plant's use of the added phosphate decreases. Also, the high pH reduces the plant's utilization of the added phosphorous.

- ✓ Also, the plant requires more phosphorous in the case of low temperatures.

- **Recommendations on nitrogen fertilization:**

- ✓ Nitrogen is the most productive element that affects plant growth, and it is an element that moves soil water, and the following facts must be known:
- ✓ The addition of large quantities of nitrogen at the beginning of the tree's life delays the fruiting stage's arrival since these additions will encourage vegetative growth and delay the balance between the root system and the shoot system.
- ✓ Nitrogen encourages flowering and fruit set, thus leading to good fruit production.
- ✓ Tree roots absorb nitrogen throughout the growth period, and the rate of absorption varies according to the different stages. Therefore, the added nitrogen must be fractionated in batches according to growth stages.
- ✓ The tree fertilization aims to meet the current fruit production season's demands while preparing for the next fruiting season. If its nitrogen provisions are insufficient, then it is directed to the sufficiency of the current season and the compounds necessary for the next growing season are not stored, then an amount of nitrogen must be added after harvesting the fruits so that the tree can form its stock necessary to cope with the next growing season.

- **Mixtures of nitrogen fertilizers:**

- ✓ Urea or ammonia nitrate can be mixed with phosphoric acid.
- ✓ Mixing urea or nitrates with magnesium sulfate or magnesium nitrate.
- ✓ Mixing urea with trace elements (iron zinc-manganese).
- ✓ Mixing urea or nitrates with potassium.
- ✓ Mixing nitric acid with calcium nitrate.
- ✓ Nitric acid with potassium sulfate.
- ✓ Never mix nitric acid with potassium hydroxide: a very dangerous reaction occurs with an explosion + toxic gases.

- **The degree of solubility of chemical fertilizers and the problems that arise from their injection into the drip irrigation network**

The degree of solubility of chemical fertilizers (nitrogen-phosphate-potassium fertilizers) varies according to the quality of irrigation water in terms of the concentration of total dissolved salts and sodium concentration chloride, sulfate, and calcium. It is known that when the level of salts in irrigation water is high, the concentration of fertilizers in the water does not exceed the limit for plant needs, and thus the plant is not exposed to the problems of the high osmotic pressure of the irrigation solution.

Also, the high amount of calcium in irrigation water reduces the efficiency of using fertilizers that contain sulfates or phosphates such as potassium sulfate and superphosphate.

The high concentration of sulfate in irrigation water reduces the efficiency of fertilizers, which contain calcium, such as calcium nitrate, as this leads to the precipitation of calcium in the form of calcium sulfate, which clogs the drips, pipes, and connections of the drip irrigation network, which leads to problems in a poor distribution of irrigation water and nutrients.

Before adding fertilizers that are difficult to dissolve through the drip irrigation network, it is necessary to ensure that they are well dissolved and then filtered, and the pure filtrate solution is taken and placed in the tank to be injected into the irrigation system.

- **Chemical fertilizer mixing:**

Fertilizers that contain sulfates (such as ammonia sulfate, potassium sulfate, or magnesium sulfate) or phosphates other than phosphoric acid (such as ordinary or concentrated superphosphate or triple phosphate) should not be mixed with fertilizers that contain calcium (lime nitrate or ammonia nitrate).

Fertilizers that contain phosphates other than phosphoric acid should not be mixed with fertilizers that contain magnesium.

Phosphate fertilizers should not have magnesium added since plants don't benefit from both.

- **Method of fertilizer addition**

The method of addition has a significant role: for example, if phosphate fertilizer is added in small trenches next to the plant, the benefit to the plant is more significant than if it were added to the ground, especially on sandy lands.

Figure 9: Photo of Head control: unit Filtration and fertilizer unit, Azraq farm.

12.2. The most critical factors that reduce the effect of fertilization

The high level of the groundwater table and the absence of a drainage system affect the absorption of the elements, so a proper drainage system must be available. Also, the decrease or increase in soil moisture to the point of drought or sinking hinders the roots' ability to carry out the absorption function. Besides, the presence of sodium carbonate salts in the soil leads to not taking full advantage of the added nutrients and treating them by adding agricultural gypsum and organic matter. The concentration of salts in irrigation water should not exceed 0.5 g per liter when added to the drip irrigation system.

It should also be considered that what is given to a single fruit tree should not exceed its needs of fertilizer sources in one day and not exceed it in drip irrigation.

The infection of trees with insects and pathogens reduces the effect of fertilization. Attention should be paid to the program to combat these pests.

- ✓ Excess nitrogen leads to a failure to hold the fruits and infestation by insects.
- ✓ Increased phosphorus results in deficiencies of Zn and Fe.
- ✓ Increased potassium results in deficiencies of Mg and Calcium.
- ✓ Organic matter provides a large portion of phosphorus in the form of mono and dicalcium phosphate, from which plants benefit.
- ✓ Nitrogen is included in most flower and fruit components' composition and controls the plant's ability to absorb phosphorous and potassium.
- ✓ Phosphorus is somewhat mobile in the soil, and it is mobile within plants.
- ✓ The organic matter of plant origin is best and does not result in soil fungi or viral diseases affecting vegetables.
- ✓ Organic matter enhances resistance to viruses that infect plants.
- ✓ The use of phosphate contributes to the prevention of fungal diseases, regeneration of root hairs, reduction of soil pH, and increased fruit size.
- ✓ If the percentage of elements in the soil and plants is very high, fertilization must be stopped immediately for a period until the leaves and soil samples are analyzed, and the availability of the excess elements in the soil and plants is known (see Annex).
- ✓ A severe deficiency in zinc and manganese is a sign of fungal disease. Care should be taken to spray the trace elements.

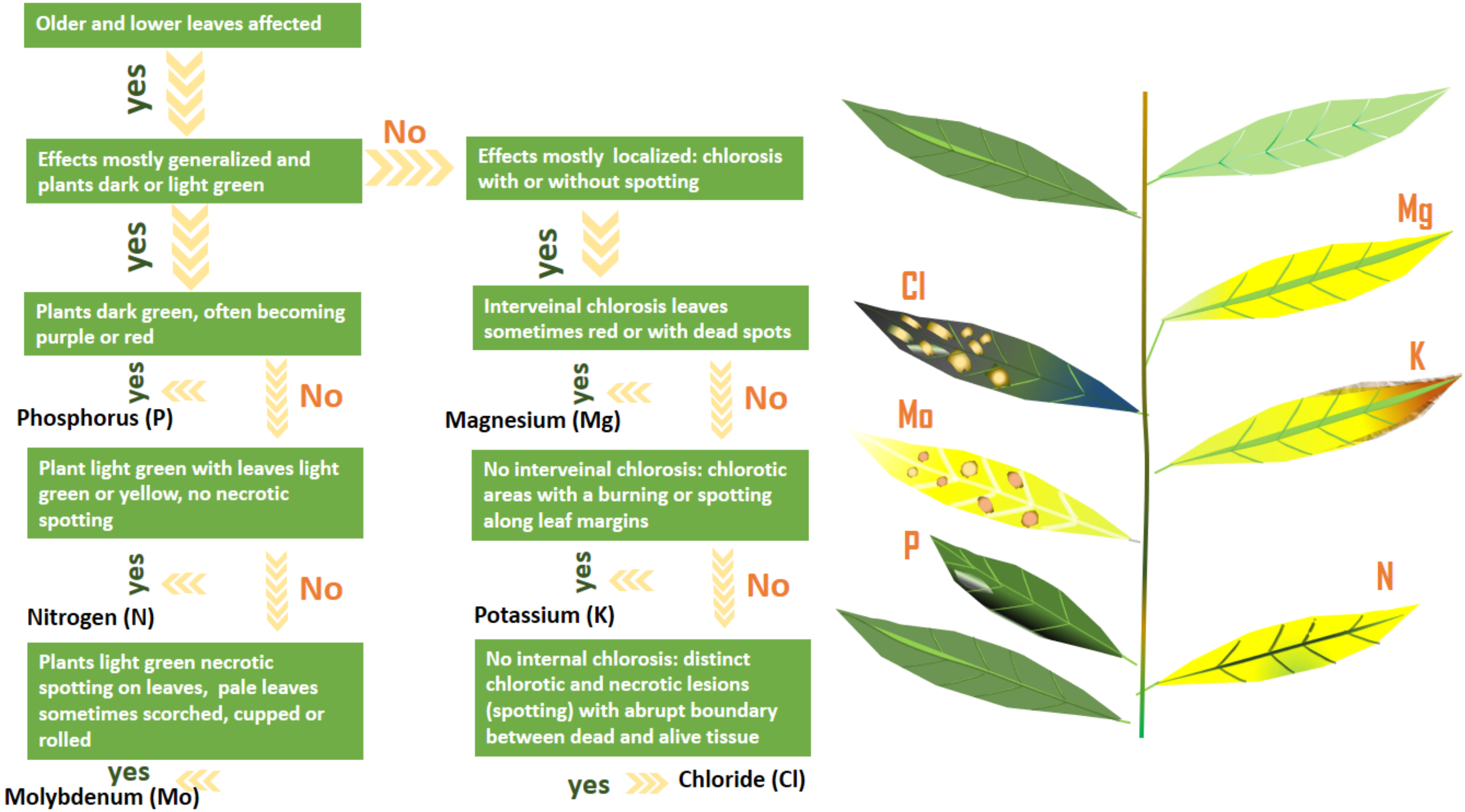


Figure 11: Visual assessment of leaves for element deficiency.

Annex: Essential Deficiency and Toxicity Symptoms

(Source: K. Afrane Okese, 2018).

NUTRIENT	DEFICIENCY SYMPTOMS	TOXICITY / EXCESS	COMMENTS
MACRONUTRIENTS			
Replace macronutrients in soils regularly, at least once per growing season.			
Nitrogen (N)	General yellowing of older leaves at the bottom of the plant. The rest of the plant is often light green.	Succulent growth, leaves are dark green, thick and brittle; poor fruit set; excess ammonia can induce calcium deficiency.	Most plants absorb nitrogen in the form of ammonium or nitrate. These forms readily dissolve in water and leach away.
Phosphorus (P)	Leaf tips look burnt, followed by older leaves turning a dark green or reddish-purple.	Shows up as micronutrient deficiency of Zn, Fe, or Co.	Plants absorb phosphorus in the form of phosphate. This form dissolves only slightly in water, but pH strongly affects uptake.
Potassium (K)	Older leaves may wilt, look scorched. Interveinal chlorosis begins at the base, scorching inward from leaf margins.	Causes N deficiency in plant and may affect the uptake of other positive ions such as Mg and Ca.	Plants absorb potassium as an ion, which can be readily leached from the soil. Desert soils and water generally have plenty of potassium, so deficiency problems are rare.
Calcium (Ca)	New leaves (top of the plant) are distorted or irregularly shaped. Causes blossom-end rot.	Interferes with Mg absorption; high Ca usually causes high pH which then precipitates many of the micronutrients, so they become unavailable to the plant.	Desert soils and water generally have plenty of calcium, so deficiency problems are rare. Excessive calcium can limit the availability of other nutrients.

Magnesium (Mg)	Older leaves turn yellow at edge leaving a green arrowhead shape in the center of the leaf.	Interferes with Ca uptake; small necrotic spots in older leaves; smaller veins in older leaves may turn brown; in the advanced stage, young leaves may be spotted.	Plants absorb magnesium as an ion (charged particle), which can be readily leached from the soil. May be readily leached from the soil if calcium is not present.
Sulfur (S)	Younger leaves turn yellow first, sometimes followed by older leaves.	Sulfur excess is usually in the form of air pollution.	Plants absorb sulfur in the form of sulfate. This readily leaches from the soil. Sulfur may acidify the soil (lower the pH).
MICRONUTRIENTS			
Replace when deficiency symptoms are evident.			
Boron (B)	Terminal buds die, witches' brooms form.	Tips and edges of leaves exhibit necrotic spots coalescing into a marginal scorch (similar to high soluble salts); oldest leaves are affected first; plants are easily damaged by excess application.	Plants absorb boron in the form of borate. Problems are seen in intensely cropped areas.
Chlorine (Cl)	Wilted leaves which become bronze then chlorotic then die; club roots.	Salt injury, leaf burn, may increase succulence.	
Copper (Cu)	Leaves are dark green; the plant is stunted.	Can occur at low pH; shows up as Fe deficiency.	Plants absorb copper as an ion.

Iron (Fe)	Yellowing occurs between the veins of young leaves.	Rare except on flooded soils.	Plants absorb iron as an ion through their foliage as well as their roots. Uptake is strongly affected by pH. Chelated iron is readily available for use by the plant, other forms of iron may be tied up in the soil.
Manganese (Mn)	Yellowing occurs between the veins of young leaves. The pattern is not as distinct as with iron. Palm fronds are stunted and deformed, called "frizzle top." Reduction in size of plant part (leaves, shoots, fruit) generally. Dead spots or patches.	Reduction in growth, brown spotting on leaves; shows up as Fe deficiency; found under strongly acid conditions.	Plants absorb manganese as an ion through their foliage as well as their roots.
Molybdenum (Mo)	General yellowing of older leaves (bottom of the plant). The rest of the plant is often light green.	Intense yellow or purple color in leaves; rarely observed.	Plants absorb molybdenum in the form of molybdate.
Zinc (Zn)	Terminal leaves may be rosetted, and yellowing occurs between the veins of the new leaves.	Severe stunting, reddening; poor germination; older leaves wilt; the entire leaf is affected by chlorosis, edges and main vein often retain more color; can be caused by galvanized metal.	Plants absorb zinc as an ion through their foliage as well as their roots. High pH may limit availability.

WATER INNOVATION TECHNOLOGIES PROJECT

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